Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards

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Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards

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List of Acronyms and Abbreviations

Act	Clean Air Act
ACS	American Cancer Society
AHR	Airway hyperresponsiveness
ANF	Atrial natriuretic factor
AOT40	Seasonal sum of the difference between an hourly concentration at the threshold value of 40 ppb, minus the threshold value of 40 ppb
AOT60	Seasonal sum of the difference between an hourly concentration at the threshold value of 60 ppb, minus the threshold value of 60 ppb
APEX	Air Pollutants Exposure model
APHEA	Air Pollution and Health: A European Approach
APHENA	Air Pollution and Health: A European and North American Approach
AQCD	Air Quality Criteria Document
AQI	Air Quality Index
AQRV	Air quality related value
AQS	Air Quality System
ARG	Arginase
AspenFACE	Aspen Free Air gas Concentration Enrichment Facility
ATS	American Thoracic Society
BALF	Bronchoalveolar Lavage Fluid
BI	Biosite Index
BRFSS	Behavioral Risk Factor Surveillance System
C	Concentration
CAA	Clean Air Act
CAL FIRE	California Department of Forestry and Fire Protection
CAMx	Comprehensive Air Quality Model with Extensions
CAMP	Childhood Asthma Management Program
CAR	Centriacinar region
CASAC	Clean Air Scientific Advisory Committee
CASTNET	Clean Air Status and Trends Network
CAT	Catalase
CBSA	Core-based statistical area
CD	Criteria Document
CDC	Centers for Disease Control
CFR	Code of Federal Regulations
CH4	Methane
CHD	Coronary Heart Disease
CHF	Congestive Heart Failure
CHS	Children's Health Study
CI	Confidence interval
CMAQ	Community Multi-scale Air Quality Model
CO	Carbon monoxide
CO2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
C-R	Concentration-response

CSA	Combined Statistical Area
CSTR	Continuous stirred tank reactor
CVD	Cardiovascular disease
DHEW	Department of Health, Education, and Welfare
ED	Emergency department
ELF	Extracellular Lining Fluid
EPA	Environmental Protection Agency
E-R	Exposure-response
eVNA	Enhanced Voronoi Neighbor Averaging
FACE	Free-air CO2 (and ozone) enrichment system
FASOMGHG	Forest and Agricultural Optimization Model – Greenhouse gas version
FEM	Federal Equivalent Method
FeNO	Exhaled nitric oxide fraction
FEV_1	Forced Expiratory Volume for 1 second
FHM/FIA	Forest Health Monitoring /Forest Inventory and Analysis Program
FHWAR	National Survey of Fishing, Hunting, and Wildlife-Associated Recreation
FIA	USDA Forest Inventory and Analysis Program
FLAG	Federal Land Managers' Air Quality Related Values Workgroup
FR	Federal Register
FRM	Federal Reference Method
FVC	Forced Vital Capacity
GEOS	Goddard Earth Observing System
GIS	Geographic Information Systems
GRSM	Great Smoky Mountains National Park
GSTM1	Glutathione-S-transferase polymorphism M1 genotypes
GSTP1	Glutathione-S-transferase polymorphism P1 genotypes
HA	Hospital Admission
HDDM	Higher Order Direct Decoupled Method
HEI	Health Effects Institute
HMOX1	Heme oxygenase-1 polymorphism
HO	Heme oxygenase
HR	Heart rate
HREA	Health Risk and Exposure Assessment
HRV	Heart rate variability
ICD-9	International Classification of Disease - 9^{th} revision
ICU	Intensive care unit
IgE	Immunoglobulin E
IL	Interleukin
I/R	Ischemia-reperfusion
ISA	Integrated Science Assessment
Max	maximum
MDA8	Maximum daily 8-hour ozone average
MMTCO2e	Million metric tonnes of carbon dioxide equivalents
MPO	Myeloperoxidase
MSA	Metropolitan Statistical Area
NAAQS	National ambient air quality standards

NAB	North American background
NB	Natural background
NCDC	National Climatic Data Center
NCLAN	National Crop Loss Assessment Network
NCORE sites	National Core multi-pollutant monitoring sites
NHLBI	National Heart, Lung, and Blood Institute
NMMAPS	National Morbidity, Mortality, and Air Pollution Study
NO	Nitric oxide
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
NOAA	National Oceanic and Atmospheric Administration
NQO1	NAD(P)H-quinone oxidoreductase genotype
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NSRE	National Survey on Recreation and the Environment
NWR	National wildlife refuges
O_3	Ozone
OC	Organic carbon
OIF	Outdoor Industry Foundation
OIRA	Office of Information and Regulatory Affairs
OMB	Office of Management and Budget
OR	Odds ratio
OTC	Open-top chamber
PA	Policy Assessment
PAMS	Photochemical Assessment Monitoring Stations
PAN	Peroxyacetyl nitrate
PAPA	Public Health and Air Pollution in Asia
PDSI	Palmer Drought Severity Index
PEFR	Peak Expiratory Flow Rate
ppm	Parts per million
ppm-hrs	part per million-hours
ppb	Parts per billion
PM	Particulate matter
$PM_{2.5}$	Particles generally less than or equal to 2.5 μm in diameter
PM_{10}	Particles generally less than or equal to 10 micrometers (μm) in diameter
PMN	Polymorphonuclear leukocyte
POMS	Portable Ozone Monitoring System
PRB	Policy relevant background
QA	Quality assurance
RBL	Relative biomass loss
ROMO	Rocky Mountain National Park
RR	Relative risk
SEKI	Sequoia and Kings Canyon National Parks
SES	Socioeconomic status
SIP	State Implementation Plans
SLAMS	State and Local Monitoring Stations

SO_2	Sulfur Dioxide
SO_x	Sulfur Oxides
SoyFACE	Soybean Free Air gas Concentration Enrichment Facility
SP	Staff Paper
SPMS	Special Purpose Monitoring Stations
STE	Stratospheric-tropospheric exchange
SUM00	Season sum of all hourly average concentrations
SUM06	Seasonal sum of all hourly average concentrations ≥ 0.06 ppm
TLC	Total Lung Capacity
TNF	Tumor Necrosis Factor
UNEP	United Nations Environmental Programme
U.S.	United States
USB	United States background
UV	Ultraviolet
$\dot{V}_E$	Ventilation rate
VNA	Voronoi neighbor Averaging
VOC	Volatile Organic Compounds
W126	Cumulative integrated exposure index with a sigmoidal weighting function
WHO	World Health Organization
wRBL	Weighted relative biomass loss
WREA	Welfare Risk and Exposure Assessment
WTP	Willingness to pay

EXECUTIVE SUMMARY

This Policy Assessment (PA) has been prepared by staff in the Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) as part of the Agency's review of the primary (health-based) and secondary (welfare-based) national ambient air quality standards (NAAQS) for ozone (O_3). The current O_3 standards were established in 2008 at the end of the previous review cycle. These standards include a primary O_3 standard of 75 ppb,[1] and a secondary O_3 standard set identical to the primary standard. These 2008 standards are now under review, as required by sections 108 and 109 of the Clean Air Act (Act). The PA presents analyses and staff conclusions regarding the policy implications of the key scientific and technical information that informs this review. Staff conclusions are presented regarding the adequacy of the current standards and potential alternative standards appropriate for consideration. Staff analyses in this PA are based on the scientific and technical information, including the uncertainties and limitations related to this information, assessed and presented in the Integrated Science Assessment for Ozone (ISA), the Health Risk and Exposure Assessment for Ozone (HREA), and the Welfare Risk and Exposure Assessment for Ozone (WREA). The PA is intended to "bridge the gap" between the relevant scientific evidence and technical information and the judgments required of the EPA Administrator in determining whether to retain or revise the current standards. Development of the PA is also intended to facilitate advice and recommendations on the standards to the Administrator from an independent scientific review committee, the Clean Air Scientific Advisory Committee (CASAC), as provided for in the Act. Staff considerations and conclusions in this final PA have been informed by comments and recommendations from CASAC, and by public comments.

Health Effects and Review of the Primary Standard

A longstanding and comprehensive evidence base, stronger now than in the last review, documents the effects of O_3 exposures on human health. It is well-understood that secondary oxidation products, which develop as a result of O_3 exposure, initiate numerous responses at the cellular, tissue, and whole organ level of the respiratory system. These key initiating events have the potential to result in a variety of adverse respiratory effects, as well as effects outside the respiratory system (e.g., cardiovascular effects). Ozone inhalation poses the greatest risk to people in certain lifestages (i.e., children, older adults), people with asthma, people with certain genetic variants (related to oxidative stress and inflammation), people with diets limited in

[1] The level of the O_3 standard is specified as 0.075 ppm rather than 75 ppb. However, in this PA we refer to ppb, which is most often used in the scientific literature and in the ISA, in order to avoid the confusion that could result from switching units when discussing the evidence in relation to the standard level.

certain nutrients (antioxidant vitamins C and E), and people experiencing the largest exposures (e.g., outdoor workers, children). The evidence from animal toxicology and controlled human exposure studies indicates that higher exposure concentrations and repeated exposures lead to a greater prevalence of effects and increasingly severe effects, including increased susceptibility to other respiratory stressors, among exposed populations, especially these at-risk populations.

As an initial matter in this PA, staff concludes that reducing ambient O_3 concentrations to meet the current standard of 75 ppb will provide important improvements in public health protection. This initial conclusion is based on (1) the strong body of scientific evidence indicating a wide range of adverse health outcomes attributable to exposures to O_3 concentrations found in the ambient air and (2) estimates indicating decreased O_3 exposures and health risks upon meeting the current standard, compared to recent air quality.

Strong support for this initial conclusion is provided by controlled human exposure studies of respiratory effects, and by quantitative estimates of exposures of concern and lung function decrements based on information in these studies. Analyses in the HREA estimate that the percentages of children (i.e., all children and children with asthma) in urban case study areas[2] experiencing exposures of concern, or experiencing abnormal and potentially adverse lung function decrements, are consistently lower for air quality that just meets the current O_3 standard than for recent air quality. The HREA estimates such reductions consistently across the urban case study areas and across years evaluated, and throughout various portions of individual urban case study areas, including in urban cores and in the portions of case study areas surrounding urban cores. These reductions in exposures of concern and O_3-induced lung function decrements reflect consistent reductions in relatively high O_3 concentrations (i.e., those in the upper portions of the distribution of ambient concentrations) following reductions in precursor emissions to meet the current standard. Thus, populations in both urban and non-urban areas would be expected to experience important reductions in O_3 exposures and O_3-induced lung function risks upon meeting the current standard.

Support for this initial conclusion is also provided by estimates of O_3-associated mortality and morbidity based on application of concentration-response relationships from epidemiologic studies to air quality adjusted to just meet the current standard. While these estimates are associated with uncertainties that complicate their interpretation, they suggest that O_3-associated mortality and morbidity would be expected to decrease nationwide following reductions in precursor emissions to meet the current O_3 standard.

[2] HREA analyses for exposures of concern and for risk of moderate or large lung function decrements covered 15 urban case study areas. HREA analyses of mortality and morbidity endpoints from epidemiologic studies covered 12 urban case study areas. Exposures and risks were evaluated for the years 2006 through 2010.

While meeting the current O_3 standard is estimated to result in important public health improvements compared to recent air quality, staff further concludes that the O_3-attributable health effects estimated to be allowed by air quality that meets the current primary standard can reasonably be judged important from a public health perspective. This conclusion is based on consideration of: (1) the scientific evidence discussed in the ISA, including controlled human exposure studies reporting abnormal or adverse respiratory effects following exposures to O_3 concentrations below the level of the current standard and epidemiologic studies indicating associations with morbidity and mortality for air quality that would likely meet the current standard; (2) HREA estimates of O_3 exposures of concern, O_3-induced lung function risks, and O_3-associated morbidity and mortality risks; (3) advice received from CASAC based on their review of draft versions of the ISA, HREA, and PA, and advice received in previous reviews; and (4) staff consideration of public comments. Staff reaches the overall conclusion that the available health evidence and exposure/risk information call into question the adequacy of the public health protection provided by the current standard.

Given this conclusion regarding the adequacy of the current standard, staff also reaches conclusions for the Administrator's consideration regarding the elements of potential alternative primary O_3 standards that could be supported by the available evidence and exposure/risk information. Any such potential alternative standards should protect public health against effects associated with exposures to O_3, alone or in combination with related photochemical oxidants, taking into account the available scientific evidence and exposure/risk information. In reaching conclusions about the range of potential alternative standards appropriate for consideration, staff is mindful that the Act requires primary standards that, in the judgment of the Administrator, are requisite to protect public health with an adequate margin of safety. In setting a primary standard that is "requisite" to protect public health, the EPA's task is to establish standards that are neither more nor less stringent than necessary. The requirement that primary standards provide an "adequate margin of safety" is intended to address uncertainties associated with inconclusive scientific and technical information. Thus, the Act does not require that primary NAAQS be set at zero-risk levels, but rather at levels that reduce risk sufficiently to protect public health with an adequate margin of safety.

The degree of public health protection provided by any NAAQS results from the collective impact of the elements of the standard, including the indicator, averaging time, form, and level. Staff's conclusions on each of these elements are summarized below.

(1) **Indicator:** It is appropriate to continue to use O_3 as the indicator for a standard that is intended to address effects associated with exposure to O_3, alone or in combination with related photochemical oxidants. Based on the available information, staff concludes that

there is no basis for considering any alternative indicator at this time. Meeting an O_3 standard can be expected to provide some degree of protection against potential health effects that may be independently associated with other photochemical oxidants, even though such effects are not discernible from currently available studies indexed by O_3 alone. Staff notes that control of ambient O_3 concentrations is generally understood to provide the best means of controlling photochemical oxidants, and thus of protecting against effects that may be associated with individual species and/or the broader mix of photochemical oxidants. CASAC concurred with these conclusions.

(2) **Averaging time:** It is appropriate to consider retaining the current 8-hour averaging time for the primary O_3 standard.

(a) Staff concludes that an 8-hour averaging time remains appropriate for addressing health effects associated with short-term exposures to ambient O_3. An 8-hour averaging time is similar to the exposure periods evaluated in controlled human exposure studies, including recent studies reporting respiratory effects following exposures to O_3 concentrations below the level of the current standard. In addition, epidemiologic studies provide evidence for health effect associations with 8-hour O_3 concentrations, as well as with 1-hour and 24-hour concentrations. Staff concludes that a standard with an 8-hour averaging time (combined with an appropriate standard form and level) would be expected to provide substantial protection against health effects attributable to 1- and 24-hour exposures. CASAC concurred, concluding that the current 8-hour averaging time is justified by the combined evidence from epidemiologic and clinical studies.

(b) Staff also concludes that a standard with an 8-hour averaging time can provide protection against respiratory effects associated with longer term O_3 exposures. Air quality analyses indicate that just meeting an 8-hour standard with an appropriate level (i.e., 70 to 60 ppb, as discussed below) would be expected to maintain long-term O_3 concentrations (i.e., seasonal average of 1-hour daily max) below those where a key study indicates the most confidence in the concentration-response relationship with respiratory mortality. In addition, risk analyses in the HREA estimate that just meeting such alternative 8-hour standards would be expected to decrease the incidence of respiratory mortality associated with long-term O_3 concentrations. In considering other long-term O_3 metrics evaluated in recent health studies, analyses in the HREA indicate that the large majority of the U.S. population lives in locations where reducing precursor emissions would be

expected to decrease warm season averages of daily 8-hour ambient O_3 concentrations, a long-term metric used in several recent studies reporting associations with respiratory morbidity. Taken together, these analyses suggest that a standard with an 8-hour averaging time, coupled with the current 4th-highest form and an appropriate level (discussed below), could provide appropriate protection against the long-term O_3 concentrations reported to be associated with respiratory morbidity and mortality. CASAC concurred, concluding that the 8-hour averaging time provides protection against the adverse impacts of long-term O_3 exposures.

(3) **Form:** For an 8-hour O_3 standard with a revised level, as described below, it is appropriate to consider retaining the current form, defined as the 3-year average of the annual 4th-highest daily maximum concentration. Staff notes that this form was selected in 1997 and 2008 in recognition of the public health protection provided, when coupled with an appropriate averaging time and level, combined with the stability provided for implementation programs. The currently available evidence and exposure/risk information do not call into question these conclusions from previous reviews. CASAC concurred with this conclusion, agreeing that the current form, combined with the current 8-hour averaging time, provides health protection while allowing for atypical meteorological conditions that can lead to abnormally high ambient O_3 concentrations which, in turn, provides programmatic stability.

(4) **Level:** The available scientific evidence and exposure/risk information provide strong support for considering a primary O_3 standard with a revised level in order to increase public health protection, including for at-risk populations and lifestages. Staff concludes that it is appropriate in this review to consider a revised primary O_3 standard level within the range of 70 ppb to 60 ppb. A standard set within this range would result in important improvements in public protection, compared to the current standard, and could reasonably be judged to provide an appropriate degree of public health protection, including for at-risk populations and lifestages. In its advice to the Administrator, CASAC also concluded that the scientific evidence and exposure/risk information support consideration of standard levels from 70 to 60 ppb. Within this range, CASAC concluded that a level of 70 ppb would provide little margin of safety and, therefore, provided the policy advice that the level of the O_3 standard should be set below 70 ppb.

The Administrator's consideration of specific standard levels will reflect her judgments as to the appropriate weight to be given to various aspects of the scientific evidence and exposure/risk information, including the appropriate weight to be given to important uncertainties. To inform these judgments, staff considers what the evidence and information indicate with regard to the degree of public health protection that could be achieved with levels from the upper (70 ppb), middle (65 ppb), and lower (60 ppb) parts of the range.

A level of 70 ppb is below the O_3 exposure concentration that has been reported to elicit a broad range of respiratory effects that includes airway hyperresponsiveness and decreased lung host defense, in addition to lung function decrements, airway inflammation, and respiratory symptoms (i.e., 80 ppb). A level of 70 ppb is also just below the lowest exposure concentration at which the combined occurrence of respiratory symptoms and lung function decrements have been reported (i.e., 72 ppb), a combination judged adverse by the ATS (section 3.1.3). A level of 70 ppb is above the lowest exposure concentration demonstrated to result in lung function decrements and pulmonary inflammation (i.e., 60 ppb). Compared to the current standard, a revised O_3 standard with a level of 70 ppb would be expected to (1) reduce the occurrence of exposures of concern to O_3 concentrations that result in respiratory effects in healthy adults (at or above 60 and 70 ppb) by about 45 to 95%, almost eliminating the occurrence of multiple exposures at or above 70 ppb; (2) reduce the occurrence of moderate-to-large O_3-induced lung function decrements (FEV_1 decrements $\geq$ 10, 15, 20%) by about 15 to 35%, most effectively limiting the occurrence of multiple decrements and decrements $\geq$ 15, 20%; (3) more effectively maintain short- and long-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard;[3] and (4) reduce the risk of O_3-associated mortality and morbidity, particularly the risk associated with the upper portions of the distributions of ambient O_3 concentrations.

A level of 65 ppb is well below the O_3 exposure concentration that has been reported to elicit the wide range of potentially adverse respiratory effects noted above, and is below the lowest exposure concentration at which the combined occurrence of respiratory

[3] Though epidemiologic studies also provide evidence for O_3 health effect associations in locations likely to have met a standard with a level of 70 ppb, as discussed below for lower standard levels.

symptoms and lung function decrements has been reported. As noted above for 70 ppb, a level of 65 ppb is above the lowest exposure concentration demonstrated to result in lung function decrements and pulmonary inflammation. Compared to a standard with a level of 70 ppb, a revised standard with a level of 65 ppb would be expected to (1) further reduce the occurrence of exposures of concern (by about 80 to 100% compared to the current standard), decreasing exposures at or above 60 ppb and almost eliminating exposures at or above 70 and 80 ppb; (2) further reduce the occurrence of FEV_1 decrements $\geq$ 10, 15, and 20% (by about 30 to 65%, compared to the current standard); (3) more effectively maintain short- and long-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard;[4] and (4) further reduce the risk of O_3-associated mortality and morbidity, particularly the risk associated with the upper portion of the distribution of ambient O_3 concentrations.

A level of 60 ppb is well below the O_3 exposure concentration shown to result in the combined occurrence of respiratory symptoms and lung function decrements, and corresponds to the lowest exposure concentration demonstrated to result in lung function decrements and pulmonary inflammation. Compared to a standard with a level of 70 or 65 ppb, a revised standard with a level of 60 ppb would be expected to (1) further reduce the occurrence of exposures of concern (by about 95 to 100% compared to the current standard), almost eliminating exposures at or above 60 ppb; (2) further reduce the occurrence of FEV_1 decrements $\geq$ 10, 15, and 20%, (by about 45 to 85% compared to the current standard); (3) more effectively maintain short- and long-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard;[5] and (4) further reduce the risk of O_3-associated mortality and morbidity, particularly the risk associated with the upper portion of the distribution of ambient O_3 concentrations.

Welfare Effects and Review of the Secondary Standard

The longstanding and comprehensive evidence base, stronger than in the last review, documents the vegetation and ecosystem-related effects of O_3 in ambient air. In particular, recent controlled studies at the molecular, biochemical and cellular scales have increased the

[4] Though epidemiologic studies also provide evidence for O_3 health effect associations in locations likely to have met a standard with a level of 65 ppb.
[5] Epidemiologic studies have not evaluated O_3 health effect associations based primarily on air quality in locations likely to have met a standard with a level of 60 ppb.

mechanistic understanding of the basic biology of how plants are affected by oxidative stress. These studies have focused on a variety of plant responses to O_3 including: 1) reduced carbon dioxide uptake due to stomatal closure; 2) the upregulation of genes associated with plant defense, signaling, hormone synthesis and secondary metabolism; 3) the down regulation of genes related to photosynthesis and general metabolism; 4) the loss of carbon assimilation capacity due to declines in the quantity and activity of key proteins and enzymes; and 5) the negative impacts on the efficiency of the photosynthetic light reactions. In addition, these effects at the plant scale can be linked to an array of effects at larger scales, as shown in recent field studies, together with previously available evidence. Specifically, plant-scale effects, such as altered rates of leaf gas exchange, growth, and reproduction at the individual plant level, can result in larger scale effects in ecosystems, such as alterations in productivity, carbon storage, water cycling, nutrient cycling, and community composition. The available information also demonstrates a relationship between changes in tropospheric O_3 concentrations and radiative forcing, and between changes in tropospheric O_3 concentrations and effects on climate.

The long-standing body of available evidence also provides a wealth of information on aspects of O_3 exposure that are important in influencing plant response. These include support for the conclusions that: O_3 effects in plants are cumulative; higher O_3 concentrations appear to be more important than lower concentrations in eliciting a response; plant sensitivity to O_3 varies with time of day and plant development stage; and quantifying exposure with indices that cumulate hourly O_3 concentrations and preferentially weight the higher concentrations improves the explanatory power of exposure/response models for growth and yield, over using indices based on mean and peak exposure values.

As an initial matter in this PA, staff concludes that reducing ambient O_3 concentrations to meet the current standard of 75 ppb will provide important improvements in public welfare protection. This initial conclusion is based on (1) the strong body of scientific evidence indicating a wide range of effects to sensitive vegetation, including tree biomass loss, crop yield loss, and visible foliar injury, and associated ecosystems and services attributable to cumulative exposures to O_3 concentrations found in the ambient air and (2) estimates indicating decreased cumulative O_3 exposures and welfare risks upon meeting the current standard, compared to recent air quality. Strong support for this conclusion is provided by the available welfare evidence; by WREA estimates of cumulative exposures to O_3 concentrations shown to result in decreased biomass loss, crop yield loss, and visible foliar injury incidence under just meeting the current secondary standard; and by WREA estimates of improvements in carbon storage and air pollution removal in urban and commercial forests. Support for this conclusion is also provided by WREA estimates of increased protection for Class I areas from O_3-associated visible foliar injury and tree biomass loss.

Staff further concludes that the O_3-attributable welfare effects estimated to be allowed by air quality that meets the current secondary standard call into question the adequacy of the public welfare protection provided by the current standard. In addition, staff also concludes that the public welfare protection is most appropriately judged through the use of a more biologically relevant form, such as the cumulative, seasonal W126-metric. These conclusions are based on consideration of: (1) the scientific evidence, including controlled exposure studies reporting effects on plant growth, productivity and carbon storage, crop yield loss, and visible foliar injury following exposures to O_3 concentrations below the level of the current standard and field based studies that support these conclusions for air quality that would likely meet the current standard; (2) the longstanding and extensive evidence demonstrating that the risk to vegetation comes from cumulative seasonal exposures; (3) evidence suggesting that in Class I areas meeting the current standard, cumulative seasonal O_3 exposures occur that are associated with estimates of tree growth impacts of a magnitude that are reasonably considered important to public welfare; (4) WREA estimates of reductions in biomass loss, crop yield loss, and visible foliar injury incidence, and improvements in carbon storage and air pollution removal in urban and commercial forests when meeting alternative W126 levels; (5) advice received from CASAC based on their review of draft versions of the ISA, WREA, and PA, and advice received in previous reviews; and (6) public comments. Staff reaches the overall conclusion that the available vegetation and ecosystem effects evidence and exposure/risk information, including for associated ecosystem services important from a public welfare perspective, call into question the adequacy of the public welfare protection provided by the current standard. Based on the evaluation presented in this PA, staff concludes that consideration should be given to revising the standard to provide increased public welfare protection. CASAC agreed with this conclusion.

Given this conclusion regarding the adequacy of the current standard, staff also reaches conclusions for the Administrator's consideration regarding the elements of potential alternative secondary O_3 standards that could be supported by the available evidence and exposure/risk information. Any such potential alternative standards should protect public welfare against known or anticipated adverse environmental effects associated with exposures to O_3, alone or in combination with related photochemical oxidants, taking into account the available scientific evidence and exposure/risk information. In reaching conclusions about the range of potential alternative standards appropriate for consideration, staff is mindful that the Act requires secondary standards that are at "a level of air quality the attainment and maintenance of which" in the "judgment of the Administrator", are "requisite to protect public welfare from any known or anticipated adverse effects". In setting a secondary standard that is "requisite" to protect public welfare, the EPA's task is to establish standards that are neither more nor less stringent

than necessary. Thus, the Act does not require that NAAQS be set at zero-risk levels, but rather at levels that reduce risk sufficiently to protect public welfare from adverse effects.

The degree of public welfare protection provided by any NAAQS results from the collective impact of the elements of the standard, including the indicator, averaging time, form, and level. Staff's conclusions on each of these elements are summarized below.

(1) **Indicator:** Staff concludes that it is appropriate to continue to use O_3 as the indicator for a standard that is intended to address welfare effects associated with exposure to O_3, alone or in combination with related photochemical oxidants. Based on the available information, staff concludes that there is no basis for considering an alternative indicator at this time. CASAC concurred with these conclusions.

(2) **Averaging time and form**: Staff concludes that it is appropriate to consider a revised secondary standard in terms of the cumulative, seasonal, concentration-weighted form, called the W126 index. This is supported by strong scientific evidence that cumulative O_3 exposures drive plant response and can cause reduced tree growth, productivity, and carbon storage; crop yield loss; visible foliar injury; and other welfare effects. With regard to the appropriate form and averaging times, staff reaches the following additional conclusions:

(a) It is appropriate to consider the consecutive 3-month period within the O_3 season with the maximum index value as the seasonal period over which to cumulate hourly O_3 exposures. Staff notes that the maximum 3-month period generally coincides with maximum biological activity for most vegetation, making the 3-month duration a suitable surrogate for longer growing seasons.

(b) It is appropriate to cumulate daily exposures for the 12-hour period from 8:00 am to 8:00 pm, generally representing the daylight period during the 3-month period identified above.

To the extent the Administrator finds it useful to consider the extent of public welfare protection that might be afforded by a revised primary standard, staff concludes that public welfare protection is appropriately judged through the use of the cumulative, seasonal W126 index form, as described above. CASAC agreed that it was

appropriate to establish a revised form of the secondary standard and that the W126 index was a more biologically relevant form than the current form of the standard.

With regard to the number of years over which it is appropriate to average, staff notes the that there is limited information to discern between the level of protection provided by an annual form or a 3-year average form of a W126 standard for crop yield loss or foliar injury, and that a multiple year form could be considered to provide a more consistent target level of protection for this endpoint. Such a form might also be appropriate for a standard intended to achieve the desired level of protection from longer-term effects, including those associated with potential compounding of biomass loss over multiple years. Further, such a form might be concluded to contribute to greater stability in air quality management programs, and thus, greater effectiveness in achieving the desired level of public welfare protection, than that that might result from a single year form. Therefore, to the extent that the greater emphasis is placed on protecting against effects associated with multi-year exposures and maintaining more year-to-year stability of public welfare protection, staff concludes that it is appropriate to consider a secondary standard form that averages the seasonal W126 index values across three consecutive years. CASAC recommended that if a 3-year averaging period is selected, the level should be set lower than if a 1-year averaging period is selected in order to provide greater protection for annual crops and against cumulative effects on perennial species.

(3) **Level:** With regard to level for a revised secondary standard, staff concludes that it is appropriate to give consideration to a range of levels from 17 to 7 ppm-hrs, expressed in terms of the W126 index. In so doing, we primarily consider the evidence- and exposure/risk-based information for cumulative seasonal O_3 exposures represented by W126 index values (including those represented by the WREA average W126 scenarios) associated with biomass loss in studied tree species, both in and outside areas that have been afforded special protections. We note CASAC's advice that a 6% median RBL is unacceptably high, and that the 2% median RBL is an important benchmark to consider. We further note that for the lower level of 7 ppm-hrs the median tree species biomass loss is at or below 2% and that for the upper level of 17 ppm-hrs the median tree biomass loss is below 6%.[6] We also note that a level of 17 ppm-hrs reduces the percent of total area having weighted RBL greater than 2% to

[6] We note that a W126 index value of 19 ppm-hrs is estimated to result in a median RBL value of 6%.

0.2%, and reduces the number of Class I areas with weighted RBL greater than 2% to 2 of the 145 assessed nationally protected Class I areas.

We also note that tree biomass loss can be an indicator of more significant ecosystem-wide effects which might reasonably be concluded to be significant to public welfare. For example, when it occurs over multiple years at a sufficient magnitude, biomass loss is linked to an array of effects on other ecosystem-level processes such as nutrient and water cycles, changes in above and below ground communities, and carbon storage and air pollution removal. These effects have the potential to be adverse to the public welfare.

In addition, a range of levels from 17 to 7 ppm-hrs would protect at least half of the crop species from a yield loss of greater than 5%. A W126 level of 10 ppm-hrs or less would also reduce prevalence of visible foliar injury and promote appreciable gains in carbon sequestration and pollutant removal.

CASAC recommended a range of W126 values of 15 ppm-hrs to 7 ppm-hrs and did not recommend levels above 15 ppm-hrs. CASAC noted that a level of 15 ppm-hrs is requisite to protect median crop yield loss to no more than 5% and that a level below 10 ppm-hrs is required to reduce foliar injury prevalence. CASAC also noted that a W126 level of 7 ppm-hrs limits median relative biomass loss for trees to no greater than 2% and offers additional protection against crop yield loss and foliar injury.

The Administrator's consideration of a particular level within the range of 17 to 7 ppm-hrs would reflect judgments as to the appropriate weight to be given to various aspects of the scientific evidence and exposure/risk information, with appropriate weight given to important uncertainties and with particular consideration of the support provided by this evidence and information regarding the protection of public welfare. To the extent the Administrator finds it useful to consider the extent of public welfare protection that might be afforded by a revised primary standard, staff concludes that public welfare protection is appropriately judged through the use of the cumulative seasonal W126-based metric.

1 INTRODUCTION

1.1 PURPOSE

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the primary (health-based) and secondary (welfare-based) national ambient air quality standards (NAAQS) for ozone (O_3). The overall plan for this review was presented in the *Integrated Review Plan for the O_3 National Ambient Air Quality Standards* (IRP, U.S. EPA, 2011a). The IRP also identified key policy-relevant issues to be addressed in this review and discussed the key documents that generally inform NAAQS reviews, including an Integrated Science Assessment (ISA), Risk and Exposure Assessments (REAs), and a Policy Assessment (PA). The PA is prepared by the staff in EPA's Office of Air Quality Planning and Standards (OAQPS). It presents a staff evaluation of the policy implications of the key scientific and technical information in the ISA and REAs for EPA's consideration.[1] The PA provides a transparent evaluation, and staff conclusions, regarding policy considerations related to reaching judgments about the adequacy of the current standards, and if revision is considered, what revisions may be appropriate to consider.

The PA is intended to help "bridge the gap" between the Agency's scientific assessments presented in the ISA and REAs, and the judgments required of the EPA Administrator in determining whether it is appropriate to retain or revise the NAAQS.[2] In evaluating the adequacy of the current standard and whether it is appropriate to consider potential alternative standards, the PA focuses on information that is most pertinent to evaluating the basic elements of the NAAQS: indicator,[3] averaging time, form,[4] and level. These elements, which together serve to define each standard, must be considered collectively in evaluating the health and welfare protection afforded by the O_3 standards. The PA integrates and interprets the information from the ISA and REAs to frame policy options for consideration by the Administrator. In so doing, the PA recognizes that the selection of a specific approach to reaching final decisions on the primary and secondary O_3 standards will reflect the judgments of the Administrator.

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[1]The terms "staff" and "we" through this document refer to personnel in the EPA's Office of Air Quality Planning and Standards (OAQPS).

[2]American Farm Bureau Federation v. EPA, 559 F. 3d 512, 521 (D.C. Cir. 2009); Natural Resources Defense Council v. EPA, 902 F. 2d 962, 967-68, 970 (D.C. Cir. 1990).

[3]The "indicator" of a standard defines the chemical species or mixture that is to be measured in determining whether an area attains the standard. The indicator for photochemical oxidants is ozone.

[4]The "form" of a standard defines the air quality statistic that is to be compared to the level of the standard in determining whether an area attains the standard. For example, the form of the current 8-hour O_3 NAAQS is the 3-year average of the annual fourth-highest daily maximum 8-hour average.

The development of the PA is also intended to facilitate advice to the Agency and recommendations to the Administrator from an independent scientific review committee, the Clean Air Scientific Advisory Committee (CASAC), as provided for in the Clean Air Act. As discussed below in section 1.2.1, the CASAC is to advise not only on the Agency's assessment of the relevant scientific information, but also on the adequacy of the existing standards, and to make recommendations as to any revisions of the standards that may be appropriate. The EPA facilitates CASAC advice and recommendations, as well as public input and comment, by requesting CASAC review and public comment on one or more drafts of the PA.

In this PA for the review of the O_3 NAAQS, we[5] consider the scientific and technical information available in this review as assessed in the *Integrated Science Assessment for O_3 and Related Photochemical Oxidants* (ISA, U.S. EPA, 2013), prepared by EPA's National Center for Environmental Assessment (NCEA), and the quantitative human exposure and health risk assessment and welfare risk assessment documents (HREA, U.S. EPA, 2014a; WREA, U.S. EPA, 2014b). The evaluation and staff conclusions presented in this PA have been informed by comments and advice received from CASAC in their reviews of draft versions of the PA, and in their reviews of the other draft Agency documents prepared for this NAAQS review.

Beyond informing the EPA Administrator and facilitating the advice and recommendations of CASAC and the public, the PA is also intended to be a useful reference to all parties interested in the NAAQS review. In these roles, it is intended to serve as a single source of the most policy-relevant information that informs the Agency's review of the NAAQS, and it is written to be understandable to a broad audience.

The remainder of chapter 1 summarizes information on the NAAQS legislative requirements and on the history of the O_3 NAAQS (section 1.2), and summarizes our general approaches to reviewing the current O_3 NAAQS (section 1.3). Chapter 2 of this PA provides an overview of the O_3 ambient monitoring network and O_3 air quality, including estimates of O_3 concentrations attributable to background sources. The remaining chapters are organized into two main parts. Chapters 3 and 4 focus on the review of the primary O_3 NAAQS while chapters 5 and 6 focus on the review of the secondary O_3 NAAQS. Staff's considerations and conclusions related to the current primary and secondary standards are discussed in chapters 3 and 5, respectively. Staff's considerations and conclusions related to potential alternative primary and secondary standards are discussed in chapters 4 and 6, respectively. Key uncertainties in the review and areas for future research and data collection are additionally identified in chapters 4 and 6 for the two types of standards.

[5]As noted above, the term "we" through this document refer to personnel in the EPA's Office of Air Quality Planning and Standards (OAQPS).

1.2 BACKGROUND

1.2.1 Legislative Requirements

Two sections of the Clean Air Act (CAA) govern the establishment and revision of the NAAQS. Section 108 (42 U.S.C. section 7408) directs the Administrator to identify and list certain air pollutants and then to issue air quality criteria for those pollutants. The Administrator is to list those air pollutants that in her "judgment, cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare;" "the presence of which in the ambient air results from numerous or diverse mobile or stationary sources;" and "for which . . . [the Administrator] plans to issue air quality criteria…." Air quality criteria are intended to "accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in the ambient air . . ." 42 U.S.C. § 7408(b). Section 109 (42 U.S.C. 7409) directs the Administrator to propose and promulgate "primary" and "secondary" NAAQS for pollutants for which air quality criteria are issued. Section 109(b)(1) defines a primary standard as one "the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health." [6] A secondary standard, as defined in section 109(b)(2), must "specify a level of air quality the attainment and maintenance of which, in the judgment of the Administrator, based on such criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air." [7]

The requirement that primary standards provide an adequate margin of safety was intended to address uncertainties associated with inconclusive scientific and technical information available at the time of standard setting. It was also intended to provide a reasonable degree of protection against hazards that research has not yet identified. See State of Mississippi v. EPA, 744 F. 3d 1334, 1353 (D.C. Cir. 2012) ("By requiring an 'adequate margin of safety', Congress was directing EPA to build a buffer to protect against uncertain and unknown dangers to human health"). See also Lead Industries Association v. EPA, 647 F.2d 1130, 1154 (D.C. Cir 1980); American Petroleum Institute v. Costle, 665 F.2d 1176, 1186 (D.C. Cir. 1981); American Farm Bureau Federation v. EPA, 559 F. 3d 512, 533 (D.C. Cir. 2009); Association of Battery

[6] The legislative history of section 109 indicates that a primary standard is to be set at "the maximum permissible ambient air level . . . which will protect the health of any [sensitive] group of the population," and that for this purpose "reference should be made to a representative sample of persons comprising the sensitive group rather than to a single person in such a group" S. Rep. No. 91-1196, 91st Cong., 2d Sess. 10 (1970).

[7] Welfare effects as defined in section 302(h) (42 U.S.C. § 7602(h)) include, but are not limited to, "effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

Recyclers v. EPA, 604 F. 3d 613, 617-18 (D.C. Cir. 2010). Both kinds of uncertainties are components of the risk associated with pollution at levels below those at which human health effects can be said to occur with reasonable scientific certainty. Thus, in selecting primary standards that provide an adequate margin of safety, the Administrator is seeking not only to prevent pollution levels that have been demonstrated to be harmful but also to prevent lower pollutant levels that may pose an unacceptable risk of harm, even if the risk is not precisely identified as to nature or degree. The CAA does not require the Administrator to establish a primary NAAQS at a zero-risk level or at background concentration levels, see Lead Industries v. EPA, 647 F.2d at 1156 n.51; State of Mississippi v. EPA, 744 F. 3d at 1343, 1351, but rather at a level that reduces risk sufficiently so as to protect public health with an adequate margin of safety.

In addressing the requirement for an adequate margin of safety, the EPA considers such factors as the nature and severity of the health effects, the size of sensitive population(s)[8] at risk, and the kind and degree of the uncertainties that must be addressed. The selection of any particular approach for providing an adequate margin of safety is a policy choice left specifically to the Administrator's judgment. See Lead Industries Association v. EPA, 647 F.2d at 1161-62; State of Mississippi, 744 F. 3d at 1353.

In setting primary and secondary standards that are "requisite" to protect public health and welfare, respectively, as provided in section 109(b), EPA's task is to establish standards that are neither more nor less stringent than necessary for these purposes. In so doing, the EPA may not consider the costs of implementing the standards. See generally, Whitman v. American Trucking Associations, 531 U.S. 457, 465-472, 475-76 (2001). Likewise, "[a]ttainability and technological feasibility are not relevant considerations in the promulgation of national ambient air quality standards." American Petroleum Institute v. Costle, 665 F. 2d at 1185.

Section 109(d)(1) requires that "not later than December 31, 1980, and at 5-year intervals thereafter, the Administrator shall complete a thorough review of the criteria published under section 108 and the national ambient air quality standards . . . and shall make such revisions in such criteria and standards and promulgate such new standards as may be appropriate . . . ." Section 109(d)(2) requires that an independent scientific review committee "shall complete a review of the criteria . . . and the national primary and secondary ambient air quality standards . . . and shall recommend to the Administrator any new . . . standards and revisions of existing

[8] As used here and similarly throughout this document, the term population refers to persons having a quality or characteristic in common, including a specific pre-existing illness or a specific age or life stage.

criteria and standards as may be appropriate . . . ." Since the early 1980's, the Clean Air Scientific Advisory Committee (CASAC) has performed this independent review function.[9]

1.2.2 History of O_3 NAAQS Reviews

Table 1-1 summarizes the O3 NAAQS that the EPA has promulgated to date. In each review, the EPA set the secondary standard at a level identical to the primary standard. These reviews are briefly described below.

Table 1-1. Summary of primary and secondary O_3 NAAQS promulgated during the period from 1971 to 2008.

Final Rule	Indicator	Averaging Time	Level (ppm)	Form
1971 (36 FR 8186)	Total photochemical oxidants	1 hour	0.08	Not to be exceeded more than one hour per year
1979 (44 FR 8202)	0_3	1 hour	0.12	Attainment is defined when the expected number of days per calendar year, with maximum hourly average concentration greater than 0.12 ppm, is equal to or less than 1
1993 (58 FR 13008)	The EPA decided that revisions to the standards were not warranted at the time.			
1997 (62 FR 38856)	0_3	8 hours	0.08	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
2008 (73 FR 16483)	0_3	8 hours	0.075	Form of the standards remained unchanged relative to the 1997 standard

The EPA first established primary and secondary NAAQS for photochemical oxidants in 1971 (36 FR 8186, April 30, 1971). The EPA set both primary and secondary standards at a level of 0.08 parts per million (ppm), 1-hr average, total photochemical oxidants, not to be exceeded more than one hour per year. The EPA based the standards on scientific information contained in the 1970 *Air Quality Criteria for Photochemical Oxidants* (U.S. DHEW, 1970). We initiated the first periodic review of the NAAQS for photochemical oxidants in 1977. Based on the 1978 *Air*

[9] Lists of CASAC members and of members of the CASAC Ozone Review Panel are available at: http://yosemite.epa.gov/sab/sabpeople.nsf/WebCommitteesSubCommittees/Ozone%20Review%20Panel.

Quality Criteria for Ozone and Other Photochemical Oxidants (U.S. EPA, 1978), the EPA published proposed revisions to the original NAAQS in 1978 (43 FR 16962) and final revisions in 1979 (44 FR 8202). At that time, the EPA revised the level of the primary and secondary standards from 0.08 to 0.12 ppm and changed the indicator from photochemical oxidants to O_3, and the form of the standards from a deterministic to a statistical form. This statistical form defined attainment of the standards as occurring when the expected number of days per calendar year with maximum hourly average concentration greater than 0.12 ppm equaled one or less.

Following the final decision in the 1979 review, the City of Houston challenged the Administrator's decision arguing that the standard was arbitrary and capricious because natural O_3 concentrations and other physical phenomena in the Houston area made the standard unattainable in that area. The U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) rejected this argument, holding (as noted above) that attainability and technological feasibility are not relevant considerations in the promulgation of the NAAQS. The court also noted that the EPA need not tailor the NAAQS to fit each region or locale, pointing out that Congress was aware of the difficulty in meeting standards in some locations and had addressed this difficulty through various compliance related provisions in the Act. See API v. Costle, 665 F.2d 1176, 1184-6 (D.C. Cir. 1981).

In 1982, we announced plans to revise the 1978 Air Quality Criteria document (47 FR 11561), and in 1983, we initiated the second periodic review of the O_3 NAAQS (48 FR 38009). We subsequently published the 1986 *Air Quality Criteria for Ozone and Other Photochemical Oxidants* (U.S. EPA, 1986) and the 1989 Staff Paper (U.S. EPA, 1989). Following publication of the 1986 Air Quality Criteria Document (AQCD), a number of scientific abstracts and articles were published that appeared to be of sufficient importance concerning potential health and welfare effects of O_3 to warrant preparation of a Supplement. On August 10, 1992, under the terms of a court order, the EPA published a proposed decision to retain the existing primary and secondary standards (57 FR 35542). The notice explained that the proposed decision would complete EPA's review of information on health and welfare effects of O_3 assembled over a 7-year period and contained in the 1986 AQCD and its 1992 Supplement. The proposal also announced EPA's intention to proceed as rapidly as possible with the next review of the air quality criteria and standards for O_3 in light of emerging evidence of health effects related to 6- to 8-hour O_3 exposures. On March 9, 1993, the EPA concluded the review by affirming its proposed decision to retain the existing primary and secondary standards. (58 FR 13008).

In August 1992, we announced plans to initiate the third periodic review of the air quality criteria and O_3 NAAQS (57 FR 35542). In December 1996, the EPA proposed to replace the then existing 1-hour primary and secondary standards with 8-hour average O_3 standards set at a level of 0.08 ppm (equivalent to 0.084 ppm using standard rounding conventions) (61 FR 65716). The

EPA also proposed to establish a new distinct secondary standard using a biologically-based cumulative, seasonal form. The EPA completed this review on July 18, 1997 (62 FR 38856) by setting the primary standard at a level of 0.08 ppm, based on the annual fourth-highest daily maximum 8-hr average concentration, averaged over three years, and setting the secondary standard identical to the revised primary standard. In reaching this decision, the EPA identified several reasons supporting its decision to reject a potential alternate standard set at 0.07 ppm. Most importantly, the EPA pointed out the scientific uncertainty at lower concentrations and placed significant weight on the fact that no CASAC panel member supported a standard level set lower than 0.08 ppm (62 FR 38868). In addition to noting the uncertainties in the health evidence for exposure concentrations below 0.08 ppm and the advice of CASAC, the EPA noted that a standard set at a level of 0.07 ppm would be closer to peak background concentrations that infrequently occur in some areas due to nonanthropogenic sources of O_3 precursors (62 FR 38856, 38868; July 18, 1997).

On May 14, 1999, in response to challenges by industry and others to EPA's 1997 decision, the U.S. Court of Appeals for the District of Columbia Circuit remanded the O_3 NAAQS to the EPA, finding that section 109 of the Act, as interpreted by the EPA, effected an unconstitutional delegation of legislative authority. American Trucking Assoc. vs. EPA, 175 F.3d 1027, 1034-1040(D.C. Cir. 1999) ("ATA I"). In addition, the court directed that, in responding to the remand, the EPA should consider the potential beneficial health effects of O_3 pollution in shielding the public from the effects of solar ultraviolet (UV) radiation, as well as adverse health effects. Id. at 1051-53. In 1999, the EPA petitioned for rehearing *en banc* on several issues related to that decision. The court granted the request for rehearing in part and denied it in part, but declined to review its ruling with regard to the potential beneficial effects of O_3 pollution. 195 F3d 4, 10 (D.C Cir., 1999) ("ATA II"). On January 27, 2000, the EPA petitioned the U.S. Supreme Court for certiorari on the constitutional issue (and two other issues), but did not request review of the ruling regarding the potential beneficial health effects of O_3. On February 27, 2001, the U.S. Supreme Court unanimously reversed the judgment of the D.C. Circuit on the constitutional issue. Whitman v. American Trucking Assoc., 531 U. S. 457, 472-74 (2001) (holding that section 109 of the CAA does not delegate legislative power to the EPA in contravention of the Constitution). The Court remanded the case to the D.C. Circuit to consider challenges to the O_3 NAAQS that had not been addressed by that court's earlier decisions. On March 26, 2002, the D.C. Circuit issued its final decision on remand, finding the 1997 O_3 NAAQS to be "neither arbitrary nor capricious," and so denying the remaining petitions for review. American Trucking Associations, Inc. v EPA, 283 F.3d 355, 379 (D.C Cir., 2002) ("ATA III").

Specifically, in ATA III, the D.C. Circuit upheld EPA's decision on the 1997 O_3 standard as the product of reasoned decision-making. The Court made clear that the most important support for EPA's decision was the health evidence and the concerns it raised about setting a standard level below 0.08 ppm. ("the record is replete with references to studies demonstrating the inadequacies of the old one-hour standard", as well as extensive information supporting the change to an 8-hour averaging time). 283 F 3d at 378. The Court also pointed to the significant weight that the EPA properly placed on the advice it received from CASAC. Id. at 379. The court further noted that "although relative proximity to peak background ozone concentrations did not, in itself, necessitate a level of 0.08, EPA could consider that factor when choosing among the three alternative levels." Id.

Independently of the litigation, the EPA also responded to the Court's remand to consider the potential beneficial health effects of O_3 pollution in shielding the public from effects of solar (ultraviolet or UV-B) radiation. The EPA provisionally determined that the information linking changes in patterns of ground-level O_3 concentrations to changes in relevant patterns of exposures to ultraviolet (UV-B) radiation of concern to public health was too uncertain, at that time, to warrant any relaxation in 1997 O_3 NAAQS. The EPA also expressed the view that any plausible changes in UV-B radiation exposures from changes in patterns of ground-level O_3 concentrations would likely be very small from a public health perspective. In view of these findings, the EPA proposed to leave the 1997 8-hour NAAQS unchanged (66 FR 57268, Nov. 14, 2001). After considering public comment on the proposed decision, the EPA published its final response to this remand on January 6, 2003, re-affirming the 8-hour O_3 NAAQS set in 1997 (68 FR 614).

The EPA initiated the fourth periodic review of the air quality criteria and O_3 standards in September 2000 with a call for information (65 FR 57810). The schedule for completion of that review was ultimately governed by a consent decree resolving a lawsuit filed in March 2003 by plaintiffs representing national environmental and public health organizations, who maintained that EPA was in breach of a mandatory legal duty to complete review of the O_3 NAAQS within a statutorily-mandated deadline. On July 11, 2007, the EPA proposed to revise the level of the primary standard within a range of 0.075 to 0.070 ppm. (72 FR 37818). Documents supporting this proposed decision included the *Air Quality Criteria for Ozone and Other Photochemical Oxidants* (U.S. EPA, 2006) and the Staff Paper (U.S EPA, 2007) and related technical support documents. The EPA also proposed two options for revising the secondary standard: (1) replace the current standard with a cumulative, seasonal standard, expressed as an index of the annual sum of weighted hourly concentrations cumulated over 12 daylight hours during the consecutive 3-month period within the O_3 season with the maximum index value, set at a level within the range of 7 to 21 ppm-hrs, and (2) set the secondary standard identical to the proposed primary

standard. The EPA completed the review with publication of a final decision on March 27, 2008 (73 FR 16436). In that final rule, the EPA revised the NAAQS by lowering the level of the 8-hour primary O_3 standard from 0.08 ppm to 0.075 ppm, not otherwise revising the primary standard, and adopting a secondary standard identical to the revised primary standard. In May 2008, state, public health, environmental, and industry petitioners filed suit challenging EPA's final decision on the 2008 O_3 standards. On September 16, 2009, the EPA announced its intention to reconsider the 2008 O_3 standards, and initiated a rulemaking to do so. At EPA's request, the Court held the consolidated cases in abeyance pending EPA's reconsideration of the 2008 decision.

On January 19, 2010 (75 FR 2938), the EPA issued a notice of proposed rulemaking to reconsider the 2008 final decision. In that notice, the EPA proposed that further revisions of the primary and secondary standards were necessary to provide a requisite level of protection to public health and welfare. The EPA proposed to decrease the level of the 2008 8-hour primary standard from 0.075 ppm to a level within the range of 0.060 to 0.070 ppm, and to change the secondary standard to a new cumulative, seasonal standard expressed as an annual index of the sum of weighted hourly concentrations, cumulated over 12 hours per day (8 am to 8 pm), during the consecutive 3-month period within the O_3 season, with a maximum index value set at a level within the range of 7 to 15 ppm-hours. The Agency also solicited CASAC review of the proposed rule on January 25, 2010 and solicited additional CASAC advice on January 26, 2011. After considering comments from CASAC and the public, the EPA prepared a draft final rule, which was submitted for interagency review pursuant to Executive Order 12866. On September 2, 2011, consistent with the direction of the President, the Administrator of the Office of Information and Regulatory Affairs ("OIRA"), Office of Management and Budget ("OMB"), returned the draft final rule to the EPA for further consideration. In view of this return and the timing of the Agency's ongoing periodic review of the O_3 NAAQS required under Clean Air Act section 109 (as announced on September 29, 2008), the EPA decided to coordinate further proceedings on its voluntary rulemaking on reconsideration with that ongoing periodic review, by deferring the completion of its voluntary rulemaking on reconsideration until it completes its statutorily-required periodic review.

In light of EPA's decision to consolidate the reconsideration with the current review, the Court proceeded with the litigation on the 2008 final decision. On July 23, 2013, the D.C. Circuit Court of Appeals upheld EPA's 2008 primary O_3 standard, but remanded the 2008 secondary standard to the EPA. State of Mississippi v. EPA, 744 F. 3d 1334. With respect to the primary standard, the court first held that the EPA reasonably determined that the existing standard was not requisite to protect public health with an adequate margin of safety, and consequently required revision. Specifically, the court noted that there were "numerous epidemiological

studies linking health effects to exposure to ozone levels below 0.08 ppm and clinical human exposure studies finding a causal relationship between health effects and exposure to ozone levels at and below 0.08 ppm". 744 F. 3d at 1345. The court also specifically endorsed the weight of evidence approach utilized by EPA in its deliberations. Id. at 1344.

The court went on to reject arguments that EPA should have adopted a more stringent primary standard. Dismissing arguments that a clinical study (as properly interpreted by EPA) to show effects at 0.06 ppm necessitated a standard level lower than that selected, the court noted that this was a single, limited study. Id. at 1350. With respect to the epidemiologic evidence, the court accepted EPA's argument that there could be legitimate uncertainty that a causal relationship between O_3 and 8-hour exposures less than 0.075 ppm exists, so that associations at lower levels reported in epidemiologic studies did not necessitate a more stringent standard. Id. at 1351-52.[10]

The court also rejected arguments that an 8-hour primary standard of 0.075 ppm failed to provide an adequate margin of safety, noting that margin of safety considerations involved policy judgments by the agency, and that by setting a standard "appreciably below" the level of the current standard (0.08 ppm), the agency had made a reasonable policy choice. Id. Finally, the court rejected arguments that EPA's decision was inconsistent with CASAC's scientific recommendations because CASAC had been insufficiently clear in its recommendations whether it was providing scientific or policy recommendations, and EPA had reasonably addressed CASAC's policy recommendations. Id. at 1357-58.

With respect to the secondary standard, the court held that because EPA had failed to identify a level of air quality requisite to protect public welfare, EPA's comparison between the primary and secondary standards for determining if requisite protection for public welfare was afforded by the primary standard was inherently arbitrary. The court thus rejected EPA's determination that the revised 8-hour primary standard afforded sufficient protection of public welfare, and remanded the standard to EPA. Id. at 1360-62.

1.2.3 Current O_3 NAAQS Review

On September 29, 2008, the EPA announced the initiation of a new periodic review of the air quality criteria for O_3 and related photochemical oxidants and issued a call for information in the Federal Register (73 FR 56581, Sept. 29, 2008). A wide range of external

[10] The court cautioned, however, that "perhaps more [clinical] studies like the Adams studies will yet reveal that the 0.060 ppm level produces significant adverse decrements that simply cannot be attributed to normal variation in lung function", and further cautioned that "agencies may not merely recite the terms 'substantial uncertainty' as a justification for their actions'". Id. at 1350, 1357 (internal citations omitted).

experts, as well as EPA staff, representing a variety of areas of expertise (e.g., epidemiology, human and animal toxicology, statistics, risk/exposure analysis, atmospheric science, ecology, biology, plant science, ecosystem services) participated in a workshop. This workshop was held on October 28-29, 2008 in Research Triangle Park, NC. The workshop provided an opportunity for a public discussion of the key policy-relevant issues around which the EPA would structure this O_3 NAAQS review and the most meaningful new science that would be available to inform our understanding of these issues.

Based in part on the workshop discussions, the EPA developed a draft Integrated Review Plan outlining the schedule, process, and key policy-relevant questions that would guide the evaluation of the air quality criteria for O_3 and the review of the primary and secondary O_3 NAAQS. A draft of the IRP was released for public review and comment in September 2009. This IRP was the subject of a consultation with the CASAC on November 13, 2009 (74 FR 54562; October 22, 2009).[11] We considered comments received from that consultation and from the public in finalizing the plan and in beginning the review of the air quality criteria. The EPA's overall plan and schedule for this review is presented in the *Integrated Review Plan for the Ozone National Ambient Air Quality Standards*.[12]

As part of the process of preparing the O_3 ISA, NCEA hosted a peer review workshop in October 29-30, 2008 (73 FR 56581, September 29, 2008) on preliminary drafts of key ISA chapters. The CASAC and the public reviewed the first external review draft ISA (U.S. EPA, 2011b; 76 FR 10893, February 28, 2011) at a meeting held in May 19-20, 2011 (76 FR 23809; April 28, 2011). Based on CASAC and public comments, NCEA prepared a second draft ISA (U.S. EPA, 2011c; 76 FR 60820, September 30, 2011). CASAC and the public reviewed this draft at a January 9-10, 2012 (76 FR 236, December 8, 2011) meeting. Based on CASAC and public comments, NCEA prepared a third draft ISA (U.S. EPA 2012a; 77 FR 36534; June 19, 2012), which was reviewed at a CASAC meeting in September 2012. The EPA released the final ISA in February 2013.

The EPA presented its plans for conducting the Risk and Exposure Assessments (REAs) that build on the scientific evidence presented in the ISA, in two planning documents titled *Ozone National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment* and *Ozone National Ambient Air Quality Standards: Scope and Methods*

[11] See http://yosemite.epa.gov/sab/sabproduct.nsf/WebProjectsbyTopicCASAC!OpenView for more information on CASAC activities related to the current O_3 NAAQS review.

[12] EPA 452/R-11-006; April 2011; Available: http://www.epa.gov/ttn/naaqs/standards/ozone/data/2011_04_OzoneIRP.pdf

Plan for Welfare Risk and Exposure Assessment (henceforth, Scope and Methods Plans).[13] These planning documents outlined the scope and approaches that staff planned to use in conducting quantitative assessments, as well as key issues that would be addressed as part of the assessments. We released these documents for public comment in April 2011, and consulted with CASAC on May 19-20, 2011 (76 FR 23809; April 28, 2011). In designing and conducting the initial health risk and welfare risk assessments, we considered CASAC comments (Samet 2011) on the Scope and Methods Plans and also considered public comments. In May 2012, we issued a memo titled *Updates to Information Presented in the Scope and Methods Plans for the Ozone NAAQS Health and Welfare Risk and Exposure Assessments* that described changes to elements of the scope and methods plans and provided a brief explanation of each change and the reason for it.

In July 2012, EPA made the first drafts of the Health and Welfare REAs available for CASAC review and public comment (77 FR 42495, July 19, 2012). The first draft PA was made available for CASAC review and public comment in August 2012. These documents were reviewed by the CASAC O_3 Panel at a public meeting in September 2012. The second draft REAs and PA were prepared by EPA in consideration of CASAC (Frey and Samet, 2012a, 2012b) and public comment and were reviewed by the CASAC O_3 Panel at a public meeting on March 25-27, 2014. This final PA reflects staff's consideration of the comments and recommendations made by CASAC, and comments made by members of the public, in their review of draft versions of the PA.

1.3 GENERAL APPROACH FOR REVIEW OF THE STANDARDS

As described in section 1.1 above, this PA presents a transparent evaluation and staff conclusions regarding policy considerations related to reaching judgments about the adequacy of the current standards and the revisions that are appropriate to consider. Staff considerations and conclusions in this document are based on the available body of scientific evidence assessed in the ISA (U.S. EPA, 2013), exposure and risk analyses presented in the REAs (U.S. EPA, 2014a, b), advice and recommendations from CASAC on the first and second draft REAs and PA and other draft and final EPA documents in this review, as well as on public comments. This evaluation and associated conclusions on the range of policy options that, in staff's view, are supported by the available scientific evidence and exposure/risk information will inform the Administrator's decisions as to whether the existing primary and/or secondary O_3 standards should be revised and, if so, what revised standard or standards is/are appropriate.

[13] EPA-452/P-11-001 and -002; April 2011; Available: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_2008_pd.html

Staff's considerations and conclusions related to the current and alternative primary and secondary O_3 standards are framed by a series of key policy-relevant questions, expanding upon those presented in the IRP at the outset of this review (U.S. EPA, 2011a). Answers to these questions in this final PA will inform the Administrator's decisions as to whether, and if so how, to revise the current O_3 standards. The first overarching question is as follows.

- **Do the currently available scientific evidence and exposure/risk information, as reflected in the ISA and REAs, support or call into question the adequacy of the protection afforded by the current O_3 standards?**

If the answer to this question, which is informed by staff's consideration of more specific questions related to the primary and secondary standards, suggests that revision of the current standards may be appropriate, then staff further considers the currently available evidence and information with regard to the following question.

- **What range of potential alternative standards is appropriate to consider based on the scientific evidence, air quality analyses, and exposure/risk-based information?**

The general approaches for consideration of these overarching questions in review of the primary and secondary standards are described separately in sections 1.3.1 and 1.3.2 below.

1.3.1 Approach for the Primary Standard

Staff's approach in this review of the current primary O_3 standard takes into consideration the approaches used in previous O_3 NAAQS reviews. The past and current approaches described below are both based, fundamentally, on using EPA's assessment of the current scientific evidence and associated quantitative analyses to inform the Administrator's judgment regarding a primary standard for O_3 that is "requisite" (i.e., neither more nor less stringent than necessary) to protect public health with an adequate margin of safety.

In reaching conclusions on options for the Administrator's consideration, we note that the final decision to retain or revise the current primary O_3 standard is a public health policy judgment to be made by the Administrator. This final decision by the Administrator will draw upon the available scientific evidence for O_3-attributable health effects, and on analyses of population exposures and health risks, including judgments about the appropriate weight to assign the range of uncertainties inherent in the evidence and analyses. Our general approach to informing these judgments, discussed more fully below, recognizes that the available health effects evidence reflects a continuum from relatively higher O_3 concentrations, at which scientists generally agree that health effects are likely to occur, through lower concentrations, at which the likelihood and magnitude of a response become increasingly uncertain. Therefore, in developing conclusions in this PA, we are mindful that the Administrator's ultimate judgments

on the primary standard will most appropriately reflect an interpretation of the available scientific evidence and exposure/risk information that neither overstates nor understates the strengths and limitations of that evidence and information. This approach is consistent with the requirements of sections 108 and 109 of the Act, as well as with how the EPA and the courts have historically interpreted the Act.

Section 1.3.1.1 below provides an overview of the general approach taken in the last review of the primary O_3 NAAQS (i.e., the 2008 review), and a summary of the rationale for the decision on the level of the standard in that review (73 FR 16436). Section 1.3.1.2 presents our approach in the current review, including our approach to considering the health evidence and exposure/risk information, and considerations regarding ambient O_3 concentrations attributable to background sources.

1.3.1.1 Approach Used in the Last Review

In the 2008 review of the O_3 NAAQS, the Administrator considered the available scientific evidence and exposure/risk information, the advice and recommendations of CASAC, and comments from the public. Based on this, he revised the level of the 8-hour primary O_3 standard from 0.08 ppm[14] to 0.075 ppm (75 ppb[15]). In reaching a decision to revise the 1997 8-hour primary O_3 standard, the Administrator noted that much new evidence had become available since the 1997 review. He noted that this body of scientific evidence was very robust and provided consistent and coherent evidence of an array of O_3-related respiratory morbidity effects, and possibly cardiovascular-related morbidity, as well as total nonaccidental and cardiorespiratory mortality. The Administrator specifically observed that (1) the evidence of a range of respiratory-related morbidity effects had been considerably strengthened; (2) newly available evidence from controlled human exposure and epidemiologic studies identified people with asthma as an important susceptible population for which estimates of respiratory effects in the general population likely underestimate the magnitude or importance of these effects; (3) newly available evidence about mechanisms of toxicity more completely explained the biological plausibility of O_3-induced respiratory effects and was beginning to suggest mechanisms that may link O_3 exposure to cardiovascular effects; and (4) there was relatively strong evidence for associations between short-term O_3 concentrations and total nonaccidental and cardiopulmonary mortality. In the opinion of the Administrator, this very robust body of evidence enhanced our understanding of O_3- related effects and provided increased confidence

[14] Due to rounding convention, the 1997 standard level of 0.08 ppm corresponded to 0.084 ppm (84 ppb).

[15] The level of the O_3 standard is specified as 0.075 ppm rather than 75 ppb. However, in this PA we refer to ppb, which is most often used in the scientific literature and in the ISA, in order to avoid the confusion that could result from switching units when discussing the evidence in relation to the standard level.

that various respiratory morbidity effects and other effects marked by indicators of respiratory morbidity are causally related to O_3 exposures, and the evidence was highly suggestive that O_3 exposures during the warm O_3 season contribute to premature mortality.[16]

The Administrator also noted important new health evidence reporting a broad array of adverse effects following short-term exposures to O_3 concentrations below the level of the 1997 standard, and concerns for such or related effects in at-risk populations,[17] including people with asthma or other lung diseases, older adults with increased susceptibility, and those who are likely to be vulnerable as a result of spending a lot of time outdoors engaged in physical activity (e.g., especially active children and outdoor workers).

He specifically noted new scientific evidence, which built upon existing evidence, demonstrating O_3-induced lung function effects and respiratory symptoms in some healthy individuals following exposures down to 80 ppb. He also noted very limited new evidence demonstrating such effects at exposure concentrations well below 80 ppb. In addition, the Administrator noted (1) epidemiologic evidence of statistically significant associations with O_3-related health effects in areas that likely would have met the then-current standard; (2) epidemiologic studies conducted in areas that likely would have violated the existing standard but which nonetheless reported statistically significant associations that generally extended down to ambient O_3 concentrations below the level of that standard; (3) the few studies that had reported statistically significant associations with respiratory morbidity outcomes and mortality in subsets of data that included only days with ambient O_3 concentrations below the level of the existing standard; and (4) controlled human exposure studies, together with animal toxicological studies, that provided considerable support for the biological plausibility of the respiratory morbidity associations observed in the epidemiologic studies. Based on the available evidence, the Administrator agreed with the CASAC and the majority of public commenters that the existing standard was not requisite to protect public health with an adequate margin of safety (73 FR 16471).

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[16] 73 FR 16470-16471 (March 27, 2008)

[17] Here, as in the ISA, the term "at-risk population" is used to encompass populations or lifestages that have a greater likelihood of experiencing health effects related to exposure to an air pollutant due to a variety of factors; other terms used in the literature include susceptible, vulnerable, and sensitive. These factors may be intrinsic, such as genetic factors, lifestage, or the presence of preexisting diseases, or they may be extrinsic, such as socioeconomic status (SES), activity pattern and exercise level, or increased pollutant exposures (U.S. EPA 2013, p. lxx, 8-1, 8-2). The courts and the Act's legislative history refer to these at-risk subpopulations as "susceptible" or "sensitive" populations. See, e.g., American Lung Ass'n v. EPA, 134 F. 3d 388, 389 (D.C. Cir. 1998) ("NAAQS must protect not only average health individuals, but also 'sensitive citizens' – children, for example, or people with asthma, emphysema, or other conditions rendering them particularly vulnerable to air pollution" (quoting S. Rep. No. 91-1196 at 10).

Beyond this focus on the available health evidence, the Administrator also considered estimates of O_3 exposures and health risks based on analyses where air quality was adjusted to simulate just meeting the existing and potential alternative standards. For the various air quality simulations, he specifically considered the pattern of estimated reductions in O_3 exposures across health benchmark concentrations of 80, 70, and 60 ppb. The 80 ppb benchmark reflected an exposure concentration for which there was strong evidence for respiratory effects in healthy people, including airway inflammation, respiratory symptoms, airway hyperresponsiveness, and impaired lung host defense (U.S. EPA, 2007, section 4.7). The 60 ppb benchmark reflected an exposure concentration for which the Administrator judged the evidence of such effects to be very limited (73 FR 16471).

The Administrator took note of the magnitudes of estimated health risks for a range of health effects, including moderate and large lung function decrements, respiratory symptoms, respiratory-related hospital admissions, and nonaccidental and cardiorespiratory mortality. He recognized that these quantitative risk estimates for a limited number of specific health effects were indicative of a much broader array of O_3-related effects, including various indicators of morbidity in at-risk populations that we could not analyze in the risk assessment (e.g., school absences, increased medication use, emergency department visits). The Administrator concluded that quantitative exposure and risk estimates, as well as the broader array of O_3-related health endpoints that could not be quantified, provided additional support for the evidence-based conclusion that the existing standard needed to be revised (73 FR 16472).

Based on the above considerations, and consistent with CASAC's unanimous conclusion that there was no scientific justification for retaining the existing standard, the Administrator concluded that the primary O_3 standard set in 1997 was not sufficient and thus not requisite to protect public health with an adequate margin of safety. He further concluded that revision of this standard was needed to provide increased public health protection (73 FR 16472).

Throughout the 2008 review, CASAC supported a standard level in the range of 60 to 70 ppb (without change to the form, indicator, or averaging time). In a letter to the Administrator on the second draft Staff Paper, CASAC unanimously recommended "that the current primary ozone standard be revised and that the level that should be considered for the revised standard be from 0.060 to 0.070 ppm'' (60 to 70 ppb) (Henderson, 2006, p. 5). This recommendation, based in part on the placement of more weight on the evidence for effects following exposures to 60 ppb O_3, followed from the CASAC's more general recommendation that the 1997 standard needed to be made substantially more protective of human health, particularly for at-risk populations. In a subsequent letter sent specifically to offer advice to aid the Administrator and Agency staff in developing the 2007 O_3 proposal, CASAC reiterated that Panel members ''were

unanimous in recommending that the level of the current primary ozone standard should be lowered from 0.08 ppm to no greater than 0.070 ppm'' (Henderson, 2007, p. 2).[18]

After considering CASACs comments, the Administrator judged that the appropriate balance to draw, based on the entire body of evidence and information available in the 2008 review, was a standard set at a level of 75 ppb (and leaving all other elements of the NAAQS unchanged). In making this decision, the Administrator placed primary emphasis on the body of available scientific evidence, while viewing the results of exposure and risk assessments as providing supporting information. Specifically, the Administrator judged that a standard set at 75 ppb would be appreciably below 80 ppb, the level in controlled human exposure studies at which adverse effects had been demonstrated at the time, and would provide a significant increase in protection compared to the then-current standard. Based on results of the exposure assessment, he also noted that exposures to O_3 concentrations at and above a benchmark level of 80 ppb would be essentially eliminated with a standard level of 75 ppb, and that exposures at and above a 70 ppb benchmark level would be substantially reduced or eliminated for the vast majority of people in at-risk groups. In addition, the Administrator concluded that the body of evidence did not support setting a lower standard level, specifically judging that the available evidence for effects following exposures to O_3 concentrations of 60 ppb was "too limited to support a primary focus at this level" (75 FR 2938). With respect to the epidemiologic evidence, the Administrator stated that a standard set at a level lower than 75 ppb "would only result in significant further public health protection if, in fact, there is a continuum of health risks in areas with 8-hour average O_3 concentrations that are well below the concentrations observed in the key controlled human exposure studies and if the reported associations observed in the epidemiological studies are, in fact, causally related to O_3 at those lower levels" (73 FR 16483).

In making his final decision about the level of the primary O_3 standard, the Administrator noted that the level of 75 ppb was above the range recommended by CASAC (i.e., 70 to 60 ppb). He concluded that "CASAC's recommendation appeared to be a mixture of scientific and policy considerations" (75 FR 2992). The Administrator reached a different policy judgment than the CASAC Panel, placing less weight than CASAC on the available controlled human exposure studies reporting effects following exposures to 60 ppb O_3 and less weight on the results from exposure and risk assessments, particularly on estimates of exposures to O_3 concentrations at or above 60 ppb (73 FR 16482-3).

[18] The D.C. Circuit, in its review of the 2008 primary standard, stated that it was unclear whether CASAC's advice reflected issues of pure science or issues of science and policy. That is, the court was unable to determine whether CASAC's conclusion in its 2007 letter that the standard be set no higher than 70 ppb "was based on its scientific judgment that adverse effects would occur at that level or instead based on its more qualitative judgment that the range it proposed would be more appropriately protective of human health with an adequate margin of safety." *Mississippi.* 744 F. 3d at 1357.

1.3.1.2 Approach for the Current Review

To identify the range of options appropriate for the Administrator to consider in the current review, we apply an approach that builds upon the general approach used in the last review (and in the 2010 reconsideration proposal) and that reflects the broader body of scientific evidence, updated exposure/risk information, and advances in O_3 air quality modeling now available. As summarized above, the Administrator's decisions in the prior review were based on an integration of information on health effects associated with exposure to O_3, judgments on the adversity and public health significance of key health effects, and expert and policy judgments as to when the standard is requisite to protect public health with an adequate margin of safety.

Staff's conclusions on the primary O_3 standard reflect our consideration of the available scientific evidence, exposure/risk information, and air quality modeling information, within the context of the overarching questions related to: (1) the adequacy of the current primary O_3 standard to protect against effects associated with both short- and long-term exposures and (2) potential alternative standards that are appropriate to consider in this review. In addressing these broad questions, we organize the discussions in chapters 3 and 4 of this document around a series of more specific questions reflecting different aspects of each overarching question. When evaluating the health protection afforded by the current and potential alternative standards, we take into account the four basic elements of the NAAQS: the indicator, averaging time, form, and level.

Figure 1-1 below provides an overview of our approach in this review. We believe that the general approach summarized in this section, and outlined in Figure 1-1, provides a comprehensive basis to help inform the judgments required of the Administrator in reaching decisions about the current and potential alternative primary O_3 standards. In the subsections below, we describe our general approaches to considering the scientific evidence (evidence-based considerations) and to considering the human exposure- and health risk information (exposure- and risk-based considerations). We also recognize considerations related to ambient O_3 attributable to background sources.

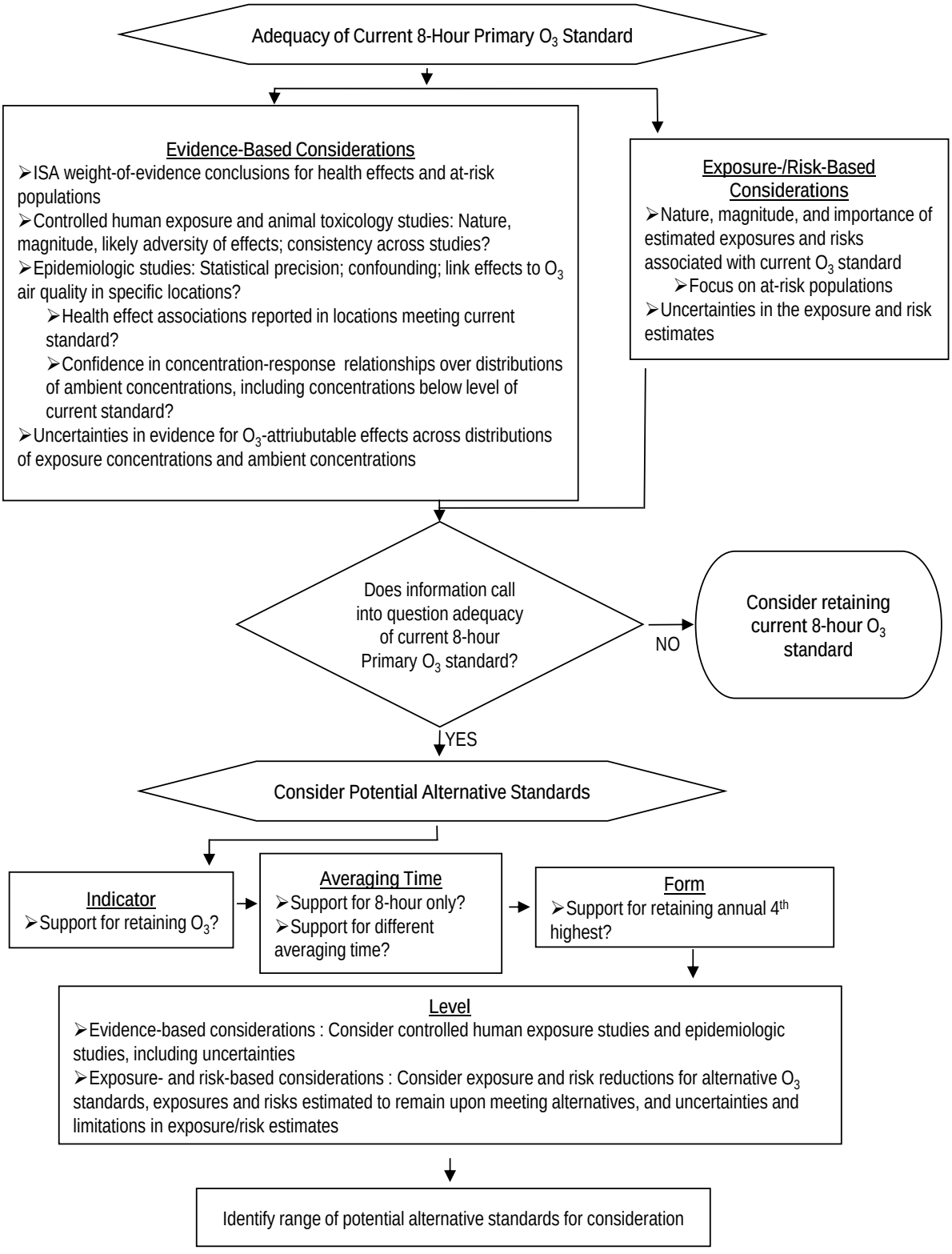

Figure 1-1. Overview of approach to reviewing the primary standard.

1.3.1.2.1 Consideration of the Scientific Evidence

Our approach in this review draws upon an integrative synthesis of the entire body of available scientific evidence for O_3-related health effects, including the evidence newly available in the current review and the evidence from previous reviews, as presented in the ISA (U.S. EPA, 2013).[19] Our approach to considering the scientific evidence is based fundamentally on using information from controlled human exposure and epidemiologic studies, supplemented by information from animal toxicology studies. Such evidence informs our consideration of the health endpoints and at-risk populations on which to focus the current review, and our consideration of the O_3 concentrations at which various health effects can occur.

Since the 2008 review of the O_3 NAAQS, the Agency has developed formal frameworks for characterizing the strength of the scientific evidence with regard to health effects associated with exposures to O_3 in ambient air and factors that may increase risk in some populations or lifestages (U.S. EPA, 2013, Preamble; Chapter 8). These frameworks provide the basis for robust, consistent, and transparent processes for evaluating the scientific evidence, including uncertainties in the evidence, and for drawing weight-of-evidence conclusions on air pollution-related health effects and at-risk populations.

With regard to characterization of health effects, the ISA uses a five-level hierarchy to classify the overall weight-of-evidence into one of the following categories: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship (U.S. EPA, 2013, Preamble Table II). In using the weight of evidence approach to inform judgments about the degree of confidence that various health effects are likely to be caused by exposure to O_3, confidence increases as the number of studies consistently reporting a particular health endpoint grows and as other factors, such as biological plausibility and strength, consistency and coherence of evidence increases. Conclusions about biological plausibility, consistency and coherence of O_3-related health effects are drawn from the integration of epidemiologic studies with mechanistic information from controlled human exposure and animal toxicological studies, as discussed in the ISA (U.S. EPA, 2013, EPA Framework for Causal Determination, p. 1viii). In this PA, we place the greatest

[19]Selection of studies for inclusion in the ISA is based on the general scientific quality of the study, and consideration of the extent to which the study is informative and policy-relevant. Policy relevant and informative studies include those that provide a basis for or describe the relationship between the criteria pollutant and effects. This includes studies that offer innovation in method or design and studies that reduce uncertainty on critical issues, such as analyses of confounding or effect modification by copollutants or other variables, analyses of concentration-response or dose-response relationships, or analyses related to time between exposure and response. Review articles, by contrast, are generally not included because they typically present summaries or interpretations of existing studies. The specific criteria applied to the various types of studies are discussed in more detail in the Preamble to the ISA (U.S. EPA, 2013, Preamble).

weight on the health effects for which the evidence has been judged in the ISA to demonstrate a causal or a "likely to be" causal relationship with O_3 exposures. Our consideration of the available evidence for such effects is presented below in Chapter 3 (consideration of the adequacy of the current standard) and in Chapter 4 (consideration of potential alternative standards).

As discussed below, we further consider the evidence base assessed in the ISA with regard to the types and levels of exposure at which health effects are indicated. This further consideration of the evidence, which directly informs EPA's conclusions regarding the adequacy of current or potential alternative standards in providing requisite public health protection, differs from consideration of the evidence in the ISA with regard to overarching determinations of causality. Therefore, studies that inform determinations of causality may or may not be concluded to be informative with regard to the adequacy of the current or potential alternative standards.[20]

As with health endpoints, the ISA's characterization of the weight-of-evidence for potential at-risk populations is based on the evaluation and synthesis of evidence from across scientific disciplines. The ISA characterizes the evidence for a number of "factors" that have the potential to place populations at increased risk for O_3-related effects. The categories considered in evaluating the evidence for these potential at-risk factors are "adequate evidence," "suggestive evidence," "inadequate evidence," and "evidence of no effect." These categories are discussed in more detail in the ISA (U.S. EPA, 2013, chapter 8, Table 8-1). In this PA, we focus our consideration of potential at-risk populations on those factors for which the ISA judges there is "adequate" evidence (U.S. EPA, 2013, Table 8-6). At-risk populations are discussed in more detail in section 3.2.1, below.

Using the available scientific evidence to inform conclusions on the current and potential alternative standards is complicated by the recognition that a population-level threshold has not been identified, below which it can be concluded with confidence that O_3-attributable effects do not occur (U.S. EPA, 2013, section 2.5.4.4). In the absence of a discernible threshold, our general approach to considering the available O_3 health evidence involves characterizing our confidence in the extent to which O_3-attributable effects occur, and the extent to which such effects are adverse, over the ranges of O_3 exposure concentrations evaluated in controlled human exposure studies and over the distributions of ambient O_3 concentrations in locations where epidemiologic studies have been conducted. As noted above, we recognize that the available

[20]For example, as discussed further in this section and in Chapters 3 and 4 of this PA, we judge that health studies evaluating exposure concentrations near or below the level of the current standard and epidemiologic studies conducted in locations meeting the current standard are particularly informative when considering the adequacy of the public health protection provided by the current standard.

health effects evidence reflects a continuum from relatively high O_3 concentrations, at which scientists generally agree that adverse health effects are likely to occur, through lower concentrations, at which the likelihood and magnitude of a response become increasingly uncertain. Aspects of our approach particular to evidence from controlled human exposure and epidemiologic studies, respectively, are discussed below.

Controlled Human Exposure Studies

Controlled human exposure studies provide direct evidence of relationships between pollutant exposures and human health effects (U.S. EPA, 2013, p.lx). Controlled human exposure studies provide data with the highest level of confidence since they provide human effects data under closely monitored conditions and can provide exposure response relationships. Such studies are particularly useful in defining the specific conditions under which pollutant exposures can result in health impacts, including the exposure concentrations, durations, and ventilation rates under which effects can occur. As discussed in the ISA, controlled human exposure studies provide clear and compelling evidence for an array of human health effects that are directly attributable to acute exposures to O_3 *per se* (i.e., as opposed to O_3 and other photochemical oxidants, for which O_3 is an indicator, or other co-occurring pollutants) (U.S. EPA, 2013, Chapter 6). Together with animal toxicological studies, which can provide information about more serious health outcomes as well as the effects of long-term exposures and mode of action, controlled human exposure studies also help to provide biological plausibility for health effects observed in epidemiologic studies.

In this PA, we consider the evidence from controlled human exposure studies in two ways. First, we consider the extent to which controlled human exposure studies provide evidence for health effects following exposures to different O_3 concentrations, down to the lowest-observed-effects levels in those studies. Second, we use such studies to inform our evaluation of the extent to which we have confidence in health effect associations reported in epidemiologic studies down through lower ambient O_3 concentrations, where the likelihood and magnitude of O_3-attributable effects become increasingly uncertain.

We consider the range of O_3 exposure concentrations evaluated in controlled human exposure studies, including concentrations near or below the level of the current standard. We consider both group mean responses, which provide insight into the extent to which observed changes are due to O_3 exposures rather than to chance alone, and inter-individual variability in responses, which provides insight into the fraction of the population that might be affected by such O_3 exposures (U.S. EPA, 2013, section 6.2.1.1). When considering the relative weight to place on various controlled human exposure studies, we consider the exposure conditions evaluated (e.g., exercising versus resting, exposure duration); the nature, magnitude, and likely adversity of effects over the range of reported O_3 exposure concentrations; the statistical

precision of reported effects; and the consistency of results across studies for a given health endpoint and exposure concentration. In addition, because controlled human exposure studies typically involve healthy individuals and do not evaluate the most sensitive individuals in the population (U.S. EPA, 2013, Preamble p. lx), when considering the implications of these studies for our evaluation of the current and potential alternative standards, we also consider the extent to which reported effects are likely to reflect the magnitude and/or severity of effects in at-risk groups.

Epidemiologic Studies

We also consider epidemiologic studies of short- and long-term O_3 concentrations in ambient air. Epidemiologic studies provide information on associations between variability in ambient O_3 concentrations and variability in various health outcomes, including lung function decrements, respiratory symptoms, school absences, hospital admissions, emergency department visits, and premature mortality (U.S. EPA, 2013, Chapters 6 and 7). Epidemiologic studies can inform our understanding of the effects in the study population (which may include at-risk groups) of real-world exposures to the range of O_3 concentrations in ambient air, and can provide evidence of associations between ambient O_3 levels and serious acute and chronic health effects that cannot be assessed in controlled human exposure studies. For these studies, the degree of uncertainty introduced by confounding variables (e.g., other pollutants, temperature) and other factors affects the level of confidence that the health effects being investigated are attributable to O_3 exposures, alone and in combination with copollutants.

Available studies have generally not indicated a discernible population threshold, below which O_3 is no longer associated with health effects (U.S. EPA, 2013, section 2.5.4.4). However, the currently available epidemiologic evidence indicates decreased confidence in reported concentration-response relationships for O_3 concentrations at the lower ends of ambient distributions (U.S. EPA, 2013, section 2.5.4.4). Therefore, our general approach to considering the results of epidemiologic studies within the context of the current and potential alternative standards focuses on characterizing the range of ambient O_3 concentrations over which we have the most confidence in O_3-associated health effects, and the concentrations below which our confidence in such health effect associations becomes appreciably lower. In doing so, we consider the statistical precision of O_3 health effect associations reported in study locations with various ambient O_3 concentrations; confidence intervals around concentration-response functions reported over distributions of ambient O_3 (where available); and the extent to which the biological plausibility of associations at various ambient O_3 concentrations is supported by evidence from controlled human exposure and/or animal toxicological studies.

We consider both multi-city and single-city studies assessed in the ISA, each of which have strengths and limitations. Multi-city studies evaluate large populations and provide greater

statistical power than single-city studies. Multi-city studies also reflect O_3-associated health impacts across a range of diverse locations, providing spatial coverage for different regions and reflecting differences in exposure-related factors that could impact O_3 risks. In addition, compared to single-city studies, multi-city studies are less prone to publication bias and they afford the possibility of generalizing to the broader national population (U.S. EPA, 2004, p. 8-30). In contrast, while single-city studies are more limited than multicity studies in terms of statistical power and geographic coverage, conclusions regarding the extent to which air quality met the current or potential alternative standards in the cities for which associations have been reported can be made with greater certainty for single-city studies (compared to multicity studies reporting only multicity effect estimates) because the associations are reported for city-specific analyses (U.S. EPA, 2011d, section 2.3.4.1).[21] In some cases, single-city studies can also provide evidence for locations or population-specific characteristics not reflected in multicity studies (U.S. EPA, 2013, section 6.2.7.1). Therefore, when considering available epidemiologic studies we evaluate both multi-city and single-city studies, recognizing the strengths and limitations of each.

In placing emphasis on specific epidemiologic studies, we focus on studies conducted in the U.S. and Canada. Such studies reflect air quality and exposure patterns that are likely more typical of the U.S. population than the air quality and exposure patterns reflected in studies conducted outside the U.S. and Canada.[22] We also focus on studies reporting associations with effects judged in the ISA to be robust to confounding by other factors, including co-occurring air pollutants.

1.3.1.2.2 Consideration of Exposure and Risk Estimates

To put judgments about O_3-related health effects into a broader public health context, we consider exposure and risk estimates from the HREA, which develops and applies models to estimate human exposures to O_3 and O_3-related health risks in urban case study areas across the United States (U.S. EPA, 2014a). The HREA estimates exposures of concern, based on interpreting quantitative exposure estimates within the context of controlled human exposure study results; lung function risks, based on applying exposure-response relationships from controlled human exposure studies to quantitative estimates of exposures; and epidemiologic-based risk estimates, based on applying concentration-response relationships drawn from epidemiologic studies to adjusted air quality. Each of these types of assessments is discussed briefly below.

[21] Though in some cases multicity studies present single-city effect estimates in addition to multi-city estimates.

[22] Though we recognize that a broader body of studies, including international studies, inform the causal determinations in the ISA.

As in the 2008 review, the HREA estimates exposures at or above benchmark concentrations of 60, 70, and 80 ppb, reflecting exposure concentrations of concern based on the available health evidence.[23] Estimates of exposures of concern, defined as personal exposures while at moderate or greater exertion to 8-hour average ambient O_3 levels, at or above these discrete benchmark concentrations provide perspective on the public health impacts of O_3-related health effects that are plausibly linked to the more serious effects seen in epidemiological studies, but cannot be evaluated in quantitative risk assessments. They also help elucidate the extent to which such impacts may be reduced by meeting the current and alternative standards. Estimates of the number of people likely to experience exposures of concern cannot be directly translated into quantitative estimates of the number of people likely to experience specific health effects due to individual variability in responsiveness. Only a subset of individuals can be expected to experience such adverse health effects, and at-risk populations or lifestages, such as people with asthma or children, are expected to be affected more by such exposures than healthy adults. Though this analysis is conducted using discrete benchmark concentrations, health-relevant exposures are more appropriately viewed as a continuum with greater confidence and less uncertainty about the existence of health effects at higher O_3 exposure concentrations and less confidence and greater uncertainty at lower exposure concentrations. This approach recognizes that there is no sharp breakpoint within the exposure-response relationship for exposure concentrations at and above 80 ppb down to 60 ppb.

The HREA also generates quantitative estimates of O_3 health risks for air quality adjusted to just meet the current and potential alternative standards. As noted above, one approach to estimating O_3 health risks is to combine modeled exposure estimates with exposure-response relationships derived from controlled human exposure studies of O_3-induced health effects. The HREA uses this approach to estimate the occurrence of O_3-induced lung function decrements in at-risk populations in urban case study areas, including school-age children, school-age children with asthma, adults with asthma, and older adults. The available exposure-response information does not support this approach for other endpoints evaluated in controlled human exposure studies (U.S. EPA, 2014a, section 2.2.5 to 2.2.7).

Another approach to estimating O_3-associated health risks is to apply concentration-response relationships derived from short- and/or long-term epidemiologic studies to air quality adjusted to just meet current and potential alternative standards. The concentration-response relationships drawn from epidemiologic studies are based on population exposure surrogates, such as 8-hour concentrations averaged across monitors and over more than one day

[23] For example, see 75 FR 2945-2946 (January 19, 2010) and 73 FR 16441-16442 (March 27, 2008) discussing "exposures of concern".

(incorporation of lag) (U.S. EPA, 2013, Chapter 6). The HREA presents epidemiologic-based risk estimates for O_3-associated mortality, hospital admissions, emergency department visits, and respiratory symptoms (U.S. EPA, 2014a, Chapter 7). These estimates are derived from the full distributions of ambient O_3 concentrations estimated for the study locations.[24] In addition, the HREA estimates mortality risks associated with various portions of distributions of short-term O_3 concentrations (U.S. EPA, 2014a). In this PA we consider risk estimates based on the full distributions of ambient O_3 concentrations and, when available, estimates of the risk associated with various portions of those ambient distributions.[25] In doing so, we take note of the ISA conclusions regarding confidence in linear concentration-response relationships over distributions of ambient concentrations, and of the extent to which health effect associations at various ambient O_3 concentrations are supported by the evidence from experimental studies for effects following specific O_3 exposures.

1.3.1.2.3 Considerations Regarding Ambient O_3 Concentration Estimates Attributable to Background Sources

As noted above, our approach in this review utilizes recent advances in modeling techniques to estimate the contributions of U.S. anthropogenic, international anthropogenic, and natural sources to ambient O_3 (discussed in detail in Chapter 2 of this PA). Such model estimates can provide insights into the extent to which different types of background emissions sources contribute to total ambient O_3 concentrations. Consideration of this issue in the current review is informed by the approaches taken in previous reviews, as well as by court decisions in subsequent litigation.

In 1979, the EPA set a 1-hour O_3 standard with a level of 0.12 ppm. Following the final decision in that review, the City of Houston argued that the standard was arbitrary and capricious because natural O_3 concentrations and other physical phenomena in the Houston area made the standard unattainable in that area. The D.C. Circuit rejected this argument, stating that attainability and technological feasibility are not relevant considerations in the promulgation of the NAAQS. The Court also noted that the EPA need not tailor the NAAQS to fit each region or locale, pointing out that Congress was aware of the difficulty in meeting standards in some

[24] In previous reviews, including the 2008 review and reconsideration, such risks were separately estimated for O_3 concentrations characterized as above policy-relevant background concentrations. Policy-relevant background concentrations were defined as the distribution of ozone concentrations attributable to sources other than anthropogenic emissions of ozone precursor emissions (e.g., VOC, CO, NOx) in the U.S., Canada, and Mexico. The decision to estimate total risk across the full range of O_3 concentrations reflects current OAQPS views and consideration of advice from CASAC (Frey and Samet, 2012b).

[25] In a series of sensitivity analyses, the HREA also evaluates a series of threshold models for respiratory mortality associated with long-term O_3 concentrations. In this PA we consider these risk estimates based on threshold models, in addition to HREA core estimates based on the linear model (sections 3.2.3.2, 4.4.2.3).

locations and had addressed this difficulty through various compliance related provisions in the Act. See API v. Costle, 665 F.2d 1176, 1184-6 (D.C. Cir. 1981).

More recently, in the 1997 review of the O_3 NAAQS, the Administrator set an 8-hour standard with a level of 0.08 ppm (84 ppb). In reaching this decision, the EPA identified several reasons supporting its decision to reject a more stringent standard of 0.07 ppm. Most importantly, the EPA pointed out the scientific uncertainty at lower concentrations and placed significant weight on the fact that no CASAC panel member supported a standard level set lower than 0.08 ppm (62 FR 38868). In addition to noting the uncertainties in the health evidence for exposure concentrations below 0.08 ppm and the advice of CASAC, the EPA noted that a standard set at a level of 0.07 ppm would be closer to peak background concentrations that infrequently occur in some areas due to nonanthropogenic sources of O_3 precursors (62 FR 38856, 38868; July 18, 1997).

In subsequent litigation, the D.C. Circuit upheld the EPA's decision as the product of reasoned decision-making. The Court made clear that the most important support for the EPA's decision was the health evidence and the concerns it raised about setting a standard level below 0.08 ppm. The Court also pointed to the significant weight that the EPA properly placed on the advice it received from CASAC. Finally (as discussed in section 1.2.2 above), the Court noted that the EPA could also consider relative proximity to peak natural background O_3 when considering alternatives within the range of reasonable values supported by the scientific evidence and judgments of the Administrator. See ATA III, 283 F.3d at 379 (D.C. Cir. 2002).

These cases provide a framework for considering the contributions of U.S. anthropogenic, international anthropogenic, and natural sources within the context of considering the health evidence and CASAC advice, when evaluating various potential alternative standards. Consistent with such a framework, this PA identifies the range of policy options for the primary O_3 standard that staff concludes are appropriate to consider in light of the available scientific evidence and exposure/risk information, and the advice of CASAC. In identifying the range of policy options supported by the evidence and information, staff has not considered proximity to background O_3 concentrations. The Administrator, when evaluating the range of possible standards that are supported by the scientific evidence, could consider proximity to background O_3 concentrations as one factor in selecting the appropriate standard.

1.3.2 Approach for the Secondary Standard

Staff's approach in this review of the current secondary standard takes into consideration aspects of the approaches used in past O_3 NAAQS reviews. The past and current approaches, generally described below, are both based fundamentally on using EPA's assessment of the current scientific evidence and associated quantitative analyses to inform the Administrator's

judgment regarding a secondary standard for O_3 that is requisite (i.e., neither more nor less stringent than necessary) to protect public welfare.

In reaching conclusions on options for the Administrator's consideration, we note that the final decision to retain or revise the current secondary O_3 standard is a public welfare policy judgment to be made by the Administrator. This final decision will draw upon the available scientific evidence for O_3-attributable welfare effects and on analyses of vegetation and ecosystem exposures and public welfare risks based on impacts to vegetation, ecosystems and their associated services, including judgments about the appropriate weight to place on the range of uncertainties inherent in the evidence and analyses. In determining the requisite level of protection for crops and trees, the Administrator will need to weigh the importance of the predicted risks of these effects in the overall context of public welfare protection, along with a determination as to the appropriate weight to place on the associated uncertainties and limitations of this information. Our general approach to informing these judgments, discussed more fully below, recognizes that the available evidence demonstrates a range of O_3 sensitivity across studied plant species and documents an array of O_3-induced effects that extend from lower to higher levels of biological organization. These effects range from those affecting cell processes and individual plant leaves to effects on the physiology of whole plants, species effects and effects on plant communities to effects on related ecosystem processes and services. Given this evidence, it is not possible to generalize across all studied species regarding which cumulative exposures are of greatest concern, as this can vary by situation due to differences in exposed species sensitivity, the importance of the observed or predicted O_3-induced effect, the role that the species plays in the ecosystem, the intended use of the affected species and its associated ecosystem and services, the presence of other co-occurring predisposing or mitigating factors, and associated uncertainties and limitations. At the same time, the evidence also demonstrates that though effects of concern can occur at very low exposures in sensitive species, at higher cumulative exposures those effects would likely occur at a greater magnitude and/or higher levels of biological organization and additional species would likely be impacted. It is important to note, however, due to the variability in the importance of the associated ecosystem services provided by different species at different exposures and in different locations, as well as differences in associated uncertainties and limitations, adverse effects observed or predicted at lower exposures along the exposure continuum may or may not have less public welfare significance than those observed at higher cumulative exposures. Therefore, in developing conclusions in this final PA, we take note of the complexity of judgments to be made by the Administrator regarding the adversity of known and anticipated effects to the public welfare and are mindful that the Administrator's ultimate judgments on the secondary standard will most appropriately reflect an interpretation of the available scientific evidence and exposure/risk

information that neither overstates nor understates the strengths and limitations of that evidence and information.

Section 1.3.2.1 below provides an overview of the general approach taken in the last review of the secondary standard for O_3 (i.e., the 2008 review), and a summary of the rationale for the decision on the standard in that review (73 FR 16436). Section 1.3.2.2 presents our approach in the current review, including our approach to considering the vegetation effects evidence and exposure/risk information, and considerations regarding ambient O_3 concentrations attributable to background sources.

1.3.2.1 Approach Used in the Last Review

In the 2008 review of the secondary NAAQS for O_3, the Administrator relied upon consideration of the available scientific evidence and exposure/risk information, information regarding biologically-relevant exposure indices, air quality information regarding the degree of overlap between different exposure index forms, the advice and recommendations of CASAC, considerations regarding adversity, and comments from the public. Based on all of this, he revised the level of the secondary O_3 standard from 0.08 ppm[26] to 0.075 ppm (75 ppb[27]).

In reaching a decision to revise the 1997 8-hour secondary standard, the Administrator found, after carefully considering the public comments, that the fundamental scientific conclusions on the effects of O_3 on vegetation and sensitive ecosystems reached in the 2006 Criteria Document and 2007 Staff Paper, as discussed in section IV.A of the final rule remained valid (73 FR 16496). He further recognized that several additional lines of evidence had progressed sufficiently since the 1997 review to provide a more complete and coherent picture of the scope of O_3-related vegetation risks (i.e., visible foliar injury, tree biomass loss, crop yield loss, and others), especially those faced by sensitive seedling, sapling and mature growth stage tree species growing in field settings, and their associated forested ecosystems. This new research reflected an increased emphasis on field-based exposure methods (e.g., free-air, ambient gradient and biomonitoring surveys) (73 FR 16490) in addition to the more traditional controlled open-top chamber (OTC) studies (73 FR 16485), and began to address one of the key data gaps cited by the Administrator in the 1997 review (73 FR 16486). Specifically, by providing additional evidence that O_3-induced crop yield loss and tree seedling biomass loss effects observed in chambers also occurs in the field, this new research qualitatively increased support

[26] As noted earlier, due to rounding convention, the 1997 standard level of 0.08 ppm corresponded to 0.084 ppm (84 ppb).

[27] As explained above, the level of the O_3 standard is specified as 0.075 ppm rather than 75 ppb. However, in this draft PA we refer to ppb, which is most often used in the scientific literature and in the ISA, in order to avoid the confusion that could result from switching units when discussing the evidence in relation to the standard level.

for, and confidence in, the continued use of OTC-derived crop and tree seedling exposure-response (E-R) functions developed in the National Crop Loss Assessment Network (NCLAN) and National Health and Environmental Effects Research Laboratory – Western Ecology Division (NHEERL-WED) studies, respectively, to predict O_3-induced impacts on crops and tree seedlings in the field (72 FR 37886). All of these areas were considered together, along with associated uncertainties, in an integrated weight-of-evidence approach (73 FR 16490).

Beyond the available vegetation effects evidence, the Administrator also considered estimates of O_3 exposures and risks when air quality was adjusted to simulate just meeting the existing and potential alternative standards. On the basis of these assessments, the Administrator concluded that O_3 exposures that would be expected to remain after meeting the existing standard would be sufficient to cause visible foliar injury and seedling and mature tree biomass loss in O_3-sensitive vegetation (73 FR 16496) and would still allow O_3-related yield loss to occur in some commodity crop species and fruit and vegetable species grown in the U.S. (73 FR 16489). Other O_3-induced effects described in the literature, including an impaired ability of many sensitive species and genotypes within species to adapt to or withstand other environmental stresses, such as freezing temperatures, pest infestations and/or disease, and to compete for available resources, would also be anticipated to occur. In the long run, the result of these impairments (e.g., loss in vigor) could lead to premature plant death in O_3 sensitive species. Though effects on other ecosystem components had only been examined in isolated cases, the Administrator noted effects such as those described above could have significant implications for plant community and associated species biodiversity and the structure and function of whole ecosystems (73 FR 16496).

Although the Administrator concluded that the then-current standard was not sufficient to protect against the known and anticipated effects described above, he also recognized that the secondary standard is not meant to protect against all known observed or anticipated O_3-related effects, but only those that can reasonably be judged to be adverse to the public welfare. The Administrator found that the degree to which such effects should be considered to be adverse depended on the intended use of the vegetation and its significance to the public welfare (73 FR 16496). In this regard, he took note of a number of actions taken by Congress to establish public lands that are set aside for specific uses that are intended to provide benefits to the public welfare, including lands that are to be protected so as to conserve the scenic value and the natural vegetation and wildlife within such areas, and to leave them unimpaired for the enjoyment of future generations. Based on these considerations, and taking into consideration the advice and recommendations of CASAC, the Administrator concluded that the protection afforded by the existing standard was not sufficient, and that the standard needed to be revised to provide

additional protection from known and anticipated adverse effects on sensitive natural vegetation and ecosystems (73 FR 16497).

Given this judgment, the Administrator then considered what revisions to the standard were requisite to protect public welfare. Regarding the form of the standard, the Administrator took note that at the conclusion of the 1997 review, the biological basis for a cumulative, seasonal form was not in dispute[28] and that the 2006 Criteria Document also concluded that O_3 exposure indices that cumulate differentially-weighted hourly concentrations are the best candidates for relating exposure to plant growth responses (EPA, 2006) (61 FR 65716; 73 FR 16486). The CASAC, in its letter to the Administrator following its review of the second draft Staff Paper, stated that "there is a clear need for a secondary standard which is distinctly different from the primary standard in averaging time, level and form" and that "the CASAC unanimously agrees that it is not appropriate to try to protect vegetation from the substantial, known or anticipated, direct and/or indirect, adverse effects of ambient ozone by continuing to promulgate identical primary and secondary standards for ozone" (Henderson, 2006, pp. 5-7). Although many possible cumulative, seasonal concentration-weighted exposure metrics exist, the Staff Paper and the CASAC Panel concluded that the W126[29] form is the most biologically-relevant cumulative, seasonal form appropriate to consider in the context of the secondary standard review (73 FR 16486-87).[30]

Although agreeing with the Criteria Document, Staff Paper and CASAC conclusions that a cumulative exposure index that differentially weights O_3 concentrations could represent a reasonable policy choice for a seasonal secondary standard to protect against the effects of O_3 on vegetation and that the most appropriate cumulative, concentration-weighted form to consider was the sigmoidally-weighted W126 form (73 FR 16498), the Administrator also took note of the 1997 decision to make the revised secondary standard identical to a revised primary standard after similar considerations (73 FR 16498). In considering the rationale for the 1997 decision, the Administrator observed that it was based in part on an analysis that compared the degree of

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[28] In the 1997 review, a different cumulative metric (SUM06) was proposed.

[29] W126 is a cumulative exposure index that is biologically based. The W126 index focuses on the higher hourly average concentrations, while retaining the mid-and lower-level values. It is defined as the sum of sigmoidally-weighted hourly O_3 concentrations over a specified period, where the daily sigmoidal weighting function is defined as: $\mathbf{1 - exp[-(W126/\eta)^{\beta}]}$

[30] In a subsequent letter offering unsolicited advice to the Administrator and Agency staff on development of the proposed rulemaking, the CASAC reiterated that Panel members ''were unanimous in supporting the recommendation in the Final Ozone Staff Paper that protection of managed agricultural crops and natural terrestrial ecosystems requires a secondary Ozone NAAQS that is substantially different from the primary ozone standard in averaging time, level and form"...and "[t]he recommended metric for the secondary ozone standard is the (sigmoidally-weighted) W126 index, accumulated over at least the 12 'daylight' hours and over at least the three maximum ozone months of the summer 'growing season" (Henderson, March 26, 2007, p.3).

overlap in county-level air quality measured in terms of alternative standard forms (62 FR 38876). Recognizing that significant uncertainty remained in 1997 regarding conclusions drawn from such analyses, the Administrator also considered the results of a similar analysis of recent monitoring data undertaken in the 2007 Staff Paper to assess the degree of overlap expected between the existing standard (4^{th} high, daily maximum 8-hour concentration averaged over three years) and potential alternative standards based on W126 cumulative seasonal forms.

The Administrator noted that this analysis showed significant overlap between the 8-hour secondary standard and selected levels of W126 standard forms, with the degree of overlap between these potential alternative standards depending greatly on the W126 level selected and the distribution of hourly O_3 concentrations within the annual and/or 3-year average period. From this analysis, the Administrator recognized that a secondary standard set identical to a revised primary standard would provide a significant degree of additional protection for vegetation as compared to that provided by the existing secondary standard. In further considering the significant uncertainties in the available body of evidence and in the exposure and risk analyses, and the difficulty in determining at what point various types of vegetation effects become adverse for sensitive vegetation and ecosystems, the Administrator focused his consideration on a level for an alternative W126 standard (with an annual form) at the upper end of the proposed range (i.e., 21 ppm-hours). The Staff Paper analysis showed that at a W126 level of 21 ppm-hours, there would be essentially no counties with air quality expected both to exceed such an alternative W126 standard and to meet the revised 8-hour primary standard—that is, based on this analysis of counties with ambient O_3 monitors, a W126-based level of 21 ppm-hours would be unlikely to provide additional protection in any areas beyond that likely to be provided by the revised 2008 primary standard (73 FR 16499/500).

The Administrator also considered the Staff Paper finding that the degree of overlap between counties (with areas of concern for vegetation) expected to meet an 8-hour level for the form of the existing standard and potential alternative levels of a W126-based standard was inconsistent across years analyzed. This variation depended greatly on levels selected for a W126-based standard and a 3-year average 4^{th} high daily maximum 8-hour standard, respectively, and the distribution of hourly O_3 concentrations within the annual and/or 3-year average period. From this, the Staff Paper recognized the need for caution in evaluating the likely vegetation impacts associated with a given level of air quality expressed in terms of the existing 8-hour average standard in the absence of parallel W126 information. In considering these findings, the Administrator "recognize[d] that the general lack of rural monitoring data made uncertain the degree to which the revised 8-hour standard or an alternative W126 standard would be protective, and that there was the potential for not providing the appropriate degree of protection for vegetation in areas with air quality distributions that resulted in a high cumulative,

seasonal exposure but did not result in high 8-hour average exposures" (73 FR 16500). With regard to the 8-hour standard, he also noted that "[w]hile this potential for under-protection was clear, the number and size of areas [then] at issue and the degree of risk [was] hard to determine. However, such a standard would also tend to avoid the potential for providing more protection than is necessary, a risk that would have arisen from moving to a new form for the secondary standard despite the significant uncertainty in determining the degree of risk for any exposure level and the appropriate level of protection, as well as uncertainty in predicting exposure and risk patterns" (73 FR 16500).

Thus, although the Administrator agreed with the views and recommendations of CASAC that a cumulative, seasonal standard was the most biologically relevant way to relate exposure to plant growth response, he also recognized that there remained significant uncertainties in determining or quantifying the degree of risk attributable to varying levels of O_3 exposure, the degree of protection that any specific cumulative, seasonal standard would produce, and the associated potential for error in determining the secondary standard that would provide a requisite degree of protection—i.e., sufficient but not more than what is necessary. Given these significant uncertainties, the Administrator concluded that establishing a new secondary standard with a cumulative, seasonal form, at that time, would have resulted in uncertain benefits beyond those afforded by the revised primary standard, and therefore, might have been more than necessary to provide the requisite degree of protection (73 FR 16500). Based on his consideration of these issues (73 FR 16497), the Administrator judged that the appropriate balance to be drawn was to set a secondary standard identical in every way to the revised 8-hour primary standard of 0.075 ppm. The Administrator believed that such a standard would be sufficient to protect public welfare from known or anticipated adverse effects, and did not believe that an alternative cumulative, seasonal standard was needed to provide this degree of protection (73 FR 16500).

As noted above, on July 23, 2013 the D.C. Circuit found this approach to be contrary to law because the EPA had failed to identify a level of air quality requisite to protect public welfare and, therefore, the EPA's comparison between the primary and secondary standards for determining if requisite protection for public welfare was afforded by the primary standard was inherently arbitrary. The court remanded the secondary standard to the EPA for further consideration. 744 F. 3d at 1360-62.

1.3.2.2 Approach for the Current Review

To identify the range of options appropriate for the Administrator to consider in the current review, we apply an approach that builds upon the general approach used in the 2008 review (and in the 2010 reconsideration proposal), and that reflects the broader body of scientific

evidence, updated exposure/risk information, and advances in O_3 air quality modeling now available. As summarized above, the Administrator's decisions in the prior review were based on an integration of information on welfare effects associated with exposure to O_3, judgments on the adversity and public welfare significance of key effects, and, expert and policy judgments as to when the standard is requisite to protect public welfare. These considerations were informed by air quality and related analyses, quantitative exposure and risk assessments, and qualitative assessment of impacts that could not be quantified. In performing the evaluation in this document, we are additionally mindful of the recent remand of the secondary standard by the D.C. Circuit and our approach in the current review incorporates our response to this remand.

Our approach in this review of the secondary O_3 standard also reflects our consideration of the available scientific evidence, information on biologically-relevant exposure indices, exposure/risk information, and air quality modeling information, within the context of overarching questions related to: (1) the adequacy of the current secondary O_3 standard to protect against effects associated with cumulative, seasonal exposures and (2) potential alternative standards, if any, that are appropriate to consider in this review. In addressing these broad questions, we have organized the discussions in chapters 5 and 6 of this document around a series of more specific questions reflecting different aspects of each overarching question. When evaluating the welfare protection afforded by the current or potential alternative standards, we take into account the four basic elements of the NAAQS: the indicator, averaging time, form, and level.

Figure 1-2 below provides an overview of our approach in this review. We believe that the general approach summarized in this section, and outlined in Figure 1-2, provides a comprehensive basis to help inform the judgments required of the Administrator in reaching decisions about the current and potential alternative secondary O_3 standards. In the subsections below, we summarize our general approaches to considering the scientific evidence (evidence-based considerations) and to considering the exposure and risk information (exposure- and risk-based considerations).

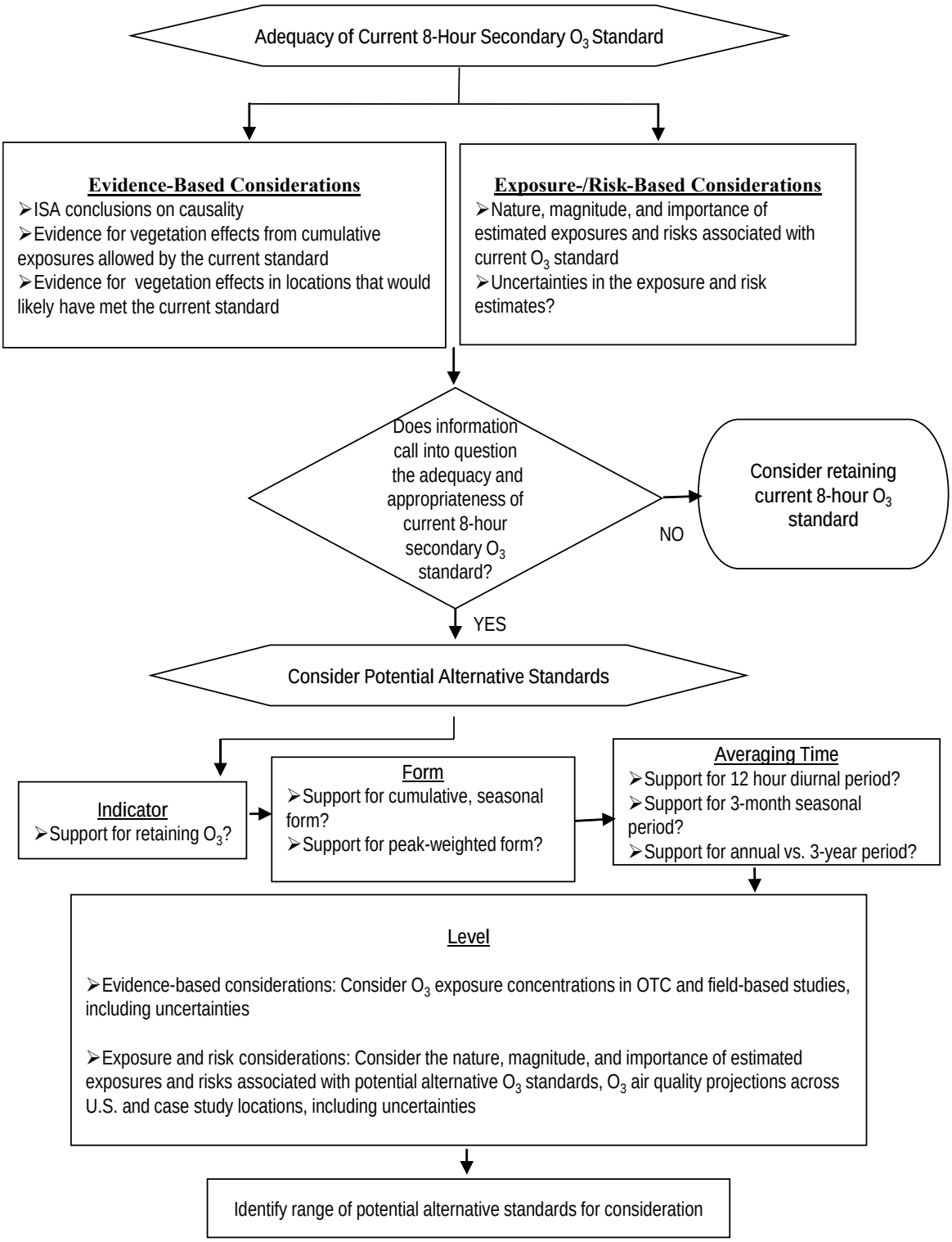

Figure 1-2. Overview of approach to reviewing the secondary standard.

1.3.2.2.1 Consideration of the Scientific Evidence

Our approach in this review draws upon an integrative synthesis of the entire body of available scientific evidence for O_3-related welfare effects, including the evidence newly available in the current review and the evidence from previous reviews, as presented in the ISA (U.S. EPA, 2013). Our approach to considering the scientific evidence for effects on vegetation is based fundamentally on using information from controlled chamber studies and field-based studies. Such evidence informs our consideration of welfare endpoints and at-risk species and ecosystems on which to focus the current review, and our consideration of the ambient O_3 conditions under which various welfare effects can occur.

As in each NAAQS review, we consider the entire body of evidence for the subject criteria pollutant. With regard to identification of the welfare effects that could be caused by a pollutant, we look to controlled exposure studies using chamber or free air methodologies and field-based observational, survey and gradient studies. Evaluating all of the evidence together, the ISA makes a determination with regard to the strength of the evidence for a causal relationship between the air pollutant and specific welfare effects. These determinations inform our identification of welfare effects for which the NAAQS may provide protection.

Since the 2008 review of the O_3 NAAQS, the Agency has developed a formal framework for characterizing the strength of the scientific evidence with regard to a causal relationship between ambient O_3 and welfare effects (U.S. EPA, 2013, Preamble; Chapter 9). This framework provides the basis for a robust, consistent, and transparent process for evaluating the scientific evidence, including uncertainties in the evidence, and for drawing weight-of-evidence conclusions regarding air pollution-related welfare effects. In so doing, the ISA uses a five-level hierarchy, classifying the overall weight of evidence into one of the following categories: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship (U.S. EPA, 2013, Preamble Table II). In our approach here, we place the greatest weight on the evidence for welfare effects that have been judged in the ISA to be caused by, or likely to be caused by, O_3 exposures. Our consideration of the available evidence for such effects is presented below in Chapter 5 (consideration of the adequacy of the current standard) and in Chapter 6 (consideration of potential alternative standards).

We further consider the evidence base, as assessed in the ISA, with regard to the types and levels of exposure at which welfare effects are indicated. This further consideration of the evidence base, which directly informs the EPA's conclusions regarding the adequacy of current or potential alternative standards in providing requisite public welfare protection, differs from consideration of the evidence in the ISA with regard to overarching determinations of causality.

Studies that have informed determinations of causality may or may not be concluded to be informative with regard to the adequacy of the current or potential alternative standards.

Our approach in this review, as in past reviews, included recognition that the available evidence has not provided identification of a threshold in exposure or ambient O_3 concentrations below which it can be concluded with confidence that O_3-attributable vegetation effects do not occur across the broad range of O_3-sensitive plant species growing within the U.S. This is due in part to the fact that research shows that there is variability in sensitivity between and within species and that numerous factors, i.e. chemical, physical, biological, and genetic, can influence the direction and magnitude of the studied effect (U.S. EPA, 2013, section 9.4.8). In the absence of a discernible threshold, our general approach to considering the available O_3 welfare evidence involves characterizing our confidence in conclusions regarding O_3-attributable vegetation effects over the ranges of cumulative seasonal O_3 exposure values evaluated in chamber studies and in field studies in areas where O_3-sensitive vegetation are known to occur, as well as characterizing the extent to which these effects can be considered adverse. In addition, because O_3 can indirectly affect other ecosystem components (such as soils, water, and wildlife, and their associated goods and services, through its effects on vegetation) our approach also considers those indirect effects for which the ISA concludes, based on multiple lines of evidence, including mechanistic and physiological processes, to have a causal or likely to be a causal relationship. With respect to ecosystem services for which we may have only limited or qualitative information regarding an association with O_3 exposures, our approach is to consider their policy-relevance in the context of section 109(b) (2) of the CAA which specifies that secondary standards provide requisite protection of "public welfare from any … known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air". As noted above, our approach to informing these judgments, discussed more fully below, recognizes that the available welfare effects evidence demonstrates a wide range in O_3 sensitivities across studied plant species. As a result, at relatively high cumulative O_3 exposures, a greater number of plant species will show effects, and the magnitude of the observed effects will be greater, particularly on the more sensitive species, while at lower cumulative O_3 exposures, fewer species will demonstrate effects and the magnitude of those observed effects will be less.

In this review, the evidence base includes quantitative information across a broad array of vegetation effects (e.g., growth impairment during seedlings, saplings and mature tree growth stages, visible foliar injury, and yield loss in annual crops) and across a diverse set of exposure methods from laboratory and field studies. These methods include the more traditional OTC studies, as well as field-based exposure studies. While we consider the full breadth of information available, we place greater weight on U.S. studies due to the often species-, site-, and climate-specific nature of O_3-related vegetation responses. We especially weight those

studies that include O_3 exposures that fall within the range of those likely to occur in the ambient air. Further, our approach in the context of the quantitative exposure and risk assessments (discussed below), places greatest emphasis on studies that have evaluated plant response over multiple exposure levels and developed exposure-response relationships that allow the prediction (estimation) of plant responses over the range of potential alternative standards being assessed.

In considering the evidence, we recognize differences across different study types in what information they provide. For example, because conditions can be controlled in laboratory studies, responses in such studies may be less variable and smaller differences may be easier to detect. However, the control conditions may limit the range of responses or incompletely reflect pollutant bioavailability, so they may not reflect responses that would occur in the natural environment. Alternatively, field data can provide important information for assessments of multiple stressors or where site-specific factors significantly influence exposure. They are also often useful for analyses of larger geographic scales and higher levels of biological organization. However, because most field study conditions cannot be controlled, variability is expected to be higher and differences harder to detect. The presence of confounding factors can also make it difficult to attribute observed effects to specific stressors.

In considering information from across multiple lines of evidence, our approach is to first integrate the evidence from both controlled and field-based studies and assess the coherence and consistency across the available evidence for each effect. We then consider the extent to which these identified effects should be considered adverse to the public welfare, relying largely on the paradigm used in the 2008 review and 2010 proposed reconsideration (e.g., 75 FR 3006). This paradigm recognizes that the significance to the public welfare of O_3-induced effects on sensitive vegetation growing within the U.S. can vary depending on the nature of the effect, the intended use of the sensitive plants or ecosystems, and the types of environments in which the sensitive vegetation and ecosystems are located. Accordingly, any given O_3-related effect on vegetation and ecosystems (e.g., biomass loss, crop yield loss, foliar injury) may be judged to have a different degree of impact on the public welfare depending, for example, on whether that effect occurs in a Class I area, a city park, or commercial cropland. Our approach takes this variation in the significance of O_3-related vegetation effects into account in evaluating the currently available evidence with regard to the extent to which it calls into question the adequacy of the current standard and, as appropriate, indicates potential alternative standards that would be appropriate for the Administrator to consider. In the 2010 proposed reconsideration, the Administrator proposed to place the highest priority and significance on vegetation and ecosystem effects to sensitive species that are known to or are likely to occur in federally protected areas such as national parks and other Class I areas, or on lands set aside by States, Tribes and public interest groups to provide similar benefits to the public welfare (75 FR 3023/24). Our approach in this

review considers whether newly available information would suggest any evolution to this paradigm, in particular in the context of considering associated ecosystem services.

Finally, our approach continues to give great weight to the scientific evidence available in this and previous reviews indicating the relevance of cumulative, seasonal, concentration-weighted exposures in inducing vegetation effects. More specifically, in the 2008 and 2010 reviews, the EPA concluded and the CASAC agreed that the W126 cumulative exposure metric was the most appropriate to use in this review to evaluate both the adequacy of the current secondary standard and the appropriateness of any potential revisions. As discussed in chapter 5 in this PA, the information available in this review continues to support the use of such a metric and does not call into question the appropriateness of using the W126 metric in this context. Therefore, both the WREA and PA continue to express exposures in terms of the W126 index, and continue to consider the important policy implications regarding selection of an appropriate exposure index for vegetation. Our approach also places primary emphasis on studies that evaluated plant response to exposures that were or can be described using such an index. The policy-relevant discussions in chapters 5 and 6 focus on vegetation effects evidence and exposure/risk information that can be associated with cumulative, seasonal peak-weighted exposures, where possible. Discussions pertaining to the adequacy of the current secondary standard will consider what cumulative seasonal exposures would be allowed under air quality that would just meet the current standard.

1.3.2.2.2 Consideration of Exposure and Risk Estimates and Air Quality Analyses

To put judgments about O_3-related vegetation and ecosystem effects and services into a broader public welfare context, we consider national scale exposure and risk assessments described in the WREA (U.S. EPA, 2014b). We particularly focused on the WREA quantitative risks related to three types of vegetation effects: foliar injury, biomass loss, and crop yield loss. These risks were assessed in a range of WREA analyses variously involving recent O_3 monitoring data and/or national-scale adjusted air quality scenarios for the current secondary standard and, in some analyses, for a cumulative, seasonal W126 form at one or more levels (15, 11 and 7 ppm-hours). Our consideration of these WREA results provide insight into the extent to which the current or potential alternative standards would be expected to maintain distributions of cumulative, seasonal O_3 exposures below those associated with adverse vegetation effects.

With regard to quantitative O_3 risks related to welfare effects and ecosystem services for foliar injury, we consider two main analyses in the WREA: a screening-level assessment of 214 National Parks and a case study focused on three National Parks. In the screening-level assessment, O_3 concentrations in national parks are assessed using criteria developed from a U.S. Forest Service nationwide dataset on foliar injury, ambient O_3 concentrations (in terms of W126

index) and soil moisture (which can influence susceptibility of vegetation to foliar injury). Additionally, we consider a case study for three Class I areas (Great Smoky Mountain National Park, Rocky Mountain National Park, and Sequoia/Kings Canyon National Park). We consider results from this case study for three metrics: 1) percent of vegetation cover affected by foliar injury; 2) percent of trails affected by foliar injury; 3) estimates of species specific biomass loss within the case study area. We also consider qualitative analyses on ecosystem services effects for this endpoint. For example, the WREA uses GIS mapping to illustrate where effects may be occurring and relates those areas to national scale statistics for recreational use and data on hiking trails, campgrounds and other park amenities that intersect with potentially affected areas. These are used to identify impacts on ecosystem services associated with recreation in national parks. We additionally consider analyses showing associations between elevated O_3 concentrations and increased vulnerability to fire risk regimes, insect attacks and impacts on hydrological cycles.

With regard to risks related to biomass and crop yield loss, we consider WREA results based on exposure-response functions for tree and crop species that predict the growth or yield response of each species, based on the exposure patterns estimated within its growing region. To compare exposure-response across species, genotypes or experiments for which absolute response values may vary greatly, the WREA instead uses estimates of relative biomass loss for trees or yield loss for crops. The WREA develops such estimates nationally and separately for more than 100 federally designated Class I areas. Additionally, we consider WREA-developed estimates of associated impacts on the agriculture and forestry sectors quantifying how O_3 exposure to vegetation is estimated to affect the provision of timber and crops and carbon sequestration. We consider estimates for impacts related to tree biomass loss on ecosystem services such as pollution removal, carbon storage and sequestration in five urban case study areas. We consider biomass and crop yield loss estimates in light of advice from CASAC, as discussed in sections 5.3 and 5.4 below.

In considering the amount of weight to place on the estimates of exposures and risks at or above specific W126 values described in the WREA, our approach: 1) evaluates the weight of the scientific evidence concerning vegetation effects associated with those O_3 exposures; 2) considers the importance, from a public welfare perspective, of the O_3-induced effects on sensitive vegetation and associated ecosystem services that are known or anticipated to occur as a result of exposures at selected W126 values; and, 3) recognizes that predictions of effects associated with any given O_3 exposure may be mitigated or exacerbated by actual conditions in the field (i.e., co-occurring modifying environmental and genetic factors). When considering analyses in the WREA that involve discrete exposure levels or varying levels of severity of effects, our approach to informing these judgments recognizes that the available welfare effects

evidence demonstrates a wide range in O_3 sensitivities across studied plant species. As a result, at relatively high cumulative O_3 exposures, a greater number of plant species will show effects, and the magnitude of the observed effects will be greater, particularly on the more sensitive species, while at lower cumulative O_3 exposures, fewer species will demonstrate effects and the magnitude of those observed effects will be less. We recognize that there is no sharp breakpoint along this continuum of effects incidence and severity, ranging from concentrations at and above the level of the current secondary standard down to the lowest cumulative, seasonal W126 value assessed. In considering these results in this PA, we consider both the potential for welfare effects and their severity and our understanding of the likelihood of such effects at different O_3 exposures.

1.3.2.2.1 Considerations Regarding Ambient O_3 Concentration Estimates Attributable to Background Sources

As noted above, our approach in this review utilizes recent advances in modeling techniques to estimate the contributions of U.S. anthropogenic, international anthropogenic, and natural sources to ambient O_3 (discussed in detail in Chapter 2 of this document). Such model estimates can provide insights into the extent to which different types of emissions sources contribute to total ambient O_3 concentrations. Our consideration of this issue in the current review is informed by the approaches taken in previous reviews, and by court decisions on subsequent litigation, as discussed in section 1.3.1.2.3 above. Further, in the 1996 proposal, O_3 background concentrations were one of the factors the Administrator considered in selecting the SUM06 index as a form for an alternative secondary standard. This and other cumulative exposure indices under consideration were judged to be equally capable at estimating exposures relevant to vegetation, given the lack of evidence for a discernible threshold for vegetation effects in general (U.S. EPA 1996, p. 225), which might have provided a scientific basis for selecting among different cumulative exposure indices. At that time, the SUM06 metric was selected over the W126 metric because it focused on the policy-relevant (above background) portion of the total cumulative seasonal exposures reaching plants (62 FR 38856). At the conclusion of that review, the Administrator ultimately chose to set the secondary standard identical to the primary standard, including using the 8-hour average instead of a cumulative seasonal form (62 FR 38868). In the 2008 review, staff analyses concluded that the W126 index was more biologically-relevant based on the available science; staff additionally noted, based on then-available estimates of background, that this form was also not likely to be significantly impacted by background concentrations given the very low weight assigned to lower O_3 concentrations by the W126 index (U.S. EPA, 2007 SP, 7-22; 72 FR 37893). In this review, the degree to which the total value of the W126 index could be contributed by background concentrations was again assessed. Based on a limited analysis, described in chapter 2 of the

PA, background O_3 (BGO3) can comprise a non-negligible portion of W126 across the U.S., have the greatest contributions to W126 in the intermountain western U.S., and because of the sigmoidal weighting function that emphasizes the background contributions to the highest hourly ozone values (when BGO3 contributions are generally lowest), proportionally contribute slightly less for the W126 than for seasonal means of maximum daily 8 hour average values. As with the primary standard, in identifying the range of policy options supported by the evidence and information, staff has not considered proximity to background O_3 concentrations. The Administrator, when evaluating the range of possible standards that are supported by the scientific evidence, could consider proximity to background O_3 concentrations as one factor in selecting the appropriate standard.

1.3.3 Organization of this Document

Chapter 2 of this PA provides an overview of the O_3 ambient monitoring network and O_3 air quality, including estimates of O_3 concentrations attributable to background sources. The remaining chapters are organized into two main parts. Chapters 3 and 4 focus on the review of the primary O_3 NAAQS while chapters 5 and 6 focus on the review of the secondary O_3 NAAQS. Staff's considerations and conclusions related to the current primary and secondary standards are discussed in chapters 3 and 5, respectively. Staff's considerations and conclusions related to potential alternative primary and secondary standards are discussed in chapters 4 and 6, respectively. Key uncertainties in the review and areas for future research and data collection are additionally identified in chapters 4 and 6 for the two types of standards.

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2 O_3 MONITORING AND AIR QUALITY

This section provides overviews of ambient O_3 monitoring in the U.S. (section 2.1); O_3 precursor emissions and atmospheric chemistry (section 2.2); ambient O_3 concentrations (section 2.3); and available evidence and information related to background O_3 (section 2.4). These issues are also discussed in detail in chapter 3 of the Integrated Science Assessment (ISA) (US EPA, 2013).

2.1 O_3 MONITORING

2.1.1 O_3 Monitoring Network

To monitor compliance with the NAAQS, state and local environmental agencies operate O_3 monitoring sites at various locations, depending on the population of the area and typical peak O_3 concentrations.[1] All of the state and local monitoring stations that report data to the EPA AQS use ultraviolet (UV) Federal Equivalent Methods (FEMs). The Federal Reference Method (FRM) is no longer used due to lack of availability and safety concerns.[2] In 2010, there were over 1,300 state, local, and tribal O_3 monitors reporting concentrations to EPA. The "State and Local Monitoring Stations" (SLAMS) minimum monitoring requirements to meet the O_3 design criteria are specified in 40 CFR Part 58, Appendix D. The requirements are both population and design value based.[3] The minimum number of O_3 monitors required in a Metropolitan Statistical Area (MSA) ranges from zero for areas with a population of at least 50,000 and under 350,000 with no recent history of an O_3 design value greater than 85 percent of the NAAQS, to four for areas with a population greater than 10 million and an O_3 design value greater than 85 percent of the NAAQS. Within an O_3 network, at least one site for each MSA, or Combined Statistical Area (CSA) if multiple MSAs are involved, must be designed to record the maximum concentration for that particular metropolitan area. Since highest O_3 concentrations tend to be associated with particular seasons for various locations, EPA requires ozone monitoring during specific ozone monitoring seasons which vary by state.[4]

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[1] The minimum O_3 monitoring network requirements for urban areas are listed in Table D-2 of Appendix D to 40 CFR Part 58.

[2] EPA is developing a new O_3 Federal Reference Method (FRM) and proposed changes to the FEM testing requirements to reflect new and improved measurement technology.

[3] A design value is a statistic that describes the air quality status of a given area relative to the level of the NAAQS. Design values are typically used to classify nonattainment areas, assess progress towards meeting the NAAQS, and develop control strategies. See http://epa.gov/airtrends/values.html (U, 2010, 677582) for guidance on how these values are defined.

[4] The required O_3 monitoring seasons for each state are listed in Table D-3 of Appendix D to 40 CFR Part 58. EPA plans to complete an analysis using certified data for the years of 2010-2012 to determine if any changes to the length of the required O_3 monitoring seasons would be needed to support a revised NAAQS.

Figure 2-1 shows the locations of the U.S. ambient O_3 monitoring sites reporting data to EPA at any time during the 2006-2010 period. The gray dots which make up over 80% of the O_3 monitoring network are SLAMS monitors, which are operated by state and local governments to meet regulatory requirements and provide air quality information to public health agencies. Thus, the SLAMS monitoring sites are largely focused on urban and suburban areas. The blue dots highlight two important subsets of monitoring sites within the SLAMS network: the "National Core" (NCore) multi-pollutant monitoring network and the "Photochemical Assessment Monitoring Stations" (PAMS) network.[5]

While the existing U.S. O_3 monitoring network has a largely urban focus, to address ecosystem impacts of O_3 such as biomass loss and foliar injury, it is equally important to focus on O_3 monitoring in rural areas. The green dots in Figure 2-1 represent the Clean Air Status and Trends Network (CASTNET) monitors which are located in rural areas. There were about 80 CASTNET sites operating in 2010, with sites in the eastern U.S. being operated by EPA and sites in the western U.S. being operated by the National Park Service (NPS). Finally, the black dots represent "Special Purpose Monitoring Stations" (SPMS), which include about 20 rural monitors as part of the "Portable O_3 Monitoring System" (POMS) network operated by the NPS. Between the CASTNET, NCore, and POMS networks, there were about 120 rural O_3 monitoring sites operating in the U.S. in 2010.

[5] EPA is currently developing proposed revisions to the PAMS network design intended to increase coverage and allow for more locale-specific flexibility.

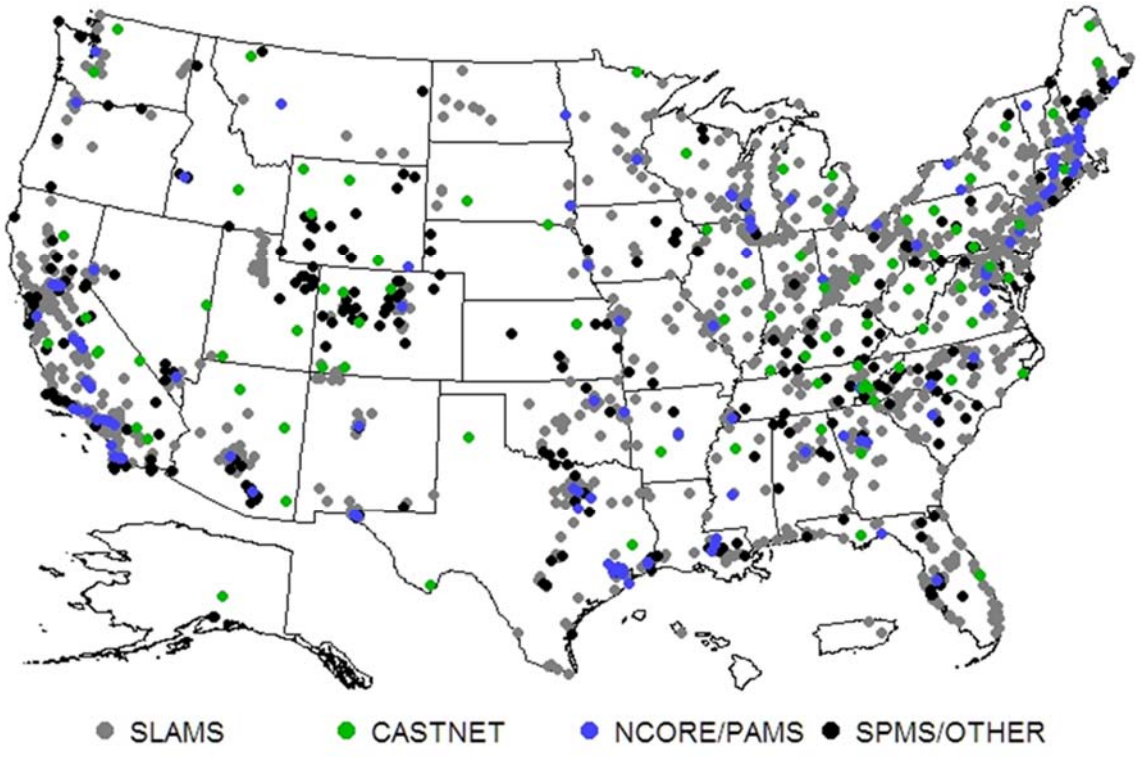

Figure 2-1. Map of U.S. ambient O_3 monitoring sites reporting data to EPA during the 2006-2010 period.

2.1.2 Recent O_3 Monitoring Data and Trends

To determine whether or not the O_3 NAAQS has been met at an ambient monitoring site, a statistic commonly referred to as a "design value" must be calculated based on three consecutive years of data collected from that site. The form of the existing O_3 NAAQS design value statistic is the 3-year average of the annual 4th highest daily maximum 8-hour O_3 concentration in parts per billion (ppb), with decimal digits truncated. The existing primary and secondary O_3 NAAQS are met at an ambient monitoring site when the design value is less than or equal to 75 ppb.[6] In counties or other geographic areas with multiple monitors, the area-wide design value is defined as the design value at the highest individual monitoring site, and the area is said to have met the NAAQS if all monitors in the area are meeting the NAAQS.

Figure 2-2 shows the trend in the annual 4th highest daily maximum 8-hour O_3 concentrations in ppb based on 933 "trends" sites with complete data records over the 2000 to 2012 period. The center line in this figure represents the median value across the trends sites, while

[6] For more details on the data handling procedures used to calculate design values for the existing O_3 NAAQS, see 40 CFR Part 50, Appendix P.

the dashed lines represent the 25th and 75th percentiles, and the bottom and top lines represent the 10th and 90th percentiles. Figures 2-3 and 2-4 show maps of the O_3 design values (ppb) at all U.S. monitoring sites for the 2009-2011 and 2010-2012 periods, respectively. The trend figure shows that the annual 4th highest daily maximum values decreased for the vast majority of monitoring sites in the U.S. between 2000 and 2009. The decreasing trend is especially sharp from 2002 to 2004, when EPA implemented the "NO_X SIP Call", a program designed to reduce summertime emissions of NO_X in the eastern U.S., but has been relatively flat since then.

The trends also show a modest increase in the 4th highest daily maximum values from 2009 to 2012. This is reflected in the design value maps, which show an increase in the number of monitors violating the existing O_3 standard in 2010-2012 relative to 2009-2011. Meteorology played an important role in these short-term trends. O_3 concentrations tend to be higher on days with hot and stagnant conditions and lower on days with cool or wet conditions. According to the National Oceanic and Atmospheric Administration's National Climatic Data Center (NOAA-NCDC), the summer of 2009 was cooler and wetter than average over most of the eastern U.S., while conversely the summers, of 2010, 2011, and 2012 were all much warmer than average. In particular, the central and eastern U.S. experienced a 2-week period of record-breaking heat in late June and early July of 2012, which contributed to hundreds of violations of the existing O_3 standard. In contrast, the most recent climatological information available from NOAA-NCDC (http://www.ncdc.noaa.gov/sotc/) shows that the summer of 2013 was cooler and wetter than average for much of the U.S. Thus, EPA does not expect the recent increasing trend in the 4th highest daily maximum O_3 concentrations to continue in 2013.

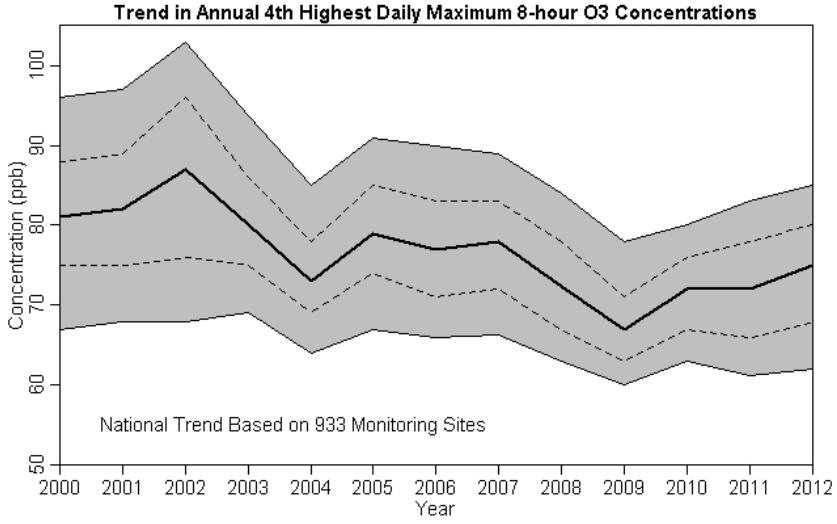

Figure 2-2. Trend in U.S. annual 4th highest daily maximum 8-hour O_3 concentrations in ppb, 2000 to 2012. Solid center line represents the median value across monitoring sites, dashed lines represent 25th and 75th percentile values, and top/bottom lines represent 10th and 90th percentile values.

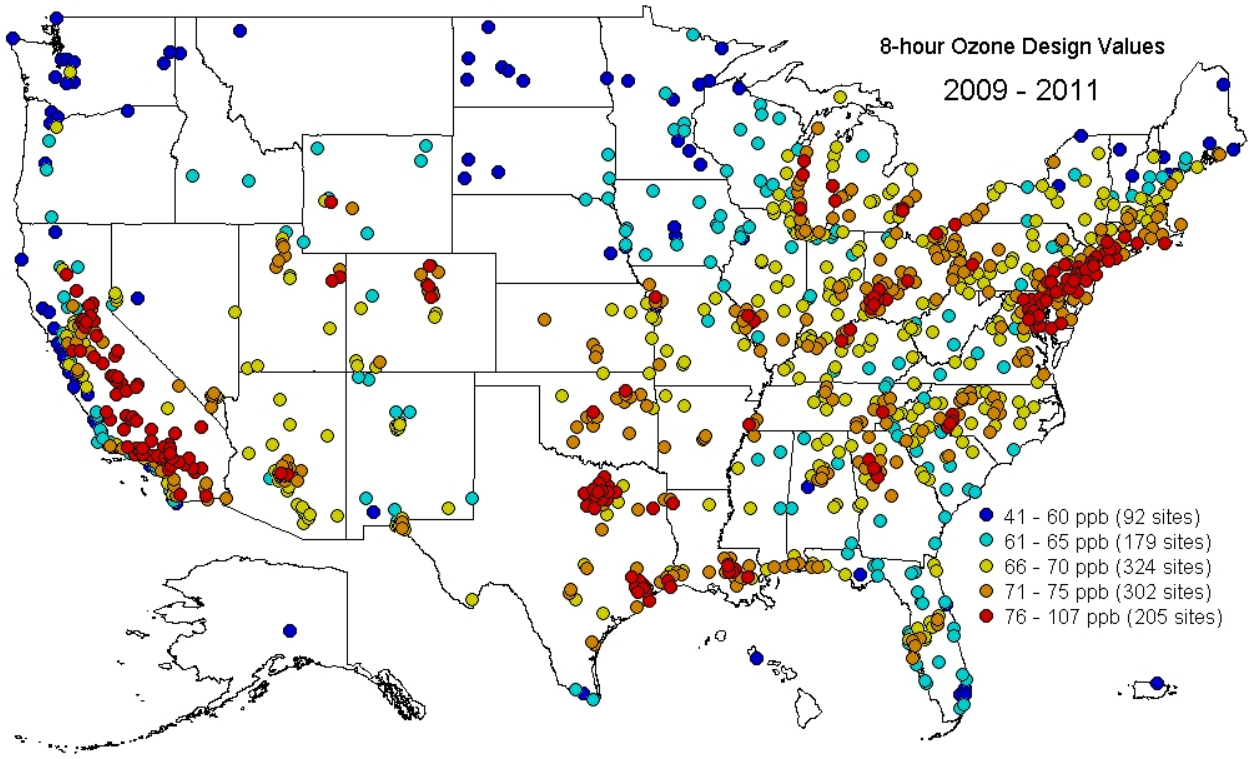

Figure 2-3. Map of 8-hour O_3 design values in ppb for the 2009-2011 period.

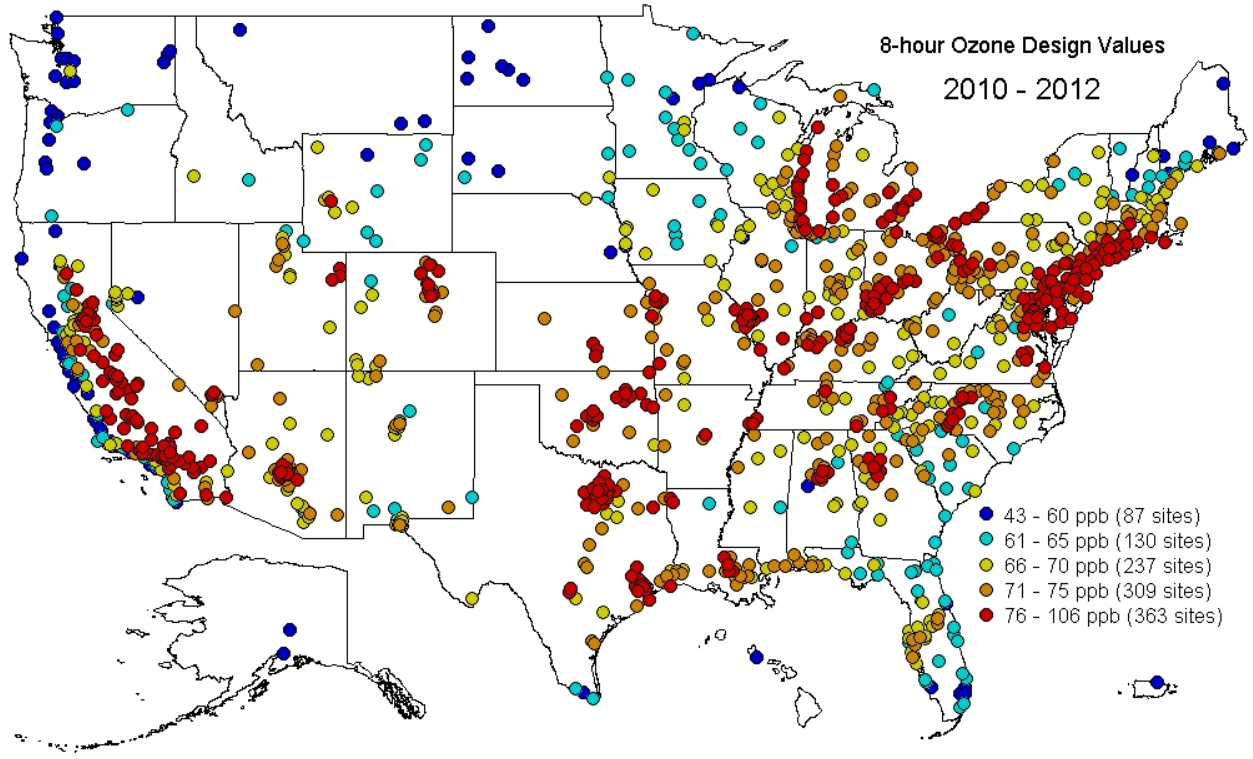

Figure 2-4. Map of 8-hour O_3 design values in ppb for the 2010-2012 period.

In addition, EPA focused our analyses of welfare and ecosystem effects on a W126 O_3 exposure metric in this review. The W126 metric[7] is a seasonal aggregate of daytime (8:00 AM to 8:00 PM) hourly O_3 concentrations, designed to measure the cumulative effects of O_3 exposure on plant and tree species, with units in parts per million-hours (ppm-hrs). The W126 metric uses a logistic weighting function to place less emphasis on exposure to low hourly O_3 concentrations and more emphasis on exposure to high hourly O_3 concentrations (Lefohn et al, 1988).

Figure 2-5 shows the trend in annual W126 concentrations in ppm-hrs based on 933 "trends" sites with complete data records over the 2000 to 2012 period. Figures 2-6 and 2-7 show maps of the 3-year average annual W126 concentrations in ppm-hrs at all U.S. monitoring sites for the 2009-2011 and 2010-2012 periods, respectively. The general patterns seen in these figures are similar to those seen in the design value metric for the existing standard.

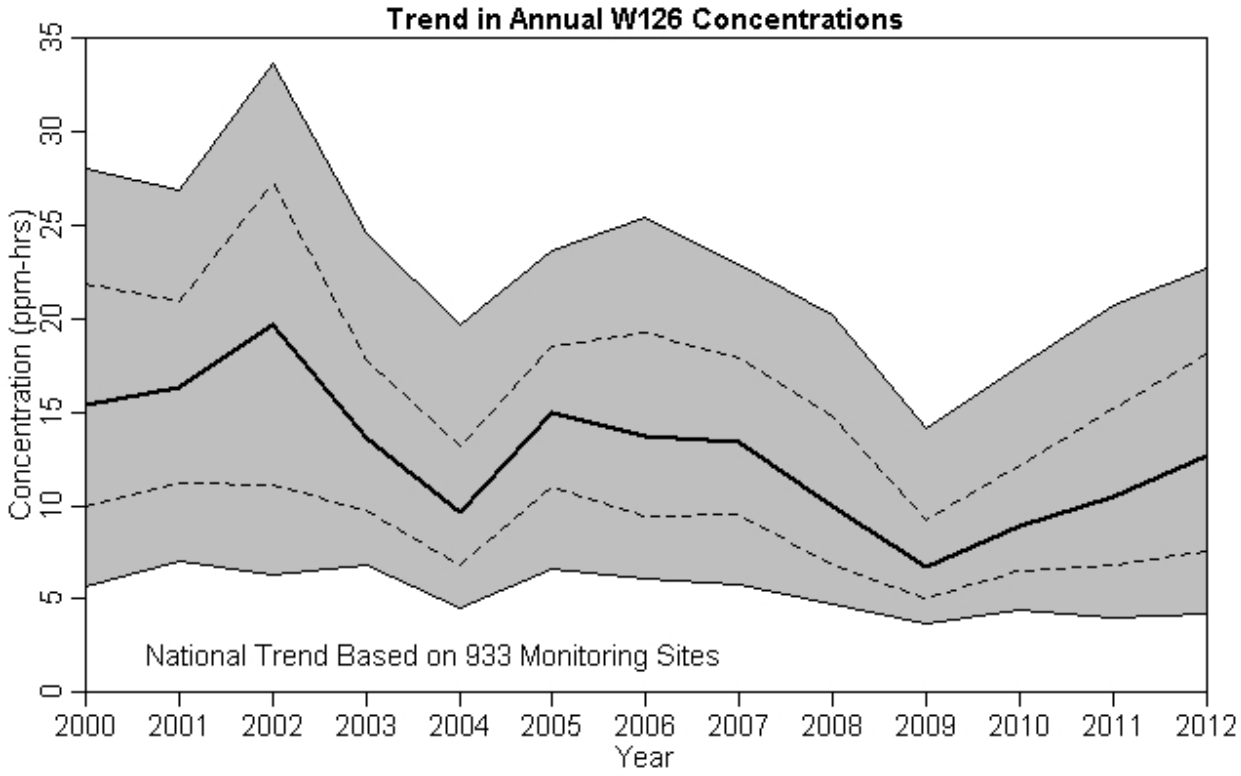

Figure 2-5. Trend in U.S. annual W126 concentrations in ppm-hrs, 2000 to 2012. Solid center line represents the median value across monitoring sites, dashed lines represent 25th and 75th percentile values, and top/bottom lines represent 10th and 90th percentile values.

[7] Details on the procedure used to calculate the W126 metric are provided in Chapter 4 of the welfare Risk and Exposure Assessment.

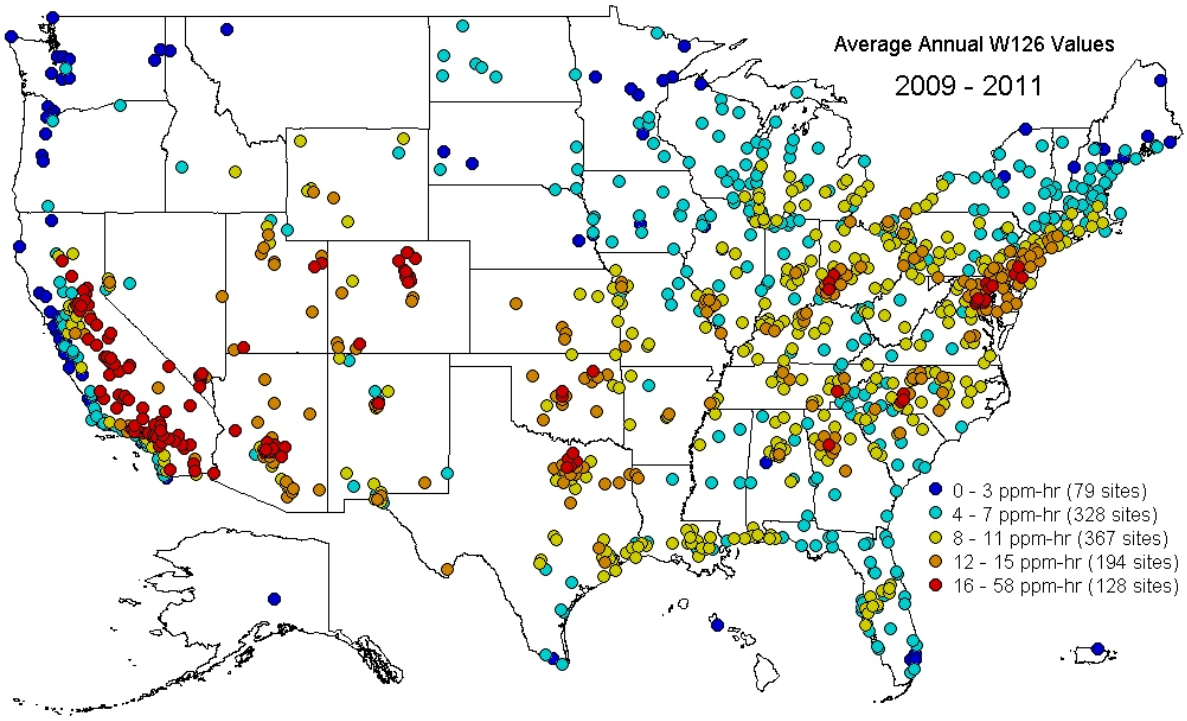

Figure 2-6. Map of 2009-2011 average annual W126 values in ppm-hrs.

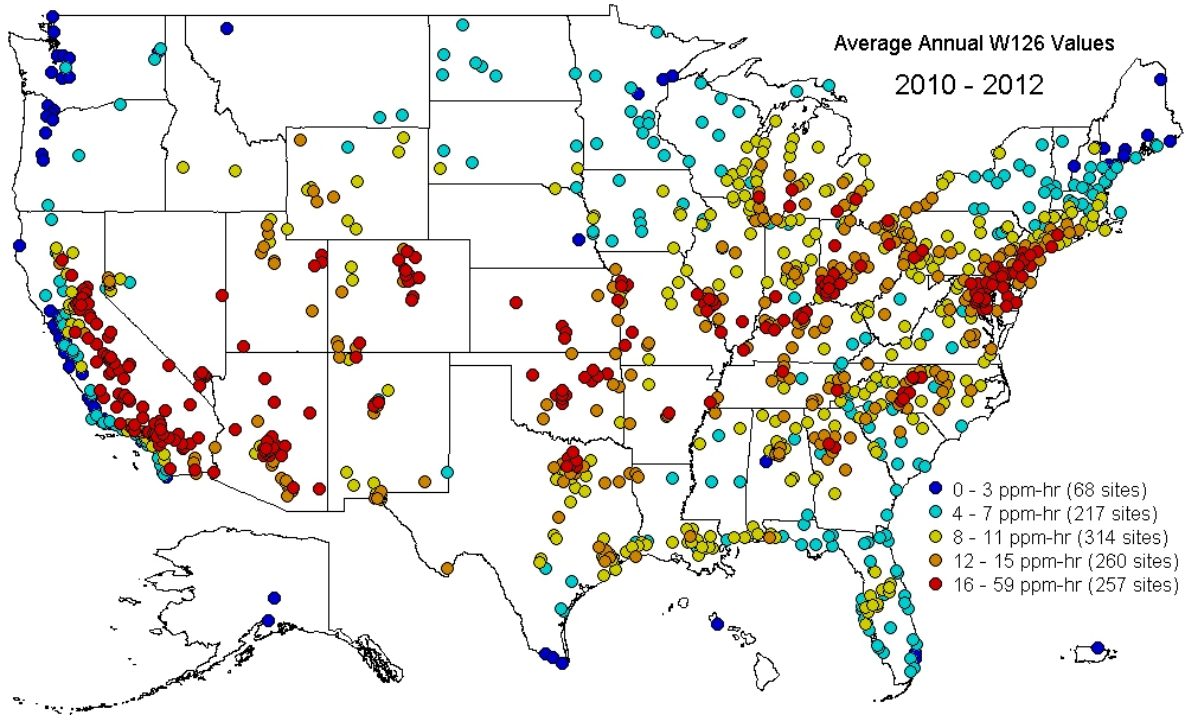

Figure 2-7. Map of 2010-2012 average annual W126 values in ppm-hrs.

Variations in meteorological conditions play an important role in determining ozone concentrations. Ozone is more readily formed on warm, sunny days when the air is stagnant. Conversely, ozone generation is more limited when it is cool, rainy, cloudy, or windy. EPA uses a statistical model to adjust for the variability in seasonal average ozone concentrations due to weather conditions to provide a more accurate assessment of the underlying trend in ozone caused by emissions (Camalier, 2007). Figure 2-8 shows the national trend in the May to September average of the daily maximum 8-hour ozone concentrations from 2000 to 2012 in 112 urban locations. The dotted red line shows the trend in observed ozone concentrations at selected monitoring sites, while the solid blue line shows the underlying ozone trend at those sites after removing the effects of weather. The solid blue lines represent ozone levels anticipated under "typical" weather conditions and serve as a more accurate assessment of the trend in ozone due to changes in precursor emissions.

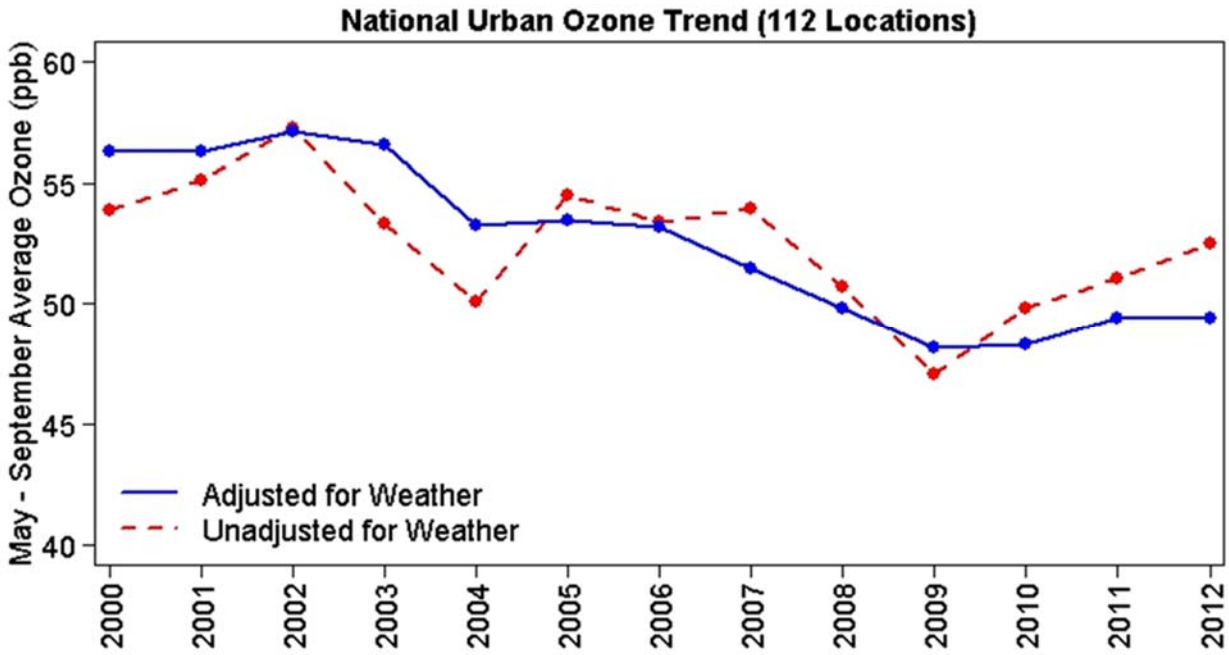

Figure 2-8. Trend in the May to September mean of the daily maximum 8-hour ozone concentrations before (dotted red line) and after (solid blue line) adjusting for year-to-year variability in meteorology[8].

Figure 2-8 shows that after adjusting for the year-to-year variability in meteorology, the overall trend in seasonal average ozone concentrations is much smoother. The adjusted trend

[8] More detailed information on these trends is available at: http://www.epa.gov/airtrends/weather.html

clearly shows that the NO_X SIP Call program resulted in a sharp decrease in summertime ozone concentrations starting in 2004. The adjusted trend also indicates that ozone levels continued to decrease between 2004 and 2009, and while there is still some evidence of an increasing trend from 2009 to 2012, there is also evidence that much of the recent increase in ozone levels is due to meteorological conditions which were more favorable to ozone formation than normal.

2.2 EMISSIONS AND ATMOSPHERIC CHEMISTRY

O_3 is formed by photochemical reactions of precursor gases and is not directly emitted from specific sources. In the stratosphere, O_3 occurs naturally and provides protection against harmful solar ultraviolet radiation. In the troposphere, near ground level, O_3 forms through atmospheric reactions involving two main classes of precursor pollutants: volatile organic compounds (VOCs) and nitrogen oxides (NO_X). Carbon monoxide (CO) and methane (CH_4) are also important for O_3 formation over longer time periods (US EPA, 2013, section 3.2.2).

Emissions of O_3 precursor compounds can be divided into anthropogenic and natural source categories, with natural sources further divided into biogenic emissions (from vegetation, microbes, and animals) and abiotic emissions (from biomass burning, lightning, and geogenic sources). Anthropogenic sources, including mobile sources and power plants, account for the majority of NO_X and CO emissions. Anthropogenic sources are also important for VOC emissions, though in some locations and at certain times of the year (e.g., southern states during summer) the majority of VOC emissions come from vegetation (US EPA, 2013, section 3.2.1). In practice, the distinction between natural and anthropogenic sources is often unclear, as human activities directly or indirectly affect emissions from what would have been considered natural sources during the preindustrial era. Thus, emissions from plants, animals, and wildfires could be considered either natural or anthropogenic, depending on whether emissions result from agricultural practices, forest management practices, lightning strikes, or other types of events (US EPA, 2013, sections 3.2 and 3.7.1).

Rather than varying directly with emissions of its precursors, O_3 changes in a nonlinear fashion with the concentrations of its precursors. NO_X emissions lead to both the formation and destruction of O_3, depending on the local quantities of NO_X, VOC, radicals, and sunlight. In areas dominated by fresh emissions of NO_X, radicals are removed, which lowers the O_3 formation rate. In addition, the scavenging of O_3 by reaction with NO is called “titration” and is often found in downtown metropolitan areas, especially near busy streets and roads, as well as in power plant plumes. This short-lived titration results in localized areas in which O_3 concentrations are suppressed compared to surrounding areas, but which contain NO_2 that contributes to subsequent O_3 formation further downwind. Consequently, O_3 response to reductions in NO_X emissions is complex and may include O_3 decreases at some times and

locations and increases of O_3 at other times and locations. In areas with relatively low NO_X concentrations, such as those found in remote continental areas and rural and suburban areas downwind of urban centers, O_3 production typically varies directly with NO_X concentrations (e.g. decreases with decreasing NO_X emissions). The NOx titration effect is most pronounced in urban core areas which have higher volume of mobile source NOx emissions from vehicles than do the surrounding areas. It should be noted that such locations, which are heavily NO_X saturated (or radical limited), tend to have much lower observed O_3 concentrations than downwind areas. As a general rule, as NOx emissions reductions occur, one can expect lower O_3 values to increase while the higher ozone values would be expected to decrease. NOx reductions are expected to result in a compressed O_3 distribution, relative to current conditions.

The formation of O_3 from precursor emissions is also affected by meteorological parameters such as the intensity of sunlight and atmospheric mixing. Major episodes of high ground-level O_3 concentrations in the eastern United States are associated with slow-moving high pressure systems. High pressure systems during the warmer seasons are associated with the sinking of air, resulting in warm, generally cloudless skies, with light winds. The sinking of air results in the development of stable conditions near the surface which inhibit or reduce the vertical mixing of O_3 precursors. The combination of inhibited vertical mixing and light winds minimizes the dispersal of pollutants, allowing their concentrations to build up. In addition, in some parts of the United States (e.g., in Los Angeles), mountain barriers limit mixing and result in a higher frequency and duration of days with elevated O_3 concentrations. Photochemical activity involving precursors is enhanced during warmer seasons because of the greater availability of sunlight and higher temperatures (US EPA, 2013, section 3.2).

O_3 concentrations in a region are affected both by local formation and by transport of O_3 and its precursors from upwind areas. O_3 transport occurs on many spatial scales including local transport between cities, regional transport over large regions of the U.S. and international/long-range transport. In addition, O_3 can be transferred into the troposphere from the stratosphere, which is rich in O_3, through stratosphere-troposphere exchange (STE). These intrusions usually occur behind cold fronts, bringing stratospheric air with them and typically affect O_3 concentrations in higher elevation areas (e.g. > 1500 m) more than areas at lower elevations (U.S. EPA, 2012, section 3.4.1.1). The role of long-range transport of ozone and other elements of ozone background is discussed in more detail in Section 2.4.

2.3 AIR QUALITY CONCENTRATIONS

Because O_3 is a secondary pollutant formed in the atmosphere from precursor emissions, concentrations are generally more regionally homogeneous than concentrations of primary pollutants emitted directly from stationary and mobile sources (US EPA, 2013, section 3.6.2.1).

However, variation in local emissions characteristics, meteorological conditions, and topography can result in daily and seasonal temporal variability in ambient O_3 concentrations, as well as local and national-scale spatial variability.

Temporal variation in ambient O_3 concentrations results largely from daily and seasonal patterns in sunlight, precursor emissions, atmospheric stability, wind direction, and temperature (US EPA, 2013, section 3.7.5). On average, ambient O_3 concentrations follow well-recognized daily and seasonal patterns, particularly in urban areas. Specifically, daily maximum 1-hr O_3 concentrations in urban areas tend to occur in mid-afternoon, with more pronounced peaks in the warm months of the O_3 season than in the colder months (US EPA, 2013, Figures 3-54, 3-156 to 3-157). Rural sites also follow this general pattern, though it is less pronounced in colder months (US EPA, 2013, Figure 3-55). With regard to day-to-day variability, median maximum daily 8-hour average (MDA8) O_3 concentrations in U.S. cities in 2007-2009 were approximately 47 ppb, with typical ranges between 35 to 60 ppb and the highest MDA8 concentrations above 100 ppb in several U.S. cities (as noted further below).

In addition to temporal variability, there is considerable spatial variability in ambient O_3 concentrations within cities and across different cities in the United States. With regard to spatial variability within a city, local emissions characteristics, geography, and topography can have important impacts. For example, as noted above, fresh NO emissions from, for example, motor vehicles titrate O_3 present in the urban background air, resulting in an O_3 gradient around roadways with O_3 concentrations increasing as distance from the road increases (US EPA, 2013, section 3.6.2.1). In comparing urban areas, the ISA notes that measured O_3 concentrations are relatively uniform and well-correlated within some cities (e.g., Atlanta) while they are more variable in others (e.g., Los Angeles) (US EPA, 2013, section 3.6.2.1 and Figures 3-28 to 3-36).

With regard to variability across cities, when the ISA evaluated the distributions of 8-hour O_3 concentrations for the years 2007 to 2009 in 20 cities, the highest concentrations were reported in Los Angeles, with high concentrations also reported in several eastern and southern cities. The maximum recorded MDA8 was 137 ppb in Los Angeles, and was near or above 120 ppb in Atlanta, Baltimore, Dallas, New York City, Philadelphia, and St. Louis (US EPA, 2013, Table 3-10). The pattern was similar for the 98th percentile of the distribution of MDA8 concentrations[9], with Los Angeles recording the highest 98th percentile concentration (91 ppb) and many eastern and southern cities reporting 98th percentile concentrations near or above 75 ppb. In contrast, somewhat lower 98th percentile O_3 concentrations were recorded in cities in the western United States outside of California (US EPA, 2013, Table 3-10).

[9] Table 3-10 in the ISA analyzes the warm season. Therefore, the 98th percentile values would be an approximation of the 4th highest value.

Rural sites can be affected by transport of O_3 or O_3 precursors from upwind urban areas and by local anthropogenic sources such as motor vehicles, power generation, biomass combustion, or oil and gas operations (US EPA, 2013, section 3.6.2.2). In addition, O_3 tends to persist longer in rural than in urban areas due to lower rates of chemical scavenging in non-urban environments. At higher elevations, increased O_3 concentrations can also result from stratospheric intrusions (US EPA, 2013, sections 3.4, 3.6.2.2). As a result, O_3 concentrations measured in some rural sites can be higher than those measured in nearby urban areas (US EPA, 2013, section 3.6.2.2), and the ISA concludes that cumulative exposures for humans and vegetation in rural areas can be substantial, often higher than cumulative exposures in urban areas (US EPA, 2013, section 3.7.5).

2.4 BACKGROUND O_3

One of the aspects of ozone that is unusual relative to the other pollutants with National Ambient Air Quality Standards (NAAQS) is that, periodically, in some locations, an appreciable fraction of the observed ozone results from sources or processes other than local and domestic regional anthropogenic emissions of ozone precursors (Fiore *et al*., 2002). Any ozone formed by processes other than the chemical conversion of local or regional ozone precursor emissions is generically referred to as "background" ozone. Background O_3 can originate from natural sources of O_3 and O_3 precursors, as well as from manmade international emissions of O_3 precursors. Natural sources of O_3 precursor emissions such as wildfires, lightning, and vegetation can lead to O_3 formation by chemical reactions with other natural sources. Another important component of background is O_3 that is naturally formed in the stratosphere through interactions of ultraviolet light with molecular oxygen. Stratospheric O_3 can mix down to the surface at high concentrations in discrete events called intrusions, especially at higher-altitude locations. The manmade portion of the background includes any O_3 formed due to anthropogenic sources of O_3 precursors emitted far away from the local area (e.g., international emissions). Finally, both biogenic and international anthropogenic emissions of methane, which can be chemically converted to O_3 over relatively long time scales, can also contribute to global background O_3 levels. Away from the surface, ozone can have an atmospheric lifetime on the order of weeks. As a result, background ozone can be transported long distances in the upper troposphere and, when meteorological conditions are favorable, be available to mix down to the surface and add to the ozone loading from non-background sources.

As indicated in the first draft policy assessment (US EPA, 2012, sections 1.3.4 and 3), EPA has updated several aspects of our methodology for estimating the change in health risk and exposure that would result from a revision to the O_3 NAAQS. First, risk estimates are now based on total O_3 concentrations, as opposed to previous reviews which only considered risk above

background levels. Second, EPA is now using air quality modeling to estimate the spatial patterns of O_3 that would result from attaining various levels of the NAAQS, as opposed to a quadratic rollback approach that required the estimation of a background "floor" beyond which the rollback would not take place. Both of these revisions have had the indirect effect of reducing the need for estimates of background O_3 levels as part of the O_3 risk and exposure assessment (REA). Regardless, EPA expects that a well-founded understanding of the fractional contribution of background sources and processes to surface O_3 levels will be valuable. Accordingly, in this section, we briefly summarize existing results on background O_3 from the ISA (US EPA, 2013, section 3.4) as supplemented by additional EPA modeling recently conducted for a 2007 base year. The summary will focus on national estimates of the:

- seasonal mean background O_3 values for three specific definitions of background O_3,
- relative proportion of background O_3 to total O_3 for the same three definitions from a seasonal mean perspective,
- distributions of background O_3 within a seasonal mean,
- ratio of background O_3 to total modeled ozone in the 12 REA case study areas,
- relative proportion of background O_3 concentrations to total W126 ozone, and
- relative contribution of different components of background to total background O_3.

The definition of background O_3 can vary depending upon context, but it generally refers to O_3 that is formed by sources or processes that cannot be influenced by actions within the jurisdiction of concern. In the first draft policy assessment document (US EPA, 2012), EPA identified three specific definitions of background O_3: natural background (NB), North American background (NAB), and United States background (USB). Natural background is the narrowest definition of background, and it is defined as the O_3 that would exist in the absence of any manmade O_3 precursor emissions. The other two definitions of background are based on a presumption that the U.S. has little influence over anthropogenic emissions outside either our continental or domestic borders. North American background is defined as that O_3 that would exist in the absence of any manmade O_3 precursor emissions from North America. U.S. background is defined as that O_3 that would exist in the absence of any manmade emissions inside the United States.

Each of these three definitions of background O_3 requires photochemical modeling simulations to estimate what the residual O_3 concentrations would be were the various anthropogenic emissions to be removed. EPA exclusively uses modeling estimates to characterize background, as opposed to using observed concentrations from a remote site, because even the most remote monitors within the U.S. can be periodically affected by U.S.

anthropogenic emissions. In most situations, without special monitoring it is impossible to determine how much of the ozone measured by a monitor originated from background sources. Prior to using the new 2007-based model simulations to estimate background O_3 levels over the U.S., EPA confirmed that this modeling was able to reproduce historical O_3 levels and that there was limited correlation between model errors and the background estimates. This evaluation is described more fully in the appendix (Appendix A) to this chapter.

Previous modeling studies have estimated what background levels would be in the absence of certain sets of emissions by simply assessing the remaining O_3 in a simulation in which certain emissions were removed (Zhang et al. (2011), Emery et al. (2012)). This basic approach is often referred to as "zero-out" modeling or "emissions perturbation" modeling. While the zero-out approach has traditionally been used to estimate natural background, North American background, and U.S. background, the methodology has an acknowledged limitation. It cannot answer the question of how much of the existing observed ozone results from background sources or processes.

A separate modeling technique can be used to estimate the contribution of background ozone and other contributing source terms to total O_3 within a model. This approach, referred to as "source apportionment" modeling, has been described and evaluated in the peer-reviewed literature (Dunker et al., 2002; Kemball-Cook et al., 2009). Source apportionment modeling has frequently been used in other regulatory settings to estimate the "contribution" to ozone of certain sets of emissions (EPA 2005, EPA 2011). The source apportionment technique provides a means of estimating the contributions of each user-identified source category to ozone formation in a single model simulation. This is achieved by using multiple tracer species to track the fate of ozone precursor emissions (VOC and NO_X) and the ozone formation resulting from these emissions. The methodology is designed so that all ozone and precursor concentrations are tracked and apportioned to the selected source categories at all times without perturbing the inherent chemistry. The primary limitation of the source apportionment modeling is that its estimations of background are explicitly linked to the emissions scenarios modeled and would change with different emissions scenarios.

EPA recently completed updated zero-out and source apportionment modeling for a 2007 base year to supplement the characterization of background O_3 that was provided in the ISA. Both of these approaches have value in assessing the potential impacts of background O_3, but they are used separately as described in Table 2-1.

Estimation Methodology	Question addressed	Background Quantities	Strengths and Limitations
Zero-out	How much ozone would remain if controllable emissions were completely removed?	NB / NAB / USB	Strength: The approach is simple to implement and provides an estimate of the lowest O_3 levels that can be attained by eliminating all U.S. anthropogenic emissions. Limitation: Estimates are based on a counterfactual, represents a quantity never to occur in real atmosphere. Additionally, sensitivity approaches can be unreliable for evaluating mass contributions to O_3 production because of non-linearity in the chemistry.
Source Apportionment	How much of the current ozone can be attributed to sources other than U.S. anthropogenic sources?	Apportionment-based USB	Strength: Provides a direct estimate of the amount of O_3 contributed by each source category while avoiding artifacts caused by non-linearity in the chemistry. Limitation: While this approach identifies important sources that contribute to O_3, it does not predict quantitatively how O_3 will respond to specific emissions reduction scenarios.

Table 2-1 Comparison of the two model methodologies used to characterize background ozone levels.

The key configuration elements of the updated modeling are described below; a more detailed description of the modeling is provided in Appendix A. The zero-out modeling was based on a model configuration that nested a regional-scale air quality model (CMAQ at 12 km horizontal grid resolution) within a global scale air quality model (GEOS-Chem at 2.0 x 2.5

degree horizontal grid resolution). The lateral boundary conditions from the global model were used as inputs for the regional simulation. Four scenarios were modeled:

- a 2007 base case simulation which was also the basis of the air quality modeling performed for the 2nd draft ozone REA and is described in more detail in Appendix 4b of EPA (2013b)
- a natural background run with anthropogenic ozone precursor emissions[10] removed in both the global and regional models[11]
- a North American background run with anthropogenic ozone precursor emissions removed across North America in both the global and regional model simulations
- a U.S. background run with anthropogenic ozone precursor emissions removed over the U.S. in both the global and regional model simulations

The source apportionment modeling was also based on a regional scale air quality model (CAMx at 12 km horizontal grid resolution) that used the same lateral boundary conditions from the 2007 base global modeling scenario. EPA used the Anthropogenic Precursor Culpability Assessment (APCA) tool in this analysis. The APCA tool attributes ozone production to manmade sources whenever ozone is determined to result from a combination of anthropogenic and biogenic emissions (Environ, 2011). The APCA methodology calculates natural ozone as the production resulting from the interaction of biogenic VOC with biogenic NO_X emissions. Eleven separate source categories were tracked in the EPA source apportionment analysis, including five boundary condition terms and six in-domain sectors:

- Boundary condition terms:[12]
    - Northern edge
    - Eastern edge
    - Southern edge
    - Western edge
    - Top boundary

[10] In the global model, only emissions from natural sources were used (i.e., VOC, NO_X, CO) and methane was reset to pre-industrial levels (700 ppb) to reflect natural contributions. In the regional modeling, the methane levels were left unchanged.

[11] Note that methane is not modeled as an explicit species in CMAQ but instead is treated as having a constant concentration. Therefore, although methane was reduced to pre-industrial levels in the global GEOS-Chem run used to create boundary conditions, methane was assumed to be equal to modern-day levels in the CMAQ model runs. Since methane reactions occur on relatively long timescales, this discrepancy is not expected to have a large impact on modeled background ozone levels.

[12] It should be noted that although boundary conditions are treated as part of apportionment-based USB for this analysis, in some cases they may be influenced by US anthropogenic emissions that are advected out of the model domain and recirculated back into the U.S. This is not expected to make a substantial impact on results.

- In-domain sectors:
    - U.S. anthropogenic emissions
    - Point sources located within the Gulf of Mexico
    - Category 3 marine vessels outside State boundaries
    - Climatologically-averaged wildfire emissions
    - Biogenic emissions
    - Canada/Mexico emissions (only those sources within the domain)

2.4.1 Seasonal Mean Background O_3 in the U.S.

The ISA (US EPA 2013, section 3.4) previously established that background concentrations vary spatially and temporally and that simulated mean background concentrations are highest at high-elevation sites within the western U.S. Background levels typically are greatest over the U.S. in the spring and early summer. The updated EPA modeling focused on the months from April to October. Figure 2-9 displays the spatial patterns of seasonal mean natural background O_3 as estimated by a 2007 zero-out scenario. Seasonal means are computed over those seven months. This figure shows the average daily maximum 8-hour O_3 concentration (MDA8) that would exist in the absence of any anthropogenic O_3 precursor emissions at monitor locations. As shown, seasonal mean NB levels range from approximately 15-35 ppb (i.e., +/- 1 standard deviation) with the highest values at higher-elevation sites in the western U.S. The median value over these locations is 24.2 ppb, and more than 50 percent of the locations have natural background levels of 20-25 ppb. The highest modeled estimate of seasonal average, natural background, MDA8 O_3 is 34.3 ppb at the high-elevation CASTNET site (Gothic) in Gunnison County, CO. Natural background levels are higher at these high-elevation locations primarily because natural stratospheric O_3 impacts and international transport impacts increase with altitude (where O_3 lifetimes are longer).

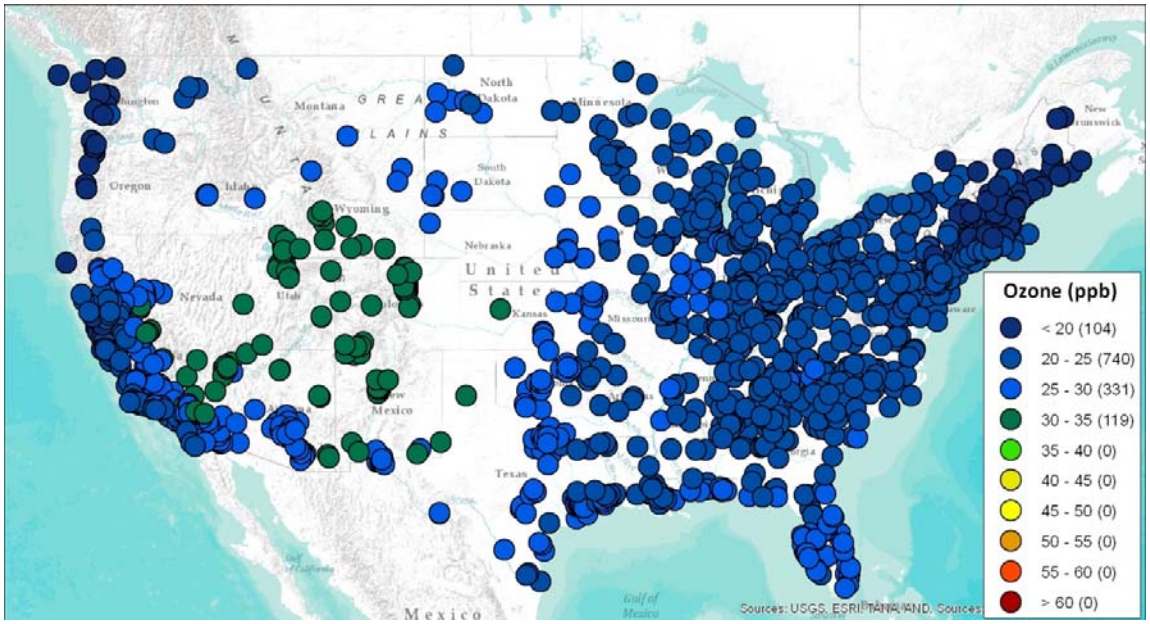

Figure 2-9. Map of 2007 CMAQ-estimated seasonal mean natural background O_3 levels (ppb) from zero-out modeling.

Figures 2-10 and 2-11 show the same information for the NAB and USB scenarios. In these model runs, all anthropogenic O_3 precursor emissions were removed from the U.S., Canada, and Mexico portions of the modeling domain (NAB scenario) and then only from the U.S. (USB scenario). The figures show that there is not a large difference between the NAB and USB scenarios. Seasonal mean NAB and USB O_3 levels range from 25-50 ppb, with the most frequent values estimated in the 30-35 ppb bin. The median seasonal mean background levels are 31.5 and 32.7 ppb (NAB and USB, respectively). Again, the highest levels of seasonal mean background are predicted over the intermountain western U.S. Locations with NAB and USB concentrations greater than 40 ppb are confined to Colorado, Nevada, Utah, Wyoming, northern Arizona, eastern California, and parts of New Mexico. The 2007 EPA modeling suggests that seasonal mean USB concentrations are on average 1-3 ppb higher than NAB background. These results were similar to those reported by Wang et al. (2009). From a seasonal mean perspective, background levels are typically well-below the NAAQS thresholds.

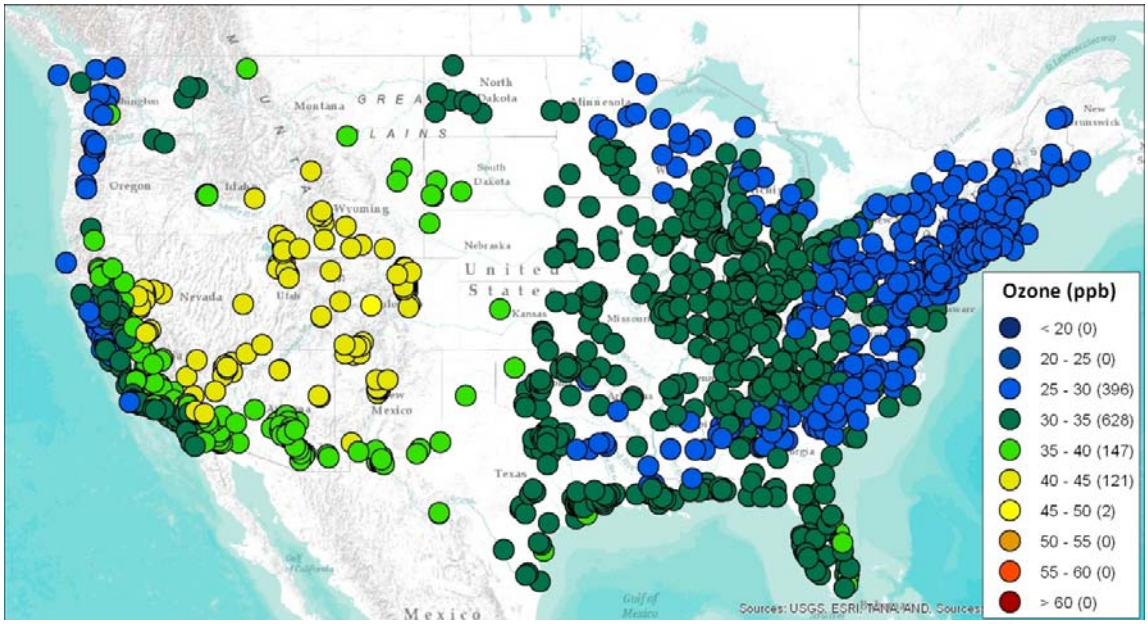

Figure 2-10. Map of 2007 CMAQ-estimated seasonal mean North American background O_3 levels (ppb) from zero-out modeling.

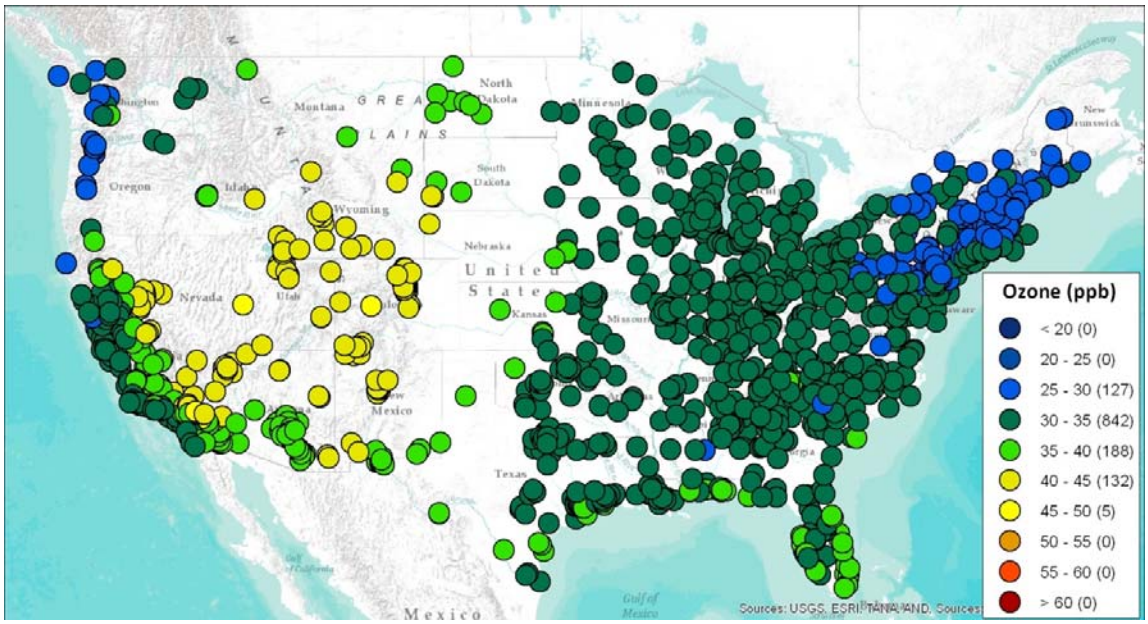

Figure 2-11. Map of 2007 CMAQ-estimated seasonal mean United States background O_3 levels (ppb) from zero-out modeling.

2.4.2 Seasonal Mean Background O_3 in the U.S. as a Proportion of Total O_3

Another informative way to assess the importance of background as part of seasonal mean O_3 levels across the U.S. is to consider the ratios of NB, NAB, and USB to total modeled O_3 at each monitoring location. Considering the proportional impact of background allows for an

initial assessment of the relative importance of background and non-background sources. Because ozone chemistry is non-linear, one should not assume that individual perturbations (e.g., zero out runs) are additive in all locations. Figures 2-12 and 2-13 show the ratio of U.S. anthropogenic sources to total O_3 using the metric of the seasonal mean MDA8 O_3 concentrations as estimated by both the zero-out and source apportionment modeling methodologies. Recall that the terms NB, NAB, and USB are explicitly linked to the zero-out modeling approach. For comparison sake, in Figure 2-13 we are extending the definition of USB to also include the source apportionment model estimates of the O_3 that is *attributable to sources other than U.S. anthropogenic emissions*. To preserve the original definition of USB, this second term will be hereafter referred to as "apportionment-based USB". As noted earlier, the advantage of the source apportionment modeling is that all of the modeled O_3 is attributed to various source terms without perturbing the inherent chemistry. Thus, this approach is not affected by the confounding occurrences of background O_3 values exceeding the base O_3 values as can happen in the zero-out modeling (i.e., background proportions > 100%). Consequently, one would expect the fractional background levels to be lower in the source apportionment methodology as a result of removing this artifact.

When averaged over all sites, O_3 from sources other than U.S. anthropogenic emissions is estimated to comprise 66 (zero-out) and 59 (source apportionment) percent of the total seasonal O_3 mean. The spatial patterns of USB and apportionment-based USB are similar across the two modeling exercises. Background O_3 is a relatively larger percentage (e.g., 70-80%) of the total seasonal mean O_3 in locations within the intermountain western U.S. and along the U.S. border. In locations where O_3 levels are generally higher, like California and the eastern U.S., the seasonal mean background fractions are relatively smaller (e.g., 40-60%). The additional 2007 modeling confirms that background ozone, while generally not approaching levels of the ozone standard, can comprise a considerable fraction of total seasonal mean ozone across the U.S.

2.4.3 Daily Distributions of Background O_3 within the Seasonal Mean

As a first-order understanding, it is valuable to be able to characterize seasonal mean levels of background O_3. However, it is well established that background levels can vary substantially from day-to-day within the seasonal mean. From an implementation perspective, the values of background O_3 on possible exceedance days are a more meaningful consideration. The first draft policy assessment (US EPA, 2012) considered this issue in detail, via summaries of the existing 2006 zero-out modeling (Henderson et al., 2012), and concluded that "results suggest that background concentrations on the days with the highest total O_3 concentrations are not dramatically higher than typical seasonal average background concentrations." Based on this finding, EPA determined that "anthropogenic sources within the U.S. are largely responsible for

4th highest 8-hour daily maximum O_3 concentrations." The recent EPA modeling using a 2007 base year and the two distinct modeling methodologies described above, supports the finding from the previous 2006-based modeling analyses. That is, the highest modeled O_3 site-days tend to have background O_3 levels similar to mid-range O_3 days. Figure 2-14 and 2-15 show the distribution of daily MDA8 apportionment-based USB levels (absolute magnitudes and relative fractions, respectively) from the source apportionment simulation[13]. Again, the 2007 modeling shows that the days with highest O_3 levels have similar distributions (i.e., means, inter-quartile ranges) of background levels as days with lower values, down to approximately 40 ppb. As a result, the proportion of total O_3 that has background origins is smaller on high O_3 days (e.g., days > 60 ppb) than on the more common lower O_3 days that tend to drive seasonal means. This helps put the results from section 2.4.2 into better context. For example, for site-days in which base O_3 is between 70-75 ppb, the source apportionment modeling estimates that approximately 37 percent of those O_3 levels originate from sources other than U.S. anthropogenic emissions (i.e., apportionment-based USB). Figure 2-15 also indicates that there are cases in which the model predicts much larger background proportions, as shown by the upper outliers in the figure. These infrequent episodes usually occur in relation to a specific event, and occur more often in specific geographical locations, such as at high elevations or wildfire prone areas during the local dry season.

It should be noted here that EPA has policies for treatment of air quality monitoring data affected by these types of events. EPA's exceptional events policy allows exclusion of certain air quality monitoring data from regulatory determinations if a State adequately demonstrates that an exceptional event has caused the exceedance or violation of a NAAQS. In addition, Section 179B of the CAA also provides for treatment of air quality data from international transport when an exceedance or violation of a NAAQS would not have occurred but for the emissions emanating from outside of the United States.

[13] Similar plots from the zero-out modeling for natural background, North American background, and U.S. background are provided in Appendix A.

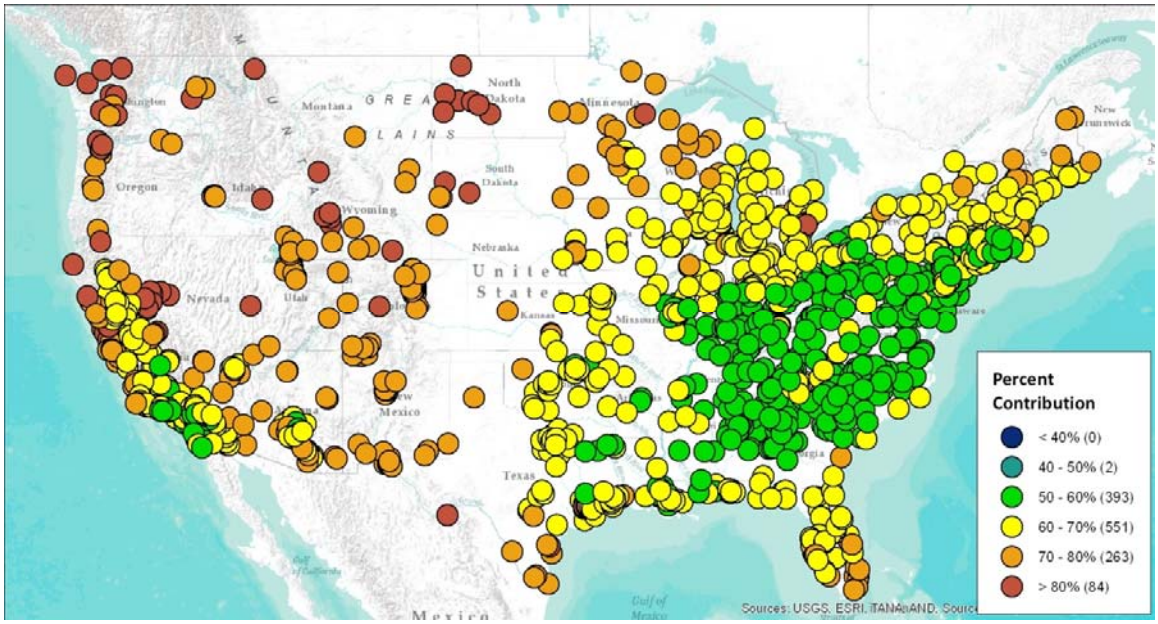

Figure 2-12. Map of site-specific ratios of U.S. background to total seasonal mean O_3 based on 2007 CMAQ zero-out modeling.

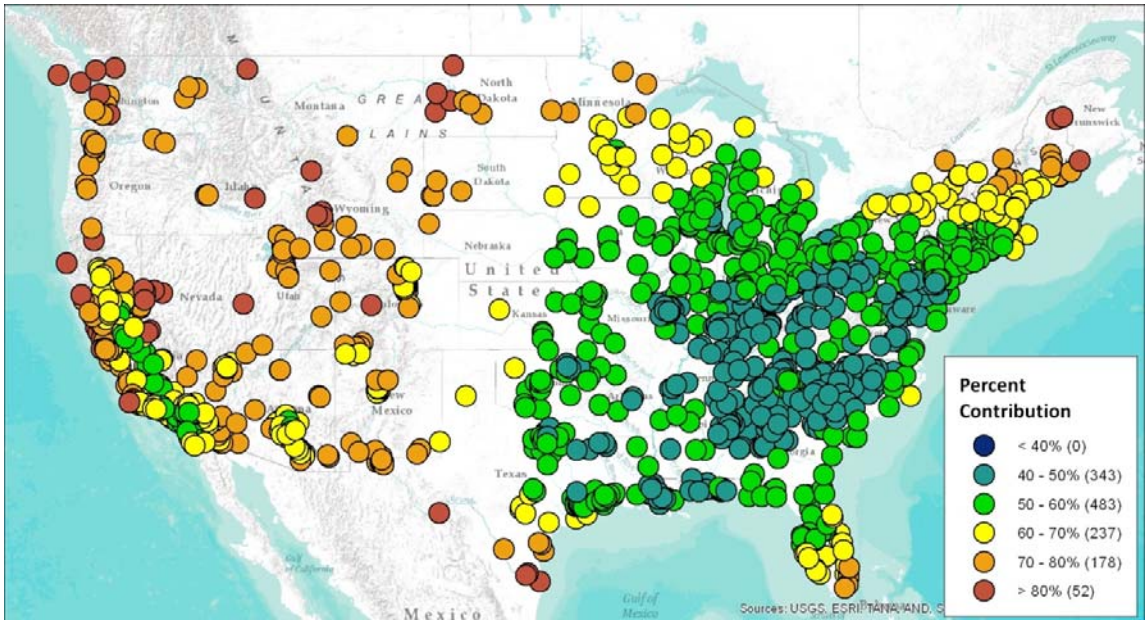

Figure 2-13. Map of site-specific ratios of apportionment-based U.S. background to seasonal mean O_3 based on 2007 CAMx source apportionment modeling.

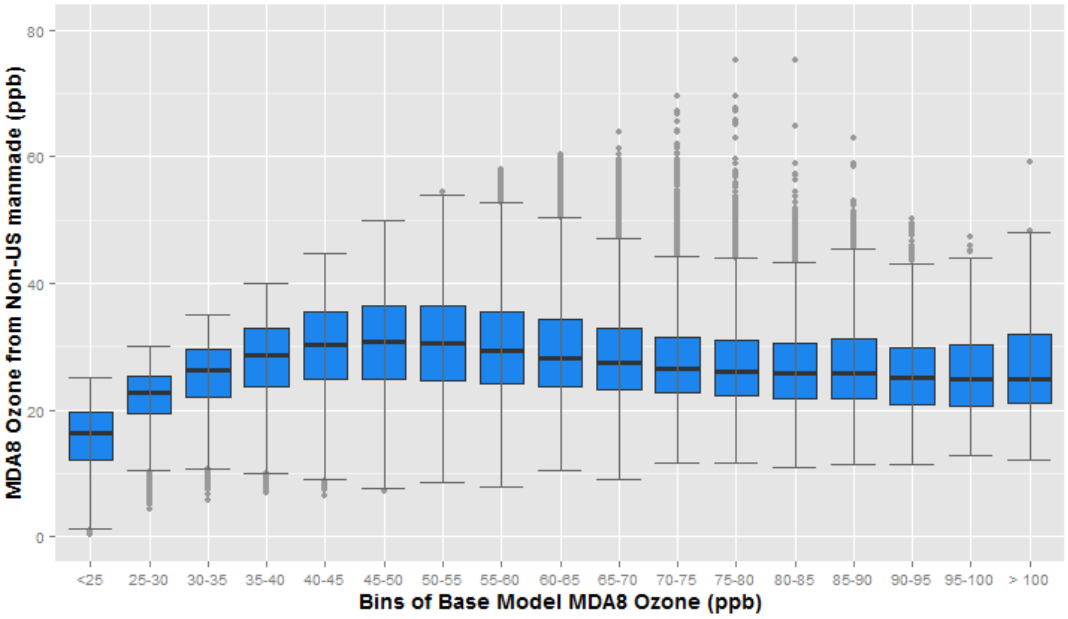

Figure 2-14. Distributions of absolute estimates of apportionment-based U.S. Background (all site-days), binned by modeled MDA8 from the 2007 source apportionment simulation.

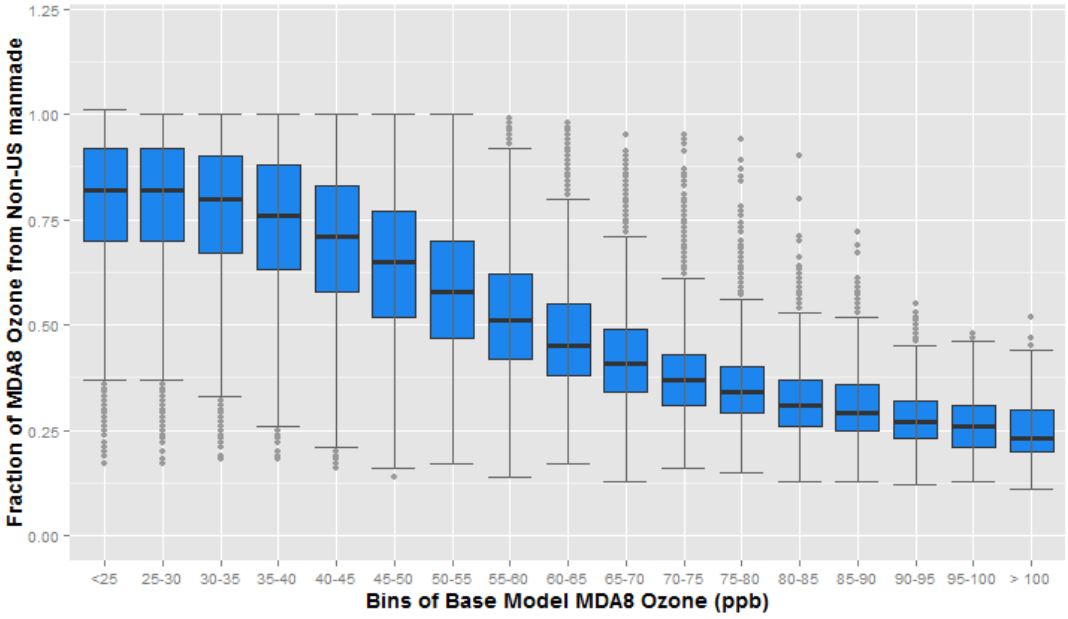

Figure 2-15. Distributions of the relative proportion of apportionment-based U.S. Background to total O_3 (all site-days), binned by modeled MDA8 from the 2007 source apportionment simulation.

2.4.4 Proportion of Background O_3 in 12 Urban Case Study Areas

This section presents estimates of the overall fraction of O_3 that is estimated to result from background sources or processes in each of the 12 urban case study areas considered in the epidemiological-based risk assessment of the REA (US EPA 2014, Chapter 7). The results are based on the recent EPA 2007 source apportionment modeling. Table 2-1 summarizes the estimated ratios of sources other than U.S. anthropogenic emissions (i.e., apportionment-based USB) to total seasonal mean MDA8 O_3 in each of the 12 urban case study areas. The table shows that the fractional contributions from sources other than anthropogenic emissions within the U.S. can range from 43 to 66 percent across these 12 urban areas. These fractions are consistent with the national ratios summarized in section 2.4.2, although the fractions of background are generally smaller at urban sites than at rural sites.

As shown in section 2.4.3, the background-to-total ratios are smaller on days with high modeled O_3 (i.e., days that may exceed the level of the NAAQS). Table 2-2 provides the fractional contributions from apportionment-based USB, only considering days in which base model MDA8 O_3 was greater than 60 ppb. As expected, the fractional background contributions are smaller, ranging from 31 to 55 percent.

Rather than taking the fractions of the seasonal means (as in Table 2-1), Table 2-3 displays the mean and median daily MDA8 background fractions. These metrics may be more appropriate for application to health studies. The fractional contributions to background calculated via this approach are very similar to the Table 2-1 calculations. For completeness, we also provide USB ratios based on the zero-out modeling for the 12 cities (see Table 2-4). The results are similar to the source apportionment findings (Table 2-1), though the zero-out technique provides slightly higher background proportions, as expected. It should be noted that all fractional contributions are based on recent conditions from 2007. These ratios would be expected to change as anthropogenic emissions and O_3 levels are lowered.

Based on the source apportionment modeling for these 12 areas, there is evidence that background levels comprise a non-negligible fraction of the total ozone observed within these locations. However, for site-days in which model MDA8 ozone exceeds 60 ppb, ozone formed from U.S. anthropogenic emissions comprise a larger fraction of the total ozone in 11 of the 12 areas (all but Denver). The major metropolitan areas in the eastern U.S. (e.g., Atlanta, New York City, Philadelphia) are less influenced by background sources than a higher-elevation, western U.S., location like Denver. Even in Denver, though, U.S. anthropogenic emissions have a large influence on total ozone (45 percent).

Table 2-2 Seasonal mean MDA8 O_3 (ppb), seasonal mean apportionment-based USB contribution (ppb), and fractional apportionment-based USB contribution to total O_3 (all site-days) in the 12 REA urban case study areas (%).

All days, CAMx	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Model MDA8 seasonal mean	59.3	54.4	43.0	48.9	47.3	39.1	48.5	51.1	45.4	48.7	46.4	49.8
Model MDA8 seasonal mean from emissions other than U.S. anthropogenic sources	25.3	25.9	26.2	25.7	31.3	23.3	27.0	29.1	24.5	24.2	29.7	24.3
Fractional contribution from background	0.43	0.48	0.61	0.53	0.66	0.60	0.56	0.57	0.54	0.50	0.64	0.49

Table 2-3 Seasonal mean MDA8 O_3 (ppb), seasonal mean apportionment-based USB contribution (ppb), and fractional apportionment-based USB contribution to total O_3 (site-days > 60 ppb) in the 12 REA urban study areas (%).

Only days w/ base MDA8 > 60 ppb	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Model MDA8 seasonal mean	74.0	75.3	70.7	72.0	67.5	68.9	70.3	74.4	74.1	74.0	68.3	70.0
Model MDA8 seasonal mean from emissions other than U.S. anthropogenic sources	25.4	23.7	24.4	25.4	37.3	24.4	28.0	31.9	23.5	22.9	32.1	25.4
Fractional contribution from background	0.34	0.31	0.35	0.35	0.55	0.35	0.40	0.43	0.32	0.31	0.47	0.36

Table 2-4 Fractional contribution of apportionment-based USB in the 12 REA urban study areas (%), using the means and medians of daily MDA8 fractions (instead of fractions of seasonal means).

	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Mean of daily MDA8 background fractions	0.46	0.53	0.68	0.58	0.69	0.64	0.59	0.61	0.61	0.56	0.67	0.52
Median of daily MDA8 background fractions	0.43	0.51	0.73	0.54	0.69	0.66	0.59	0.60	0.63	0.54	0.66	0.49

Table 2-5 Seasonal mean MDA8 O_3 (ppb), seasonal mean USB (ppb), and USB/Total ratio (all site-days) in the 12 REA urban case study areas (%).

All days, CMAQ	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Model MDA8 seasonal mean	58.6	55.6	45.2	51.8	57.1	43.5	49.4	54.8	47.7	50.5	51.9	52.6
Model MDA8 seasonal mean USB	30.0	29.9	28.5	31.6	42.2	31.7	33.0	33.3	29.1	29.4	34.4	32.0
Ratio of USB/Total MDA8 O3	0.51	0.54	0.63	0.61	0.74	0.73	0.67	0.61	0.61	0.58	0.66	0.61

2.4.5 Influence of Background O_3 on W126 levels

EPA also conducted a limited assessment of the impacts of background O_3 sources on the W126 metric. The W126 metric (LeFohn et al., 1988) is a cumulative peak-weighted index designed to estimate longer-term effects of daytime ozone levels on sensitive vegetation and ecosystems. EPA used the 2007 zero-out modeling to assess NB, NAB, and USB influences at

four sample locations: Atlanta GA, Denver CO, Farmington NM, and Riverside CA. Each of the four analyses locations had relatively high observed values of W126 in 2007, as averaged over all sites in the area: Atlanta (25.1 ppm-hrs), Denver (19.6 ppm-hrs), Farmington (20.2 ppm-hrs), and Riverside (36.0 ppm-hrs).

As discussed above, in the current review, EPA is supplementing the counterfactual assessment used in previous reviews (zero out modeling) with analyses that estimate the portion of the existing ozone that is due to background sources (source apportionment). This has important ramifications for assessing the influence of background on W126 concentrations, because of the non-linear weighting function used in the metric, which emphasizes high ozone hours (e.g., periods in which ozone is greater than ~60 ppb). As an example, consider a sample site in the intermountain western U.S. region with very high modeled estimates of U.S background (e.g., seasonal mean of 45 ppb with some days as high as 65 ppb). Even at this high background location, the USB simulations estimate annual W126 (USB) values that are quite low, on the order of 3 ppm-hrs. Sites in the domain with lower U.S. background levels have even smaller USB W126 values, on the order of the 1 ppm-hrs, which is consistent with values mentioned in past reviews (US EPA, 2007). Using the counterfactual scenarios, background ozone has a relatively small impact on W126 levels across the U.S.

However, because of the non-linear weighting function used in the W126 calculation, the sum of the W126 from the USB scenario and the W126 resulting from U.S. anthropogenic sources will not equal the total W126. In most cases, the sum of those two components will be substantially less than total W126. As a result, EPA believes it is more informative to estimate the fractional influence of background ozone to W126 levels. Using a methodology that is described in more detail in Appendix A, EPA considered the fractional influence of background ozone on annual W126 levels in four locations. The fractional influence methodology utilizes the 2007 zero-out modeling but places higher weights on background fractions on days that are going to contribute most substantially to the yearly W126 value. Figure 2-16 shows the results. Based on the fractional influence methodology, natural background sources are estimated to contribute 29-50% of the total modeled W126 with the highest relative influence in the intermountain western U.S. (i.e., Farmington NM) and the lowest relative influence in the eastern U.S. (i.e., Atlanta). U.S. background is estimated to contribute 37-65% of the total modeled W126. The proportional impacts of background are slightly less for the W126 metric than for seasonal mean MDA8 (discussed in section 2.4.2), because of the sigmoidal weighting function that places more emphasis on higher ozone days when background fractions are generally lower.

The key conclusion from this cursory analysis is that background ozone can comprise a non-negligible portion of current W126 levels across the U.S. These fractional influences are greatest in the intermountain western U.S. and are slightly smaller than the seasonal mean

MDA8 metric. This conclusion was also reached in a separate analysis recently completed by Lapina et al. (2014).

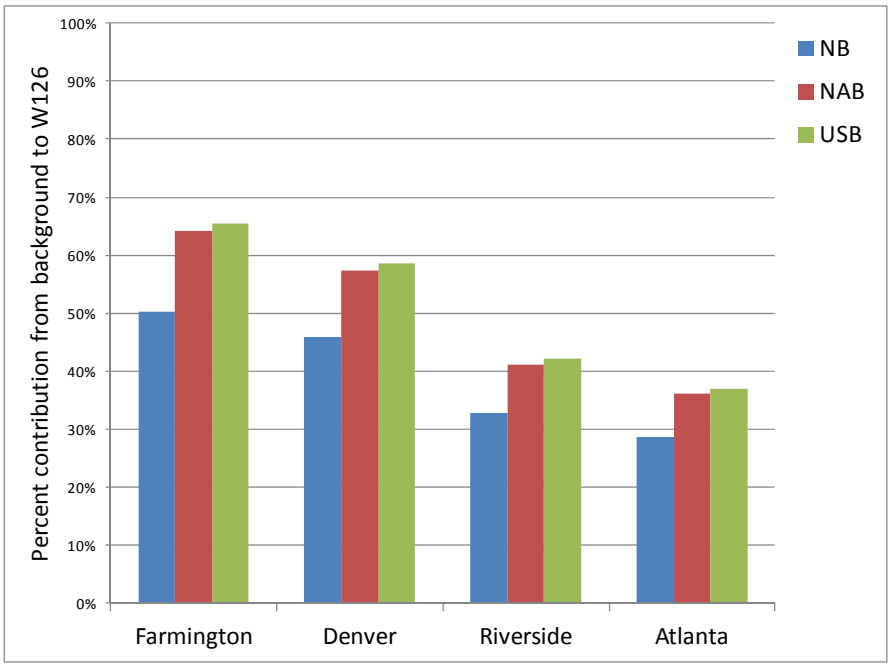

Figure 2-16. Fractional influence of background sources to W126 levels in four sample locations. Model estimates based on 2007 CMAQ zero-out modeling.

2.4.6 Estimated Magnitude of Individual Components of Background O_3

To provide a fuller characterization of background O_3 levels, it is useful to develop an understanding of the relative contributions of various background elements to total background O_3. This section will utilize the supplemental 2007 air quality modeling estimates to consider the relative contribution of specific elements of background O_3. Several background elements were isolated in either the zero-out or source apportionment modeling. Appendix A provides more detail on these analyses. In conjunction with the previous analyses summarized in the ISA, some broad characterizations of the individual components of background O_3 can be developed.

The recent 2007 EPA modeling confirms the importance of methane emissions and international ozone precursor emissions in contributing to background O_3. Methane has an atmospheric lifetime of about a decade and can be an important contributor to ozone on longer time scales. Anthropogenic methane emission sources include agriculture, coal mines, landfills, and natural gas and oil systems. The difference between the NAB and NB zero-out scenarios provides an estimate of contributions from international anthropogenic emissions and anthropogenic methane, which is modeled by reducing model concentrations from present-day values to pre-industrial levels. The ISA (US EPA, 2013, section 3.4) estimated that roughly half of the difference between the NB and NAB scenarios resulted from the removal of anthropogenic

methane emissions and that the other half resulted from international anthropogenic emissions of shorter-lived O_3 precursors (e.g., NO_X and VOC). Figure 2-17 shows the difference in seasonal mean MDA8 O_3 levels between the NB and NAB scenarios. North American seasonal mean background is 6-15 ppb higher than comparable natural background levels. The most frequent increment is an 8-10 ppb increase when the methane is increased and the non-North American emissions are added. These estimates of seasonal-mean external enhancement are similar to previous estimates summarized in the ISA (e.g., Fiore et al., 2009; Zhang et al., 2011). It is not possible via the EPA 2007 modeling to parse out what fraction of this change is due to emissions outside of North America, as opposed to what fraction is due to anthropogenic methane emissions, but the modeling suggests that any control measures to reduce emissions from either of these terms have the potential to contribute in an important way to reduce average background O_3 levels in the U.S.

The difference between the NAB and USB scenarios is easier to interpret as it only involves one change, the inclusion of anthropogenic emissions from the in-domain portion of Canada and Mexico. These emissions (not shown here, but depicted in Appendix A) contribute less than 2 ppb to the seasonal mean MDA8 O_3 levels over most of the U.S. There are 70 sites, near an international border, where the modeling estimates Canadian/Mexican seasonal average impacts of 2-4 ppb. Peak single-day MDA8 impacts from these specific international emissions sources can approach 25 ppb (e.g., San Diego, Buffalo NY).

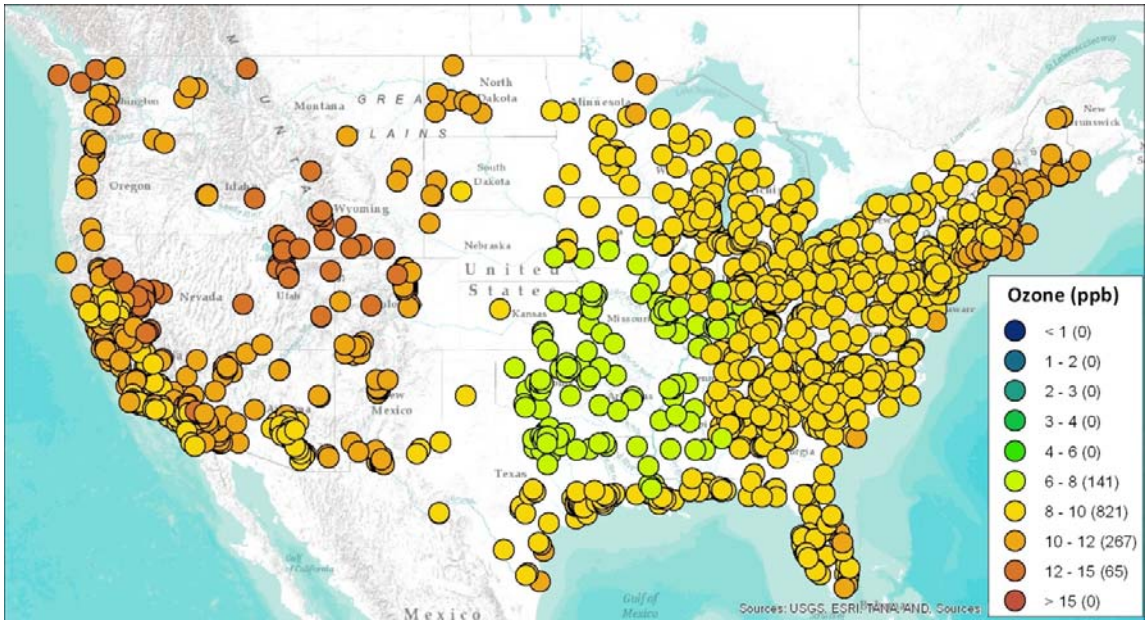

Figure 2-17. Differences in seasonal mean O_3 (ppb) between the NAB and NB scenarios.

Eleven separate source categories were tracked in the source apportionment modeling, including five boundary condition terms (East, South, West, North, and top) and six emissions sectors within the domain. The contributions of each of these terms is provided in the Appendix and summarized below. At most locations, the five model boundary terms contributed an aggregate 40-60 percent of the total seasonal mean MDA8 O_3 across the U.S. The highest proportional impacts from the boundary conditions are along the coastlines and the intermountain West. The O_3 entering the model domain via the boundary conditions can have a variety of origins including: a) natural sources of O_3 and precursors emanating from outside the domain, b) anthropogenic sources of O_3 precursors emanating from outside the domain, and c) some fraction of U.S. emissions (natural and anthropogenic) which exit the regional model domain but get re-imported into the domain via synoptic-scale recirculation. Accordingly, it is not possible to relate the boundary condition contribution to any specific background element. The single largest sector that was tracked in the source apportionment modeling was U.S. anthropogenic emissions. Figure 2-18 shows the contributions from this sector to seasonal mean MDA8 O_3 levels. Over most of the U.S. this term contributes 40-60 percent to the total seasonal mean O_3. As discussed in section 2.4.3, these contributions are even higher when only high O_3 days are considered. International shipping emissions, as well as fires and other biogenic emissions also contribute in a non-negligible way to background O_3 over the U.S. The key finding from this analysis is that air quality planning efforts to reduce anthropogenic methane emissions and international NO_X/VOC emissions (e.g., migrating from Asia, Canada, and Mexico; and from commercial shipping) have the potential to lower background O_3 levels.

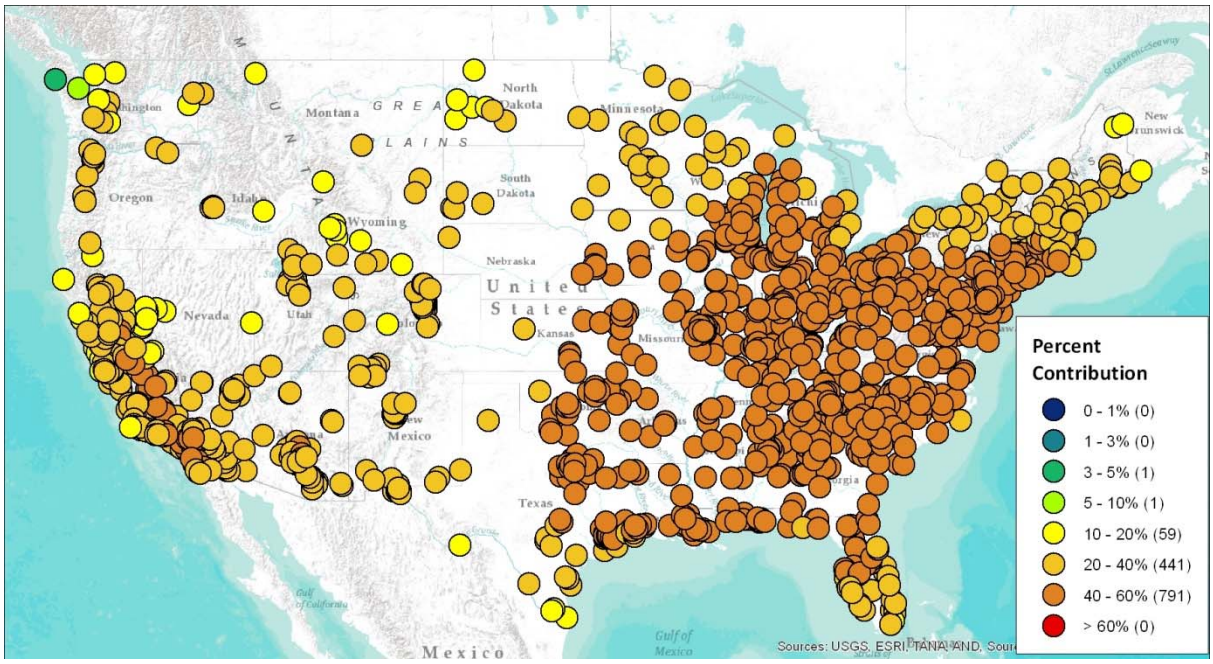

Figure 2-18. Percent contribution of U.S. anthropogenic emissions to total seasonal mean MDA8 O_3 levels, based on 2007 source apportionment modeling.

2.4.7 Summary

For a variety of reasons, it is challenging to present a comprehensive summary of all the components and implications of background O_3. In many forums the term "background" is used generically and the lack of specificity can lead to confusion as to what sources are being considered. Additionally, it is well established that the impacts of background sources can vary greatly over space and time which makes it difficult to present a simple summary of background O_3 levels. Further, background O_3 can be generated by a variety of processes, each of which can lead to differential patterns in space and time, and which often have different regulatory ramifications. Finally, background O_3 is difficult to measure and thus, typically requires air quality modeling which has inherent uncertainties and potential errors and biases.

That said, EPA believes the following concise and three step summary of the implications of background O_3 on the NAAQS review is appropriate, as based on previous modeling exercises and the more recent EPA analyses summarized herein. First, background O_3 exists and can comprise a considerable fraction of total seasonal mean MDA8 O_3 and W126 across the U.S. Air quality models can estimate the fractional contribution of background sources to total O_3 in an individual area. The largest absolute values of background (NB, NAB, USB, or apportionment-

based USB) are modeled to occur at locations in the intermountain western U.S. and are maximized in the spring and early summer seasons. Second, the modeling indicates that U.S. anthropogenic emission sources are the dominant contributor to the majority of modeled O_3 exceedances of the NAAQS. Higher O_3 days generally have smaller fractional contributions from background. This finding indicates that the relative importance of background O_3 would increase were O_3 concentrations to decrease with a lower level of the O_3 NAAQS. Third and finally, while the majority of modeled O_3 exceedances have local and domestic regional emissions as their primary cause, there can be events where O_3 levels approach or exceed 60-75 ppb due to the influence of background sources. These events are relatively infrequent and EPA has policies that could allow for the exclusion of air quality monitoring data affected by these types of events from design value calculations.

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3 Adequacy of the Current Primary Standard

This chapter presents staff's considerations and conclusions regarding the adequacy of the current primary O_3 NAAQS. In doing so, we pose the following overarching question:

Does the currently available scientific evidence and exposure/risk information, as reflected in the ISA and HREA, support or call into question the adequacy of the current O_3 standard?

As discussed more fully in this chapter, staff reaches the conclusion that the available evidence and exposure and risk information clearly calls into question the adequacy of public health protection provided by the current primary standard. This evidence and information provides strong support for the occurrence of a range of adverse respiratory effects, and mortality, under air quality conditions that would meet the current standard. Based on the analyses in the HREA, we conclude that the exposures and risks projected to remain upon meeting the current standard are indicative of risks that can reasonably be judged to be important from a public health perspective. Thus, staff concludes that the evidence and information provides strong support for giving consideration to revising the current primary standard in order to provide increased public health protection against an array of adverse health effects that range from decreased lung function and respiratory symptoms to more serious indicators of morbidity (e.g., including emergency department visits and hospital admissions), and mortality. The remainder of this chapter discusses the evidence and exposure/risk information, and the considerations and conclusions based on that evidence and information, supporting staff's overarching conclusion regarding the adequacy of the current primary O_3 standard.

In addressing the overarching question for this chapter, we pose a series of more specific questions, as discussed in sections 3.1 through 3.4 below. Section 3.1 presents our consideration of the available scientific evidence (i.e., evidence-based considerations) about the health effects associated with short- and long-term O_3 exposures. Section 3.2 presents our consideration of available estimates of O_3 exposures and health risks (exposure- and risk-based considerations). Section 3.3 discusses the advice and recommendations that we have received from the CASAC on the first draft O_3 PA, and on documents from previous reviews of the O_3 NAAQS. Section 3.4 revisits the overarching question of this section, and presents staff's conclusions regarding the adequacy of the current primary O_3 NAAQS.

3.1 EVIDENCE-BASED CONSIDERATIONS

This section presents our consideration of the available scientific evidence with regard to the adequacy of the current O_3 standard. Our approach, as summarized in section 1.3.1 above, is based on the full body of evidence in this review. We use information from the full evidence base to characterize our confidence in the extent to which O_3-attributable effects occur, and the extent to which such effects are adverse, over the ranges of O_3 exposure concentrations evaluated in controlled human exposure studies and over the distributions of ambient O_3 concentrations in locations where epidemiologic studies have been conducted. In doing so, we recognize that the available health effects evidence reflects a continuum from relatively high O_3 concentrations, at which scientists generally agree that adverse health effects are likely to occur, through lower concentrations, at which the likelihood and magnitude of a response become increasingly uncertain.

Section 3.1.1 summarizes a mode of action framework for understanding the effects of both short- and long-term O_3 exposures, based on Chapter 5 of the ISA (U.S. EPA, 2013). Section 3.1.2 presents our consideration of the evidence for health effects attributable to short-term and long-term O_3 exposures. Section 3.1.3 discusses the adversity of the effects. Section 3.1.4 presents our consideration of evidence with regard to concentrations associated with health effects and section 3.1.5 presents our consideration of the public health implications of exposures to O_3, including the adversity of effects and evidence for at-risk populations and lifestages.[1]

3.1.1 Modes of Action

Our consideration of the evidence of effects attributable to short-and long-term exposures and the factors that increase risk in populations and lifestages builds upon evidence about the modes of action by which O_3 exerts effects (U.S. EPA, 2013; section 5.3). Mode of action refers to a sequence of key events and processes that result in a given toxic effect; elucidation of mechanisms provides a more detailed understanding of these key events and processes. The purpose of this section is to describe the key events and pathways that contribute to health effects resulting from both short-term and long-term exposures to O_3. The extensive research carried out

[1] Here, as in the ISA, the term "at-risk population" is used to encompass populations or lifestages that have a greater likelihood of experiencing health effects related to exposure to an air pollutant due to a variety of factors; other terms used in the literature include susceptible, vulnerable, and sensitive. These factors may be intrinsic, such as genetic factors, lifestage, or the presence of preexisting diseases, or they may be extrinsic, such as socioeconomic status (SES), activity pattern and exercise level, or increased pollutant exposures (U.S. EPA, 2013, p. lxx, 8-1, 8-2). The courts and the Act's legislative history refer to these at-risk subpopulations as "susceptible" or "sensitive" populations. See, e.g., American Lung Ass'n v. EPA, 134 F. 3d 388, 389 (D.C. Cir. 1998) ("NAAQS must protect not only average health individuals, but also 'sensitive citizens' – children, for example, or people with asthma, emphysema, or other conditions rendering them particularly vulnerable to air pollution" (quoting S. Rep. No. 91-1196 at 10).

over several decades in humans and animals has yielded numerous studies on mechanisms by which O_3 exerts its effects. It is well-understood that secondary oxidation products, which form as a result of O_3 exposure, initiate numerous responses at the cellular, tissue and whole organ level of the respiratory system. These responses include the activation of neural reflexes, initiation of inflammation, alteration of barrier epithelial function, sensitization of bronchial smooth muscle, modification of lung host defenses, and airways remodeling, as discussed below. These key events have the potential to affect other organ systems such as the cardiovascular system. It has been proposed that secondary oxidation products, which are bioactive and cytotoxic in the respiratory system, are also responsible for systemic effects. Recent studies in animal models show that inhalation of O_3 results in systematic oxidative stress.

Figure 3.1 below, adapted from Figure 5-8 of the ISA (ISA, Section 5.3.10, U.S. EPA, 2013), shows key events in the toxicity pathway of O_3 that are described in more detail below. The initial key event in the toxicity pathway of O_3 is the formation of secondary oxidation products in the respiratory tract (ISA, section 5.3, U.S. EPA, 2013). This mainly involves direct reactions with components of the extracellular lining fluid (ELF). Although the ELF has inherent capacity to quench (based on individual antioxidant capacity), this capacity can be overwhelmed, especially with exposure to elevated concentrations of O_3.[2] The resulting secondary oxidation products transmit signals to the epithelium, pain receptive nerve fibers and, if present, immune cells (i.e., eosinophils, dendritic cells and mast cells) involved in allergic responses. Thus, the effects of O_3 are mediated by components of ELF and by the multiple cell types found in the respiratory tract. Further, oxidative stress[3] is an implicit part of this initial key event.

[2] The ELF is a complex mixture of lipids (fats), proteins, and antioxidants that serve as the first barrier and target for inhaled O_3. The quenching ability of antioxidant substances present in the ELF appear in most cases to limit interaction of O_3 with underlying tissues and to prevent penetration of O_3 deeper into the lung. However, as the ELF thickness decreases and becomes ultra thin in the alveolar region, it may be possible for direct interaction of O_3 with the underlying epithelial cells to occur. The formation of secondary oxidation products is likely related to the concentration of antioxidants present and the quenching ability of the lining fluid.

[3] Oxidative stress reflects an imbalance between the systemic manifestation of reactive oxygen species, such as superoxide, and a biological system's ability to readily detoxify the reactive intermediates or to repair the resulting damage.

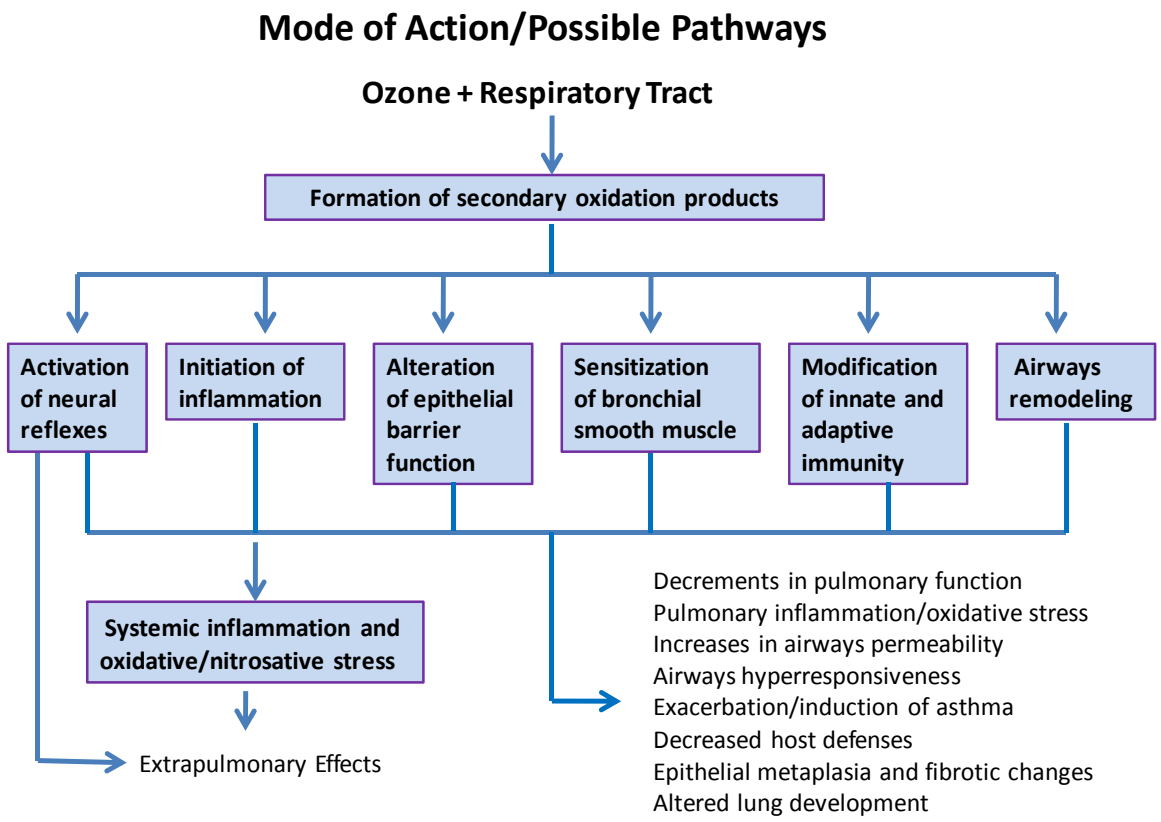

Figure 3-1. Modes of action/possible pathways underlying the health effects resulting from inhalation exposure to O_3. (Adapted from U.S. EPA, 2013, Figure 5-8)

Another key event in the toxicity pathway of O_3 is the activation of neural reflexes which lead to lung function decrements. Evidence is accumulating that secondary oxidation products are responsible for this effect. Different receptors on bronchial sensory nerves (i.e., C-fibers) have been shown to mediate separate effects of O_3 on pulmonary function. For example, pain (i.e., nociceptive) sensory nerves are involved in the involuntary truncation of inspiration which results in decreases in FVC, FEV_1, tidal volume and pain upon deep inspiration. Ozone exposure also results in activation of vagal sensory nerves and a mild increase in airway obstruction measured as increased sRaw. Activation of neural reflexes also results in extrapulmonary effects such as slow resting heart rate (i.e., bradycardia).

Initiation of inflammation is also a key event in the toxicity pathway of O_3. Secondary oxidation products, as well as cell signaling molecules (i.e., chemokines and cytokines) from airway epithelial cells and white blood cells (i.e., macrophages), have been implicated in the initiation of inflammation. Airways neutrophilia has been demonstrated in bronchoalveolar lavage fluid (BALF), mucosal biopsy and induced sputum samples. Influx of other cells (i.e., mast cells, monocytes and macrophages) also occur. Inflammation further contributes to

O_3-mediated oxidative stress. It should be noted that inflammation, as measured by airways neutrophilia, is not correlated with decrements in pulmonary function as measured by spirometry.

A fourth key event in the toxicity pathway of O_3 is alteration of epithelial barrier function. Increased permeability[4] occurs as a result of damage to tight junctions between epithelial cells subsequent to O_3-induced injury and inflammation. It may play a role in allergic sensitization and in airway hyperresponsiveness (AHR). Genetic susceptibility has been associated with this pathway.

A fifth key event in the toxicity pathway of O_3 is the sensitization of bronchial smooth muscle. Airway hyperresponsiveness, or increased bronchial reactivity, can be both a rapidly occurring and a persistent response. The mechanisms responsible for AHR are not well-understood. Tachykinins, peptides that can excite neurons and cause smooth muscle contraction, and the secondary oxidation products of O_3 have been proposed as mediators of the early response and inflammation-derived products have been proposed as mediators of the later response. Other chemical signaling molecules (i.e., cytokines and chemokines) have been implicated in the AHR response to O_3 in animal models. Antioxidants may confer protection.

A sixth key event in the toxicity pathway of O_3 is the modification of innate/adaptive immunity. While the majority of evidence for this key event comes from animal studies, there are several studies suggesting that this pathway may also be relevant in humans. Ozone exposure of human subjects resulted in recruitment of activated innate immune cells to the airways. Animal studies further linked O_3-mediated activation of the innate immune system to the development of nonspecific AHR, demonstrated an interaction between allergen and O_3 in the induction of nonspecific AHR, and found that O_3 acted as an adjuvant for allergic sensitization through the activation of both innate and adaptive immunity. These studies provide evidence that O_3 can alter host immunologic response and lead to immune system dysfunction. These mechanisms may underlie the exacerbation and induction of asthma, as well as decreases in lung host defense.

Another key event in the toxicity pathway of O_3 is airways remodeling. Persistent inflammation and injury, which are observed in animal models of chronic and intermittent

[4] Cells in epithelium are very densely packed together, leaving very little intercellular space. All epithelial cells rest on a basement membrane, a thin sheet of fibers that acts as scaffolding on which epithelium can grow and regenerate after injuries. Epithelial tissue is innervated but avascular; it must be nourished by substances diffusing from the blood vessels in the underlying tissue. Injury to epithelial cells, such as caused by oxidative stress, can cause the epithelium to become more permeable to substances in the underlying vasculature.

exposure to O_3, are associated with morphologic changes such as mucous cell metaplasia[5] of nasal epithelium, bronchiolar metaplasia of alveolar ducts and fibrotic changes in small airways (see Section 7.2.3 of the ISA, U.S. EPA, 2013). Mechanisms responsible for these responses are not well-understood. However, a recent study in mice demonstrated a key role for a signaling pathway in the deposition of collagen in the airway wall following chronic intermittent exposure to O_3. Chronic intermittent exposure to O_3 has also been shown to result in effects on the developing lung and immune system.

Systemic inflammation and vascular oxidative/nitrosative stress are also key events in the toxicity pathway of O_3. Extrapulmonary effects of O_3 occur in numerous organ systems, including the cardiovascular, central nervous, reproductive, and hepatic systems (see Sections 6.3 to 6.5 and Sections 7.3 to 7.5 of the ISA, U.S. EPA, 2013). It has been proposed that lipid oxidation products resulting from reaction of O_3 with lipids and/or cellular membranes in the ELF are responsible for systemic responses; however, it is not known whether they gain access to the circulation. Alternatively, release of diffusible mediators from the lung into the circulation may initiate or propagate inflammatory responses in the circulation or other organ systems.

Responses to O_3 exposure are variable within the population. Although studies have shown a large range of pulmonary function (i.e., spirometric) responses to O_3 among healthy young adults, responses within an individual are relatively consistent over time. Other responses to O_3 have also been characterized by a large degree of inter-individual variability. For example, a 3- to 20-fold difference among subjects in their studies in airways inflammation (i.e., neutrophilia influx) following O_3 exposure has been reported (Schelegle et al., 1991 and Devlin et al., 1991, respectively). Reproducibility of an individual's inflammatory response to O_3 exposure in humans, measured as sputum neutrophilia, was demonstrated by Holz et al. (1999). Since individual inflammatory responses were relatively consistent across time, it was thought that inflammatory responsiveness reflected an intrinsic characteristic of the subject (Mudway and Kelly, 2000). While the basis for the observed inter-individual variability in responsiveness to O_3 is not clear, section 5.4.2 of the ISA (U.S. EPA, 2013) discusses mechanisms that may underlie the variability in responses seen among individuals. Certain functional genetic polymorphisms, pre-existing conditions or diseases, nutritional status, lifestages, and co-exposures contribute to altered risk of O_3-induced effects.

[5] Metaplasia is the reversible replacement of one differentiated cell type with another mature differentiated cell type. The change from one type of cell to another may generally be a part of normal maturation process or caused by some sort of abnormal stimulus. In simplistic terms, it is as if the original cells are not robust enough to withstand the new environment, and so they change into another type more suited to the new environment. If the stimulus that caused metaplasia is removed or ceases, tissues return to their normal pattern of differentiation.

Experimental evidence for such O_3-induced changes contributes to our understanding of the biological plausibility of adverse O_3-related health effects, including a range of respiratory effects as well as effects outside the respiratory system (e.g., cardiovascular effects) (U.S. EPA, 2013, Chapters 6 and 7).

3.1.2 Nature of Effects

- **To what extent does the currently available scientific evidence alter or strengthen our conclusions from the last review regarding health effects attributable to O_3 exposure in ambient air? Are previously identified uncertainties reduced or do important uncertainties remain?**

The health effects of ozone are described in detail in the assessment of the evidence available in this review which is largely consistent with conclusions of past Air Quality Criteria Documents (AQCD). In some categories of health effects, there is newly available evidence regarding some aspects of the effects described in the last review or that strengthens our conclusions regarding aspects of O_3 toxicity on a particular physiological system (U.S. EPA, 2013, Table 1-1). A sizeable number of studies on O_3 health effects are newly available in this review and are critically assessed in the ISA as part of the full body of evidence. Based on this assessment, the ISA determined that a causal relationship[6] exists between short-term exposure to O_3 in ambient air[7] and effects on the respiratory system and that a likely to be causal relationship[8] exists between long-term exposure to O_3 in ambient air and respiratory effects (U.S. EPA, 2013, pp. 1-6 to 1-7). As stated in the ISA, "[c]ollectively, a very large amount of evidence spanning several decades supports a relationship between exposure to O_3 and a broad range of respiratory effects" (ISA, p. 1-6). Additionally, the ISA determined that the relationships between short-term exposures to O_3 in ambient air and both total mortality and cardiovascular effects are likely to be causal, based on expanded evidence bases in the current review (U.S. EPA, 2013, pp. 1-7 to 1-8). In the ISA, EPA additionally determined that the currently available evidence for additional endpoints is suggestive of causal relationships between short-term (central nervous system effects) and long-term exposure (cardiovascular effects, central nervous system effects and total mortality) to ambient O_3. Consistent with emphasis in past reviews on O_3 health effects for which

[6] Since the last O3 NAAQS review, the ISAs which have replaced CDs in documenting each review of the scientific evidence (or air quality criteria) employ a systematic framework for weighing the evidence and describing associated conclusions with regard to causality, using established descriptors, as summarized in section 1.3.1 above (U.S. EPA, 2013, Preamble).

[7] In determining that a causal relationship exists for O_3 with specific health effects, EPA has concluded that "[e]vidence is sufficient to conclude that there is a causal relationship with relevant pollutant exposures" (ISA, p. lxiv).

[8] In determining a likely to be a causal relationship exists for O_3 with specific health effects, EPA has concluded that "[e]vidence is sufficient to conclude that a causal relationship is likely to exist with relevant pollutant exposures, but important uncertainties remain" (ISA, p. lxiv).

the evidence is strongest, we place the greatest emphasis on studies of health effects that have been judged in the ISA to be caused by, or likely to be caused by, O_3 exposures (U.S. EPA, 2013, section 2.5.2).

This section presents our consideration of the evidence for health effects attributable to O_3 exposures, including respiratory morbidity and mortality effects attributable to short- and long-term exposures, and cardiovascular system effects (including mortality) and total mortality attributable to short-term exposures. We focus particularly on considering the extent to which the scientific evidence available in the current review has been strengthened since the last review, and the extent to which important uncertainties and limitations in the evidence from the last review have been addressed. In section 3.1.2.2, we then consider the extent to which the available evidence indicates health effects may be attributable to ambient O_3 concentrations likely to be allowed by the current O_3 NAAQS. In this section, we address the following specific question for each category of health effects considering the evidence available in the 2008 review of the standard as well as evidence that has become available since then. The ISA summarizes the longstanding body of evidence for O_3 respiratory effects as follows (U.S. EPA, 2013, p. 1-6).

> *The clearest evidence for health effects associated with exposure to O_3 is provided by studies of respiratory effects. Collectively, a very large amount of evidence spanning several decades supports a relationship between exposure to O3 and a broad range of respiratory effects (see Section 6.2.9 and Section 7.2.8). The majority of this evidence is derived from studies investigating short-term exposures (i.e., hours to weeks) to O_3, although animal toxicological studies and recent epidemiologic evidence demonstrate that long-term exposure (i.e., months to years) may also harm the respiratory system.*

The extensive body of evidence supporting a causal relationship between short-term O_3 exposures and respiratory effects is discussed in detail in Chapter 6 of the ISA (U.S. EPA, 2013), while evidence for respiratory effects associated with long-term or repeated O_3 exposures are discussed in chapter 7 of that document (U.S., EPA, 2013).

3.1.2.1 Respiratory Effects – Short-term Exposures

- **To what extent does the currently available scientific evidence, including related uncertainties, strengthen or alter our understanding from the last review of respiratory effects attributable to short-term O_3 exposures?**

The 2006 O_3 AQCD concluded that there was clear, consistent evidence of a causal relationship between short-term O_3 exposure and respiratory effects (U.S. EPA, 2006). This conclusion was substantiated by evidence from controlled human exposure and toxicological studies indicating a range of respiratory effects in response to short-term O_3 exposures, including pulmonary function decrements and increases in respiratory symptoms, lung inflammation, lung

permeability, and airway hyperresponsiveness. Toxicological studies provided additional evidence for O_3-induced impairment of host defenses. Combined, these findings from experimental studies provided support for epidemiologic evidence, in which short-term increases in ambient O_3 concentration were consistently associated with decreases in lung function in populations with increased outdoor exposures, especially children with asthma and healthy children; increases in respiratory symptoms and asthma medication use in children with asthma; and increases in respiratory-related hospital admissions and asthma-related ED visits (U.S. EPA, 2013, pp. 6-1 to 6-2).

As discussed in detail in the ISA (U.S. EPA, 2013, section 6.2.9), studies evaluated since the completion of the 2006 O_3 AQCD support and expand upon the strong body of evidence that, in the last review, indicated a causal relationship between short-term O_3 exposures and respiratory health effects. Recent controlled human exposure studies conducted in young, healthy adults with moderate exertion have reported FEV_1 decrements and pulmonary inflammation following prolonged exposures to O_3 concentrations as low as 60 ppb, and respiratory symptoms following exposures to concentrations as low as 70 ppb.[9] Epidemiologic studies provide evidence that increases in ambient O_3 exposures can result in lung function decrements, increases in respiratory symptoms, and pulmonary inflammation in children with asthma; increases in respiratory-related hospital admissions and emergency department visits; and increases in respiratory mortality. Some of these studies report such associations even for O_3 concentrations at the low end of the distribution of daily concentrations. Recent epidemiologic studies report that associations with respiratory morbidity and mortality are stronger during the warm/summer months and remain robust after adjustment for copollutants. Recent toxicological studies reporting O_3-induced inflammation, airway hyperresponsiveness, and impaired lung host defense continue to support the biological plausibility and modes of action for the O_3-induced respiratory effects observed in the controlled human exposure and epidemiologic studies. Further support is provided by recent studies that found O_3-associated increases in indicators of airway inflammation and oxidative stress in children with asthma (U.S. EPA, 2013, section 6.2.9). Together, epidemiologic and experimental studies support a continuum of respiratory effects associated with O_3 exposure that can result in respiratory-related emergency department visits, hospital admissions, and/or mortality (U.S. EPA, 2013, section 6.2.9).

Across respiratory endpoints, evidence indicates antioxidant capacity may modify the risk of respiratory morbidity associated with O_3 exposure (U.S. EPA, 2013, section 6.2.9, p. 6-161) (section 3.1.1, above). The potentially elevated risk of populations with diminished

[9] Schelegle et al. (2009) reported a statistically significant increase in respiratory symptoms in healthy adults at a target O_3 exposure concentration of 70 ppb. For this 70 ppb target, Schelegle et al. (2009) reported an actual exposure concentration, averaged over the study period, of 72 ppb.

antioxidant capacity and the reduced risk of populations with sufficient antioxidant capacity is supported by epidemiologic and controlled human exposure studies. Additional evidence characterizes O_3-induced decreases in antioxidant levels as a key event in the mode of action for downstream effects.

We describe key aspects of this evidence below with regard to lung function decrements; pulmonary inflammation, injury, and oxidative stress; airway hyperresponsiveness; respiratory symptoms and medication use; lung host defense; allergic and asthma-related responses; hospital admissions and emergency department visits; and respiratory mortality.

Lung Function Decrements

In the 2008 review, a large number of controlled human exposure studies reported O_3-induced lung function decrements in young, healthy adults engaged in intermittent, moderate exertion following 6.6 hour exposures to O_3 concentrations at or above 80 ppb. Although two studies also reported effects following exposures to lower concentrations, an important uncertainty in the last review was the extent to which exposures to O_3 concentrations below 80 ppb result in lung function decrements. In addition, in the last review epidemiologic panel studies had reported O_3-associated lung function decrements in a variety of different populations (e.g., children, outdoor workers) likely to experience increased exposures. In the current review, additional controlled human exposure studies are available that have evaluated exposures to O_3 concentrations of 60 or 70 ppb. The available evidence from controlled human exposure and panel studies is assessed in detail in the ISA (U.S. EPA, 2013, section 6.2.1) and is summarized below.

Controlled exposures to O_3 concentrations that can be found in the ambient air can result in a number of lung function effects, including decreased inspiratory capacity; mild bronchoconstriction; and rapid, shallow breathing patterns during exercise. Reflex inhibition of inspiration results in a decrease in forced vital capacity (FVC) and total lung capacity (TLC) and, in combination with mild bronchoconstriction, contributes to a decrease in the forced expiratory volume in 1 second (FEV_1) (U.S. EPA, 2013, section 6.2.1.1).[10] Accumulating evidence indicates that such effects are mediated by activation of sensory nerves, resulting in the involuntary truncation of inspiration and a mild increase in airway obstruction due to bronchoconstriction (U.S. EPA, 2013, section 5.3.10).

[10] The controlled human exposure studies emphasized in this PA utilize only healthy adult subjects. In the near absence of controlled human exposure data for children, HREA estimates of lung function decrements are based on the assumption that children exhibit the same lung function responses following O_3 exposures as healthy 18 year olds (U.S. EPA, 2014, sections 6.2.4 and 6.5). This assumption is justified in part by the findings of McDonnell et al. (1985), who reported that children 8-11 year old experienced FEV_1 responses similar to those observed in adults 18-35 years old. Thus, the conclusions about the occurrence of lung function decrements that follow generally apply to children as well as to adults.

Data from controlled human exposure studies indicate that increasing the duration of O_3 exposures and increasing ventilation rates decreases the O_3 exposure concentrations required to impair lung function. Ozone exposure concentrations well above those typically found in ambient air are required to impair lung function in healthy resting adults, while exposure to O_3 concentrations at or below those in the ambient air have been reported to impair lung function in healthy adults exposed for longer durations while undergoing intermittent, moderate exertion (U.S. EPA, 2013, section 6.2.1.1). With repeated O_3 exposures over several days, FEV_1 responses become attenuated in both healthy adults and adults with mild asthma, though this attenuation of response is lost after about a week without exposure (U.S. EPA, 2013, section 6.2.1.1; page 6-27).

When considering controlled human exposures studies of O_3-induced lung function decrements we evaluate both group mean changes in lung function and the interindividual variability in the magnitude of responses. An advantage of O_3 controlled human exposure studies (i.e., compared to the epidemiologic panel studies discussed below) is that reported effects necessarily result from exposures to O_3 itself.[11] To the extent studies report statistically significant decrements in mean lung function following O_3 exposures after controlling for other factors, we have more confidence that measured decrements are due to the O_3 exposure itself, rather than to chance alone. As discussed below, group mean changes in lung function are often small, especially following exposures to relatively low O_3 concentrations (e.g., 60 ppb). However, even when group mean decrements in lung function are small, some individuals could experience decrements that are "clinically meaningful" (Pellegrino et al., 2005; ATS, 1991) with respect to criteria for spirometric testing, and/or that could be considered "adverse" with respect to public health policy decisions (section 3.1.3 below).

At the time of the last review, a number of controlled human exposure studies had reported lung function decrements in young, healthy adults following prolonged (6.6-hour) exposures while at moderate exertion to O_3 concentrations at and above 80 ppb. In addition, there were two controlled human exposure studies by Adams (2002, 2006) that examined lung function effects following exposures to O_3 concentrations of 60 ppb. The EPA's analysis of the data from the Adams (2006) study reported a small but statistically significant O_3-induced decrement in group mean FEV_1 following exposures of young, healthy adults, while at moderate exertion, to 60 ppb O_3, when compared with filtered air controls (Brown, 2008).[12] Further

[11] The ISA notes that the use of filtered air responses as a control for the assessment of responses following O3 exposure in controlled human exposure studies serves to eliminate alternative explanations other than O3 itself in causing the measured responses (U.S. EPA, 2013, section 6.2.1.1).

[12] Adams (2006) did not find effects on FEV_1 at 60 ppb to be statistically significant. In an analysis of the Adams (2006) data, even after removal of potential outliers, Brown et al. (2008) found the average effect on FEV1 at 60 ppb to be small, but highly statistically significant ($p < 0.002$) using several common statistical tests.

examination of the post-exposure FEV_1 data, and mean data for other time points and other concentrations, indicated that the temporal pattern of the response to 60 ppb O_3 was generally consistent with the temporal patterns of responses to higher O_3 concentrations in this and other studies. (75 FR 2950, January 19, 2010). This suggested a pattern of response following exposures to 60 ppb O_3 that was consistent with a dose-response relationship, rather than random variability. See also *State of Mississippi v. EPA*, 744 F. 3d at 1347 (upholding EPA's interpretation of the Adams studies).

Figure 6-1 in the ISA summarizes the currently available evidence from multiple controlled human exposure studies evaluating group mean changes in FEV_1 following prolonged O_3 exposures (i.e., 6.6 hours) in young, healthy adults engaged in moderate levels of physical activity (U.S. EPA, 2013, section 6.2.1.1). With regard to the group mean changes reported in these studies, the ISA specifically notes the following (U.S. EPA, 2013, section 6.2.1.1, Figure 6-1):

1. Prolonged exposure to 40 ppb O_3 results in a small decrease in group mean FEV_1 that is not statistically different from responses following exposure to filtered air (Adams, 2002; Adams, 2006).

2. Prolonged exposure to an average O_3 concentration of 60 ppb results in group mean FEV_1 decrements ranging from 1.8% to 3.6% (Adams 2002; Adams, 2006;[13] Schelegle et al., 2009;[14] Kim et al., 2011). Based on data from multiple studies, the weighted average group mean decrement was 2.7%. In some analyses, these group mean decrements in lung function were statistically significant (Brown et al., 2008; Kim et al., 2011), while in other analyses they were not (Adams, 2006; Schelegle et al., 2009).[15]

3. Prolonged exposure to an average O_3 concentration of 70 ppb results in a statistically significant group mean decrement in FEV_1 of about 6% (Schelegle et al., 2009).[16]

4. Prolonged square-wave exposure to average O_3 concentrations of 80 ppb, 100 ppb, or 120 ppb O_3 results in statistically significant group mean decrements in FEV_1 ranging from 6 to 8%, 8 to 14%, and 13 to 16%, respectively (Folinsbee et al., 1988; Horstman et al., 1990; McDonnell et al., 1991; Adams, 2002; Adams, 2003; Adams, 2006).

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[13] Adams (2006; 2002) both provide data for an additional group of 30 healthy subjects that were exposed via facemask to 60 ppb (square-wave) O_3 for 6.6 hours with moderate exercise ($\dot{V}_E$ = 23 L/min per m^2 BSA). These subjects are described on page 133 of Adams (2006) and pages 747 and 761 of Adams (2002). The FEV_1 decrement may be somewhat increased due to a target $\dot{V}_E$ of 23 L/min per m^2 BSA relative to other studies having the target $\dot{V}_E$ of 20 L/min per m^2 BSA. The facemask exposure is not expected to affect the FEV_1 responses relative to a chamber exposure.

[14] Schelegle et al. (2009) reported an actual mean exposure concentration of 63 ppb for the target of 60 ppb.

[15] Adams (2006) did not find effects on FEV_1 at 60 ppb to be statistically significant. In an analysis of the Adams (2006) data, Brown et al. (2008) addressed the more fundamental question of whether there were statistically significant differences in responses before and after the 6.6 hour exposure period and found the average effect on FEV_1 at 60 ppb to be small, but highly statistically significant using several common statistical tests, even after removal of potential outliers.

[16] Schelegle et al. (2009) reported an actual mean exposure concentration of 72 ppb for the target of 70 ppb.

As illustrated in Figure 6-1 of the ISA, there is a smooth dose-response curve without evidence of a threshold for exposures between 40 and 120 ppb O_3 (U.S. EPA, 2013, Figure 6-1). When these data are taken together, the ISA concludes that "mean FEV_1 is clearly decreased by 6.6-h exposures to 60 ppb O_3 and higher concentrations in [healthy, young adult] subjects performing moderate exercise" (U.S. EPA, 2013, p. 6-9).

With respect to interindividual variability in lung function, in an individual with relatively "normal" lung function, with recognition of the technical and biological variability in measurements, within-day changes in FEV_1 of $\geq$ 5% are clinically meaningful (Pellegrino et al., 2005; ATS, 1991). The ISA (U.S. EPA, 2013, section 6.1.) focuses on individuals with >10% decrements in FEV_1 for two reasons. A 10% FEV_1 decrement is accepted by the American Thoracic Society (ATS) as an abnormal response and a reasonable criterion for assessing exercise-induced bronchoconstriction (Dryden et al., 2010; ATS, 2000). (U.S. EPA, 2013, section 6.2.1.1). Also, some individuals in the Schelegle et al. (2009) study experienced 5-10% FEV_1 decrements following exposure to filtered air.

In previous NAAQS reviews, the EPA has made judgments regarding the potential implications for individuals experiencing FEV_1 decrements of varying degrees of severity.[17] For people with lung disease, the EPA judged that moderate functional decrements (e.g., FEV_1 decrements $\geq$ 10 percent but < 20 percent, lasting up to 24 hours) would likely interfere with normal activity for many individuals, and would likely result in more frequent use of medication (75 FR 2973, January 19, 2010). In previous reviews CASAC has endorsed these conclusions. In the context of standard setting, in the last review O_3 review CASAC indicated that it is appropriate to focus on the lower end of the range of moderate functional responses (e.g., FEV_1 decrements $\geq$ 10 percent) when estimating potentially adverse lung function decrements in people with lung disease, especially children with asthma (Henderson, 2006). More specifically, CASAC stated that "[a] 10% decrement in FEV_1 can lead to respiratory symptoms, especially in individuals with pre-existing pulmonary or cardiac disease. For example, people with chronic obstructive pulmonary disease have decreased ventilatory reserve (i.e., decreased baseline FEV_1) such that a $\geq$ 10% decrement could lead to moderate to severe respiratory symptoms" (Samet, 2011). In this review, CASAC reiterated its support for this conclusion, stating that "[a]n FEV_1 decrement of $\geq$10% is a scientifically relevant surrogate for adverse health outcomes for people with asthma and lung disease" (Frey, 2014 p. 3). Therefore, in considering interindividual variability in

[17] Such judgments have been made for decrements in FEV_1 as well as for increased airway responsiveness and symptomatic responses (e.g., cough, chest pain, wheeze). Ranges of pulmonary responses and their associated potential impacts are presented in Tables 3-2 and 3-3 of the Staff Paper (U.S. EPA, 2007).

O_3-induced lung function decrements in the current review, we also focus on the extent to which individuals were reported to experience FEV_1 decrements of 10% or greater.

New studies (Schelegle et al., 2009; Kim et al., 2011) add to the previously available evidence for interindividual variability in the responses of healthy adults following exposures to O_3. Following prolonged exposures to 80 ppb O_3 while at moderate exertion, the proportion of healthy adults experiencing FEV_1 decrements greater than 10% was 17% by Adams (2006), 26% by McDonnell (1996), and 29% by Schelegle et al. (2009). Following exposures to 60 ppb O_3, that proportion was 20% by Adams (2002), 3% by Adams (2006), 16% by Schelegle et al. (2009), and 5% by Kim et al. (2011). Based on these studies, the weighted average proportion of young, healthy adults with >10% FEV_1 decrements is 25% following exposure to 80 ppb O_3 and 10% following exposure to 60 ppb O_3 (U.S. EPA, 2013, page 6-19).[18] The ISA notes that responses within an individual tend to be reproducible over a period of several months, indicating that interindividual differences reflect differences in intrinsic responsiveness. Given this, the ISA concludes that "a considerable fraction" of healthy individuals experience clinically meaningful decrements in lung function when exposed for 6.6 hours to 60 ppb O_3 during quasi continuous, moderate exertion (U.S. EPA, 2013, section 6.2.1.1, p. 6-20).

As discussed above (Figure 3-1) and in the ISA (U.S EPA, 2013, Section 5.3.2), secondary oxidation products formed following O_3 exposures can activate neural reflexes leading to decreased lung function. Two new quantitative models, discussed in section 6.2.1.1 of the ISA (U.S. EPA, 2013, p. 6-15), included mathematical approaches to simulate the protective effect of antioxidants in the ELF at lower ambient O_3 concentrations, and include a threshold below which changes in lung function do not occur (McDonnell et al., 2012; Schelegle et al., 2012).

McDonnell et al. (2012) and Schelegle et al. (2012) developed models using data on O_3 exposure concentrations, ventilation rates, duration of exposures, and lung function responses from a number of controlled human exposure studies. The McDonnell et al. (2012) and Schelegle et al. (2012) studies analyzed large datasets to fit compartmental models that included the concept of a dose of onset in lung function response or a response threshold based upon the inhaled O_3 dose. The first compartment in the McDonnell et al. (2012) model considers the level of oxidant stress in response to O_3 exposure to increase over time as a function of dose rate ($C \times \dot{V}_E$) and decrease by clearance or metabolism over time. In the second compartment of the McDonnell model, once oxidant stress reaches a threshold level the decrement in FEV_1 increases

[18] The ISA also notes that by considering responses uncorrected for filtered air exposures, during which lung function typically improves (which would increase the size of the change, pre-and post-exposure), 10% is an underestimate of the proportion of healthy individuals that are likely to experience clinically meaningful changes in lung function following exposure for 6.6 hours to 60 ppb O_3 during intermittent moderate exertion (U.S. EPA, 2013, section 6.2.1.1).

as a sigmoid-shaped function. In the Schelegle et al. (2012) model, a first compartment acts as a reservoir in which oxidant stress builds up until the dose of onset, at which time it spills over into a second compartment. The second compartment is identical to the first compartment in McDonnell et al. (2012) model. The oxidant levels in the second compartment were multiplied by a responsiveness coefficient to predict FEV_1 responses for the Schelegle et al. (2012) model.

The McDonnell et al. (2012) model was fit to a large dataset consisting of the FEV_1 responses of 741 young, healthy adults (18-35 years of age) from 23 individual controlled exposure studies. Concentrations across individual studies ranged from 40 ppb to 400 ppb, activity level ranged from rest to heavy exercise, duration of exposure was from 2 to 7.6 hours. The extension of the McDonnell et al. (2012) model to children and older adults is discussed in section 6.2.1 of the ISA (U.S. EPA, 2013). Schelegle et al. (2012) also analyzed a large dataset with substantial overlap to that used by McDonnell et al. (2012). The Schelegle et al. (2012) model was fit to the FEV_1 responses of 220 young healthy adults (taken from a dataset of 704 individuals) from 21 individual controlled exposure studies. The resulting empirical models can estimate the frequency distribution of individual lung function responses for any exposure scenario as well as summary measures of the distribution such as the mean or median response and the proportions of individuals with FEV_1 decrements > 10%, 15%, and 20%.

The predictions of the McDonnell and Schelegle models are consistent with the observed results from the individual studies of O_3-induced FEV_1 decrements. Specifically, the model developed by McDonnell et al. (2012) predicts that 9% of healthy exercising adults would experience FEV_1 decrements greater than 10% following 6.6 hour exposure to 60 ppb O_3, and that 22% would experience such decrements following exposure to 80 ppb O_3 (U.S. EPA, 2013, p. 6-18 and Figure 6-3). The model developed by Schelegle et al. (2012) predicts that, for a prolonged (6.6 hours) O_3 exposure with moderate, quasi continuous exercise, the average dose of onset for FEV_1 decrement would be reached following 4 to 5 hours of exposure to 60 ppb, and following 3 to 4 hours of exposure to 80 ppb. However, 14% of the individuals had a dose of onset that was less than 40% of the average. Those individuals would reach their dose of onset following 1 to 2 hours of exposure to 50 to 80 ppb O_3 (U.S. EPA, 2013, p. 6-16), which is consistent with the threshold FEV_1 responses reported by McDonnell et al. (2012).

Epidemiologic studies[19] have consistently linked short-term increases in ambient O_3 concentrations with lung function decrements in diverse populations and lifestages, including children attending summer camps, adults exercising or working outdoors, and groups with pre-existing respiratory diseases such as asthmatic children (U.S. EPA, 2013, section 6.2.1.2). Some

[19] Unless otherwise specified, the epidemiologic studies discussed in this PA evaluate only adults.

of these studies reported ozone-associated lung function decrements accompanied by respiratory symptoms[20] in asthmatic children (Just et al., 2002; Mortimer et al., 2002; Ross et al., 2002; Gielen et al., 1997; Romieu et al., 1997; Thurston et al., 1997; Romieu et al., 1996). In contrast, studies of children in the general population have reported similar O_3-associated lung function decrements but without accompanying respiratory symptoms (Ward et al., 2002; Gold et al., 1999; Linn et al., 1996) (U.S. EPA, 2013, section 6.2.1.2).

Several epidemiologic panel studies reported that associations with lung function decrements persisted at relatively low ambient O_3 concentrations. For outdoor recreation or exercise, associations were reported in analyses restricted to 1-hour average O_3 concentrations less than 80 ppb (Spektor et al., 1988a; Spektor et al., 1988b), 60 ppb (Brunekreef et al., 1994; Spektor et al., 1988a), and 50 ppb (Brunekreef et al., 1994). Among outdoor workers, Brauer et al. (1996) found a robust association using daily 1-hour max O_3 concentrations less than 40 ppb. Ulmer et al. (1997) found a robust association in schoolchildren using 30-minute maximum O_3 concentrations less than 60 ppb. For 8-hour average O_3 concentrations, associations with lung function decrements in children with asthma were found to persist at concentrations less than 80 ppb in a U.S. multicity study (Mortimer et al., 2002) and less than 51 ppb in a study conducted in the Netherlands (Gielen et al., 1997).

Epidemiologic panel studies investigating the effects of short-term exposure to O_3 provided information on potential confounding by copollutants such as $PM_{2.5}$, PM_{10}, NO_2, or SO_2. These studies varied in how they evaluated confounding. Some studies of subjects exercising outdoors indicated that ambient concentrations of copollutants such as NO_2, SO_2, or acid aerosol were low, and thus not likely to confound associations observed for O_3 (Hoppe et al., 2003; Brunekreef et al., 1994; Hoek et al., 1993). In other studies of children with increased outdoor exposures, O_3 was consistently associated with decreases in lung function, whereas other pollutants such as $PM_{2.5}$, sulfate, and acid aerosol individually showed variable associations across studies (Thurston et al., 1997; Castillejos et al., 1995; Berry et al., 1991; Avol et al., 1990; Spektor et al., 1988a). Studies that conducted copollutant modeling generally found O_3-associated lung function decrements to be robust (i.e., most copollutant-adjusted effect estimates fell within the 95% CI of the single-pollutant effect estimates) (U.S. EPA, 2013, Figure 6-10 and Table 6-14). Most O_3 effect estimates for lung function were robust to adjustment for temperature, humidity, and copollutants such as $PM_{2.5}$, PM_{10}, NO_2, or SO_2. Although examined

[20] Reversible loss of lung function in combination with the presence of symptoms meets the ATS definition of adversity (ATS, 2000).

in only a few epidemiologic studies, O_3 also remained associated with decreases in lung function with adjustment for pollen or acid aerosols (U.S. EPA, 2013, section 6.2.1.2).

Several epidemiologic studies demonstrated the protective effects of vitamin E and vitamin C supplementation, and increased dietary antioxidant intake, on O_3-induced lung function decrements (Romieu et al., 2002) (U.S. EPA, 2013, Figure 6-7 and Table 6-8).[21] These results provide support for the new, quantitative models (McDonnell et al., 2012; Schelegle et al., 2012), discussed above, which make use of the concept of oxidant stress to estimate the occurrence of lung function decrements following exposures to relatively low O_3 concentrations.

In conclusion, new information from controlled human exposure studies considerably strengthens the evidence and reduces the uncertainties, relative to the evidence that was available at the time of the 2008 review, regarding the presence and magnitude of lung function decrements in healthy adults following prolonged exposures to O_3 concentrations below 80 ppb. As discussed in Section 6.2.1.1 in the ISA (U.S. EPA, 2013, p. 6-12), there is information available from four separate studies that evaluated exposures to 60 ppb O_3 (Kim et al., 2011; Schelegle et al., 2009; Adams 2002; 2006). Although not consistently statistically significant, group mean FEV_1 decrements following exposures to 60 ppb O_3 are consistent among these studies. Moreover, as is illustrated in Figure 6-1 of the ISA (U.S. EPA, 2013), the group mean FEV_1 responses at 60 ppb fall on a smooth intake dose-response curve for exposures between 40 and 120 ppb O_3. These studies also indicate that, on average, 10% of young, healthy adults experience clinically meaningful decrements in lung function when exposed for 6.6 hours to 60 ppb O_3 during intermittent, moderate exertion. One recent study has also reported statistically significant decrements following exposures to 70 ppb O_3 (Schelegle et al., 2009). Predictions from newly developed quantitative models, based on the concept that O_3-induced oxidation results in lung function decrements, are consistent with these experimental results. Additionally, as discussed in more detail in section 3.1.4 below, epidemiologic studies continue to provide evidence of lung function decrements in people who are active outdoors, including people engaged in outdoor recreation or exercise, children, and outdoor workers, at low ambient O_3 concentrations. While few new epidemiologic studies of O_3-associated lung function decrements are available in this review, previously available studies have reported associations with decrements, including at relatively low ambient O_3 concentrations.

Pulmonary Inflammation, Injury, and Oxidative Stress

Ozone exposures result in increased respiratory tract inflammation and epithelial permeability. Inflammation is a host response to injury, and the induction of inflammation is

[21] Evidence from controlled human exposure studies is mixed, suggesting that supplementation may be ineffective in the absence of antioxidant deficiency (U.S. EPA, 2013, p. 5-63).

evidence that injury has occurred. Oxidative stress has been shown to play a key role in initiating and sustaining O_3-induced inflammation. Secondary oxidation products formed as a result of reactions between O_3 and components of the ELF can increase the expression of molecules (i.e., cytokines, chemokines, and adhesion molecules) that can enhance airway epithelium permeability (U.S. EPA, 2013, Sections 5.3.3 and 5.3.4). As discussed in detail in the ISA (U.S. EPA, 2013, section 6.2.3), O_3 exposures can initiate an acute inflammatory response throughout the respiratory tract that has been reported to persist for at least 18-24 hours after exposure.

Inflammation induced by exposure of humans to O_3 can have several potential outcomes: (1) inflammation induced by a single exposure (or several exposures over the course of a summer) can resolve entirely; (2) continued acute inflammation can evolve into a chronic inflammatory state; (3) continued inflammation can alter the structure and function of other pulmonary tissue, leading to diseases such as asthma; (4) inflammation can alter the body's host defense response to inhaled microorganisms, particularly in potentially at-risk populations or lifestages such as the very young and old; and (5) inflammation can alter the lung's response to other agents such as allergens or toxins (U.S. EPA, 2013, Section 6.2.3). Thus, lung injury and the resulting inflammation provide a mechanism by which O_3 may cause other more serious morbidity effects (e.g., asthma exacerbations).

In the last review, controlled human exposure studies reported O_3-induced airway inflammation following exposures at or above 80 ppb. In the current review, the link between O_3 exposures and airway inflammation and injury has been evaluated in additional controlled human exposure studies, as well as in recent epidemiologic studies. Controlled human exposure studies have generally been conducted in young, healthy adults or in adults with asthma using lavage (proximal airway and bronchoalveolar), bronchial biopsy, and more recently, induced sputum. These studies have evaluated one or more indicators of inflammation, including neutrophil[22] (PMN) influx, markers of eosinophilic inflammation, increased permeability of the respiratory epithelium, and/or prevalence of proinflammatory molecules (U.S. EPA, 2013, section 6.2.3.1). Epidemiologic studies have generally evaluated associations between ambient O_3 and markers of inflammation and/or oxidative stress, which plays a key role in initiating and sustaining inflammation (U.S. EPA, 2013, section 6.2.3.2).

There is an extensive body of evidence from controlled human exposure studies indicating that short-term exposures to O_3 can cause pulmonary inflammation. Previously

[22] Referred to as either neutrophils or polymorphonuclear neutrophils (or PMNs), these are the most abundant type of white blood cells in mammals. PMNs are recruited to the site of injury following trauma and are the hallmark of acute inflammation. The presence of PMNs in the lung has long been accepted as a hallmark of inflammation and is an important indicator that O_3 causes inflammation in the lungs. Neutrophilic inflammation of tissues indicates activation of the innate immune system and requires a complex series of events, that then are normally followed by processes that clear the evidence of acute inflammation.

available evidence indicated that O_3 causes an inflammatory response in the lungs (U.S. EPA, 1996). A single acute exposure (1-4 hours) of humans to moderate concentrations of O_3 (200-600 ppb) while exercising at moderate to heavy intensities resulted in a number of cellular and biochemical changes in the lung, including inflammation characterized by increased numbers of PMNs, increased permeability of the epithelial lining of the respiratory tract, cell damage, and production of proinflammatory molecules (i.e., cytokines and prostaglandins, U.S. EPA, 2006). A meta-analysis of 21 controlled human exposure studies (Mudway and Kelly, 2004) using varied experimental protocols (80-600 ppb O_3 exposures; 1-6.6 hours exposure duration; light to heavy exercise; bronchoscopy at 0-24 hours post-O_3 exposure) reported that PMN influx in healthy subjects is linearly associated with total O_3 dose. Animal toxicological studies also provided evidence for increases in inflammation and permeability in rabbits at levels as low as 100 ppb O_3 (Section 2.5.3.1, ISA, U.S. EPA, 2013).

Several studies, including one published since the last review (Alexis et al., 2010), have reported O_3-induced increases in PMN influx and permeability following exposures at or above 80 ppb (Alexis et al., 2010; Peden et al., 1997; Devlin et al., 1991), and eosinophilic inflammation following exposures at or above 160 ppb (Scannell et al., 1996; Peden et al., 1997; Hiltermann et al., 1999; Vagaggini et al., 2002). In addition, one recent controlled human exposure study has reported O_3-induced PMN influx following exposures of healthy adults to O_3 concentrations of 60 ppb (Kim et al., 2011), the lowest concentration at which inflammatory responses have been evaluated in human studies.

As with FEV_1 responses to O_3, inflammatory responses to O_3 are generally reproducible within individuals, with some individuals experiencing more severe O_3-induced airway inflammation than indicated by group averages (Holz et al., 2005; Holz et al., 1999). Unlike O_3-induced decrements in lung function, which are attenuated following repeated exposures over several days (U.S. EPA, 2013, section 6.2.1.1), some markers of O_3-induced inflammation and tissue damage remain elevated during repeated exposures, indicating ongoing damage to the respiratory system (U.S. EPA, 2013, section 6.2.3.1, p. 6-81).

Most controlled human exposure studies have reported that asthmatics experience larger O_3-induced inflammatory responses than non-asthmatics. Specifically, asthmatics exposed to 200 ppb O_3 for 4-6 hours with exercise show significantly more neutrophils in bronchoalveolar lavage fluid (BALF) than similarly exposed healthy individuals (Scannell et al., 1996; Basha et al., 1994). Bosson et al. (2003) reported significantly greater expression of a variety of pro-inflammatory cytokines in asthmatics, compared to healthy subjects, following exposure to 200 ppb O_3 for 2 hours. In addition, research available in the last review, combined with a recent study newly available in this review, indicates that pretreatment of asthmatics with corticosteroids can prevent the O_3-induced inflammatory response in induced sputum, though

pretreatment did not prevent FEV_1 decrements (Vagaggini et al., 2001; 2007). In contrast, Stenfors et al. (2002) did not detect a difference in the O_3-induced increases in neutrophil numbers between 15 subjects with mild asthma and 15 healthy subjects by bronchial wash at the 6 hours postexposure time point, although the neutrophil increase in the asthmatic group was on top of an elevated baseline.

In people with allergic airway disease, including people with rhinitis and asthma, evidence available in the last review indicated that proinflammatory mediators also cause accumulation of eosinophils in the airways (Jorres et al., 1996; Peden et al.,1995 and 1997; Frampton et al., 1997; Hiltermann et al., 1999; Holz et al., 2002; Vagaggini et al., 2002). The eosinophil, which increases inflammation and allergic responses, is the cell most frequently associated with exacerbations of asthma (75 CFR 2969, January 19, 2010).

Studies reporting inflammatory responses and markers of lung injury have clearly demonstrated that there is important variation in the responses of exposed subjects (75 FR 2953, January 19, 2010). Some individuals also appear to be intrinsically more susceptible to increased inflammatory responses from O_3 exposure (Holz et al., 2005). In healthy adults exposed to each 80 and 100 ppb O_3, Devlin et al. (1991) observed group average increases in neutrophilic inflammation of 2.1- and 3.8-fold, respectively. However, there was a 20-fold range in inflammatory responses between individuals at both concentrations. Relative to an earlier, similar study conducted at 400 ppb (Koren et al., 1989), Devlin et al. (1991) noted that although some of the study population showed little or no increase in inflammatory and cellular injury indicators analyzed after exposures to lower levels of O_3 (i.e., 80 and 100 ppb), others had changes that were as large as those seen when subjects were exposed to 400 ppb O_3. The data suggest that as a whole the healthy population, on average, may have small inflammatory responses to near-ambient levels of O_3, though there may be a substantial subpopulation that is very sensitive to low levels of O_3. Devlin et al. (1991) expressed the view that ‘‘susceptible subpopulations such as the very young, elderly, and people with pulmonary impairment or disease may be even more affected.’’

A number of studies report that O_3 exposures increase epithelial permeability. Increased BALF protein, suggesting O_3-induced changes in epithelial permeability, has been reported at 1 hour and 18 hours postexposure (Devlin et al., 1997; Balmes et al., 1996). A meta-analysis of results from 21 publications (Mudway and Kelly, 2004) for varied experimental protocols (80-600 ppb O_3; 1-6.6 hours duration; light to heavy exercise; bronchoscopy at 0-24 hours post-O_3 exposure; healthy subjects), showed that increased BALF protein is associated with total inhaled O_3 dose (i.e., the product of O_3 concentration, exposure duration, and $\dot{V}_E$). As noted in the 2009 PM ISA (U.S. EPA, 2009), it has been postulated that changes in permeability associated with acute inflammation may provide increased access of inhaled antigens, particles, and other

inhaled substances deposited on lung surfaces to the smooth muscle, interstitial cells, immune cells underlying the epithelium, and the blood (U.S. EPA, 2013, sections 5.3.4, 5.3.5). Animal toxicology studies have provided some support for this hypothesis (Adamson and Prieditis, 1995; Chen et al., 2006), though these studies did not specifically evaluate O_3 exposures (U.S. EPA, 2009). Because of this potentially increased access, it has been postulated that increases in epithelial permeability following O_3 exposure might lead to increases in airway responsiveness to specific and nonspecific agents. In a recent study, Que et al. (2011) investigated this hypothesis in healthy young adults (83M, 55 F) exposed to 220 ppb O_3 for 2.25 hours (alternating 15 min periods of rest and brisk treadmill walking). As has been observed for FEV_1 responses, within-individual changes in permeability were correlated between sequential O_3 exposures, indicating intrinsic differences among individuals in susceptibility to epithelial damage following O_3 exposures. However, increases in epithelial permeability at 1 day post-O_3 exposure were not correlated with with changes in airway responsiveness assessed 1 day post-O_3 exposure. The authors concluded that changes in epithelial permeability is relatively constant over time in young healthy adults, although changes in permeability and AHR appear to be mediated by different physiologic pathways.

The limited epidemiologic evidence reviewed in the 2006 O_3 AQCD (U.S. EPA, 2006) demonstrated an association between short-term increases in ambient O_3 concentrations and airways inflammation in children (1-hour max O_3 of approximately 100 ppb). In the 2006 O_3 AQCD (U.S. EPA, 2006), there was limited evidence for increases in nasal lavage levels of inflammatory cell counts and molecules released by inflammatory cells (i.e., eosinophilic cationic protein, and myeloperoxidases). Since 2006, as a result of the development of less invasive methods, there has been a large increase in the number of studies assessing ambient O_3-associated changes in airway inflammation and oxidative stress, the types of biological samples collected, and the types of indicators. Most of these recent studies have evaluated biomarkers of inflammation or oxidative stress in exhaled breath, nasal lavage fluid, or induced sputum (U.S. EPA, 2013, section 6.2.3.2). These recent studies form a larger database to establish coherence with findings from controlled human exposure and animal studies that have measured the same or related biological markers. Additionally, results from these studies provide further biological plausibility for the associations observed between ambient O_3 concentrations and respiratory symptoms and asthma exacerbations.

A number of epidemiologic studies provide evidence that short-term increases in ambient O_3 exposure increase pulmonary inflammation and oxidative stress in children, including those with asthma (Sienra-Monge et al., 2004; Barraza-Villarreal et al., 2008; Romieu et al., 2008;

Berhane et al., 2011). Multiple studies examined and found increases in exhaled NO (eNO)[23] (Berhane et al., 2011; Khatri et al., 2009; Barraza-Villarreal et al., 2008). In some studies of subjects with asthma, increases in ambient O_3 concentration at the same lag were associated with both increases in pulmonary inflammation and respiratory symptoms (Khatri et al., 2009; Barraza-Villarreal et al., 2008). Although more limited in number, epidemiologic studies also found associations with cytokines such as IL-6 or IL-8 (Barraza-Villarreal et al., 2008; Sienra-Monge et al., 2004), eosinophils (Khatri et al., 2009), antioxidants (Sienra-Monge et al., 2004), and indicators of oxidative stress (Romieu et al., 2008) (ISA, Section 6.2.3.2, U.S. EPA, 2013). Because associations with inflammation were attenuated with higher antioxidant intake the study by Sienra-Monge et al. (2004) provides additional evidence that inhaled O_3 is likely to be an important source of reactive oxygen species in airways and/or may increase pulmonary inflammation via oxidative stress-mediated mechanisms among all age groups. Limitations in some recent studies have contributed to inconsistent results in adults (U.S. EPA, 2013, section 6.2.3.2).

Exposure to ambient O_3 on multiple days can result in larger increases in pulmonary inflammation and oxidative stress, as discussed in section 6.2.3.2 of the ISA (U.S. EPA, 2013). In studies that examined multiple O_3 lags, multiday averages of 8-hour maximum or 8-hour average concentrations were associated with larger increases in pulmonary inflammation and oxidative stress (Berhane et al., 2011; Delfino et al., 2010a; Sienra-Monge et al., 2004), consistent with controlled human exposure (U.S. EPA, 2013, section 6.2.3.1) and animal studies (U.S. EPA, 2013, section 6.2.3.3) reporting that some markers of pulmonary inflammation remain elevated with O_3 exposures repeated over multiple days. Evidence from animal toxicological studies also clearly indicates that O_3 exposures result in damage and inflammation in the lung (ISA, Section 5.3, U.S. EPA, 2013). In the few studies that evaluated the potential for confounding, O_3 effect estimates were not confounded by temperature or humidity, and were robust to adjustment for $PM_{2.5}$ or PM_{10} (Barraza-Villarreal et al., 2008; Romieu et al., 2008; Sienra-Monge et al., 2004).

In conclusion, a relatively small number of controlled human exposure studies evaluating O_3-induced airway inflammation have become available since the last review. For purposes of reviewing the current O_3 NAAQS, the most important of these recent studies reported a statistically significant increase in airway inflammation in healthy adults at moderate exertion following exposures to 60 ppb O_3, the lowest concentration that has been evaluated for inflammation. In addition, a number of recent epidemiologic studies report O_3-associated

[23] Exhaled NO has been shown to be a useful biomarker for airway inflammation in large population-based studies (ISA, U.S. EPA, 2013, Section 7.2.4).

increases in markers of pulmonary inflammation, particularly in children. Thus, recent studies continue to support the evidence for airway inflammation and injury that was available in previous reviews, with new evidence for such effects following exposures to lower concentrations than had been evaluated previously.

Airway Hyperresponsiveness

Airway hyperresponsiveness (AHR) refers to a condition in which the conducting airways undergo enhanced bronchoconstriction in response to a variety of stimuli. Airway hyperresponsiveness is an important consequence of exposure to ambient O_3 because its presence reflects a change in airway smooth muscle reactivity, and indicates that the airways are predisposed to narrowing upon inhalation of a variety of ambient stimuli including specific triggers (i.e., allergens) and nonspecific triggers (e.g., SO_2, and cold air). People with asthma are generally more sensitive to bronchoconstricting agents than those without asthma, and the use of an airway challenge to inhaled bronchoconstricting agents is a diagnostic test in asthma. Standards for airway responsiveness testing have been developed for the clinical laboratory (ATS, 2000), although variation in the methodology for administering the bronchoconstricting agent may affect the results (Cockcroft et al., 2005). There is a wide range of airway responsiveness in people without asthma, and responsiveness is influenced by a number of factors, including cigarette smoke, pollutant exposures, respiratory infections, occupational exposures, and respiratory irritants. Dietary antioxidants have been reported to attenuate O_3-induced bronchial hyperresponsiveness in people with asthma (Trenga et al., 2001).

Evidence for airway hyperresponsiveness following O_3 exposures is derived primarily from controlled human exposure and toxicological studies (U.S. EPA, 2013, section 6.2.2). Airway responsiveness is often quantified by measuring changes in pulmonary function following the inhalation of an aerosolized allergen or a nonspecific bronchoconstricting agent (e.g., methacholine), or following exposure to a bronchoconstricting stimulus such as cold air. In the last review, controlled human exposure studies of mostly adults (≥ 18 years of age) had shown that exposures to O_3 concentrations at or above 80 ppb increase airway responsiveness, as indicated by a reduction in the concentration of specific (e.g., ragweed) and non-specific (e.g., methacholine) agents required to produce a given reduction in lung function (e.g., as measured by FEV_1 or specific airway resistance) (U.S. EPA, 2013, section 6.2.2.1). This O_3-induced AHR has been reported to be dose-dependent (Horstman et al., 1990). Animal toxicology studies have reported O_3-induced airway hyperresponsiveness in a number of species, with some rat strains exhibiting hyperresponsiveness following 4-hour exposures to O_3 concentrations as low as 50 ppb (Depuydt et al., 1999). Since the last review, there have been relatively few new controlled human exposure and animal toxicology studies of O_3 and airway hyperresponsiveness, and no

new studies have evaluated exposures to O_3 concentrations at or below 80 ppb (U.S. EPA, 2013, section 6.2.2.1)

Airway hyperresponsiveness is linked with the accumulation and/or activation of eosinophils in the airways of asthmatics, which is followed by production of mucus and a late-phase asthmatic response (75 FR 2970, January 19, 2010). In a study of 16 intermittent asthmatics, Hiltermann et al. (1999) found that there was a significant inverse correlation between the O_3-induced change in the percentage of eosinophils in induced sputum and the concentration of methacholine causing a 20% decrease in FEV_1. Hiltermann et al. (1999) concluded that the results point to the role of eosinophils in O_3-induced airway hyperresponsiveness. Increases in O_3-induced nonspecific airway responsiveness incidence and duration could have important clinical implications for children and adults with asthma, such as exacerbations of their disease.

Airway hyperresponsiveness after O_3 exposure appears to resolve more slowly than changes in FEV_1 or respiratory symptoms (Folinsbee and Hazucha, 2000). Studies suggest that O_3-induced AHR usually resolves 18 to 24 hours after exposure, but may persist in some individuals for longer periods (Folinsbee and Hazucha, 1989). Furthermore, in studies of repeated exposure to O_3, changes in AHR tend to be somewhat less susceptible to attenuation with consecutive exposures than changes in FEV_1 (Gong et al., 1997; Folinsbee et al., 1994; Kulle et al., 1982; Dimeo et al., 1981) (U.S. EPA, 2013, section 6.2.2). In animal studies a 3-day continuous exposure resulted in attenuation of O_3-induced airway hyperresponsiveness (Johnston et al., 2005) while repeated exposures for 2 hours per day over 10 days did not (Chhabra et al., 2010), suggesting that attenuation could be lost when repeated exposures are interspersed with periods of rest (U.S. EPA, 2013, section 6.2.2.2).

Increases in airway responsiveness do not appear to be strongly associated with decrements in lung function or increases in symptoms (Aris et al., 1995). Recently, Que et al. (2011) assessed methacholine responsiveness in healthy young adults (83M, 55 F) one day after exposure to 220 ppb O_3 and filtered air for 2.25 hours (alternating 15 minute periods of rest and brisk treadmill walking). Increases in airways responsiveness at 1 day post-O_3 exposure were not correlated with FEV_1 responses immediately following the O_3 exposure or with changes in epithelial permeability assessed 1-day post-O_3 exposure. This indicates that airway hyper-responsiveness also appears to be mediated by a differing physiologic pathway.

As mentioned above, in addition to human subjects a number of species, including nonhuman primates, dogs, cats, rabbits, and rodents, have been used to examine the effect of O_3 exposure on airway hyperresponsiveness (see Table 6-14, (U.S. EPA, 1996) of the 1996 O_3 AQCD and Annex Table AX5-12 on page AX5-36 (U.S. EPA, 2006) of the 2006 O_3 AQCD). A body of animal toxicology studies, including some recent studies conducted since the last review,

provides support for the O_3-induced AHR reported in humans (U.S. EPA, 2013, section 6.2.2.2). Although most of these studies evaluated O_3 concentrations above those typically found in ambient air in cities in the United States (i.e., most studies evaluated O_3 concentrations of 100 ppb or greater), one study reported that a very low exposure concentration (50 ppb for 4 hours) induced AHR in some rat strains (Depuydt et al., 1999). Additional recent rodent studies reported O_3-induced AHR following exposures to O_3 concentrations from 100 to 500 ppb (Johnston et al., 2005; Chhabra et al., 2010; Larsen et al., 2010). In characterizing the relevance of these exposure concentrations, the ISA noted that a study using radiolabeled O_3 suggests that even very high O_3 exposure concentrations in rodents could be equivalent to much lower exposure concentrations in humans. Specifically, a 2000 ppb (2 ppm) O_3 exposure concentration in resting rats was reported to be roughly equivalent to a 400 ppb exposure concentration in exercising humans (Hatch et al., 1994). Given this relationship, the ISA noted that animal data obtained in resting conditions could underestimate the risk of effects for humans (U.S. EPA, 2013, section 2.4, p. 2-14).

The 2006 AQCD (U.S. EPA, 2006, p. 6-34) concluded that spirometric responses to O_3 are independent of inflammatory responses and markers of epithelial injury or integrity (Balmes et al., 1996; Blomberg et al., 1999; Torres et al., 1997). Significant inflammatory responses to O_3 exposures that did not elicit significant spirometric responses have been reported (Holz et al., 2005). A recent study (Que et al., 2011) indicates that airway hyper-responsiveness also appears to be mediated by a differing physiologic pathway. These results from controlled human exposure studies indicate that sub-populations of healthy study subjects consistently experience larger than average lung function decrements, greater than average inflammatory responses and pulmonary injury as expressed by increased epithelial permeability, and greater than average airway responsiveness, and that these effects are mediated by apparently different physiologic pathways. Except for lung function decrements, we do not have the concentration- or exposure-response function information about the other, potentially more sensitive,[24] clinical endpoints (i.e., inflammation, increased epithelial permeability, airway hyperresponsiveness) that would allow us to quantitatively estimate the size of the population affected and the magnitude of their responses. Moreover, some uncertainties about the exact physiological pathways underlying these endpoints prevents us from knowing whether the exaggerated responses are distributed in sub-populations evenly across the population, or may be clustered with more than one type of exaggerated response in particular sub-populations, or both.

[24] CASAC noted that "…[W]hile measures of FEV_1 are quantitative and readily obtainable in humans, they are not the only measures — and perhaps not the most sensitive measures — of the adverse health effects induced by ozone exposure." (Henderson, 2006).

In summary, a strong body of controlled human exposure and animal toxicological studies, most of which were available in the last review of the O_3 NAAQS, report O_3-induced airway hyperresponsiveness after either acute or repeated exposures (U.S. EPA, 2013, section 6.2.2.2). People with asthma often exhibit increased airway responsiveness at baseline relative to healthy controls, and they can experience further increases in responsiveness following exposures to O_3. Studies reporting increased airway responsiveness after O_3 exposure contribute to a plausible link between ambient O_3 exposures and increased respiratory symptoms in asthmatics, and increased hospital admissions and emergency department visits for asthma (U.S. EPA, 2013, section 6.2.2.2).

Respiratory Symptoms and Medication Use

Because respiratory symptoms are associated with adverse outcomes such as limitations in activity, and are the primary reason for people with asthma to use quick relief medication and seek medical care, studies evaluating the link between O_3 exposures and such symptoms allow a more direct characterization of the clinical and public health significance of ambient O_3 exposure than measures of lung function decrements and pulmonary inflammation. Controlled human exposure and toxicological studies have described modes of action through which short-term O_3 exposures may increase respiratory symptoms by demonstrating O_3-induced airway hyperresponsiveness (U.S. EPA, 2013, section 6.2.2) and pulmonary inflammation (U.S. EPA, 2013, section 6.2.3).

The link between subjective respiratory symptoms and O_3 exposures has been evaluated in both controlled human exposure and epidemiologic studies, and the link with medication use has been evaluated in epidemiologic studies. In the last review, several controlled human exposure studies reported respiratory symptoms following exposures to O_3 concentrations at or above 80 ppb. In addition, one study reported such symptoms following exposures to 60 ppb O_3, though the increase was not statistically different from filtered air controls. Epidemiologic studies reported associations between ambient O_3 and respiratory symptoms and medication use in a variety of locations and populations, including asthmatic children living in U.S. cities. In the current review, additional controlled human exposure studies have evaluated respiratory symptoms following exposures to O_3 concentrations below 80 ppb and recent epidemiologic studies have evaluated associations with respiratory symptoms and medication use (U.S. EPA, 2013, sections 6.2.1, 6.2.4).

In controlled human exposure studies available in the last review as well as newly available studies, statistically significant increases in respiratory symptoms have been consistently reported in healthy adult volunteers engaged in intermittent, moderate exertion following 6.6 hour exposures to average O_3 concentrations at or above 80 ppb (Adams, 2003; Adams, 2006; Schelegle et al., 2009). Such symptoms have been reported to increase with

increasing O_3 exposure concentrations, duration of exposure, and activity level (McDonnell et al., 1999). For example, in a study available during the last review, Adams (2006) reported an increase in respiratory symptoms in healthy adults during a 6.6 hour exposure protocol with an average O_3 exposure concentration of 60 ppb. This increase was significantly different from initial respiratory symptoms, but not from filtered air controls. Two recent controlled human exposure studies that have become available since the last review did not report statistically significant increases in respiratory symptoms following exposures of healthy adults to 60 ppb O_3 (Schelegle et al., 2009; Kim et al., 2011). A recent study by Schelegle et al. (2009) did report a statistically significant increase in respiratory symptoms in healthy adults following 6.6 hour exposures to an average O_3 concentration of 70 ppb. The findings for O_3-induced respiratory symptoms in controlled human exposure studies, and the evidence integrated across disciplines describing underlying modes of action, provide biological plausibility for epidemiologic associations observed between short-term increases in ambient O_3 concentration and increases in respiratory symptoms (U.S. EPA, 2013, section 6.2.4).

In epidemiologic studies of respiratory symptoms, data typically are collected by having subjects (or their parents) record symptoms and medication use in a diary without direct supervision by study staff. Several limitations of symptom reports are well recognized, as described in the ISA (U.S. EPA, 2013, section 6.2.4). Nonetheless, symptom diaries remain a convenient tool to collect individual-level data from a large number of subjects and allow modeling of associations between daily changes in O_3 concentration and daily changes in respiratory morbidity over multiple weeks or months. Importantly, many of the limitations in these studies are sources of random measurement error that can bias effect estimates to the null or increase the uncertainty around effect estimates (U.S. EPA, 2013, Section 6.2.4). Because respiratory symptoms are associated with limitations in activity and daily function and are the primary reason for using medication and seeking medical care, the evidence is directly coherent with the associations consistently observed between increases in ambient O_3 concentration and increases in asthma emergency department visits, discussed below (U.S. EPA, 2013, Section 6.2.4).

Most epidemiologic studies of O_3 and respiratory symptoms and medication use have been conducted in children and/or adults with asthma, with fewer studies, and less consistent results, in non-asthmatic populations (U.S. EPA, 2013, section 6.2.4). The 2006 AQCD (U.S. EPA, 2006, U.S. EPA, 2013, section 6.2.4) concluded that the collective body of epidemiologic evidence indicated that short-term increases in ambient O_3 concentrations are associated with increases in respiratory symptoms in children with asthma. A large body of single-city and single-region studies of asthmatic children provides consistent evidence for associations between

short-term increases in ambient O_3 concentrations and increased respiratory symptoms and asthma medication use in children with asthma (U.S. EPA, 2013, Figure 6-12, Table 6-20).

Methodological differences among studies make comparisons across recent multicity studies of respiratory symptoms difficult. Because of fewer person-days of data (Schildcrout et al., 2006) or examination of 19-day averages of ambient O_3 concentrations (O'Connor et al., 2008), the ISA did not give greater weight to results from recent multicity studies than results from single-city studies (U.S. EPA, 2013, section 6.2.4.5). While evidence from the few available U.S. multicity studies is less consistent (O'Connor et al., 2008; Schildcrout et al., 2006; Mortimer et al., 2002), the overall body of epidemiologic evidence with respect to the association betweeen exposure to O_3 and respiratory symptoms in asthmatic children remains compelling (U.S. EPA, 2013, section 6.2.4.1). Findings from a small body of studies indicate that O_3 is also associated with increased respiratory symptoms in adults with asthma (Khatri et al., 2009; Feo Brito et al., 2007; Ross et al., 2002) (U.S. EPA, 2013, section 6.2.4.2).

Available evidence indicates that O_3-associated increases in respiratory symptoms are not confounded by temperature, pollen, or copollutants (primarily PM) (U.S. EPA, 2013, section 6.2.4.5; Table 6-25; Romieu et al., 1996; Romieu et al., 1997; Thurston et al., 1997; Gent et al., 2003). However, identifying the independent effects of O_3 in some studies was complicated due to the high correlations observed between O_3 and PM or different lags and averaging times examined for copollutants. Nonetheless, the ISA noted that the robustness of associations in some studies of individuals with asthma, combined with findings from controlled human exposure studies for the direct effects of O_3 exposure, provide substantial evidence supporting the independent effects of short-term ambient O_3 exposure on respiratory symptoms (U.S. EPA, 2013, section 6.2.4.5).

Epidemiologic studies of medication use have reported associations with 1-hour maximum O_3 concentrations and with multiday average O_3 concentrations (Romieu et al., 2006; Just et al., 2002). Some studies reported O_3 associations for both respiratory symptoms and asthma medication use (Escamilla-Nuñez et al., 2008; Romieu et al., 2006; Schildcrout et al., 2006; Jalaludin et al., 2004; Romieu et al., 1997; Thurston et al., 1997) while others reported associations for either respiratory symptoms or medication use (Romieu et al., 1996; Rabinovitch et al., 2004; Just et al., 2002; Ostro et al., 2001).

In summary, both controlled human exposure and epidemiologic studies have reported respiratory symptoms attributable to short-term O_3 exposures. In the last review, the majority of the evidence from controlled human exposure studies in young, healthy adults was for symptoms following exposures to O_3 concentrations at or above 80 ppb. Although studies that have become available since the last review have not reported respiratory symptoms in young, healthy adults following exposures with moderate exertion to 60 ppb, one recent study has reported increased

symptoms in young, healthy adults while at moderate exertion following exposures to O_3 concentrations as low as 70 ppb.[25] As was concluded in the 2006 O_3 AQCD (U.S. EPA, 2006, 1996), the collective body of epidemiologic evidence indicates that short-term increases in ambient O_3 concentration are associated with increases in respiratory symptoms in children with asthma (U.S. EPA, 2013, section 6.2.4). Recent studies of respiratory symptoms and medication use, primarily in asthmatic children, add to this evidence. In a smaller body of studies, increases in ambient O_3 concentration were associated with increases in respiratory symptoms in adults with asthma.

Lung Host Defense

The mammalian respiratory tract has a number of closely integrated defense mechanisms that, when functioning normally, provide protection from the potential health effects of exposures to a wide variety of inhaled particles and microbes. These defense mechanisms include mucociliary clearance, alveolobronchiolar transport mechanism, alveolar macrophages[26], and adaptive immunity[27] (U.S. EPA, 2013, section 6.2.5). The previous O_3 AQCD (U.S. EPA, 2006) concluded that animal toxicological studies provided evidence that acute exposure to O_3 concentrations as low as 100 to 500 ppb can increase susceptibility to infectious diseases due to modulation of these lung host defenses. This conclusion was based in large part on animal studies of alveolar macrophage functioning and mucociliary clearance (U.S. EPA, 2013, section 6.2.5).

With regard to alveolar macrophage functioning, the previous O_3 AQCD (U.S. EPA, 2006) concluded that short periods of O_3 exposure can cause a reduction in the number of free alveolar macrophages available for pulmonary defense, and that these alveolar macrophages are more fragile, less able to engulf particles (i.e., phagocytic), and exhibit decreased lysosomal[28] enzyme activities (U.S. EPA, 2013, section 6.2.5). These conclusions were based largely on studies conducted in animals exposed for several hours up to several weeks to O_3 concentrations from 100 to 250 ppb (Hurst et al., 1970; Driscoll et al., 1987; Cohen et al., 2002). Consistent with the animal evidence, a controlled human exposure study available in the last review had reported decrements in the ability of alveolar macrophages to phagocytize yeast following exposures of healthy volunteers to O_3 concentrations of 80 and 100 ppb for 6.6-hour during

[25]As noted above, for the 70 ppb exposure concentration Schelegle et al. (2009) reported that the actual mean exposure concentration was 72 ppb.
[26] Phagocytic white blood cells within the alveoli of the lungs that ingest inhaled particles.
[27] The adaptive immune system, is also known as the acquired immune system. Acquired immunity creates immunological memory after an initial response to a specific pathogen, leading to an enhanced response to subsequent encounters with that same pathogen.
[28] Lysosomes are cellular organelles that contain acid hydrolase enzymes that break down waste materials and cellular debris.

moderate exercise (Devlin et al., 1991). Integrating the animal study results with human exposure evidence available in the 1996 Criteria Document, the 2006 Criteria Document concluded that available evidence indicates that short-term O_3 exposures have the potential to impair host defenses in humans, primarily by interfering with alveolar macrophage function. Any impairment in alveolar macrophage function may lead to decreased clearance of microorganisms or nonviable particles. Compromised alveolar macrophage functions in asthmatics may increase their susceptibility to other O_3 effects, the effects of particles, and respiratory infections (EPA, 2006, p. 8–26).

With regard to mucociliary clearance, in the last review a number of studies conducted in different animal species had reported morphological damage to the cells of the tracheobronchial tree from acute and sub-chronic exposure to O_3 concentrations at or above 200 ppb. The cilia were either completely absent or had become noticeably shorter or blunt. In general, functional studies of mucociliary transport had observed a delay in particle clearance soon after acute exposure, with decreased clearance more evident at higher doses (1 ppm) (U.S. EPA, 2013, section 6.2.5.1).

Alveolobronchiolar transport mechanisms refers to the transport of particles deposited in the deep lung (alveoli) which may be removed either up through the respiratory tract (bronchi) by alveolobronchiolar transport or through the lymphatic system. The pivotal mechanism of alveolobronchiolar transport involves the movement of alveolar macrophages with ingested particles to the bottom of the conducting airways. These airways are lined with ciliated epithelial cells and cells that produce mucous, which surrounds the macrophages. The ciliated epithelial cells move the mucous packets up the resiratory tract, hence the term "mucociliary escalator." Although some studies show reduced tracheobronchial clearance after O_3 exposure, alveolar clearance of deposited material is accelerated, presumably due to macrophage influx, which in itself can be damaging.

With regard to adaptive immunity, a limited number of epidemiologic studies have examined associations between O_3 exposure and hospital admissions or ED visits for respiratory infection, pneumonia, or influenza. Results have been mixed, and in some cases conflicting (U.S. EPA, 2013, Sections 6.2.7.2 and 6.2.7.3). With the exception of influenza, it is difficult to ascertain whether cases of respiratory infection or pneumonia are of viral or bacterial etiology. A recent study that examined the association between O_3 exposure and respiratory hospital admissions in response to an increase in influenza intensity did observe an increase in respiratory hospital admissions (Wong et al., 2009), but information from toxicological studies of O_3 and viral infections is ambiguous.

In summary, relatively few studies conducted since the last review have evaluated the effects of O_3 exposures on lung host defense. When the available evidence is taken as a whole,

the ISA concludes that acute O_3 exposures impair the host defense capability of animals, primarily by depressing alveolar macrophage function and perhaps also by decreasing mucociliary clearance of inhaled particles and microorganisms. Coupled with limited evidence from controlled human exposure studies, this suggests that humans exposed to O_3 could be predisposed to bacterial infections in the lower respiratory tract (EPA, 2013, section 6.2.5.5). The seriousness of such infections may depend on how quickly bacteria develop virulence factors and how rapidly PMNs are mobilized to compensate for the deficit in alveolar macrophage function.

Allergic and Asthma-Related Responses

Effects resulting from combined exposures to O_3 and allergens have been studied in a variety of animal species, generally as models of experimental asthma. Pulmonary function and AHR in animal models of asthma are discussed in detail in Section 6.2.1.3 and Section 6.2.2.2, respectively, in the ISA (U.S. EPA, 2013). Studies of allergic and asthma-related responses are discussed in detail in sections 5.3.6 and 6.2.6 of the ISA (U.S. EPA, 2013).

Evidence available in the last review indicates that O_3 exposure skews immune responses toward an allergic phenotype. For example, Gershwin et al. (1981) reported that O_3 (800 and 500 ppb for 4 days) exposure caused a 34-fold increase in the number of IgE (allergic antibody)-containing cells in the lungs of mice. In general, the number of IgE-containing cells correlated positively with levels of anaphylactic sensitivity. In humans, allergic rhinoconjunctivitis symptoms are associated with increases in ambient O_3 concentrations (Riediker et al., 2001). Controlled human exposure studies have observed O_3-induced changes indicating allergic skewing. Airway eosinophils, which are white blood cells that participate in allergic disease and inflammation, were observed to increase in volunteers with atopy[29] and mild asthma (Peden et al., 1997). In a more recent study, expression of IL-5, a cytokine involved in eosinophil recruitment and activation, was increased in subjects with atopy but not in healthy subjects (Hernandez et al., 2010). Epidemiologic studies describe associations between eosinophils in both short- (U.S. EPA, 2013, Section 6.2.3.2) and long-term (U.S. EPA, 2013, Section 7.2.5) O_3 exposure, as do chronic exposure studies in non-human primates. Collectively, findings from these studies suggest that O_3 can induce or enhance certain components of allergic inflammation in individuals with allergy or allergic asthma.

Evidence available in the last review indicates that ozone may also increase AHR to specific allergen triggers (75 FR 2970, January 19, 2010). Two studies (Jörres et al., 1996; Holz et al., 2002) observed increased airway responsiveness to O_3 exposure with bronchial allergen

[29] Atopy is a predisposition toward developing certain allergic hypersensitivity reactions. A person with atopy typically presents with one or more of the following: eczema (atopic dermatitis), allergic rhinitis (hay fever), allergic conjunctivitis, or allergic asthma.

challenge in subjects with preexisting allergic airway disease. Ozone-induced exacerbation of airway responsiveness persists longer and attenuates more slowly than O_3-induced lung function decrements and respiratory symptom responses and can have important clinical implications for asthmatics.

Animal toxicology studies indicate that O_3 enhances inflammatory and allergic responses to allergen challenge in sensitized animals. In addition to exacerbating existing allergic responses, toxicology studies indicate that O_3 can also act as an adjuvant to produce sensitization in the respiratory tract. Along with its pro-allergic effects (inducing or enhancing certain components of allergic inflammation in individuals with allergy or allergic asthma), O_3 could also make airborne allergens more allergenic. When combined with NO_2, O_3 has been shown to enhance nitration of common protein allergens, which may increase their allergenicity Franze et al. (2005).

Hospital Admissions and Emergency Department Visits

The 2006 O_3 AQCD evaluated numerous studies of respiratory-related emergency department visits and hospital admissions. These were primarily time-series studies conducted in the U.S., Canada, Europe, South America, Australia, and Asia. Based on such studies, the 2006 O_3 AQCD concluded that "the overall evidence supports a causal relationship between acute ambient O_3 exposures and increased respiratory morbidity resulting in increased ED visits and [hospital admissions] during the warm season[30]" (U.S. EPA, 2006). This conclusion was "strongly supported by the human clinical, animal toxicologic[al], and epidemiologic evidence for [O_3-induced] lung function decrements, increased respiratory symptoms, airway inflammation, and airway hyperreactivity" (U.S. EPA, 2006).

The results of recent studies largely support the conclusions of the 2006 O_3 AQCD (U.S. EPA, 2013, section 6.2.7). Since the completion of the 2006 O_3 AQCD, relatively fewer studies conducted in the U.S., Canada, and Europe have evaluated associations between short-term O_3 concentrations and respiratory hospital admissions and emergency department visits, with a growing number of studies conducted in Asia. This epidemiologic evidence is summarized in Appendix 3A and discussed in detail in the ISA (U.S. EPA, 2013, section 6.2.7).

In considering this body of evidence, the ISA focused primarily on multicity studies because they examine associations with respiratory-related hospital admissions and emergency department visits over large geographic areas using consistent statistical methodologies (U.S. EPA, 2013, section 6.2.7.1). The ISA also focused on single-city studies that encompassed a large number of daily hospital admissions or emergency department visits, included long study-

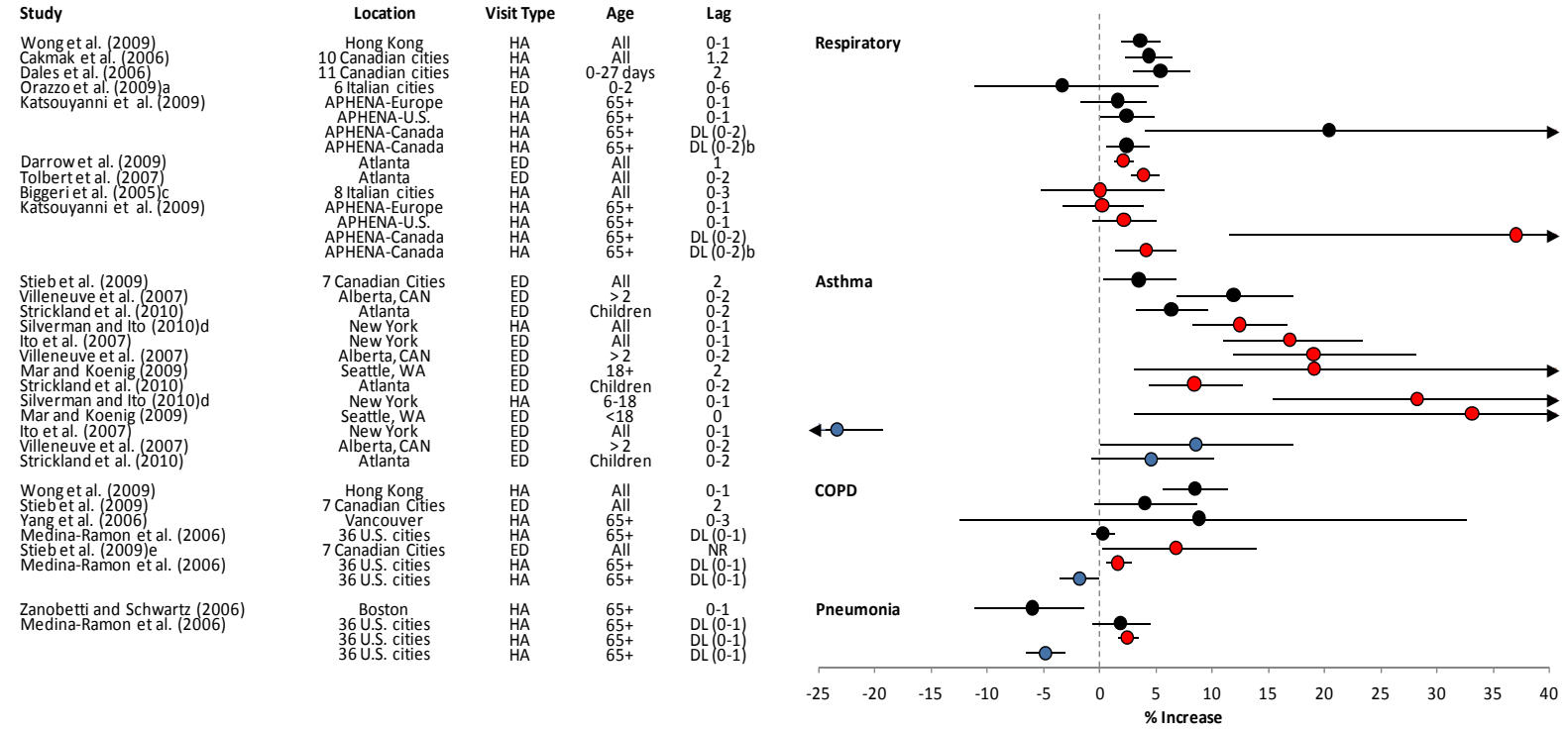
[30]Epidemiologic associations for O_3 are more robust during the warm season than during cooler months (e.g., smaller measurement error, less potential confounding by copollutants). Rationale for focusing on warm season epidemiologic studies for O_3 can be found at 72 FR 37838-37840.

durations, were conducted in locations not represented by the larger studies, or examined population-specific characteristics that may increase the risk of O_3-related health effects but were not evaluated in the larger studies (U.S. EPA, 2013, section 6.2.7.1). When examining the association between short-term O_3 exposure and respiratory health effects that require medical attention, the ISA distinguishes between hospital admissions and emergency department visits because it is likely that a small percentage of respiratory emergency department visits will be admitted to the hospital; therefore, respiratory emergency department visits may represent potentially less serious, but more common outcomes (U.S. EPA, 2013, section 6.2.7.1).

Several recent multicity studies (e.g., Cakmak et al., 2006; Dales et al., 2006) and a multi-continent study (Katsouyanni et al., 2009) report associations between short-term O_3 concentrations and increased respiratory-related hospital admissions and emergency department visits. These multicity studies are supported by single-city studies also reporting consistent positive associations using different exposure assignment approaches (i.e., average of multiple monitors, single monitor, population-weighted average) and averaging times (i.e., 1-hour max and 8-hour max) (U.S. EPA, 2013, sections 6.2.7.1 to 6.2.7.5). When examining cause-specific respiratory outcomes, recent studies report positive associations with hospital admissions and emergency department visits for asthma (Strickland et al., 2010; Stieb et al., 2009) and COPD (Stieb et al., 2009; Medina-Ramon et al., 2006), with more limited evidence for pneumonia (Medina-Ramon et al., 2006; Zanobetti and Schwartz, 2006). In seasonal analyses (Figure 3-2 below; U.S. EPA, 2013, Figure 6-19, Table 6-28), stronger associations were reported in the warm season or summer months (red circles), when O_3 concentrations are higher, compared to the cold season (blue circles), particularly for asthma (Strickland et al., 2010; Ito et al., 2007) and COPD (Medina-Ramon et al., 2006).[31] The available evidence indicates that children are at greatest risk for O_3-induced respiratory effects (Silverman and Ito, 2010; Strickland et al., 2010; Mar and Koenig, 2009; Villeneuve et al., 2007; Dales et al., 2006).

Although the collective evidence across studies indicates a mostly consistent positive association between O_3 exposure and respiratory-related hospital admissions and ED visits, the magnitude of these associations may be underestimated due to behavioral modification in response to air quality forecasts (U.S. EPA, 2013, Section 4.6.6).

[31] The study by Strickland et al. (2010) is discussed in more detail in section 3.1.4.2, below.



Note: Effect estimates are for a 20 ppb increase in 24-hour; 30 ppb increase in 8-hour max; and 40 ppb increase in 1-hour max O_3 concentrations. HA=hospital admission; ED=emergency department. Black=All-year analysis; Red=Summer only analysis; Blue=Winter only analysis.

[a] Wheeze used as indicator of lower respiratory disease.

[b] APHENA-Canada results standardized to approximate IQR of 5.1 ppb for 1-h max O_3 concentrations.

[c] Study included 8 cities; but of those 8, only 4 had O_3 data.

[d] non-ICU effect estimates.

[e] The study did not specify the lag day of the summer season estimate.

Figure 3-2. Percent increase in respiratory-related hospital admission and emergency department visits in studies that presented all-year and/or seasonal results.

Studies examining the potential confounding effects of copollutants have reported that O_3 effect estimates remained relatively robust upon the inclusion of PM and gaseous pollutants in two-pollutant models (U.S. 2013, Figure 6-20, Table 6-29). Additional studies that conducted copollutant analyses, but did not present quantitative results, also support these conclusions (Strickland et al., 2010; Tolbert et al., 2007; Medina-Ramon et al., 2006) (U.S. 2013, section 6.2.7.5).

In the last review, studies had not evaluated the concentration-response relationship between short-term O_3 exposure and respiratory-related hospital admissions and emergency department visits. A preliminary examination of this relationship in studies that have become available since the last review found no evidence of a deviation from linearity when examining the association between short-term O_3 exposure and asthma hospital admissions (U.S. EPA, 2013, page 6-157, and Silverman and Ito, 2010). In addition, an examination of the concentration-response relationship for O_3 exposure and pediatric asthma emergency department visits found no evidence of a threshold at O_3 concentrations as low as 30 ppb (for daily maximum 8-hour concentrations) (Strickland et al., 2010). However, in both studies there is uncertainty in the shape of the concentration-response curve at the lower end of the distribution of O_3 concentrations due to the low density of data in this range (U.S. 2013, page 6-157).

Respiratory Mortality

The controlled human exposure, epidemiologic, and toxicological studies discussed in section 6.2 of the ISA (U.S. EPA, 2013, section 6.2) provide strong evidence for respiratory morbidity effects, including ED visits and hospital admissions, in response to short-term O_3 exposures. Moreover, evidence from experimental studies indicates multiple potential pathways of respiratory effects from short-term O_3 exposures, which support the continuum of respiratory effects that could potentially result in respiratory-related mortality in adults (U.S. EPA, 2013, section 6.2.8). The 2006 O_3 AQCD found inconsistent evidence for associations between short-term O_3 concentrations and respiratory mortality (U.S. EPA, 2006). Although some studies reported a strong positive association between O_3 and respiratory mortality, additional studies reported small associations or no associations. New epidemiologic evidence for respiratory mortality is discussed in detail in section 6.2.8 of the ISA (U.S. EPA, 2013). The majority of recent multicity studies have reported positive associations between short-term O_3 exposures and respiratory mortality, particularly during the summer months (U.S. EPA, 2013, Figure 6-36).

Specifically, recent multicity studies from the U.S. (Zanobetti and Schwartz, 2008b), Europe (Samoli et al., 2009), Italy (Stafoggia et al., 2010), and Asia (Wong et al., 2010), as well as a multi-continent study (Katsouyanni et al., 2009), reported associations between short-term O_3 concentrations and respiratory mortality (U.S. EPA, 2013, Figure 6-37, page 6-259). With

respect to respiratory mortality, summer-only analyses were consistently positive and most were statistically significant. In all-year analyses associations were positive, but smaller in magnitude.

Of the studies evaluated, only the studies by Katsouyanni et al. (2009) and by Stafoggia et al. (2010) analyzed the potential for copollutant confounding of the O_3-respiratory mortality relationship. Based on the results of these analyses, the ISA concluded that O_3 respiratory mortality risk estimates appear to be moderately to substantially sensitive (e.g., increased or attenuated) to inclusion of PM_{10}. However, in the APHENA study (Katsouyanni et al., 2009), the mostly every-6th-day sampling schedule for PM_{10} in the Canadian and U.S. datasets greatly reduced their sample size and limits the interpretation of these results (U.S. EPA, 2013, section 6.2.8).

In summary, recent epidemiologic studies support and reinforce the epidemiologic evidence for O_3-associated respiratory hospital admissions and emergency department visits from the last review. In addition, the evidence for associations with respiratory mortality has been strengthened considerably since the last review, with the addition of several large multicity studies. The biological plausibility of the associations reported in these studies is supported by the experimental evidence for respiratory effects.

3.1.2.2 Respiratory Effects – Long-term Exposures

- **To what extent does the currently available scientific evidence, including related uncertainties, strengthen or alter our understanding from the last review of respiratory effects attributable to long-term O_3 exposures?**

As recognized in section 3.1.2.1, "the clearest evidence for health effects associated with exposure to O_3 is provided by studies of respiratory effects" (U.S. EPA, 2013, section 1, p. 1-6). Collectively, there is a vast amount of evidence spanning several decades that supports a causal association between exposure to O_3 and a continuum of respiratory effects (U.S. EPA, 2013, section 2.5). While the majority of this evidence is derived from studies investigating short-term exposures, evidence from animal toxicological studies and recent epidemiologic evidence indicate that long-term exposures (i.e., months to years) may also be detrimental to the respiratory system. Across this evidence, particularly the epidemiologic evidence, the exposures of focus vary, often involving repeated short concentrations extending over a long period, rather than a continuous long-term exposure period.

In the 2006 O_3 AQCD, evidence was examined for relationships between long-term O_3 exposure and effects on respiratory health outcomes including declines in lung function, increases in inflammation, and development of asthma in children and adults. Animal toxicology data provided a clearer picture indicating that long-term O_3 exposure may have lasting effects.

Chronic[32] exposure studies in animals have reported biochemical and morphological changes suggestive of irreversible long-term O_3 impacts on the lung. In contrast to supportive evidence from chronic animal studies, the epidemiologic studies on longer-term (annual) lung function declines, inflammation, and new asthma development remained inconclusive.

Several epidemiologic studies collectively indicated that O_3 exposure averaged over several summer months was associated with smaller increases in lung function growth in children. For longer averaging periods (annual), the analysis in the Children's Health Study (CHS) reported by Gauderman et al. (2004) provided little evidence that such long-term exposure to ambient O_3 was associated with significant deficits in the growth rate of lung function in children. Limited epidemiologic research examined the relationship between long-term O_3 exposures and inflammation. Cross-sectional studies detected no associations between long-term O_3 exposures and asthma prevalence, asthma-related symptoms or allergy to common aeroallergens in children. However, longitudinal studies provided evidence that long-term O_3 exposure influences the risk of asthma development in children and adults.

The currently available body of evidence supporting a relationship between long-term O_3 exposures and adverse respiratory health effects that is likely to be causal is discussed in detail in the ISA (EPA 2013, section 7.2). New evidence reports interactions between genetic variants and long-term O_3 exposure affect the occurrence of new-onset asthma in multi-community, U.S. cohort studies where protection by specific oxidant gene variants was restricted to children living in low O_3 communities. A new line of evidence reports a positive concentration-response relationship between first asthma hospitalization and long-term O_3 exposure. Related studies report coherent relationships between asthma severity and control, and respiratory symptoms among asthmatics and long-term O_3 exposure. There is also limited evidence for an association between long-term exposure to ambient O_3 concentrations and respiratory mortality. These studies are summarized briefly below for new-onset asthma and asthma prevalence, asthma hospital admissions and other morbidity effects, pulmonary structure and function, and respiratory mortality.

Currently available scientific evidence of the adverse health effects attributable to long-term O_3 exposures, even considering related uncertainties, is much stronger than the body of evidence available at the time of the 2008 review of the O_3 standard. The 2006 O_3 AQCD (U.S. EPA, 2006) concluded that epidemiologic studies provided no evidence of associations between long-term (annual) O_3 exposures and asthma-related symptoms, asthma prevalence, or allergy to common allergens after controlling for covariates. It found limited evidence for a relationship

[32] Unless otherwise specified, the term "chronic" generally refers to an annual exposure duration for epidemiologic studies and a duration of greater than 10% of the lifespan of the animal in toxicological studies.

between long-term exposures to ambient O_3 and deficits in the growth rate of lung-function in children, pulmonary inflammation and other endpoints. Episodic exposures were also known to cause more severe pulmonary morphological changes than continuous exposure.

The evidence base available in this review includes additional epidemiologic studies using a variety of designs and analysis methods evaluating the relationship between long-term O_3 exposures and measures of respiratory morbidity and mortality effects conducted by different research groups in different locations. The ISA (U.S. EPA, 2013, p. 7-33), in Table 7-2 presents selected key new longitudinal and cross-sectional studies of respiratory health effects and associated O_3 concentrations. The positive results from various designs and locations support a relationship between long-term exposure to ambient O_3 and respiratory health effects and mortality.

In this review, the evidence of effects associated with long-term exposures strengthens the relationship between O_3 exposure and health effects defined as adverse by the ATS, a definition that has been used in previous reviews of the O_3 standard. As discussed in more detail in section 3.1.3 below, the ATS (1985) defined adverse as "medically significant physiologic or pathologic changes generally evidenced by one or more of the following: (1) interference with the normal activity of the affected person or persons, (2) episodic respiratory illness, (3) incapacitating illness, (4) permanent respiratory injury, and/or (5) progressive respiratory dysfunction." As discussed below, in this review there is now credible evidence of respiratory health effects associated with long-term O_3 exposures that would fall in to each of these five categories that define adversity.

From a policy perspective, the recent epidemiologic studies from the CHS of long-term O_3 exposures that shed light on the interaction between genetic variability, O_3 exposures, and health effects in children are important, not only because they help clarify previous findings, but also because the effects evaluated, such as new-onset asthma, are clearly adverse. The ISA (U.S. EPA, 2013, p. 7-12) notes that the collective evidence from CHS provides an important demonstration of gene-environment interactions. It further notes that in the complex gene-environment setting a modifying effect might not be reflected in an exposure main effect and that the simultaneous occurrence of main effect and interaction effect can occur. Moreover, the study of gene-environment interactions elucidates disease mechanisms in humans by using information on susceptibility genes to focus on the biological pathways that are most relevant to that disease.

In the CHS cohort of children in 12 Southern California communities, long-term exposure to O_3 concentrations was not associated with increased risk of developing asthma (McConnell et al., 2010); however, greater outdoor exercise was associated with development of asthma in children living in communities with higher ambient O_3 concentrations (McConnell et

al., 2002). Recent CHS studies examined interactions among genetic variants, long-term O_3 exposure, and new onset asthma in children. These prospective cohort studies are methodologically rigorous epidemiologic studies, and evidence indicates gene-O_3 interactions. These studies have provided data supporting decreased risk of certain genetic variants on new onset asthma (e.g., HMOX-1, ARG) that is limited to children either in low (Islam et al., 2008) or high (Salam et al., 2009) O_3 communities. Gene-environment interaction also was demonstrated with findings that greater outdoor exercise increased risk of asthma in GSTP1 Ile/Ile children living in high O_3 communities (Islam et al., 2009). Biological plausibility for these gene-O_3 environment interactions is provided by evidence that these enzymes have antioxidant and/or anti-inflammatory activity and participate in well recognized modes of action in asthma pathogenesis. As O_3 is a source of oxidants in the airways, oxidative stress serves as the link among O_3 exposure, enzyme activity, and asthma. Cross-sectional studies by Akinbami et al. (2010) and Hwang et al. (2005) provide further evidence relating O_3 exposures with asthma prevalence.

Studies using a cross-sectional design provide support for a relationship between long-term O_3 exposure and adverse health effects in asthmatics, including: bronchitic symptoms (related to TNF-308 genotype in asthmatic children) (Lee et al., 2009); asthma severity (Rage et al., 2009) and asthma control (Jacquemin et al., in press) in an adult cohort; respiratory-related school absences (related to CAT and MPO variant genes) (Wenten et al., 2009); asthma ED visits in adults (Meng et al., 2010); and, asthma hospital admissions in adults and children (Lin et al., 2008b; Meng et al., 2010; Moore et al., 2008). Several studies, shown in Table 7-3 (ISA, U.S. EPA, 2013, p. 7-35), provide results adjusted for potential confounders presenting results for both O_3 and PM (in single and multipollutant models) as well as other pollutants where PM effects were not provided. As shown in this table, O_3 associations were generally robust to adjustment by potential confounding by PM.

Information from toxicological studies in nonhuman primates indicates that long term exposure to O_3 during gestation or development can result in irreversible morphological changes in the lung, which in turn can influence the function of the respiratory tract. This nonhuman primate evidence of an O_3-induced change in airway responsiveness supports the biologic plausibility of long term exposure to O_3 contributing to effects of asthma in children. However, results from epidemiologic studies examining long-term O_3 exposure and pulmonary function effects are inconclusive with some new studies relating effects at higher exposure levels.

The ISA (U.S. EPA, 2013, p. 7-31) concludes that there is limited evidence for an association between long-term exposure to ambient O_3 concentrations and respiratory mortality in adults (Jerrett et al., 2009). This effect was robust to the inclusion of $PM_{2.5}$ and insensitive to a number of different model specifications. Moreover, there is evidence that long-term exposure to

O_3 is associated with mortality among individuals that had previously experienced an emergency hospital admission due to COPD (Zanobetti and Schwartz, 2011).

In conclusion, since the last review, the body of evidence about the effects of long-term O_3 exposure has been considerably strengthened. The scientific evidence available for this review, including related uncertainties, provides an overall strong body of evidence of adverse health effects attributable to long-term O_3 exposures. These include a coherent range of asthma morbidity effects such as new-onset asthma, asthma prevalence, symptoms, school absences, ED visits and hospital admissions. There is also new evidence of respiratory mortality associated with long-term O_3 exposure. Further discussion of key studies is below.

New-onset Asthma and Asthma Prevalence

Asthma is a heterogeneous disease with a high degree of temporal variability. The on-set, progression, and symptoms can vary within an individual's lifetime, and the course of asthma may vary markedly in young children, older children, adolescents, and adults. In the previous review, longitudinal cohort studies that examined associations between long-term O_3 exposures and the onset of asthma in adults and children indicated a direct effect of long-term O_3 exposures on asthma risk in adults (McDonnell et al., 1999, 15-year follow-up; Greer et al., 1993, 10-year follow-up) and effect modification by O_3 in children (McConnell et al., 2002). Since that review, new evidence has become available about the association between long-term exposures to O_3 and new-onset asthma that has increased our understanding of the gene-environment interaction and the mechanisms and biological pathways most relevant to assessing O_3-related effects.

In children, the relationship between long-term O_3 exposure and new-onset asthma has been extensively studied in the CHS; a long-term study that was initiated in the early1990's which has evaluated effects in several cohorts of children. The CHS was initially designed to examine whether long-term exposure to ambient pollution was related to chronic respiratory outcomes in children in 12 communities in southern California. In the CHS, new-onset asthma was classified as having no prior history of asthma at study entry with subsequent report of physician-diagnosed asthma at follow-up, with the date of onset assigned to be the midpoint of the interval between the interview date when asthma diagnosis was first reported and the previous interview date. The results of one study (McConnell et al., 2002) available in the previous review indicated that within high O_3 communities, asthma risk was 3.3 times greater for children who played three or more outdoor sports as compared with children who played no sports.

For this review, as discussed in section 7.2.1.1 of the ISA (U.S. EPA, 2013), recent studies from the CHS provide evidence for gene-environment interactions in effects on new-onset asthma by indicating that the lower risks associated with specific genetic variants are found in children who live in lower O_3 communities. These studies indicate that the risk for new-onset

asthma is related in part to genetic susceptibility, as well as behavioral factors and environmental exposure. The onset of a chronic disease, such as asthma, is partially the result of a sequence of biochemical reactions involving exposures to various environmental agents metabolized by enzymes related to a number of different genes. Oxidative stress has been proposed to underlie the mechanistic hypotheses related to O_3 exposure. Genetic variants may impact disease risk directly, or modify disease risk by affecting internal dose of pollutants and other environmental agents and/or their reaction products, or by altering cellular and molecular modes of action. Understanding the relation between genetic polymorphisms and environmental exposure can help identify high-risk subgroups in the population and provide better insight into pathway mechanisms for these complex diseases.

The CHS analyses (Islam et al., 2008; Islam et al. 2009; Salam et al., 2009) have found that asthma risk is related to interactions between O_3 and variants in genes for enzymes such as heme-oxygenase (HO-1), arginases (ARG1 and 2), and glutathione S transferase P1 (GSTP1). Biological plausibility for these findings is provided by evidence that these enzymes have antioxidant and/or anti-inflammatory activity and participate in well-recognized modes of action in asthma pathogenesis. Further, several lines of evidence demonstrate that secondary oxidation products of O_3 initiate the key modes of action that mediate downstream health effects (ISA, Section 5.3, U.S. EPA, 2013). For example, HO-1 responds rapidly to oxidants, has anti-inflammatory and anti-oxidant effects, relaxes airway smooth muscle, and is induced in the airways during asthma. Gene-environment interactions are discussed in detail in Section 5.4.2.1 in the ISA (U.S. EPA, 2013).

Asthma Hospital Admissions

In the 2006 AQCD, studies on O_3-related hospital discharges and emergency department (ED) visits for asthma and respiratory disease mainly looked at short-term (daily) metrics. The short-term O_3 studies presented in section 6.2.7.5 of the ISA (U.S. EPA, 2013) and discussed above in section 3.1.2.1 continue to indicate that there is evidence for increases in both hospital admissions and ED visits in children and adults related to all respiratory outcomes, including asthma, with stronger associations in the warm months. New studies, discussed in section 7.2.2 of the ISA (U.S. EPA, 2013) also evaluated long-term O_3 exposure metrics, providing a new line of evidence that suggests a positive exposure-response relationship between the first hospital admission for asthma and long-term O_3 exposure, although the ISA cautions in attributing the associations in that study to long-term exposures since there is potential for short-term exposures to contribute to the observed associations.

Evidence associating long-term O_3 exposure to first asthma hospital admission in a positive concentration-response relationship is provided in a retrospective cohort study (Lin et al., 2008b). This study investigated the association between chronic exposure to O_3 and

childhood asthma admissions by following a birth cohort of more than 1.2 million babies born in New York State (1995-1999) to first asthma admission or until 31 December 2000. Three annual indicators (all 8-hour maximum from 10:00 a.m. to 6:00 p.m.) were used to define chronic O_3 exposure: (1) mean concentration during the follow-up period (41.06 ppb); (2) mean concentration during the O_3 season (50.62 ppb); and (3) proportion of follow-up days with O_3 levels >70 ppb. The effects of co-pollutants were controlled, and interaction terms were used to assess potential effect modifications. A positive association between chronic exposure to O_3 and childhood asthma hospital admissions was observed, indicating that children exposed to high O_3 levels over time are more likely to develop asthma severe enough to be admitted to the hospital. The various factors were examined and differences were found for younger children (1-2 years), poor neighborhoods, Medicaid/self-paid births, geographic region and others. As shown in the ISA, Figure 7-3 (U.S. EPA, 2013, p. 7-16), positive concentration-response relationships were observed. Asthma admissions were significantly associated with increased O_3 levels for all chronic exposure indicators.

In considering the relationship between long-term pollutant exposures and chronic disease heath endpoints, where chronic pathologies are found with acute expression of chronic disease, Künzli (2012) hypothesizes that if the associations of pollution with events are much larger in the long-term studies, it provides some indirect evidence that air pollution increases the pool of subjects with chronic disease, and that more acute events are to be expected to be seen for higher exposures. The results of Lin et al. (2008b) for first asthma hospital admission, presented in Figure 7-3 (U.S. EPA, 2013, p. 7-16), show effects estimates that are larger than those reported in a study of childhood asthma hospital admission in New York state (Silverman and Ito, 2010), discussed in section 3.1.2.1 and 3.1.2.2 above. The ISA (U.S. EPA, 2013, p. 7-16) notes that this provides some support for the hypothesis that O_3 exposure may not only have triggered the events but also increased the pool of asthmatic children, but cautions in attributing the associations in Lin et al. (2008b) study to long-term exposures since there is potential for short-term exposures to contribute to the observed associations.

Pulmonary structure and function

In the 2006 O_3 AQCD, few epidemiologic studies had investigated the effect of chronic O_3 exposure on pulmonary function. The definitive 8-year follow-up analysis of the first cohort of the CHS (U.S. EPA, 2013, section 7.2.3.1) provided little evidence that long-term exposure to ambient O_3 was associated with significant deficits in the growth rate of lung function in children. The strongest evidence was for medium-term effects of extended O_3 exposures over several summer months on lung function (FEV_1) in children, i.e., reduced lung function growth being associated with higher ambient O_3 levels. Short-term O_3 exposure studies presented in ISA (U.S. EPA, 2013, Section 6.2.1.2), and above in section 3.1.2.1, provide a cumulative body of

epidemiologic evidence that strongly supports associations between ambient O_3 exposure and decrements in lung function among children. A later CHS study (Islam et al., 2007) included in this review (U.S. EPA, 2013, section 7.2.3.1) also reported no substantial differences in the effect of O_3 on lung function. However, in a more recent CHS study, Breton et al. (2011) hypothesized that genetic variation in genes on the glutathione metabolic pathway may influence the association between ambient air pollutant exposures and lung function growth in children, and found that variation in the GSS locus was associated with differences in risk of children for lung function growth deficits associated ambient air pollutants, including O_3. A recent study (Rojas-Martinez et al., 2007) of long-term exposure to O_3, described in section 7.2.3.1 of the ISA (U.S. EPA, 2013, p. 7-19), observed a relationship with pulmonary function declines in school-aged children where O_3 and other pollutant levels were higher (90 ppb at high end of the range) than those in the CHS. Two studies of adult cohorts provide mixed results where long-term exposures were at the high end of the range.

Long-term studies in animals allow for greater insight into the potential effects of prolonged exposure to O_3 that may not be easily measured in humans, such as structural changes in the respiratory tract. Despite uncertainties, epidemiologic studies observing associations of O_3 exposure with functional changes in humans can attain biological plausibility in conjunction with long-term toxicological studies, particularly O_3-inhalation studies performed in non-human primates whose respiratory systems most closely resembles that of the human. An important series of studies, discussed in section 7.2.3.2 of the ISA (U.S. EPA, 2013), have used nonhuman primates to examine the effect of O_3 alone, or in combination with an inhaled allergen, house dust mite antigen (HDMA), on morphology and lung function. These animals exhibit the hallmarks of allergic asthma defined for humans, including: a positive skin test for HDMA with elevated levels of IgE in serum and IgE-positive cells within the tracheobronchial airway walls; impaired airflow which is reversible by treatment with aerosolized albuterol; increased abundance of immune cells, especially eosinophils, in airway exudates and bronchial lavage; and development of nonspecific airway responsiveness (NHLBI, 2007). These studies and others have demonstrated changes in pulmonary function and airway morphology in adult and infant nonhuman primates repeatedly exposed to environmentally relevant concentrations of O_3 (ISA, U.S. EPA, 2013, section 7.2.3.2).

The initial observations in adult nonhuman primates have been expanded in a series of experiments using infant rhesus monkeys repeatedly exposed to 0.5 ppm O_3 starting at 1 month of age (Plopper et al., 2007). The purpose of these studies was to determine if a cyclic regimen of O_3 inhalation would amplify the allergic responses and structural remodeling associated with allergic sensitization and inhalation in the infant rhesus monkey. After several episodic exposures of infant monkeys to O_3, they observed a significant increase in the baseline airway

resistance, which was accompanied by a small increase in airway responsiveness to inhaled histamine (Schelegle et al., 2003), although neither measurement was statistically different from filtered air control values. Exposure of animals to inhaled house dust mite antigen alone also produced small but not statistically significant changes in baseline airway resistance and airway responsiveness, whereas the combined exposure to both (O_3 + antigen) produced statistically significant and greater than additive changes in both functional measurements. This nonhuman primate evidence of an O_3-induced change in airway resistance and responsiveness provides biological plausibility of long-term exposure, or repeated short-term exposures, to O_3 contributing to the effects of asthma in children.

To understand which conducting airways and inflammatory mechanisms are involved in O_3-induced airway hyperresponsiveness in the infant rhesus monkey, results of a follow-up study (Joad et al., 2006) suggest that effect of O_3 on airway responsiveness occurs predominantly in the smaller bronchioles, where dosimetric models indicate the dose would be higher.
The functional changes in the conducting airways were accompanied by a number of cellular and morphological changes, including a significant 4-fold increase in eosinophils. Thus, these studies demonstrate both functional and cellular changes in the lung of infant monkeys after cyclic exposure to 0.5 ppm O_3, providing relevant information to understanding the potentially damaging effects of ambient O_3 exposure on the respiratory tract of children.

In addition, noteworthy structural changes in the respiratory tract development, during which conducting airways increase in diameter and length, have been observed in infant rhesus monkeys after cyclic exposure to O_3 (Fanucchi et al., 2006). Observed changes included more proximal first alveolar outpocketing, decreases in the diameter and length of the terminal and respiratory bronchioles, increases in mucus-producing goblet cell mass, alterations in smooth muscle orientation in the respiratory bronchioles, epithelial nerve fiber distribution, and basement membrane zone morphometry. The latter effects are important because of their potential contribution to airway obstruction and airway hyperresponsiveness which are central features of asthma. A number of studies in both non-human primates and rodents demonstrate that O_3 exposure can increase collagen synthesis and deposition, including fibrotic-like changes in the lung (ISA, U.S. EPA, 2013, section 7.2.3.2,).

Collectively, evidence from animal studies strongly suggests that chronic O_3 exposure is capable of damaging the distal airways and proximal alveoli, resulting in lung tissue remodeling and leading to apparent irreversible changes. Potentially, persistent inflammation and interstitial remodeling play an important role in the progression and development of chronic lung disease. Further discussion of the modes of action that lead to O_3-induced morphological changes can be found in Section 5.3.7 of the ISA (U.S. EPA, 2013). Discussion of mechanisms involved in lifestage susceptibility and developmental effects can be found in Section 5.4.2.4 of the ISA

(U.S. EPA, 2013). The findings reported in chronic animal studies offer insight into potential biological mechanisms for the suggested association between seasonal O_3 exposure and reduced lung function development in children as observed in epidemiologic studies (see Section 7.2.3.1).

Respiratory Mortality

A limited number of epidemiologic studies have assessed the relationship between long-term exposure to O_3 and mortality in adults. The 2006 O_3 AQCD concluded that an insufficient amount of evidence existed "to suggest a causal relationship between chronic O_3 exposure and increased risk for mortality in humans" (U.S. EPA, 2006). Though total and cardio-pulmonary mortality were considered in these studies, respiratory mortality was not specifically considered. In the most recent follow-up analysis of the ACS cohort (Jerrett et al., 2009), cardiopulmonary deaths were separately subdivided into respiratory and cardiovascular deaths, rather than combined as in the Pope et al. (2002) work. Increased O_3 exposure was associated with the risk of death from respiratory causes, and this effect was robust to the inclusion of $PM_{2.5}$. The association between increased O_3 concentrations and increased risk of death from respiratory causes was insensitive to the use of different models and to adjustment for several ecologic variables considered individually. Additionally, a recent multi-city time series study (Zanobetti and Schwartz, 2011), which followed (from 1985 to 2006) four cohorts of Medicare enrollees with chronic conditions that might predispose to O_3-related effects, observed an association between long-term (warm season) exposure to O_3 and elevated risk of mortality in the cohort that had previously experienced an emergency hospital admission due to COPD. A key limitation of this study is the inability to control for $PM_{2.5}$, because data were not available in these cities until 1999.

3.1.2.3 Total Mortality – Short-term Exposures

- **To what extent does the currently available scientific evidence, including related uncertainties, strengthen or alter our understanding from the last review of mortality attributable to short-term O_3 exposures?**

The 2006 O_3 AQCD concluded that the overall body of evidence was highly suggestive that short-term exposure to O_3 directly or indirectly contributes to nonaccidental and cardiopulmonary-related mortality in adults, but additional research was needed to more fully establish underlying mechanisms by which such effects occur (U.S. EPA, 2006; U.S. EPA, 2013, p. 2-18). In building on the 2006 evidence, the ISA states the following (U.S. EPA, 2013, p. 6-261).

> *The evaluation of new multicity studies that examined the association between short-term O_3 exposures and mortality found evidence that supports the conclusions of the 2006 AQCD. These new studies reported consistent positive associations between short-term O_3 exposure and all-cause (non-accidental)*

mortality, with associations persisting or increasing in magnitude during the warm season, and provide additional support for associations between O_3 exposure and cardiovascular and respiratory mortality

The 2006 O_3 AQCD reviewed a large number of time-series studies of associations between short-term O_3 exposures and total mortality including single- and multicity studies, and meta-analyses. In the large U.S. multicity studies that examined all-year data, effect estimates corresponding to single-day lags ranged from a 0.5-1% increase in all-cause (nonaccidental) total mortality per a 20 ppb (24-hour), 30 ppb (8-hour maximum), or 40 ppb (1-hour maximum) increase in ambient O_3 (U.S. EPA, 2013, section 6.6.2). Available studies reported some evidence for heterogeneity in O_3 mortality risk estimates across cities and across studies. Studies that conducted seasonal analyses reported larger O_3 mortality risk estimates during the warm season. Overall, the 2006 O_3 AQCD identified robust associations between various measures of daily ambient O_3 concentrations and all-cause mortality, which could not be readily explained by confounding due to time, weather, or copollutants. With regard to cause-specific mortality, consistent positive associations were reported between short-term O_3 exposure and cardiovascular mortality, with less consistent evidence for associations with respiratory mortality. The majority of the evidence for associations between O_3 and cause-specific mortality were from single-city studies, which had small daily mortality counts and subsequently limited statistical power to detect associations. The 2006 O_3 AQCD concluded that "the overall body of evidence is highly suggestive that O_3 directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality" (U.S. EPA, 2013, section 6.6.1).

Recent studies have strengthened the body of evidence that supports the association between short-term O_3 concentrations and mortality in adults. This evidence includes a number of studies reporting associations with non-accidental as well as cause-specific mortality. Multi-continent and multicity studies have consistently reported positive and statistically significant associations between short-term O_3 concentrations and all-cause mortality, with evidence for larger mortality risk estimates during the warm or summer months (Figure 3-3 below, reprinted from the ISA) (U.S. EPA, 2013, Figure 6-27; Table 6-42). Similarly, evaluations of cause-specific mortality have reported consistently positive associations with O_3, particularly in analyses restricted to the warm season (U.S. EPA, 2013, Figure 6-37; Table 6-53).[33]

[33] Respiratory mortality is discussed in more detail above.

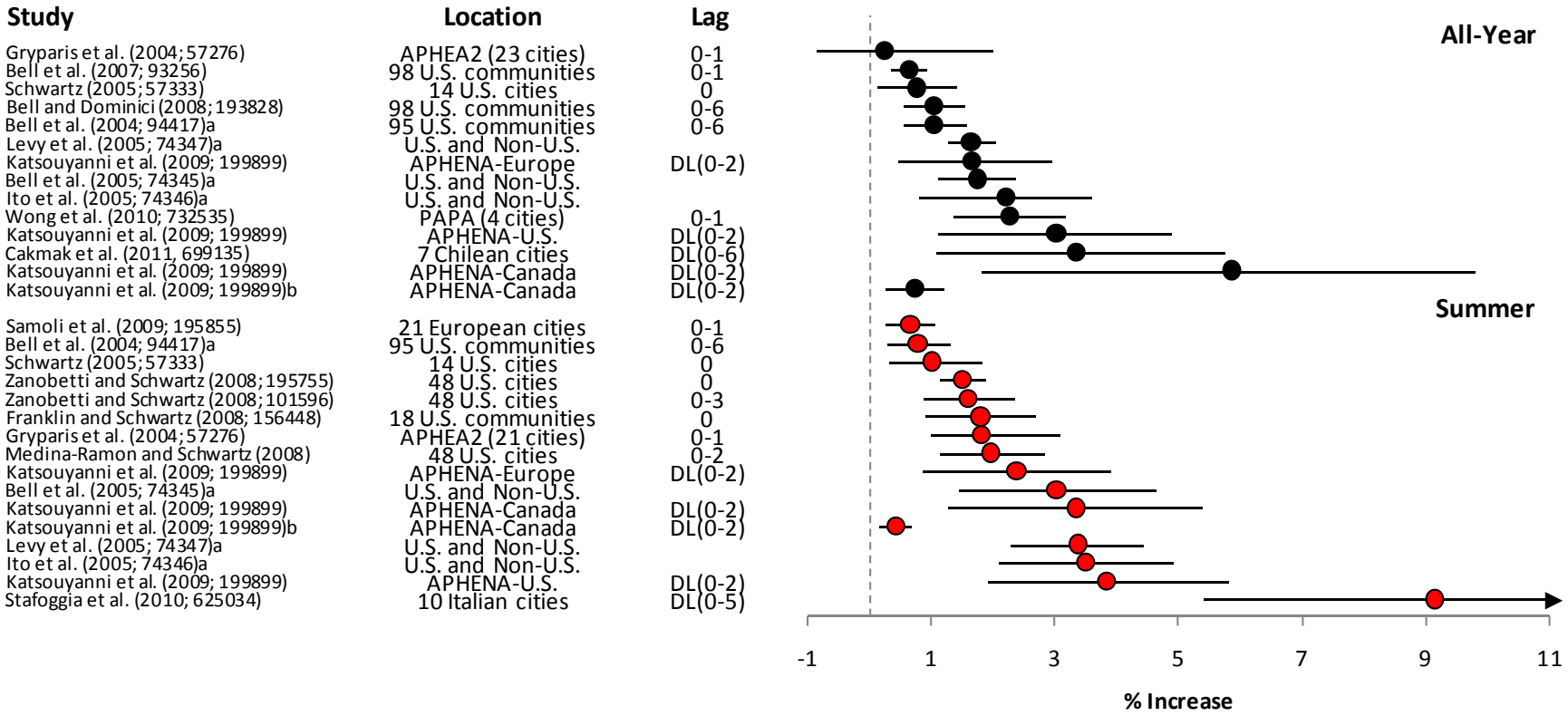


Figure 3-3. Summary of mortality risk estimates for short-term O_3 and all-cause (nonaccidental) mortality.[34]

[34] Reprinted from the ISA (U.S. EPA, 2013, Figure 6-27).

In assessing the evidence for O_3-related mortality, the 2006 AQCD also noted that multiple uncertainties remained regarding the relationship between short-term O_3 concentrations and mortality, including the extent of residual confounding by co-pollutants; characterization of the factors that modify the O_3-mortality association; the appropriate lag structure for identifying O_3-mortality effects; and the shape of the O_3-mortality concentration-response function and whether a threshold exists. Many of the studies, published since the last review, have attempted to address one or more of these uncertainties. The ISA (U.S. EPA, 2013, Section 6.6.2) discusses the extent to which recent studies have evaluated these uncertainties in the relationship between O_3 and mortality.

In particular, recent studies have evaluated different statistical approaches to examine the shape of the O_3-mortality concentration-response relationship and to evaluate whether a threshold exists for O_3-related mortality. In an analysis of the NMMAPS data, Bell et al. (2006) evaluated the potential for a threshold in the O_3-mortality relationship. The authors reported positive and statistically significant associations with mortality in a variety of subset analyses, including analyses restricted to days with 24-hour area-wide average O_3 concentrations below 60, 55, 50, 45, 40, 35, and 30 ppb. In these restricted analyses O_3 effect estimates were of similar magnitude, were statistically significant, and had similar statistical precision. In analyses restricted to days with 24-hour average O_3 concentrations below 25 ppb, the O_3 effect estimate was similar in magnitude to the effect estimates resulting from analyses with the higher cutoffs, but had somewhat lower statistical precision, with the estimate approaching statistical significance (i.e., based on observation of Figure 2 in Bell et al., 2006). In analyses restricted to days with lower 24-hour average O_3 concentrations, effect estimates were not statistically significant (i.e., based on observation of Figure 2 in Bell et al., 2006).

Bell et al. (2006) also evaluated the shape of the concentration-response relationship between O_3 and mortality. Although the results of this analysis suggested the lack of threshold in the O_3-mortality relationship, the ISA noted that it is difficult to interpret such a curve because: (1) there is uncertainty around the shape of the concentration-response curve at 24-hour average O_3 concentrations generally below 20 ppb and (2) the concentration-response curve does not take into consideration the heterogeneity in O_3-mortality risk estimates across cities (U.S. EPA, 2013, section 6.6.2.3).

Several additional studies have used the NMMAPS dataset to evaluate the concentration-response relationship between short-term O_3 concentrations and mortality. For example, using the same data as Bell et al. (2006), Smith et al. (2009) conducted a subset analysis, but instead of restricting the analysis to days with O_3 concentrations below a cutoff the authors only included days *above* a defined cutoff. The results of this analysis were consistent with those reported by Bell et al. (2006). Specifically, the authors reported consistent positive associations for all cutoff

concentrations up to concentrations where the total number of days available were so limited that the variability around the central estimate was increased (U.S. EPA, 2013, section 6.6.2.3). In addition, using NMMAPS data for 1987-1994 for Chicago, Pittsburgh, and El Paso, Xia and Tong (2006) reported evidence for a threshold around a 24-hour average O_3 concentration of 25 ppb, though the threshold values estimated in the analysis were sometimes in the range of where data density was low (U.S. EPA, 2013, section 6.6.2.3). Stylianou and Nicolich (2009) examined the existence of thresholds following an approach similar to Xia and Tong (2006) using data from NMMAPS for nine major U.S. cities (i.e., Baltimore, Chicago, Dallas/Fort Worth, Los Angeles, Miami, New York, Philadelphia, Pittsburgh, and Seattle) for the years 1987-2000. The authors reported that the estimated O_3-mortality risks varied across the nine cities, with the models exhibiting apparent thresholds in the 10-45 ppb range for O_3 (24-hour average). Additional studies in Europe, Canada, and Asia did not report evidence for a threshold (Katsouyanni et al., 2009).

3.1.2.4 Cardiovascular effects – Short-term Exposure

- **To what extent does the currently available scientific evidence, including related uncertainties, strengthen or alter our understanding from the last review of cardiovascular effects attributable to short-term O_3 exposures?**

A relatively small number of studies have examined the potential effect of short-term O_3 exposure on the cardiovascular system. The 2006 O_3 AQCD (U.S. EPA, 2006, p. 8-77) concluded that "O_3 directly and/or indirectly contributes to cardiovascular-related morbidity" but added that the body of evidence was limited. This conclusion was based on a controlled human exposure study that included hypertensive adult males; a few epidemiologic studies of physiologic effects, heart rate variability, arrhythmias, myocardial infarctions, and hospital admissions; and toxicological studies of heart rate, heart rhythm, and blood pressure.

More recently, the body of scientific evidence available that has examined the effect of O_3 on the cardiovascular system has expanded. There is an emerging body of animal toxicological evidence demonstrating that short-term exposure to O_3 can lead to autonomic nervous system alterations (in heart rate and/or heart rate variability) and suggesting that proinflammatory signals may mediate cardiovascular effects. Interactions of O_3 with respiratory tract components result in secondary oxidation product formation and subsequent production of inflammatory mediators, which have the potential to penetrate the epithelial barrier and to initiate toxic effects systemically. In addition, animal toxicological studies of long-term exposure to O_3 provide evidence of enhanced atherosclerosis and ischemia/reperfusion (I/R) injury, corresponding with development of a systemic oxidative, proinflammatory environment. Recent experimental and epidemiologic studies have investigated O_3-related cardiovascular events and

are summarized in Section 6.3 of the ISA (U.S. EPA, 2013, Section 6.3). Overall, the ISA summarized the evidence in this review as follows (U.S. EPA, 2013, p. 6-211).

> *In conclusion, animal toxicological studies demonstrate O_3-induced cardiovascular effects, and support the strong body of epidemiologic evidence indicating O_3-induced cardiovascular mortality. Animal toxicological and controlled human exposure studies provide evidence for biologically plausible mechanisms underlying these O_3-induced cardiovascular effects. However, a lack of coherence with epidemiologic studies of cardiovascular morbidity remains an important uncertainty.*

Animal toxicological studies support that short-term O_3 exposure can lead to cardiovascular morbidity. Animal studies provide evidence for both increased and decreased heart rate (HR), however it is uncertain if O_3-induced reductions in HR are relevant to humans. Animal studies also provide evidence for increased heart rate variability (HRV), arrhythmias, vascular disease and injury following short-term O_3 exposure. In addition, a series of studies highlight the role of genetic variability and age in the induction of effects and attenuation of responses to O_3 exposure.

Biologically plausible mechanisms have been described for the cardiovascular effects observed in animal exposure studies (U.S. EPA, 2013, Section 5.3.8). Evidence that parasympathetic pathways may underlie cardiac effects is described in more detail in Section 5.3.2 of the ISA (U.S. EPA, 2013). Recent studies suggest that O_3 exposure may disrupt the endothelin system that constricts blood vessels and increase blood pressure, which can result in an increase in HR, HRV; and disrupt the $NO^{\cdot}$ system and the production of atrial natriuretic factor (ANF), vasodilators that reduce blood pressure. Additionally, O_3 may increase oxidative stress and vascular inflammation promoting the progression of atherosclerosis and leading to increased susceptibility to I/R injury. As O_3 reacts quickly with the ELF and does not translocate to the heart and large vessels, studies suggest that the cardiovascular effects exhibited could be caused by secondary oxidation products resulting from O_3 exposure. However, direct evidence of translocation of O_3 reaction products to the cardiovascular system has not been demonstrated *in vivo*. Alternatively, extrapulmonary release of diffusible mediators (such as cytokines or endothelins) may initiate or propagate inflammatory responses throughout the body leading to the cardiovascular effects reported in toxicology studies. Ozone reacts within the lung to induce pulmonary inflammation and the influx and activation of inflammatory cells, resulting in a cascading proinflammatory state, and may lead to the extrapulmonary release of diffusible mediators that could result in cardiovascular injury.

Controlled human exposures studies discussed in previous AQCDs have not demonstrated any consistent extrapulmonary effects. In this review, evidence from controlled human exposure studies suggests cardiovascular effects in response to short-term O_3 exposure

(see ISA, U.S. EPA, 2013, Section 6.3.1) and provides some coherence with evidence from animal toxicology studies. Controlled human exposure studies also support the animal toxicological studies by demonstrating O_3-induced effects on blood biomarkers of systemic inflammation and oxidative stress, as well as changes in biomarkers that can indicate a prothrombogenic response to O_3. Increases and decreases in high frequency HRV have been reported following relatively low (120 ppb during rest) and high (300 ppb with exercise) O_3 exposures, respectively. These changes in cardiac function observed in animal and human studies provide preliminary evidence for O_3-induced modulation of the autonomic nervous system through the activation of neural reflexes in the lung (see ISA, U.S. EPA, 2013, Section 5.3.2).

Overall, the ISA concludes that the available body of epidemiologic evidence examining the relationship between short-term exposures to O_3 concentrations and cardiovascular morbidity is inconsistent (U.S. EPA, 2013, Section 6.3.2.9). Across studies, different definitions, (i.e., ICD-9 diagnostic codes) were used for both all-cause and cause-specific cardiovascular morbidity (ISA, U.S. EPA, 2013, see Tables 6-35 to 6-39), which may contribute to inconsistency in results. However, within diagnostic categories, no consistent pattern of association was found with O_3. Generally, the epidemiologic studies used nearest air monitors to assess O_3 concentrations, with a few exceptions that used modeling or personal exposure monitors. The inconsistencies in the associations observed between short-term O_3 and cardiovascular disease (CVD) morbidities are unlikely to be explained by the different exposure assignment methods used (see Section 4.6, ISA, U.S. EPA, 2013). The wide variety of biomarkers considered and the lack of consistency among definitions used for specific cardiovascular disease endpoints (e.g., arrhythmias, HRV) make comparisons across studies difficult.

Despite the inconsistent evidence for an association between O_3 concentration and CVD morbidity, mortality studies indicate a consistent positive association between short-term O_3 exposure and cardiovascular mortality in multicity studies and in a multicontinent study. When examining mortality due to cardiovascular disease, epidemiologic studies consistently observe positive associations with short-term exposure to O_3. Additionally, there is some evidence for an association between long-term exposure to O_3 and mortality, although the association between long-term ambient O_3 concentrations and cardiovascular mortality can be confounded by other pollutants as evident by a study of cardiovascular mortality that reported no association after adjustment for $PM_{2.5}$ concentrations. The ISA (U.S. EPA, 2013, section 6.3.4) states that taken together, the overall body of evidence across the animal and human studies is sufficient to conclude that there is likely to be a causal reationship between relevant short-term exposures to O3 and cardiovascular system effects.

3.1.3 Adversity of Effects

In this section we address the following question:

- **To what extent does the currently available scientific evidence expand our understanding of the adversity of O_3-related health effects?**

In making judgments as to when various O_3-related effects become regarded as adverse to the health of individuals, in previous NAAQS reviews staff has relied upon the guidelines published by the ATS and the advice of CASAC. In 2000, the ATS published an official statement on "What Constitutes an Adverse Health Effect of Air Pollution?" (ATS, 2000), which updated and built upon its earlier guidance (ATS, 1985). The earlier guidance defined adverse respiratory health effects as "medically significant physiologic changes generally evidenced by one or more of the following: (1) interference with the normal activity of the affected person or persons, (2) episodic respiratory illness, (3) incapacitating illness, (4) permanent respiratory injury, and/or (5) progressive respiratory dysfunction", while recognizing that perceptions of "medical significance" and "normal activity" may differ among physicians, lung physiologists and experimental subjects (ATS, 1985). The 2000 ATS guidance builds upon and expands the 1985 definition of adversity in several ways. The guidance concludes that transient, reversible loss of lung function in combination with respiratory symptoms should be considered adverse. There is also a more specific consideration of population risk (ATS, 2000). Exposure to air pollution that increases the risk of an adverse effect to the entire population is adverse, even though it may not increase the risk of any individual to an unacceptable level. For example, a population of asthmatics could have a distribution of lung function such that no individual has a level associated with clinical impairment. Exposure to air pollution could shift the distribution to lower levels that still do not bring any individual to a level that is associated with clinically relevant effects. However, this would be considered to be adverse because individuals within the population would have diminished reserve function, and therefore would be at increased risk to further environmental insult (U.S. EPA, 2013, p. lxxi; and 75 FR at 35526/2, June 22, 2010).

The ATS also concluded that elevations of biomarkers such as cell types, cytokines and reactive oxygen species may signal risk for ongoing injury and more serious effects or may simply represent transient responses, illustrating the lack of clear boundaries that separate adverse from nonadverse events. More subtle health outcomes also may be connected mechanistically to health effects that are clearly adverse, so that small changes in physiological measures may not appear clearly adverse when considered alone, but may be part of a coherent and biologically plausible chain of related health outcomes that include responses that are clearly adverse, such as mortality (section 3.1.2.1, above).

In this review, the new evidence provides further support for relationships between O_3 exposures and a spectrum of health effects, including effects that meet the ATS criteria for being adverse (ATS, 1985 and 2000). The ISA judgment that there is a causal relationship between short-term O_3 exposure and a full range of respiratory effects, including respiratory morbidity (e.g., lung function decrements, respiratory symptoms, inflammation, hospital admissions, and emergency department visits) and mortality, provides support for concluding that short-term O_3 exposure is associated with adverse effects (U.S. EPA, 2013, section 2.5.2). Overall, including new evidence of cardiovascular system effects, the evidence supporting an association between short-term O_3 exposures and total (non-accidental, cardiopulmonary) respiratory mortality is stronger in this review (U.S. EPA, 2013, section 2.5.2). And the judgment of likely causal associations between long-term measures of O_3 exposure and respiratory effects such as new-onset asthma, prevalence of asthma, asthma symptoms and control, and asthma hospital admissions provides support for concluding that long-term O_3 exposure is associated with adverse effects ranging from episodic respiratory illness to permanent respiratory injury or progressive respiratory decline (U.S. EPA, 2013, section 7.2.8).

This review provides additional evidence of O_3-attributable effects that are clearly adverse, including premature mortality. Application of the ATS guidelines to the least serious category of effects related to ambient O_3 exposures, which are also the most numerous and therefore are also potentially important from a public health perspective, involves judgments about which medical experts on CASAC panels and public commenters have in the past expressed diverse views. To help frame such judgments, EPA staff defined gradations of individual functional responses (e.g., decrements in FEV_1 and airway responsiveness) and symptomatic responses (e.g., cough, chest pain, wheeze), together with judgments as to the potential impact on individuals experiencing varying degrees of severity of these responses. These gradations were used in the 1997 O_3 NAAQS review and slightly revised in the 2008 review (U.S. EPA, 1996, p. 59; 2007, p. 3-72; 72 FR 37849, July 11, 2007). These gradations and impacts are summarized in Tables 3-2 and 3-3 in the 2007 O_3 Staff Paper (U.S. EPA, 2007, pp. 3-74 to 3-75).

For active healthy people, including children, moderate levels of functional responses (e.g., FEV_1 decrements of $\geq$ 10% but < 20%, lasting 4 to 24 hours) and/or moderate symptomatic responses (e.g., frequent spontaneous cough, marked discomfort on exercise or deep breath, lasting 4 to 24 hours) would likely interfere with normal activity for relatively few sensitive individuals (U.S. EPA, 2007, p. 3-72; 72 FR 37849, July 11, 2007); whereas large functional responses (e.g., FEV_1 decrements $\geq$ 20%, lasting longer than 24 hours) and/or severe symptomatic responses (e.g., persistent uncontrollable cough, severe discomfort on exercise or deep breath, lasting longer than 24 hours) would likely interfere with normal activities for many

sensitive individuals (U.S. EPA, 2007, p. 3-72; 72 FR 37849, July 11, 2007) and therefore would be considered adverse under ATS guidelines. For the purpose of estimating potentially adverse lung function decrements in active healthy people in the 2008 O_3 NAAQS review, the CASAC panel for that review indicated that a focus on the mid to upper end of the range of moderate levels of functional responses is most appropriate (e.g., FEV_1 decrements ≥ 15% but < 20%) (Henderson, 2006; U.S. EPA, 2007, p. 3-76). In this review, CASAC concurred that the "[e]stimation of FEV_1 decrements of ≥15% is appropriate as a scientifically relevant surrogate for adverse health outcomes in active healthy adults" (Frey, 2014, p. 3). However, for children and adults with lung disease, even moderate functional (e.g., FEV_1 decrements ≥ 10% but < 20%, lasting up to 24 hours) or symptomatic responses (e.g., frequent spontaneous cough, marked discomfort on exercise or with deep breath, wheeze accompanied by shortness of breath, lasting up to 24 hours) would likely interfere with normal activity for many individuals, and would likely result in additional and more frequent use of medication (U.S. EPA, 2007, p.3-72; 72 FR 37849, July 11, 2007). For people with lung disease, large functional responses (e.g., FEV_1 decrements ≥ 20%, lasting longer than 24 hours) and/or severe symptomatic responses (e.g., persistent uncontrollable cough, severe discomfort on exercise or deep breath, persistent wheeze accompanied by shortness of breath, lasting longer than 24 hours) would likely interfere with normal activity for most individuals and would increase the likelihood that these individuals would seek medical treatment (U.S. EPA, 2007, p.3-72; 72 FR 37849, July 11, 2007). In the last O_3 NAAQS review, for the purpose of estimating potentially adverse lung function decrements in people with lung disease the CASAC panel indicated that a focus on the lower end of the range of moderate levels of functional responses is most appropriate (e.g., FEV_1 decrements ≥10%) (Henderson, 2006; U.S. EPA, 2007, p. 3-76). In addition, in the reconsideration of the 2008 final decision, CASAC stated that "[a] 10% decrement in FEV1 can lead to respiratory symptoms, especially in individuals with pre-existing pulmonary or cardiac disease. For example, people with chronic obstructive pulmonary disease have decreased ventilatory reserve (i.e., decreased baseline FEV_1) such that a ≥10% decrement could lead to moderate to severe respiratory symptoms" (Samet, 2011) (section 3.1.2.1, above). In this review, CASAC concurred that "[a]n FEV_1 decrement of ≥10% is a scientifically relevant surrogate for adverse health outcomes for people with asthma and lung disease" (Frey, 2014, p. 3).

In judging the extent to which these impacts represent effects that should be regarded as adverse to the health status of individuals, in previous NAAQS reviews we also considered whether effects were experienced repeatedly during the course of a year or only on a single occasion (Staff Paper, U.S. EPA, 2007). Although some experts would judge single occurrences of moderate responses to be a ''nuisance,'' especially for healthy individuals, a more general consensus view of the adversity of such moderate responses emerges as the frequency of

occurrence increases. Thus it has been judged that repeated occurrences of moderate responses, even in otherwise healthy individuals, may be considered to be adverse since they could well set the stage for more serious illness (61 FR 65723). The CASAC panel in the 1997 NAAQS review expressed a consensus view that these "criteria for the determination of an adverse physiological response were reasonable" (Wolff, 1995). In the review completed in 2008, estimates of repeated occurrences continued to be an important public health policy factor in judging the adversity of moderate lung function decrements in healthy and asthmatic people (72 FR 37850, July 11, 2007).

Evidence new to this review indicates that 6.6-hour exposures to 60 ppb O_3 during moderate exertion can result in pulmonary inflammation in healthy adults. As discussed in section 3.1.2 above, the initiation of inflammation can be considered as evidence that injury has occurred. Inflammation induced by a single O_3 exposure can resolve entirely, but continued acute inflammation can evolve into a chronic inflammatory state (ISA, U.S. EPA, 2013, p. 6-76), which is clearly adverse. Therefore, like moderate lung function decrements, whether inflammation is experienced repeatedly during the course of a year or only on a single occasion is judged by staff to be reasonable criteria for determining adverse inflammatory effects attributable to O_3 exposures at 60 ppb.

Responses measured in controlled human exposure studies indicate that the range of effects elicited in humans exposed to ambient O_3 concentrations include: decreased inspiratory capacity; mild bronchoconstriction; rapid, shallow breathing pattern during exercise; and symptoms of cough and pain on deep inspiration (EPA, 2013, section 6.2.1.1). Some young, healthy adults exposed to O_3 concentrations $\geq$ 60 ppb, while engaged in 6.6 hours of intermittent moderate exertion, develop reversible, transient decrements in lung function, symptoms of breathing discomfort, and inflammation if minute ventilation or duration of exposure is increased sufficiently (EPA, 2013, section 6.2.1.1). Among healthy subjects there is considerable interindividual variability in the magnitude of the FEV_1 responses, but averaged across studies at 60 ppb (EPA, 2013, pp. 6-17 to 6-18), 10% of healthy subjects had >10% FEV_1 decrements. Moreover, consistent with the findings of the ISA (EPA, 2013, section 6.2.1.1), CASAC concluded that "[a]sthmatic subjects appear to be at least as sensitive, if not more sensitive, than non-asthmatic subjects in manifesting ozone-induced pulmonary function decrements" (Frey, 2014, p. 4). The combination of lung function decrements and respiratory symptoms, which has been considered adverse in previous reviews, has been demonstrated in healthy adults following prolonged (6.6 hour) exposures, while at intermittent moderate exertion, to 70 ppb. For these types of effects, information from controlled human exposure studies, which provides an indication of the magnitude and thus adversity of effects at different O_3 concentrations,

combined with estimates of occurrences in the population from the HREA, provide information about their importance from a policy perspective.

3.1.4 Ozone Concentrations Associated With Health Effects

In evaluating O_3 exposure concentrations reported to result in health effects, within the context of the adequacy of the current standard, we first consider the following specific question:

- **To what extent does the currently available scientific evidence indicate morbidity and/or mortality attributable to exposures to O_3 concentrations lower than previously reported or that would meet the current standard?**

In addressing this question, we characterize the extent to which O_3-attributable effects have been reported over the ranges of O_3 exposure concentrations evaluated in controlled human exposure studies and over the distributions of ambient O_3 concentrations in locations where epidemiologic studies have been conducted.

3.1.4.1 Concentrations in Controlled Human Exposure Studies and in Epidemiologic Panel Studies

In considering what the currently available evidence indicates with regard to effects associated with exposure concentrations lower than those identified in the last review, or that could meet the current standard, we first consider the evidence from controlled human exposure studies and epidemiologic panel studies. This evidence is assessed in section 6.2 of the ISA and is summarized in section 3.1.2 above. Controlled human exposure studies have generally been conducted with young, healthy adults, and have evaluated exposure durations less than 8 hours. Epidemiologic panel studies have evaluated a wider range of study populations, including children, and have generally evaluated associations with O_3 concentrations averaged over several hours (U.S. EPA, 2013, section 6.2.1.2).[35]

As summarized above (section 3.1.2.1), and as discussed in detail in the ISA (U.S. EPA, 2013, section 6.2), a large number of controlled human exposure studies have reported lung function decrements, respiratory symptoms, airway inflammation, airway hyperresponsiveness, and/or impaired lung host defense in young, healthy adults engaged in moderate, intermittent exertion, following 6.6-hour O_3 exposures. These studies have consistently reported such effects following exposures to O_3 concentrations of 80 ppb or greater. Available studies have also evaluated some of these effects (i.e., lung function decrements, respiratory symptoms, airway inflammation) following exposures to O_3 concentrations below 75 ppb. Table 3-1 highlights the

[35] In this section we focus on panel studies that used on-site monitoring, and that are highlighted in the ISA for the extent to which monitored ambient O_3 concentrations reflect exposure concentrations in their study populations (U.S. EPA, 2013, section 6.2.1.2).

group mean results of individual controlled human exposure studies that have evaluated exposures of healthy adults to O_3 concentrations below 75 ppb. The studies included in Table 3-1 indicate lung function decrements, airway inflammation, and respiratory symptoms in healthy adults following exposures to O_3 concentrations below 75 ppb.

Table 3-1. Group mean results of controlled human exposure studies that have evaluated exposures to ozone concentrations below 75 ppb in young, healthy adults.

Endpoint	O_3 Exposure Concentration	Study	Statistically Significant O_3-Induced Effect[36]
FEV_1 decrements	70 ppb	Schelegle et al., 2009[37]	yes
	60 ppb	Kim et al., 2011	yes
		Schelegle et al., 2009[38]	no
		Adams, 2006	yes[39]
		Adams, 2002	no
	40 ppb	Adams, 2006	no
		Adams, 2002	no
Respiratory Symptoms	70 ppb	Schelegle et al., 2009	yes
	60 ppb	Kim et al., 2011	no
		Schelegle et al., 2009	no
		Adams, 2006	no[40]
	40 ppb	Adams, 2006	no
		Adams, 2002	no
Airway Inflammation (neutrophil influx)	60 ppb	Kim et al., 2011	yes

In further evaluating O_3-induced FEV_1 decrements following exposures to O_3 concentrations below 75 ppb, the ISA also combined the individual data from multiple studies of healthy adults exposed for 6.6 hours to 60 ppb O_3 (Kim et al., 2011; Schelegle et al., 2009; Adams, 2006, 2002, 1998). Based on these data, the ISA reports that 10% of exposed subjects experienced FEV_1 decrements of 10% or more (i.e., abnormal and large enough to be potentially adverse for people with pulmonary disease, based on past CASAC advice (section 3.1.3, above))[41] (U.S. EPA, 2013, section 6.2.1.1). Consistent with these findings, recently developed

[36] Based on study population means.
[37] As noted above, for the 70 ppb exposure concentration Schelegle et al. (2009) reported that the actual mean exposure concentration was 72 ppb.
[38] As noted above, for the 60 ppb exposure concentration Schelegle et al. (2009) reported that the actual mean exposure concentration was 63 ppb.
[39] In an analysis of the Adams (2006) data for square-wave chamber exposures, even after removal of potential outliers, Brown et al. (2008) reported the average effect on FEV1 at 60 ppb to be statistically significant ($p < 0.002$) using several common statistical tests (U.S. EPA, 2013, section 6.2.1.1) (section 3.1.2.1, above).
[40] Adams (2006) reported increased respiratory symptoms during a 6.6 hour exposure protocol with an average O_3 exposure concentration of 60 ppb. The increase in symptoms was reported to be statistically different from initial respiratory symptoms, though not statistically different from filtered air controls.
[41] As noted above (section 3.1.3), CASAC has previously stated that "[a] 10% decrement in FEV1 can lead to respiratory symptoms, especially in individuals with pre-existing pulmonary or cardiac disease. For example, people with chronic obstructive pulmonary disease have decreased ventilatory reserve (i.e., decreased baseline FEV1) such that a ≥10% decrement could lead to moderate to severe respiratory symptoms" (Samet, 2011).

empirical models predict that the onset of O_3-induced FEV_1 decrements in healthy adults occurs following exposures to 60 ppb O_3 for 4 to 5 hours while at moderate, intermittent exertion (Schelegle et al., 2012), and that 9% of healthy adults exposed to 60 ppb O_3 for 6.6 hours would experience FEV_1 decrements greater than or equal to 10% (McDonnell et al., 2012) (U.S. EPA, 2013, section 6.2.1.1; section 3.1.2.1, above). When the evidence for O_3-induced lung function decrements was taken together, the ISA concluded that (1) "mean FEV_1 is clearly decreased by 6.6-h exposures to 60 ppb O_3 and higher concentrations in subjects performing moderate exercise" (U.S. EPA, 2013, p. 6-9) and (2) although group mean decrements following exposures to 60 ppb O_3 are biologically small, "a considerable fraction of exposed individuals experience clinically meaningful decrements in lung function" (U.S. EPA, 2013, p. 6-20).

In considering the specific question above, controlled human exposure studies have reported decreased lung function, increased airway inflammation, and increased respiratory symptoms in healthy adults following exposures to O_3 concentrations below 75 ppb. Such impairments in respiratory function have the potential to be adverse, based on ATS guidelines for adversity and based on previous advice from CASAC (section 3.1.3, above). In addition, if they become serious enough, these respiratory effects could lead to the types of clearly adverse effects commonly reported in O_3 epidemiologic studies (e.g., respiratory emergency department visits, hospital admissions). Therefore, following exposures to O_3 concentrations lower than 75 ppb, controlled human exposure studies have reported respiratory effects that could be adverse in some individuals, particularly if experienced by members of at-risk populations (e.g., asthmatics, children).[42]

In further considering effects following exposures to O_3 concentrations below 75 ppb, we also note that the ISA highlights some epidemiologic panel studies for the extent to which monitored ambient O_3 concentrations reflect exposure concentrations in their study populations (U.S. EPA, 2013, section 6.2.1.2). Specifically, Table 3-2 below includes O_3 panel studies that have evaluated associations with lung function decrements for O_3 concentrations at or below 75 ppb, and that measured O_3 concentrations with monitors located in the areas where study subjects were active (e.g., on site at summer camps or in locations where exercise took place) (U.S. EPA, 2013, section 6.2.1.2 and Table 6-6). Epidemiologic panel studies have evaluated a wider range of populations and lifestages than controlled human exposure studies of O_3 concentrations below 75 ppb (e.g., including children).

[42] These effects were reported in healthy individuals. Consistent with past CASAC advice (Samet, 2011), and evidence in the ISA (U.S. EPA, 2013, p. 6-77), it is a reasonable inference that the effects would be greater in magnitude and potential severity for at-risk groups. See *National Environmental Development Ass'n Clean Air Project v.* EPA, 686 F. 3d 803, 811 (D.C. Cir. (2012) (making this point).

Table 3-2. Panel studies of lung function decrements with analyses restricted to O_3 concentrations below 75 ppb.

Study	Population	O_3 Concentrations	Statistically Significant Association with Lung Function Decrements
Spektor et al. (1988a)	Children at summer camp	Restricted to 1-hour concentrations below 60 ppb	Yes
Chan and Wu (2005)	Mail carriers	Maximum 8-hour average was 65 ppb	Yes
Korrick et al. (1998)	Adult hikers	2- to 12-hour average from 40 to 74 ppb during hikes	Yes
Brauer et al. (1996)	Farm workers	Restricted to 1-hour maximum below 40 ppb	Yes
		Restricted to 1-hour maximum below 30 ppb	No
Brunekreef et al. (1994)	Exercising adults	Restricted to 10-minute to 2.4-hour averages below 61 ppb	No
		Restricted to 10-minute to 2.4-hour averages below 51 ppb	No
		Restricted to 10-minute to 2.4-hour averages below 41 ppb	No

Although these studies report health effect associations for different averaging times, and it is not clear the extent to which specific O_3 exposure conditions (i.e., concentrations, durations of exposure, degrees of activity) were responsible for eliciting reported decrements, they are consistent with the findings of the controlled human exposure studies discussed above. Specifically, the epidemiologic panel studies in Table 3-2 indicate O_3-associated lung function decrements when on-site monitored concentrations (ranging from minutes to hours) were below 75 ppb, with the evidence becoming less consistent at lower O_3 concentrations.

3.1.4.2 Concentrations in Epidemiologic Studies – Short-term Metrics

We next consider distributions of ambient O_3 concentrations in locations where epidemiologic studies have evaluated O_3-associated hospital admissions, emergency department visits, and/or mortality. When considering epidemiologic studies within the context of the current standard, we emphasize those studies conducted in the U.S. and Canada. Such studies reflect air quality and exposure patterns that are likely more typical of the U.S. population than the air quality and exposure patterns reflected in studies conducted outside the U.S. and Canada (section 1.3.1.2, above).[43] We also emphasize studies reporting associations with effects judged in the ISA to be robust to confounding by other factors, including co-occurring air pollutants. In addition to these factors, we consider the statistical precision of study results, the extent to which

[43] Nonetheless, we recognize the importance of all studies, including international studies, in the ISA's assessment of the weight of the evidence that informs causality determinations.

studies report associations in at-risk populations, and the extent to which the biological plausibility of associations at various ambient O_3 concentrations is supported by controlled human exposure and/or animal toxicological studies. These considerations help inform the range of ambient O_3 concentrations over which we have the most confidence in O_3-associated health effects, and the range of concentrations over which our confidence in such associations is appreciably lower. We place particular emphasis on characterizing those portions of distributions of ambient O_3 concentrations likely to meet the current standard.

In our consideration of these issues, we first address the following question:

- **To what extent have U.S. and Canadian epidemiologic studies reported associations with mortality or morbidity in locations that would have met the current O_3 standard during the study period?**

Addressing this question can provide important insights into the extent to which O_3-health effect associations are present for distributions of ambient O_3 concentrations that would be allowed by the current standard. To the extent O_3 health effect associations are reported in study areas that would have met the current standard, we have greater confidence that the current standard could allow the clearly adverse O_3-associated effects indicated by those studies (e.g., mortality, hospital admissions, emergency department visits).[44]

Epidemiologic studies evaluate statistical associations between variation in the incidence of health outcomes and variation in ambient O_3 concentrations. In many of the O_3 epidemiologic studies assessed in the ISA, ambient concentrations are averaged across multiple monitors within study areas, and in some cases over multiple days. These averages are used as surrogates for the spatial and temporal patterns of O_3 exposures in study populations. In this PA, we refer to these averaged concentrations as "area-wide" O_3 concentrations.

The area-wide concentrations reported in many epidemiologic studies do not identify the actual O_3 exposures that may be eliciting the observed health outcomes. Thus, in considering epidemiologic studies of mortality and morbidity, we are not drawing conclusions regarding single short-duration O_3 concentrations in ambient air that, alone, are eliciting the reported health outcomes. Rather, our focus in this section is to consider what these studies convey regarding the extent to which health effects may be occurring (i.e., as indicated by associations) under air quality conditions meeting the current standard.

[44] See *ATA III*, 283 F.3d at 370 (EPA justified in revising NAAQS when health effect associations are observed at levels allowed by the NAAQS).

In order to facilitate consideration of the question above, we have identified U.S. and Canadian studies of respiratory hospital admissions, respiratory emergency department visits,[45] and mortality (total, respiratory, cardiovascular) from the ISA (studies identified from U.S. EPA, 2013, Tables 6-28, 6-42, and 6-53, and section 6.2.8) (Appendix 3B). For each monitor in the areas evaluated by these studies, we have identified the 3-year averages of the annual 4th highest daily maximum 8-hour O_3 concentrations (Appendix 3B).[46] To provide perspective on whether study cities would have met or violated the current O_3 NAAQS during the study period, these O_3 concentrations were compared to the level of the current standard. Based on this approach, a study city was judged to have met the current standard during the study period if all of the 3-year averages of annual 4th highest 8-hour O_3 concentrations in that area were at or below 75 ppb.

Based on these analyses, the large majority of epidemiologic study areas evaluated would have violated the current standard during study periods (Appendix 3B). Table 3-3 below highlights the subset of U.S. and Canadian studies that evaluated O_3 health effect associations in locations that would have met the current standard during study periods. This includes a U.S. single-city study that would have met the current standard over the entire study period (Mar and Koenig, 2009) and four Canadian multicity studies for which the majority of study cities would have met the current standard over the entire study periods (Cakmak et al., 2006; Dales et al., 2006; Katsouyanni et al., 2009; Stieb et al., 2009).[47]

[45] Given the inconsistency in results across cardiovascular morbidity studies (U.S. EPA, 2013, section 6.3.2.9), our consideration of the morbidity evidence in this section focuses on studies of respiratory hospital admissions and emergency department visits.

[46] These concentrations are referred to as "design values." A design value is a statistic that is calculated at individual monitors and based on 3 consecutive years of data collected from that site. In the case of O_3, the design value for a monitor is based on the 3-year average of the annual 4th highest daily maximum 8-hour O_3 concentration in parts per billion (ppb). For U.S. study areas, we used EPA's Air Quality System (AQS) (http://www.epa.gov/ttn/airs/airsaqs/) to identify design values. For Canadian study areas, we used publically available air quality data from the Environment Canada National Air Pollution Surveillance Network (http://www.etc-cte.ec.gc.ca/napsdata/main.aspx). We followed the data handling protocols for calculating design values as detailed in 40 CFR Part 50, Appendix P.

[47] In addition, a study by Vedal et al. (2003) was included in the 2006 CD (U.S. EPA, 2006). This study reported positive and statistically significant associations with mortality in Vancouver during a time period when the study area would have met the current standard (U.S. EPA, 2007). This study was not highlighted in the ISA in the current review (U.S. EPA, 2013).

Table 3-3. U.S. and Canadian epidemiologic studies reporting O_3 health effect associations in locations that would have met the current standard during study periods.

Authors	Study Results	Cities	Number of cities meeting the current standard over entire study period
Cakmak et al. (2006)	Positive and statistically significant association with respiratory hospital admissions	10 Canadian cities	7
Dales et al. (2006)	Positive and statistically significant association with respiratory hospital admissions	11 Canadian cities	7
Katsouyanni et al. (2009)	Positive and statistically significant associations with respiratory hospital admissions	12 Canadian cities	10
Katsouyanni et al. (2009)	Positive and statistically significant associations with all-cause and cardiovascular mortality[48]	12 Canadian cities	8
Mar and Koenig (2009)	Positive and statistically significant associations with asthma emergency department visits in children (< 18 years) and adults (> 18 years)	Seattle	1
Stieb et al. (2009)	Positive and statistically significant association with asthma emergency department visits	7 Canadian cities	5

As illustrated in Table 3-3, Mar and Koenig reported health effect associations with asthma emergency department visits in a location that would have met the current standard over the entire study period. This analysis indicates that the current standard would allow the distribution of ambient O_3 concentrations that provided the basis for reported associations with respiratory emergency department visits.

In addition, four multicity studies reported associations with mortality or morbidity when the majority of study locations would have met the current standard over the entire study periods. Thus, the current standard would allow the majority of the distributions of ambient O_3 concentrations that provided the basis for positive and statistically significant associations with mortality or morbidity. Our interpretation of these results is complicated by uncertainties in the extent to which multicity effect estimates (i.e., which are based on combining estimates from multiple study locations) can be attributed to ambient O_3 in the subset of locations that would have met the current standard, versus O_3 in the smaller number of locations that would have violated the standard. While there is uncertainty in ascribing the multicity effect estimates reported in these Canadian studies to ambient concentrations that would have met the current

[48] Katsouyanni et al. (2009) report a positive and statistically significant association with cardiovascular mortality for people aged 75 years or older.

standard, the information in Table 3-3 suggests that reported multicity effect estimates are largely influenced by locations meeting the current standard (i.e., given that most study areas would have met this standard). Together, these U.S. and Canadian epidemiologic studies suggest a relatively high degree of confidence in the presence of associations with mortality and morbidity for ambient O_3 concentrations meeting the current standard.

We next consider the extent to which additional epidemiologic studies of mortality or morbidity, specifically those conducted in locations that violated the current standard, can also inform our consideration of adequacy of the current standard. In doing so, we note that health effect associations reported in epidemiologic studies are influenced by the full distributions of ambient O_3 concentrations, including concentrations below the level of the current standard. We focus on studies that have explicitly characterized such O_3 health effect associations, including confidence in those associations, for various portions of distributions of ambient O_3 concentrations. In doing so, we consider the following question:

- **To what extent do analyses from epidemiologic studies indicate confidence in health effect associations over distributions of ambient O_3 concentrations, including at concentrations lower than previously identified or below the current standard?**

We first focus on those studies that have reported confidence intervals around concentration-response functions over distributions of ambient O_3 concentrations. Confidence intervals around concentration-response functions can provide insights into the range of ambient concentrations over which the study indicates the most confidence in the reported health effect associations (i.e., where confidence intervals are narrowest), and into the range of ambient concentrations below which the study indicates that uncertainty in the nature of such associations becomes notably greater (i.e., where confidence intervals become markedly wider). The concentrations below which confidence intervals become markedly wider in such analyses are intrinsically related to data density, and do not necessarily indicate the absence of an association.

The ISA identifies several epidemiologic studies that have reported confidence intervals around concentration-response functions in U.S. cities. The ISA concludes that studies generally indicate a linear concentration-response relationship "across the range of 8-h max and 24 h avg O_3 concentrations most commonly observed in the U.S. during the O_3 season" and that "there is less certainty in the shape of the C-R curve at the lower end of the distribution of O_3 concentrations" (U.S. EPA, 2013, pp. 2-32 to 2-34). In characterizing the O_3 concentrations below which such certainty decreases, the ISA discusses area-wide O_3 concentrations as low as 20 ppb and as high as 40 ppb (U.S. EPA, 2013, section 2.5.4.4).

Consistent with these conclusions, the range of ambient concentrations over which the evidence indicates the most certainty in concentration-response relationships can vary across

studies. Such variation is likely due at least in part to differences in the O_3 metrics evaluated and differences in the distributions of ambient concentrations and health events. Thus, although consideration of confidence intervals around concentration-response functions can provide valuable insights into the ranges of ambient concentrations over which studies indicate the most confidence in reported health effect associations, there are limitations in the extent to which these analyses can be generalized across O_3 metrics, study locations, study populations, and health endpoints.

The ISA emphasizes two U.S. single-city studies that have reported confidence intervals around concentration-response functions (Silverman and Ito, 2010; Strickland et al., 2010). These studies, and their associated O_3 air quality, are discussed below.

Silverman and Ito (2010) evaluated associations between 2-day rolling average O_3 concentrations[49] and asthma hospital admissions in New York City from 1999 to 2006 (a time period when the study area would have violated the current standard, Appendix 3B). As part of their analysis, the authors evaluated the shape of the concentration-response relationship for O_3 using a co-pollutant model that included $PM_{2.5}$ (reprinted in Figure 3-4, below). Based on their analyses, Silverman and Ito (2010) concluded a linear relationship between O_3 and hospital admissions is a reasonable approximation of the concentration-response function throughout much of the range of ambient O_3 concentrations. Based on visual inspection of Figure 3-4 below (Figure 3 from published study), we note that confidence in the reported concentration-response relationship is highest for area-wide average O_3 concentrations around 40 ppb (i.e., near the reported median of 41 ppb), and decreases notably for concentrations at and below about 20 ppb.

[49] 2-day rolling averages of daily maximum 8-hour O_3 concentrations were calculated throughout the study period, averaged across study monitors.

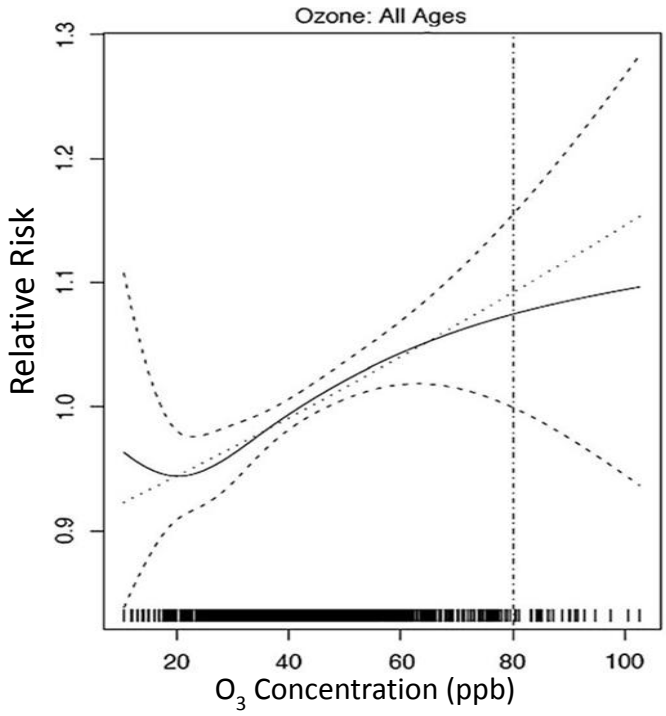


Figure 3-4. Concentration-response function for asthma hospital admissions over the distribution of area-wide averaged O_3 concentrations (adapted from Silverman and Ito, 2010).[50]

In considering the concentration-response function presented by Silverman and Ito (2010) within the context of the adequacy of the current standard, we recognize that true design values cannot be identified for the subsets of air quality data contributing to various portions of the concentration-response function.[51] Therefore, to use this analysis to inform our consideration of the adequacy of the current standard we evaluate the extent to which the concentration-response function indicates a relatively high degree of confidence in the reported health effect association on days when all monitored 8-hour O_3 concentrations were below 75 ppb (Table 3-4, below). This approach can provide insight into the extent to which the reported O_3 health effect association is present when all monitored O_3 concentrations are below the level of the current standard.

Based on the information in Table 3-4 below, when 2-day averaged O_3 concentrations ranged from 36 to 45 ppb (i.e., around the median, where confidence intervals are narrowest), there were 3 days (out of 432) with at least one monitor recording a daily maximum 8-hour O_3 concentration above the level of the current standard (approximately 0.7% of days). When 2-day

[50]This figure was also reprinted in the ISA (U.S. EPA, 2013; Figure 6-16).
[51]As discussed above, O_3 design values are calculated using all data available from a monitor.

averaged O_3 concentrations ranged from 26 to 45 ppb (i.e., extending to concentrations below the median, but still above the concentrations where confidence intervals widen notably), there were 4 days (out of 816) with at least one monitor recording a daily maximum 8-hour O_3 concentration above the level of the current standard (approximately 0.5% of days). Thus, on over 99% of the days when area-wide "averaged" O_3 concentrations were between 26 and 45 ppb, the highest daily maximum 8-hour O_3 concentrations were below 75 ppb. For comparison, the annual 4th highest daily maximum 8-hour O_3 concentration generally corresponds to the 98th or 99th percentile of the seasonal distribution, depending on the length of the O_3 season.

Table 3-4. Distributions of daily 8-hour maximum ozone concentrations from highest monitors over range of 2-day moving averages from composite monitors (for study area evaluated by Silverman and Ito, 2010)

Distribution of 8-hr max from highest monitors	2-day moving average across monitors (ppb)								
	11 to 20 (62 days)	21 to 25 (92 days)	26 to 30 (178 days)	31 to 35 (206 days)	36 to 40 (236 days)	41 to 45 (196 days)	46 to 50 (153 days)	51 to 55 (111 days)	56 to 60 (71 days)
Min	15	21	19	26	25	15	31	30	41
5th	16	23	25	33	34	37	38	37	46
25th	20	28	32	38	42	46	51	54	60
50th	24	31	36	43	47	52	59	62	68
75th	29	36	42	47	52	59	65	69	78
95th	37	49	50	55	61	72	77	80	90
98th	41	56	60	71	67	75	85	89	93
99th	41	57	67	75	69	87	91	94	93
Max	42	59	80	75	79	91	97	94	93
Days > 75 ppb	**0**	**0**	**1**	**0**	**1**	**2**	**9**	**15**	**20**

In a separate study, Strickland et al. (2010) evaluated associations between 3-day rolling average O_3 concentrations[52] and asthma hospital admissions in Atlanta during the warm season from 1994 to 2004 (a time period when the study area would have violated the current standard, Appendix 3B). As part of this analysis, Strickland et al. (2010) evaluated the concentration-response relationship for O_3 and pediatric asthma emergency department visits. The authors reported the shape of the concentration-response function to be approximately linear with no evidence of a threshold when 3-day averaged daily maximum 8-hour O_3 concentrations were approximately 30 to 80 ppb (Figure 3-5 below and U.S. EPA, 2013, Figure 6-18). Figure 3-5 below illustrates that the confidence intervals around the concentration-response function are

[52] Three-day rolling averages of population-weighted daily maximum 8-hour O_3 concentrations were calculated throughout the study period (Strickland et al., 2010).

narrowest around the study mean (i.e., 55 ppb), and that these confidence intervals do not widen notably for "averaged" O_3 concentrations as low as about 30 ppb.

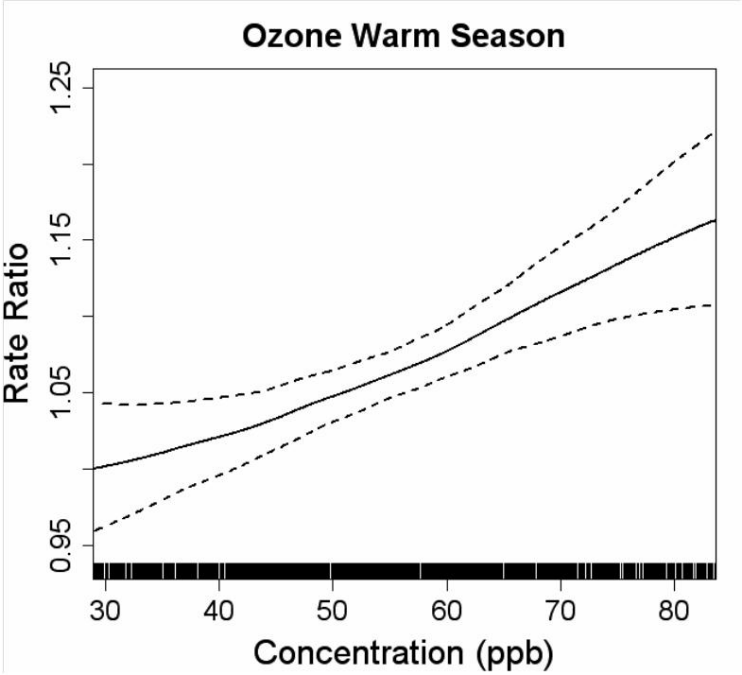


Figure 3-5. Concentration-response function for pediatric asthma emergency department visits over the distribution of averaged, population-weighted 8-hour O_3 concentrations (reprinted from Strickland et al., 2010).[53]

Similar to the study by Silverman and Ito (2010), we consider the extent to which the reported concentration-response function indicates a relatively high degree of confidence in health effect associations on days when all monitored 8-hour O_3 concentrations are below 75 ppb (Table 3-5, below).[54] In considering the information presented in Table 3-5, we first note that when 3-day averaged O_3 concentrations were in the range of the mean (i.e., 51 to 60 ppb), there were 77 days (out of 516; 14.9%) with at least one monitor recording a daily maximum 8-hour O_3 concentration above the level of the current standard. In contrast, during the 519 days when averaged O_3 concentrations were in the lower portion of the distribution where study authors indicate relatively high confidence in the reported concentration-response relationship (i.e., between 31 and 45 ppb), there were 4 days with at least one monitor in the study area measuring a daily maximum 8-hour O_3 concentration greater than 75 ppb (approximately 0.8% of days).

[53] This figure was also reprinted in the ISA (U.S. EPA, 2013; Figure 6-18).

[54] The study by Strickland et al. (2010) used five monitors. For our evaluation of highest daily maximum 8-hour concentrations (i.e., from the individual monitor recording the highest such concentration), we obtained information from the four of these study area monitors that report data to AQS (Appendix 3B).

Thus, on over 99% of the days when "averaged" O_3 concentrations were between 31 and 45 ppb, all monitors measured daily maximum 8-hour O_3 concentrations below 75 ppb.

Table 3-5. Distribution of daily 8-hour maximum ozone concentrations from highest monitors over range of 3-day moving averages of population-weighted concentrations (for study area evaluated by Strickland et al., 2010)

Distribution of 8-hr max from highest monitors	3-day moving average across monitors (ppb)						
	26-30 (75 days)	31-35 (144 days)	36-40 (165 days)	41-45 (210 days)	46-50 (235 days)	51-55 (244 days)	56-60 (272 days)
Min	15	18	21	19	25	23	25
5th	20	22	28	27	35	38	39
25th	29	31	35	37	46	52	54
50th	33	37	42	47	52	60	63
75th	40	44	49	56	62	67	73
95th	53	55	68	69	75	80	88
98th	67	59	74	72	83	88	95
99th	68	63	78	78	85	95	99
Max	70	64	82	90	92	97	106
Days > 75	**0**	**0**	**2**	**2**	**10**	**24**	**53**

In summary, analyses of air quality data from the study locations evaluated by Silverman and Ito (2010) and Strickland et al. (2010) indicate a relatively high degree of confidence in reported statistical associations with respiratory health outcomes on days when virtually all monitored 8-hour O_3 concentrations were 75 ppb or below. Though these analyses do not identify true design values, the presence of O_3-associated respiratory effects on such days provides insight into the types of health effects that could occur in locations with maximum ambient O_3 concentrations below the level of the current standard.

We next consider the following question:

- **To what extent are there important uncertainties in analyses of confidence in concentration-response functions?**

There are several important uncertainties that are specifically related to our analyses of distributions of O_3 air quality in the study locations evaluated by Silverman and Ito (2010) and Strickland et al. (2010). Although these studies report health effect associations with two-day (Silverman and Ito) and three-day (Strickland) averages of daily O_3 concentrations, it is possible that the respiratory morbidity effects reported in these studies were also at least partly attributable to the days immediately preceding these two- and three-day periods. In support of this possibility, Strickland et al. reported positive and statistically significant associations with emergency department visits for multiple lag periods, including lag periods exceeding three days.

Our analysis of highest monitored concentrations focuses on two- and three- day periods, as used in the published study to generate concentration-response functions. This could have important implications for our interpretation of the reported concentration-response functions if a 2-day period with no monitors measuring 8-hour concentrations at or above 75 ppb is immediately preceded by one or more days with monitors that do exceed 75 ppb. Although we do not know the extent to which O_3 concentrations on a larger number of days could have contributed to reported health effect associations, we note this as a potentially important uncertainty in our consideration of concentration-response functions within the context of the current standard.

In addition, an important uncertainty that applies to epidemiologic studies in general is the extent to which reported health effects are caused by exposures to O_3 itself, as opposed to other factors such as co-occurring pollutants or other pollutant mixtures. Although both of the studies evaluated above reported health effect associations in co-pollutant models, this uncertainty becomes an increasingly important consideration as health effect associations are evaluated at lower ambient O_3 concentrations (i.e., presumably corresponding to lower exposure concentrations).

One approach to considering the potential importance of this uncertainty in epidemiologic studies is to evaluate the extent to which there is coherence with the results of experimental studies (i.e., in which the study design dictates that exposures to O_3 itself are responsible for reported effects). Therefore, in further considering uncertainties associated with the above air quality analyses for the study areas evaluated by Silverman and Ito (2010) and Strickland et al. (2010), we evaluate the following question:

- **To what extent is there coherence between evidence from controlled human exposure studies and epidemiologic studies supporting the occurrence of O_3-attributable respiratory effects when daily maximum 8-hour ambient O_3 concentrations are at or below 75 ppb?**

As summarized above and as discussed in the ISA (U.S. EPA, 2013, section 6.2), controlled human exposure studies demonstrate the occurrence of respiratory effects in an appreciable percentage of healthy adults following single short-term exposures to O_3 concentrations as low as 60 ppb. As O_3 exposure concentrations exceed 60 ppb: 1) effects in healthy adults become larger and more serious; 2) a broader range of effects are observed in a greater percentage of exposed individuals; and 3) effects are reported more consistently across studies. In addition, exposure concentrations below 60 ppb could potentially result in respiratory effects, particularly in at-risk populations such as children and asthmatics. Thus, as the potential increases for portions of epidemiologic study populations to be exposed to O_3 concentrations approaching or exceeding 60 ppb, our confidence increases that reported respiratory health effects could be caused by exposures to the ambient O_3 concentrations present in study locations.

As discussed above, for the study by Silverman and Ito (2010), 26 to 45 ppb represents the lower end of the range of "averaged" concentrations over which the study indicates a relatively high degree of confidence in the statistical association with respiratory hospital admissions (and for which virtually all monitored concentrations were 75 ppb or below). As averaged concentrations increase from 26 to 45 ppb, the number of days with maximum monitored concentrations approaching or exceeding 60 ppb increases (Table 3-4, above).[55] For example, of the 178 days with area-wide average concentrations from 26 to 30 ppb, only about 5% had monitors recording ambient concentrations of 50 ppb or greater and about 2% had monitors recording concentrations of 60 ppb or greater. In contrast, of the 196 days with area-wide average concentrations from 41 to 45 ppb, about half had one or more monitors recording ambient concentrations above 50 ppb and about 25% had monitors recording concentrations at or above 60 ppb. On a small number of these days, at least one monitored concentration exceeded 70 or 80 ppb. Thus as averaged concentrations approach 45 ppb there is an increasing likelihood that at least some portion of the Silverman and Ito study population could have been exposed to O_3 concentrations near or above those shown to cause respiratory effects in healthy adults. If these effects become serious enough (e.g., in people with asthma) they could lead to the respiratory-related hospital admissions reported in the study. This analysis is consistent with the occurrence of O_3-attributable respiratory hospital admissions, even when virtually all monitored concentrations were below the level of the current standard. Similar results were obtained for the study by Strickland et al. (2010) (Table 3-5, above).

In further evaluating O_3 concentration-response relationships within the context of the adequacy of the current standard, we note that some epidemiologic studies report health effect associations for air quality subsets restricted to ambient pollutant concentrations below one or more predetermined cut points. Such "cut point" analyses can provide information on the magnitude and statistical precision of effect estimates for defined distributions of ambient concentrations, which may in some cases include distributions that would meet the current standard. Therefore, we next consider the following question:

- **To what extent do cut-point analyses from epidemiologic studies report health effect associations at ambient O_3 concentrations lower than previously identified or that would likely meet the current standard?**

By considering the magnitude and statistical significance of effect estimates for restricted air quality distributions, cut-point analyses can provide insight into the extent to which health

[55] Though, as noted above, the epidemiologic studies by Silverman and Ito (2010) and Strickland et al. (2010) do not provide information on the extent to which reported health effects result from exposures to any specific O_3 concentrations.

effect associations are driven by ambient concentrations above the cut point, versus concentrations below the cut point. For studies that evaluate multiple cut points, these analyses can provide insights into the magnitude and statistical precision of health effect associations for different portions of the distribution of ambient concentrations, including insights into the ambient concentrations below which uncertainty in reported associations becomes notably greater. As with analyses of concentration-response functions, discussed above, the cut points below which confidence intervals become notably wider depend in large part on data density.[56]

In the U.S. multicity study by Bell et al. (2006), study authors used the NMMAPS data set to evaluate associations between 2-day rolling average O_3 concentrations[57] and total (non-accidental) mortality in 98 U.S. cities from 1987 to 2000. Based on the full distributions of ambient O_3 concentrations in study cities, the large majority of the NMMAPS cities would have violated the current standard during the study period (Appendix 3B). However, Bell et al. (2006) also reported health effect associations in a series of cut-point analyses, with effect estimates based only on the subsets of days contributing to "averaged" O_3 concentrations below cut points ranging from 5 to 60 ppb (see Figure 2 in Bell et al., 2006). The lowest cut-point for which the association between O_3 and mortality was reported to be statistically significant was 30 ppb (based on visual inspection of Figure 2 in the published study). As with the studies by Silverman and Ito (2010) and Strickland et al. (2010), discussed above, we consider what these cut point analyses indicate with regard to the potential for health effect associations to extend to ambient O_3 concentrations likely to be allowed by the current O_3 NAAQS.

We attempted to recreate the subsets of air quality data used in the cut point analyses presented by Bell et al. (2006). In doing so, we applied the criteria described in the published study to generate air quality subsets corresponding to those defined by the cut points evaluated by study authors.[58] From the days with averaged O_3 concentrations below each cut point, we identified 3-year averages of annual 4th highest daily maximum 8-hour O_3 concentrations in each study area. We then compared these 4th highest O_3 concentrations to the level of the current standard in order to provide insight into the extent to which the air quality distributions included in various cut point analyses would likely have met the current standard.

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[56] As such, these analyses provide insight into the ambient concentrations below which the available air quality information becomes too sparse to support conclusions about the nature of concentration-response relationships, with a high degree of confidence.

[57] Two-day rolling averages of 24-hour average O_3 concentrations were calculated throughout the study period. This calculation was done across study monitors in study cities with multiple monitors.

[58] We were unable to obtain the air quality data used to generate the cut-point analyses in the study published by Bell et al. (2006). Therefore, we generated 2-day averages of 24-hour O_3 concentrations in study locations using the air quality data available in AQS, combined with the published description of study area definitions. In doing so, we did not recreate the trimmed means used by Bell. As discussed below, this represents an important uncertainty in our analysis.

We particularly focus on the lowest cut-point for which the association between O_3 and mortality was reported in this study to be statistically significant (i.e., 30 ppb, as noted above). Based on the O_3 air quality concentrations that met the criteria for inclusion in the 30 ppb cut point analysis, 95% of study areas had 3-year averages of annual 4th highest daily maximum 8-hour O_3 concentration at or below 75 ppb over the entire study period. For the 35 ppb cut point, which also resulted in a statistically significant association with mortality, 68% of study areas had 3-year averages of annual 4th highest daily maximum 8-hour O_3 concentration at or below 75 ppb. This suggests that the large majority of air quality distributions that provided the basis for positive and statistically significant associations with mortality (i.e., for the 30 and 35 ppb cut points) would likely have met the current O_3 standard. For higher cut points, all of which also resulted in statistically significant associations with mortality, the majority of study cities had 3-year averages of annual 4th highest daily maximum 8-hour concentrations greater than 75 ppb.

Table 3-6. Number of study cities with 4th highest daily maximum 8-hour concentrations greater than 75 ppb, for various cut-point analyses presented in Bell et al. (2006)

	Cut-point for 2-day moving average across monitors and cities (24-hour average)								
	25	30	35	40	45	50	55	60	All
Number (%) of Cities with 4th highest ≥75 (any 3-yr period; 1987-2000)	0 (0%)	5 (5%)	31 (32%)	70 (71%)	86 (88%)	88 (90%)	92 (94%)	92 (94%)	92 (94%)

In addition to the uncertainties noted above for our analysis of the single-city studies by Silverman and Ito (2010) and Strickland et al. (2010) (e.g., attributing effects specifically to air quality included in various subsets), an important uncertainty related to this analysis is that we were unable to obtain the air quality data used to generate the cut-point analyses in the study published by Bell et al. (2006). Therefore, as noted above, we generated 2-day averages of 24-hour O_3 concentrations in study locations using the air quality data available in AQS, combined with the published description of study area definitions. In doing so, we did not recreate the trimmed means used by Bell. An important uncertainty in this approach is the extent to which we were able to appropriately recreate the cut-point analyses in the published study.

The ISA also notes important uncertainties inherent in multicity studies that evaluate the potential for thresholds to exist, as was done in the study by Bell et al. (2006). Specifically, the ISA highlights the regional heterogeneity in O_3 health effect associations as a factor that could obscure the presence of thresholds, should they exist, in multicity studies (U.S. EPA, 2013, sections 2.5.4.4 and 2.5.4.5). The ISA notes that community characteristics (e.g., activity patterns, housing type, age distribution, prevalence of air conditioning) could be important contributors to reported regional heterogeneity (U.S. EPA, 2013, section 2.5.4.5). Given this heterogeneity, the ISA concludes that "a national or combined analysis may not be appropriate to identify whether a threshold exists in the O_3-mortality C-R relationship" (U.S. EPA, 2013, p. 2-33). This represents an important source of uncertainty when characterizing our confidence in reported concentration-response relationships over distributions of ambient O_3 concentrations, based on multicity studies. This uncertainty becomes increasingly important when interpreting concentration-response relationships at lower ambient O_3 concentrations, particularly those concentrations corresponding to portions of distributions where data density decreases notably.

3.1.4.3 Concentrations in Epidemiologic Studies – "Long-term" Metrics

We next consider the extent to which epidemiologic studies employing longer-term ambient O_3 concentration metrics inform our understanding of the air quality conditions

associated with O_3-attributable health effects, and specifically inform consideration of the extent to which such effects could occur under air quality conditions meeting the current standard. Unlike for the studies of short-term O_3 discussed above, the available U.S. and Canadian epidemiologic studies evaluating long-term ambient O_3 concentration metrics have not been conducted in locations likely to have met the current 8-hour O_3 standard during the study period (Appendix 3B). Therefore, although these studies contribute to our understanding of health effects associated with long-term or repeated exposures to ambient O_3 (as summarized in section 3.1.2 above), consideration of study area design values does not inform our consideration of the extent to which those health effects may be occurring in locations that met the current standard.

In further considering epidemiologic studies of long-term O_3 concentrations, we also evaluate the extent to which concentration-response functions, including associated confidence intervals, have been characterized for distributions of ambient O_3, and what those functions can tell us about health effect associations for O_3 concentrations likely to be allowed by the current standard. Specifically, we consider the following question:

- **To what extent do confidence intervals around concentration-response functions indicate O_3-associated health outcomes at ambient concentrations meeting the current O_3 standard?**

The ISA identifies a single epidemiologic study reporting confidence intervals around a concentration-response function for "long-term" O_3 concentrations and respiratory mortality (Jerrett et al., 2009; U.S. EPA, 2013, sections 7.2.7, 7.2.8 and 7.7). Jerrett et al. (2009) reported that when seasonal averages of 1-hour daily maximum O_3 concentrations[59] ranged from 33 to 104 ppb, there was no statistical deviation from a linear concentration-response relationship between O_3 and respiratory mortality across 96 U.S. cities (U.S. EPA, 2013, section 7.7). However, the authors reported "limited evidence" for an effect threshold at an O_3 concentration of 56 ppb ($p=0.06$).[60] Visual inspection of this concentration-response function (Figure 3-6) confirms the possibility of an inflection point just below 60 ppb, which is close to the median concentration across cities (i.e., 57 ppb).

[59] Jerrett et al. (2009) evaluated the April to September averages of 1-hour daily maximum O_3 concentrations across 96 U.S. metropolitan areas from 1977- 2000. In urban areas with multiple monitors, April to September 1-hour daily maximum concentrations from each individual monitor were averaged. This step was repeated for each year in the study period. Finally, each yearly averaged O_3 concentrations was then averaged again to yield the single averaged 1-hour daily maximum O_3 concentration depicted on the x axis of Figure 3-6 below.

[60] This issue is discussed further in section 3.2.3.2, below.

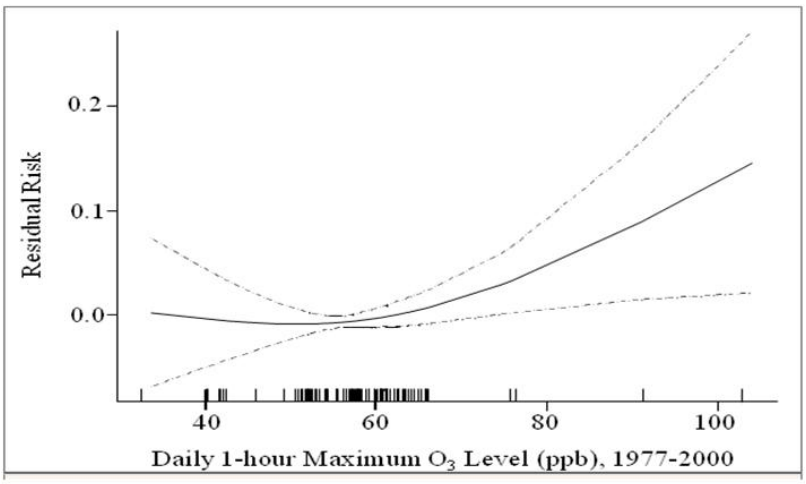

Figure 3-6. Exposure-Response relationship between risk of death from respiratory causes and ambient O_3 concentration study metric (Jerrett et al., 2009).

We consider the extent to which this concentration-response function indicates confidence in the reported health effect association at various ambient O_3 concentrations. In identifying the concentrations over which we have the greatest confidence, we note the following: (1) most of the study cities had O_3 concentrations above 53.1 ppb (i.e., the upper bound of the first quartile), accounting for approximately 72% of the respiratory deaths in the cohort (Table 2 in Jerrett et al. 2009); (2) confidence intervals widen notably for O_3 concentrations in the first quartile (based on visual inspection of Figure 3-6); and (3) study authors noted limited evidence for a threshold at 56 ppb.[61] In considering this information, we conclude that the analysis reported by Jerrett indicates a relatively high degree of confidence in the linear concentration-response function for "long-term" O_3 concentrations at least as low as 56 ppb, and notably decreased confidence in the linear function for concentrations at or below about 53 ppb (i.e., the upper bound of the first quartile of O_3 concentrations).

Based on information in the published study (Figure 1 in Jerrett et al., 2009), we identified 72 of the 96 study cities as having ambient O_3 concentrations in the highest three quartiles (Appendix 3B). As noted above, these 72 cities account for approximately 72% of the respiratory deaths in the cohort (Table 2 in Jerrett et al. 2009). Of these 72 cities, 71 had 3-year averages of annual 4th highest daily maximum 8-hour O_3 concentrations above 75 ppb (Appendix 3B). Thus, the current 8-hour NAAQS would have been violated during the study period in virtually all of the study cities that contribute to the range of long-term O_3 concentrations over which we have the greatest confidence in the reported relationship with respiratory mortality.

[61] The ISA does not reach conclusions regarding the potential for a threshold in the association between "long-term" O_3 concentrations and respiratory mortality.

Thus, while the study by Jerrett et al. (2009) contributes to our understanding of health effects associated with ambient O_3 (as summarized in section 3.1.2 above), it is less informative regarding the extent to which those health effects may be occurring under air quality conditions allowed by the current standard.

3.1.5 Public Health Implications

In this section, we address the public health implications of O_3 exposures with respect to the factors that put populations at increased risk from exposures (section 3.1.5.1), the size of at-risk populations (section 3.1.5.2), and the potential effects of averting behavior on reducing O_3 exposures and associated health effects (section 3.1.5.3). Providing appropriate public health protection requires consideration of the factors that put populations at greater risk from O_3 exposure. In order to estimate potential public health impacts, it is important to consider not only the adversity of the health effects, but also the populations at greater risk and potential behaviors that may reduce exposure.

3.1.5.1 At-Risk Populations

In this section we address the following question:

- **To what extent does the currently available scientific evidence expand our understanding of at-risk populations?**

The currently available evidence expands our understanding of populations that were identified to be at greater risk of O_3-related health effects at the time of the last review (i.e., people who are active outdoors, people with lung disease, children and older adults and people with increased responsiveness to O_3) and supports the identification of additional factors that may lead to increased risk (U.S. EPA, 2006, section 3.6.2; U.S. EPA, 2013, chapter 8). Populations and lifestages may be at greater risk for O_3-related health effects due to factors that contribute to their susceptibility and/or vulnerability to ozone. The definitions of susceptibility and vulnerability have been found to vary across studies, but in most instances "susceptibility" refers to biological or intrinsic factors (e.g., lifestage, sex, preexisting disease/conditions) while "vulnerability" refers to non-biological or extrinsic factors (e.g., socioeconomic status [SES]) (U.S. EPA, 2013, p. 8-1). In some cases, the terms "at-risk" and "sensitive" have been used to encompass these concepts more generally. In the ISA and this PA, "at-risk" is the all-encompassing term used to define groups with specific factors that increase their risk of O_3-related health effects. Further discussion of at-risk populations can be found below.

There are multiple avenues by which groups may experience increased risk for O_3-related health effects. A population or lifestage[62] may exhibit greater effects than other populations or lifestages exposed to the same concentration or dose, or they may be at greater risk due to increased exposure to an air pollutant (e.g., time spent outdoors). A group with intrinsically increased risk would have some factor(s) that increases risk through a biological mechanism and, in general, would have a steeper concentration-risk relationship, compared to those not in the group. Factors that are often considered intrinsic include pre-existing asthma, genetic background, and lifestage. A group of people could also have extrinsically increased risk, which would be through an external, non-biological factor, such as socioeconomic status (SES) and diet. Some groups are at risk of increased internal dose at a given exposure concentration, for example, because of breathing patterns. This category would include people who work or exercise outdoors. Finally, there are those who might be placed at increased risk for experiencing greater exposures by being exposed to higher O_3 concentrations. This would include, for example, groups of people with greater exposure to ambient O_3 due to less availability or use of home air conditioners such that they are more likely to be in locations with open windows on high ozone days. Some groups may be at increased risk of O_3-related health effects through a combination of factors. For example, children tend to spend more time outdoors when O_3 levels are high, and at higher levels of activity than adults, which leads to increased exposure and dose, and they also have biological, or intrinsic, risk factors (e.g., their lungs are still developing) (U.S. EPA, 2013, Chapter 8). An at-risk population or lifestage is more likely to experience adverse health effects related to O_3 exposures and/or, develop more severe effects from exposure than the general population.

People with Specific Genetic Variants

Overall, for variants in multiple genes there is adequate evidence for involvement in populations being more at-risk than others to the effects of O_3 exposure on health (U.S. EPA, 2013, section 8.1). Controlled human exposure and epidemiologic studies have reported evidence of O_3-related increases in respiratory symptoms or decreases in lung function with variants including GSTM1, GSTP1, HMOX1, and NQO1. NQO1 deficient mice were found to be resistant to O_3-induced AHR and inflammation, providing biological plausibility for results of studies in humans. Additionally, studies of rodents have identified a number of other genes that may affect O_3-related health outcomes, including genes related to innate immune signaling and pro- and anti-inflammatory genes, which have not been investigated in human studies.

People with Asthma

[62] Lifestages, which in this case includes childhood and older adulthood, are experienced by most people over the course of a lifetime, unlike other factors associated with at-risk populations.

Previous O_3 AQCDs identified individuals with asthma as a population at increased risk of O_3-related health effects. Multiple new epidemiologic studies included in the ISA have evaluated the potential for increased risk of O_3-related health effects in people with asthma, including: lung function; symptoms; medication use; airway hyperresponsiveness (AHR); and airway inflammation (also measured as exhaled nitric oxide fraction, or FeNO). A study of lifeguards in Texas reported decreased lung function with short-term O_3 exposure among both individuals with and without asthma, however, the decrease was greater among those with asthma (Thaller et al., 2008). A Mexican study of children ages 6-14 detected an association between short-term O_3 exposure and wheeze, cough, and bronchodilator use among asthmatics but not non-asthmatics, although this may have been the result of a small non-asthmatic population (Escamilla-Nuñez et al., 2008). A study of modification by AHR (an obligate condition among asthmatics) reported greater short-term O_3-associated decreases in lung function in elderly individuals with AHR, especially among those who were obese (Alexeeff et al., 2007). With respect to airway inflammation, in one study, a positive association was reported for airway inflammation among asthmatic children following short-term O_3 exposure, but the observed association was similar in magnitude to that of non-asthmatics (Barraza-Villarreal et al., 2008). Similarly, another study of children in California reported an association between O_3 concentration and FeNO that persisted both among children with and without asthma as well as those with and without respiratory allergy (Berhane et al., 2011). Finally, Khatri et al. (2009) found no association between short-term O_3 exposure and altered lung function for either asthmatic or non-asthmatic adults, but did note a decrease in lung function among individuals with allergies.

New evidence for difference in effects among asthmatics has been observed in studies that examined the association between O_3 exposure and altered lung function by asthma medication use. A study of children with asthma living in Detroit reported a greater association between short-term O_3 and lung function for corticosteroid users compared with noncorticosteroid users (Lewis et al., 2005). Conversely, another study found decreased lung function among noncorticosteroid users compared to users, although in this study, a large proportion of non-users were considered to be persistent asthmatics (Hernández-Cadena et al., 2009). Lung function was not related to short-term O_3 exposure among corticosteroid users and non-users in a study taking place during the winter months in Canada (Liu et al., 2009). Additionally, a study of airway inflammation reported a counterintuitive inverse association with O_3 of similar magnitude for all groups of corticosteroid users and non-users (Qian et al., 2009).

Controlled human exposure studies that have examined the effects of O_3 on adults with asthma and healthy controls are limited. Based on studies reviewed in the 1996 and 2006 O_3 AQCDs, subjects with asthma appeared to be more sensitive to acute effects of O_3 in terms of

FEV_1 and inflammatory responses than healthy non-asthmatic subjects. For instance, Horstman et al. (1995) observed that mild-to-moderate asthmatics, on average, experienced double the O_3-induced FEV_1 decrement of healthy subjects (19% versus 10%, respectively, $p = 0.04$). Moreover, a statistically significant positive correlation between FEV_1 responses to O_3 exposure and baseline lung function was observed in individuals with asthma, i.e., responses increased with severity of disease. Minimal evidence exists suggesting that individuals with asthma have smaller O_3-induced FEV_1 decrements than healthy subjects (3% versus 8%, respectively) (Mudway et al., 2001). However, the asthmatics in that study also tended to be older than the healthy subjects, which could partially explain their lesser response since FEV_1 responses to O_3 exposure diminish with age. Individuals with asthma also had significantly more neutrophils in the BALF (18 hours postexposure) than similarly exposed healthy individuals (Peden et al., 1997; Scannell et al., 1996; Basha et al., 1994). Furthermore, a study examining the effects of O_3 on individuals with atopic asthma and healthy controls reported that greater numbers of neutrophils, higher levels of cytokines and hyaluronan, and greater expression of macrophage cell-surface markers were observed in induced sputum of atopic asthmatics compared with healthy controls (Hernandez et al., 2010). Differences in O_3-induced epithelial cytokine expression were noted in bronchial biopsy samples from asthmatics and healthy controls (Bosson et al., 2003). Cell-surface marker and cytokine expression results, and the presence of hyaluronan, are consistent with O_3 having greater effects on innate and adaptive immunity in these asthmatic individuals. In addition, studies have demonstrated that O_3 exposure leads to increased bronchial reactivity to inhaled allergens in mild allergic asthmatics (Kehrl et al., 1999; Jorres et al., 1996) and to the influx of eosinophils in individuals with pre-existing allergic disease (Vagaggini et al., 2002; Peden et al., 1995). Taken together, these results point to several mechanistic pathways which could account for the enhanced sensitivity to O_3 in subjects with asthma (see Section 5.4.2.2 in the ISA).

Toxicological studies provide additional evidence of the biological basis for the greater effects of O_3 among those with asthma or AHR (U.S. EPA, 2013, section 8.2.2). In animal toxicological studies, an asthmatic phenotype is modeled by allergic sensitization of the respiratory tract. Many of the studies that provide evidence that O_3 exposure is an inducer of AHR and remodeling utilize these types of animal models. For example, a series of experiments in infant rhesus monkeys have shown these effects, but only in monkeys sensitized to house dust mite allergen. Similarly, adverse changes in pulmonary function were demonstrated in mice exposed to O_3; enhanced inflammatory responses were in rats exposed to O_3, but only in animals sensitized to allergen. In general, it is the combined effects of O_3 and allergic sensitization which result in measurable effects on pulmonary function. In a pulmonary fibrosis model, exposure O_3 for 5 days increased pulmonary inflammation and fibrosis, along with the frequency of

bronchopneumonia in rats. Thus, short-term exposure to O_3 may enhance damage in a previously injured lung (U.S. EPA, 2013, section 8.2.2).

In the 2006 O_3 AQCD, the potential for individuals with asthma to have greater risk of O_3-related health effects was supported by a number of controlled human exposure studies, evidence from toxicological studies, and a limited number of epidemiologic studies. In section 8.2.2, the ISA reports that in the recent epidemiologic literature some, but not all, studies report greater risk of health effects among individuals with asthma. Studies examining effect measure modification of the relationship between short-term O_3 exposure and altered lung function by corticosteroid use provided limited evidence of O_3-related health effects. However, recent studies of behavioral responses have found that studies do not take into account individual behavioral adaptations to forecasted air pollution levels (such as avoidance and reduced time outdoors), which may underestimate the observed associations in studies that examined the effect of O_3 exposure on respiratory health (Neidell and Kinney, 2010). This could explain some inconsistency observed among recent epidemiologic studies. The evidence from controlled human exposure studies provides support for increased detriments in FEV_1 and greater inflammatory responses to O_3 in individuals with asthma than in healthy individuals without a history of asthma. The collective evidence for increased risk of O_3-related health effects among individuals with asthma from controlled human exposure studies is supported by recent toxicological studies which provide biological plausibility for heightened risk of asthmatics to respiratory effects due to O_3 exposure. Overall, the ISA finds there is adequate evidence for asthmatics to be an at-risk population.

Children

Children are considered to be at greater risk from O_3 exposure because their respiratory systems undergo lung growth until about 18-20 years of age and are therefore thought to be intrinsically more at risk for O_3-induced damage (U.S. EPA, 2006). It is generally recognized that children spend more time outdoors than adults, and therefore would be expected to have higher exposure to O_3 than adults. The ventilation rates also vary between children and adults, particularly during moderate/heavy activity. Children aged 11 years and older and adults have higher absolute ventilation rates than children aged 1-11 years. However, children have higher ventilation rates relative to their lung volumes, which tends to increase dose normalized to lung surface area. Exercise intensity has a substantial effect on ventilation rate, with high intensity activities resulting in nearly double the ventilation rate during moderate activity among children and those adults less than 31 years of age. For more information on time spent outdoors and ventilation rate differences by age group, see Section 4.4.1 in the ISA (U.S. EPA, 2013).

The 1996 O_3 AQCD reported clinical evidence that children, adolescents, and young adults (<18 years of age) appear, on average, to have nearly equivalent spirometric responses to

O_3 exposure, but have greater responses than middle-aged and older adults (U.S. EPA, 1996). Symptomatic responses (e.g., cough, shortness of breath, pain on deep inspiration) to O_3 exposure, however, appear to increase with age until early adulthood and then gradually decrease with increasing age (U.S. EPA, 1996). Complete lung growth and development is not achieved until 18-20 years of age in women and the early 20s for men; pulmonary function is at its maximum during this time as well.

Recent epidemiologic studies have examined different age groups and their risk to O_3-related respiratory hospital admissions and emergency department (ED) visits. Evidence for greater risk in children was reported in several studies. A study in Cyprus of short-term O_3 concentrations and respiratory hospital admissions (HA) detected possible effect measure modification by age with a larger association among individuals < 15 years of age compared with those > 15 years of age; the effect was apparent only with a 2-day lag (Middleton et al., 2008). Similarly, a Canadian study of asthma-ED visits reported the strongest O_3-related associations among 5- to 14-year olds compared to the other age groups (ages examined 0-75+) (Villeneuve et al., 2007). Greater O_3-associated risk in asthma-related ED visits were also reported among children (<15 years) as compared to adults (15 to 64 years) in a study from Finland (Halonen et al., 2009). A study of New York City hospital admissions demonstrated an increase in the association between O_3 exposure and asthma-related hospital admissions for 6- to 18-year olds compared to those < 6 years old and those > 18 years old (Silverman and Ito, 2010). When examining long-term O_3 exposure and asthma HA among children, associations were determined to be larger among children 1 to 2 years old compared to children 2 to 6 years old (Lin et al., 2008b). A few studies reported positive associations among both children and adults and no modification of the effect by age.

The evidence reported in epidemiologic studies is supported by recent toxicological studies which observed O_3-induced health effects in immature animals. Early life exposures of multiple species of laboratory animals, including infant monkeys, resulted in changes in conducting airways at the cellular, functional, ultra-structural, and morphological levels. The studies conducted on infant monkeys are most relevant for assessing effects in children. Carey et al. (2007) conducted a study of O_3 exposure in infant rhesus macaques, whose respiratory tract closely resemble that of humans. Monkeys were exposed either acutely or in episodes designed to mimic human exposure. All monkeys acutely exposed to O_3 had moderate to marked necrotizing rhinitis, with focal regions of epithelial exfoliation, numerous infiltrating neutrophils, and some eosinophils. The distribution, character, and severity of lesions in episodically exposed infant monkeys were similar to that of acutely exposed animals. Neither exposure protocol for the infant monkeys produced mucous cell metaplasia proximal to the lesions, an adaptation observed in adult monkeys exposed in another study (Harkema et al., 1987). Functional and

cellular changes in conducting airways were common manifestations of exposure to O_3 among both the adult and infant monkeys (Plopper et al., 2007). In addition, the lung structure of the conducting airways in the infant monkeys was significantly stunted by O_3 and this aberrant development was persistent 6 months postexposure (Fanucchi et al., 2006).

Age may also affect the inflammatory response to O_3 exposure. Toxicological studies reported that the difference in effects among younger lifestage test animals may be due to age-related changes in antioxidants levels and sensitivity to oxidative stress. Further discussion of these studies may be found in section 8.3.1.1 of the ISA (U.S. EPA, 2013, p. 8-18).

The previous and recent human clinical and toxicological studies reported evidence of increased risk from O_3 exposure for younger ages, which provides coherence and biological plausibility for the findings from epidemiologic studies. Although there was some inconsistency, generally, the epidemiologic studies reported positive associations among both children and adults or just among children. The interpretation of these studies is limited by the lack of consistency in comparison age groups and outcomes examined. However, overall, the epidemiologic, controlled human exposure, and toxicological studies provide adequate evidence that children are potentially at increased risk of O_3-related health effects.

Older Adults

The ISA notes that older adults are at greater risk of health effects associated with O_3 exposure through a variety of intrinsic pathways (U.S. EPA, 2013, section 8.3.1.2). In addition, older adults may differ in their exposure and internal dose. Older adults were outdoors for a slightly longer proportion of the day than adults aged 18-64 years. Older adults also have somewhat lower ventilation rates than adults aged 31 - less than 61 years. For more information on time spent outdoors and ventilation rate differences by age group, see Section 4.4 in the ISA (U.S. EPA, 2013). The gradual decline in physiological processes that occur with aging may lead to increased risk of O_3-related health effects (U.S. EPA, 2006). Respiratory symptom responses to O_3 exposure appears to increase with age until early adulthood and then gradually decrease with increasing age (U.S. EPA, 1996); lung function responses to O_3 exposure also decline from early adulthood (U.S. EPA, 1996). The reductions of these responses with age may put older adults at increased risk for continued O_3 exposure. In addition, older adults, in general, have a higher prevalence of preexisting diseases compared to younger age groups and this may also lead to increased risk of O_3-related health effects (U.S. EPA, 2013, section 8.3.1.2). With the number of older Americans increasing in upcoming years (estimated to increase from 12.4% of the U.S. population to 19.7% between 2000 to 2030, which is approximately 35 million and 71.5 million individuals, respectively) this group represents a large population potentially at risk of O_3-related health effects (SSDAN CensusScope, 2010; DeNavas-Walt et al., 2011).

The majority of recent studies reported greater effects of short-term O_3 exposure and mortality among older adults, which is consistent with the findings of the 2006 O_3 AQCD. A study (Medina-Ramón and Schwartz, 2008) conducted in 48 cities across the U.S. reported larger effects among adults ≥ 65 years old compared to those < 65 years; further investigation of this study population revealed a trend of O_3-related mortality risk that gets larger with increasing age starting at age 51 (Zanobetti and Schwartz, 2008a). Another study conducted in 7 urban centers in Chile reported similar results, with greater effects in adults ≥ 65 years old (Cakmak et al., 2007). More recently, a study conducted in the same area reported similar associations between O_3 exposure and mortality in adults aged < 64 years old and 65 to 74 years old, but the risk was increased among older age groups (Cakmak et al., 2011). A study performed in China reported greater effects in populations ≥ 45 years old (compared to 5 to 44 year olds), with statistically significant effects present only among those ≥ 65 years old (Kan et al., 2008). An Italian study reported higher risk of all-cause mortality associated with increased O_3 concentrations among individuals ≥85 year old as compared to those 35 to 84 years old (Stafoggia et al., 2010). The Air Pollution and Health: A European and North American Approach (APHENA) project examined the association between O_3 exposure and mortality for those <75 and ≥ 75 years of age. In Canada, the associations for all-cause and cardiovascular mortality were greater among those ≥75 years old. In the U.S., the association for all-cause mortality was slightly greater for those <75 years of age compared to those ≥75 years old in summer-only analyses. No consistent pattern was observed for CVD mortality. In Europe, slightly larger associations for all-cause mortality were observed in those <75 years old in all-year and summer-only analyses. Larger associations were reported among those <75 years for CVD mortality in all-year analyses, but the reverse was true for summer-only analyses (Katsouyanni et al., 2009).

With respect to epidemiologic studies of O_3 exposure and hospital admissions, a positive association was reported between short-term O_3 exposure and respiratory hospital admissions for adults ≥ 65 years old but not for those adults aged 15 to 64 years (Halonen et al., 2009). In the same study, no association was observed between O_3 concentration and respiratory mortality among those ≥ 65 years old or those 15 to 64 years old. No modification by age (40 to 64 year olds versus > 64 year olds) was observed in a study from Brazil examining O_3 levels and COPD ED visits.

Although some outcomes reported mixed findings regarding an increase in risk for older adults, recent epidemiologic studies report consistent positive associations between short-term O_3 exposure and mortality in older adults. The evidence from mortality studies is consistent with the results reported in the 2006 O_3 AQCD and is supported by toxicological studies providing biological plausibility for increased risk of effects in older adults. Also, older adults may be experiencing increased exposure compared to younger adults. Overall, the ISA (U.S. EPA, 2013)

concludes adequate evidence is available indicating that older adults are at increased risk of O_3-related health effects.

People with Diets Lower in Vitamins C and E

Diet was not examined as a factor potentially affecting risk in previous O_3 AQCDs, but recent studies have examined modification of the association between O_3 and health effects by dietary factors. Because O_3 mediates some of its toxic effects through oxidative stress, the antioxidant status of an individual is an important factor that may contribute to increased risk of O_3-related health effects. Supplementation with vitamins C and E has been investigated in a number of studies as a means of inhibiting O_3-mediated damage.

Two epidemiologic studies have examined effect measure modification by diet and found evidence that certain dietary components are related to the effect O_3 has on respiratory outcomes. In one recent study the effects of fruit/vegetable intake and Mediterranean diet were examined. Increases in these food patterns, which have been noted for their high vitamins C and E and omega-3 fatty acid content, were positively related to lung function in asthmatic children living in Mexico City, and modified by O_3 exposure (Romieu et al., 2009). Another study examined supplementation of the diets of asthmatic children in Mexico with vitamins C and E (Sienra-Monge et al., 2004). Associations were detected between short-term O_3 exposure and nasal airway inflammation among children in the placebo group but not in those receiving the supplementation.

The epidemiologic evidence is supported by controlled human exposure studies, discussed in section 8.4.1 of the ISA (U.S. EPA, 2013), that have shown that the first line of defense against oxidative stress is antioxidants-rich extracellular lining fluid (ELF) which scavenge free radicals and limit lipid peroxidation. Exposure to O_3 depletes antioxidant levels in nasal ELF probably due to scrubbing of O_3; however, the concentration and the activity of antioxidant enzymes either in ELF or plasma do not appear to be related to O_3 responsiveness. Controlled studies of dietary antioxidant supplementation have demonstrated some protective effects of α-tocopherol (a form of vitamin E) and ascorbate (vitamin C) on spirometric measures of lung function after O_3 exposure but not on the intensity of subjective symptoms and inflammatory responses. Dietary antioxidants have also afforded partial protection to asthmatics by attenuating postexposure bronchial hyperresponsiveness. Toxicological studies discussed in section 8.4.1 of the ISA (U.S. EPA, 2013) provide evidence of biological plausibility to the epidemiologic and controlled human exposure studies.

There is adequate evidence that individuals with diets lower in vitamins C and E are at risk for O_3-related health effects. The evidence from epidemiologic studies is supported by controlled human exposure and toxicological studies.

Outdoor Workers

Studies included in the 2006 O_3 AQCD reported that individuals who participate in outdoor activities or work outside to be a population at increased risk based on consistently reported associations between O_3 exposure and respiratory health outcomes in these groups (U.S. EPA, 2006). Outdoor workers are exposed to ambient O_3 concentrations for a greater period of time than individuals who spend their days indoors. As discussed in Section 4.7 of the ISA (U.S. EPA, 2013) outdoor workers sampled during the work shift had a higher ratio of personal exposure to fixed-site monitor concentrations than health clinic workers who spent most of their time indoors. Additionally, an increase in dose to the lower airways is possible during outdoor exercise due to both increases in the amount of air breathed (i.e., minute ventilation) and a shift from nasal to oronasal breathing. The association between FEV_1 responses to O_3 exposure and minute ventilation is discussed more fully in Section 6.2.3.1 of the 2006 O_3 AQCD.

Previous studies have shown that increased exposure to O_3 due to outdoor work leads to increased risk of O_3-related health effects, specifically decrements in lung function (U.S. EPA, 2006). The strong evidence from the 2006 O_3 AQCD which demonstrated increased exposure, dose, and ultimately risk of O_3-related health effects in this population supports the conclusion that there is adequate evidence to indicate that increased exposure to O_3 through outdoor work increases the risk of O_3-related health effects.

In some cases, it is difficult to determine a factor that results in increased risk of effects. For example, previous assessments have included controlled human exposure studies in which some healthy individuals demonstrate greater O_3-related health effects compared to other healthy individuals. Intersubject variability has been observed for lung function decrements, symptomatic responses, pulmonary inflammation, AHR, and altered epithelial permeability in healthy adults exposed to O_3 and these results tend to be reproducible within a given individual over a period of several months indicating differences in the intrinsic responsiveness. In many cases the reasons for the variability is not clear. This may be because one or some of the factors described above have not been evaluated in studies, or it may be that additional, unidentified factors influence individual responses to O_3 (U.S. EPA, 2013, section 8.5).

As discussed in chapter 8 of the ISA the challenges and limitations in evaluating the factors that can increase risk for experiencing O_3-related health effects may contribute to a lack of information about the factors that may increase risk from O_3 exposures. This lack of information may contribute to conclusions that evidence for some factors, such as sex, SES, and obesity provided "suggestive" evidence of increased risk, or that for a number of factors the evidence was inadequate to draw conclusions about potential increase in risk of effects. Overall, the factors for which the ISA concludes there is adequate evidence of increased risk for

experiencing O_3-related effects were related to asthma, lifestage (children and older adults), genetic variability, dietary factors, and working outdoors.

3.1.5.2 Size of At-Risk Populations and Lifestages in the United States

One consideration in the assessment of potential public health impacts is the size of various population groups for which there is adequate evidence of increased risk for health effects associated with O_3-related air pollution exposure. The factors for which the ISA judged the evidence to be "adequate" with respect to contributing to increased risk of O_3-related effects among various populations and lifestages included: asthma; childhood and older adulthood; diets lower in vitamins C and E; certain genetic variants and, working outdoors (U.S. EPA, 2013, section 8.5).

With regard to asthma, Table 3-7 below summarizes information on the prevalence of current asthma by age in the U.S. adult population in 2010 (Schiller et al., 2012; children - Bloom et al., 2011). Individuals with current asthma constitute a fairly large proportion of the population, including more than 25 million people. Asthma prevalence tends to be higher in children than adults.

Within the U.S., approximately 8.2% of adults have reported currently having asthma (Schiller et al., 2012) and 9.5% of children have reported currently having asthma (Bloom et al., 2011). Table 3-12 below provides more detailed information on prevalence of asthma by age in the U.S.

Table 3-7. Prevalence of asthma by age in the U.S.

Age (years)	N (in thousands)	Percent
0-4	1,285	6.0
5-11	3,020	10.5
12-17	2,672	10.9
18-44	8,902	8.1
45-64	6,704	8.4
65-74	1,849	8.7
75+	1,279	7.4

Asthma prevalence is reported for "still has asthma"

Source: Statistics for adults: Schiller et al. (2012); Statistics for children: Bloom et al. (2011)

With regard to lifestages, based on U.S. census data from 2010 (Howden and Meyer, 2011), about 74 million people, or 24% of the U.S. population, are under 18 years of age and more than 40 million people, or about 13% of the U.S. population, are 65 years of age or older. Hence, a large proportion of the U.S. population, more than 33%, is included in age groups that are considered likely to be at increased risk for health effects from ambient O_3 exposure.

With regard to dietary factors, no statistics are available to estimate the size of an at-risk population based on nutritional status.

With regard to outdoor workers, in 2010 approximately 11.7% of the total number of people (143 million people) employed, or about 16.8 million people, worked outdoors one or more day per week (based on worker surveys).[63] Of these approximately 7.4% of the workforce, or about 7.8 million people, worked outdoors three or more days per week.

The health statistics data illustrate what is known as the "pyramid" of effects. At the top of the pyramid, there are approximately 2.5 million deaths from all causes per year in the U.S. population, with about 250 thousand respiratory-related deaths (CDC-WONDER[64]). For respiratory health diseases, there are nearly 3.3 million hospital discharges per year (HCUP[65]),

[63] The O*NET program is the nation's primary source of occupational information. Central to the project is the O*NET database, containing information on hundreds of standardized and occupation-specific descriptors. The database, which is available to the public at no cost, is continually updated by surveying a broad range of workers from each occupation. http://www.onetcenter.org/overview.html
http://www.onetonline.org/find/descriptor/browse/Work_Context/4.C.2/

[64] http://wonder.cdc.gov/

[65] http://www.hcup-us.ahrq.gov/

8.7 million respiratory ED visits (HCUP, 2007), 112 million ambulatory care visits (Woodwell and Cherry, 2004), and an estimated 700 million restricted activity days per year due to respiratory conditions (Adams et al., 1999). Combining small risk estimates with relatively large baseline levels of health outcomes can result in quite large public health impacts. Thus, even a small percentage reduction in O_3 health impacts on cardiopulmonary diseases would reflect a large number of avoided cases.

3.1.5.3 Averting Behavior

The activity pattern of individuals is an important determinant of their exposure (ISA, U.S. EPA, 2013, section 4.4.1). Variation in O_3 concentrations among various microenvironments means that the amount of time spent in each location, as well as the level of activity, will influence an individual's exposure to ambient O_3. Activity patterns vary both among and within individuals, resulting in corresponding variations in exposure across a population and over time. Individuals can reduce their exposure to O_3 by altering their behaviors, such as by staying indoors, being active outdoors when air quality is better, and by reducing their activity levels or reducing the time being active outdoors on high-O_3 days (U.S. EPA, 2013, section 4.4.2). The evidence in this topic area, while not addressed in the 2006 AQCD, is evaluated in the ISA for this review.

The widely reported Air Quality Index (AQI) conveys advice to the public, and particularly at-risk populations, on reducing exposure on days when ambient levels of common air pollutants are elevated (www.airnow.gov). The AQI describes the potential for health effects from O_3 (and other individual pollutants) in six color-coded categories of air-quality, ranging from Good (green), Moderate (yellow), Unhealthy for Sensitive Groups (orange), Unhealthy (red), and Very Unhealthy (purple), and Hazardous (maroon). Levels in the unhealthy ranges (i.e., Unhealthy for Sensitive Groups and above) come with recommendations about reducing exposure. Forecasted and actual AQI values for O_3 are reported to the public during the O_3 season. The AQI advisories explicitly state that children, older adults, people with lung disease, and people who are active outdoors, may be at greater risk from exposure to O_3. People are advised to reduce exposure depending on the predicted O_3 levels and the likelihood of risk. This advice includes being active outdoors when air quality is better, and reducing activity levels or reducing the time being active outdoors on high-O_3 days. Staying indoors to reduce exposure is not recommended until air quality reaches the Very Unhealthy or Hazardous categories.

Evidence of individual averting behaviors in response to AQI advisories has been found in several studies, including activity pattern and epidemiologic studies, especially for the at-risk populations, such as children, older adults, and people with asthma, who are targeted by the advisories. Such effects are less pronounced in the general population, possibly due to the opportunity cost of behavior modification. Epidemiologic evidence from a study (Neidell and

Kinney, 2010) conducted in the 1990's in Los Angeles, CA reports increased asthma hospital admissions among children and older adults when O_3 alert days (1-hour max O_3 concentration >200 ppb) were excluded from the analysis of daily hospital admissions and O_3 concentrations (presumably thereby eliminating averting behavior based on high O_3 forecasts). The lower rate of admissions observed when alert days were included in the analysis suggests that estimates of health effects based on concentration-response functions that do not account for averting behavior may be biased towards the null (U.S. EPA, 2013, section 4.4.2).

3.2 AIR QUALITY-, EXPOSURE-, AND RISK-BASED CONSIDERATIONS

In order to inform judgments about the public health impacts of O_3-related health effects, the HREA has developed and applied models to estimate human exposures to O_3 and O_3-associated health risks across the United States, with a specific focus on urban case study areas (U.S. EPA, 2014).[66] The HREA uses photochemical modeling to adjust air quality from the 2006-2010 O_3 seasons to just meet the current and alternative standards for the 2006-2008 and 2008-2010 periods.[67] In this section, staff considers estimates of short-term O_3 exposures and estimates of health risks associated with short- and long-term O_3 exposures, for air quality adjusted to just meet the current O_3 standard. In section 3.2.1, we consider the implications for exposure and risk estimates of the approach used in the HREA to adjust air quality. Sections 3.2.2 and 3.2.3 discuss our exposure-based and risk-based considerations, respectively. In these sections we specifically consider the following question:

- **What are the nature and magnitude of O_3 exposures and health risks remaining upon adjusting recent air quality to just meet the current O_3 standard, and what are the important uncertainties associated with those exposure and risk estimates?**

3.2.1 Consideration of the Adjusted Air Quality Used in Exposure and Risk Assessments

In the first draft HREA for this review, as in the last review, the EPA relied upon quadratic rollback to adjust hourly O_3 concentrations in urban case study areas to just meet the current O_3 standard (U.S. EPA, 2014). Although the quadratic rollback method reproduces

[66] The 15 urban case study areas analyzed for exposures are Atlanta, Baltimore, Boston, Chicago, Cleveland, Dallas, Denver, Detroit, Houston, Los Angeles, New York, Philadelphia, Sacramento, St. Louis, and Washington, DC. Morbidity and mortality risk estimates are presented for these same areas, with the exception of Chicago, Dallas, and Washington, DC. The HREA also presents a national scale mortality risk assessment for unadjusted (recent) air quality. This national-scale assessment, which focuses on existing air quality conditions and does not estimate the health risks associated with just meeting the current or alternative standards, can provide perspective on the relationship between national-scale O_3 public health impacts and impacts estimated in specific urban areas.

[67] Three-year periods are used recognizing that the current standard is the average across three years of the annual fourth-highest daily maximum 8-hour average concentration.

historical patterns of air quality changes better than some alternative methods, it relies on statistical relationships without explicitly accounting for atmospheric chemistry and precursor emissions (U.S. EPA, 2014, Chapter 4). An important drawback of the quadratic rollback approach, recognized in the first draft HREA (U.S. EPA, 2012b), is that it forces all monitors in an assessment area to exhibit the same response when air quality is adjusted. It does not allow for the spatial or temporal heterogeneity in responses that result from the non-linear atmospheric chemistry that influences ambient O_3 concentrations (U.S. EPA, 2014, Chapter 4). Because quadratic rollback does not account for physical and chemical atmospheric processes, or the sources of emissions precursors that lead to O_3 formation, a backstop or "floor" must be used when applying quadratic rollback to just meet current or alternative standards to ensure that estimated O_3 is not reduced in a manner inconsistent with O_3 chemistry, such as to reduce concentrations below that associated with background sources (U.S. EPA, 2014, Chapter 4).

Consistent with recommendations from the National Research Council of the National Academies (NRC, 2008), the HREA uses a photochemical model to estimate sensitivities of O_3 to changes in precursor emissions, in order to estimate ambient O_3 concentrations that would just meet the current and alternative standards (U.S. EPA, 2014, Chapter 4).[68] For the urban case study areas evaluated in the HREA, this model-based adjustment approach was set up to estimate hourly O_3 concentrations at each monitor location when modeled U.S. anthropogenic precursor emissions (i.e., NO_X, VOC)[69] were reduced to estimate air quality that just meets the current and alternative O_3 standards.[70]

As discussed in Chapter 4 of the HREA (U.S. EPA, 2014), this approach models the physical and chemical atmospheric processes that influence ambient O_3 concentrations. Compared to the quadratic rollback approach, it provides more realistic estimates of the spatial and temporal responses of O_3 to reductions in precursor emissions. These improved estimates avoid many of the limitations inherent in the quadratic rollback method, including the requirement that all monitors in an assessment area exhibit the same response upon air quality

[68] The HREA uses the CMAQ photochemical model instrumented with the higher order direct decoupled method (HDDM) to estimate ozone concentrations that would occur with the achievement of the current and alternative O_3 standards (U.S. EPA, 2014, Chapter 4).

[69] Exposure and risk analyses for most urban case study areas focus on reducing NO_X emissions alone (NO_X emissions were reduced by about 10 to 85% for the current standard, and up to about 95% for alternatives). In most of the urban case study areas, reducing VOC emissions did not alter the NO_X emissions reductions required to just meet the current or alternative standards. However, in Chicago and Denver, reductions in VOC emissions allowed for smaller NO_X emissions reductions. Therefore, exposure and risk analyses for Chicago and Denver are based on reductions in emissions of both NO_X and VOC (U.S. EPA, 2014, section 4.3.3.1, Table 4-3).

[70] Although this chapter focuses on the current standard, our overarching considerations regarding adjusted air quality also apply to alternative standards simulated in the HREA. Alternative standards are discussed in chapter 4 of this PA.

adjustment to the current and/or alternative standards. Because adjusted air quality scenarios are based on reducing only U.S. anthropogenic emissions, this approach also does not require the specification of background concentrations as a rollback "floor" (U.S. EPA, 2014, section 4.3.3).

The use of this model-based air quality adjustment approach in the HREA has important implications for the patterns of ambient O_3 concentrations estimated in urban case study areas. Specifically, in locations and time periods when NO_X is predominantly contributing to O_3 formation (e.g., downwind of important NO_X sources, where the highest O_3 concentrations often occur), model-based adjustment to the current and alternative standards decreases estimated ambient O_3 concentrations compared to recent monitored concentrations (U.S. EPA, 2014, section 4.3.3.2). In contrast, in locations and time periods when NO_X is predominantly contributing to O_3 titration (e.g., in urban centers with high concentrations of NO_X emissions, where ambient O_3 concentrations are often suppressed and thus relatively low[71]), model-based adjustment increases ambient O_3 concentrations compared to recent measured concentrations (U.S. EPA, 2014, section 4.3.3.2) (Chapter 2, above).

Within urban case study areas, the overall impacts of model-based air quality adjustment are to reduce relatively high ambient O_3 concentrations (i.e., concentrations at the upper ends of ambient distributions) and to increase relatively low O_3 concentrations (i.e., concentrations at the lower ends of ambient distributions) (U.S. EPA, 2014, section 4.3.3.2, Figures 4-9 and 4-10). Seasonal means of daily concentrations generally exhibit only modest changes upon air quality adjustment, reflecting the seasonal balance between daily decreases and increases in ambient concentrations (U.S. EPA, 2014, Figures 4-9 and 4-10). The resulting compression in distributions of ambient O_3 concentrations is evident in all of the urban case study areas evaluated, though the degree of compression varies considerably across areas (U.S. EPA, 2014, Figures 4-9 and 4-10).

Adjusted patterns of O_3 air quality have important implications for exposure and risk estimates in urban case study areas. Estimates influenced largely by the upper ends of the distribution of ambient concentrations (i.e., exposures of concern and lung function risk estimates, as discussed in sections 3.2.2 and 3.2.3.1 below) will decrease with model-adjustment to the current and alternative standards. In contrast, seasonal risk estimates influenced by the full distribution of ambient O_3 concentrations (i.e., epidemiology-based risk estimates, as discussed in section 3.2.3.2 below) either increase or decrease in response to air quality adjustment,

[71] Titration is also prominent during time periods when photochemistry is limited, such as at night and on cool, cloudy days.

depending on the balance between the daily decreases in high O_3 concentrations and increases in low O_3 concentrations.[72]

We further consider the implications of the spatial and temporal patterns of adjusted air quality within the context of exposure (section 3.2.2) and risk (section 3.2.3) estimates for O_3 concentrations adjusted to just meet the current standard. As discussed below (section 3.2.3.2), these altered patterns are particularly important to consider when interpreting epidemiology-based risk estimates.

3.2.2 Exposure-Based Considerations

The exposure assessment presented in the HREA (U.S. EPA, 2014, Chapter 5) provides estimates of the number of people exposed to various concentrations of ambient O_3, while at specified exertion levels. The HREA estimates exposures in 15 urban case study areas for school-age children (ages 5 to 18), asthmatic school-age children, asthmatic adults, and older adults, reflecting the strong evidence indicating that these populations are potentially at increased risk for O_3-attributable effects (EPA, 2013, Chapter 8; section 3.1.2, above). An important purpose of these exposure estimates is to provide perspective on the extent to which air quality adjusted to just meet the current O_3 NAAQS could be associated with exposures to O_3 concentrations reported to result in respiratory effects.[73] Estimates of such "exposures of concern" provide perspective on the potential public health impacts of O_3-related effects, including for effects that cannot currently be evaluated in a quantitative risk assessment (e.g., airway inflammation).

In the absence of large scale exposure studies that encompass the general population, as well as at-risk populations, modeling is the preferred approach to estimating exposures to O_3. The use of exposure modeling also facilitates the estimation of exposures resulting from ambient air concentrations differing from those in exposure studies (e.g., concentrations just meeting the current standard). In the HREA, population exposures to ambient O_3 concentrations are estimated using the current version of the Air Pollutants Exposure (APEX) model. The APEX model simulates the movement of individuals through time and space and estimates their exposures to a given pollutant in indoor, outdoor, and in-vehicle microenvironments (U.S. EPA, 2014, section 5.1.3). APEX takes into account the most critical factors that contribute to total

[72] In addition, because epidemiology-based risk estimates use "area-wide" average O_3 concentrations, calculated by averaging concentrations across multiple monitors in urban case study areas (section 3.2.3.2 below), risk estimates on a given day depend on the daily balance between increasing and decreasing O_3 concentrations at individual monitors.

[73] In addition, the range of modeled personal exposures to ambient O_3 provide an essential input to the portion of the health risk assessment based on exposure-response functions (for lung function decrements) from controlled human exposure studies. The health risk assessment based on exposure-response information is discussed in section 3.2.3, below.

human exposure to ambient O_3, including the temporal and spatial distributions of people and O_3 concentrations throughout an urban area, the variation of O_3 concentrations within various microenvironments, and the effects of exertion on breathing rate in exposed individuals (U.S. EPA, 2014, section 5.1.3). To the extent spatial and/or temporal patterns of ambient O_3 concentrations are altered upon air quality adjustment, as discussed above, exposure estimates reflect population exposures to those altered patterns.

The HREA estimates 8-hour exposures at or above benchmark concentrations of 60, 70, and 80 ppb for individuals engaged in moderate or greater exertion. Benchmarks reflect exposure concentrations at which O_3-induced respiratory effects are known to occur in some healthy adults engaged in moderate, intermittent exertion, based on evidence from controlled human exposure studies (section 3.1.2.1 above and U.S. EPA, 2013, section 6.2). The amount of weight to place on the estimates of exposures at or above specific benchmark concentrations depends in part on the weight of the scientific evidence concerning health effects associated with O_3 exposures at that concentration. It also depends on judgments about the importance, from a public health perspective, of the health effects that are known or can reasonably be inferred to occur as a result of exposures at benchmark concentrations (sections 3.1.3, 3.1.5 above).

As discussed in more detail above (section 3.1.2.1), the health evidence that supports evaluating exposures of concern at or above benchmark concentrations of 60, 70, and 80 ppb comes from a large body of controlled human exposure studies reporting a variety of respiratory effects in healthy adults. The lowest O_3 exposure concentration for which controlled human exposure studies have reported respiratory effects in healthy adults is 60 ppb, with more evidence supporting this benchmark concentration in the current review than in the last review. In healthy adults, exposures to 60 ppb O_3 have been reported to decrease lung function and to increase airway inflammation. Exposures of healthy adults to 70 ppb O_3 have been reported to result in larger lung function decrements, compared to 60 ppb, as well as in increased respiratory symptoms.[74] Exposures of healthy adults to 80 ppb O_3 have been reported to result in larger lung function decrements than following exposures to 60 or 70 ppb, increased airway inflammation, increased respiratory symptoms, increased airways responsiveness, and decreased lung host defense (section 3.1.2.1, above). As discussed above (section 3.1.3), respiratory effects reported following exposures to O_3 concentrations of 60, 70, or 80 ppb meet ATS criteria for adverse effects, result in effects judged important by CASAC in past reviews, and/or could contribute to the clearly adverse effects reported in epidemiologic studies evaluating broader populations. Compared to the healthy individuals included in the studies that provided the basis for the

[74] As noted above, for the 70 ppb exposure concentration Schelegle et al. (2009) reported that the actual mean exposure concentration was 72 ppb.

benchmarks, at-risk populations (e.g., asthmatics, children) are more likely to experience larger and/or more serious effects (e.g., U.S. EPA, 2013, p. 6-21).

In considering estimates of O_3 exposures of concern at or above benchmarks of 60, 70, and 80 ppb, within the context of the adequacy of the current standard, we first address the following specific question:

- **What are the nature and magnitude of the short-term O_3 exposures of concern remaining upon adjustment of air quality to just meet the current O_3 standard?**

In addressing this question, we focus on modeled exposures for school-age children (ages 5-18) and asthmatic school-age children, two of the at-risk populations identified in the ISA (section 3.1.5 above). The percentages of children estimated to experience exposures of concern are larger than the percentages estimated for adult populations (i.e., approximately 3-fold larger across cities) (U.S. EPA, 2014, sections 5.3.2, 5.3.3 and Figures 5-5 to 5-8). The larger exposure estimates for children are due primarily to the larger percentage of children estimated to spend an extended period of time being physically active outdoors when O_3 concentrations are elevated (U.S. EPA, 2014, sections 5.3.2 and 5.4.1).

Although exposure estimates differ between children and adults, the patterns of results across the cities and years are similar among all of the populations evaluated (U.S. EPA, 2014, Figures 5-5 to 5-8). Therefore, while we highlight estimates in children, we also note that the patterns of exposures estimated for children represent the patterns estimated for adult asthmatics and older adults.

Key results for children are summarized below for air quality adjusted to simulate just meeting the current O_3 NAAQS (Figures 3-7 to 3-10).[75] Estimates for all children and asthmatic children are virtually indistinguishable (U.S. EPA, 2014, section 5.3.2). The estimates presented in Figures 3-7 to 3-10 below reflect consistent reductions in estimated exposures of concern across urban case study areas, relative to recent (i.e., unadjusted) air quality (U.S. EPA, 2014, Appendix 5F). When averaged over the years evaluated in the HREA, reductions of up to about 70% were estimated, compared to recent air quality. These reductions in estimated exposures of concern, relative to unadjusted air quality, reflect the consistent reductions in the highest ambient O_3 concentrations upon air quality adjustment to just meet the current standard (section 3.2.1 above; U.S. EPA, 2014, Chapter 4). Such reductions in estimated exposures of concern are evident throughout urban case study areas, including in urban cores and in surrounding areas (U.S. EPA, 2014, section 9.6, Appendix 9A). Figures 3-7 (Average over years) and 3-8 (Worst-Case Years) present estimates of one or more exposures of concern. Figures 3-9 (Average over years) and 3-10 (Worst-Case Years) present estimates of two or more exposures of concern.

[75] Figures 3-7 and 3-8 present estimates of one or more exposures of concern. Figures 3-9 and 3-10 present estimates of two or more exposures of concern.

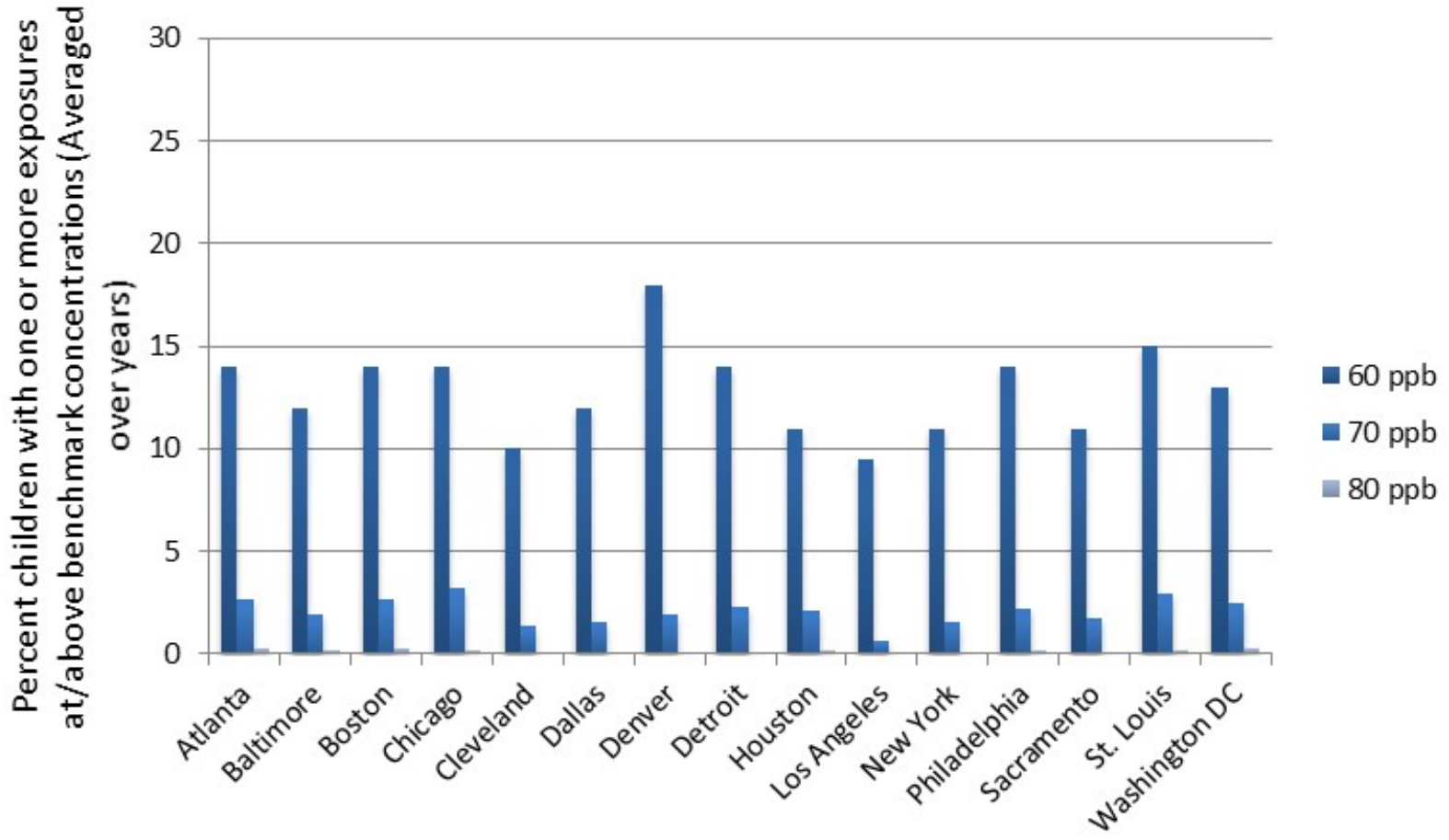

Figure 3-7. Percent of children estimated to experience one or more exposures of concern at or above 60, 70, 80 ppb with air quality adjusted to just meet the current standard - Averaged Over 2006 to 2010.

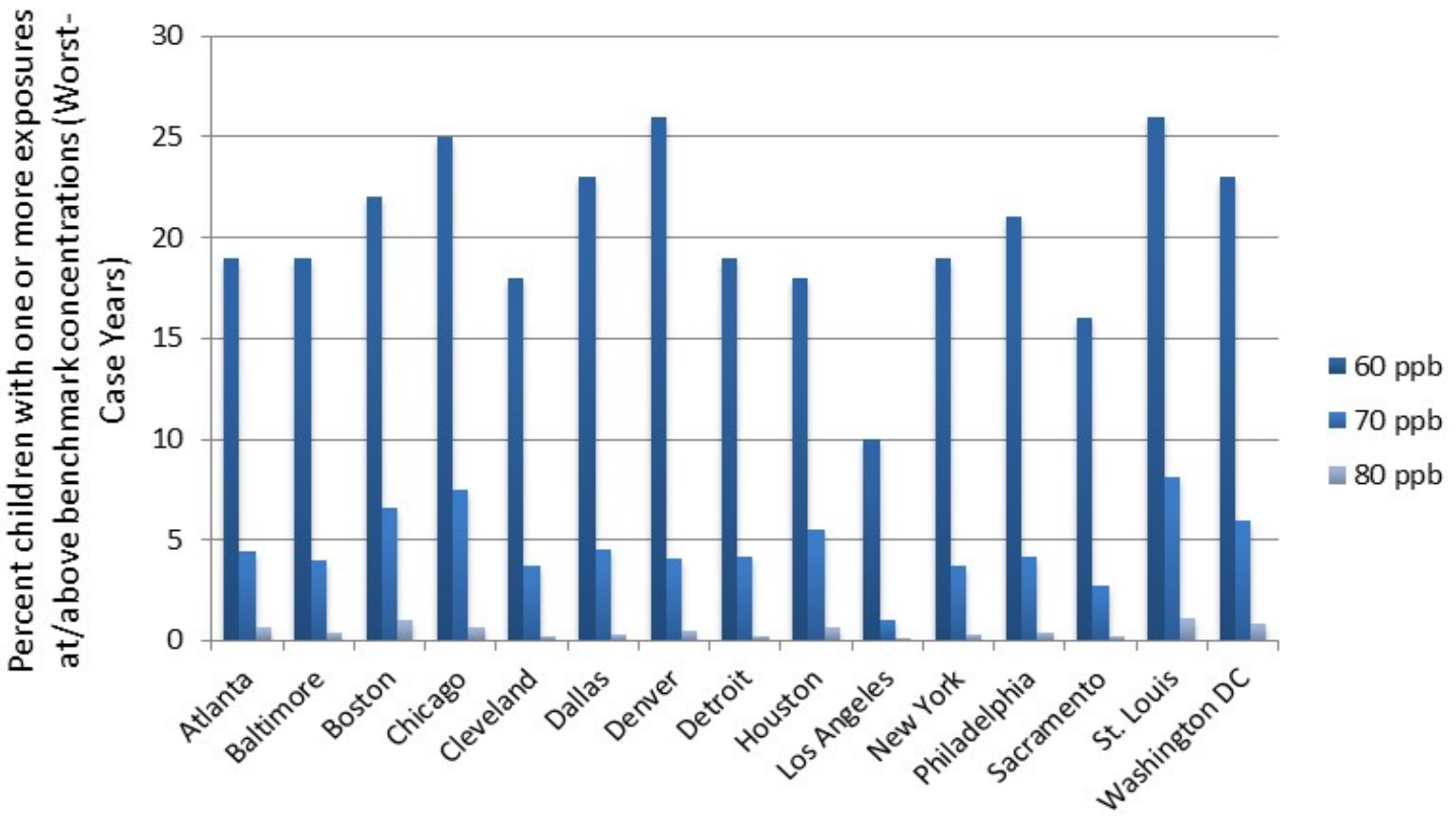

Figure 3-8. Percent of children estimated to experience one or more exposures of concern at or above 60, 70, 80 ppb with air quality adjusted to just meet the current standard - Worst-Case Year from 2006 to 2010.

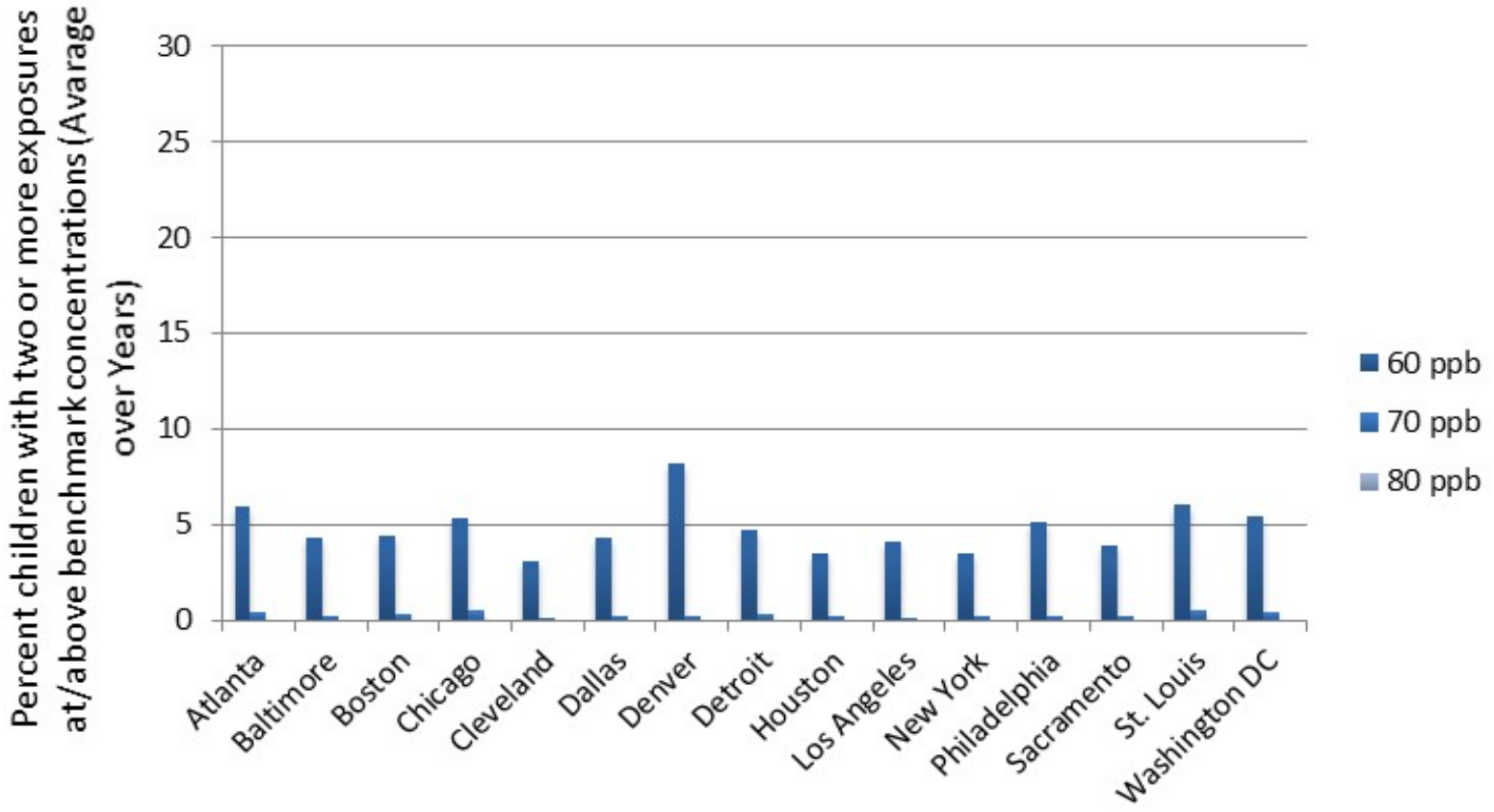

Figure 3-9. Percent of children estimated to experience two or more exposures of concern at or above 60, 70, 80 ppb with air quality adjusted to just meet the current standard - Averaged Over 2006 to 2010.

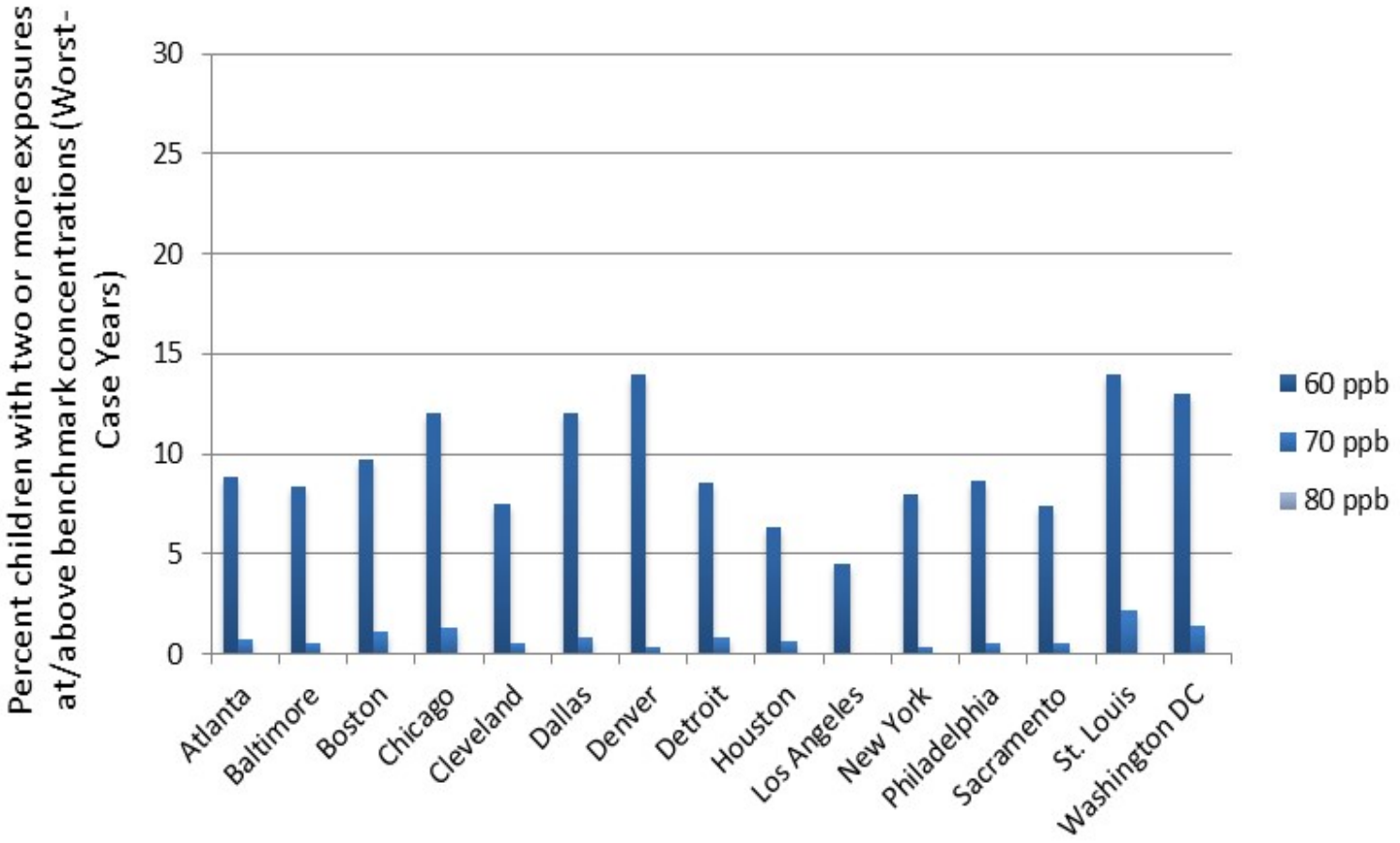

Figure 3-10. Percent of children estimated to experience two or more exposures of concern at or above 60, 70, 80 ppb with air quality adjusted to just meet the current standard - Worst-Case Year from 2006 to 2010.

Based on Figures 3-7 to 3-10 and the associated details described in the HREA (U.S. EPA, 2014, Chapter 5), we take note of the following with regard to exposures that are estimated to be allowed by the current standard:

1. For exposures of concern at or above 60 ppb:
    a. On average over the years 2006 to 2010, the current standard is estimated to allow approximately 10 to 17% of children in urban case study areas to experience one or more exposures of concern at or above 60 ppb. Summing across urban case study areas, these percentages correspond to almost 2.5 million children experiencing approximately 4 million exposures of concern at or above 60 ppb during a single O_3 season. Of these children, almost 250,000 are asthmatics.

    b. On average over the years 2006 to 2010, the current standard is estimated to allow approximately 3 to 8% of children in urban case study areas to experience two or more exposures of concern to O_3 concentrations at or above 60 ppb. Summing across the urban case study areas, these percentages correspond to almost 900,000 children (including about 90,000 asthmatic children) estimated to experience at least two O_3 exposure concentrations at or above 60 ppb during a single O_3 season.

    c. In the worst-case years (i.e., those with the largest exposure estimates), the current standard is estimated to allow approximately 10 to 26% of children to experience one or more exposures of concern at or above 60 ppb, and approximately 4 to 14% to experience two or more exposures of concern at or above 60 ppb.

2. For exposures of concern at or above 70 ppb:
    a. On average over the years 2006 to 2010, the current standard is estimated to allow up to approximately 3% of children in urban case study areas to experience one or more exposures of concern at or above 70 ppb. Summing across urban case study areas, more than 350,000 children (including about 40,000 asthmatic children) are estimated to experience O_3 exposure concentrations at or above 70 ppb during a single O_3 season.

    b. On average over the years 2006 to 2010, the current standard is estimated to allow less than 1% of children in urban case study areas to experience two or more exposures of concern to O_3 concentrations at or above 70 ppb.

    c. In the worst-case years, the current standard is estimated to allow approximately 1 to 8% of children to experience one or more exposures of concern at or above 70 ppb, and up to approximately 2% to experience two or more exposures of concern, at or above 70 ppb.

3. For exposures of concern at or above 80 ppb: The current standard is estimated to allow about 1% or fewer children in urban case study areas to experience exposures of concern at or above 80 ppb, even in years with the highest exposure estimates.

In further evaluating estimated exposures of concern from the HREA, we next consider the following question:

- **What are the important sources of uncertainty associated with exposure estimates?**

Due to variability in responsiveness, only a subset of individuals who experience exposures at or above a benchmark concentration can be expected to experience health effects. Given the lack of sufficient exposure-response information for most of the health effects that informed benchmark concentrations, estimates of the number of people likely to experience exposures at or above benchmark concentrations generally cannot be translated into quantitative estimates of the number of people likely to experience specific health effects.[76] We view health-relevant exposures as a continuum with greater confidence and certainty about the existence of adverse health effects at higher O_3 exposure concentrations, and less confidence and greater uncertainty as one considers lower exposure concentrations. This view draws from the overall body of available health evidence, which indicates that as exposure concentrations increase the incidence, magnitude, and severity of effects increases.

Though we have less confidence in the likelihood of adverse health effects as O_3 exposure concentrations decrease, we also note that the controlled human exposure studies that provided the basis for health benchmark concentrations have not evaluated at-risk populations. Compared to the healthy individuals included in controlled human exposure studies, members of at-risk populations (e.g., asthmatics, children) could be more likely to experience adverse effects, could experience larger and/or more serious effects, and/or could experience effects following exposures to lower O_3 concentrations. In considering estimated exposures of concern within the context of drawing conclusions on the adequacy of the current standard (section 3.4, below), we balance concerns about the potential for adverse health effects, including effects in at-risk populations, with our increasing uncertainty regarding the likelihood of such effects following exposures to lower O_3 concentrations.

Uncertainties associated with the APEX exposure modeling also have the potential to be important in our consideration of the adequacy of the current standard (U.S. EPA, 2014, section 5.5.2, Table 5-10). For example, the HREA concludes that exposures of concern could be underestimated for some individuals who are frequently and routinely active outdoors during the warm season (U.S. EPA, section 5.5.2). This could include outdoor workers and children who are frequently active outdoors. The HREA specifically notes that long-term diary profiles (i.e., monthly, annual) do not exist for such populations, limiting the extent to which APEX outputs reflect people who follow similar daily routines resulting in high exposures, over extended

[76] The exception to this is lung function decrements, as discussed below (section 3.2.3.1).

periods of time. Thus, exposure estimates generated from the general pool of available diary profiles likely do not reflect the most highly exposed individuals in the population.

In order to evaluate the potential implications of this uncertainty for exposure estimates, the HREA reports the results of limited sensitivity analyses using subsets of diaries specifically selected to reflect groups spending a larger proportion of time being active outdoors during the O_3 season. When diaries were selected to mimic exposures that could be experienced by outdoor workers, the percent of modeled individuals estimated to experience exposures of concern increased compared to other adult populations evaluated. The percent of outdoor workers estimated to experience exposures of concern were generally similar to the percentages estimated for children (i.e., using the full database of diary profiles) in the worst-case cities and years (i.e., cities and years with the highest exposure estimates) (U.S. EPA, 2014, section 5.4.3.2, Figure 5-14). In addition, when diaries were restricted to children who did not report any time spent inside a school or performing paid work (i.e., to mimic children spending particularly large portions of their time outdoors during the summer), the number experiencing exposures of concern increased by approximately 30% (U.S. EPA, 2014, section 5.4.3.1). Though these sensitivity analyses are limited to single urban case study areas, and though there is uncertainty associated with diary selection approaches to mimic highly exposed populations, they suggest the possibility that some at-risk groups could experience more frequent exposures of concern than indicated by estimates based on the full database of activity diary profiles.

In further considering activity diaries, the HREA also notes growing evidence indicating that people can change their behavior in response to high O_3 concentrations, reducing the time spent being active outdoors (U.S. EPA, 2014, section 5.4.3.3). Commonly termed "averting behaviors," these altered activity patterns could reduce personal exposure concentrations. Therefore, the HREA also performed limited sensitivity analyses to evaluate the potential implications of averting behavior for estimated exposures of concern. These analyses suggest that averting behavior could reduce the percentages of children estimated to experience exposures of concern at or above the 60 or 70 ppb benchmark concentrations by approximately 10 to 30%, with larger reductions possible for the 80 ppb benchmark (U.S. EPA, 2014, Figure 5-15). As discussed above for other sensitivity analyses, these analyses are limited to a single urban case study area and are subject to uncertainties associated with assumptions about the prevalence and duration of averting behaviors. However, the results suggest that exposures of concern could be overestimated, particularly in children (Neidell et al., 2009; U.S. EPA, 2013, Figures 4-7 and 4-8), if the possibility for averting behavior is not incorporated into estimates.

3.2.3 Risk-Based Considerations

For some health endpoints, there is sufficient scientific evidence and information available to support the development of quantitative estimates of O_3-related health risks. In the last review of the O_3 NAAQS, the quantitative health risk assessment estimated O_3-related lung function decrements, respiratory symptoms, respiratory-related hospital admissions, and non-accidental and cardiorespiratory-related mortality (U.S. EPA, 2007). In those analyses, both controlled human exposure and epidemiologic studies were used for the quantitative assessment of O_3-related human health risks.

In the current review, for short-term O_3 concentrations the HREA estimates lung function decrements; respiratory symptoms in asthmatics; hospital admissions and emergency department visits for respiratory causes; and all-cause mortality (U.S. EPA, 2014, Chapters 6 and 7). For "long-term" O_3 concentrations, the HREA estimates respiratory mortality (U.S. EPA, 2014, Chapter 7).[77] Estimates of O_3-induced lung function decrements are based on exposure modeling, as noted above, combined with exposure-response relationships from controlled human exposure studies (U.S. EPA, 2014, Chapter 6). Estimates of O_3-associated respiratory symptoms; hospital admissions and emergency department visits; and mortality are based on concentration-response relationships from epidemiologic studies (U.S. EPA, 2014, Chapter 7). As with the exposure assessment discussed above, O_3-associated health risks are estimated for recent air quality and for ambient concentrations adjusted to just meet the current 8-hour O_3 NAAQS, based on 2006-2010 air quality and adjusted precursor emissions.

Section 3.2.3.1 below discusses risk results for O_3-induced lung function decrements following short-term exposures, based on exposure modeling results and exposure-response relationships from controlled human exposure studies. Section 3.2.3.2 discusses epidemiology-based risk estimates, with a focus on all-cause mortality (short-term O_3 concentrations); respiratory-related morbidity outcomes (short-term O_3 concentrations); and respiratory mortality (long-term O_3 concentrations).

3.2.3.1 Risk of Lung Function Decrements

In the last review, EPA conducted a health risk assessment that produced risk estimates for the number and percent of school-aged children, asthmatic school-aged children, and the general population experiencing lung function decrements associated with O_3 exposures for 12 urban areas. These estimates were based on exposure-response relationships developed from

[77] Risk estimates for "long-term" concentrations are based on the concentration-response relationship identified in the study by Jerrett et al. (2009). As discussed above, study authors used April to September averages of 1-hour daily maximum O_3 concentrations as surrogates for "long-term" exposures.

analysis of data from several controlled human exposure studies, combined with exposure estimates developed for children and adults (U.S. EPA, 2007).

In the current review, the HREA estimates risks of lung function decrements in school-aged children (ages 5 to 18), asthmatic school-aged children, and the general adult population for 15 urban case study areas.[78] The results presented in the HREA are based on an updated dose-threshold model that estimates FEV_1 responses for individuals following short-term exposures to O_3 (McDonnell et al., 2012), reflecting methodological improvements since the last review (U.S. EPA, 2014, section 6.2.4; section 3.1.2.1, above). The impact of the dose threshold is that O_3-induced FEV_1 decrements result primarily from exposures on days with ambient O_3 concentrations above about 40 ppb (U.S. EPA, 2013, section 6.3.1, Figure 6-9).[79]

As discussed above (section 3.1.3), for effects such as lung function decrements, which are transient and reversible, aspects such as the likelihood that these effects would occur repeatedly and would interfere with normal activities are important to consider in making judgments about adversity to individuals. As stated in the 2006 Criteria Document (Table 8-3, p. 8-68), for people with lung disease even moderate functional responses (e.g., FEV_1 decrements $\geq$ 10% but < 20%) would likely interfere with normal activities for many individuals, and would likely result in more frequent medication use. Moreover, as noted above, in a recent letter to the Administrator, the CASAC O_3 Panel stated that "[c]linically relevant effects are decrements > 10%, a decrease in lung function considered clinically relevant by the American Thoracic Society" (Samet, 2011, p.2). The CASAC O_3 Panel also stated that:

> [A] 10% decrement in FEV_1 can lead to respiratory symptoms, especially in individuals with pre-existing pulmonary or cardiac disease. For example, people with chronic obstructive pulmonary disease have decreased ventilatory reserve (i.e., decreased baseline FEV_1) such that a $\geq$ 10% decrement could lead to moderate to severe respiratory symptoms (Samet, 2011, p.7).

Consistent with this advice from the last review, in the current review CASAC has concluded that "estimation of FEV_1 decrements of $\geq$15% is appropriate as a scientifically relevant surrogate for adverse health outcomes in active healthy adults, whereas an FEV_1 decrement of $\geq$10% is a scientifically relevant surrogate for adverse health outcomes for people with asthma and lung disease" (Frey, 2014, p. 3).

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[78] As noted for the exposure assessment above, the 15 cities assessed are Atlanta, Baltimore, Boston, Chicago, Cleveland, Dallas, Denver, Detroit, Houston, Los Angeles, New York, Philadelphia, Sacramento, St. Louis, and Washington, DC.

[79] **Error! Reference source not found.** in the HREA shows that more than 90% of daily instances of FEV_1 decrements $\geq$ 10% occur when 8-hr average ambient concentrations are above 40 ppb for 2006 air quality in Los Angeles. The distribution of decrements will be different for different study areas, years, and air quality scenarios (U.S. EPA, 2014, section 6.3.1).

In judging the extent to which moderate lung function decrements represent effects that should be regarded as adverse to the health status of individuals, in previous NAAQS reviews we have also considered the extent to which decrements were experienced repeatedly during the course of a year (U.S. EPA, 2007). Although some experts would judge single occurrences of moderate responses to be a ‘‘nuisance,’’ especially for healthy individuals,[80] a more general consensus view of the adversity of such moderate responses emerges as the frequency of occurrence increases. Thus in the past EPA has judged that repeated occurrences of moderate responses, even in otherwise healthy individuals, may be considered to be adverse since they could well set the stage for more serious illness (61 FR 65723). The CASAC panel in the 1997 NAAQS review expressed a consensus view that these "criteria for the determination of an adverse physiological response were reasonable" (Wolff, 1995).

The HREA estimates risks of moderate to large lung function decrements, defined as FEV_1 decrements $\geq$ 10%, $\geq$ 15%, or $\geq$ 20%. In evaluating these lung function risk estimates within the context of considering the adequacy of the current O_3 standard, we first consider the following specific question:

- **What are the nature and magnitude of lung function risks remaining upon just meeting the current O_3 standard?**

In considering risks of O_3-induced FEV_1 decrements, we focus on the percent of children estimated to experience decrements $\geq$ 10, 15, and 20%, noting that the percentage of asthmatic children estimated to experience such decrements is virtually indistinguishable from the percentage estimated for all children.[81] Compared to children, smaller percentages of adults are estimated to experience O_3-induced FEV_1 decrements (U.S. EPA, 2014, section 6.3.1, Table 6-4). As for exposures of concern (see above), the patterns of results across urban case study areas and over the years evaluated are similar in children and adults (U.S. EPA, 2014, Appendix 6E). Therefore, while we highlight estimates in children, we note that these results are also representative of the patterns estimated for adult populations.

Key results for children are summarized below for air quality adjusted to just meet the current O_3 NAAQS (Figures 3-11 to 3-14).[82] The estimates presented in Figures 3-11 to 3-14 below reflect consistent reductions across urban case study areas in the percent of children estimated to experience O_3-induced lung function decrements, relative to recent (i.e., unadjusted) air quality (U.S. EPA, 2014, Appendix 6B). When averaged over the years evaluated in the

[80]Though not all experts, as indicated by the advice received on this issue from past CASAC O_3 Panels (Samet, 2011).
[81] Though see below for discussion of uncertainty in lung function responses of children and asthmatics.
[82] Figures 3-11 and 3-12 present estimates of one or more decrements. Figures 3-13 and 3-14 present estimates of two or more decrements.

HREA, reductions of up to about 40% were estimated compared to recent air quality. These reductions reflect the consistent decreases in relatively high ambient O_3 concentrations upon adjustment to just meet the current standard (section 3.2.1 above; U.S. EPA, 2014, Chapter 4).[83] Such reductions in estimated lung function risks are evident throughout urban case study areas, including in urban cores and in surrounding areas (U.S. EPA, 2014, section 9.6). Figures 3-11 (Average over years) and 3-12 (Worst-Case Years) present estimates of one or more O_3-induced lung function decrements. Figures 3-13 (Average over years) and 3-14 (Worst-Case Years) present estimates of two or more decrements.

[83] As noted above, the impact of the dose threshold is that O_3-induced FEV_1 decrements result primarily from days with average ambient O_3 concentrations above about 40 ppb.

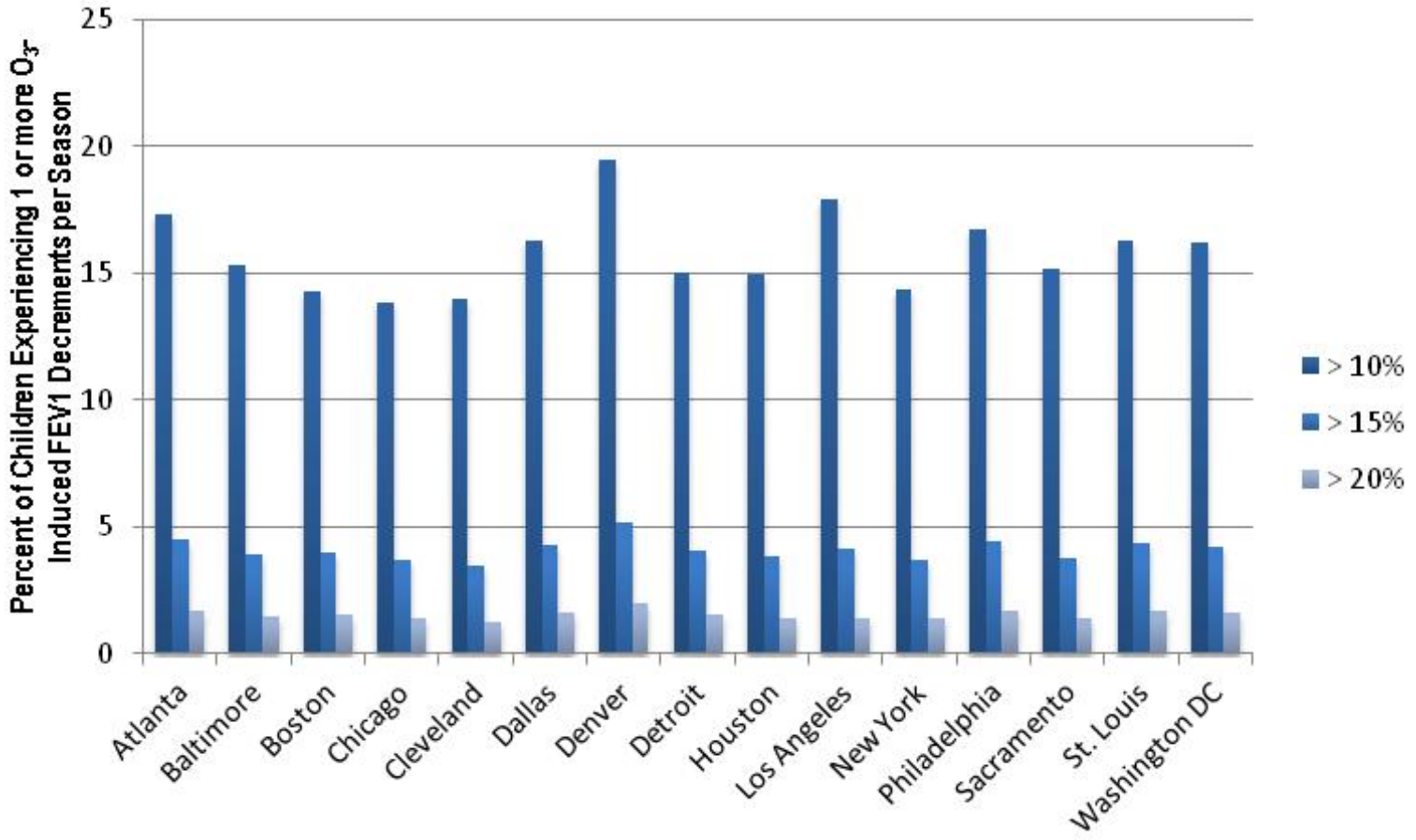

Figure 3-11. Percent of school-aged children (5-18 yrs) estimated to experience one or more days with FEV_1 decrements $\geq$ 10, 15, or 20% with air quality adjusted to just meet the current standard – Averaged over 2006 to 2010

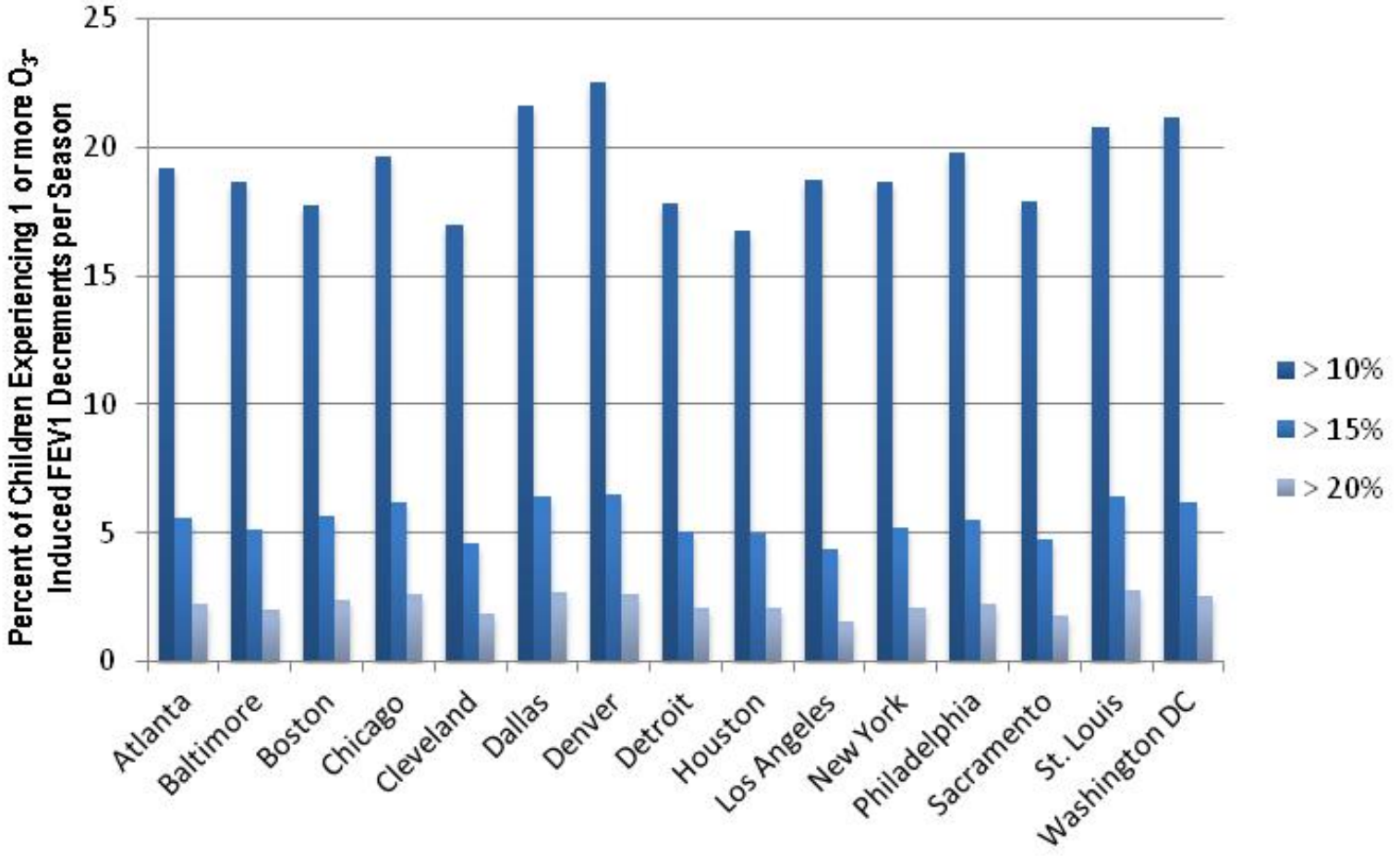

Figure 3-12. Percent of school-aged children (5-18 yrs) estimated to experience one or more days with FEV_1 decrements $\geq$ 10, 15, or 20% with air quality adjusted to just meet the current standard – Worst-Case Year from 2006 to 2010

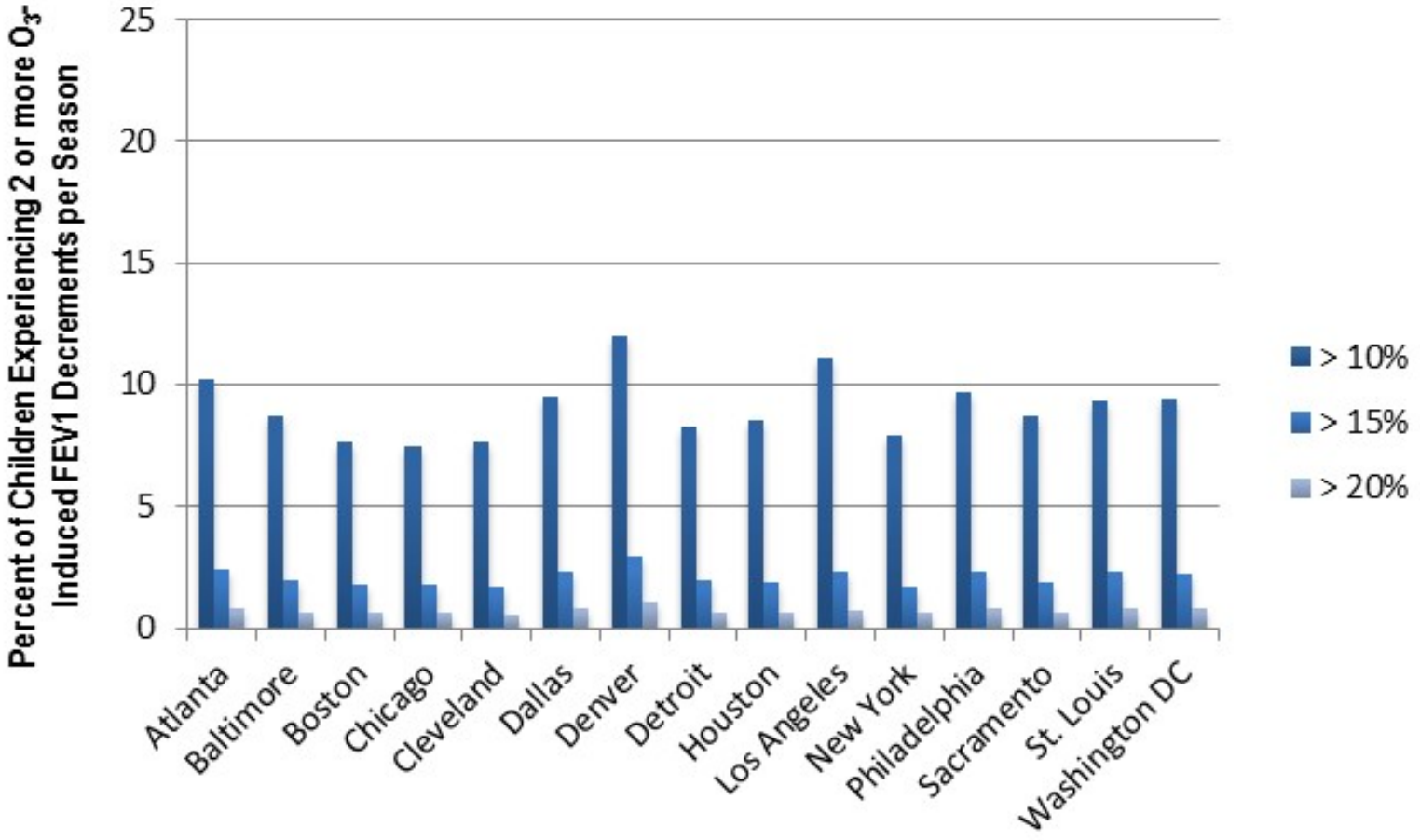

Figure 3-13. Percent of school-aged children (aged 5-18 yrs) estimated to experience two or more days with FEV_1 decrements $\geq$ 10, 15, or 20% with air quality adjusted to just meet the current standard – Averaged over 2006 to 2010

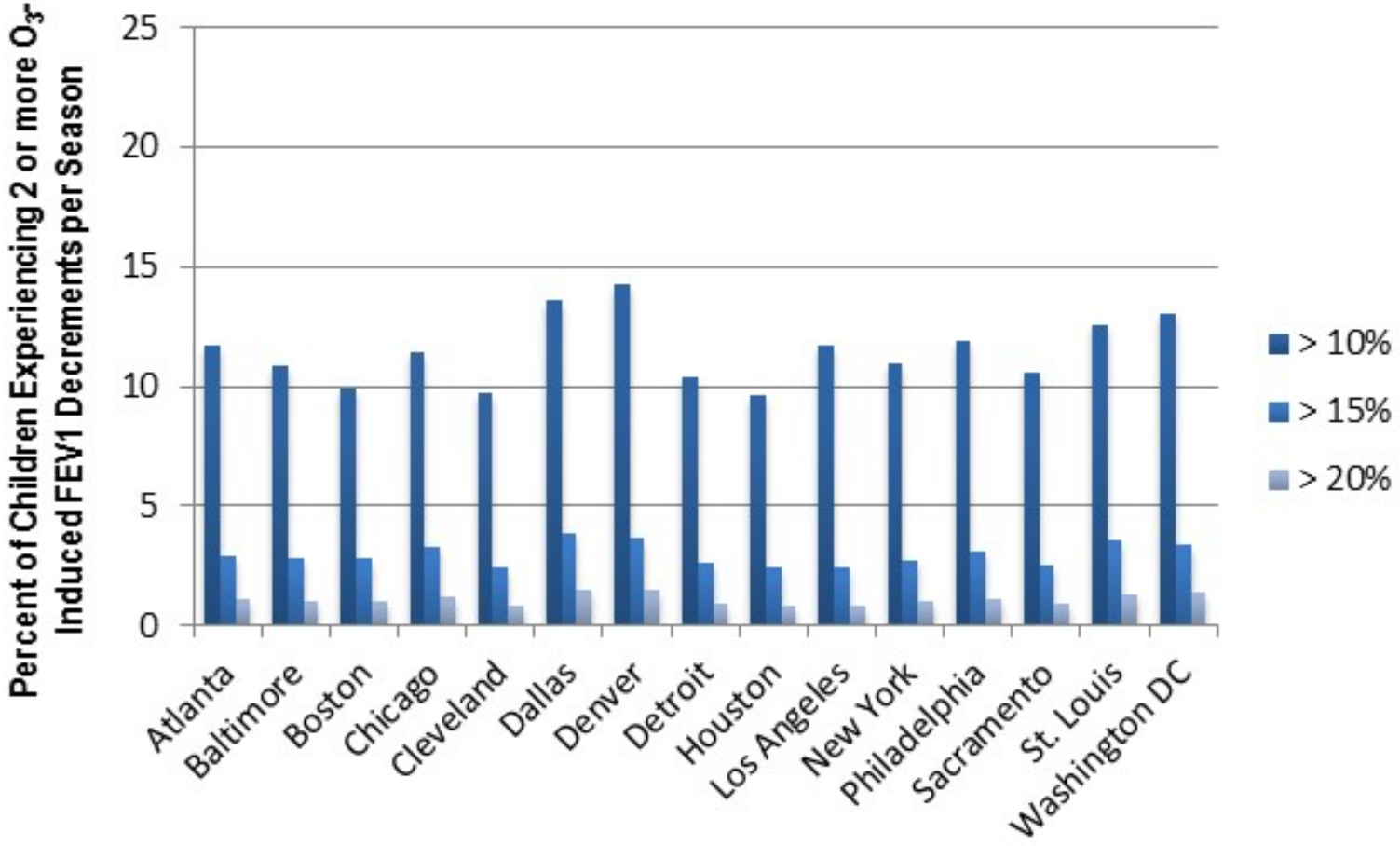

Figure 3-14. Percent of school-aged children (5-18 yrs) estimated to experience two or more days with FEV_1 decrements $\geq$ 10, 15, or 20% with air quality adjusted to just meet the current standard - Worst-Case Year from 2006 to 2010

Based on Figures 3-11 to 3-14 and the associated details described in the HREA (U.S. EPA, 2014, Chapter 6), we take note of the following with regard to lung function decrements estimated to be allowed by the current standard:

1. For FEV_1 decrements $\geq$ 10%:
   a. On average over the years 2006 to 2010, the current standard is estimated to allow approximately 14 to 19% of children in urban case study areas to experience one or more lung function decrements $\geq$ 10%. Summing across urban case study areas, this corresponds to approximately 3 million children experiencing 15 million O_3-induced lung function decrements $\geq$ 10% during a single O_3 season. Of these children, about 300,000 are asthmatics.

   b. On average over the years 2006 to 2010, the current standard is estimated to allow approximately 8 to 12% of children in urban case study areas to experience two or more O_3-induced lung function decrements $\geq$ 10%. Summing across the urban case study areas, this corresponds to almost 2 million children (including almost 200,000 asthmatic children) estimated to experience two or more O_3-induced lung function decrements greater than 10% during a single O_3 season.

   c. In the worst-case years, the current standard is estimated to allow approximately 17 to 22% of children in urban case study areas to experience one or more lung function decrements $\geq$ 10%, and approximately 10 to 14% to experience two or more O_3-induced lung function decrements $\geq$ 10%.

2. For FEV_1 decrements $\geq$ 15%:
   a. On average over the years 2006 to 2010, the current standard is estimated to allow approximately 3 to 5% of children in urban case study areas to experience one or more lung function decrements $\geq$ 15%. Summing across urban case study areas, this corresponds to over 750,000 children (including approximately 80,000 asthmatic children) estimated to experience at least one O_3-induced lung function decrement $\geq$ 15% during a single O_3 season.

   b. On average over the years 2006 to 2010, the current standard is estimated to allow approximately 2 to 3% of children in urban case study areas to experience two or more O_3-induced lung function decrements $\geq$ 15%.

   c. In the worst-case years, the current standard is estimated to allow approximately 4 to 7% of children in urban case study areas to experience one or more lung function decrements $\geq$ 15%, and approximately 2 to 4% to experience two or more O_3-induced lung function decrements $\geq$ 15%.

3. For FEV_1 decrements $\geq$ 20%:
   a. On average over the years 2006 to 2010, the current standard is estimated to allow approximately 1 to 2% of children in urban case study areas to experience one or more lung function decrements $\geq$ 20%. Summing across urban case study areas, this corresponds to almost 300,000 children (including approximately 30,000 asthmatic

children) estimated to experience at least one O_3-induced lung function decrement $\geq$ 20% during a single O_3 season.

b. On average over the years 2006 to 2010, the current standard is estimated to allow less than about 1% of children in urban case study areas to experience two or more O_3-induced lung function decrements $\geq$ 20%.

c. In the worst-case years, the current standard is estimated to allow approximately 2 to 3% of children to experience one or more lung function decrements $\geq$ 20%, and less than 2% to experience two or more O_3-induced lung function decrements $\geq$ 20%.

In further considering estimated lung function risks from the HREA, we next consider the following question:

- **What are the important sources of uncertainty associated with lung function risk estimates?**

In addition to the uncertainties noted above for exposure estimates, the HREA identifies several key uncertainties associated with estimates of O_3-induced lung function decrements. An uncertainty with particular potential to impact our consideration of risk estimates in this Policy Assessment stems from the lack of exposure-response information in children. In the absence of controlled human exposure data for children, risk estimates are based on the assumption that children exhibit the same lung function response following O_3 exposures as healthy 18 year olds (i.e., the youngest age for which controlled human exposure data is available) (U.S. EPA, 2014, section 6.5.3). This assumption was justified in part by the findings of McDonnell et al. (1985), who reported that children 8-11 year old experienced FEV_1 responses similar to those observed in adults 18-35 years old. In addition, as discussed in the ISA (U.S. EPA, 2013, section 6.2.1), summer camp studies of school-aged children reported O_3-induced lung function decrements similar in magnitude to those observed in controlled human exposure studies using adults. In extending the risk model to children, the HREA fixes the age term in the model at its highest value, the value for age 18. This approach could result in either over- or underestimates of O_3-induced lung function decrements in children, depending on how children compare to the adults used in controlled human exposure studies (U.S. EPA, 2014, section 6.5.3).

A related source of uncertainty is that the risk assessment estimates O_3-induced decrements in asthmatics using the exposure-response relationship developed from data collected from healthy individuals. Although the evidence has been mixed (U.S. EPA, 2013, section 6.2.1.1), several studies have reported larger O_3-induced lung function decrements in asthmatics than in non-asthmatics (Kreit et al., 1989; Horstman et al., 1995; Jorres et al., 1996; Alexis et al., 2000). Consistent with the findings of the ISA (U.S. EPA, 2013, section 6.2.1.1), CASAC noted that "[a]sthmatic subjects appear to be at least as sensitive, if not more sensitive, than non-asthmatic subjects in manifesting ozone-induced pulmonary function decrements" (Frey, 2014,

p. 4). To the extent asthmatics experience larger O_3-induced lung function decrements than the healthy adults used to develop exposure-response relationships, the HREA could underestimate the impacts of O_3 exposures on lung function in asthmatics, including asthmatic children. The HREA notes that the magnitude this uncertainty might have on risk estimates remains unknown at this time (U.S. EPA, 2014, section 6.5.4).

3.2.3.2 Estimated Health Risks Associated with Short- or Long-Term O_3 Exposures, Based on Epidemiologic Studies

Risk estimates based on epidemiologic studies can provide perspective on the most serious O_3-associated public health outcomes (e.g., mortality, hospital admissions, emergency department visits) in populations that often include at-risk groups. The HREA estimates O_3-associated risks in 12 urban case study areas[84] using concentration-response relationships drawn from epidemiologic studies. These concentration-response relationships are based on "area-wide" average O_3 concentrations.[85] The HREA estimates risks for the years 2007 and 2009 in order to provide estimates of risk for a year with generally higher O_3 concentrations (2007) and a year with generally lower O_3 concentrations (2009) (U.S. EPA, 2014, section 7.1.1).

In the last review, epidemiologic-based risks were estimated for O_3 concentrations above mean "policy-relevant background concentrations." As discussed above (Chapter 2), policy-relevant background (PRB) concentrations were defined as the distribution of ozone concentrations that would be observed in the U.S. in the absence of anthropogenic (man-made) emissions of ozone precursor emissions (e.g., VOC, CO, NOx) in the U.S., Canada, and Mexico. This approach provided a focus on O_3 concentrations "that can be controlled by U.S. regulations (or through international agreements with neighboring countries)" (U.S. EPA, 2007, pp. 2-48 to 2-54).

As in the last review, we recognize that ambient O_3 concentrations, and therefore O_3-associated health risks, result from precursor emissions from various types of sources. Based on the air quality modeling discussed above in chapter 2, approximately 30 to 60% of average daytime O_3 during the warm season (i.e., daily maximum 8-hour concentrations averaged from April to October) is attributable to precursor emissions from U.S. anthropogenic sources (section 2.4.4). The remainder is attributable to precursor emissions from international anthropogenic

[84] The 12 urban areas evaluated are Atlanta, Baltimore, Boston, Cleveland, Denver, Detroit, Houston, Los Angeles, New York, Philadelphia, Sacramento, and St. Louis.

[85] In the epidemiologic studies that provide the health basis for HREA risk assessments, concentration-response relationships are based on daytime O_3 concentrations, averaged across multiple monitors within study areas. These daily averages are used as surrogates for the spatial and temporal patterns of exposures in study populations. Consistent with this approach, the HREA epidemiologic-based risk estimates also utilize daytime O_3 concentrations, averaged across monitors, as surrogates for population exposures. In this PA, we refer to these averaged concentrations as "area-wide" O_3 concentrations. Area-wide concentrations are discussed in more detail in section 3.1.4, above.

sources and natural sources. Because the HREA characterizes health risks from all O_3, regardless of source, risk estimates reflect emissions from U.S. anthropogenic, international anthropogenic, and natural sources.

In evaluating epidemiology-based risk estimates within the context of the adequacy of the current standard, we first consider the following question:

- **What are the nature and magnitude of the O_3-associated mortality and morbidity risks remaining upon adjustment of air quality to just meet the current O_3 standard?**

In addressing this question, we note that the HREA estimates mortality and morbidity risks associated with just meeting the current standard by applying concentration-response relationships from epidemiologic studies to the entire distributions of adjusted "area-wide" average O_3 concentrations present in urban case study areas (U.S. EPA, 2014, Chapter 7). Implicit in this approach to estimating risks is the assumption that concentration-response relationships are linear over those distributions. Therefore, as noted in section 3.2.1, when air quality is adjusted to just meet the current standard, risk estimates are influenced by the decreases in area-wide O_3 concentrations at the upper ends of warm season distributions and the increases in area-wide O_3 concentrations at the lower ends of those distributions (U.S. EPA, 2014, section 4.3.3.2, Figures 4-9 and 4-10).[86] When the decreases and increases are of the same magnitude, they result in the same degree of change in estimated risks, though opposite in direction. Therefore, seasonal estimates of O_3-associated mortality and morbidity risks either increase or decrease in response to air quality adjustment, depending on the seasonal balance between the modeled daily decreases in high area-wide O_3 concentrations and increases in low area-wide O_3 concentrations. One consequence is that the estimated impacts on mortality and morbidity risks of adjusting air quality to just meet the current standard are more modest, and less directionally consistent across urban case study areas, than on either exposures of concern or O_3-induced lung function decrements.

In the remainder of this section, we consider estimates of total (non-accidental) mortality and respiratory morbidity associated with short-term O_3 concentrations, and respiratory mortality associated with "long-term" O_3 concentrations.

Total Mortality – Short-Term O_3

Risk estimates for total mortality are based on concentration-response relationships described by Smith et al. (2009). To generate risk estimates, the HREA uses "area-wide"

[86] On a given day, area-wide O_3 concentrations and estimated risks decrease when the sum of the changes at monitors with decreasing O_3 (e.g., downwind of important NO_X sources, where the highest O_3 concentrations often occur) are larger than the sum of the changes at monitors with increasing O_3 (e.g., often in urban centers with high concentrations of NO_X emissions, where ambient O_3 concentrations are suppressed and thus relatively low). Area-wide O_3 concentrations and estimated risks increase when the opposite occurs.

averages of daily maximum 8-hour O_3 concentrations over the full monitoring periods in urban case study areas. When 2007 air quality was adjusted to the current standard (the year with generally "higher" O_3-associated risks), 10 of 12 urban case study areas exhibited either decreases or virtually no change in estimates of the number of O_3-associated deaths (U.S. EPA, 2014, Appendix 7B). Increases were estimated in two of the urban case study areas (Houston, Los Angeles) (U.S. EPA, 2014, Appendix 7B).[87]

Figure 3-15 below presents estimates of O_3-associated all-cause mortality in urban case study areas for 2007 and 2009, with air quality adjusted to just meet the current O_3 standard. The HREA estimates that upon just meeting the current standard, O_3 could be associated with from 0.8 to 4.1% of all-cause mortality across the urban case study areas. This corresponds to approximately 60 to 3,200 O_3-associated deaths per season in individual urban case study areas, and approximately 7,000 to 7,500 O_3-associated deaths per season summed over the 12 urban case study areas (U.S. EPA, 2014, Tables 7-7 and 7-8).

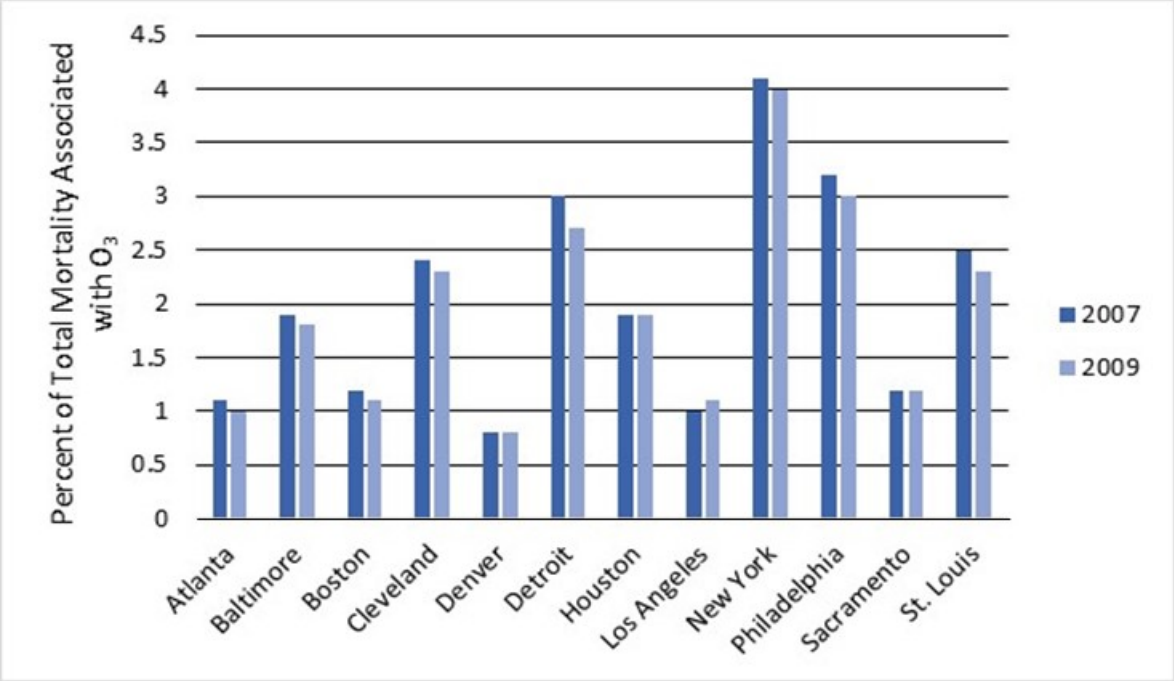

Figure 3-15. Percent of all-cause mortality associated with O_3 for air quality adjusted to just meet the current standard.

In considering the risk estimates presented in Figure 3-15, which are based on applying linear concentration-response relationships to the full distributions of daily 8-hour "area-wide"

[87] For 2009 (i.e., the year with generally lower O_3 concentrations), changes in risk were generally smaller than in 2007 (i.e., most changes about 2% or smaller). Increases were estimated for Houston, Los Angeles, and New York City.

O_3 concentrations, we note the ISA conclusion that there is less certainty in the shape of concentration-response functions for area-wide O_3 concentrations at the lower ends of warm season distributions (i.e., below about 20 to 40 ppb depending on the O_3 metric, health endpoint, and study population) (U.S. EPA, 2013, section 2.5.4.4). We also recognize that for the range of health endpoints evaluated, controlled human exposure and animal toxicological studies provide greater certainty in the increased incidence, magnitude, and severity of effects at higher exposure concentrations (discussed in sections 3.1.2.2 and 3.1.4.2, above).[88] Thus, in addition to considering estimates of total O_3-associated risks, we also consider the extent to which risks are associated with days with higher, versus lower, area-wide O_3 concentrations.

Figure 3-16 presents risk estimates, summed across urban case study areas, for days with area-wide concentrations at or above 20, 40, and 60 ppb. Daytime O_3 concentrations in the upper portion of the distribution of area-wide concentrations (e.g., at or above 40 or 60 ppb) are estimated to be associated with hundreds to thousands of deaths per year in urban case study areas.[89]

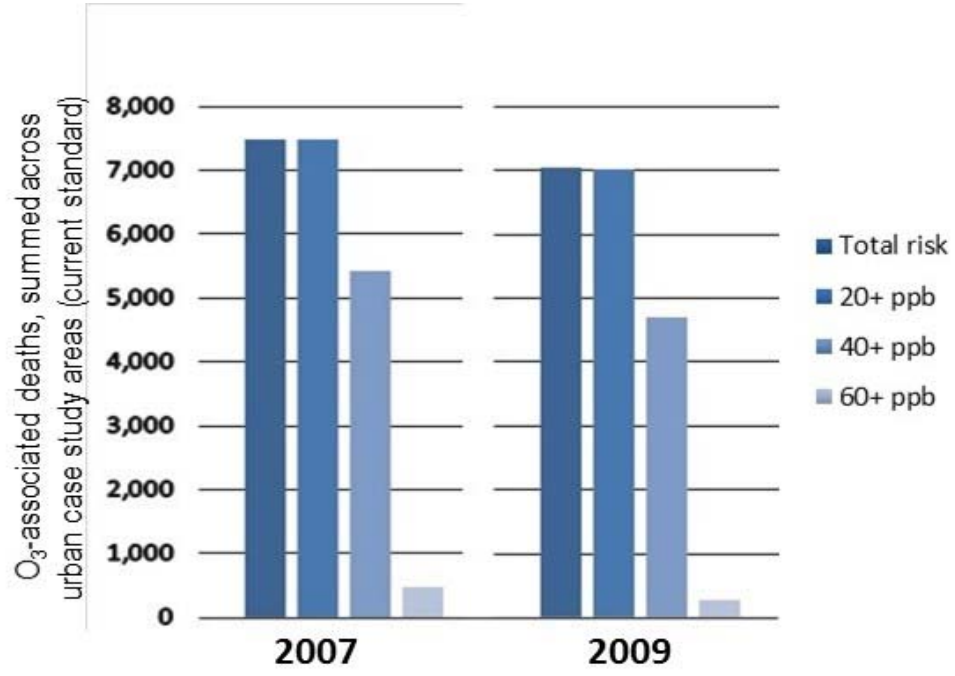

Figure 3-16. Estimated O_3-associated deaths attributable to various area-wide average O_3 concentrations, with air quality adjusted to just meet current standard.

[88] As discussed in section 3.1.4.2, as ambient concentrations increase the potential for exposures to higher O_3 concentrations also increases. Thus with increasing ambient concentrations, controlled human exposure and animal toxicological studies support the increased incidence, magnitude, and severity of O_3-attributable effects.

[89] The relatively small proportion of O_3-associated deaths attributable to days with area-wide concentrations of 60 ppb or greater reflects the relatively small proportion of days with such elevated area-wide concentrations.

Respiratory Mortality – "Long-Term" O_3

The HREA estimates the risk of respiratory mortality associated with long-term O_3 exposures, based on the study by Jerrett et al. (2009) (U.S. EPA, 2014, Chapter 7). As discussed above (section 3.1.4.3), Jerrett et al. (2009) reported that when seasonal averages of 1-hour daily maximum O_3 concentrations ranged from 33 to 104 ppb, there was no statistically significant deviation from a linear concentration-response relationship between O_3 and respiratory mortality across 96 U.S. cities (U.S. EPA, 2013, section 7.7). However, the authors reported "limited evidence" for an effect threshold at an O_3 concentration of 56 ppb (p=0.06). In communications with EPA staff (described in Sasser, 2014), the study authors indicated that it is not clear whether a threshold model is a better predictor of respiratory mortality than the linear model, and that "considerable caution should be exercised in accepting any specific threshold." Consistent with this communication, the HREA estimated respiratory mortality associated with long-term O_3 concentrations based on the linear model from the published study, and in a series of sensitivity analyses with models that included thresholds ranging from 40 to 60 ppb (U.S. EPA, 2014, Figure 7-9).

To generate risk estimates, the HREA uses "area-wide" averages of 1-hour daily maximum O_3 concentrations during the warm season (April to September). When 2007 air quality was adjusted to just meet the current standard (i.e., the year with generally higher O_3 concentrations) all 12 of the urban case study areas exhibited decreases in estimated O_3-associated respiratory mortality (i.e., compared to recent, unadjusted air quality). For 2009 adjusted air quality (i.e., the year with generally lower O_3 concentrations), urban case study areas exhibited either no change in estimated risk, or decreases in risk that were smaller than those for 2007 (U.S. EPA, 2014, Appendix 7B, Tables 7B-6 and 7B-7). Risk estimates based on the linear model, for air quality adjusted to just meet the current standard, are presented below in Figure 3-17.

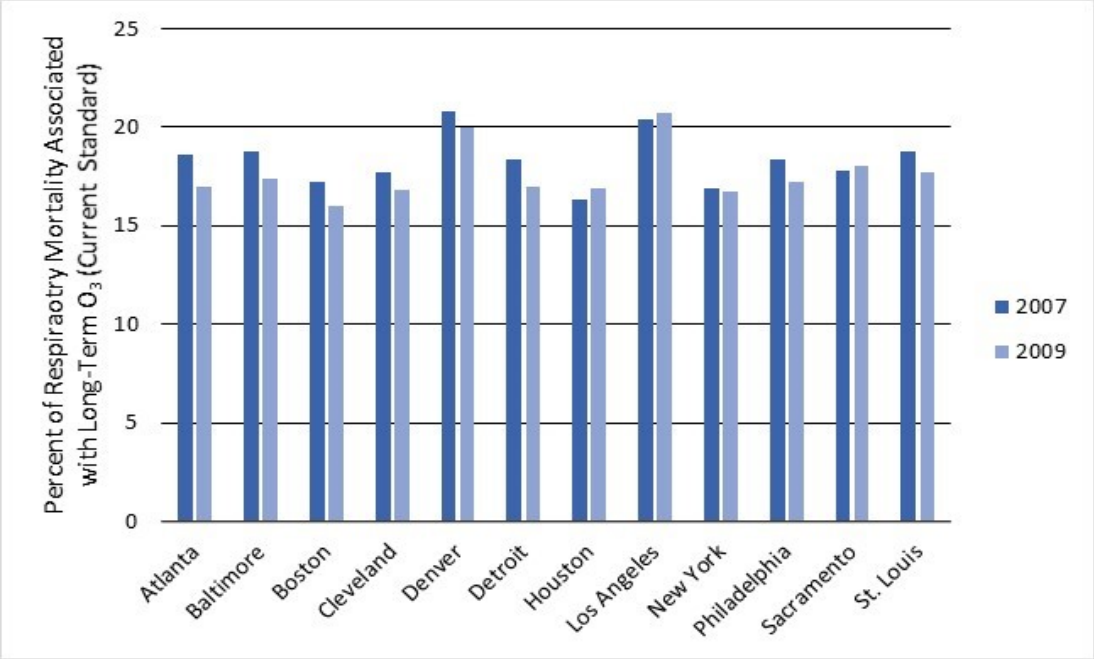

Figure 3-17. Percent of baseline respiratory mortality estimated to be associated with long-term O_3.

Based on a concentration-response function that is linear over the entire distribution of long-term O_3 concentrations, O_3 is estimated to be associated with approximately 16 to 21% of respiratory deaths in urban case study areas during the warm season. This corresponds to approximately 300 to 2,100 O_3-associated deaths per season in individual urban case study areas, and a total of approximately 8,000 to 9,000 O_3-associated deaths summed across all 12 case study areas. Based on threshold models, HREA sensitivity analyses indicate that the number of respiratory deaths associated with long-term O_3 concentrations could potentially be considerably lower (i.e., by more than 75% if a threshold exists at 40 ppb, and by about 98% if a threshold exists at 56 ppb) (U.S. EPA, 2014, Figure 7-9).

Hospital Admissions, Emergency Department Visits, and Asthma Exacerbations

Risk estimates for respiratory-related hospital admissions, emergency department visits, and asthma exacerbations associated with air quality adjusted to just meet the current standard are based on several studies, as presented in Table 7-2 of the HREA (U.S. EPA, 2014).[90] Estimates indicate that O_3-associated respiratory-related hospital admissions generally account for approximately 2 to 3% of total respiratory-related admissions in urban case study locations. Depending on the city, this corresponds to 10's to 100's of O_3-associated hospital admissions per season. Estimates indicate that O_3-associated respiratory-related emergency department visits

[90]As with respiratory mortality above, the HREA does not characterize distributions of respiratory morbidity risks over distributions of ambient O_3 concentrations. Therefore, in considering respiratory morbidity risks we evaluate estimates of total risk.

account for approximately 3 to 20% of total respiratory-related emergency department visits in Atlanta and New York City (corresponding to thousands of visits per season in these two cities), and that O_3-associated asthma exacerbations account for approximately 15 to 30% of total exacerbations in Boston (30,000 to 80,000 exacerbations per season). Full estimates are presented in Tables 7-9 to 7-11 in the HREA (U.S. EPA, 2014).

Based on the detailed information presented in Chapter 7 of the HREA (U.S. EPA, 2014), we note the following key observations:

1. In focusing on total risk, the current standard is estimated to allow thousands of O_3-associated deaths per year in the urban case study areas. These estimates are based on concentration-response functions from epidemiologic studies that used either 8-hour daily O_3 concentrations (total mortality associated with short-term O_3) or seasonal averages of 1-hour daily O_3 concentrations (respiratory mortality associated with long-term O_3).

2. In focusing on the risks associated with the upper portions of distributions of ambient concentrations, the current standard is estimated to allow hundreds to thousands of O_3-associated deaths per year in the urban case study areas. These estimates are based on concentration-response functions from an epidemiologic study that evaluated associations between 8-hour daily O_3 concentrations and total mortality.

3. In urban case study areas, the current standard is estimated to allow tens to thousands of O_3-associated morbidity events per year. Distributions of O_3-associated morbidity over distributions of ambient O_3 concentrations would likely be similar to mortality, though the HREA did not analyze such distributions for morbidity endpoints.

In further considering estimated O_3-associated mortality and morbidity risks from the HREA, we next consider the following question:

- **What are the important sources of uncertainty associated with mortality and morbidity risk estimates?**

Compared to estimates of O_3 exposures of concern and estimates of O_3-induced lung function decrements (discussed above), the HREA conclusions reflect somewhat lower confidence in epidemiologic-based risk estimates, given important uncertainties. In particular, the HREA highlights the unexplained heterogeneity in effect estimates between locations, the potential for exposure measurement errors, and uncertainty in the interpretation of the shape of concentration-response functions at lower O_3 concentrations (U.S. EPA, 2014, section 9.6). The HREA also concludes that lower confidence should be placed in the results of the assessment of respiratory mortality risks associated with long-term O_3 exposures, primarily because that analysis is based on only one study (even though that study is well-designed) and because of the uncertainty in that study about the existence and level of a potential threshold in the concentration-response function (U.S. EPA, 2014, section 9.6). This section discusses some of the key uncertainties in epidemiologic-based risk estimates, with a focus on uncertainties that can

have particularly important implications for our consideration of epidemiology-based risk estimates in this PA

Estimating air quality that just meets the current standard based on modeled responses to reductions in NO_X emissions generally reduces O_3-associated mortality and morbidity risks in locations and time periods with relatively high ambient O_3 concentrations and increases risks in locations and time periods with relatively low concentrations. When evaluating uncertainties in epidemiologic risk estimates, it is important to consider the extent to which the pattern of air quality changes in response to reductions in NO_X emissions is representative of trends in ambient O_3; the extent to which estimated changes in risks in urban case study areas are representative of the changes that would be experienced broadly across the U.S. population; and the extent to which the O_3 response to reductions in precursor emissions could differ with emissions reduction strategies that are different from those used in REA risk estimates.

To evaluate the first issue, the HREA conducted a national analysis evaluating trends in monitored ambient O_3 concentrations during a time period when the U.S. experienced large-scale reductions in NO_X emissions (i.e., 2001 to 2010). Analyses of trends in monitored O_3 indicate that over such a time period, the upper end of the distribution of monitored O_3 concentrations (i.e., indicated by the 95th percentile) generally decreased in urban and non-urban locations across the U.S. (U.S. EPA, 2014, Figure 8-29). During this same time period, median O_3 concentrations decreased in suburban and rural locations, and in some urban locations. However, median concentrations increased in some large urban centers (U.S. EPA, 2014, Figure 8-28). As discussed in the REA, and above (II.C.1), these increases in median concentrations likely reflect the increases in relatively low O_3 concentrations that can occur near important sources of NO_X upon reductions in NO_X emissions (U.S. EPA, 2014, section 8.2.3.1). These patterns of monitored O_3 during a period when the U.S. experienced large reductions in NO_X emissions are qualitatively consistent with the modeled responses of O_3 to reductions in NO_X emissions.

To evaluate the second issue, the HREA conducted national air quality modeling analyses. These analyses estimated the proportion of the U.S. population living in locations where seasonal averages of daily O_3 concentrations are estimated to decrease in response to reductions in NO_X emissions, and the proportion living in locations where such seasonal averages are estimated to increase. Given the strong relationship between changes in seasonal averages of daily O_3 concentrations and changes in seasonal risk estimates, this analysis informs consideration of the extent to which the risk results in urban case study areas represent the U.S. population as a whole. This representativeness analysis indicates that the 12 urban case study areas may not represent the response of O_3 in other populated areas of the U.S., including suburban areas, smaller urban areas, and rural areas. This analysis also indicates that the majority of the U.S. population lives in locations where reducing NO_X emissions would be expected to

result in decreases in warm season averages of daily maximum 8-hour ambient O_3 concentrations. One implication of these results is that HREA risk estimates for the urban case study areas may understate the average reduction in O_3-associated mortality and morbidity risk that would be experienced across the U.S. population upon reducing NO_X emissions (U.S. EPA, 2014, sections 8.2.3.2 and 8.4).

To evaluate the third issue, the HREA assesses the O_3 air quality response to reducing both NO_X and VOC (i.e., in addition to assessing reductions in NO_X emissions alone) for a subset of seven urban case study areas. As noted above (section 3.2.1), in most of these urban case study areas the inclusion of VOC emissions reductions did not alter the NO_X emissions reductions required to meet the current or alternative standards.[91] However, the addition of VOC reductions generally resulted in larger decreases in mid-range O_3 concentrations (25^{th} to 75^{th} percentiles) (U.S. EPA, 2014, Appendix 4D, section 4D-4.7).[92] In addition, in all seven of the urban case study areas evaluated, the increases in low O_3 concentrations were smaller for the NO_X/VOC scenarios than the NO_X alone scenarios (U.S. EPA, 2014, Appendix 4D, section 4D-4.7). This was most apparent for Denver, Houston, Los Angeles, New York, and Philadelphia. Given the impacts on total risk estimates of increases in low O_3 concentrations, these results suggest that in some locations better-optimized emissions reduction strategies could result in larger reductions in O_3-associated mortality and morbidity than indicated in the HREA core estimates.

Section 7.4 of the HREA also highlights some additional uncertainties associated with epidemiologic-based risk estimates (U.S. EPA, 2014). This section of the HREA identifies and discusses sources of uncertainty and presents a qualitative evaluation of key parameters that can introduce uncertainty into risk estimates (U.S. EPA, 2014, Table 7-4). For several of these parameters the HREA also presents quantitative sensitivity analyses (U.S. EPA, 2014, section 7.5.3). Of the uncertainties discussed in Chapter 7 of the HREA, those related to the application of concentration-response functions from epidemiologic studies can have particularly important implications for our consideration of epidemiology-based risk estimates in this PA, as discussed below.

An important uncertainty is the shape of concentration-response functions at low ambient O_3 concentrations (U.S. EPA, 2014, Table 7-4).[93] Consistent with the ISA conclusion that there

[91] The exception is Chicago and Denver, for which the HREA risk estimates are based on reductions in both NO_X and VOC (U.S. EPA, 2014, section 4.3.3.1). Emissions of NO_X and VOC were reduced by equal percentages, a scenario not likely to reflect the optimal combination for reducing risks.

[92] This was the case for all of the urban case study areas evaluated, with the exception of New York (U.S. EPA, 2014, Appendix 4D, section 4D-4.7).

[93] A related uncertainty is the existence, or not, of a threshold. The HREA addresses this issue for long-term O_3 by evaluating risks in models that include potential thresholds (see above).

is no discernible population threshold in O_3-associated health effects, the HREA estimates epidemiology-based mortality and morbidity risks for entire distributions of ambient O_3 concentrations, with the assumption that concentration-response relationships remain linear over those distributions. In addition, in recognition of the ISA conclusion that certainty in the shape of O_3 concentration-response functions decreases at low ambient concentrations, the HREA also estimates distributions of total mortality incidence for various portions of the distribution of ambient O_3 concentrations. In this PA, we consider both types of risk estimates while recognizing that we have greater certainty in the increased incidence and severity of O_3-attributable effects at higher ambient O_3 concentrations (which drive higher exposure concentrations, section 3.2.2 above), as compared to lower concentrations.[94]

The HREA also notes important uncertainties associated with using a concentration-response relationship developed for a particular population in a particular location to estimate health risks in different populations and locations (U.S. EPA, 2014, Table 7-4). As discussed above, concentration-response relationships derived from epidemiologic studies reflect the spatial and temporal patterns of population exposures during the study. The HREA applies concentration-response relationships from epidemiologic studies to adjusted air quality in study areas that are different from, and often larger in spatial extent than, the areas used to generate the relationships. This approach ensures the inclusion of the actual non-attainment monitors that often determine the magnitude of emissions reductions for the air quality adjustments throughout the urban case study areas. This approach also allows the HREA to estimate patterns of health risks more broadly across a larger area, including a broader range of air quality concentrations and a larger population. The HREA notes that it is not possible to quantify the impacts of this uncertainty on risk estimates in most urban case study locations, though the HREA notes that mortality effect estimates for different portions of the New York City CBSA-based assessment area vary by a factor of almost 10 (U.S. EPA, 2014, section 7.5.3).

An additional, related uncertainty is that associated with applying concentration-response functions from epidemiologic studies to adjusted air quality. Concentration-response functions from the O_3 epidemiologic studies used in the HREA are based on associations between day to day variation in "area-wide" O_3 concentrations (i.e., averaged across multiple monitors) and variation in health effects. Epidemiologic studies use these area-wide O_3 concentrations, which reflect the particular spatial and temporal patterns of ambient O_3 present in study locations, as surrogates for the pattern of O_3 exposures experienced by study populations. To the extent adjusting O_3 concentrations to just meet the current standard results in important alterations in

[94] As discussed above, we also consider the potential implications of the existence of a threshold in the association between long-term O_3 and respiratory mortality.

the spatial and/or temporal patterns of ambient O_3, there is uncertainty in the appropriateness of applying concentration-response functions from epidemiologic studies to estimate health risks associated with adjusted O_3 air quality.[95] In particular, this uncertainty could be important to the extent that (1) factors associated with space modify the effects of O_3 on health or (2) spatial mobility is a key driver of individual-level exposures. Although the impact of this uncertainty on risk estimates cannot be quantified (U.S. EPA, 2014, Table 7-4), it has the potential to become more important as air quality adjustment results in larger changes in spatial and temporal patterns of ambient O_3 concentrations across urban case study areas.

There is also uncertainty related specifically to the public health importance of the increases in relatively low O_3 concentrations following air quality adjustment. This uncertainty relates to the fact that HREA risk estimates are equally influenced by decreasing high concentrations and increasing low concentrations, when the increases and decreases are of equal magnitude. Even on days with increases in relatively low area-wide average concentrations, resulting in increases in estimated risks, some portions of the urban case study areas could experience decreases in high O_3 concentrations. To the extent it is reasonable to conclude that O_3-attributable effects are more strongly supported for higher ambient concentrations (see above), likely resulting in higher exposure concentrations for some portions of study areas, the impacts on risk estimates of increasing low O_3 concentrations reflect an important source of uncertainty.

The use of a national concentration-response function to estimate respiratory mortality associated with long-term O_3 is a source of uncertainty. Risk estimates generated in sensitivity analyses using region-specific effect estimates differ substantially from the core estimates based on a single national-level effect estimate (U.S. EPA, 2014; Table 7-14). Furthermore, the risk estimates generated using the regional effect estimates display considerable variability across urban case study areas (U.S. EPA, 2014; Table 7-14), reflecting the substantial variability in the underlying effect estimates (see Jerrett et al., 2009, Table 4). While the results of the HREA sensitivity analyses evaluating this uncertainty point to the potential for regional heterogeneity in the long-term risk estimates, the relatively large confidence intervals associated with regional effect estimates resulted in the HREA conclusion that staff does not have confidence in the regionally-based risk estimates themselves.

Finally, we note the HREA does not quantify any reductions in risk that could be associated with reductions in the ambient concentrations of pollutants other than O_3, resulting from control of NO_X. For example as discussed in chapter 2 of this PA, NO_x emissions contribute to ambient NO_2, and NO_x and VOCs can contribute to secondary formation of $PM_{2.5}$

[95] As discussed above (section 3.2.1), decreasing modeled NO_X emissions to just meet the current standard can dramatically alter the spatial and temporal patterns of ambient O_3 concentrations across urban case study areas.

constituents, including ammonium sulfate (NH_4SO_4), ammonium nitrate (NH_4NO_3), and organic carbon (OC). Therefore, at some times and in some locations, control strategies that would reduce NO_X emissions (i.e., to meet an O_3 standard) could reduce ambient concentrations of NO_2 and $PM_{2.5}$, resulting in health benefits beyond those directly associated with reducing ambient O_3 concentrations.[96]

3.3 CASAC ADVICE AND PUBLIC COMMENTERS' VIEWS ON THE ADEQUACY OF THE CURRENT STANDARD

Beyond the evidence- and risk/exposure-based information discussed above, staff has also taken into account the comments and advice of CASAC, based on their reviews of the ISA, the HREA and PA, as well as comments provided by public commenters. The range of views summarized here generally reflects differing judgments as to the relative weight to place on various types of evidence, the exposure- and risk-based information, and the associated uncertainties, as well as differing judgments about the importance of various O_3-related health effects from a public health perspective.

Following the 2008 decision to revise the primary O_3 standard by setting the level at 0.075 ppm (75 ppb), CASAC strongly questioned whether the standard met the requirements of the CAA, further described below. In September 2009, EPA announced its intention to reconsider the 2008 standards, issuing a notice of proposed rulemaking in January 2010 (FR 75 2938). Soon after, EPA solicited CASAC review of that proposed rule and in January 2011 solicited additional advice. This proposal was based on the scientific and technical record from the 2008 rulemaking, including public comments and CASAC advice and recommendations. As further described in section 1.2.2 above, EPA in the fall of 2011 did not revise the standard as part of the reconsideration process but decided to coordinate further proceedings on the reconsideration rulemaking with this ongoing periodic review. Accordingly, in this section we describe CASAC's advice related to the 2008 final decision and the subsequent reconsideration, as well as its advice on the NAAQS review that was initiated in September 2008.

In April 2008, the members of the CASAC Ozone Review Panel sent a letter to EPA stating "[I]n our most-recent letters to you on this subject—dated October 2006 and March 2007—the CASAC unanimously recommended selection of an 8-hour average Ozone NAAQS within the range of 0.060 to 0.070 parts per million [60 to 70 ppb] for the primary (human health-based) Ozone NAAQS" (Henderson, 2008). The letter continued:

[96] We expect little focus by states on controlling NO_X for purposes of controlling $PM_{2.5}$ given the more efficient control of $PM_{2.5}$ through reduction of SO_2 and direct $PM_{2.5}$ emissions in most locations. Thus, consideration in this review of reductions in ambient $PM_{2.5}$ resulting from putative NO_X control would not double-count $PM_{2.5}$ emission reductions.

The CASAC now wishes to convey, by means of this letter, its additional, unsolicited advice with regard to the primary and secondary Ozone NAAQS. In doing so, the participating members of the CASAC Ozone Review Panel are unanimous in strongly urging you or your successor as EPA Administrator to ensure that these recommendations be considered during the next review cycle for the Ozone NAAQS that will begin next year … numerous medical organizations and public health groups have also expressed their support of these CASAC recommendations' … [The CASAC did] not endorse the new primary ozone standard as being sufficiently protective of public health. The CASAC—as the Agency's statutorily-established science advisory committee for advising you on the national ambient air quality standards—unanimously recommended decreasing the primary standard to within the range of 0.060–0.070 ppm [60 to 70 ppb]. It is the Committee's consensus scientific opinion that your decision to set the primary ozone standard above this range fails to satisfy the explicit stipulations of the Clean Air Act that you ensure an adequate margin of safety for all individuals, including sensitive populations.

In response to EPA's solicitation of their advice on the Agency's proposed rulemaking as part of the reconsideration, CASAC conveyed support (Samet, 2011).

CASAC fully supports EPA's proposed range of 0.060 – 0.070 parts per million (ppm) for the 8-hour primary ozone standard. CASAC considers this range to be justified by the scientific evidence as presented in the Air Quality Criteria for Ozone and Related Photochemical Oxidants (March 2006) and Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper (July 2007). As stated in our letters of October 24, 2006, March 26, 2007 and April 7, 2008 to former Administrator Stephen L. Johnson, CASAC unanimously recommended selection of an 8-hour average ozone NAAQS within the range proposed by EPA (0.060 to 0.070 ppm). In proposing this range, EPA has recognized the large body of data and risk analyses demonstrating that retention of the current standard would leave large numbers of individuals at risk for respiratory effects and/or other significant health impacts including asthma exacerbations, emergency room visits, hospital admissions and mortality.

In response to EPA's request for additional advice on the reconsideration in 2011, CASAC reaffirmed their conclusion that "the evidence from controlled human and epidemiological studies strongly supports the selection of a new primary ozone standard within the 60 – 70 ppb range for an 8-hour averaging time" (Samet, 2011). As requested by EPA, CASAC's advice and recommendations were based on the scientific and technical record from the 2008 rulemaking. In considering the record for the 2008 rulemaking, CASAC stated the following to summarize the basis for their conclusions (Samet, 2011, pp. ii to iii).

- *The evidence available on dose-response for effects of ozone shows associations extending to levels within the range of concentrations currently experienced in the United States.*

- *There is scientific certainty that 6.6-hour exposures with exercise of young, healthy, non-smoking adult volunteers to concentrations ≥ 80 ppb cause clinically relevant decrements of lung function.*
- *Some healthy individuals have been shown to have clinically relevant responses, even at 60 ppb.*
- *Since the majority of clinical studies involve young, healthy adult populations, less is known about health effects in such potentially ozone sensitive populations as the elderly, children and those with cardiopulmonary disease. For these susceptible groups, decrements in lung function may be greater than in healthy volunteers and are likely to have a greater clinical significance.*
- *Children and adults with asthma are at increased risk of acute exacerbations on or shortly after days when elevated ozone concentrations occur, even when exposures do not exceed the NAAQS concentration of 75 ppb.*
- *Large segments of the population fall into what EPA terms a "sensitive population group,'' i.e., those at increased risk because they are more intrinsically susceptible (children, the elderly, and individuals with chronic lung disease) and those who are more vulnerable due to increased exposure because they work outside or live in areas that are more polluted than the mean levels in their communities.*

With respect to evidence from epidemiologic studies, CASAC stated "while epidemiological studies are inherently more uncertain as exposures and risk estimates decrease (due to the greater potential for biases to dominate small effect estimates), specific evidence in the literature does not suggest that our confidence on the specific attribution of the estimated effects of ozone on health outcomes differs over the proposed range of 60-70 ppb." (Samet, 2011, p. 10).

Following their review of the second draft PA in the current review, which considers an updated scientific and technical record since the 2008 rulemaking, CASAC concluded that "there is clear scientific support for the need to revise the standard" (Frey, 2014, p. ii). In particular, CASAC noted the following (Frey, 2014, p. 5):

> *[T]he scientific evidence provides strong support for the occurrence of a range of adverse respiratory effects and mortality under air quality conditions that would meet the current standard. Therefore, CASAC unanimously recommends that the Administrator revise the current primary ozone standard to protect public health.*

In supporting these conclusions, CASAC judged that the strongest evidence comes from controlled human exposure studies of respiratory effects. The Committee specifically noted that "the combination of decrements in FEV_1 together with the statistically significant alterations in symptoms in human subjects exposed to 72 ppb ozone meets the American Thoracic Society's definition of an adverse health effect" (Frey, 2014, p. 5). CASAC further judged that "the level at

which adverse effects might be observed would likely be lower for more sensitive subgroups, such as those with asthma" (Frey, 2014, p. 5).

With regard to lung function risk estimates based on information from controlled human exposure studies, CASAC concluded that "estimation of FEV1 decrements of ≥15% is appropriate as a scientifically relevant surrogate for adverse health outcomes in active healthy adults, whereas an FEV1 decrement of ≥10% is a scientifically relevant surrogate for adverse health outcomes for people with asthma and lung disease" (Frey, 2014, p. 3). The Committee further concluded that "[a]sthmatic subjects appear to be at least as sensitive, if not more sensitive, than non-asthmatic subjects in manifesting O_3-induced pulmonary function decrements" (Frey, 2014, p. 4). In considering estimates of the occurrence of these decrements in urban case study areas, CASAC specifically noted that the current standard is estimated to allow 11 to 22% of school age children to experience at least one day with an FEV_1 decrement ≥ 10%.

While CASAC judged that controlled human exposure studies of respiratory effects provide the strongest evidence supporting their conclusion on the current standard, the Committee judged that there is also "sufficient scientific evidence based on epidemiologic studies for mortality and morbidity associated with short-term exposure to ozone at the level of the current standard" (Frey, 2014, p. 5). In support of the biological plausibility of the associations reported in these epidemiologic studies, CASAC noted that "[r]ecent animal toxicological studies support identification of modes of action and, therefore, the biological plausibility associated with the epidemiological findings" (Frey, 2014, p. 5).

Consistent with the advice of CASAC, several public commenters supported revising the primary O_3 standard to provide increased public health protection. In considering the available evidence as a basis for their views, these commenters generally noted that the health evidence is stronger in the current review than in past reviews. These commenters often noted that causal determinations were strengthened to "likely causal" for total mortality and cardiovascular effects from short-term O_3 exposures, and for respiratory effects from long-term O_3 exposures. These commenters also noted the increase in controlled human exposure studies showing lung function decrements and new evidence of inflammation in healthy young adults at 60 ppb O_3, as well as the increase in the number of epidemiologic studies showing consistent, positive associations between O_3 exposures and hospital admissions, emergency department visits, and premature mortality. Some commenters noted that children have long been known to be more vulnerable than adults to the effects of air pollution due to ongoing lung development, the greater permeability of their airways epithelial layer, and greater resting minute ventilation (when normalized to body mass or lung volume) resulting in increased exposure compared with adults. These commenters noted that adverse effects have been described on early lung development and the evidence for O_3 as a contributor to childhood respiratory disease is extremely strong. They

expressed the view that O_3 in particular has long been known to induce asthma exacerbations in children and, in one well characterized population-based cohort study in California, exposure to ozone was associated with the development of asthma. Some commenters expressed the view that young children and small infants should be included in the exposure and risk assessment. Other commenters noted that the health endpoints considered in the HREA are limited, and do not represent the comprehensive array of health effects attributable to O_3 exposure.

In contrast to the views discussed above, other public commenters opposed considering revised standards. These commenters discussed a variety of reasons for their views. A number of commenters expressed the view that EPA should not lower the level of the standard because a lower level would be closer to background O_3 concentrations. In addition, several commenters challenged the interpretation of the evidence presented in the ISA. For example, some commenters questioned the ISA's judgments regarding the strength of evidence for cardiovascular system effects from short-term O_3 exposures. With respect to the risk assessment, several commenters expressed the view that the EPA should only estimate risks above O_3 background concentrations, or above threshold concentrations. In some cases these commenters noted that (1) the O_3 mode of action indicates that there are thresholds for O_3 effects; (2) that these thresholds are considered in the lung function risk assessment; and (3) that there is no reason to believe that similar thresholds would not also be associated with other health effects, particularly more serious effects. Some commenters also expressed the view that, based on the mortality and morbidity risk estimates in the HREA, there is little to no difference between the risks estimated for the current O_3 standard and the risks estimated for revised standards with lower levels. These commenters concluded that the HREA and PA have not shown that the public health improvements likely to be achieved by a revised O_3 standard would be greater than the improvements likely to be achieved by the current standard.

3.4 STAFF CONCLUSIONS ON ADEQUACY OF PRIMARY STANDARD

This section presents staff's conclusions for the Administrator to consider in deciding whether it is appropriate to revise the existing primary O_3 standard. Staff conclusions are based on our consideration of the assessment and integrative synthesis of the evidence presented in the ISA, the air quality distributions in locations of selected epidemiologic studies, exposure and risk analyses in the HREA, the advice of CASAC, and comments received from members of the public.

As an initial matter, staff concludes that reducing precursor emissions to achieve O_3 concentrations that meet the current standard will provide important improvements in public health protection. This initial conclusion is based on (1) the strong body of scientific evidence indicating a wide range of adverse health outcomes attributable to exposures to O_3

concentrations commonly found in the ambient air and (2) estimates indicating decreased occurrences of O_3 exposures of concern and decreased health risks upon meeting the current standard, compared to recent air quality.

Strong support for this initial conclusion is provided by controlled human exposure studies of respiratory effects, and by quantitative estimates of exposures of concern and lung function decrements based on information in these studies. Analyses in the HREA estimate that the percentages of children (i.e., all children and children with asthma) in urban case study areas experiencing exposures of concern, or experiencing abnormal and potentially adverse lung function decrements, are consistently lower for air quality that just meets the current O_3 standard than for recent air quality. The HREA estimates such reductions consistently across the urban case study areas evaluated and throughout various portions of individual urban case study areas, including in urban cores and the portions of case study areas surrounding urban cores. These reductions in exposures of concern and O_3-induced lung function decrements reflect the consistent decreases in the highest O_3 concentrations following reductions in precursor emissions to meet the current standard. Thus, populations in both urban and non-urban areas would be expected to experience important reductions in O_3 exposures and O_3-induced lung function risks upon meeting the current standard.

Support for this initial conclusion is also provided by estimates of O_3-associated mortality and morbidity based on application of concentration-response relationships from epidemiologic studies to air quality adjusted to just meet the current standard. These estimates, which are based on the assumption that concentration-response relationships are linear over entire distributions of ambient O_3 concentrations, are associated with uncertainties that complicate their interpretation (discussed below). However, risk estimates for effects associated with short- and long-term O_3 exposures, combined with the HREA's national analysis of O_3 responsiveness to reductions in precursor emissions and the consistent reductions estimated for the highest ambient O_3 concentrations, suggest that O_3-associated mortality and morbidity would be expected to decrease nationwide following reductions in precursor emissions to meet the current O_3 standard.

As discussed in section 3.2.3.2, reductions in O_3 precursor emissions (i.e., NO_X) could also increase public health protection by reducing the ambient concentrations of pollutants other than O_3. For example, NO_X emissions contribute to ambient NO_2, and NO_X and VOCs can contribute to secondary formation of $PM_{2.5}$ constituents, including ammonium sulfate (NH_4SO_4), ammonium nitrate (NH_4NO_3), and organic carbon (OC). Therefore, at some times and in some locations, control strategies that would reduce NO_X emissions (i.e., to meet an O_3 standard) could reduce ambient concentrations of NO_2 and $PM_{2.5}$, resulting in health benefits beyond those directly associated with reducing ambient O_3 concentrations.

We next revisit the overarching policy question for this chapter, taking into consideration the responses to the specific questions focused on the adequacy of the current primary O_3 standard, as discussed above.

- **Does the currently available scientific evidence and exposure/risk information, as reflected in the ISA and HREA, support or call into question the adequacy of the protection afforded by the current primary O_3 standard?**

In considering the available evidence and information, staff concludes that the O_3-attributable health effects estimated to be allowed by air quality that meets the current primary standard for O_3 can reasonably be judged important from a public health perspective. Thus, we conclude that the available health evidence and exposure/risk information call into question the adequacy of the public health protection provided by the current standard. We further conclude that it is appropriate in this review to consider alternative standards that would increase public health protection, compared to the current standard. The basis for these conclusions is discussed below.

Studies evaluated since the completion of the 2006 O_3 AQCD support and expand upon the strong body of evidence that, in the last review, indicated a causal relationship between short-term O_3 exposures and respiratory health effects. Together, experimental and epidemiologic studies support conclusions regarding a continuum of O_3 respiratory effects ranging from small reversible changes in pulmonary function to more serious effects that can result in respiratory-related emergency department visits, hospital admissions, and/or mortality. Recent animal toxicological studies support descriptions of modes of action for these respiratory effects and augment support for biological plausibility for the role of O_3 in reported effects. With regard to mode of action, evidence indicates that antioxidant capacity may modify the risk of respiratory morbidity associated with O_3 exposure. In addition, based on the consistency of findings across studies and evidence for the coherence of results from different scientific disciplines, strong evidence indicates that certain populations are at increased risk of experiencing O_3-related effects. These include populations and lifestages identified in previous reviews (i.e., people with asthma, children, older adults, outdoor workers) and populations identified since the last review (i.e., people with certain genotypes related to anti-oxidant and/or anti-inflammatory status; people with reduced intake of certain nutrients, such as Vitamins C and E).

Evidence for adverse respiratory health effects attributable to "long-term" or repeated daily O_3 exposures is much stronger than in previous reviews, and the ISA concludes that the evidence supports a "likely to be" causal relationship between such O_3 exposures and adverse respiratory health effects. Uncertainties related to the extrapolation of data generated by rodent toxicology studies to the understanding of health effects in humans have been reduced by studies

in non-human primates and by recent epidemiologic studies. The evidence available in this review includes new epidemiologic studies using a variety of designs and analysis methods, conducted by different research groups in different locations, evaluating the relationships between long-term O_3 exposures and measures of respiratory morbidity and mortality. New evidence supports associations between long-term or repeated O_3 exposures and the development of asthma in children, with several studies reporting interactions between genetic variants and such O_3 exposures. Studies also report associations between long-term or repeated O_3 exposure and asthma prevalence, asthma severity and control, respiratory symptoms among asthmatics, and respiratory mortality.

In considering the O_3 exposure concentrations reported to elicit respiratory effects, we note that controlled human exposure studies provide the most certain evidence indicating the occurrence of health effects in humans following exposures to specific O_3 concentrations. Consistent with this, CASAC also concluded that "the scientific evidence supporting the finding that the current standard is inadequate to protect public health is strongest based on the controlled human exposure studies of respiratory effects" (Frey, 2014, p. 5). As discussed above, recent evidence includes controlled human exposure studies reporting lung function decrements and pulmonary inflammation in healthy adults engaged in intermittent, moderate exertion following 6.6 hour exposures to O_3 concentrations as low as 60 ppb, and lung function decrements and respiratory symptoms following exposures to concentrations as low as 72 ppb.[97] Compared to the evidence available in the last review, these studies have strengthened support for the occurrence of abnormal and adverse respiratory effects attributable to short-term exposures to O_3 concentrations below 80 ppb.[98] Consistent with CASAC advice, we conclude that exposures to such O_3 concentrations are potentially important from a public health perspective given the following:

1. The respiratory effects reported to occur in healthy adults following exposures to O_3 concentrations of 60 and 72 ppb, while at moderate exertion, can reasonably be judged adverse based on ATS criteria and advice from CASAC. In considering the 72 ppb exposure concentration, CASAC noted that "the combination of decrements in FEV_1 together with the statistically significant alterations in symptoms in human subjects exposed to 72 ppb ozone meets the American Thoracic Society's definition of an adverse health effect" (Frey, 2014, p. 5). With regard to 60 ppb O_3, CASAC agreed that "a level of 60 ppb corresponds to the lowest exposure concentration demonstrated to result in

[97] As noted above, for the 70 ppb exposure concentration Schelegle et al. (2009) reported that the actual mean exposure concentration was 72 ppb.

[98] Cf. *Misisssippi*. 744 F.3d at 1350 ("Perhaps more studies like the Adams studies will yet reveal that the 0.060 ppm level produces significant adverse decrements that simply cannot be attributed to normal variation in lung function.").

lung function decrements large enough to be judged an abnormal response by ATS and that could be adverse in individuals with lung disease" (Frey, 2014, p. 7). CASAC further noted that "a level of 60 ppb also corresponds to the lowest exposure concentration at which pulmonary inflammation has been reported" (Frey, 2014, p. 7).

2. The controlled human exposure studies reporting these respiratory effects were conducted in healthy adults, while at-risk groups (e.g., children, people with asthma) could experience larger and/or more serious effects. In their advice to the Administrator, CASAC concurred with this conclusion (Frey, 2014, p. 5).

3. These respiratory effects are coherent with the serious health outcomes that have been reported in epidemiologic studies (e.g., respiratory-related hospital admissions, emergency department visits, and mortality).

Given the above considerations, our conclusions regarding the adequacy of the current primary O_3 standard place a large amount of weight on the results of controlled human exposure studies conducted at 60 and 72 ppb, and on HREA analyses based on information from controlled human exposure studies (i.e., exposures of concern to O_3 concentrations at or above 60, 70, and 80 ppb and O_3-induced FEV_1 decrements $\geq$ 10%, 15%, and 20%).

Recent epidemiologic studies also provide support, beyond that available in the last review, for associations between short-term O_3 exposures and a wide range of adverse respiratory outcomes (including respiratory-related hospital admissions, emergency department visits, and mortality) and with total mortality. Associations with morbidity and mortality are stronger during the warm or summer months, and remain robust after adjustment for co-pollutants. Many epidemiologic studies of morbidity effects and mortality were conducted in locations that did not meet the current standard. However, in one U.S. single-city study associations with respiratory morbidity were reported in a location that would likely have met the current O_3 standard over the entire study period, suggesting that health effect associations persist in locations meeting the current standard. In addition, associations with respiratory morbidity or mortality were reported in several Canadian multicity studies, and in cut point analyses included in a U.S. multicity study, when the majority of study locations would likely have met the current O_3 standard. While there is additional uncertainty in interpreting the relationship between air quality meeting the current standard and health effects in these multicity studies (i.e., compared to single-city studies), they provide supporting evidence for the occurrence of health effect associations in locations that meet the current standard. Even in some study locations where the current standard was likely not met, considering reported concentration-response functions in the context of available air quality data support the occurrence of O_3-health effect associations on the subsets of days with ambient O_3 concentrations below the level of the current standard. Taken together, these studies and associated air quality data support the occurrence of O_3-associated

hospital admissions, emergency department visits, and mortality at ambient concentrations that meet the current standard.

Beyond our consideration of the evidence, we also consider the results of the HREA exposure and risk analyses in reaching conclusions regarding the adequacy of the current primary O_3 standard. In doing so, we focus primarily on estimates of the occurrence of exposures of concern to O_3 concentrations at or above 60 and 70 ppb and lung function decrements $\geq$ 10%, 15% and 20%. We place relatively less weight on epidemiologic-based risk estimates, noting that the overall conclusions from the HREA likewise reflect less confidence in estimates of epidemiologic-based risks than in estimates of exposures and lung function risks (U.S. EPA, 2014, section 9.6). Our determination to attach less weight to the epidemiologic-based estimates reflects the uncertainties associated with mortality and morbidity risk estimates, including the heterogeneity in effect estimates between locations, the potential for exposure measurement errors, and uncertainty in the interpretation of the shape of concentration-response functions at lower O_3 concentrations. The HREA also concludes that lower confidence should be placed in the results of the assessment of respiratory mortality risks associated with long-term O_3 exposures, primarily because that analysis is based on only one study (even though that study is well-designed) and because of the uncertainty in that study about the existence and level of a potential threshold in the concentration-response function (U.S. EPA, 2014, section 9.6).

With regard to HREA estimates of exposures of concern we note the CASAC conclusion that 60 ppb is an appropriate exposure of concern for asthmatic children (Frey, 2014, p. 8). Exposure estimates from the HREA indicate that, if the 15 urban case study areas were to just meet the current O_3 standard, approximately 10 to 20% of children (on average over the years of analysis) in those areas, including asthmatic children, could experience one or more exposures of concern to O_3 concentrations of 60 ppb or above. In the case study areas evaluated, this corresponds to over 2 million children (including over 200,000 asthmatic children) experiencing approximately 4 million such exposures. Nationally, far more children would be expected to experience such exposures of concern. On average over the years evaluated in the HREA, approximately 3 to 8% of children are estimated to experience two or more exposures of concern to O_3 concentrations of 60 ppb or greater. For the worst-case years in the worst-case locations (i.e., years and locations with air quality patterns resulting in the largest exposure estimates), approximately 25% of children are estimated to experience one or more exposures of concern at or above 60 ppb, and about 14% are estimated to experience two or more such exposures. Although the current standard more effectively limits exposures of concern at or above higher O_3 concentrations (i.e., 70, 80 ppb), we note that in the worst-case year and location about 8% of children are estimated to experience one or more exposures of concern at or above 70 ppb and about 2% of children are estimated to experience two or more such exposures.

Though we focus on children in these analyses of O_3 exposures, we also recognize that exposures to 8-hour average O_3 concentrations at or above 60, 70, or 80 ppb could be of concern for adult populations as well. As discussed above, the patterns of exposure estimates over years and across cities are similar in adult asthmatics, older adults, and children, though smaller percentages of adult populations are estimated to experience exposures of concern. Thus, the results for children are one part of a broader range of at-risk populations that also includes asthmatic adults and older adults.

Consistent with estimates of exposures of concern, the HREA also estimates that under air quality conditions just meeting the current O_3 NAAQS, hundreds of thousands of asthmatic children would be expected to experience O_3-induced lung function decrements that are large enough to be potentially adverse in people with lung disease. On average over the years evaluated in the HREA, the current standard is estimated to allow about 14% to 19% of children in the 15 urban case study areas, including asthmatic children, to experience one or more O_3-induced lung function decrements $\geq$ 10% (a decrement judged by CASAC to be a "scientifically-relevant surrogate for adverse health outcomes for people with asthma and lung disease" (Frey, 2014, p. 4)). This corresponds to about 300,000 asthmatic children. Nationally, far more children would be expected to experience such O_3-induced lung function decrements. Across the 15 urban areas, about 8% to 12% of children are estimated to experience two or more decrements $\geq$ 10%, on average over the analysis years. In the worst-case year and location, approximately 22% of children are estimated to experience one or more decrements $\geq$ 10% and about 14% are estimated to experience two or more such decrements. As with exposures of concern, the current standard more effectively limits the larger O_3-induced lung function decrements evaluated (i.e., $\geq$ 15%, 20%). However, about 7% of children are estimated to experience one or more O_3-induced decrements $\geq$ 15% in the worst-case city and year analyzed in the HREA, and about 4% are estimated to experience two or more such decrements. As discussed above, CASAC judged decrements $\geq$ 15% to be an appropriate "surrogate for adverse health outcomes in active healthy adults" (Frey, 2014, p. 4).

As noted above, compared to the weight given to HREA estimates of exposures of concern and lung function risks, we place relatively less weight on epidemiologic-based risk estimates. For epidemiology-based risk estimates, we consider total risks (i.e., based on the full distributions of ambient O_3 concentrations) and risks associated with O_3 concentrations in the upper portions of ambient distributions. A focus on estimates of total risks places greater weight on the possibility that concentration-response relationships remain linear over the entire distributions of ambient O_3 concentrations. With regard to total risks, the HREA estimates thousands of O_3-associated hospital admissions, emergency department visits, and deaths per year for air quality conditions associated with just meeting the current standard in the 12 urban

case study areas evaluated. A focus on risks associated with O_3 concentrations in the upper portions of ambient distributions places greater weight on the uncertainty associated with the shapes of concentration-response curves for O_3 concentrations in the lower portions of ambient distributions (section 3.2.3.2). Based on area-wide O_3 concentrations from the upper portions of seasonal distributions, the current standard is estimated to allow hundreds to thousands of O_3-associated deaths per year in urban case study areas. As with the exposures of concern and lung function risks, this number would be much greater if risks were assessed across the entire U.S. population.

Although we note the HREA conclusions indicating somewhat less confidence in estimates of O_3-associated mortality and morbidity risks compared to estimates of exposures of concern and lung function risks, we conclude that the general magnitude of mortality and morbidity risk estimates suggests the potential for a substantial number of O_3-associated deaths and adverse respiratory events nationally when the current standard is met. This is the case even based on the risks associated with the upper ends of distributions of ambient O_3 concentrations, where experimental evidence indicates increasing support for the occurrence of adverse effects attributable to O_3 exposures.

In addition to the evidence and exposure/risk information discussed above, we also take note of the CASAC advice provided to the EPA Administrator on the proposed reconsideration of the 2008 decision establishing the current standard and the advice of CASAC in the current review. In commenting on the proposed reconsideration, the prior CASAC O_3 Panel recommended revision of the standard to one with a lower level based on the evidence and information in the record for the 2008 standard (Samet, 2011), which has been substantially strengthened in the current review. As discussed in more detail above, the current CASAC also "unanimously recommends that the Administrator revise the current primary ozone standard to protect public health" (Frey, 2014, p. 6).

In consideration of all of the above, staff reaches the conclusion that the available evidence and exposure and risk information clearly calls into question the adequacy of public health protection provided by the current primary standard. The evidence from controlled human exposure studies provides strong support for the occurrence of adverse respiratory effects following exposures to O_3 concentrations below the level of the current standard. Epidemiologic studies provide support for the occurrence of adverse respiratory effects and mortality under air quality conditions that would likely meet the current standard. In addition, based on the analyses in the HREA, we conclude that the exposures and risks projected to remain upon meeting the current standard are indicative of risks that can reasonably be judged to be important from a public health perspective. Thus, staff concludes that the evidence and information provides strong support for giving consideration to revising the current primary standard in order to

provide increased public health protection against an array of adverse health effects that range from decreased lung function and respiratory symptoms to more serious indicators of morbidity (e.g., including emergency department visits and hospital admissions), and mortality. In consideration of all of the above, staff draws the conclusion that it is appropriate for the Administrator to consider revision of the current primary O_3 standard to provide increased public health protection.

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4 CONSIDERATION OF ALTERNATIVE PRIMARY STANDARDS

Having reached the conclusion that the currently available scientific evidence and exposure/risk information calls into question the adequacy of the current O_3 standard, we next consider the following overarching question:

- **What is the range of potential alternative standards that are supported by the currently available scientific evidence and exposure/risk information, as reflected in the ISA and HREA respectively?**

To address this overarching question, in the sections below we evaluate a series of more specific questions related to the major elements of the NAAQS: indicator (section 4.1), averaging time (section 4.2), form (section 4.3), and level (section 4.4). In addressing these questions, we consider the currently available scientific evidence and exposure/risk information, including the evidence and information available at the time of the last review and that newly available in the current review, as assessed in the ISA and the HREA. In so doing, we note that the final decision by the Administrator in this review will consider these elements collectively in evaluating the health protection afforded by the primary standard.[1]

4.1 INDICATOR

In the last review, EPA focused on O_3 as the most appropriate indicator for a standard meant to provide protection against ambient photochemical oxidants. In this review, while the complex atmospheric chemistry in which O_3 plays a key role has been highlighted, no alternatives to O_3 have been advanced as being a more appropriate indicator for ambient photochemical oxidants. More specifically, the ISA noted that O_3 is the only photochemical oxidant (other than NO_2) that is routinely monitored and for which a comprehensive database exists (ISA section 3.6). Data for other photochemical oxidants (e.g., PAN, H_2O_2, etc.) typically have been obtained only as part of special field studies. Consequently, no data on nationwide patterns of occurrence are available for these other oxidants; nor are extensive data available on the relationships of concentrations and patterns of these oxidants to those of O_3 (U.S. EPA, 2013, section 3.6). In its review of the second draft PA, CASAC concurred, stating "The indicator of ozone is appropriate based on its causal or likely causal associations with multiple adverse health outcomes and its representation of a class of pollutants known as photochemical oxidants" (Frey, 2014, p. ii).

[1]We also take note of the 1997 review (discussed in section 1.3.1.2.3), in which O_3 background concentrations were an additional consideration in EPA's selection of a standard from among a range of scientifically acceptable alternatives. Background O_3 is discussed in more detail in chapter 2 of this PA.

We further note that meeting an O_3 standard can be expected to provide some degree of protection against potential health effects that may be independently associated with other photochemical oxidants, even though such effects are not discernible from currently available studies indexed by O_3 alone. That is, since the precursor emissions that lead to the formation of O_3 generally also lead to the formation of other photochemical oxidants, measures leading to reductions in population exposures to O_3 can generally be expected to lead to reductions in population exposures to other photochemical oxidants. Taken together, we conclude that O_3 remains the most appropriate indicator for a standard meant to provide protection against photochemical oxidants.[2]

4.2 AVERAGING TIME

The EPA established the current 8-hour averaging time[3] for the primary O_3 NAAQS in 1997 (62 FR 38856). The decision on averaging time in that review was based on numerous controlled human exposure and epidemiologic studies reporting associations between 6 to 8 hour O_3 concentrations and adverse respiratory effects (62 FR 38861). It was also noted that a standard with a max 8-hour averaging time is likely to provide substantial protection against respiratory effects associated with 1-hour peak O_3 concentrations. Similar conclusions were reached in the last O_3 NAAQS review and thus, the 8-hour averaging time was retained in 2008.

In the current review, we first consider the following question related to averaging time:

- **To what extent does the available evidence continue to support the appropriateness of a standard with an 8-hour averaging time?**

In reaching conclusions related to this question, staff considers causality judgments from the ISA, as well as results from the specific controlled human exposure and epidemiologic studies that informed those judgments. These considerations are described below in more detail.

As an initial consideration with respect to the most appropriate averaging time for the O_3 NAAQS, we note that the strongest evidence for O_3-associated health effects is for respiratory effects following short-term exposures. More specifically, the ISA concludes that evidence relating short-term O_3 exposures to respiratory effects is "sufficient to infer a causal relationship." The ISA also judges that the evidence for short-term exposures to O_3 indicates "likely to be" causal relationships with both cardiovascular effects and mortality (U.S. EPA, 2013, section 2.5.2). Therefore, as in past reviews, the strength of the available scientific

[2]The D.C. Circuit upheld the use of O_3 as the indicator for photochemical oxidants based on these same considerations. *American Petroleum Inst. v. Costle*, 665 F. 2d 1176, 1186 (D.C. Cir. 1981).

[3]This 8-hour averaging time reflects daily max 8-hour average O_3 concentrations.

evidence provides strong support for a standard that protects the public health against short-term exposures to O_3.

In first considering the level of support available for specific short-term averaging times, we note the evidence available from controlled human exposure studies. As discussed in more detail in chapter 3 of this PA, substantial health effects evidence from controlled human exposure studies demonstrates that a wide range of respiratory effects (e.g., pulmonary function decrements, increases in respiratory symptoms, lung inflammation, lung permeability, decreased lung host defense, and airway hyperresponsiveness) occur in healthy adults following 6.6 hour exposures to O_3 (EPA 2013, section 6.2.1.1). Compared to shorter exposure durations (e.g., 1-hour), studies evaluating 6.6 hour exposures in healthy adults have reported respiratory effects at lower O_3 exposure concentrations and at more moderate levels of exertion.

We also note the strength of evidence from epidemiologic studies that have evaluated a wide variety of populations (e.g., including at-risk lifestages and populations, such as children and people with asthma, respectively). A number of different averaging times are used in O_3 epidemiologic studies, with the most common being the max 1-hour concentration within a 24-hour period (1-hour max), the max 8-hour average concentration within a 24-hour period (8-hour max), and the 24-hour average. These studies are discussed in chapter 3 of this PA, and are assessed in detail in chapter 6 of the ISA (U.S. EPA, 2013). Limited evidence from time-series and panel epidemiologic studies comparing risk estimates across averaging times does not indicate that one exposure metric is more consistently or strongly associated with respiratory health effects or mortality, though the ISA notes some evidence for "smaller O_3 risk estimates when using a 24-hour average exposure metric" (EPA 2013, section 2.5.4.2; p. 2-31). For single- and multi-day average O_3 concentrations, lung function decrements were associated with 1-hour max, 8-hour max, and 24-hour average ambient O_3 concentrations, with no strong difference in the consistency or magnitude of association among the averaging times (EPA 2013, p. 6-71). Similarly, in studies of short-term exposure to O_3 and mortality, Smith et al. (2009) and Darrow et al. (2011) have reported high correlations between risk estimates calculated using 24-hour average, 8-hour max, and 1-hour max averaging times (EPA 2013, p. 6-253). Thus, the epidemiologic evidence alone does not provide a strong basis for distinguishing between the appropriateness of 1-hour, 8-hour, and 24-hour averaging times.

Considering the health information discussed above, we conclude that an 8-hour averaging time remains appropriate for addressing health effects associated with short-term exposures to ambient O_3. An 8-hour averaging time is similar to the exposure periods evaluated in controlled human exposure studies, including recent studies that provide evidence for respiratory effects following exposures to O_3 concentrations below the level of the current standard. In addition, epidemiologic studies provide evidence for health effect associations with

8-hour O_3 concentrations, as well as with 1-hour and 24-hour concentrations. As in previous reviews, we note that a standard with an 8-hour averaging time (combined with an appropriate standard form and level) would also be expected to provide substantial protection against health effects attributable to 1-hour and 24-hour exposures (e.g., 62 FR 38861, July 18, 1997). In its review of the second draft PA, CASAC concurred stating that "the current 8-hour averaging time is justified by the combined evidence from epidemiologic and clinical studies" (Frey, 2014, p. 6).

The ISA also concludes that the evidence for long-term O_3 exposures indicates that there is "likely to be a causal relationship" with respiratory effects (US EPA, 2013, chapter 7). Thus, in this review we also consider the extent to which currently available evidence and exposure/risk information suggests that a standard with an 8-hour averaging time can provide protection against respiratory effects associated with longer term exposures to ambient O_3. In doing so, staff considers the following question:

- **To what extent does the available evidence and exposure/risk information indicate that a standard with the current 8-hour averaging time could provide protection against long-term exposures to ambient O_3?**

In considering this issue in the last review of the O_3 NAAQS, staff noted that "because long-term air quality patterns would be improved in areas coming into attainment with an 8-hr standard, the potential risk of health effects associated with long-term exposures would be reduced in any area meeting an 8-hr standard" (U.S. EPA, 2007, p. 6-57).

In the current review, we further evaluate this issue, with a focus on the "long-term" O_3 metrics reported to be associated with mortality or morbidity in recent epidemiologic studies. As discussed in section 3.1.3, much of the recent evidence for such associations is based on studies that defined long-term O_3 in terms of seasonal averages of daily max concentrations (e.g., seasonal averages of 1-hour or 8-hour daily max concentrations).

As an initial consideration, we note the risk results from the HREA for respiratory mortality associated with long-term O_3 concentrations. As discussed in section 3.2.3.2, HREA analyses indicate that as air quality is adjusted to just meet the current 8-hour standard, most urban case study areas are estimated to experience reductions in respiratory mortality associated with long-term O_3 concentrations based on the seasonal averages of 1-hour daily max O_3 concentrations evaluated in the study by Jerrett et al. (2009) (U.S. EPA, 2014, chapter 7). As air quality is adjusted to meet lower potential alternative standard levels, for standards based on 3-year averages of the annual fourth-highest daily max 8-hour O_3 concentrations, respiratory mortality risks are estimated to be reduced further in urban case study areas (section 4.4.2.3,below). This analysis indicates that an O_3 standard with an 8-hour averaging time, when coupled with an appropriate form and level, can reduce respiratory mortality reported to be associated with "long-term" O_3 concentrations.

In further considering the study by Jerrett et al. (2009), we compare long-term O_3 concentrations following air quality adjustment in urban case study areas (i.e., adjusted to meet the current and potential alternative 8-hour standards) to the concentrations present in study cities that provided the basis for the positive and statistically significant association with respiratory mortality. As indicated below (Table 4-3), this comparison suggests that a standard with an 8-hour averaging time can decrease seasonal averages of 1-hour daily max O_3 concentrations, and can maintain those O_3 concentrations below the seasonal average where we have the most confidence in the reported concentration-response relationship with respiratory mortality (see section 4.4.1 for further discussion).

The HREA also conducted analyses evaluating the impacts of reducing regional NO_X emissions on the seasonal averages of 8-hour daily max O_3 concentrations.[4] Seasonal averages of 8-hour daily max O_3 concentrations reflect long-term metrics that have been reported to be associated with respiratory morbidity effects in several recent O_3 epidemiologic studies (e.g., Islam et al., 2008; Lin et al., 2008; Salam et al., 2009). The HREA analyses indicate that the large majority of the U.S. population lives in locations where reducing NO_X emissions would be expected to result in decreases in seasonal averages of daily max 8-hour ambient O_3 concentrations (U.S. EPA, 2014, section 8.2.3.2). Thus, consistent with the respiratory mortality risk estimates noted above, this analysis suggests that reductions in O_3 precursor emissions in order to meet a standard with an 8-hour averaging time would also be expected to reduce the long-term O_3 concentrations that have been reported in recent epidemiologic studies to be associated with respiratory morbidity.

Taken together, we conclude that a standard with an 8-hour averaging time, coupled with the current 4th high form and an appropriate level, would be expected to provide appropriate protection against the long-term O_3 concentrations that have been reported to be associated with respiratory morbidity and mortality. In its review of the second draft PA, CASAC concurred, stating that "The 8-hour averaging window also provides protection against the adverse impacts of long-term ozone exposures, which were found to be "likely causal" for respiratory effects and premature mortality" (Frey, 2014, p. 6). This issue is considered further, within the context of specific potential alternative standard levels, in section 4.4 below.

4.3 FORM

The "form" of a standard defines the air quality statistic that is to be compared to the level of the standard in determining whether an area attains the standard. The foremost consideration in selecting a form for potential alternative primary standards is the adequacy of

[4]Analyses are based on regional NO_X reductions, which are effective in bringing down peak ambient O_3 concentrations, but can have variable impacts on seasonal mean concentrations.

the public health protection provided by the combination of the form and the other elements of the standard. As such, in reaching staff conclusions regarding the appropriate form(s) to consider for a potential alternative primary O_3 standard, we consider the following question:

- **To what extent do the available evidence and/or information continue to support the appropriateness of a standard with a form defined by the 3-year average of annual 4th-highest 8-hour daily max O_3 concentrations?**

The EPA established the current form of the primary O_3 NAAQS in 1997 (62 FR 38856). Prior to that time, the standard had a "1-expected-exceedance" form.[5] An advantage of the current concentration-based form recognized in the 1997 review is that such a form better reflects the continuum of health effects associated with increasing ambient O_3 concentrations. Unlike an expected exceedance form, a concentration-based form gives proportionally more weight to years when 8-hour O_3 concentrations are well above the level of the standard than to years when 8-hour O_3 concentrations are just above the level of the standard. It was judged appropriate to give more weight to higher O_3 concentrations, given that available health evidence indicated a continuum of effects associated with exposures to varying concentrations of O_3, and given that the extent to which public health is affected by exposure to ambient O_3 is related to the actual magnitude of the O_3 concentration, not just whether the concentration is above a specified level.

During the 1997 review, EPA considered a range of alternative "concentration-based" forms, including the second-, third-, fourth- and fifth-highest daily max 8-hour concentrations in an O_3 season. The fourth-highest daily max was selected, recognizing that a less restrictive form (e.g., fifth highest) would allow a relatively large percentage of sites to experience O_3 peaks well above the level of the standard, and would allow more days on which the level of the standard may be exceeded when attaining the standard (62 FR 38856). Consideration was also given to setting a standard with a form that would provide a margin of safety against possible but uncertain chronic effects, and would provide greater stability to ongoing control programs.[6] A more restrictive form was not selected, recognizing that the differences in the degree of protection afforded by the alternatives were not well enough understood to use any such differences as a basis for choosing the most restrictive forms (62 FR 38856).

In the 2008 review, EPA additionally considered the potential value of a percentile-based form. In doing so, EPA recognized that such a statistic is useful for comparing datasets of

[5]For a standard with a 1-expected-exceedance form to be met at an air quality monitoring site, the fourth-highest air quality value in 3 years, given adjustments for missing data, must be less than or equal to the level of the standard.
[6] See American Trucking Assn's v. EPA, 283 F. 3d 355, 374-75 (D.C. Cir. 2002) (less stable implementation programs may be less effective, and therefore EPA can consider programmatic stability in determining the form of a NAAQS).

varying length because it samples approximately the same place in the distribution of air quality values, whether the dataset is several months or several years long. However, EPA concluded that a percentile-based statistic would not be effective in ensuring the same degree of public health protection across the country. Specifically, a percentile-based form would allow more days with higher air quality values in locations with longer O_3 seasons relative to places with shorter O_3 seasons. Thus, in the 2008 review EPA concluded that a form based on the nth-highest max O_3 concentration would more effectively ensure that people who live in areas with different length O_3 seasons receive the same degree of public health protection.

Based on analyses for forms specified in terms of an nth-highest concentration (n ranged from 3 to 5), advice from CASAC, and public comment,[7] the Administrator concluded that a 4th-highest daily max should be retained (73 FR 16465). In reaching this decision, the Administrator recognized that "there is not a clear health-based threshold for selecting a particular nth-highest daily maximum form of the standard" and that "the adequacy of the public health protection provided by the combination of the level and form is a foremost consideration" (73 FR 16475). Based on this, the Administrator judged that the existing form (4th-highest daily maximum 8-hour average concentration) should be retained, recognizing the increase in public health protection provided by combining this form with a lower standard level (i.e., 75 ppb).

The Administrator also recognized that it is important to have a form that provides stability with regard to implementation of the standard. In the case of O_3, for example, he noted the importance of a form insulated from the impacts of the meteorological events that are conducive to O_3 formation. Such events could have the effect of reducing public health protection, to the extent they result in frequent shifts in and out of attainment due to meteorological conditions. The Administrator noted that such frequent shifting could disrupt an area's ongoing implementation plans and associated control programs (73 FR 16474). In his final decision, the Administrator judged that a "4^{th} high form provides a stable target for implementing programs to improve air quality" (73 FR 16475).

In the current review, we consider the extent to which newly available information provides support for consideration of alternative forms. In so doing, we take note of the conclusions of prior reviews summarized above. We recognize the value of an nth-high statistic over that of an expected exceedance or percentile-based form in the case of the O_3 standard, for

[7]In the 2008 review, one group of commenters expressed the view that the standard was not adequate and supported a more health-protective form (e.g., a second- or third-highest daily max form). Another group of commenters expressed the view that the standard was adequate and did not provide any views on alternative forms that would be appropriate should the Administrator consider revisions to the standard. The Administrator considered the protection afforded by the combination of level and form in revising the standard in 2008 to 75 ppb, as a 3-year average of the annual fourth-highest daily max 8-hour concentrations (73 FR 16475).

the reasons summarized above. We additionally take note of the importance of stability in implementation to achieving the level of protection specified by the NAAQS. Specifically, we note that to the extent that areas engaged in implementing the O_3 NAAQS frequently shift from meeting to violating the standard, it is possible that ongoing implementation plans and associated control programs could be disrupted, thereby reducing public health protection.

In light of this, while giving foremost consideration to the adequacy of public health protection provided by the combination of all elements of the standard, including the form, we consider particularly findings from prior reviews with regard to the use of the nth-high metric. As noted above, the 4th-highest daily max was selected in recognition of the public health protection provided by this form, when coupled with an appropriate averaging time and level, and recognizing that such a form can provide stability for implementation programs. The currently available evidence and information does not call into question these conclusions from previous reviews. Moreover, in its review of the second draft PA, CASAC concurred that the O_3 standard should be based on the fourth highest, daily maximum 8-hour average value (averaged over three years), stating that this form "provides health protection while allowing for atypical meteorological conditions that can lead to abnormally high ambient ozone concentrations which, in turn, provides programmatic stability" (Frey, 2014, p. 6). Thus a standard with the current 4th high form, coupled with a level lower than 75 ppb as discussed below, would be expected to increase public health protection relative to the current standard while continuing to provide stability for implementation programs. Therefore, we conclude that it would be appropriate to consider retaining the current 4th-highest daily max form for an O_3 standard with an 8-hour averaging time and a revised level, as discussed below.

4.4 LEVEL

In considering potential alternative standards levels to provide greater protection than that afforded by the current standard against O_3-related adverse health effects, we address the following overarching question.

- **For an O_3 standard defined in terms of the current indicator, averaging time, and form, what alternative levels are appropriate to consider in order to provide adequate public health protection against short- and long- term exposures to O_3 in ambient air?**

In considering this question, we take into account the experimental and epidemiologic evidence as presented in the ISA, as well as the uncertainties and limitations associated with this evidence (section 4.4.1). In addition, we consider the quantitative estimates of exposure and risk provided by the HREA, as well as the uncertainties and limitations associated with these risk estimates (section 4.4.2).

4.4.1 Evidence-based Considerations

In this section, we consider the available evidence from controlled human exposure and epidemiologic studies, including the uncertainties and limitations associated with that evidence, within the context of potential alternative standard levels. We consider both the exposure concentrations at which controlled human exposure studies provide evidence for health effects, and the ambient O_3 concentrations present in locations where epidemiologic studies have reported health effect associations (see also section 3.1).

Controlled human exposure studies and epidemiologic panel studies

We consider the following question related to controlled human exposure studies and panel studies:

- **To what extent does the available evidence from controlled human exposure studies and panel studies provide support for consideration of potential alternative standard levels lower than 75 ppb?**

To inform our conclusions regarding this question, we consider the lowest O_3 concentrations at which various effects have been evaluated and statistically significant effects reported. We also consider the potential for reported effects to be adverse, including in at-risk populations.

As discussed in section 3.1.2.1, data from controlled human exposure studies show that group mean O_3-induced lung function decrements in healthy adults exhibit a smooth dose-response relationship without evidence of a threshold from 40 to 120 ppb O_3 (US EPA, 2013, Figure 6-1). The lowest O_3 exposure concentration for which statistically significant decrements have been reported is 60 ppb (Brown, 2008; Kim et al., 2011). The ISA concludes that mean FEV_1 is clearly decreased by 6.6-hour exposures to O_3 concentrations of 60 ppb and higher in young, healthy adults during moderate exertion (US EPA, 2013, p. 6-9). As discussed in section 3.1.3, such a decrease in mean lung function meets the ATS criteria for an adverse response given that a downward shift in the distribution of FEV_1 would result in diminished reserve function, and therefore would increase risk from further environmental insult. In addition, based on data from studies by Kim et al. (2011), Schelegle et al. (2009), Adams (2006), and Adams (1998), the ISA notes that following exposures to 60 ppb O_3 10% of healthy adults experience FEV_1 decrements > 10% (U.S. EPA, 2013, page 6-19).[8] A 10% decrement in FEV_1 is accepted

[8]As discussed in Chapter 3 of this PA (section 3.1.2.1), these estimates are consistent with the predictions of quantitative models developed by McDonnell et al. (2012) and Schelegle et al. (2012). The McDonnell model, as discussed in McDonnell et al. (2010), provides the basis for lung function risk estimates in the HREA (section 4.4.2.2, below). For the target of 60 ppb, Schelegle et al. (2009) reported an actual mean exposure concentration of 63 ppb.

by ATS as an abnormal response. Based on advice received from CASAC in this (Frey, 2014, p. 3) and previous reviews, such decrements could be adverse in people with lung disease (section 3.1.3). Moreover, as discussed in section 3.1.3 of this PA, repeated occurrences of moderate responses may be considered adverse since they could set the stage for more serious effects.

One recent controlled human exposure study has reported O_3-induced pulmonary inflammation (PMN increased in sputum from lower airways) following exposures of young, healthy adults to O_3 concentrations of 60 ppb (Kim et al., 2011), the lowest concentration at which inflammatory responses have been evaluated in human studies (see discussion in section 3.1.2.1). Induction of pulmonary inflammation is evidence that injury has occurred. The possibility of chronic effects due to repeated inflammatory events has been evaluated in animal studies. Repeated events of acute inflammation can have several potentially adverse outcomes including: induction of a chronic inflammatory state; altered pulmonary structure and function, leading to diseases such as asthma; altered lung host defense response to inhaled microorganisms, particularly in potentially at-risk populations such as the very young and old; and, altered lung response to other agents such as allergens or toxins (U.S. EPA, 2013, Section 6.2.3). Thus, lung injury and the resulting inflammation, particularly if experienced repeatedly, provide a mechanism by which O_3 may cause other more serious respiratory effects (e.g., asthma exacerbations) and possibly extrapulmonary effects.

With respect to respiratory symptoms, a recent study by Schelegle et al. (2009) reported a statistically significant increase in respiratory symptoms in young, healthy adults following 6.6 hour exposures to an average O_3 concentration of 70 ppb.[9] This study also reported a statistically significant decrease in FEV_1 following such exposures. As discussed in section 3.1.3, the occurrence of both lung function decrements and respiratory symptoms meets criteria established by the ATS defining an "adverse" respiratory response. Although some studies have reported that respiratory symptoms develop during exposures at 60 ppb, the increases in symptoms in these studies have not reached statistical significance by the end of the 6.6 hour exposures (Adams 2006; Schelegle et al., 2009).[10]

Based on the results discussed above and in section 3.1.2.1, we conclude that controlled human exposure studies provide evidence of potentially adverse lung function decrements and airway inflammation in healthy adults following exposures to 60 ppb O_3, and evidence of

[9] For the target of 70 ppb, Schelegle et al. (2009) reported an actual mean exposure concentration of 72 ppb.

[10] Adams (2006) reported an increase in respiratory symptoms in healthy adults during a 6.6 hour exposure protocol with an average O_3 exposure concentration of 60 ppb. This increase was significantly different from initial respiratory symptoms, but not from the filtered air control day. For the target of 60 ppb, Schelegle et al. (2009) reported an actual mean exposure concentration of 63 ppb and did not observe a statistically significant increase in respiratory symptoms.

respiratory symptoms combined with lung function decrements (an "adverse" response based on ATS criteria) following exposures to 70 ppb. In reaching these conclusions, we recognize that most studies have not evaluated exposure concentrations below 60 ppb, and that 60 ppb does not necessarily reflect an exposure concentration below which effects no longer occur. Specifically, given the occurrence of airway inflammation in healthy adults following exposures to 60 ppb and higher, it may be reasonable to expect that inflammation would also occur following exposures to O_3 concentrations somewhat below 60 ppb. Although some studies show that respiratory symptoms develop during exposures at 60 ppb, they have not reached statistical significance by the end of the 6.6 hour exposures (Adams 2006; Schelegle et al. 2009). Thus, respiratory symptoms combined with lung function decrements are likely to occur to some degree in healthy adults with 6.6-hour exposures to concentrations below 70 ppb, and are more likely to occur with 8-hour exposures to 70 ppb and below. Further, we note that these controlled human exposure studies were conducted in healthy adults and that people with asthma, including asthmatic children, are likely to be more sensitive to O_3-induced respiratory effects. Therefore, these exposure concentrations are more likely to cause adverse respiratory effects in children and adults with asthma, and more generally in people with respiratory disease.

With regard to other O_3-induced effects, we note that airway hyperresponsiveness and impaired lung host defense capabilities have been reported in healthy adults engaged in moderate exertion following exposures to O_3 concentrations as low as 80 ppb, the lowest concentration evaluated for these effects.[11] As discussed in section 3.1.2.1, these physiological effects have been linked to aggravation of asthma and increased susceptibility to respiratory infection, potentially leading to increased medication use, increased school and work absences, increased visits to doctors' offices and emergency departments, and increased hospital admissions. These are all indicators of adverse O_3-related morbidity effects, which are consistent with, and provide plausibility for, the adverse morbidity effects and mortality effects observed in epidemiologic studies.

In further considering effects following exposures to O_3 concentrations below 75 ppb, in section 3.1.4.1 we discuss panel studies highlighted in the ISA for the extent to which monitored ambient O_3 concentrations reflect exposure concentrations in their study populations (U.S. EPA, 2013, section 6.2.1.2). These panel studies used on-site monitoring to evaluate O_3-attributable lung function decrements in people engaged in outdoor recreation, exercise, or work. Table 3-2 includes O_3 panel studies that report analyses of O_3-attributable lung function decrements for O_3 concentrations at or below 75 ppb, and that measure O_3 concentrations with monitors located in the areas where study subjects were active (e.g., on site at summer camps or in locations where

[11]There is no evidence that 80 ppb is a threshold for these effects (72 FR 37878, July 11, 2007).

exercise took place). Consistent with the results of controlled human exposure studies discussed above, these panel studies report associations with lung function decrements for subjects exposed to on-site monitored O_3 concentrations below 75 ppb. Associations in panel studies have been reported for a wider range of populations than has been evaluated in controlled human exposure studies, including children.

With regard to the question above, we conclude that the available controlled human exposure evidence and evidence from panel studies supports an upper end of the range of potential alternative standard levels for consideration no higher than 70 ppb. As just discussed, 6.6-hour exposures of healthy adults to 70 ppb O_3 result in lung function decrements and respiratory symptoms, a combination of effects that meet ATS criteria for an adverse response (as discussed in section 3.1.3).[12] In addition, while 70 ppb is below the 80 ppb concentration shown in 6.6-hour exposure studies to cause potentially adverse respiratory effects such as airway hyperresponsiveness and impaired host-defense capabilities, these effects have not been evaluated at exposure concentrations below 80 ppb and there is no reason to believe that 80 ppb represents a threshold for such effects. As discussed in section 3.1.2.1 of this PA, the physiological effects reported in controlled human exposure studies down to 60 ppb O_3 have been linked to aggravation of asthma and increased susceptibility to respiratory infection, potentially leading to increased medication use, increased school and work absences, increased visits to doctors' offices and emergency departments, and increased hospital admissions.

Based on the above considerations, we also conclude that the evidence from controlled human exposure studies and panel studies supports considering alternative O_3 standard levels at least as low as 60 ppb. Potentially adverse lung function decrements and pulmonary inflammation have been demonstrated to occur in healthy adults at 60 ppb, with little evidence for potentially adverse effects following exposures to O_3 concentrations below 60 ppb. Thus, 60 ppb is a short-term exposure concentration that may be reasonably concluded to elicit adverse effects in at-risk groups. Pulmonary inflammation, particularly if experienced repeatedly, provides a mechanism by which O_3 may cause other more serious respiratory morbidity effects (e.g., asthma exacerbations) and possibly extrapulmonary effects.

Epidemiologic evidence

We also consider what the information from epidemiologic studies indicates with regard to potential alternative standard levels appropriate for consideration. Based on the information in

[12] Based on the Schelegle et al. (2009) study, CASAC observed that, "adverse health effects in young healthy adults occur with exposures to 72 ppb of ozone for 6.6 hours" and that "It is the judgment of CASAC that if subjects had been exposed to ozone using the 8-hour averaging period used in the standard, adverse effects could have occurred at [a] lower concentration. Further, in our judgment, the level at which adverse effects might be observed would likely be lower for more sensitive subgroups, such as those with asthma" (Frey, 2014, p. 5).

section 3.1.4.2 of this PA (see Table 3-3), we first note that several epidemiologic studies have reported positive and statistically significant associations with hospital admissions, emergency department visits, and/or mortality in study areas where ambient O_3 concentrations would have met the current standard (i.e., with its level of 75 ppb). This includes Canadian multicity studies in which the majority of study cities would have met the current standard over entire study periods (Cakmak et al., 2006; Dales et al., 2006; Katsouyanni et al., 2009; Stieb et al., 2009), and a U.S. single-city study conducted in a location likely to have met the current standard over the entire study period (Mar and Koenig, 2009).

In further evaluating these studies, and building upon our conclusions based on controlled human exposures studies, as discussed above, we consider the following question related to the epidemiologic evidence:

- **To what extent have U.S. and Canadian epidemiologic studies reported associations with mortality or morbidity in locations likely to have met potential alternative O_3 standards with levels from 70 to 60 ppb?**

Our focus in addressing this question is on what epidemiologic studies convey regarding the extent to which O_3-associated health effects may be occurring (i.e., as indicated by associations) under air quality conditions allowed by potential alternative standards with levels of 70, 65, and 60 ppb (Table 4-1).[13]

[13]See *ATA III*, 283 F.3d at 370 (EPA justified in revising NAAQS when health effect associations are observed at levels allowed by the NAAQS).

Table 4-1 Numbers of epidemiologic study locations likely to have met potential alternative standards with levels of 70, 65, and 60 ppb

			Number of study cities meeting potential alternative standards during entire study period		
Study	**Result**	**Cities**	**70 ppb**	**65 ppb**	**60 ppb**
Cakmak et al. (2006)	Positive and statistically significant association with respiratory hospital admissions	10 Canadian cities	7	6	2
Dales et al. (2006)	Positive and statistically significant association with respiratory hospital admissions	11 Canadian cities	5	4	0
Katsouyanni et al. (2009)	Positive and statistically significant associations with respiratory hospital admissions	12 Canadian cities	9	9	5
Katsouyanni et al. (2009)	Positive and statistically significant associations with total and cardiovascular mortality	12 Canadian cities	7	5	1
Mar and Koenig (2009)	Positive and statistically significant associations with asthma emergency department visits	Single city: Seattle	0	0	0
Stieb et al. (2009)	Positive and statistically significant association with respiratory emergency department visits	7 Canadian cities	5	4	3

As discussed in section 3.1.4.2, the single-city study by Mar and Koenig reported associations with respiratory emergency department visits in a location that would have met the current standard over the entire study period. In contrast, over at least part of the study period this area would have violated alternative O_3 standards with levels of 70 ppb or below. Thus, while this study indicates that the current standard would allow the reported associations with respiratory emergency department visits, it does not provide information on the extent to which those health effect associations would be present if ambient O_3 concentrations were reduced to meet a revised standard with a level at or below 70 ppb.

With regard to the multicity studies included in Table 4-1, none were conducted in study locations that all would have met an O_3 standard with a level at or below 70 ppb. However, for the studies by Cakmak et al. (2006), Katsouyanni et al. (2009), and Stieb et al. (2009), the majority of study locations would likely have met a standard with a level of either 70 or 65 ppb (Cakmak et al., 2006; Katsouyanni et al., 2009; Stieb et al., 2009). Thus the majority of the distributions of ambient O_3 concentrations that provided the basis for positive and statistically significant associations with mortality or morbidity in these studies would likely be allowed

under alternative standards with levels of 70 or 65 ppb, though not 60 ppb. However, our interpretation of these results is complicated by uncertainties in the extent to which multicity effect estimates can be attributed to ambient O_3 in the majority of locations, which would have met alternative standards, versus O_3 in the smaller number of locations that would have violated those alternatives.

As with our consideration of the current standard (section 3.1.4.2), we next consider the extent to which epidemiologic studies have characterized O_3 health effect associations, including confidence in those associations, for various portions of distributions of ambient O_3 concentrations. In considering such analyses within the context of potential alternative standards, we focus on the extent to which epidemiologic studies report health effect associations for air quality distributions restricted to ambient pollutant concentrations below one or more predetermined cut-points. As discussed in section 3.1.4.2, such "cut-point" analyses can provide information on the magnitude and statistical precision of effect estimates for defined distributions of ambient concentrations, which may in some cases include distributions that would be allowed by potential alternative standards. Specifically, we consider the following question:

- **To what extent do cut-point analyses from epidemiologic studies report health effect associations at ambient O_3 concentrations that are likely to be allowed by potential alternative standards with levels from 70 to 60 ppb?**

As with our consideration of the current standard in section 3.1.4.2 of this PA, we evaluate the cut-point analyses presented in the U.S. multicity study by Bell et al. (2006). These cut-point analyses can provide insights into the magnitude and statistical precision of health effect associations for different portions of the distribution of ambient concentrations, including insights into the ambient concentrations below which uncertainty in reported associations becomes notably greater. Our analysis of air quality data associated with the cut-points evaluated by Bell et al., and uncertainties associated with that analysis, is described elsewhere in this document (section 3.1.4.2). In this section, we consider what these cut-point analyses indicate with regard to the potential for health effect associations to extend to ambient O_3 concentrations likely to be allowed by a revised O_3 NAAQS with a level below 75 ppb.

We particularly focus on the lowest cut-point for which the association between O_3 and mortality was reported to be statistically significant (i.e., 30 ppb, as discussed in section 3.1.4.2). Based on the O_3 air quality concentrations that met the criteria for inclusion in the 30 ppb cut-point analysis, 84% of study areas had 3-year averages of annual 4th highest 8-hour daily max O_3 concentrations at or below 70 ppb over the entire study period (Table 4-2). In addition, 64% of study areas had 3-year averages of annual 4th highest 8-hour daily max O_3 concentrations at or

below 65 ppb (Table 4-2). In contrast, the majority of study areas had 4th highest concentrations above 60 ppb.

Consistent with our interpretation of multicity effect estimates discussed above, these results suggest that the majority of the air quality distributions included in the 30 ppb O_3 cut point would have been allowed by a standard with a level of 70 or 65 ppb. Thus the majority of the distributions of ambient O_3 concentrations that provided the basis for a positive and statistically significant association with mortality would be allowed by alternative standards with levels of 70 or 65 ppb, but not 60 ppb. However, as discussed below our interpretation of these cut point analyses is complicated by important uncertainties.

Table 4-2 Number of study cities with 3-year averages of 4th highest 8-hour daily max concentrations greater than 70, 65, or 60 ppb, for various cut-point analyses presented in Bell et al. (2006)

	Cut-point for 2-day moving average across monitors and cities (24-h avg)[14]								
	25	30	35	40	45	50	55	60	All
Number (%) of Cities with 4th highest >70 (any 3-yr period; 1987-2000)	0 (0%)	16 (16%)	55 (56%)	82 (84%)	89 (91%)	92 (94%)	94 (96%)	95 (97%)	95 (97%)
Number (%) of Cities with 4th highest >65 (any 3-yr period; 1987-2000)	3 (3%)	35 (36%)	77 (79%)	89 (91%)	94 (96%)	95 (97%)	95 (97%)	95 (97%)	95 (97%)
Number (%) of Cities with 4th highest >60 (any 3-yr period; 1987-2000)	16 (16%)	61 (62%)	86 (88%)	94 (96%)	95 (97%)	96 (8%)	96 (8%)	96 (8%)	96 (8%)

In further considering the implications of Tables 4-1 and 4-2 for potential alternative standard levels, we also note the important uncertainties described in section 3.1.4 of this document. General uncertainties include the geographic heterogeneity in effect estimates, which could obscure presence of potential thresholds in multicity studies; uncertainty in the extent to which multicity effect estimates can be attributed to ambient O_3 in the majority of locations, which would have met alternative standards with levels of 70 or 65 ppb, versus O_3 in the smaller number of locations that would have violated those alternatives; and uncertainty in the extent to which the relatively low ambient O_3 concentrations present in some study areas caused or

[14]Cut point analyses presented in the study by Bell et al. (2006) are described in more detail in sections 3.1.2.3 and 3.1.4.2 of this document.

contributed to reported effects. Additional uncertainties specific to our analysis of the cut points presented by Bell et al. (2006) include the appropriateness of identifying 4th highest concentrations from air quality subsets, rather than the entire air quality distributions that existed in study locations, and uncertainty associated with the air quality data used to re-create the cut-point analyses from the published study. With regard to this second uncertainty, as described in more detail in section 3.1.4.2 of this document, our re-creation of the cut points was based on air quality data available in AQS, combined with the published descriptions of cut point criteria and study area definitions. In doing so, we did not recreate the trimmed means used by Bell. Therefore, an important uncertainty in this approach is the extent to which we were able to appropriately re-create the cut-point analyses in the published study.

Overall, our analyses of air quality in U.S. and Canadian epidemiologic study locations indicate that (1) single-city studies have not been conducted in locations that would have met alternative O_3 standards with levels of 70 ppb or below and that (2) multicity epidemiologic studies report positive and statistically significant associations with mortality and morbidity based largely on distributions of ambient O_3 that would have been allowed by alternative standards with levels of 70 or 65 ppb, but not 60 ppb. While important uncertainties, mentioned above, complicate our interpretation of the multicity studies, at a minimum these results suggest that an alternative standard level of 60 ppb would not allow the distributions of ambient O_3 concentrations present in the majority of study locations that provided the basis for statistically significant health effect associations. While the potential implications for alternative standard levels of 70 and 65 ppb are less clear, given the important uncertainties in these analyses, the results suggest that positive and statistically significant associations with mortality or morbidity in some studies were largely influenced by air quality distributions that would be allowed under alternative standards with such levels.

We next consider the extent to which epidemiologic studies employing longer-term ambient O_3 concentration metrics can inform our consideration of potential alternative standard levels. In doing so, we consider the following question:

- **To what extent does the available evidence indicate that an O_3 standard with a level from 70 to 60 ppb, combined with the current 8-hour averaging time and 4th high form, could provide protection from long-term exposures to ambient O_3 concentrations for which there is evidence of health effects?**

We first note that, as discussed in section 3.1.4.3 of this PA, virtually all of the study cities that provided the basis for the positive and statistically significant association between long-term O_3 and respiratory mortality (Jerrett et al., 2009) would have violated the current standard, and therefore potential alternative standards with lower levels. Thus, as with our

consideration of the current standard in section 3.1.4.3, while the study by Jerrett et al. (2009) contributes to our understanding of health effects associated with ambient O_3 (summarized in section 3.1.2), it is less informative regarding the extent to which those health effects may be occurring under air quality conditions that would meet potential alternative standards.

To further evaluate this issue, we use the adjusted air quality in urban case study areas, as described in the HREA, to consider the extent to which just meeting alternative O_3 standards with levels of 70, 65, and 60 ppb could maintain long-term O_3 concentrations below those in the cities that provided the basis for the positive and statistically significant association with respiratory mortality reported by Jerrett et al. (2009).[15] Upon adjustment of air quality in U.S. urban case study areas to meet the current and potential alternative 8-hour standards, seasonal average 1-hour daily max concentrations were calculated and compared to the concentrations in study cities.

As discussed in section 3.1.4.3, Jerrett et al. (2009) reported that when seasonal averages of 1-hour daily max O_3 concentrations[16] ranged from 33 to 104 ppb, there was no statistical deviation from a linear concentration-response relationship between O_3 and respiratory mortality across 96 U.S. cities (U.S. EPA, 2013, section 7.7). However, as discussed in section 3.1.4.3, the study suggests notably decreased confidence in the reported linear concentration-response function for "long-term" O_3 concentrations in the first quartile (i.e., at or below about 53 ppb), given the widening in confidence intervals for lower concentrations (based on visual inspection of Figure 3-6 in section 3.1.4.3); the fact that most study cities contributing to the linear function had O_3 concentrations in the highest three quartiles, accounting for approximately 72% of the respiratory deaths in the cohort (based on Table 2 in the published study); and the limited evidence presented in the published study for a threshold at or near 56 ppb.[17]

Given the above, we note the extent to which long-term O_3 concentrations (i.e., seasonal average of 1-hour daily max) in urban case study areas are estimated to be at or below 53 ppb following air quality adjustment to meet potential alternative standards with levels of 70, 65, and 60 ppb. To the extent air quality adjustment to just meet potential alternative short-term standards results in long-term concentrations near or below 53 ppb, we have greater confidence

[15]Air quality in U.S. urban case study areas was adjusted to just meet the current 8-hour standard at 75 ppb, as well as potential potential alternative 8-hour standards at 70 ppb, 65 ppb, and 60 ppb, as described in the HREA (chapter 4). After a given adjustment, seasonal average 1-hour daily max concentrations were calculated.

[16]Jerrett et al. (2009) evaluated the April to September averages of 1-hour daily max O_3 concentrations across 96 U.S. metropolitan areas from 1977- 2000. In urban areas with multiple monitors, April to September 1-hour daily max concentrations from each individual monitor were averaged. This step was repeated for each year in the study period. Finally, each yearly averaged O_3 concentrations was then averaged again to yield the single averaged 1-hour daily max O_3 concentration depicted on the x-axis of Figure 3-6 below.

[17]The issue of potential thresholds based on the Jerrett study is discussed in more detail in section 3.2.3.2 of this PA.

in the degree to which those short-term standards could protect against the health effects associated with longer term O_3 exposures. Though there is uncertainty associated with these comparisons (e.g., due to uncertainty in the potential for a threshold to exist; uncertainty in the identification of such a threshold, should one exist; uncertainty in the long-term concentration below which confidence intervals widen notably, based on visual inspection of concentration-response function in the published study; and the limited number of urban case study areas for which adjusted air quality is available), this analysis can provide insight into the extent to which various alternative short-term standards would be expected to maintain long-term O_3 concentrations below those where we have the most confidence in the reported concentration-response relationship with respiratory mortality.

Table 4-3 indicates that when considering recent (i.e., unadjusted) air quality, 2 of 12 urban case study areas had seasonal average 1-hour daily max O_3 concentrations at or below 53 ppb in all of the years examined. When air quality was adjusted to just meet the current 8-hour standard (75 ppb in Table 4-3), 6 of 12 urban case study areas had seasonal average 1-hour daily max O_3 concentrations at or below 53 ppb in all of the years examined. When air quality is further adjusted to just meet potential alternative standards with lower levels, seasonal averages of 1-hour daily max O_3 concentrations are estimated to be at or below 53 ppb in 9 of 12 urban case study areas (70 ppb level), 10 of 12 urban case study areas (65 ppb level), and 11 of 11 urban case study areas (60 ppb level).[18] Though as noted above there are important uncertainties associated with interpreting these comparisons, they suggest that in many locations across the U.S. a standard with an 8-hour averaging time, when combined with the current 4th high form and an appropriate standard level, would be expected to maintain seasonal averages of 1-hour daily max O_3 concentrations below those where analyses indicate the most confidence in the concentration-response relationship with respiratory mortality reported by Jerrett et al. (2009).

[18]As described in the HREA, a standard level of 60 ppb was not evaluated in New York City (U.S. EPA, 2014, chapter 4).

Table 4-3 Seasonal averages of 1-hour daily max O_3 concentrations in U.S. urban case study areas for recent air quality and air quality adjusted to just meet the current and potential alternative standards.

	Air Quality Adjusted to:	2006 (Adj Yrs 2006-2008)	2007 (Adj Yrs 2006-2008)	2008 (Adj Yrs 2008-2010)	2009 (Adj Yrs 2008-2010)	2010 (Adj Yrs 2008-2010)
Atlanta	Recent	65	63	57	50	56
	75	53	52	53	47	52
	70	50	49	49	44	49
	65	47	46	46	42	46
	60	45	44	44	40	44
Baltimore	Recent	60	59	57	52	60
	75	54	54	53	49	55
	70	52	51	51	48	53
	65	49	49	48	46	50
	60	46	46	46	44	48
Boston	Recent	49	50	46	45	49
	75	48	49	49	45	48
	70	46	47	48	44	48
	65	44	45	46	43	46
	60	43	43	44	41	44
Cleveland	Recent	51	52	53	49	54
	75	49	50	51	47	51
	70	47	48	48	45	48
	65	45	45	45	43	45
	60	41	41	41	40	42
Denver	Recent	63	63	63	58	60
	75	62	61	63	58	60
	70	60	59	62	58	58
	65	58	58	59	56	55
	60	53	53	53	51	50
Detroit	Recent	50	54	51	48	52
	75	50	52	NA	NA	NA
	70	48	50	51	49	52
	65	47	49	49	47	50
	60	45	46	46	45	47
Houston	Recent	53	48	47	47	46
	75	48	46	47	48	46
	70	47	45	46	47	46
	65	46	44	45	46	45
	60	45	43	43	44	44
Los Angeles	Recent	65	61	64	62	57
	75	58	59	60	60	58
	70	55	56	57	58	56
	65	52	53	54	54	53
	60	50	51	52	52	50
New York City	Recent	53	54	55	48	55
	75	47	47	51	47	51
	70	44	45	48	45	48
	65	36	36	39	38	39
	60	NA	NA	NA	NA	NA
Philadelphia	Recent	56	59	57	51	58
	75	51	52	54	49	54
	70	49	50	51	47	52
	65	47	48	49	45	49
	60	45	46	47	43	47
Sacramento	Recent	66	59	65	61	55
	75	55	50	54	51	48
	70	52	48	51	49	46
	65	50	46	49	47	44
	60	47	44	46	44	42
Saint Louis	Recent	58	58	52	51	55
	75	53	53	51	50	54
	70	50	51	50	48	52
	65	47	48	48	46	49
	60	44	45	45	43	46

Based on the above analyses, we conclude that the available epidemiologic evidence is consistent with the available evidence from controlled human exposure studies in providing support for consideration of an O_3 standard level in the range of 70 to 60 ppb. Compared to the current standard, a standard level from within this range would expected to be more effective at maintaining short-term and long-term ambient O_3 concentrations below those present in studies reporting O_3-associated mortality and/or morbidity.

In reaching overall staff conclusions about an appropriate range of standard levels for consideration, we further evaluate the results of the exposure and risk assessments that are based on modeling changes in the entire distribution of ambient O_3 concentrations to simulate just meeting potential alternative standards. These results are discussed below in section 4.4.2.

4.4.2 Air Quality-, Exposure-, and Risk-Based Considerations

Beyond considering the available evidence, we also consider the extent to which specific potential alternative standard levels, in conjunction with the current averaging time and form (3-year average of annual 4th highest 8-hour daily max), could reduce estimated O_3 exposures and health risks. In the first draft PA (U.S. EPA, 2012b), we concluded that the available evidence supports conducting further exposure and risk analyses of potential alternative O_3 standard levels in the range of 70 down to 60 ppb. Based on these conclusions, the HREA evaluates exposures and risks estimated to be associated with potential alternative standard levels from the upper (70 ppb), middle (65 ppb), and lower (60 ppb) portions of this range. In considering these analyses in this PA, we consider the following question:

- **To what extent does the available exposure and risk information provide support for considering potential alternative standard levels from 70 to 60 ppb, when combined with the current 8-hour averaging time and 4th high form?**

In considering exposure and risk analyses, we emphasize the nature and magnitude of the O_3 exposures and health risks estimated to remain upon just meeting each alternative standard level, and the changes in exposures and risks estimated for each alternative level when compared to the current standard. Section 4.4.2.1 below discusses our exposure-based considerations. Sections 4.4.2.2 and 4.4.2.3 discuss our consideration of estimates of lung function risks and estimates of epidemiology-based mortality/morbidity risks, respectively.

4.4.2.1 Exposure-Based Considerations

As discussed in more detail in section 3.2.2 of this PA, the exposure assessment presented in the HREA (U.S. EPA, 2014, Chapter 5) provides estimates of the number and percent of people exposed to O_3 concentrations at or above benchmark concentrations of 60, 70, and 80 ppb, while at moderate or greater exertion. Estimates of such "exposures of concern"

provide perspective on the potential public health impacts of O_3-related effects, including for effects that cannot currently be evaluated in a quantitative risk assessment. The approach taken in the HREA to estimating exposures of concern, and the key uncertainties associated with exposure estimates, are summarized in section 3.2.2 for air quality adjusted to just meet the current standard and are discussed in more detail in chapter 5 of the HREA (U.S. EPA, 2014). As discussed in section 3.2.2, when evaluating potential alternative standard levels we focus on modeled exposures for school-age children (ages 5-18), noting that percentages of asthmatic school-age children estimated to experience exposures of concern are virtually indistinguishable from those for all children, and that patterns of exposure in children represent a broader range of at-risk populations, which includes adult asthmatics and older adults. In this review, CASAC advised EPA to focus on the 60 ppb benchmark as being relevant for considering adverse effects on people with asthma (Frey, 2014, p. 6).

In this section, we consider the following question:

- **To what extent are potential alternative standards with revised levels estimated to reduce the occurrence of O_3 exposures of concern, compared to the current standard, and what are the nature and magnitude of the exposures remaining for each alternative standard level evaluated?**

Key results related to this question are summarized below (Figures 4-1 to 4-4). Figures 4-1 (estimates averaged over years) and 4-2 (estimates from worst-case years) present estimates of one or more exposures of concern, and Figures 4-3 (estimates averaged over years) and 4-4 (estimates from worst-case years) present estimates of two or more exposures of concern.

Figure 4-1. Percent of children estimated to experience one or more exposures of concern at or above 60, 70, or 80 ppb for air quality adjusted to just meet the current and potential alternative standards (averaged over 2006 to 2010)

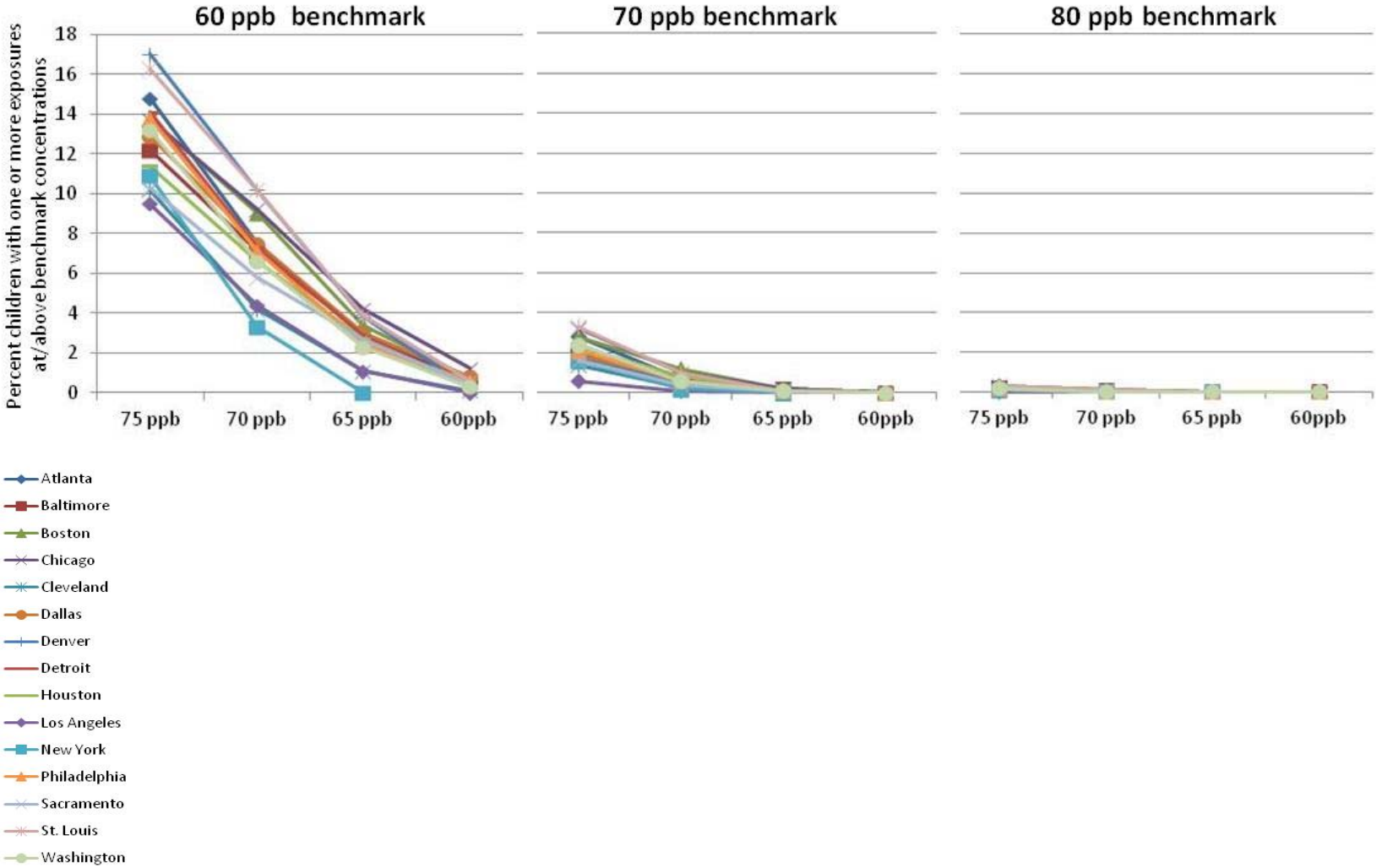
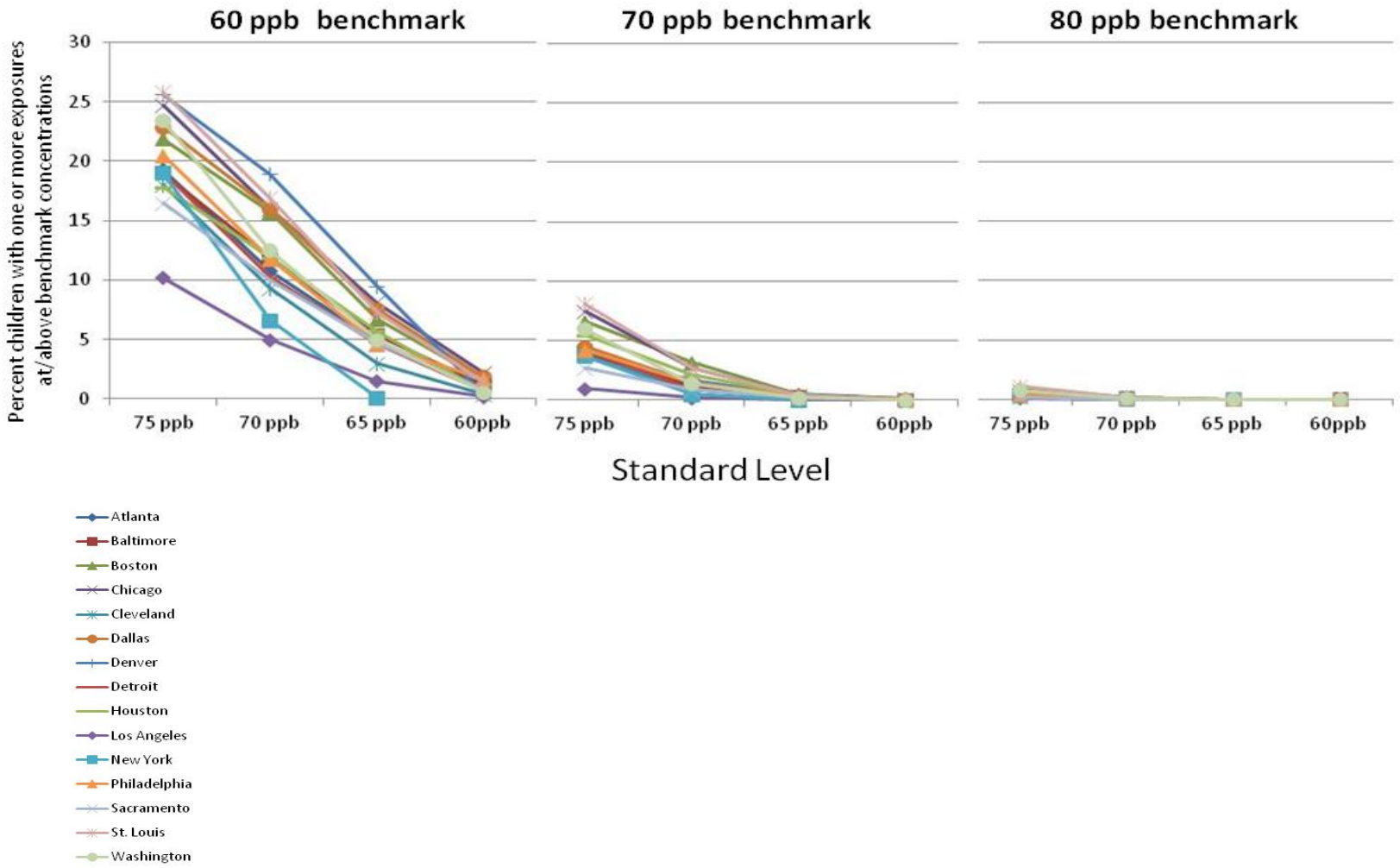


Figure 4-2. Percent of children estimated to experience one or more exposures of concern at or above 60, 70, or 80 ppb for air quality adjusted to just meet the current and potential alternative standards (worst-case year from 2006 to 2010[19])



[19]"Worst-case" year refers to the year in each urban case study area with the largest percentage of children estimated to experience exposures of concern.

Figure 4-3. Percent of children estimated to experience two or more exposures of concern at or above 60, 70, or 80 ppb for air quality adjusted to just meet the current and potential alternative standards (averaged over 2006 to 2010)

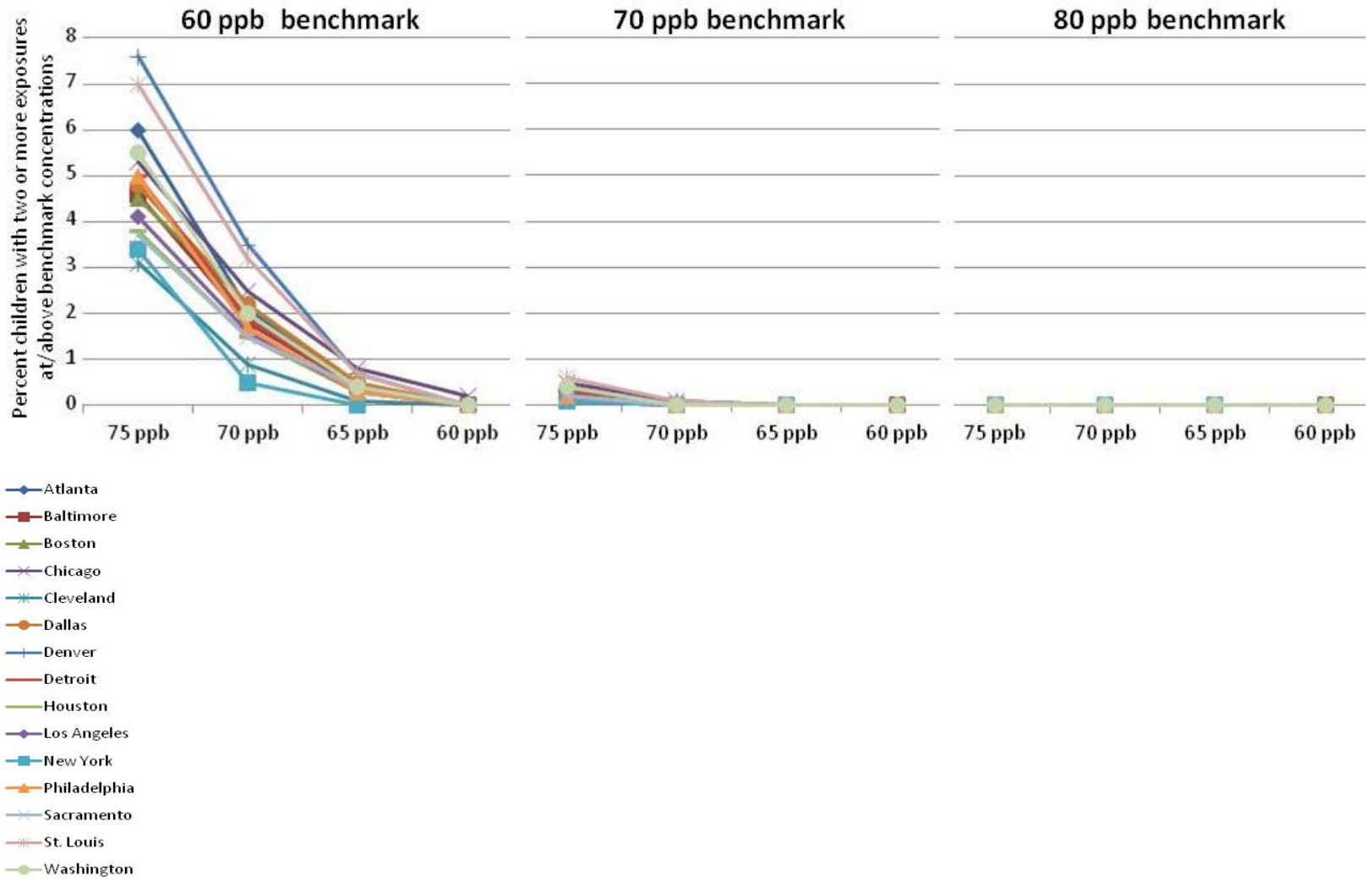
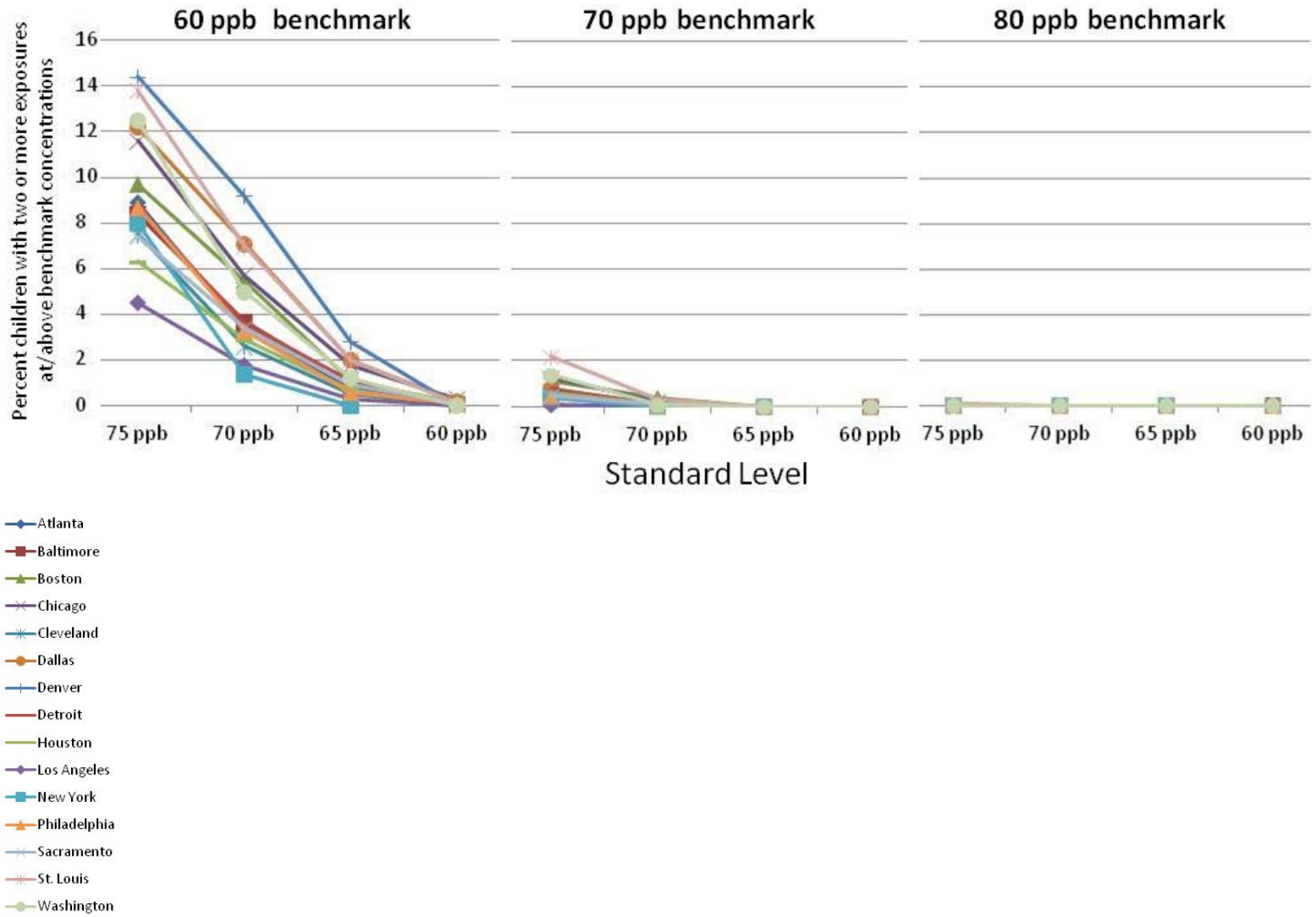


Figure 4-4. Percent of children estimated to experience two or more exposures of concern at or above 60, 70, or 80 ppb for air quality adjusted to just meet the current and potential alternative standards (worst-case year from 2006 to 2010)



As illustrated above in Figures 4-1 to 4-4, adjusting air quality to just meet progressively lower potential alternative standard levels reduces estimated exposures of concern consistently across urban case study areas. These results reflect the consistent reductions in the highest ambient O_3 concentrations upon air quality adjustment, as summarized in section 3.2.1 and as discussed in more detail in the HREA (U.S. EPA, 2014, chapter 4). Based on Figures 4-1 to 4-4 and the associated details described in the HREA (U.S. EPA 2014, chapter 5), we take note of the following with regard to exposures of concern for specific potential alternative standard levels:

1. For an O_3 standard level of 70 ppb:
    a. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow approximately 3 to 10% of children in urban case study areas to experience one or more exposures of concern at or above 60 ppb (approximately 30 to 70% reduction, relative to current standard). Summing across urban case study areas, these percentages correspond to over 1 million children experiencing over 1.5 million exposures of concern at or above 60 ppb during a single O_3 season. Of these children, over 100,000 are asthmatics.

    b. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow approximately 0.5 to 3.5% of children in urban case study areas to experience two or more exposures of concern at or above 60 ppb (approximately 50 to 85% reduction, relative to current standard).

    c. In the worst-case years (i.e., those with the largest exposure estimates), a standard with a level of 70 ppb is estimated to allow approximately 5 to 19% of children in urban case study areas to experience one or more exposures of concern at or above 60 ppb, and approximately 2 to 9% to experience two or more.

    d. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow approximately 1% or less of children to experience one or more exposures of concern at or above 70 ppb (approximately 55 to 90% reduction, relative to current standard), and far less than 1% to experience two or more such exposures (approximately 65 to 100% reduction, relative to current standard).

    e. In the worst-case years, approximately 3% or less of children are estimated to experience one or more exposures of concern at or above 70 ppb, and less than 1% are estimated to experience two or more such exposures.

    f. A standard with a level of 70 ppb is estimated to allow less than 1% of children to experience one or more exposures of concern at or above 80 ppb, even in the worst-case years. No children are estimated to experience two or more such exposures.

2. For an O_3 standard level of 65 ppb:

a. On average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow approximately 4% or less of children in urban case study areas to experience one or more exposures of concern at or above 60 ppb (approximately 70 to 100% reduction, relative to current standard). Summing across urban case study areas, these percentages correspond to almost 400,000 children experiencing almost 500,000 exposures of concern at or above 60 ppb during a single O_3 season. Of these children, about 40,000 are asthmatics.

b. On average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow less than 1% of children to experience two or more exposures of concern at or above 60 ppb (approximately 85 to 100% reduction, relative to current standard).

c. In the worst-case years, a standard with a level of 65 ppb is estimated to allow approximately 10% or less of children to experience one or more exposures of concern at or above 60 ppb, and approximately 3% or less to experience two or more such exposures.

d. On average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow approximately 1% or less of children to experience one or more exposures of concern at or above 70 ppb (approximately 90 to 100% reduction, relative to current standard), and almost no children to experience two or more such exposures. Even in the worst-case years, a level of 65 ppb is estimated to allow less than 1% of children to experience exposures of concern at or above 70 ppb.

e. A standard with a level of 65 ppb is estimated to allow virtually no children to experience exposures of concern at or above 80 ppb, even in the worst-case years.

3. For an O_3 standard level of 60 ppb:
   a. On average over the years 2006 to 2010, a standard with a level of 60 ppb is estimated to allow approximately 1% or less of children to experience one or more exposures of concern at or above 60 ppb (approximately 90 to 100% reduction, relative to current standard), and virtually no children to experience multiple such exposures.

   b. In the worst-case years, a standard with a level of 60 ppb is estimated to allow approximately 2% or less of children to experience one or more exposures of concern at or above 60 ppb, and almost no children to experience multiple such exposures.

   c. On average over the years 2006 to 2010, a standard with a level of 60 ppb is estimated to almost eliminate exposures of concern at or above 70 ppb or 80 ppb. Even in years with the highest exposure estimates, virtually no children are estimated to experience such exposures.

In further considering these exposure estimates, we take note of the associated uncertainties, as discussed in more detail in section 3.2.2 of this PA (and in Chapter 5 of the

HREA, U.S. EPA, 2014). These include (1) individual variability in responsiveness to O_3 exposures such that only a subset of individuals who experience exposures at (or above) a benchmark concentration would experience health effects; (2) potential to underestimate exposures in most highly exposed populations; and (3) potential to overestimate exposures in populations who alter behavior in response to high O_3 days (i.e., spend less time being active outdoors). The implications of estimated exposures of concern for potential alternative standard levels are discussed below in section 4.6.

4.4.2.2 Risk-Based Considerations: Lung Function

As discussed above in more detail in section 3.2.3.1 of this PA, the assessment of lung function risks presented in the HREA (U.S. EPA, 2014, Chapter 6) provides estimates of the number and percent of people experiencing O_3-induced lung function decrements greater than or equal to 10, 15, and 20%. In the current and past reviews, CASAC has advised EPA to focus on decrements of 10% or greater when considering people with pre-existing lung disease (Frey, 2014; Samet, 2011).

Lung function risk estimates are based on an updated dose-threshold model that estimates FEV_1 responses for healthy adults following short-term exposures to O_3 (McDonnell, Stewart, and Smith, 2010), reflecting methodological improvements since the last review (U.S. EPA, 2014, section 6.2.4). The approach taken in the HREA to estimating O_3-induced lung function decrements, and the key uncertainties associated with these estimates, are summarized in section 3.2.3.1 for air quality adjusted to just meet the current standard and are discussed in more detail in chapter 6 of the HREA (U.S. EPA, 2014).

As discussed in section 3.2.3.1, in evaluating potential alternative standard levels we focus on modeled exposures for school-age children, with an emphasis on asthmatic children. As with exposures of concern, the percentages of all school age children and asthmatic school age children estimated to experience particular O_3-induced lung function decrements are virtually indistinguishable.

In this section, we consider the following question:

- **To what extent are potential alternative standards with revised levels estimated to decrease the occurrence of O_3-induced lung function decrements, compared to the current standard, and what are the nature and magnitude of the decrements remaining for each alternative standard level evaluated?**

Key results related to this question are summarized below (Figures 4-5 to 4-8). Figures 4-5 (estimates averaged over years) and 4-6 (estimates from worst-case years) present estimates of one or more O_3-induced lung function decrements, and Figures 4-7 (estimates averaged over years) and 4-8 (estimates from worst-case years) present estimates of two or more decrements.

Figure 4-5. Percent of children estimated to experience one or more O_3-induced lung function decrements greater than 10, 15, or 20% for air quality adjusted to just meet the current and potential alternative standards (averaged over 2006 to 2010)

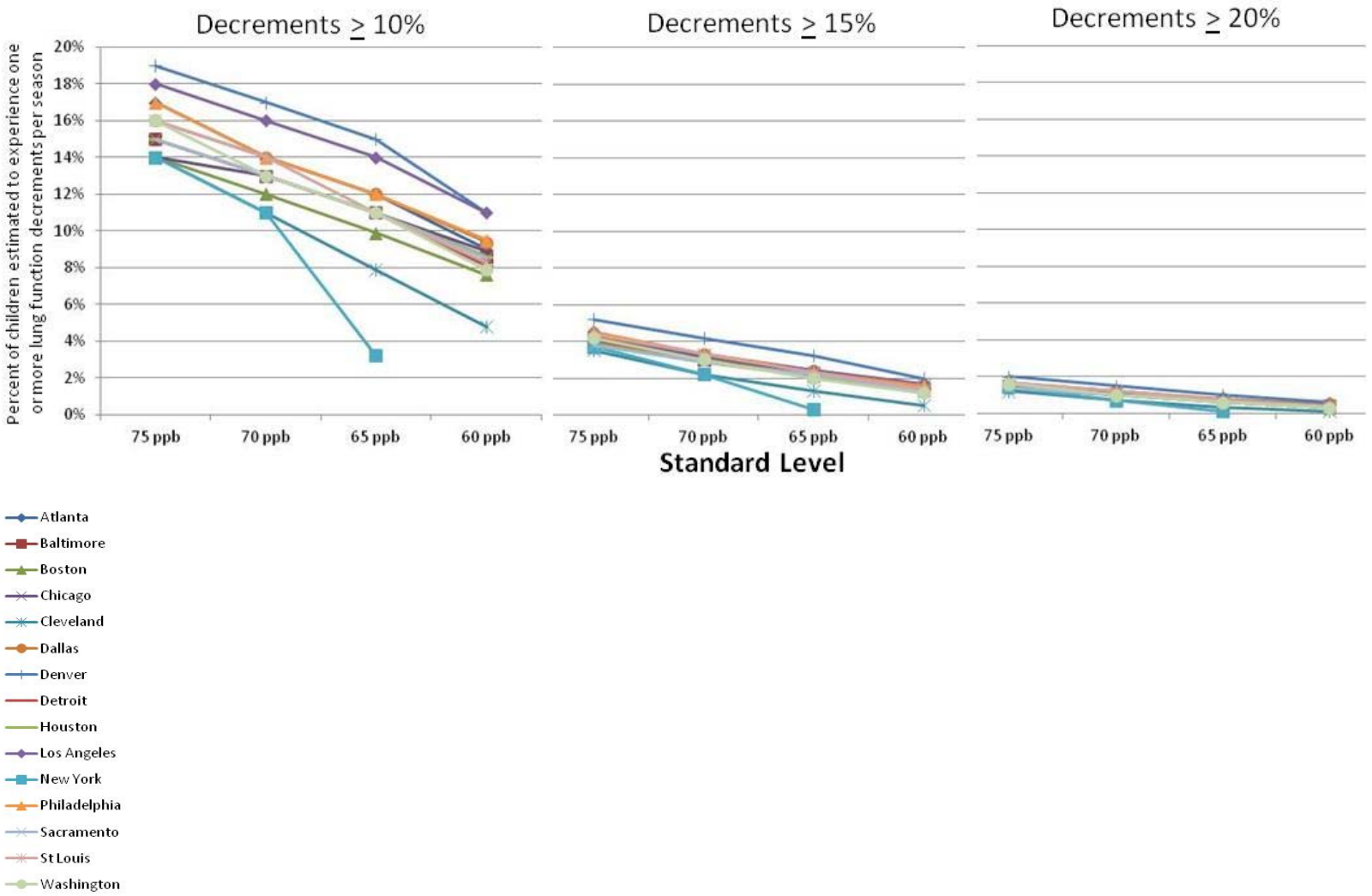


Figure 4-6. Percent of children estimated to experience one or more O_3-induced lung function decrements greater than 10, 15, or 20% for air quality adjusted to just meet the current and potential alternative standards (worst-case year from 2006 to 2010)

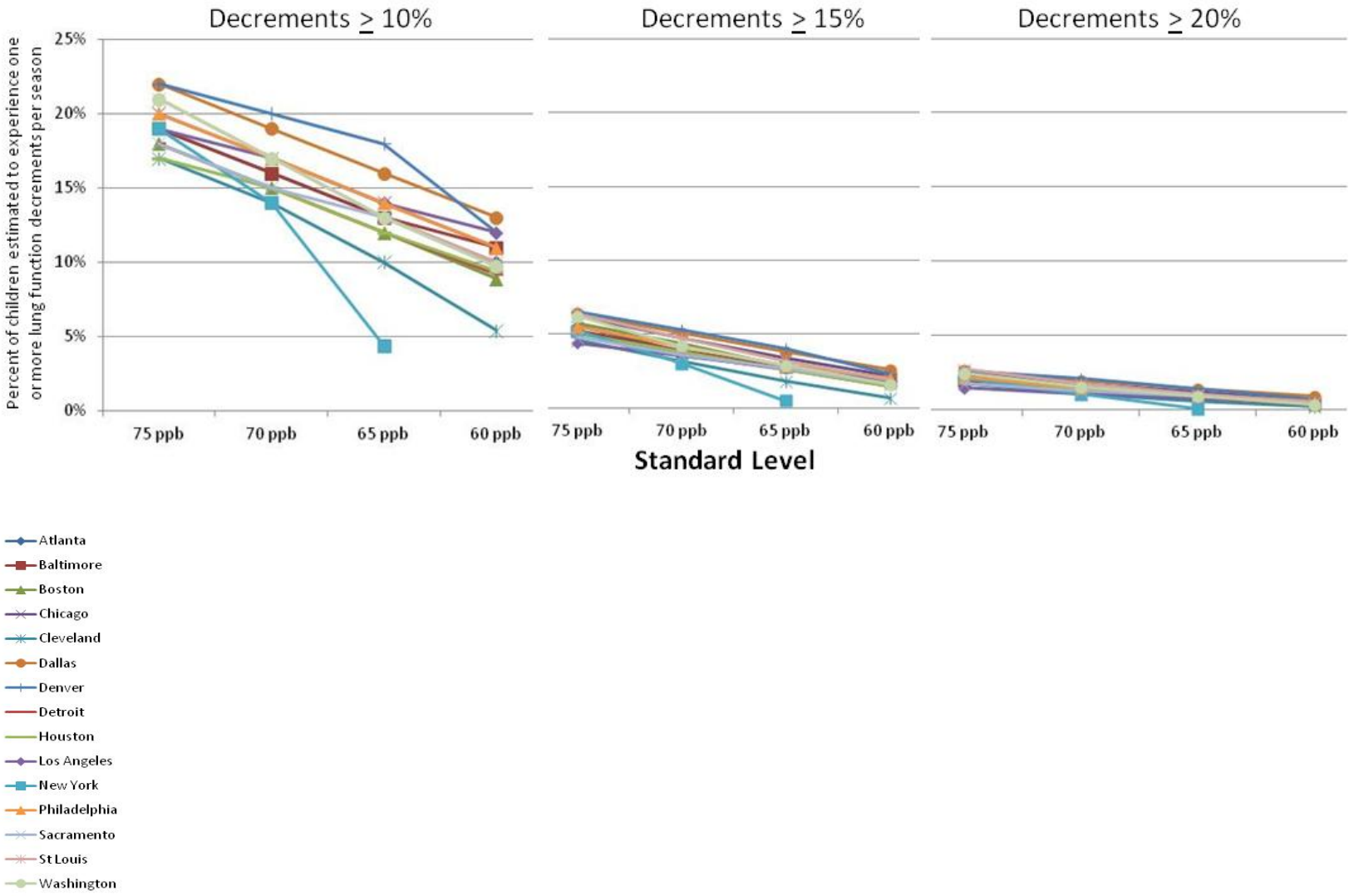


Figure 4-7. Percent of children estimated to experience two or more O_3-induced lung function decrements greater than 10, 15, or 20% for air quality adjusted to just meet the current and potential alternative standards (averaged over 2006 to 2010)

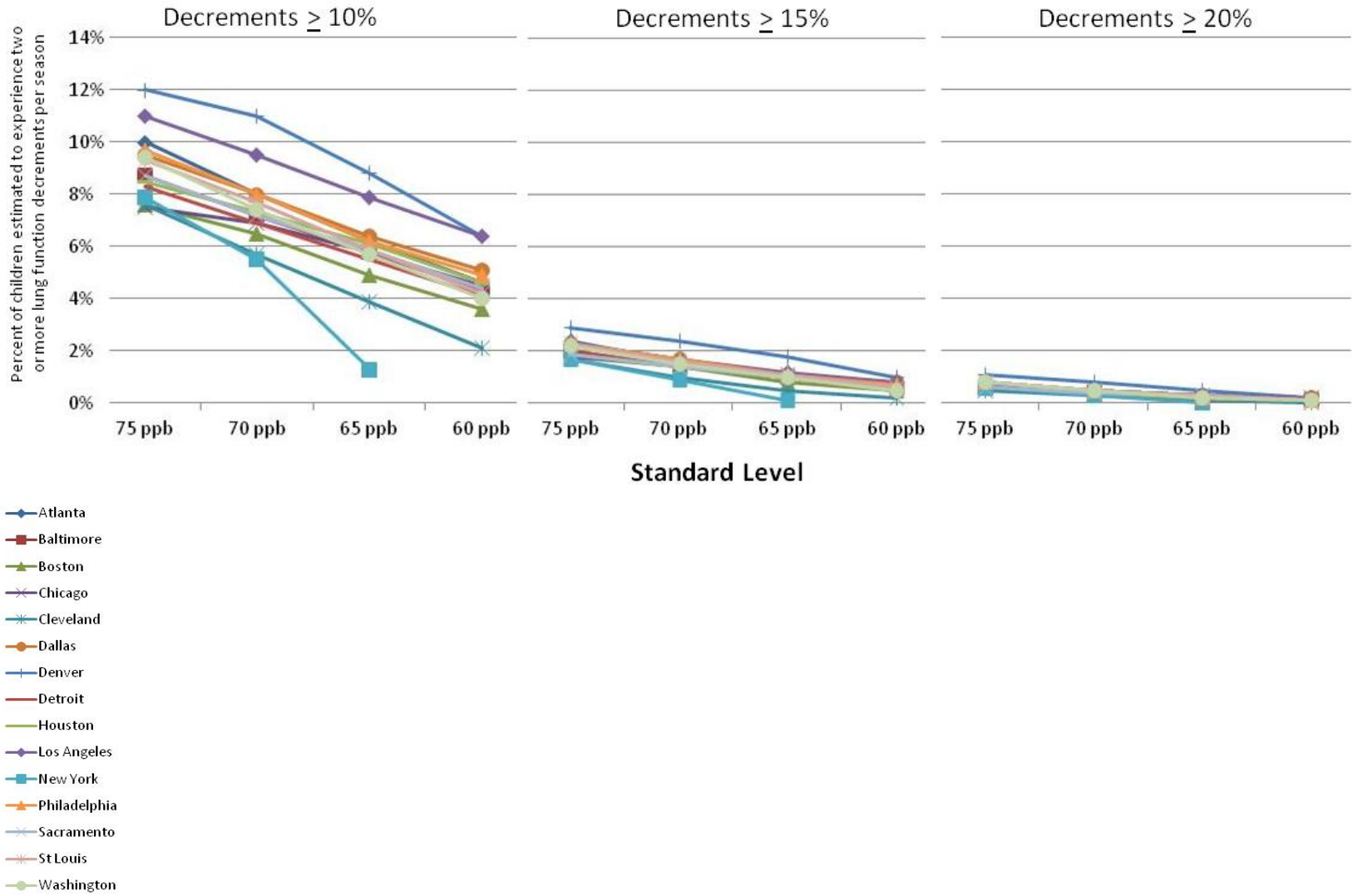
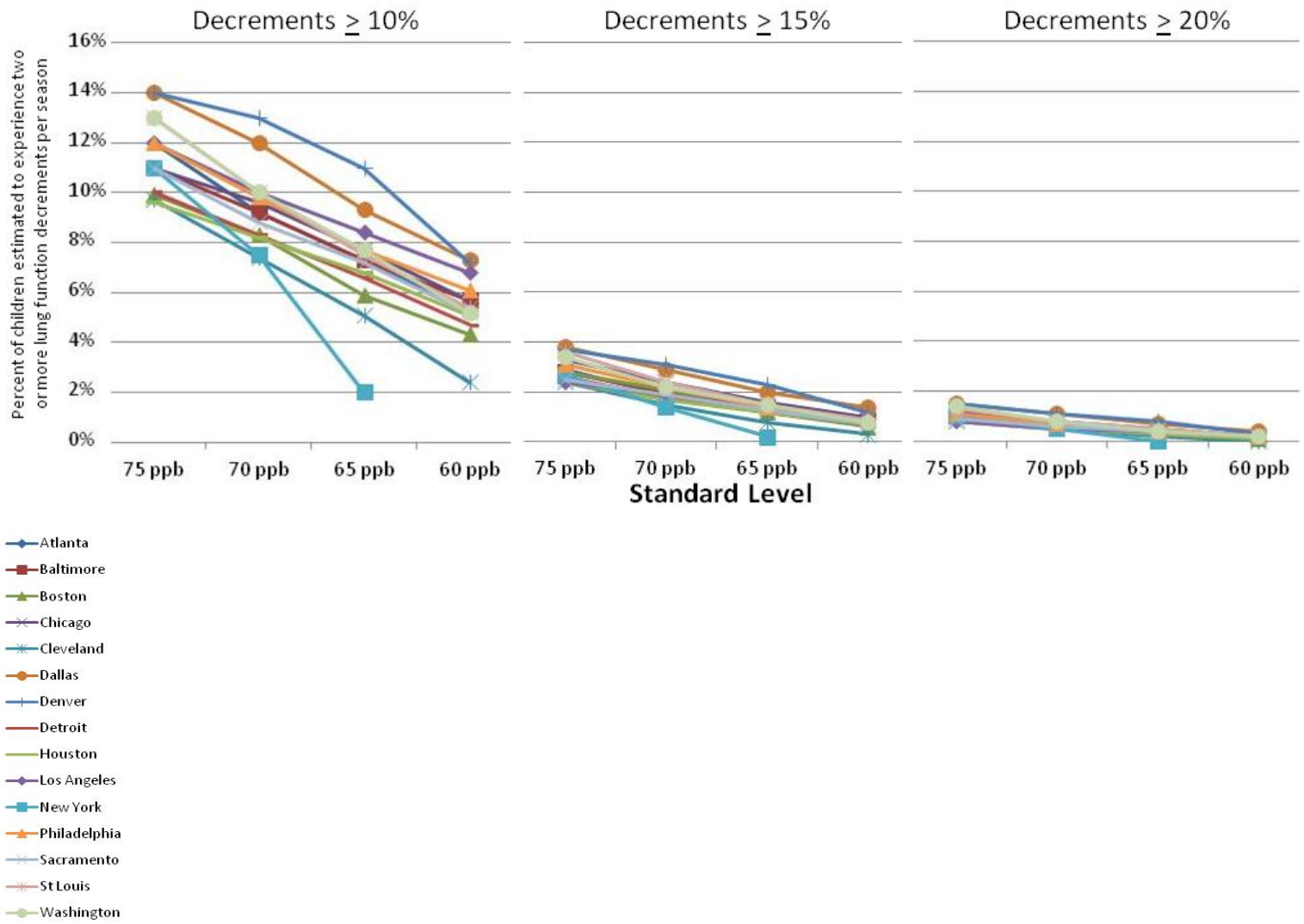


Figure 4-8. Percent of children estimated to experience two or more O_3-induced lung function decrements greater than 10, 15, or 20% for air quality adjusted to just meet the current and potential alternative standards (worst-case year from 2006 to 2010)



As illustrated above in Figures 4-5 to 4-8, adjusting air quality to just meet progressively lower potential alternative standard levels consistently reduces the percent of children estimated to experience potentially adverse lung function decrements. These results reflect the consistent reductions in the highest ambient O_3 concentrations upon air quality adjustment (section 3.2.1; U.S. EPA, 2014, chapter 4).[20] Based on Figures 4-5 to 4-8 and the associated details described in the HREA (U.S. EPA 2014, chapter 6), we take note of the following with regard to specific potential alternative standard levels:

1. For an O_3 standard level of 70 ppb:
    a. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow approximately 11 to 17% of children in urban case study areas, including asthmatic children, to experience one or more O_3-induced lung function decrements ≥ 10% (approximately 6 to 27% reduction, relative to current standard) per season. Summing across case study areas, these percentages correspond to approximately 260,000 asthmatic children experiencing approximately 1 million total occurrences of O_3-induced lung function decrements greater than or equal to 10%.

    b. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow approximately 6 to 11% of children, including asthmatic children, to experience two or more O_3-induced lung function decrements ≥ 10% (approximately 8 to 30% reduction, relative to current standard).

    c. In the worst-case years, a standard with a level of 70 ppb is estimated to allow approximately 14 to 20% of children, including asthmatic children, to experience one or more O_3-induced lung function decrements ≥10%, and approximately 7 to 13% to experience two or more such decrements.

    d. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow approximately 2 to 4% of children, including asthmatic children, to experience one or more O_3-induced lung function decrements ≥ 15%, and approximately 1 to 2.5% of children to experience two or more such O_3-induced decrements. In the worst-case years, approximately 3 to 5% of children are estimated to experience one or more O_3-induced lung function decrements ≥15%, and approximately 1 to 3% are estimated to experience two or more such decrements.

    e. A standard with a level of 70 ppb is estimated to allow 2% or fewer children to experience any O_3-induced lung function decrements ≥ 20%, even in the worst-case years. Approximately 1% or fewer children are estimated to experience two

[20]As discussed in section 3.2.3.1, the impact of the dose threshold in the lung function risk model is that O_3-induced FEV_1 decrements result primarily from exposures on days with average ambient O_3 concentrations above about 40 ppb (US EPA, 2014, section 6.3.1, Figure 6-9).

or more O_3-induced lung function decrements ≥ 20%, even in the worst-case years.

2. For an O_3 standard level of 65 ppb:
    a. On average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow approximately 3 to 15% of children, including asthmatic children, to experience one or more O_3-induced lung function decrements ≥ 10% (approximately 20 to 77% reduction, relative to current standard). Summing across urban case study areas, these percentages correspond to approximately 190,000 asthmatic children experiencing almost 750,000 total occurrences of O_3-induced lung function decrements ≥ 10%.

    b. On average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow approximately 1 to 9% of children, including asthmatic children, to experience two or more O_3-induced lung function decrements ≥ 10% (approximately 20 to 80% reduction, relative to current standard).

    c. In the worst-case years, a standard with a level of 65 ppb is estimated to allow approximately 4 to 18% of children to experience one or more O_3-induced lung function decrements ≥ 10%, and approximately 2 to 11% to experience two or more such decrements.

    d. On average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow approximately 3% or less of children to experience one or more O_3-induced lung function decrements ≥ 15%, and approximately 2% or less of children to experience two or more such O_3-induced decrements. In the worst-case years, approximately 4% or less of children are estimated to experience one or more O_3-induced lung function decrements ≥ 15%, and up to approximately 2% are estimated to experience two or more such decrements.

    e. A standard with a level of 65 ppb is estimated to allow less than 1.5% of children to experience any O_3-induced lung function decrements ≥ 20%, even in the worst-case years. A standard with a level of 65 ppb is estimated to allow less than 1% of children to experience two or more O_3-induced lung function decrements ≥ 20%, even in the worst-case years.

3. For an O_3 standard level of 60 ppb:
    a. On average over the years 2006 to 2010, a standard with a level of 60 ppb is estimated to allow approximately 5 to 11% of children, including asthmatic children, to experience one or more O_3-induced lung function decrements ≥ 10% (approximately 35 to 77% reduction, relative to current standard). Summing across urban case study areas, these percentages correspond to approximately 140,000 asthmatic children experiencing approximately 500,000 total occurrences of O_3-induced lung function decrements ≥ 10%.

b. On average over the years 2006 to 2010, a standard with a level of 60 ppb is estimated to allow approximately 2 to 6% of children to experience two or more O_3-induced lung function decrements ≥ 10% (approximately 40 to 70% reduction, relative to current standard).

c. In the worst-case years, a standard with a level of 60 ppb is estimated to allow approximately 5 to 13% of children to experience one or more O_3-induced lung function decrements ≥ 10%, and approximately 2 to 7% to experience two or more such decrements.

d. A standard with a level of 60 ppb is estimated to allow less than about 3% of children to experience any O_3-induced lung function decrements ≥ 15% and less than 1% to experience decrements greater than 20%, even in the worst-case years. A standard with a level of 60 ppb is estimated to allow less than 1.5% of children to experience two or more O_3-induced lung function decrements ≥ 15% and less than 0.5% to experience two or more decrements ≥ 20%, even in the worst-case years.

In further considering these exposure estimates, we take note of the associated uncertainties, as discussed in more detail in section 3.2.2 of this PA. In addition to the uncertainties in exposure estimates noted above, these include the relative lack of exposure-response information for key at-risk populations (i.e., children and asthmatics), since most controlled human exposures studies are conducted in healthy adults. Section 4.6 (below) discusses the implications of estimates of the occurrence of O_3-induced lung function decrements for potential alternative standard levels.

4.4.2.3 Risk-Based Considerations: Epidemiology-Based Mortality and Morbidity

The epidemiology-based risk assessments presented in the HREA (U.S. EPA, 2014, chapter 7) provide estimates of total mortality, respiratory hospital admissions and emergency department visits, and asthma exacerbations associated with short-term O_3 concentrations. The HREA also presents estimates of respiratory mortality associated with long-term[21] concentrations. In evaluating these risk estimates, we consider the following question:

[21]Estimates of respiratory mortality associated with long-term O_3 concentrations are based on the study by Jerrett et al. (2009). Consistent with the O_3 metric used in the study, risk estimates are based on seasonal averages of 1-hour daily max O_3 concentrations.

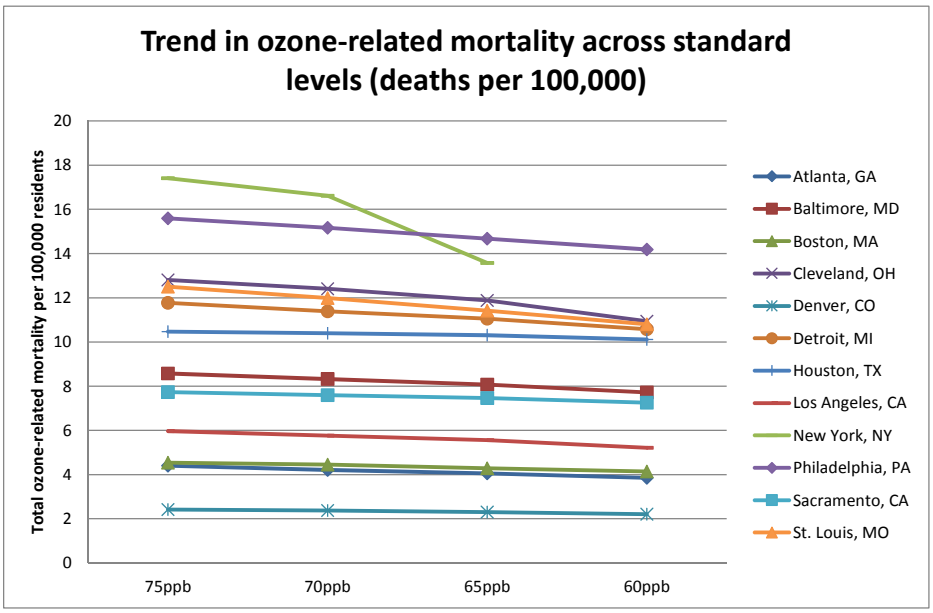
- **To what extent are potential alternative standards with revised levels estimated to decrease O_3 health risks, compared to the current standard, and what are the nature and magnitude of the health risks remaining for each alternative standard level evaluated?**

As discussed in more detail in section 3.2.3.2 of this PA, in considering this question we are mindful that the model-based approach used to adjust air quality in the HREA has important implications for risk estimates developed by applying concentration-response relationships from epidemiologic studies (section 3.2.1). In particular, given the use of linear concentration-response relationships, risk estimates are equally influenced by decreasing high O_3 concentrations and increasing low O_3 concentrations following air quality adjustment, when the increases and decreases are of equal magnitude. This and other uncertainties associated with risk estimates are discussed in section 3.2.3.2.

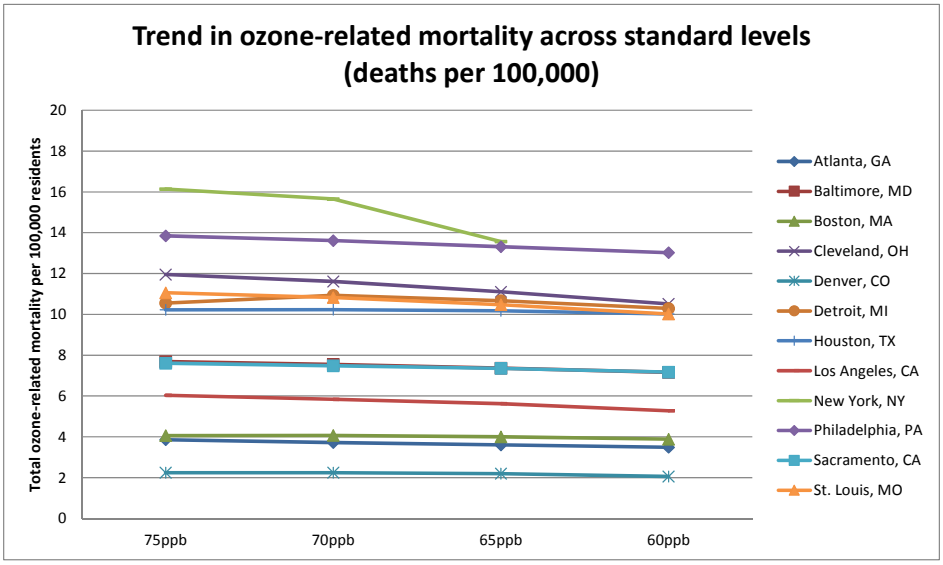
Key results from the HREA (U.S. EPA, 2014, chapter 7) are summarized below for estimates of total mortality associated with short-term O_3 concentrations (Figures 4-9 and 4-10) and respiratory hospital admissions associated with short-term O_3 concentrations (Figure 4-11). The other morbidity effects evaluated in the HREA (i.e., respiratory emergency department visits and asthma symptoms associated with short-term concentrations) exhibit patterns across standard levels that are similar to those reported for total mortality and respiratory hospital admissions (U.S. EPA, 2014, chapter 7).

Figure 4-9. Estimates of Total Mortality Associated with Short-Term O_3 Concentrations in Urban Case Study Areas (Air Quality Adjusted to Current and Potential alternative standard levels) – Total Risk

2007 Simulation year



2009 Simulation year



The risk estimates presented in Figure 4-9 above are based on applying linear concentration-response relationships to the full distributions of daily 8-hour "area-wide" O_3 concentrations. However, as in section 3.2.3.2 we note the ISA conclusion that there is less certainty in the shape of concentration-response functions for area-wide O_3 concentrations at the lower ends of warm season distributions (i.e., below about 20 to 40 ppb depending on the O_3

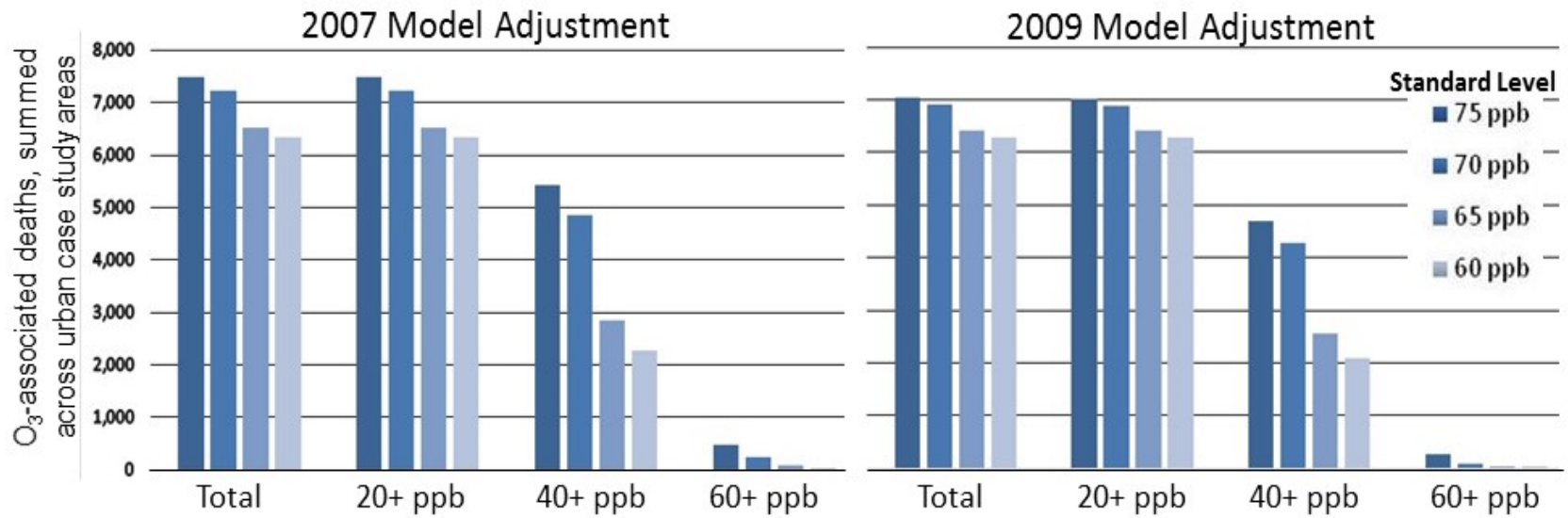
metric, health endpoint, and study population) (U.S. EPA, 2013, section 2.5.4.4). We also recognize that for the range of health endpoints evaluated, controlled human exposure and animal toxicological studies provide greater certainty in the increased incidence, magnitude, and severity of effects at higher exposure concentrations (discussed in sections 3.1.2.2 and 3.1.4.2 of this document).[22] Thus, in addition to considering estimates of total O_3-associated risks, we also consider the extent to which risks are associated with days with higher, versus lower, area-wide O_3 concentrations.

Figure 4-10 presents estimates of O_3-associated deaths, summed across urban case study areas, for days with area-wide concentrations at or above 20, 40, and 60 ppb. As discussed in more detail in section 3.2.1 of this document, daytime O_3 concentrations in the upper portions of the distributions of area-wide concentrations tend to decrease upon adjustment to meet lower potential alternative standard levels, while concentrations in the lower portions of these distributions tend to increase. As a result, lower standard levels are estimated to be more effective at reducing deaths associated with the upper portions of these distributions of ambient O_3 concentrations than deaths associated with the full distributions.[23]

[22]As discussed in section 3.1.4.2, as ambient concentrations increase the potential for exposures to higher O_3 concentrations also increases. Thus with increasing ambient concentrations, controlled human exposure and animal toxicological studies provide greater certainty in the increased incidence, magnitude, and severity of O_3-attributable effects.

[23]The relatively small proportion of O_3-associated deaths attributable to days with area-wide concentrations of 60 ppb or greater reflects the relatively small proportion of days with such elevated area-wide concentrations.

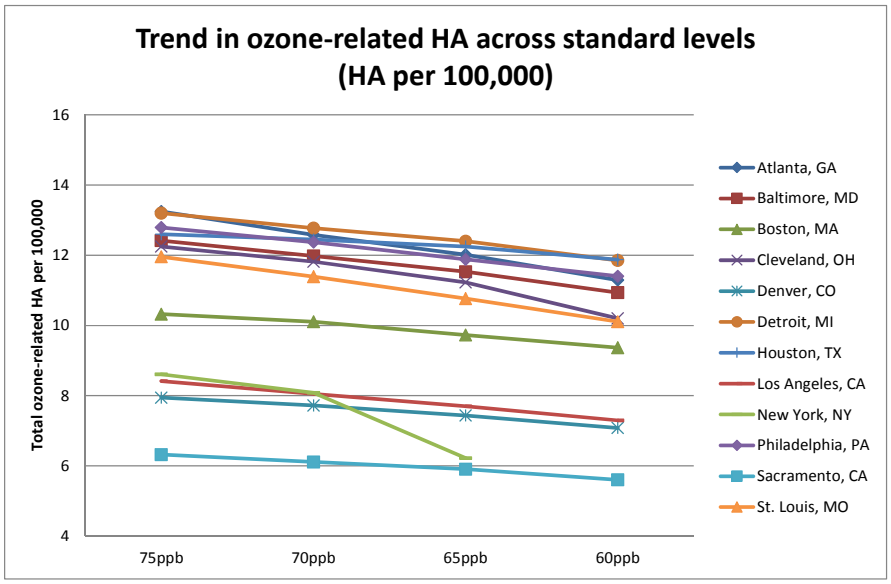
Figure 4-10. Estimates of O_3-Associated Deaths Attributable to Full Distribution of 8-Hour Area-Wide O_3 Concentrations and to Concentrations at or above 20, 40, or 60 ppb - Deaths Summed Across Urban Case Study Areas[24]



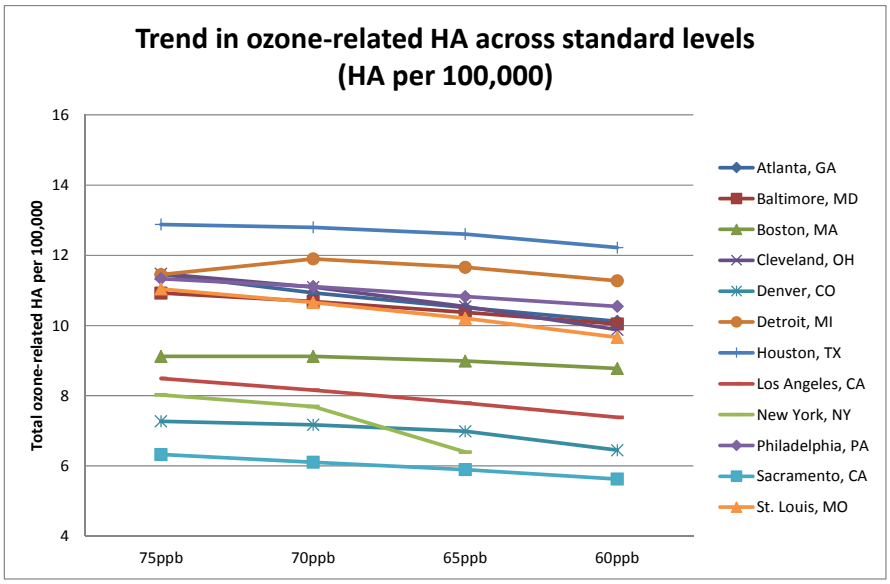
[24]As discussed in section 4.3.3 of the HREA, the model-based air quality adjustment approach used to estimate risks associated with the current and alternative standards was unable to estimate the distribution of ambient O_3 concentrations in New York City upon just meeting an alternative standard with a level of 60 ppb. Therefore, the total number of deaths indicated for the 60 ppb standard level in Figure 4-10 reflects the 60 ppb estimates for all urban case study areas except New York City. For New York City, the estimated number of O_3-associated deaths for the 65 ppb standard level was assumed.

Figure 4-11. Estimates of Respiratory Hospital Admissions Associated with Short-Term O_3 Concentrations in Urban Case Study Areas (Air Quality Adjusted to Current and Potential alternative standard levels) – Total Risk

2007 Simulation year



2009 Simulation year

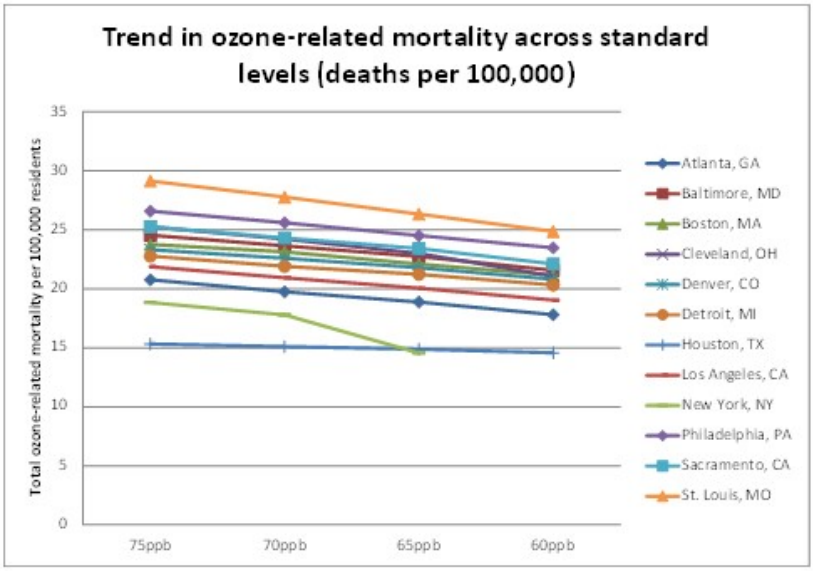


Key results from the HREA (U.S. EPA, 2014, chapter 7) are summarized in Figure 4-12 below for estimates of respiratory mortality associated with long-term O_3 concentrations, based on the study by Jerrett et al. (2009). As discussed in section 3.2.3.2 of this PA, Jerrett et al. (2009) reported that when seasonal averages of 1-hour daily maximum O_3 concentrations ranged from 33 to 104 ppb, there was no statistical deviation from a linear concentration-response relationship between O_3 and respiratory mortality across 96 U.S. cities (U.S. EPA, 2013, section 7.7). However, the authors reported "limited evidence" for an effect threshold at an O_3 concentration of 56 ppb ($p=0.06$). In communications with EPA staff (described in Sasser, 2014), the study authors indicated that it is not clear whether a threshold model is a better predictor of respiratory mortality than the linear model, and that "considerable caution should be exercised in accepting any specific threshold." Consistent with this communication, the HREA estimated respiratory mortality associated with long-term O_3 concentrations based on the linear model from the published study, and in a series of sensitivity analyses with models that included thresholds ranging from 40 to 60 ppb (U.S. EPA, 2014, Figure 7-9).

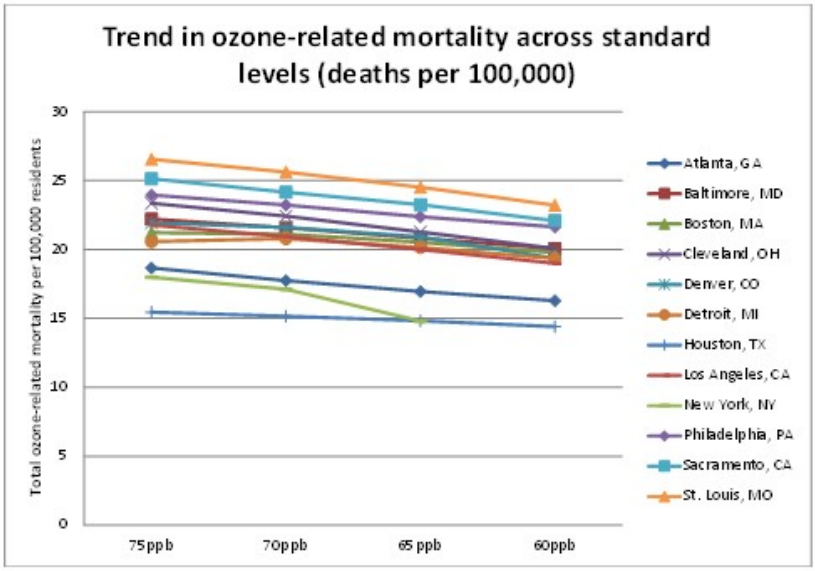
Figure 4-12 presents estimates of total O_3-associated respiratory deaths, based on a linear concentration-response relationship. As discussed for the current standard (section 3.2.3.2), HREA sensitivity analyses indicate that, if a threshold exists between 40 and 60 ppb, the number of respiratory deaths associated with long-term O_3 concentrations could potentially be considerably smaller than indicated by the no threshold model (U.S. EPA, 2014, Figure 7-9).

Figure 4-12. Estimates of Respiratory Mortality Associated with long-term O_3 Concentrations in Urban Case Study Areas (Air Quality Adjusted to Current and Potential alternative standard levels) – Total Risk

2007 Simulation Year



2009 Simulation Year



Based on Figures 4-9 to 4-12 and the associated details described in the HREA (U.S. EPA 2014, chapter 7), we take note of the following for an O_3 standard level of 70 ppb:

1. Total mortality associated with short-term O_3 concentrations:

a. Across urban case study areas, risks are estimated to decrease by up to approximately 5% for a standard level of 70 ppb, compared to the current standard. Risk reductions are estimated consistently for the model year with generally higher O_3-associated risks (2007). In the year with generally lower risks (2009), a standard level of 70 ppb results in either no change or more modest reductions in estimated risks in most urban case study areas. In one area (Detroit) for the 2009 model year, O_3-associated mortality is estimated to increase by approximately 4%, compared to the current standard (see section 3.2.3.2 for further discussion of increased risk estimates following air quality adjustment[25]).

b. When summed across urban case study areas, a standard level of 70 ppb is estimated to reduce O_3-associated deaths by approximately 4% (2007 model year) and 2% (2009 model year), compared to the current standard. For area-wide concentrations at or above 40 ppb, a standard level of 70 ppb is estimated to reduce O_3-associated deaths by approximately 10% (2007 model year) and 9% (2009 model year). For area-wide concentrations at or above 60 ppb, a standard level of 70 ppb is estimated to reduce O_3-associated deaths by approximately 50% (2007 model year) and 70% (2009 model year).[26]

2. Respiratory hospital admissions associated with short-term O_3 concentrations: Compared to the current standard, changes in total risk estimated for a standard level of 70 ppb are similar to the changes in total risks estimated for total mortality (U.S. EPA, 2014, chapter 7).

3. Respiratory mortality associated with long-term O_3 concentrations: A standard level of 70 ppb reduces total risk, compared to the current standard. Across urban case study areas, risks are estimated to decrease by up to approximately 6%. These risk reductions are estimated most consistently for the model year with generally higher O_3-associated risks (2007). In the year with generally lower O_3 concentrations (2009), a standard level of 70 ppb results in smaller reductions in estimated risks in most urban case study areas. In one area (Detroit) for the 2009 model year, O_3-associated mortality is estimated to increase by approximately 1%, compared to the current standard.

Based on Figures 4-9 to 4-12 and the associated details described in the HREA (U.S. EPA 2014, chapter 7), we take note of the following for an O_3 standard level of 65 ppb:

1. Total mortality associated with short-term O_3 concentrations:
    a. Across most urban case study areas, risks are estimated to decrease by up to approximately 9% for a standard level of 65 ppb, compared to the current

[25]As discussed in more detail above (section 3.2.3.2), because of the influence of the entire distribution of ambient O_3 concentrations on total risk estimates, the impacts of adjusting air quality to just meet potential alternative standards are more modest, and are less directionally consistent across urban case study areas, than observed for exposures of concern or O_3-induced lung function decrements.

[26]These results reflect the fact that increases in area-wide O_3 concentrations upon air quality adjustment occur primarily at relatively low concentrations (i.e., on days with initial O_3 concentrations in the range of 10 to 40) (U.S. EPA, 2014, section 4.3.3.2 and appendix 7B, section 9.6).

standard. In one area (New York City), risks are estimated to decrease by up to approximately 22%.[27] These risk reductions are estimated most consistently for the model year with generally higher O_3-associated risks (2007). In the year with generally lower risks (2009), a standard level of 65 ppb results in smaller reductions in estimated risks in most urban case study areas. In one area (Detroit) for the 2009 model year, O_3-associated mortality is estimated to increase by approximately 1% compared to the current standard.

b. When summed across urban case study areas, a standard level of 65 ppb is estimated to reduce O_3-associated deaths by approximately 13% (2007 model year) and 9% (2009 model year), compared to the current standard. For area-wide concentrations at or above 40 ppb, a standard level of 65 ppb is estimated to reduce O_3-associated deaths by approximately 47% (2007) and 46% (2009). For area-wide concentrations at or above 60 ppb, a standard level of 65 ppb is estimated to reduce O_3-associated deaths by over 80% (2007 and 2009 model years).

2. Respiratory hospital admissions associated with short-term O_3 concentrations: Compared to the current standard, changes in total risk estimated for a standard level of 65 ppb are similar to the changes in total risk estimated for total mortality (U.S. EPA, 2014, chapter 7).

3. Respiratory mortality associated with long-term O_3 concentrations: A standard level of 65 ppb reduces total risk, compared to the current standard. Across most urban case study areas, risks are estimated to decrease by up to approximately 10%. In one area (New York City), risks are estimated to decrease by up to approximately 24%. Risk reductions are estimated across all urban case study areas and in both model years evaluated, with larger reductions estimated for 2007 (i.e., the model year with generally higher O_3-associated risks).

Based on Figures 4-9 to 4-12 and the associated details described in the HREA (U.S. EPA 2014, chapter 7), we take note of the following for an O_3 standard level of 60 ppb:

1. Total mortality associated with short-term O_3 concentrations:
    a. A standard level of 60 ppb is estimated to reduce total risk, compared to the current standard, in all urban case study areas. Across urban case study areas, risks are estimated to decrease by up to approximately 14%. Estimated risk reductions are larger for the model year with generally higher O_3-associated risks (2007).

    b. When summed across urban case study areas, a standard level of 60 ppb is estimated to reduce O_3-associated deaths by approximately 15% (2007 model year) and 11% (2009 model year), compared to the current standard. For area-wide concentrations at or above 40 ppb, a standard level of 60 ppb is estimated to

[27] Because of the approach to adjusting air quality in New York (and Los Angeles), which differed from other urban case study areas (U.S. EPA, 2014, sections 4.3.3.1, 4.5), the HREA notes less overall confidence in results for these areas.

reduce O_3-associated deaths by almost 60% (2007 and 2009 model years). For area-wide concentrations at or above 60 ppb, a standard level of 60 ppb is estimated to reduce O_3-associated deaths by over 95% (2007 and 2009 model years).

2. Respiratory hospital admissions associated with short-term O_3 concentrations: Compared to the current standard, changes in total risk estimated for a standard level of 60 ppb are similar to the changes in total risk estimated for total mortality (U.S. EPA, 2014, chapter 7).

3. Respiratory mortality associated with long-term O_3 concentrations: A standard level of 60 ppb reduces total risk, compared to the current standard. Across urban case study areas, risks are estimated to decrease by up to approximately 17%. Risk reductions are estimated across all urban case study areas and in both model years evaluated, with larger reductions estimated for 2007 (i.e., the model year with generally higher O_3-associated risks).

In further considering these risk estimates, we take note of the associated uncertainties, as discussed in more detail in section 3.2.3.2 of this PA. In particular, these include (1) the national representativeness of urban case study areas in terms of the O_3 response to reductions in NO_X emissions; (2) the representativeness of risk changes based primarily on reductions in NO_X emissions versus changes that could be achieved with better-optimized emissions reduction strategies; (3) the shape of the concentration-response function at lower ambient concentrations, including the potential for a threshold in the association between long-term O_3 and respiratory mortality; (4) the presence of unexplained heterogeneity in effect estimates between locations; (5) the potential for exposure measurement errors; and (6) the possibility for reductions in risk associated with reductions in PM and/or NO_2 resulting from control of NO_X.

4.5 CASAC ADVICE AND PUBLIC COMMENTERS' VIEWS ON ALTERNATIVE STANDARDS

As discussed in section 3.3, staff recognizes that decisions regarding the weight to place on various types of evidence, exposure/risk information, and associated uncertainties reflect public health policy judgments that are ultimately left to the Administrator. To help inform those judgments with regard to the range of alternative primary O_3 standards appropriate for consideration, CASAC has provided advice to the Administrator based on their reviews of the O_3 ISA, HREA, and PA. This section summarizes the advice provided by CASAC regarding potential alternative standards, as well as the views expressed at the CASAC meetings by public commenters.

In the fall of 2011, rather than revising the O_3 NAAQS as part of the reconsideration process, EPA elected to coordinate further proceedings on the reconsideration rulemaking with the current ongoing periodic review. Accordingly, in this section we briefly describe CASAC advice from the reconsideration of the 2008 final decision on the level of the standard, as well as

CASAC advice received during the current review as it pertains to potential alternative standards.

Consistent with their advice in 2008, CASAC reiterated during the reconsideration its support for an 8-hour primary O_3 standard with a level ranging from 60 to 70 ppb, combined with the current indicator, averaging time, and form. Specifically, in response to EPA's solicitation of their advice during the reconsideration, the CASAC letter (Samet 2010) to the Administrator stated:

> *CASAC fully supports EPA's proposed range of 0.060 – 0.070 parts per million (ppm) for the 8-hour primary ozone standard. CASAC considers this range to be justified by the scientific evidence as presented in the Air Quality Criteria for Ozone and Related Photochemical Oxidants (March 2006) and Review of the National Ambient Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper (July 2007).*

Similarly, in response to EPA's request for additional advice on the reconsideration in 2011, CASAC reaffirmed their conclusion that "the evidence from controlled human and epidemiological studies strongly supports the selection of a new primary ozone standard within the 60 – 70 ppb range for an 8-hour averaging time" (Samet, 2011). CASAC further concluded that this range "would provide little margin of safety at its upper end" (Samet, 2011, p. 2).

In the current review of the Second Draft PA, as noted above, CASAC concurred with staff's conclusions that it is appropriate to consider retaining the current indicator (O_3), averaging time (8-hour average) and form (three-year average of the 4th highest maximum daily 8-hour average. With regard to level, CASAC stated the following (Frey, 2014, p. ii to iii):

> *The CASAC further concludes that there is adequate scientific evidence to recommend a range of levels for a revised primary ozone standard from 70 ppb to 60 ppb. The CASAC reached this conclusion based on the scientific evidence from clinical studies, epidemiologic studies, and animal toxicology studies, as summarized in the Integrated Science Assessment (ISA), the findings from the exposure and risk assessments as summarized in the HREA, and the interpretation of the implications of these sources of information as given in the Second Draft PA.*
>
> *The CASAC acknowledges that the choice of a level within the range recommended based on scientific evidence* [i.e., 70 to 60 ppb] *is a policy judgment under the statutory mandate of the Clean Air Act. The CASAC advises that, based on the scientific evidence, a level of 70 ppb provides little margin of safety for the protection of public health, particularly for sensitive subpopulations.*
>
> *Thus, our policy advice is to set the level of the standard lower than 70 ppb within a range down to 60 ppb, taking into account your judgment regarding the desired*

margin of safety to protect public health, and taking into account that lower levels will provide incrementally greater margins of safety.

The public commenters who expressed the view that the current primary O_3 standard is not adequate (section 3.3) also submitted comments that supported revising the level of the primary O_3 standard. Several of these commenters expressed the view that the level should be revised to the lower end of the range of 70 to 60 ppb, or in some cases to a level below 60 ppb. The basis for these commenters' views on the level of the standard is generally reflected in the rationale given by CASAC for their advice, and is discussed in section 3.3 of this PA. Public commenters who expressed the view that revision of the current standard is not necessary did not provide any provisional views on alternative levels that would be appropriate for consideration should the Administrator consider revisions to the standard. These views are also discussed in section 3.3 of this PA.

4.6 STAFF CONCLUSIONS ON ALTERNATIVE PRIMARY STANDARDS FOR CONSIDERATION

Staff's consideration of alternative primary O_3 standards builds upon our conclusion, discussed in section 3.4, that the overall body of evidence and exposure/risk information call into question the adequacy of public health protection afforded by the current standard, particularly for at-risk populations. We further conclude that it is appropriate in this review to consider alternative standards that would increase public health protection, compared to the current standard.

As discussed in sections 4.1 to 4.3 above, in the current review we conclude that it is appropriate for the Administrator to consider retaining O_3 as the indicator for the standard that protects against exposures to ambient O_3 and other photochemical oxidants (section 4.1), and to consider retaining the current averaging time (section 4.2) and form (section 4.3) for the primary O_3 standard. For a primary O_3 standard that is defined in terms of the current indicator, averaging time, and form, we reach the conclusion that, depending on the public health policy judgments made by the Administrator, the scientific evidence and exposure/risk information available in this review support considering alternative O_3 standard levels from 70 down to 60 ppb. The basis for this conclusion is discussed in detail in section 4.4 of this PA, and is summarized in this section.

Below, we summarize our approach to considering the scientific evidence and exposure/risk information, and the specific evidence and information that supports the range of levels from 70 to 60 ppb. In doing so, we focus particularly on the evidence and information as it relates to the upper (70 ppb), middle (65 ppb), and lower (60 ppb) portions of this range. Key exposure/risk information is summarized in Tables 4-4, and 4-5, and Figure 4-13.

Table 4-4 Summary of Estimated Exposures of Concern for Potential Alternative O_3 Standard Levels of 70, 65, and 60 ppb in Urban Case Study Areas[28]

Benchmark Level	Alternative Standard Level (ppb)	Average % Children Exposed[29]	Number of Children (5 to 18 years) [Number of Asthmatic Children][30]	Average % Reduction from Current Standard	% Children - Worst Year and Worst Area
One or more exposures of concern per season					
≥ 70 ppb	70	0.1-1.2	94,000 [10,000]	73	3.2
	65	0-0.2	14,000 [2,000]	95	0.5
	60	0[31]	1,400 [200][32]	100	0.1
≥ 60 ppb	70	3.3-10.2	1,176,000 [126,000]	46	18.9
	65	0-4.2	392,000 [42,000]	80	9.5
	60	0-1.2	70,000 [8,000]	96	2.2
Two or more exposures of concern per season					
≥ 70 ppb	70	0-0.1	5,400 [600]	95	0.4
	65	0	300 [100]	100	0
	60	0	0 [0]	100	0
≥ 60 ppb	70	0.5-3.5	320,000 [35,000]	61	9.2
	65	0-0.8	67,000 [7,500]	92	2.8
	60	0-0.2	5,100 [700]	100	0.3

[28] As illustrated above in Figures 4-1 to 4-4, all alternative standard level s evaluated in the HREA were effective at limiting exposures of concern at or above 80 ppb. Therefore, Table 4-4 focuses on exposures of concern at or above the 70 and 60 ppb benchmark concentrations.

[29] Estimates for each urban case study area were averaged for the years evaluated in the HREA (2006 to 2010). Ranges reflect the ranges across urban case study areas.

[30] Numbers of children exposed in each urban case study area were averaged over the years 2006 to 2010. These averages were then summed across urban case study areas. Numbers are rounded to nearest thousand unless otherwise indicated.

[31] Estimates smaller than 0.1% were rounded to zero.

[32] As discussed in section 4.3.3 of the HREA, the model-based air quality adjustment approach used to estimate risks associated with the current and alternative standards was unable to estimate the distribution of ambient O_3 concentrations in New York City upon just meeting an alternative standard with a level of 60 ppb. Therefore, for the 60 ppb standard level the numbers of children and asthmatic children reflect all of the urban case study areas except New York.

Table 4-5 Summary of Estimated Lung Function Decrements for Potential Alternative O_3 Standard Levels of 70, 65, and 60 ppb in Urban Case Study Areas

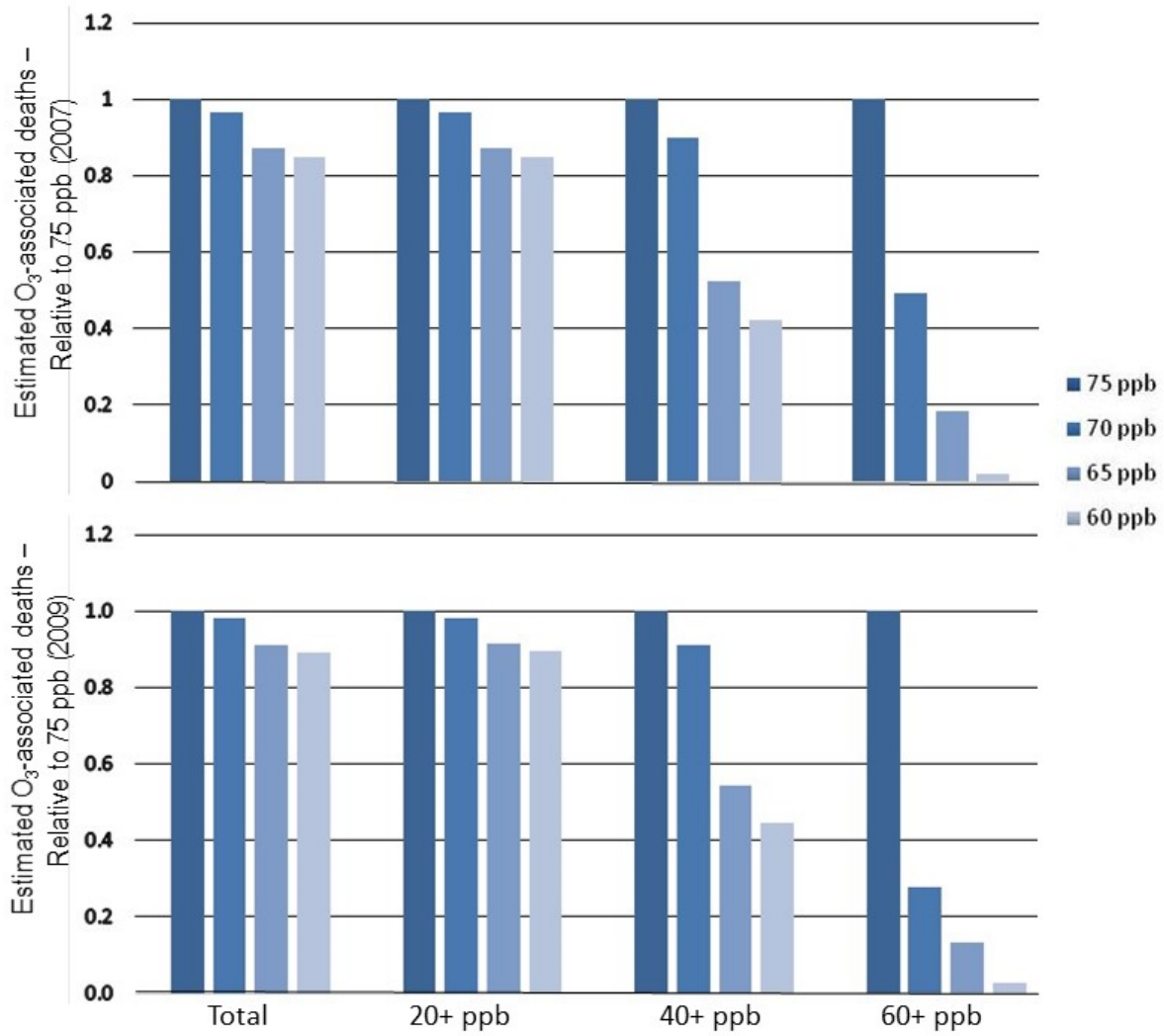
Lung Function Decrement	Alternative Standard Level	Average % Children[33]	Number of Children (5 to 18 years) [Number of Asthmatic Children][34]	Average % Reduction from Current Standard	% Children Worst Year and Area
One or more decrements per season					
≥ 10%	70	11-17	2,527,000 [261,000]	15	20
	65	3-15	1,896,000 [191,000]	31	18
	60	5-11	1,404,000 [139,000][35]	45	13
≥ 15%	70	2-4	562,000 [58,000]	26	5
	65	0-3	356,000 [36,000]	50	4
	60	1-2	225,000 [22,000]	67	3
≥ 20%	70	1-2	189,000 [20,000]	32	2.1
	65	0-1	106,000 [11,000]	59	1.4
	60	0-1	57,000 [6,000]	77	0.7
Two or more decrements per season					
≥ 10%	70	5.5-11	1,414,000 [145,000]	17	13
	65	1.3-8.8	1,023,000 [102,000]	37	11
	60	2.1-6.4	741,000 [73,000]	51	7.3
≥ 15%	70	0.9-2.4	276,000 [28,000]	29	3.1
	65	0.1-1.8	168,000 [17,000]	54	2.3
	60	0.2-1.0	101,000 [10,000]	71	1.4
≥ 20%	70	0.3-0.8	81,000 [8,000]	34	1.1
	65	0-0.5	43,000 [4,000]	66	0.8
	60	0-0.2	21,000 [2,000]	83	0.4

[33] Estimates in each urban case study area were averaged for the years evaluated in the HREA (2006 to 2010). Ranges reflect the ranges across urban case study areas.

[34] Numbers of children estimated to experience decrements in each study urban case study area were averaged over 2006 to 2010. These averages were then summed across urban case study areas. Numbers are rounded to nearest thousand unless otherwise indicated. As discussed above, for the 60 ppb standard level the numbers of children and asthmatic children included in Table 4-5 reflect all of the urban case study areas except New York.

[35] As discussed in section 4.3.3 of the HREA, the model-based air quality adjustment approach used to estimate risks associated with the current and alternative standards was unable to estimate the distribution of ambient O_3 concentrations in New York City upon just meeting an alternative standard with a level of 60 ppb. Therefore, for the 60 ppb standard level the numbers of children and asthmatic children reflect all of the urban case study areas except New York.

Figure 4-13. Estimates of O_3-Associated Deaths Attributable to Full Distributions of 8-Hour Area-Wide O_3 Concentrations and to Concentrations at or above 20, 40, or 60[36] ppb O_3 - Deaths Summed Across Urban Case Study Areas and Expressed Relative to a Standard with a Level of 75 ppb



[36]As discussed in section 4.3.3 of the HREA, the model-based air quality adjustment approach used to estimate risks associated with the current and alternative standards was unable to estimate the distribution of ambient O_3 concentrations in New York City upon just meeting an alternative standard with a level of 60 ppb. Therefore, the total number of deaths indicated for the 60 ppb standard level in Figure 4-10 reflects the 60 ppb estimates for all urban case study areas except New York City. For New York City, the estimated number of O_3-associated deaths for the 65 ppb standard level was assumed.

Summary of approach to reaching conclusions on alternative standard levels

In this PA, our approach to reaching conclusions on alternative standard levels focuses on the evidence from controlled human exposure and epidemiologic studies, as assessed in the ISA (U.S. EPA, 2013), and the exposure and health risk analyses presented in the HREA (U.S. EPA, 2014). This approach is discussed in detail in Chapter 1 (section 1.3), and is summarized below.

As an initial matter, we note that controlled human exposure studies provide the most certain evidence indicating the occurrence of health effects in humans following exposures to specific O_3 concentrations. Consistent with this, CASAC concluded that "the scientific evidence supporting the finding that the current standard is inadequate to protect public health is strongest based on the controlled human exposure studies of respiratory effects" (Frey, 2014, p. 5). As discussed above and in section 3.1.2.1, controlled human exposure studies have reported a variety of respiratory effects in healthy adults following exposures to O_3 concentrations of 60, 72,[37] or 80 ppb, and higher. The largest respiratory effects, and the broadest range of effects, have been studied and reported following exposures of healthy adults to 80 ppb O_3 or higher, with most exposure studies conducted at these higher concentrations. Exposures to O_3 concentrations of 80 ppb or higher have been reported to decrease lung function, increase airway inflammation, increase respiratory symptoms, result in airway hyperresponsiveness, and decrease lung host defenses in healthy adults.

Most of these effects have also been reported in healthy adults following exposures to O_3 concentrations below 80 ppb.[38] Exposures to O_3 concentrations of 72 ppb have been reported to decrease lung function and increase respiratory symptoms, a combination that meets the ATS criteria for an "adverse" response (section 3.1.3). Exposures to O_3 concentrations of 60 ppb have been demonstrated to decrease lung function, with decrements in some people large enough to be judged an abnormal response by ATS, and which CASAC has indicated could be adverse to people with lung disease.[39] In addition, as discussed in section 3.1.3, such a decrease in mean lung function meets the ATS criteria for an adverse response given that a downward shift in the distribution of FEV_1 would result in diminished reserve function, and therefore would increase risk from further environmental insult. Exposures to O_3 concentrations of 60 ppb have also been reported in one study (Kim et al., 2011) to increase airway inflammation, which provides a

[37] As noted above, for the 70 ppb exposure concentration Schelegle et al. (2009) reported that the actual mean exposure concentration was 72 ppb.

[38] Airway hyperresponsiveness and reductions in lung host defense have not been evaluated following exposures to O_3 concentrations below 80 ppb. The extent to which these respiratory effects occur following lower exposure concentrations is not clear from the available evidence, though we have no basis for concluding that an exposure concentration of 80 ppb reflects an effects threshold.

[39] In their advice to the Administrator based on the second draft PA, the CASAC indicated that "60 ppb is an appropriate exposure of concern for asthmatic children" (Frey, 2014).

mechanism by which O_3 may cause other more serious respiratory effects (e.g., asthma exacerbations).

Given the evidence for respiratory effects from controlled human exposure studies, we consider the extent to which standards with revised levels would be estimated to protect at-risk populations against exposures of concern to O_3 concentrations at or above the health benchmark concentrations of 60, 70, and 80 ppb (i.e., based on HREA estimates of one or more and two or more exposures of concern). In doing so, we note that, due to individual variability in responsiveness, only a subset of people who experience exposures at or above the three benchmark concentrations can be expected to experience associated health effects, and that available data are not sufficient to quantify that subset of people. We view the health effects evidence as a continuum with greater confidence and less uncertainty about the occurrence of adverse health effects at higher O_3 exposure concentrations, and less confidence and greater uncertainty as one considers lower exposure concentrations (discussed in more detail in section 3.2.2).

While there is greater uncertainty regarding the occurrence of adverse health effects at lower concentrations, we also note that the controlled human exposure studies that provided the basis for benchmark concentrations have not evaluated responses in populations at the greatest risk from exposures to O_3. Thus, the effects reported in healthy adults at each of the benchmark concentrations may underestimate effects in these at-risk groups. Compared to the healthy people included in most controlled human exposure studies, members of at-risk populations, including lifestages, (e.g., asthmatics, children) are at greater risk of experiencing adverse effects. In considering the health evidence within the context of drawing conclusions on potential alternative standard levels, we balance concerns about the potential for adverse health effects, especially in at-risk populations, with our increasing uncertainty regarding the likelihood of such effects following exposures to lower O_3 concentrations.

With respect to the lung function decrements that have been evaluated in controlled human exposure studies, we consider the extent to which standards with revised levels would be estimated to protect healthy and at-risk populations against O_3-induced lung function decrements large enough to be adverse in some people (based on quantitative risk estimates in the HREA). As discussed in section 3.1.3, although some experts would judge single occurrences of moderate responses to be a "nuisance," especially for healthy individuals, a more general consensus view of the adversity of moderate lung function decrements emerges as the frequency of occurrence increases. Repeated occurrences of moderate responses, even in otherwise healthy individuals, may be considered to be adverse, since they could well set the stage for more serious illness (61 FR 65723). For the purpose of estimating potentially adverse lung function decrements in active, healthy people, in the 2008 review the CASAC panel indicated that a focus on the mid to upper

end of the range of moderate (i.e., FEV_1 decrements ≥ 15%) functional responses is appropriate. However, for children and adults with lung disease, FEV_1 decrements ≥ 10% could lead to respiratory symptoms, would likely interfere with normal activities for many individuals, and therefore could be adverse. Large (i.e., FEV_1 decrements ≥ 20%) lung function decrements would likely interfere with normal activities for most people with lung disease and would increase the likelihood that they would seek medical attention. In the current review, CASAC judges that an FEV_1 decrement ≥ 15% is an appropriate surrogate for adverse health outcomes in active healthy adults, while a decrement ≥ 10% is a scientifically relevant surrogate for adverse health outcomes for people with asthma and lung disease (Frey, 2014). In reaching conclusions on alternative standard levels, we consider the extent to which standards with revised levels would be estimated to protect healthy and at-risk populations against one or more, and two or more, moderate (i.e., FEV_1 decrements ≥ 10% and ≥ 15%) and large (i.e., FEV_1 decrements ≥ 20%) lung function decrements.

In evaluating the epidemiologic evidence within the context of drawing conclusions on potential alternative standard levels, we consider the extent to which available studies have reported associations with emergency department visits, hospital admissions, and/or mortality in locations that would likely have met potential alternative standards with levels below 75 ppb (based on analyses presented in section 4.4.1). In evaluating the epidemiologic evidence in this way, we consider both multicity and single-city studies, recognizing the strengths and limitations of each. Specifically, multicity studies evaluate large populations and provide greater statistical power than single-city studies; multicity studies reflect O_3-associated health impacts across a range of diverse locations, providing spatial coverage for different regions across the country and reflecting differences in exposure-related factors that could impact O_3 risks; and multicity studies afford a greater possibility of generalizing to the national population. In contrast, while single-city studies are more limited than multicity studies in terms of statistical power and geographic coverage, conclusions linking air quality in a specific area with health effect associations in that same area can be made with greater certainty for single-city studies (i.e., compared to multicity studies reporting only multicity effect estimates).

We also consider the epidemiologic evidence within the context of epidemiology-based risk estimates. Compared to the weight given to HREA estimates of exposures of concern and lung function risks (sections 4.4.2.1 and 4.4.2.2, above), and the weight given to the evidence (section 4.4.1), we place relatively less weight on epidemiologic-based risk estimates. In doing so, we note that the overall conclusions from the HREA likewise reflect less confidence in estimates of epidemiologic-based risks than in estimates of exposures and lung function risks. Our determination to attach less weight to the epidemiologic-based estimates reflects the uncertainties associated with mortality and morbidity risk estimates, including the heterogeneity

in effect estimates between locations, the potential for exposure measurement errors, and uncertainty in the interpretation of the shape of concentration-response functions at lower O_3 concentrations (U.S. EPA, 2014, section 9.6). The HREA also concludes that lower confidence should be placed in the results of the assessment of respiratory mortality risks associated with long-term O_3 exposures, primarily because that analysis is based on only one study (even though that study is well-designed) and because of the uncertainty in that study about the existence and level of a potential threshold in the concentration-response function (U.S. EPA, 2014, section 9.6).

In considering the epidemiology-based risk estimates, we focus on the extent to which potential alternative O_3 standards with levels below 75 ppb are estimated to reduce the risk of O_3-associated mortality (based on the HREA results summarized in section 4.4.2.3).[40] As discussed in section 3.4 for the current standard, we consider estimates of total risk (i.e., based on the full distributions of ambient O_3 concentrations) and estimates of risk associated with O_3 concentrations in the upper portions of ambient distributions. A focus on estimates of total risks would place greater weight on the possibility that concentration-response relationships remain linear over the entire distribution of ambient O_3 concentrations, and thus on the potential for mortality and morbidity to be affected by changes in relatively low O_3 concentrations. A focus on risks associated with O_3 concentrations in the upper portions of the ambient distribution would place greater weight on the uncertainty associated with the shapes of concentration-response curves for O_3 concentrations in the lower portions of the distribution. Given that both types of risk estimates could reasonably inform a decision on standard level, depending on the weight placed on uncertainties in the occurrence and the estimation of O_3-attributable effects at relatively low O_3 concentrations, in reaching conclusions we consider what both types of estimates indicate with regard to potential alternative levels.

Staff conclusions on the range of levels appropriate for consideration

Using the approach discussed above to consider the scientific evidence and exposure/risk information, we reach the conclusion that it is appropriate for the Administrator to consider alternative primary O_3 standard levels from 70 to 60 ppb. The basis for this conclusion is discussed in detail in sections 4.4.1 and 4.4.2 above, and is summarized below.

With regard to controlled human exposure studies, we consider the lowest O_3 exposure concentrations at which various effects have been evaluated and statistically significant effects reported. We also consider the potential for reported effects to be adverse, including in at-risk populations and lifestages. As discussed in section 3.1.2.1, controlled human exposure studies

[40] Differences in estimated respiratory morbidity risks between potential alternative standard levels are similar to the differences estimated for total mortality associated with short-term O_3 concentrations.

provide evidence of respiratory symptoms combined with lung function decrements (an "adverse" response based on ATS criteria) in healthy adults following exposures to O_3 concentrations as low as 72 ppb, and evidence of potentially adverse lung function decrements and airway inflammation following exposures to O_3 concentrations as low as 60 ppb. Although some studies show that respiratory symptoms also develop during exposures to 60 ppb O_3, the increase in symptoms has not been reported to reach statistical significance by the end of the 6.6 hour exposure period (Adams 2006; Schelegle et al. 2009). Thus, while significant increases in respiratory symptoms combined with lung function decrements have not been reported following exposures to 60 ppb O_3, this combination of effects is likely to occur to some degree in healthy adults with 6.6-hour exposures to concentrations below 72 ppb, and also are more likely to occur with longer (i.e., 8-hour) exposures.[41]

With regard to the lowest exposure concentration shown to cause respiratory effects (i.e., 60 ppb), we note that most controlled human exposure studies have not evaluated O_3 concentrations below 60 ppb. Therefore, 60 ppb does not necessarily reflect an exposure concentration below which effects such as lung function decrements and airway inflammation no longer occur. This is particularly the case given that controlled human exposure studies were conducted in healthy adults, while people with asthma, including asthmatic children, are likely to be more sensitive to O_3-induced respiratory effects. In support of this, some epidemiologic panel studies, which can include members of at-risk groups such as children and outdoor workers, have found respiratory effects at ambient concentrations lower than 60 ppb (section 3.1.2.1).

With regard to other O_3-induced effects, we note that airway hyperresponsiveness and impaired lung host defense capabilities have been reported in healthy adults engaged in moderate exertion following exposures to O_3 concentrations as low as 80 ppb, the lowest concentration evaluated for these effects. As discussed in section 3.1.2.1, these physiological effects have been linked to aggravation of asthma and increased susceptibility to respiratory infection, potentially leading to increased medication use, increased school and work absences, increased visits to doctors' offices and emergency departments, and increased hospital admissions. These are all indicators of adverse O_3-related morbidity effects, which are consistent with, and provide plausibility for, the adverse morbidity effects and mortality effects observed in epidemiologic studies.

[41] In addition, CASAC observed that, "adverse health effects in young healthy adults occur with exposures to 72 ppb of ozone for 6.6 hours" and that "It is the judgment of CASAC that if subjects had been exposed to ozone using the 8-hour averaging period used in the standard, adverse effects could have occurred at [a] lower concentration. Further, in our judgment, the level at which adverse effects might be observed would likely be lower for more sensitive subgroups, such as those with asthma" (Frey, 2014, p. 5).

Based on consideration of the above evidence, we conclude that available controlled human exposure studies support a level no higher than 70 ppb as the upper end of the range for consideration in the current review. In reaching this conclusion, we note that 70 ppb is just below the O_3 exposure concentration reported to result in lung function decrements and respiratory symptoms in healthy adults (i.e., 72 ppb), a combination of effects that meet ATS criteria for an adverse response. In addition, while 70 ppb is well below the 80 ppb exposure concentration shown to cause potentially adverse respiratory effects such as airway hyperresponsiveness and impaired host-defense capabilities, these effects have not been evaluated at exposure concentrations below 80 ppb and there is no reason to believe that 80 ppb represents a threshold for such effects.

We further conclude that the evidence from controlled human exposure studies[42] supports considering alternative O_3 standard levels at least as low as 60 ppb. Potentially adverse lung function decrements and pulmonary inflammation have been demonstrated to occur in healthy adults at 60 ppb. Thus, 60 ppb is a short-term exposure concentration that may be reasonably concluded to elicit adverse effects in at-risk groups. Pulmonary inflammation, particularly if experienced repeatedly, provides a mechanism by which O_3 may cause other more serious respiratory morbidity effects (e.g., asthma exacerbations) and possibly extrapulmonary effects. As discussed in section 3.1.2.1, the physiological effects reported in controlled human exposure studies down to 60 ppb O_3 have been linked to aggravation of asthma and increased susceptibility to respiratory infection, potentially leading to increased medication use, increased school and work absences, increased visits to doctors' offices and emergency departments, and increased hospital admissions.

We further note that the range of alternative levels from 70 to 60 ppb is supported by evidence from epidemiologic studies and by exposure and risk estimates from the HREA. This evidence and exposure/risk information indicate that a level from anywhere in the range of 70 to 60 ppb would be expected to result in important public health improvements over the current standard. In particular, compared to the current standard a revised standard with a level from 70 to 60 ppb would be expected to (1) more effectively maintain short- and long-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard; (2) reduce the occurrence of exposures of concern to O_3 concentrations that result in respiratory effects in healthy adults (at or above 60, 70, and 80 ppb); (3) reduce the occurrence of moderate-to-large O_3-induced lung function decrements; and (4) reduce the risk of O_3-associated mortality and

[42] As discussed in sections 3.1.2.1 and 4.4.1above, panel studies also provide supporting evidence for these conclusions.

morbidity, particularly the risk associated with the upper portions of the distributions of ambient O_3 concentrations.

In reaching a conclusion on whether it is appropriate to consider alternative standard levels below 60 ppb, we note the following:

- While controlled human exposure studies provide evidence for O_3-induced respiratory effects following exposures to O_3 concentrations as low as 60 ppb, they do not provide evidence for adverse effects following exposures to lower concentrations. On this issue, CASAC concurred that 60 ppb O_3 is an appropriate and justifiable scientifically based lower bound for a revised primary standard, based upon findings of "adverse effects, including clinically significant lung function decrements and airway inflammation, after exposures to 60 ppb ozone in healthy adults with moderate exertion (Adams 2006; Schelegle et al., 2009; Brown et al. 2008; Kim et al., 2011), with limited evidence of adverse effects below 60 ppb" (Frey, 2014, p. 7).

- Based on the HREA results, meeting an O_3 standard with a level of 60 ppb would be expected to almost eliminate exposures of concern to O_3 concentrations at or above 60 ppb. To the extent lower exposure concentrations may result in adverse health effects in some people, a standard level of 60 ppb would be expected to also reduce exposures to O_3 concentrations below 60 ppb.

- U.S. and Canadian epidemiologic studies have not reported O_3 health effect associations based primarily on study locations likely to have met a standard with a level of 60 ppb.

- In all of the urban case study areas evaluated, a standard with a level of 60 ppb would be expected to maintain long-term O_3 concentrations below those where a key study indicates the most confidence in a linear concentration-response relationship with respiratory mortality.

Beyond the above considerations, we also note the HREA estimates indicating that meeting an O_3 standard with a level of 60 ppb would result in important reductions in the risk of O_3-induced lung function decrements and O_3-associated mortality and morbidity. Although some risk is estimated to remain based on these metrics, even with a level of 60 ppb, we have decreasing confidence in further public health improvements with levels below 60 ppb. We reach this conclusion because, as noted above, at a level of 60 ppb virtually no one in the population would be expected to experience exposures to O_3 concentrations at or above 60 ppb under conditions demonstrated in controlled human exposure studies to result in respiratory effects, and because epidemiologic studies have not reported O_3 health effect associations based primarily on study locations likely to have met a standard with a level of 60 ppb. Given all of the above considerations we conclude that, compared to standards with levels from 70 to 60 ppb, the extent to which standards with levels below 60 ppb could result in further public health improvements

becomes notably less certain. Therefore, we conclude that it is not appropriate in this review to consider standard levels below 60 ppb.

The range of levels from 70 to 60 ppb corresponds to the range of levels recommended for consideration by CASAC, based on the available evidence and information (Frey, 2014). While CASAC further offered the "policy advice" to set the level below 70 ppb, based on margin of safety considerations, the Committee acknowledged that "the choice of a level within the range recommended based on scientific evidence [i.e., 70 to 60 ppb] is a policy judgment under the statutory mandate of the Clean Air Act" (Frey, 2014). Therefore, we note that our conclusions on the appropriate range for alternative primary O_3 standard levels are consistent with CASAC conclusions that the scientific evidence and exposure/risk information supports consideration of levels from 70 to 60 ppb, and that the ultimate identification of a standard that protects public health with an adequate margin of safety will reflect policy judgments that are explicitly reserved for the Administrator (section 1.2.1).

The following sections summarize the specific scientific evidence and exposure/risk information as they relate to revised O_3 standards with levels from the upper (70 ppb), middle (65 ppb), and lower (60 ppb) portions of the range of 70 to 60 ppb.

O_3 standard level of 70 ppb

A level of 70 ppb is below 80 ppb, an O_3 exposure concentration that has been reported to elicit a range of respiratory effects that includes airway hyperresponsiveness and decreased lung host defense, in addition to lung function decrements, airway inflammation, and respiratory symptoms. A level of 70 ppb is also below the lowest exposure concentration at which the combined occurrence of respiratory symptoms and lung function decrements have been reported (i.e., 72 ppb), a combination judged adverse by the ATS (section 3.1.3). A level of 70 ppb is above the lowest exposure concentration demonstrated to result in lung function decrements large enough to be judged an abnormal response by ATS and above the lowest exposure concentration demonstrated to result in pulmonary inflammation (i.e., 60 ppb).

Compared to the current standard, the HREA estimates that a revised O_3 standard with a level of 70 ppb would reduce exposures of concern to O_3 concentrations of 60, 70, and 80 ppb in urban case study areas, with such a standard level estimated to be most effective at limiting exposures at or above the higher health benchmark concentrations and at limiting multiple occurrences of such exposures. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow only up to about 1% of children (i.e., ages 5 to 18) to experience exposures of concern at or above 70 ppb (73% reduction, compared to current standard), and far less than 1% to experience two or more such exposures (95% reduction, compared to current standard). In the worst-case location and year (i.e., location and year with the largest exposure

estimate), about 3% of children are estimated to experience one or more exposures of concern at or above 70 ppb, and less than 1% are estimated to experience two or more. A standard with a level of 70 ppb is estimated to allow far less than 1% of children to experience exposures of concern at or above the 80 ppb benchmark concentration, even in the worst-case year (Table 4-4).[43]

An O_3 standard with a level of 70 ppb is estimated to allow about 3 to 10% of children, including asthmatic children, to experience one or more exposures of concern at or above 60 ppb in a single O_3 season. As noted above, CASAC advised EPA that 60 ppb is an appropriate exposure of concern with respect to adverse effects on people with asthma, including children (Frey, 2014, p. 6, 8). Compared to the current standard, this reflects about a 46% reduction, on average across the urban case study areas. A standard with a level of 70 ppb is estimated to allow about 1% to 4% of children to experience two or more exposures of concern at or above 60 ppb. In the worst-case location and year, a standard set at 70 ppb is estimated to allow about 19% of children to experience one or more exposures of concern at or above 60 ppb, and 9% to experience two or more such exposures (Table 4-4).

Compared to the current standard, the HREA estimates that a revised O_3 standard with a level of 70 ppb would also reduce O_3-induced lung function decrements in children. A level of 70 ppb is estimated to be most effective at limiting the occurrences of moderate and large lung function decrements (i.e., FEV_1 decrements $\geq$ 15% and $\geq$ 20%, respectively), and at limiting multiple occurrences of O_3-induced decrements. On average over the years 2006 to 2010, a standard with a level of 70 ppb is estimated to allow about 2 to 4% of children in the urban case study areas to experience one or more moderate O_3-induced lung function decrements (i.e., FEV_1 decrement $\geq$ 15%), which would be of concern for healthy people, and about 1 to 2.5% of children to experience two or more such decrements (approximately 30% reduction, compared to the current standard). In the worst-case location and year, up to 5% of children are estimated to experience one or more O_3-induced lung function decrements $\geq$ 15%, and up to 3% are estimated to experience two or more such decrements. A standard set at 70 ppb is estimated to allow about 2% or fewer children to experience large O_3-induced lung function decrements (i.e., FEV_1 decrement $\geq$ 20%), and to allow about 1% or fewer children to experience two or more such decrements, even in the worst-case years and locations (Table 4-5).

On average over the years 2006 to 2010, an O_3 standard set at 70 ppb is estimated to allow about 11 to 17% of children in the urban case study areas to experience one or more moderate O_3-induced lung function decrements (i.e., FEV_1 decrement $\geq$ 10%), which could be

[43] As noted above, due to interindividual variability, children (or adults) exposed at these levels will not necessarily experience health effects; the information available for some health effects is not sufficient to quantify the numbers of children in the urban case study areas who might experience these effects.

adverse for people with lung disease. This reflects an average reduction of about 15%, compared to the current standard. A standard with a level of 70 ppb is also estimated to allow about 6 to 11% of children to experience two or more such decrements (17% reduction, compared to current standard). In the worst-case location and year, a standard set at 70 ppb is estimated to allow about 20% of children in the urban case study areas to experience one or more O_3-induced lung function decrements ≥ 10%, and 13% to experience two or more such decrements (Table 4-5).

Compared to the current standard, a revised standard with a level of 70 ppb would also more effectively maintain short-term ambient O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard. In particular, the single-city study by Mar and Koenig (2009) reported positive and statistically significant associations with respiratory emergency department visits in children and adults in a location that likely would have met the current O_3 standard over the entire study period but violated a revised standard with a level of 70 ppb or below. Thus, none of the single-city studies evaluated in section 4.4.1 provide evidence for O_3 health effect associations in locations meeting a standard with a level of 70 ppb or below. While this analysis does not provide information on the extent to which the reported O_3-associated emergency department visits would persist upon meeting an O_3 standard with a level of 70 ppb, or on the extent to which standard levels below 70 ppb could further reduce the incidence of such emergency department visits, it suggests that a revised O_3 standard with a level at or below 70 ppb would require reductions in the ambient O_3 concentrations that provided the basis for the health effect associations reported by Mar and Koenig.

As discussed above, compared to single-city studies, there is greater uncertainty in linking air quality concentrations from individual study cities to multicity effect estimates. With regard to multicity studies, we note that Dales et al. (2006) reported significant associations with respiratory hospital admissions based on air quality in 11 Canadian cities, most of which would likely have met the current standard over the entire study period but violated a revised standard with a level of 70 ppb or below over at least part of that period (Table 4-1). This analysis suggests that while the current standard would allow the ambient O_3 concentrations in most of the study locations that provided the basis for the association with hospital admissions, a revised O_3 standard with a level at or below 70 ppb would require reductions in those ambient O_3 concentrations. As with the study by Mar and Koenig, this analysis does not provide information on the extent to which the reported O_3-associated hospital admissions would persist upon

meeting an O_3 standard with a level of 70 ppb, or on the extent to which standard levels below 70 ppb could further reduce the incidence of such hospital admissions.[44]

With regard to long-term O_3 concentrations, we evaluated the "long-term" O_3 metrics reported to be associated with mortality or morbidity in recent epidemiologic studies (e.g., seasonal averages of 1-hour or 8-hour daily max concentrations). Compared to the current standard, a revised standard with a level of 70 ppb would be expected to reduce the risk of respiratory mortality associated with long-term O_3 concentrations, based on information from the study by Jerrett et al. (2009), though we note the HREA conclusion, discussed above, that lower confidence should be placed in respiratory mortality risk estimates based on this study (U.S. EPA, 2014, section 9.6). In addition, a standard with a level of 70 ppb would be expected to more effectively maintain long-term O_3 concentrations below those where the study by Jerrett et al. (2009) indicates the most confidence in the reported association with respiratory mortality. Specifically, air quality analyses indicate this to be the case in 9 out of the 12 urban case study areas for a level of 70 ppb, compared to 6 out of 12 areas for the current standard. Finally, a revised standard with a level of 70 ppb would be expected to reduce long-term O_3 concentrations based on the types of metrics that have been reported in recent epidemiologic studies to be associated with respiratory morbidity (i.e., seasonal averages of daily maximum 8-hour concentrations).

In further considering the potential implications of epidemiology studies for alternative standard levels, we note estimates of total mortality associated with short-term O_3 concentrations.[45] As discussed above, we consider estimates of total risk (i.e., based on the full distributions of ambient O_3 concentrations) and estimates of risk associated with O_3 concentrations in the upper portions of ambient distributions. With regard to total risk we note that, when summed across urban case study areas, a standard with a level of 70 ppb is estimated to reduce the number of deaths associated with short-term O_3 concentrations by about 4% (2007) and 2% (2009), compared to the current standard.[46] Based on a national modeling analysis, the majority of the U.S. population would be expected to experience reductions in such risks upon reducing precursor emissions.

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[44] In addition, for the other multicity studies identified in Table 4-1 (Cakmak et al., 2006; Stieb et al., 2009; Katsouyanni et al., 2009), and for the study by Bell et al. (2006) (for the 30 ppb cut point) (Table 4-2), the majority of study locations would likely have met a standard with a level of 70 ppb.

[45] As discussed above, compared to the weight given to the evidence and to HREA estimates of exposures of concern and lung function risks, we place relatively less weight on epidemiologic-based risk estimates.

[46] A standard with a level of 70 ppb is also estimated to reduce respiratory mortality associated with long-term O_3 concentrations in urban case study areas. However, given uncertainties associated with these risk estimates, as discussed above, we give them limited weight.

Compared to the total risk estimates noted above, an O_3 standard with a level of 70 ppb is estimated to be more effective at reducing the number of deaths associated with short-term O_3 concentrations at the upper ends of ambient distributions. Specifically, for area-wide O_3 concentrations at or above 40 ppb, a standard with a level of 70 ppb is estimated to reduce the number of deaths associated with short-term O_3 concentrations by about 10% compared to the current standard. In addition, for area-wide concentrations at or above 60 ppb, a standard with a level of 70 ppb is estimated to reduce O_3-associated deaths by about 50% to 70% (Figure 4-13).

As discussed above, CASAC concluded that there is adequate scientific evidence to consider a range of levels for a primary standard that includes an upper end at 70 ppb. However, CASAC differentiated its advice from the conclusions in the second draft PA by also advising that a level of 70 ppb would provide little margin of safety for protection of public health, particularly for sensitive subpopulations (Frey, 2014, p. 8). In particular, CASAC stated that:

> *At 70 ppb, there is substantial scientific certainty of a variety of adverse effects, including decrease in lung function, increase in respiratory symptoms, and increase in airway inflammation. Although a level of 70 ppb is more protective of public health than the current standard, it may not meet the statutory requirement to protect public health with an adequate margin of safety (Frey, 2014, p.8).*

However, the committee also acknowledged that "the choice of a level within the range recommended based on scientific evidence [i.e., 70 to 60 ppb] is a policy judgment under the statutory mandate of the Clean Air Act" (Frey, 2014).

In summary, compared to the current standard, a revised O_3 standard with a level of 70 ppb would be expected to (1) reduce the occurrence of exposures of concern to O_3 concentrations that result in respiratory effects in healthy adults (at or above 60 and 70 ppb) by about 45 to 95%, almost eliminating the occurrence of multiple exposures at or above 70 ppb; (2) reduce the occurrence of moderate-to-large O_3-induced lung function decrements (FEV_1 decrements $\geq$ 10, 15, 20%) by about 15 to 35%, most effectively limiting the occurrence of multiple decrements and decrements $\geq$ 15, 20%; (3) more effectively maintain short- and long-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard;[47] and (4) reduce the risk of O_3-associated mortality and morbidity, particularly the risk associated with the upper portions of the distributions of ambient O_3 concentrations.

[47] Though epidemiologic studies also provide evidence for O_3 health effect associations in locations likely to have met a standard with a level of 70 ppb, as discussed below for lower standard levels.

O_3 standard level of 65 ppb

Next, we consider a standard with a level of 65 ppb. A level of 65 ppb is well below 80 ppb, an O_3 exposure concentration that has been reported to elicit a range of respiratory effects that includes airway hyperresponsiveness and decreased lung host defense, in addition to lung function decrements, airway inflammation, and respiratory symptoms. A standard level of 65 ppb is also below the lowest exposure concentration at which the combined occurrence of respiratory symptoms and lung function decrements has been reported (i.e., 72 ppb), a combination judged adverse by the ATS (section 3.1.3). A level of 65 ppb is above the lowest exposure concentration demonstrated to result in lung function decrements large enough to be judged an abnormal response by ATS, where statistically significant changes in group mean responses would be judged to be adverse by ATS, and which the CASAC has indicted could be adverse in people with lung disease (i.e., 60 ppb). A level of 65 ppb is also above the lowest exposure concentration at which pulmonary inflammation has been reported in healthy adults (i.e., 60 ppb).

Compared to the current standard and a revised standard with a level of 70 ppb, the HREA estimates that a standard with a level of 65 ppb would reduce exposures of concern to the range of O_3 benchmark concentrations analyzed (i.e., 60, 70, and 80 ppb). The HREA estimates that meeting a standard with a level of 65 ppb would eliminate exposures of concern at or above 80 ppb in the urban case study areas. Such a standard is estimated to allow far less than 1% of children in the urban case study areas to experience one or more exposures of concern at or above the 70 ppb benchmark level, even in the worst-case years and locations, and is estimated to eliminate the occurrence of two or more exposures at or above 70 ppb (Table 4-4).

In addition, on average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow between 0 and about 4% of children (including asthmatic children) in urban case study areas to experience exposures of concern at or above 60 ppb, which CASAC has indicated is an appropriate exposure of concern for people with asthma, including children. This reflects an 80% reduction (on average across areas), relative to the current standard. A standard with a level of 65 ppb is estimated to allow less than 1% of children to experience two or more exposures of concern at or above 60 ppb (> 90% reduction, compared to current standard). In the worst-case location and year, about 10% of children are estimated to experience one or more exposures of concern at or above 60 ppb, with about 3% estimated to experience two or more such exposures (Table 4-4).

Compared to the current standard and a revised standard with a level of 70 ppb, the HREA estimates that a standard with a level of 65 ppb would also reduce the occurrence of O_3-induced lung function decrements. A level of 65 ppb is estimated to allow about 4% or less of children to experience moderate O_3-induced FEV_1 decrements $\geq$ 15% (50% reduction, compared

to current standard), even considering the worst-case location and year. Such a standard is estimated to allow about 2% or less of children to experience two or more such decrements. A standard set at 65 ppb is estimated to allow about 1% or less of children to experience large O_3-induced lung function decrements (i.e., FEV_1 decrement ≥ 20%), even in the worst-case year and location (Table 4-5).

On average over the years 2006 to 2010, a standard with a level of 65 ppb is estimated to allow about 3 to 15% of children to experience one or more moderate O_3-induced lung function decrements (i.e., FEV_1 decrement ≥ 10%), which CASAC has indicated could be adverse for people with lung disease. This reflects an average reduction of about 30%, relative to the current standard. A standard with a level of 65 ppb is also estimated to allow about 1 to 9% of children in the urban case study areas to experience two or more such decrements (37% reduction, compared to current standard). In the worst-case location and year, a standard set at 65 ppb is estimated to allow up to about 18% of these children to experience one or more moderate O_3-induced lung function decrements ≥ 10%, and up to 11% to experience two or more such decrements (Table 4-5).

With regard to O_3 epidemiologic studies we note that, compared to a standard with a level of 70 ppb, a revised standard with a level of 65 ppb would more effectively maintain short-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard. In particular, Katsouyanni et al. (2009) reported statistically significant associations with mortality based on air quality in 12 Canadian cities, most of which would likely have met a standard with a level of 70 ppb over the entire study period but violated a revised standard with a level of 65 ppb or below over at least part of that period (Table 4-1). This analysis suggests that while the current standard or a standard with a level of 70 ppb would allow the ambient O_3 concentrations in most of the study locations that provided the basis for the association with mortality in this study, a revised O_3 standard with a level at or below 65 ppb would require reductions in those ambient O_3 concentrations. As discussed above for a level of 70 ppb, this analysis does not provide information on the extent to which O_3-associated mortality would persist upon meeting an O_3 standard with a level of 65 ppb, or on the extent to which standard levels below 65 ppb could further reduce the incidence of this mortality.[48]

With regard to long-term O_3 concentrations, as for 70 ppb (above) we evaluate the "long-term" O_3 metrics reported to be associated with mortality or morbidity in recent epidemiologic

[48] For the other multicity studies identified in Table 4-1 (Cakmak et al., 2006; Stieb et al., 2009; Katsouyanni et al., 2009 (for hospital admissions)), and for the study by Bell et al. (2006) (for the 30 ppb cut point) (Table 4-2), the majority of study locations would have met a standard with a level of 65 ppb.

studies (e.g., seasonal averages of 1-hour or 8-hour daily max concentrations). Compared to the current standard or a revised O_3 standard with a level of 70 ppb, a revised standard with a level of 65 ppb would be expected to further reduce the risk of respiratory mortality associated with long-term O_3 concentrations, based on information from the study by Jerrett et al. (2009).[49] In addition, a standard with a level of 65 ppb would be expected to more effectively maintain long-term O_3 concentrations below those where the study by Jerrett et al. (2009) indicates the most confidence in the reported association with respiratory mortality. Specifically, air quality analyses indicate this to be the case in 10 out of the 12 urban case study areas for a level of 65 ppb, compared to 6 out of 12 areas for the current standard and 9 out of 12 for a standard with a level of 70 ppb (Table 4-3). Finally, a revised standard with a level of 65 ppb would be expected to further reduce long-term O_3 concentrations based on the types of metrics that have been reported in recent epidemiologic studies to be associated with respiratory morbidity (i.e., seasonal averages of daily maximum 8-hour concentrations).

In further considering the potential implications of epidemiology studies for alternative standard levels, we note estimates of total mortality associated with short-term O_3.[50] As discussed above, we consider estimates of total risk (i.e., based on the full distributions of ambient O_3 concentrations) and estimates of risk associated with O_3 concentrations in the upper portions of ambient distributions. With regard to total risk we note that, when summed across urban case study areas, a standard with a level of 65 ppb is estimated to reduce the number of deaths associated with short-term O_3 exposures by about 13% (2007) and 9% (2009), compared to the current standard.[51] For area-wide concentrations at or above 40 ppb, a standard level of 65 ppb is estimated to reduce O_3-associated deaths by almost 50% compared to the current standard, when summed across cities. For area-wide concentrations at or above 60 ppb, a standard level of 65 ppb is estimated to reduce O_3-associated deaths by more than 80% (Figure 4-13).

As discussed above, although CASAC concluded that the scientific evidence supports considering standard levels as high as 70 ppb, it also concluded that a level of 70 ppb would provide little margin of safety (Frey, 2014, p. 8). In support of its policy advice that the level should be set below 70 ppb, CASAC noted that an alternative standard with a level of 65 ppb would further reduce, though not eliminate, the frequency of lung function decrements $\geq$ 15%

[49] Though as discussed above, we note the lower confidence we place in these risk results (U.S. EPA, 2014a, section 9.6).

[50] As discussed above, compared to the weight given to the evidence and to HREA estimates of exposures of concern and lung function risks, we place relatively less weight on epidemiologic-based risk estimates.

[51] A standard with a level of 65 ppb is also estimated to reduce respiratory mortality associated with long-term O_3 concentrations in urban case study areas. However, given uncertainties associated with these risk estimates, as discussed above, we give them limited weight.

and would lead to lower frequency of short-term premature mortality (i.e., compared to a standard with a level of 70 ppb) (Frey, 2014, p. 8).

In summary, compared to a standard with a level of 70 ppb, a revised standard with a level of 65 ppb would be expected to (1) further reduce the occurrence of exposures of concern (by about 80 to 100% compared to the current standard), decreasing exposures at or above 60 ppb and almost eliminating exposures at or above 70 and 80 ppb; (2) further reduce the occurrence of FEV_1 decrements $\geq$ 10, 15, and 20% (by about 30 to 65%, compared to the current standard); (3) more effectively maintain short- and long-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard;[52] and (4) further reduce the risk of O_3-associated mortality and morbidity, particularly the risk associated with the upper portion of the distribution of ambient O_3 concentrations.

O_3 standard level of 60 ppb

We next consider a standard with a level of 60 ppb. A level of 60 ppb is well below the O_3 exposure concentration that has been reported to elicit a wide range of potentially adverse respiratory effects in healthy adults (i.e., 80 ppb). A level of 60 ppb is also below the concentration where the combined occurrence of respiratory symptoms and lung function decrements was observed, a combination judged adverse by the ATS (i.e., 72 ppb, discussed in section 3.1.3). A level of 60 ppb corresponds to the lowest exposure concentration demonstrated to result in lung function decrements that are large enough to be judged an abnormal response by ATS, that meet ATS criteria for adversity based on a downward shift in the distribution of FEV1, and that the CASAC indicated could be adverse in people with lung disease. A level of 60 ppb also corresponds to the lowest exposure concentration at which pulmonary inflammation has been reported in controlled human exposure studies.

Based on the HREA analyses of O_3 exposures of concern, a standard with a level of 60 ppb is estimated to eliminate exposures of concern at or above the 70 and 80 ppb benchmark concentrations and to be more effective than the higher standard levels at limiting exposures of concern at or above 60 ppb. On average over the years 2006 to 2010, a standard with a level of 60 ppb is estimated to allow between 0 and about 1% of children, including asthmatic children, in urban case study areas to experience exposures of concern at or above 60 ppb, which CASAC indicated is an appropriate exposure of concern for asthmatic children. This reflects a 96% reduction (on average across areas), compared to the current standard. A standard with a level of

[52]Though epidemiologic studies also provide evidence for O_3 health effect associations in locations likely to have met a standard with a level of 65 ppb, as discussed below for a level of 60 ppb.

60 ppb is estimated to allow virtually no children to experience two or more exposures of concern at or above 60 ppb. In the worst-case location and year, about 2% of children are estimated to experience exposures of concern at or above 60 ppb, with far less than 1% estimated to experience two or more such exposures (Table 4-4).

Based on the HREA analyses of O_3-induced lung function decrements, a standard with a level of 60 ppb would be expected to be more effective than a level of 70 or 65 ppb at limiting the occurrence of O_3-induced lung function decrements. A standard with a level of 60 ppb is estimated to allow about 2% or less of children in the urban case study areas to experience one or more moderate O_3-induced FEV_1 decrements $\geq$ 15% (almost 70% reduction, compared to current standard), and about 1% or less to experience two or more such decrements (3% in the location and year with the largest estimates). A standard set at 60 ppb is estimated to allow about 1% or less of children to experience large O_3-induced lung function decrements (i.e., FEV_1 decrement $\geq$ 20%), even in the worst-case locations and year (Table 4-5).

On average over the years 2006 to 2010, a standard with a level of 60 ppb is estimated to allow about 5 to 11% of children in the urban case study areas to experience one or more moderate O_3-induced lung function decrements that CASAC indicated could be adverse for people with lung disease (i.e., FEV_1 decrements $\geq$ 10%). This reflects an average reduction of about 45%, compared to current standard. A standard with a level of 60 ppb is also estimated to allow about 2 to 6% of children in these areas to experience two or more such decrements (51% reduction, compared to current standard). In the worst-case location and year, a standard set at 60 ppb is estimated to allow up to about 13% of children to experience one or more moderate O_3-induced FEV_1 decrements $\geq$ 10%, and 7% to experience two or more such decrements (Table 4-5).

With regard to O_3 epidemiologic studies we note that, compared to a standard with a level of 70 or 65 ppb, a revised standard with a level of 60 ppb would more effectively maintain short-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard. Specifically, in all of the U.S. and Canadian epidemiologic studies evaluated, the majority of study cities had ambient O_3 concentrations that would likely have violated a standard with a level of 60 ppb. Thus, none of the U.S. and Canadian epidemiologic studies analyzed provide evidence for O_3 health effect associations when the majority of study locations would likely have met a standard with a level of 60 ppb (Tables 4-1 and 4-2). As discussed above, while this analysis does not provide information on the extent to which the O_3-associated morbidity or mortality would persist upon meeting an O_3 standard with a level of 60 ppb, it suggests that a revised O_3 standard with a level of 60 ppb would require reductions in the ambient O_3 concentrations that provided the basis for those health effect associations.

With regard to long-term O_3 concentrations, compared to the current standard or a revised O_3 standard with a level of 70 or 65 ppb, a revised standard with a level of 60 ppb would be expected to further reduce the risk of respiratory mortality associated with long-term O_3 concentrations, based on information from the study by Jerrett et al. (2009).[53] In addition, a standard with a level of 60 ppb would be expected to more effectively maintain long-term O_3 concentrations below those where the study by Jerrett et al. (2009) indicates the most confidence in the reported association with respiratory mortality. Specifically, air quality analyses indicate this to be the case in all of the urban case study areas evaluated at a level of 60 ppb, compared to 6 out of 12 areas for the current standard, 9 out of 12 for a standard with a level of 70 ppb, and 10 out of 12 for a standard with a level of 65 ppb (Table 4-3). Finally, a revised standard with a level of 60 ppb would be expected to further reduce long-term O_3 concentrations based on the types of metrics that have been reported in recent epidemiologic studies to be associated with respiratory morbidity (i.e., seasonal averages of daily maximum 8-hour concentrations).

In further considering the potential implications of epidemiology studies for alternative standard levels, we note estimates of total mortality associated with short-term O_3 concentrations.[54] As discussed above, we consider estimates of total risk (i.e., based on the full distributions of ambient O_3 concentrations) and estimates of risk associated with O_3 concentrations in the upper portions of ambient distributions. With regard to total risk we note that, when summed across urban case study areas, a standard with a level of 60 ppb is estimated to reduce the number of deaths associated with short-term O_3 exposures by about 15% (2007) and 11% (2009), compared to the current standard (Figure 4-13).[55] For area-wide concentrations at or above 40 ppb, a standard with a level set at 60 ppb is estimated to reduce O_3-associated deaths by almost 60% compared to the current standard. For area-wide concentrations at or above 60 ppb, a standard level of 60 ppb is estimated to reduce O_3-associated deaths by over 95% compared to the current standard (Figure 4-13).

Relative to the current standard, or alternative O_3 standards with levels of 70 or 65 ppb, CASAC stated the following:

> *The frequency of lung function decrements and premature mortality from short-term exposure to ozone decreases even further when the alternative standard is lowered to 60 ppb (Frey, 2014, p.8).*

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[53] Though as discussed above, we note the lower confidence we place in these risk results (U.S. EPA, 2014a, section 9.6).

[54] As discussed above, compared to the weight given to the evidence and to HREA estimates of exposures of concern and lung function risks, we place relatively less weight on epidemiologic-based risk estimates.

[55] A standard with a level of 60 ppb is also estimated to reduce respiratory mortality associated with long-term O_3 concentrations in urban case study areas. However, given uncertainties associated with these risk estimates, as discussed above, we give them limited weight.

CASAC also concluded that "the recommended lower bound of 60 ppb would certainly offer more public health protection than levels of 70 ppb or 65 ppb and would provide an adequate margin of safety" (Frey, 2014, p. ii).

In summary, compared to a standard with a level of 70 or 65 ppb, a revised standard with a level of 60 ppb would be expected to (1) further reduce the occurrence of exposures of concern (by about 95 to 100% compared to the current standard), almost eliminating exposures at or above 60 ppb; (2) further reduce the occurrence of FEV_1 decrements $\geq$ 10, 15, and 20%, (by about 45 to 85% compared to the current standard); (3) more effectively maintain short- and long-term O_3 concentrations below those present in the epidemiologic studies that reported significant O_3 health effect associations in locations likely to have met the current standard;[56] and (4) further reduce the risk of O_3-associated mortality and morbidity, particularly the risk associated with the upper portion of the distribution of ambient O_3 concentrations.

4.7 KEY UNCERTAINTIES AND AREAS FOR FUTURE RESEARCH AND DATA COLLECTION

It is important to highlight the uncertainties associated with establishing standards for O_3 during and after completion of the NAAQS review process. Research needs go beyond what is necessary to understand health effects, population exposures, and risks of exposure for purposes of setting standards. Research can also support the development of more efficient and effective control strategies. In this section, we highlight areas for future health-related research, model development, and data collection activities to address these uncertainties and limitations in the current body of scientific evidence.

As has been presented and discussed in the ISA, particularly chapters 4 through 7, the scientific body of evidence informing our understanding of health effects associated with long- and short-term exposures to O_3 has been broadened and strengthened since the O_3 NAAQS review completed in 2008. Still, we have concluded that O_3 health research needs and priorities have not changed substantially since the 2007 O_3 Staff Paper (EPA 2007). Key uncertainties and research needs that continue to be high priority for future reviews of the health-based standards are identified below:

(1) An important aspect of risk characterization and decision making for air quality standard levels for the O_3 NAAQS is the characterization of the shape of exposure-response functions for O_3, including the identification of potential population threshold levels. Recent controlled human exposure studies of measurable lung function effects provide evidence for a smooth dose-response curve without evidence of a threshold for exposures between 40 and 120

[56]As discussed above, these studies do not provide information on the extent to which O_3 health effect associations would persist following reductions in ambient O_3 concentrations in order to meet a standard with a level of 60 ppb.

ppb O_3 (US EPA, 2013, Figure 6-1). Considering the importance of estimating health risks in the range below 80 ppb O_3, additional research is needed to evaluate responses in healthy and especially people with asthma in the range of 40 to 70 ppb for 6-8 hour exposures while engaged in moderate exertion.

(2) Similarly, for health endpoints reported in epidemiologic studies such as hospital admissions, ED visits, and premature mortality, an important aspect of characterizing risk is the shape of concentration-response functions for O_3, including identification of potential population threshold levels. Most of the recent studies and analyses continue to show no evidence for a clear threshold in the relationships between O_3 concentrations commonly observed in the U.S. during the O_3 season and these health endpoints, though evidence indicates less certainty in the shape of the concentration-response curve at the lower end of the distribution of O_3 concentrations. However, there continues to be heterogeneity in the O_3-mortality relationship across cities (or regions), including effect modifiers that are also expected to vary regionally, which are sources of uncertainty. Additionally, whether or not exposure errors, misclassification of exposure, or potential impacts of other copollutants may be obscuring potential population thresholds is still unknown.

(3) The extent to which the broad mix of photochemical oxidants and more generally other copollutants in the ambient air (e.g., PM, NO_2, SO_2, etc.) may play a role in modifying or contributing to the observed associations between ambient O_3 and various morbidity effects and mortality continues to be an important research question. Ozone has long been known as an indicator of health effects of the entire photochemical oxidant mix in the ambient air and has served as a surrogate for control purposes. A better understanding of sources of the broader pollutant mix, of human exposures, and of how other pollutants may modify or contribute to the health effects of O_3 in the ambient air, and vice versa, is needed to better inform future NAAQS reviews.

(4) As epidemiologic research has continued to be an important factor in assessing the public health impacts of O_3, methodological issues in epidemiologic studies have received greater visibility and scrutiny. There remains a need to further examine alternative modeling specifications and control of time-varying factors, and to better understand the role of copollutants in the ambient air. Additionally, there remains uncertainty around the role of temperature as a potential confounder or effect modifier in epidemiologic models.

(5) Recent animal toxicological evidence, combined with limited evidence from controlled human exposure studies of cardiovascular morbidity and epidemiologic studies of cardiovascular mortality, have provided evidence of both direct and indirect effects on the cardiovascular system. However, additional work will need to examine biologically plausible mechanisms of cardiovascular effects, expand upon preliminary evidence from controlled human

exposure studies, address inconsistencies observed in epidemiologic studies of cardiovascular morbidity, and determine the extent to which O_3 is directly implicated or works together with other pollutants in causing adverse cardiovascular effects in both at-risk and the general populations.

(6) Most epidemiologic studies of short-term exposure effects have employed time-series or case-crossover study designs and have been conducted in large populations. These study designs remain subject to uncertainty due to use of ambient fixed-site data serving as a surrogate for ambient exposures, and to the difficulty of determining the impact of any single pollutant among the mix of pollutants in the ambient air. Measurements made at stationary outdoor monitors have been used as independent variables for air pollution, but the accuracy with which these measurements actually reflect subjects' exposure is not yet fully understood. Also, additional research is needed to improve the characterization of the degree to which discrepancy between stationary monitor measurements and actual pollutant exposures introduces error into statistical estimates of pollutant effects in epidemiologic studies.

(7) Recent studies of "long-term" O_3 often evaluate associations with daily maximum concentrations, averaged over the O_3 season. Research is needed to better understand the extent to which health effects associated with such long-term metrics are attributable to long-term average concentrations versus the repeated occurrence of daily maximum concentrations.

(8) Improved understanding of human exposures to ambient O_3 and to related copollutants is an important research need. Population-based information on human exposure for healthy adults and children and at-risk populations, including people with asthma, to ambient O_3 concentrations, including exposure information in various microenvironments, is needed to better evaluate current and future O_3 exposure models. Such information is needed for sufficient periods to facilitate evaluation of exposure models throughout the O_3 season.

(9) Information is needed to improve inputs to current and future population-based O_3 exposure and health risk assessment models. Collection of time-activity data over longer time periods is needed to reduce uncertainty in the modeled exposure distributions that form an important part of the basis for decisions regarding NAAQS for O_3 and other air pollutants. Research addressing energy expenditure and associated breathing rates in various population groups, particularly healthy children and children with asthma, in various locations, across the spectrum of physical activity, including sleep to vigorous exertion, is needed.

(10) An important consideration in the O_3 NAAQS review is the characterization of background levels. There still remain substantial uncertainties in the characterization of 8-hour daily max O_3 background concentrations. Further research to improve the evaluation of the global and regional models which have been used to characterize estimates of background levels

would improve understanding of the role of non-U.S. anthropogenic emissions on O_3 levels over the U.S.

4.8 SUMMARY OF STAFF CONCLUSIONS ON PRIMARY STANDARD

In this section, we summarize our conclusions regarding the primary O_3 standard. These conclusions are informed by our consideration of the available scientific evidence as assessed in the ISA, air quality/exposure/risk information assessed in the final HREA, recommendations and advice received from CASAC, and comments received from members of the public.

As an initial matter in this PA, staff concludes that reducing ambient O_3 concentrations to meet the current standard will provide important improvements in public health protection. This initial conclusion is based on (1) the strong body of scientific evidence indicating a wide range of adverse health outcomes attributable to exposures to O_3 concentrations found in the ambient air and (2) estimates indicating decreased O_3 exposures and health risks upon meeting the current standard, compared to recent air quality. Strong support for this conclusion is provided by the available health evidence, and by HREA estimates of exposures to O_3 concentrations shown to result in respiratory effects in healthy adults (exposures of concern $\geq$ 60, 70 and 80 ppb); O_3-induced lung function risks (FEV_1 decrements $\geq$ 10, 15 and 20%); and O_3-associated mortality and morbidity risks.

Staff further concludes that the O_3-attributable health effects estimated to be allowed by air quality that meets the current primary standard can reasonably be judged important from a public health perspective. This conclusion is based on consideration of the scientific evidence assessed in the ISA, including controlled human exposure studies reporting abnormal or adverse respiratory effects following exposures to O_3 concentrations below the level of the current standard and epidemiologic studies indicating associations with morbidity and mortality for air quality that would meet the current standard. This conclusion is also based on the HREA estimates of exposures of concern, lung function risks, and morbidity and mortality risks; on advice received from CASAC in their review of draft versions of the PA; on CASAC advice received in previous reviews; and on consideration of public comments. Staff reaches the overall conclusion that the available health evidence and exposure/risk information calls into question the adequacy of the public health protection provided by the current standard.

Given this conclusion regarding the adequacy of the current standard, staff also reaches conclusions for the Administrator's consideration regarding the elements of alternative primary O_3 standards that could be supported by the available evidence and exposure/risk information. In reaching conclusions about the range of potential alternative standards appropriate for consideration, staff is mindful that the Act requires primary standards that, in the judgment of the Administrator, are requisite to protect public health with an adequate margin of safety. The

primary standards are to be neither more nor less stringent than necessary. Thus, the Act does not require that primary NAAQS be set at zero-risk levels, but rather at levels that reduce risk sufficiently to protect public health with an adequate margin of safety.

The degree of public health protection provided by any NAAQS results from the collective impact of the elements of the standard, including the indicator, averaging time, level, and form. Staff's conclusions on each of these elements are summarized below.

(1) **Indicator:** It is appropriate to continue to use O_3 as the indicator for a standard that is intended to address effects associated with exposure to O_3, alone or in combination with related photochemical oxidants. Based on the available information, staff concludes that there is no basis for considering any alternative indicator at this time. Meeting an O_3 standard can be expected to provide some degree of protection against potential health effects that may be independently associated with other photochemical oxidants, even though such effects are not discernible from currently available studies indexed by O_3 alone. Staff notes that control of ambient O_3 levels is generally understood to provide the best means of controlling photochemical oxidants, and thus of protecting against effects that may be associated with individual species and/or the broader mix of photochemical oxidants.

(2) **Averaging time:** It is appropriate to consider continuing to use an 8-hour averaging time for the primary O_3 standard.

(a) Staff concludes that an 8-hour averaging time remains appropriate for addressing health effects associated with short-term exposures to ambient O_3. An 8-hour averaging time is similar to the exposure periods evaluated in controlled human exposure studies, including recent studies reporting respiratory effects following exposures to O_3 concentrations below the level of the current standard. In addition, epidemiologic studies provide evidence for health effect associations with 8-hour O_3 concentrations, as well as with 1-hour and 24-hour concentrations. A standard with an 8-hour averaging time (combined with an appropriate standard form and level) would also be expected to provide substantial protection against health effects attributable to 1- and 24-hour exposures.

(b) Staff also concludes that a standard with an 8-hour averaging time can provide protection against respiratory effects associated with longer term O_3 exposures. Analyses in the HREA show that as air quality is adjusted to just meet the current

or alternative 8-hour standards, most study areas are estimated to experience reductions in respiratory mortality associated with long-term O_3 concentrations. In addition, analyses in this PA indicate that just meeting an 8-hour standard with an appropriate level would be expected to maintain long-term O_3 concentrations (i.e., seasonal average of 1-hour daily max) below those where a key study indicates the most confidence in the concentration-response relationship with respiratory mortality. In considering other long-term O_3 metrics evaluated in recent health studies, analyses in the HREA indicate that the large majority of the U.S. population lives in locations where reducing NO_X emissions would be expected to decrease warm season averages of daily 8-hour ambient O_3 concentrations, a long-term metric used in several recent studies reporting associations with respiratory morbidity. Taken together, these analyses suggest that a standard with an 8-hour averaging time, coupled with the current 4th-highest form and an appropriate level, could provide appropriate protection against the long-term O_3 concentrations reported to be associated with respiratory morbidity and mortality.

(3) **Form:** For an 8-hour O_3 standard with a revised level (as discussed below), it is appropriate to consider retaining the current form, defined as the 3-year average of the annual 4th-highest daily maximum concentration. Staff notes that this form was selected in 1997 and 2008 in recognition of the public health protection provided, when coupled with an appropriate averaging time and level, combined with the stability provided for implementation programs. The currently available evidence and exposure/risk information does not call into question these conclusions from previous reviews.

(4) **Level:** The available scientific evidence and exposure/risk information provide strong support for considering an O_3 standard with a revised level in order to increase public health protection. Staff concludes that it is appropriate in this review to consider a revised standard level within the range of 70 ppb to 60 ppb, reflecting the judgment that a standard set within this range could provide an appropriate degree of public health protection and would result in important improvements in protection for at-risk populations and lifestages.

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5 ADEQUACY OF THE CURRENT SECONDARY STANDARD

This chapter presents staff's considerations and conclusions regarding the adequacy of the current secondary O_3 NAAQS. In doing so, we pose the following overarching question:

- **Does the currently available scientific evidence- and exposure/risk-based information, as reflected in the ISA and WREA, support or call into question the adequacy and appropriateness of the protection afforded by the current secondary O_3 standard?**

In addressing this overarching question, we pose a series of more specific questions, as discussed in sections 5.1 through 5.5 below. We consider the nature of O_3-induced effects, including the nature of the exposures that drive the biological and ecological response and related biologically relevant exposure metrics (section 5.1); the scientific evidence and exposure/risk information, including that for associated ecosystem services, regarding (a) tree growth, productivity and carbon storage (section 5.2), (b) crop yield loss (section 5.3), (c) visible foliar injury (section 5.4), and (d) other welfare effects (section 5.5). Section 5.6 describes advice and recommendations received from CASAC. In section 5.7, we revisit the overarching question of this chapter and present staff conclusions on the adequacy and appropriateness of the current secondary standard.

5.1 NATURE OF EFFECTS AND BIOLOGICALLY RELEVANT EXPOSURE METRIC

- **Does the current evidence alter our conclusions from the previous review regarding the nature of O_3-induced welfare effects?**

As discussed further below, the current body of O_3 welfare effects evidence confirms and strengthens the conclusions reached in the last review on the nature of O_3-induced welfare effects. Ozone's phytotoxic effects were first identified on grape leaves in a study published in 1958 (Richards et al., 1958). In the more than fifty years that have followed, extensive research has been conducted both in and outside of the U.S. to examine the impacts of O_3 on plants and their associated ecosystems, since "of the phytotoxic compounds commonly found in the ambient air, O_3 is the most prevalent, impairing crop production and injuring native vegetation and ecosystems more than any other air pollutant" (U.S. EPA, 1989, 1996). Recent studies, assessed in the ISA, together with this longstanding and well established vegetation effects literature, further contribute to the coherence and consistency of the vegetation effects evidence.

In assessing the strength of the evidence, it is important to note that different types of studies can provide different types of information, each with different associated uncertainties

(U.S. EPA, 2013, Chapter 9, section 9.2). Controlled chamber studies are the best method for isolating or characterizing the role of O_3 in inducing the observed plant effects, and in assessing plant response to O_3 at the finer scales (U.S. EPA, 2013, Chapter 9, section 9.3). Recent controlled studies have focused on a variety of plant responses to O_3 including: 1) the underlying mechanisms as they relate to growth, productivity and carbon storage including: reduced carbon dioxide uptake due to stomatal closure (U.S. EPA 2013, section 9.3.2.1); 2) the upregulation of genes associated with plant defense, signaling, hormone synthesis and secondary metabolism (U.S. EPA 2013, section 9.3.3.2); 3) the down regulation of genes related to photosynthesis and general metabolism (U.S. EPA 2013, section 9.3.3.2); 4) the loss of carbon assimilation capacity due to declines in the quantity and activity of key proteins and enzymes (U.S. EPA, 2013, section 9.3.5.1); and 5) the negative impacts on the efficiency of the photosynthetic light reactions (U.S. EPA, 2013, section 9.3.5.1). As described in the ISA, these new studies "have increased knowledge of the molecular, biochemical and cellular mechanisms occurring in plants in response to O_3", adding "to the understanding of the basic biology of how plants are affected by oxidative stress…" (U.S. EPA, 2013, p. 9-11). The ISA further concluded that controlled studies "have clearly shown that exposure to O_3 is causally linked to visible foliar injury, decreased photosynthesis, changes in reproduction, and decreased growth" in many species of vegetation (U.S. EPA 2013, p. 1-15).

Such effects at the plant scale can also be linked to an array of effects at larger spatial scales. For example, recent field studies at larger spatial scales, together with previously available evidence, support the controlled exposure study results and indicate that "ambient O_3 exposures can affect ecosystem productivity, crop yield, water cycling, and ecosystem community composition" (U.S. EPA, 2013, p. 1-15; Chapter 9, section 9.4).

The ISA summarizes the coherence across the full range of effects, from the least serious to the most serious, as follows (U.S. EPA, 2013, p. 1-8):

> *The welfare effects of O_3 can be observed across spatial scales, starting at the subcellular and cellular level, then the whole plant and finally, ecosystem-level processes. Ozone effects at small spatial scales, such as the leaf of an individual plant, can result in effects along a continuum of larger spatial scales. These effects include altered rates of leaf gas exchange, growth, and reproduction at the individual plant level, and can result in broad changes in ecosystems, such as productivity, carbon storage, water cycling, nutrient cycling, and community composition.*

Based on its assessment of this extensive body of science, the ISA determined that, with respect to vegetation and ecosystems, a causal relationship exists between exposure to O_3 in ambient air and visible foliar injury effects on vegetation, reduced vegetation growth, reduced

productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops and alteration of below-ground biogeochemical cycles (U.S. EPA 2013, Table 1-2). Additionally, the ISA determined that a likely to be causal relationship exists between exposures to O_3 in ambient air and reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial ecosystem water cycling and alteration of terrestrial community composition (U.S. EPA, 2013, Table 1-2). With regard to the relationship between O_3 and radiative forcing and climate change, the ISA determined that there is a causal relationship between changes in tropospheric O_3 concentrations and radiative forcing, and likely to be a causal relationship between changes in tropospheric O_3 concentrations and effects on climate (U.S. EPA, 2013, p. 1-13, and Table 1-3). From this set of effects that the ISA has concluded to be causally or likely causally related to O_3 in ambient air, we focus the discussion in the PA primarily on: 1) impacts on tree growth, productivity and carbon storage; 2) crop yield loss; 3) visible foliar injury. Each of these discussions also includes where appropriate, a discussion of any known or anticipated impacts that such individual plant or species level effects could have at larger scales, including ecosystems, and on associated ecosystem services.

In considering the available vegetation effects evidence, we make note of several important contextual features that frame our understanding of the science and how it informs our evaluation of the adequacy of the protection afforded by the current secondary NAAQS. First, we acknowledge that under natural conditions, a variety of factors can either mitigate or exacerbate the predicted O_3-plant interactions and are recognized sources of uncertainty and variability. These include: 1) multiple genetically influenced determinants of O_3 sensitivity; 2) changing sensitivity to O_3 across vegetative growth stages; 3) co-occurring stressors and/or modifying environmental factors (U.S. EPA, 2013, section 9.4.8).

Second, we acknowledge that the species that have been studied for O_3 sensitivity represent only a fraction of the tens of thousands of plant species that grow in the U.S. (USDA NRCS, 2014)[1], and that these species were typically selected because of their commercial importance (e.g., commodity crop or timber species) or because of observed O_3-induced visible foliar injury in the field. Of the species known to be sensitive to O_3 for foliar injury, 66 species have been identified on National Park Service (NPS) and U.S. Fish and Wildlife Service lands[2] and a subset of these are used in the USFS biomonitoring program (discussed in section 5.4 below). A number of these species have also been identified as important to tribal cultural practices (see Appendix 5-A). Appendix 7J of the 2007 Staff Paper showed that no state in the

[1] USDA NRCS. 2014. The PLANTS Database (http://plants.usda.gov, 3 January 2014). National Plant Data Team, Greensboro, NC 27401-4901 USA.

[2] See http://www2.nature.nps.gov/air/Pubs/pdf/flag/NPSozonesensppFLAG06.pdf

lower 48 states had less than seven known O_3-sensitive plant species, with the majority of states having between 11 and 30 (see Appendix 7J–2 in U.S. EPA, 2007). We would not expect this information to have changed since the previous review because there has been very little change in the list of sensitive species and the occurrence of any of these plant species within a state would not be expected to change. With respect to agricultural species, a number of important commodity crops such as soybean and additional fruit and vegetable species such as lettuce have been shown to be sensitive to O_3 for either foliar injury or yield loss (U.S. EPA, 2013, section 9.4.4.1; Abt Associates, Inc., 1995).

Third, we acknowledge that out of the group of species known to be sensitive to O_3, we have chosen to focus primarily on species for which we have robust exposure-response (E-R) functions for biomass loss and yield loss using the W126 form (i.e., 11 tree and 10 crop species) in order to be able to quantitatively relate predicted changes in O_3 to predicted changes in plant exposures, responses and associated risks.[3] However, while we recognize that this small group represents only a fraction of all species known or anticipated to be sensitive to O_3 in the U.S., we also note, as did CASAC, that among the studied species, there is a fairly large range of O_3 sensitivities represented, so that it could be reasonable to assume that other non-studied species might have sensitivities that fall within or near this range. Specifically, CASAC states "[i]t should not be assumed that species of unknown sensitivity are tolerant to ozone. It is more appropriate to assume that the sensitivity of species without E-R functions might be similar to the range of sensitivity for those species with E-R functions" (Frey, 2014, p. 11).

Fourth, we acknowledge that in addition to the well-studied effects of biomass loss in trees and crops and visible foliar injury in bioindicator plants that we can quantify, numerous other more subtle and less easily observed effects occur along the continuum of spatial scales that lead to ecosystem effects. While these effects are more difficult to quantify, we acknowledge that any secondary standard set to protect the public welfare against the known and quantifiable adverse effects to vegetation should also consider the anticipated, but currently unquantifiable, potential adverse effects on vegetation, ecosystems and associated services.

Finally, we further acknowledge that in light of the above, when considering the available evidence, we seek to find the right balance between placing weight on the associated uncertainties and limitations of the evidence and placing weight on its well-established strength, coherence and consistency. In so doing, we note that CASAC, in commenting on section 6.7 which describes key uncertainties and future research areas, states that "[w]hile these scientific research priorities will enhance future scientific reviews of the ozone primary and secondary

[3] There is an E-R function available for a 12th tree species (cottonwood), but this E-R function is considered less robust because it is based on the results of a single gradient study (Gregg et al., 2003).

standards, we also make clear that there is sufficient scientific evidence, and sufficient confidence in the available research results, to support the advice we have given above for this review cycle of the primary and secondary standards" (Frey, 2014, p. iv).

- **Does the current evidence continue to support a cumulative, seasonal exposure index as a biological-relevant and appropriate metric for assessment of the evidence and exposure/risk information?**

In this review, the ISA assessment of the full body of currently available evidence stated the following regarding biological indices (U.S. EPA, 2013, p. 2-44):

> *The main conclusions from the 1996 and 2006 O_3 AQCDs [Air Quality Criteria Documents] regarding indices based on ambient exposure remain valid. These key conclusions can be restated as follows:*
>
> - *ozone effects in plants are cumulative;*
> - *higher O_3 concentrations appear to be more important than lower concentrations in eliciting a response;*
> - *plant sensitivity to O_3 varies with time of day and plant development stage;*
> - *quantifying exposure with indices that cumulate hourly O_3 concentrations and preferentially weight the higher concentrations improves the explanatory power of exposure/response models for growth and yield, over using indices based on mean and peak exposure values.*

The long-standing body of available evidence upon which these conclusions are based, provides a wealth of information on aspects of O_3 exposure that are important in influencing plant response. Specifically, a variety of "factors with known or suspected bearing on the exposure-response relationship, including concentration, time of day, respite time, frequency of peak occurrence, plant phenology, predisposition, etc.," have been identified (U.S. EPA, 2013, section 9.5.2). In addition, the importance of the duration of the exposure and the relatively greater importance of higher concentrations over lower in determining plant response to O_3 have been consistently well documented (U.S. EPA, 2013, section 9.5.3). Much of this evidence was assessed in the 1996 Criteria Document (CD) (U.S. EPA, 1996), while more recent work substantiating this evidence is assessed in the subsequent 2006 CD and 2013 ISA.

Understanding of the biological basis for plant response to O_3 exposure led to the development of a large number of "mathematical approaches for summarizing ambient air quality information in biologically meaningful forms for O_3 vegetation effects assessment purposes …" (U.S. EPA, 2013, section 9.5.3), including those that cumulate exposures over some specified period while weighting higher concentrations more than lower (U.S. EPA, 2013, section 9.5.2). As with any summary statistic, these exposure indices retain information on

some, but not all, characteristics of the original observations. As discussed in greater detail in section 6.2 below, the 1996 CD contained an extensive review of the published literature on different types of exposure-response metrics, including comparisons between metrics, from which the 1996 Staff Paper built its assessment of forms appropriate to consider in the context of the secondary NAAQS review. The result of these assessments was a decision by the EPA to focus on cumulative, concentration-weighted indices, which were recognized as the most appropriate biologically based metrics to consider in this context, with attention given primarily to two cumulative, concentration weighted index forms: SUM06 and W126. The SUM06 index is a threshold-based approach described as the sum of all hourly O_3 concentrations greater or equal to 0.06 ppm observed during a specified daily and seasonal time window (U.S. EPA, 2013, section 9.5.2). The W126 index is a non-threshold approach described as the sigmoidally weighted sum of all hourly O_3 concentrations observed during a specified daily and seasonal time window, where each hourly O_3 concentration is given a weight that increases from 0 to 1 with increasing concentration (Lefohn et al., 1988; Lefohn and Runeckles, 1987; U.S. EPA, 2013, section 9.5.2).

In both the 1997 and 2008 reviews, the EPA concluded that the risk to vegetation comes primarily from cumulative exposures to O_3 over a season or seasons[4] and proposed, as one policy alternative, a secondary standard set in terms of such a form: SUM06 (61 FR 65716) and W126 (72 FR 37818) in the 1997 and 2008 reviews, respectively. Although in both reviews the policy decision was made to set the secondary standard to be identical to a revised primary standard (with an 8-hour averaging time), the Administrator, in both cases, also concluded, consistent with CASAC advice, that a cumulative, seasonal index was the most biologically relevant way to relate exposure to plant growth response (62 FR 38856, 73 FR 16436). Similarly, in the 2010 proposed reconsideration of the 2008 decision, the EPA proposed to conclude that O_3 exposure indices that cumulate differentially weighted hourly concentrations are the best candidates for relating exposure to plant growth responses and proposed as the only policy option to set the secondary standard in terms of one such form, the W126 (75 FR 2938). This approach of establishing a secondary standard that was separate and distinct from the primary standard and in particular using a cumulative seasonal exposure index such as W126 received strong support from CASAC in both 2008 and 2010 reviews (Henderson, 2006, 2008; Samet, 2010), as it has again in this review, as discussed in section 5.6 below.

An alternative to using ambient exposure durations and concentrations to predict plant response has been developed in recent years, primarily in Europe, i.e., flux models. While

[4] In describing the form as "seasonal", the EPA is referring generally to the growing season of O_3-sensitive vegetation, not to the seasons of the year (i.e., spring, summer, fall, winter).

"some researchers have claimed that using flux models can be used to better predict vegetation responses to O_3 than exposure-based approaches…" because flux models estimate the ambient O_3 concentration that actually enters the leaf (i.e., flux or deposition) (U.S. EPA, 2013, p. 9-114), it is important to note that "[f]lux calculations are data intensive and must be carefully implemented" (U.S. EPA, 2013, p. 9-114). Further, "[t]his uptake-based approach to quantify the vegetation impact of O_3 requires inclusion of those factors that control the diurnal and seasonal O_3 flux to vegetation (e.g., climate patterns, species and/or vegetation-type factors and site-specific factors)" (U.S. EPA, 2013, p. 9-114). In addition to these data requirements, each species has different amounts of internal detoxification potential that may protect species to differing degrees. This balance between O_3 flux and detoxification processes has been termed the "effective flux". Accordingly, the "models have to distinguish between stomatal and non-stomatal components of O_3 deposition to adequately estimate actual concentration reaching the target tissue of a plant to elicit a response" and " ultimately the 'effective' flux" (U.S. EPA, 2013, pp. 9-114). The lack of detailed species- and site-specific data required for flux modeling in the U.S. and the lack of understanding of detoxification processes have continued to make this technique less viable for use in vulnerability and risk assessments at the national scale in the U.S. (U.S. EPA, 2013, section 9.5.4).

Therefore, consistent with the ISA conclusions regarding the appropriateness of considering cumulative exposure indices that preferentially weight higher concentrations over lower for predicting O_3 effects of concern based on the long-established conclusions and long-standing supporting evidence described above, and in light of continued CASAC support, we continue to focus on the aspects of ambient O_3 exposures that have biological relevance and the biologically relevant exposure indices or metrics that have been designed in light of this consideration, i.e., cumulative concentration-weighted indices. In addition, given the lack of any information in the current review to the contrary, we therefore again conclude that the current evidence, as in recent reviews, continues to support a cumulative, seasonal exposure index as a biologically relevant and appropriate metric for assessment of the evidence and exposure/risk information, and in particular, the W126 cumulative, seasonal metric (U.S. EPA, 2013, section 2.6.6.1, section 9.5.2). Such a metric, as stated above, has an "explanatory power" that is improved "over using indices based on mean and peak exposure values" (U.S. EPA, 2013, section 2.6.6.1, p. 2-44). Thus, as in the WREA, discussions of the effects evidence and exposure/risk results in sections 5.2 through 5.5 of this PA are provided in terms of the W126 index, where available.

- **What paradigm is being used to consider which of the known or anticipated O_3-induced effects have the potential to be adverse to the public welfare?**

The Clean Air Act (CAA), in section 109 (b) (2) requires that "[a]ny national secondary ambient air quality standard… shall specify a level of air quality the attainment and maintenance of which in the judgment of the Administrator, based on such criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air." The "criteria" referred to in this text are defined earlier in CAA section 108 (a) (2) which states in part that "[a]ir quality criteria for an air pollutant shall accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of such pollutant in the ambient air, in varying quantities." Thus, while the criteria include "all identifiable effects", Congress directed the EPA to establish the secondary NAAQS based on the Administrator's judgement of what is requisite to protect against "adverse effects" in the context of the public welfare. However, the CAA does not provide specific standards for determining what constitutes an effect that is adverse to the public welfare leaving these determinations instead to the "judgment of the Administrator". As stated above in section 1.1, the PA is intended to help "bridge the gap" between the Agency's scientific assessments presented in the ISA and REAs, which constitute "the criteria" and the judgments required of the EPA Administrator regarding whether it is appropriate to retain or revise the NAAQS.[5] In the context of the secondary standard, the PA thus serves the function of translating the information assessed in both the ISA and WREA into the public welfare policy context. In order to do this, the PA applies a specific approach or paradigm (see also section 1.3.2. above), that guides staff's consideration and interpretation of the available information and which then informs staff conclusions regarding policy options that are appropriate for the Administrator to consider. The following discussion describes the evolution of this paradigm throughout the last several reviews and into the current review.

In the 1997 secondary O_3 NAAQS review, a policy-relevant distinction was made between the terms "injury" and "damage". Specifically, O_3-induced "injury" to vegetation was defined as encompassing all plant reactions, including reversible changes or changes in plant metabolism (e.g., altered photosynthetic rate), altered plant quality or reduced growth. In contrast, "damage" was defined to include only those injury effects that reach sufficient magnitude as to also reduce or impair the intended use or value of the plant, thus potentially being adverse to the public welfare. In published scientific literature, on the other hand, the terms "adverse", "injury" or "damage" continue to be used interchangeably. The early O_3 NAAQS reviews focused primarily on O_3-induced effects at the individual and species level. In such

[5]American Farm Bureau Federation v. EPA, 559 F. 3d 512, 521 (D.C. Cir. 2009); Natural Resources Defense Council v. EPA, 902 F. 2d 962, 967-68, 970 (D.C. Cir. 1990).

cases, examples of vegetation effects that were also classified as damage included reductions in aesthetic values (e.g., visible foliar injury in ornamental species or occurring in valued natural landscapes such as national parks) and tree growth/biomass and crop yield losses (i.e., in terms of weight, number, quality, appearance, or size of harvestable crop or timber species). In the context of evaluating effects on single plants or species grown in monocultures such as managed forests, this construct continues to remain useful (73 FR 16492/96).

In subsequent reviews, however, the scientific literature linking O_3 effects on plants or species to effects at the community or ecosystem level continued to increase. As a result, more recent reviews have considered a more expansive construct or paradigm of what appropriately constitutes O_3 "damage" to extend beyond that of the individual or species level. A number of these broader paradigms have been discussed in the literature (72 FR 37890; Hogsett et al., 1997; Young and Sanzone, 2002). Thus, in the 2008 review, the Administrator, while continuing to express support for relying on a definition of "adverse" discussed in section IV.A.3 of the proposal (72 FR 37889-37890) that embeds "the concept of 'intended use' of the ecological receptors and resources that are affected", also supported applying "that concept beyond the species level to the ecosystem level" (73 FR 16496). In so doing, the Administrator took note of "a number of actions taken by Congress to establish public lands that are set aside for specific uses that are intended to provide benefits to the public welfare, including lands that are to be protected so as to conserve the scenic value and the natural vegetation and wildlife within such areas, and to leave them unimpaired for the enjoyment of future generations" (73 FR 16496). Thus, this paradigm recognized that the significance to the public welfare of O_3-induced effects on sensitive vegetation growing within the U.S. can vary depending on the nature of the effect, the intended use of the sensitive plants or ecosystems, and the types of environments in which the sensitive vegetation and ecosystems are located. Accordingly, any given O_3-related effect on vegetation and ecosystems (e.g., biomass loss, crop yield loss, visible foliar injury) may be judged to have a different degree of impact on the public welfare depending, for example, on whether that effect occurs in a Class I area, a city park, or commercial cropland. In the 2010 proposed reconsideration, the Administrator proposed to place the highest priority and significance on vegetation and ecosystem effects to sensitive species that are known to or are likely to occur in federally protected areas such as national parks and other Class I areas, or on lands set aside by states, tribes and public interest groups to provide similar benefits to the public welfare (75 FR 3023/24). Effects occurring in such areas would likely have the highest potential for being classified as adverse to the public welfare, due to the expectation that these areas need to be maintained in a more pristine condition to ensure their intended use is met. In contrast, in that proposal, the Administrator considered it less clear the degree to which O_3 vegetation impacts potentially predicted to occur in areas and on species that are already heavily managed

to obtain a particular output (such as commodity crops or commercial timber production), would impair the intended use at a level that would be judged adverse to the public welfare and also noted that these species would likely receive some protection for a standard set to provide protection in areas set aside to be maintained in a more pristine condition (75 FR 3024).

In the current review, we revisited the appropriateness of using this paradigm and whether the available information supported any further evolution. In so doing, we noted the ISA text, which states that "[o]n a broader scale, ecosystem services may provide indicators for ecological impacts. Ecosystem services are the benefits that people obtain from ecosystems (UNEP, 2003)" (U.S. EPA, 2013, Preamble, p. 1xxii) and the ISA list of a number of ecosystem services that can be affected by O_3-induced effects on plants and ecosystems, including decreased productivity, decreased carbon sequestration, altered water cycling, and altered community composition (U.S. EPA, 2013, Figure 2-2, pp. 2-36; Figure 9-1, p. 9-3). We further noted that other recent EPA documents have already incorporated this concept. For example, the recent review of the secondary NAAQS for oxides of nitrogen and sulfur recognized that changes in ecosystem services may be used to aid in characterizing a known or anticipated adverse effect to public welfare and that an evaluation of adversity to the public welfare might consider the likelihood, type, magnitude, and spatial scale of the effect, as well as the potential for recovery and any uncertainties relating to these conditions (77 FR 20232). Similarly, the EPA document, *Ecological Benefits Assessment Strategic Plan,* includes a definition of ecological goods and services used for the purposes of benefits assessment that EPA has relied upon in regulatory impact analyses for previous rulemakings. This definition states that ecological goods and services are the ''outputs of ecological functions or processes that directly or indirectly contribute to social welfare or have the potential to do so in the future"…and that "[s]ome outputs may be bought and sold, but most are not marketed'' (U.S. EPA, 2006b).

After considering this information, and given the accepted use of these concepts and their clear applicability to the secondary NAAQS review, we concluded that while it is still appropriate to apply the paradigm used in the 2010 reconsideration that takes into account the variation in public welfare significance of O_3-related vegetation effects when evaluating the potential adversity of the currently available evidence, there is also sufficient support for an expansion of this paradigm to explicitly include consideration of impacts to ecosystem goods and services. Doing so can help clarify the relationship between predicted O_3-induced vegetation effects and anticipated impacts on public welfare benefits received from those impacted species or ecosystems, and, as was done in the WREA, clarify how those services might be expected to change under air quality scenarios representing the current and potential alternative secondary standards (U.S. EPA, 2014a, chapter 5). The expansion of this paradigm to include ecosystem

goods and services brings with it a number of additional considerations. Specifically, when considering the potential public welfare benefits from these goods and services, it is important to note that they can accrue across a range of dimensions, including spatial, temporal, and social, and these likely will vary depending on the type of effect being characterized. For example, ecosystems can cover a range of spatial scales, and the services they provide can accrue locally or be distributed more broadly such as when crops are sold and eaten locally and/or also sold in regional, national and world markets. Ecosystem services can likewise be realized over a range of temporal scales from immediate up to long term (e.g., the removal of air pollutants that have a short-term impact on human health but are also climate forcers with long atmospheric lifetimes, such that their removal may have immediate as well as long-term benefits). The size of the societal unit receiving benefits from ecosystem services can also vary dramatically. For example, a national park can provide direct recreational services to the thousands of visitors that come each year, but also provide an indirect value to the millions who may not visit but receive satisfaction from knowing it exists and is preserved for the future (U.S. EPA, 2014a, chapter 5, section 5.5.1).

We thus conclude that it is appropriate for the Administrator, in specifying what "level of air quality" for a pollutant "is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air," to evaluate the scientific evidence regarding these effects in the context of the most recent paradigm discussed above. This paradigm integrates the concepts of: 1) variability in public welfare significance given intended use and value of the affected entity such as an individual species; 2) relevance of associated ecosystem services to public welfare; 3) variability in spatial, temporal, and social distribution of ecosystem services associated with known and anticipated welfare effects. In so doing, we recognize that there is no bright-line rule delineating the set of conditions or scales at which known or anticipated effects become adverse to public welfare. Thus, the evidence and exposure/risk information discussed in this chapter will be further evaluated in Chapter 6 using the concepts incorporated in this paradigm to help inform the Administrator's judgments with respect to the adversity of the effects to the public welfare and what is considered requisite protection.

5.2 FOREST TREE GROWTH, PRODUCTIVITY AND CARBON STORAGE

Trees merit consideration from a public welfare perspective because they provide many services that people value, including aesthetic value (also discussed in section 5.4 below), food, fiber, timber, other forest products, habitat, recreational opportunities, climate regulation, erosion control, air pollution removal, hydrologic and fire regime stabilization (U.S. EPA, 2014a, section

6.1, Figure 6-1, section 6.4, Table 6-13). One source identifies as many as 1,497 native tree species growing in the lower 48 of the U.S.[6] Ozone has been shown to be phytotoxic to a number of important U.S. tree species with respect to growth, productivity, and carbon storage, including for cumulative exposures that have occurred under recent U.S. air quality. This section includes a discussion of the policy-relevant evidence and weight-of-evidence conclusions discussed in the ISA (section 5.2.1) and the exposure/risk results, including both quantitative and qualitative results for these effects, as well as associated ecosystem services (section 5.2.2) as described in the final WREA (U.S. EPA, 2014a). Important uncertainties and limitations in the available information are also discussed in each section. These discussions highlight the information we consider relevant to answering the overarching question and associated policy-relevant questions included in this section.

5.2.1 Evidence-based Considerations

- **To what extent has scientific information become available that alters or substantiates our prior conclusions of O_3-related effects on forest tree growth, productivity and carbon storage and of factors that influence associations between O_3 concentrations and these effects?**

Research published since the 2006 CD substantiates prior conclusions regarding O_3-related effects on forest tree growth, productivity and carbon storage. The ISA states that "previous O_3 AQCDs concluded that there is strong evidence that exposures to O_3 decreases photosynthesis and growth in numerous plant species" and that "[s]tudies published since the 2008 review support those conclusions" (U.S. EPA, 2013, p. 9-42). The recent studies that support the previous conclusions come from a variety of different study types that cover an array of different species, effects endpoints, levels of biological organization and exposure methods and durations. As stated in Chapter 1, and above, the documentation of O_3-induced species-specific responses across multiple lines of evidence, and over the full range of levels of biological organization highlights and strengthens the consistency and coherence of the evidence available in this review.

The previously available strong evidence for trees includes robust exposure-response (E-R) functions for seedling biomass loss in 11 species developed under the National Health and Environmental Effects Research Laboratory-Western Ecology Division (NHEERL-WED) program. This series of experiments used open-top-chambers (OTC) to study seedling growth response for a single growing season under a variety of O_3 exposures (ranging from near

[6] USDA, NRCS. 2014. The PLANTS Database (http://plants.usda.gov, 7 July 2014). National Plant Data Team, Greensboro, NC 27401-4901 USA.

background to well above current ambient concentrations) and growing conditions (U.S. EPA 2013, section 9.6.2, Lee and Hogsett, 1996). The evidence from these studies shows that there is a wide range in sensitivity across the studied species in the seedling growth stage over the course of a single growing season, with some species being extremely sensitive and others being very insensitive, or alternatively quite tolerant, over the range of cumulative O_3 exposures studied (See Figure 5-1, below).

In addition, field-based studies of species growing in natural stands have compared observed plant response across a number of different sites and/or years when exposed to varying ambient O_3 exposure conditions only. For example, a study conducted in forest stands in the southern Appalachian Mountains found that the cumulative effects of ambient levels of O_3 decreased seasonal stem growth (measured as a change in circumference) by 30-50% for most of the examined tree species (i.e., tulip poplar, black cherry, red maple, sugar maple) in a high O_3 year in comparison to a low O_3 year (McLaughlin et al., 2007a). The authors also reported that high ambient O_3 concentrations can increase whole-tree water use and in turn reduce late-season streamflow (McLaughlin et al., 2007b) (U.S. EPA, 2013, p. 9-43). This study used ambient O_3 conditions found at several different sites to create the variation in O_3 exposures.

Because trees and other perennials are long lived, it is important to consider the potential for impacts beyond a single year. Limited evidence in previous reviews reported that vegetation effects from a single year of exposure to elevated O_3 could be observed in the following year. For example, growth affected by a reduction in carbohydrate storage in one year may result in the limitation of growth in the following year**. S**uch "carry-over" effects have been documented in the growth of some tree seedlings and in roots (U.S. EPA, 2013, section 9.4.8; Andersen, et al., 1997). In the current review, additional field-based evidence expands our understanding of the consequences of single and multi-year O_3 exposures in subsequent years. A number of studies were conducted at a planted forest at the Aspen Free-Air Carbon Dioxide Enrichment (FACE) site in Wisconsin. These studies, which occurred in a field setting more similar to natural forest stands than OTC studies, observed tree growth responses when grown in single or two species stands within 30-m diameter rings and exposed to ambient and above ambient conditions over a period of ten years. Some researchers similarly recognized the potential for carry-over effects when they observed that the effects of O_3 on birch seeds (reduced weight, germination, and starch levels) could lead to a negative impact on species regeneration in subsequent years, and that the effect of reduced aspen bud size might have been related to the observed delay in spring leaf development. These effects suggest that elevated O_3 exposures have the potential to alter carbon metabolism of overwintering buds, which may have subsequent effects in the following year (Darbah, et al., 2008, 2007; Riikonen et al., 2008; U.S. EPA, 2013, section 9.4.3). Other studies found that, in addition to affecting tree heights, diameters, and main

stem volumes in the aspen community, elevated O_3 over a 7-year study period was reported to increase the rate of conversion from a mixed aspen-birch community to a community dominated by the more tolerant birch, leading the authors to conclude that elevated O_3 may alter intra- and inter-species competition within a forest stand (Kubiske et al., 2006; Kubiske et al., 2007) (U.S. EPA, 2013, section 9.4.3). These studies confirm earlier FACE results showing large decreases in growth for aspen over a 6-7 year period when exposed to elevated O_3 (King et al., 2005) and that yearly biomass loss cumulated over that timeframe.

In addition to individual studies, recent meta-analyses have quantified the effect of O_3 on trees across large numbers of studies. In particular, a recent meta-analysis (Wittig, et al., 2007) indicates a relationship between O_3 concentrations in the northern hemisphere and stomatal conductance and photosynthesis, which decrease growth (U.S. EPA, 2013, section 9.4.3.1; Wittig et al., 2007).[7] This analysis reported that recent O_3 concentrations in the northern hemisphere are decreasing stomatal conductance (13%) and photosynthesis (11%) across tree species. It also found that younger trees (<4 years) were affected less by O_3 than older trees (Wittig, et al., 2007). A second meta-analysis, Wittig, et al. (2009), which quantitatively compiled peer-reviewed studies from the past 40 years, found that ambient O_3 concentrations reported in those studies significantly decreased annual total biomass growth (7%) across the 263 studies (U.S. EPA, 2013, section 9.4.3.1). The ISA states that this meta-analysis demonstrates the coherence of O_3 effects across numerous studies and species that used a variety of experimental techniques, and these results support the conclusion of the previous CD that exposure to O_3 decreases plant growth. Other meta-analyses have examined the effect of O_3 exposure on root growth and generally found that O_3 exposure reduced carbon allocated to roots. For example, Grantz et al. (2006) found that O_3 exposure reduced the ratio between the relative growth rate of the root and shoot by 5.6% (U.S. EPA, 2013, pp. 9-45 to 9-46).

In our consideration of the recent studies discussed above, in combination with the entire body of available evidence, we note that the recent scientific literature further strengthens and contributes to the consistency and coherence of the evidence base by substantiating and expanding prior conclusions regarding O_3-related effects on tree growth, productivity and carbon storage, including mixed species forest stands and the ecosystems and services that derive from them, as discussed more fully below. We also note that the ISA concludes that the currently available evidence supports causal determinations regarding O_3 effects on tree growth and productivity and the associated effects of altered carbon allocation to below ground tissues, rates of leaf and root production, turnover and decomposition that can alter below-ground

[7] Meta-analysis allows for the objective development of a quantitative consensus of the effects of a treatment across a wide body of literature.

biogeochemical cycles, as well as the likely to be a causal relationship with reduced carbon sequestration and alteration of terrestrial community composition and water cycling (U.S. EPA, 2013, Table 2-2; 9-19). Finally, we note that except for the recent limited information on cottonwood in the ISA (U.S. EPA, 2013, section 9.6.3.3), there has not been an expansion in the number of tree species for which we have E-R functions, so only 12 species have available E-R functions for use in quantitative exposure and risk analyses and for predicting tree seedling response under a range of O_3 exposure conditions/scenarios. While these 12 species represent only a small fraction (0.8%) of the total number of native tree species in the contiguous U.S. (1,497), this small subset includes eastern and western species, deciduous and coniferous species, and species that grow in a variety of ecosystems and represent a range of tolerance to O_3 (Figure 5-1 below, U.S. EPA 2013, section 9.6.2; U.S. EPA, 2014a, section 6.2, Figure 6-2, Table 6-1). The CASAC states in their letter to the Administrator on the second draft PA, that while "[t]here is considerable uncertainty in extrapolating from the 12 forest tree species to all forest tree species in the U.S...[i]t is scientifically justifiable to extrapolate from the known E-R curves, assuming that they are representative of the un-sampled population" (Frey, 2014, p. 15).

As we further consider the results from the quantitative exposure and risk analyses, described below and in the WREA (U.S. EPA, 2014a), that in addition to the quantifiable portion of risks associated with the robust information on tree species, it is also reasonable to consider, based on the long-standing evidence and recent CASAC advice, the anticipated risks to other tree species that have not had their sensitivity to O_3 studied in a robust quantifiable way but that potentially have O_3 sensitivities that fall within the range for known species (see U.S. EPA, 2007, Table 7J-1 in Appendix 7J and Table 7J-2).

- **To what extent have important uncertainties in the evidence identified in the last review been reduced and/or new uncertainties emerged?**

As stated above, the ISA concludes that the new evidence confirms, strengthens and expands our understanding of O_3 effects on plants. Much of this new evidence is focused on the molecular and genetic level, providing important new mechanistic information that in some cases enhances our understanding of the complexity of the O_3–plant response. This information has, in general, reduced overall uncertainties at the subcellular and cellular scales (U.S. EPA, 2013, section 9.3.6).

Other recent information has also reduced some associated uncertainties regarding O_3 impacts at the whole plant, species, and ecosystem scales. Importantly, one key uncertainty related to the potential broader applicability of OTC-generated tree seedling E-R functions to estimate biomass loss under different (i.e., field) O_3 exposure conditions has been significantly reduced (U.S. EPA, 2013, section 9.6). Using recent field-based information available in the

current review, we conducted an analysis comparing OTC data with FACE data for one crop and one tree species (U.S. EPA, 2013, section 9.6.3.2). One comparison was done using soybean OTC data from the National Crop Loss Assessment Network (NCLAN)[8] and more recent field-based data from the SoyFACE experiment, as discussed in section 5.3 below. The second was done using aspen seedling OTC data from the NHEERL-WED studies and more recent field-based data from the Aspen FACE study site. The result of the aspen analysis showed very close agreement between the biomass loss predictions based on OTC data and Aspen FACE observations, even when comparing the results of experiments that used different exposure methodologies, different genotypes, locations, and durations. The soybean analysis showed similar agreement between the OTC data and the SoyFACE experiment. Based on this analysis, the ISA concluded that "[o]verall, the studies at the Aspen FACE experiment were consistent with many of the open-top chamber (OTC) studies that were the foundation of previous O_3 NAAQS reviews" and that "[t]hese {recent} results strengthen the understanding of O_3 effects on forests and demonstrate the relevance of the knowledge gained from trees grown in OTC studies" (U.S. EPA 2013, p. 2-38, Section 9.6.3). The ISA additionally notes that with respect to aspen, "the function based on one year of growth was applicable to subsequent years" (of the six-year dataset) (U.S. EPA, 2013, section 9.6.3.2). This result is significant in that it shows that at least for this species, the seedling E-R function was able to predict responses beyond the seedling growth stage. While recognizing that some uncertainties remain for E-R functions for some individual species for which the database is relatively less robust, taken together, this information substantially reduces uncertainties associated with use of the tree seedling OTC-derived E-R functions to predict the response of tree seedlings in field settings and in some cases beyond the seedling growth stage. This information in combination with results from recent meta-analyses, as discussed above, reduces the uncertainties associated with potential impacts of other experimental factors on the O_3-plant response. Thus, in the current review, we have greater confidence than in the last review in using these E-R functions to estimate tree growth response outside the chamber setting (U.S. EPA, 2013, section 9.6.2; U.S. EPA, 2014a, section 6.2).

Several uncertainties are specific to studying or modeling O_3 impacts on trees, and derive from the long lifespan of trees, which can range from decades to centuries. Because most studies are designed to take place within an annual or 2-3 year timeframe, typically information is available for only a small fraction of the lifetime of a tree. Given this reality, one uncertainty

[8] The NCLAN program was conducted from 1980 to 1987 at five different locations across the US. At each site, open top chambers were used to expose plants to O_3 treatments that represented the range of concentrations that occur in different areas of the world. The NCLAN focused on the most important U.S agricultural crops (Heagle et al., 1989; http://www.ars.usda.gov/Main/docs.htm?docid=12462).

that remains is the degree to which exposures in a single year or over multiple years affect trees over the longer term. However, as discussed above, recent studies from the Aspen FACE site have reduced this uncertainty by providing additional evidence that demonstrates that exposures in one year have the potential to cause effects in a subsequent year (carry-over effects) and that the annual effects from exposures over multiple years have the potential to compound (U.S. EPA, 2013, 9.4.3, pp. 9-42 to 9-47). Such effects, when they cumulate from one or more years of elevated O_3 exposures, can lead to more serious longer-term impacts on growth, reproduction, recruitment, and competitive interactions within forest stands, and at larger spatial scales (U.S. EPA, 2013, p. 1-8), which would also have ramifications for any associated ecosystem services. In recognition of this recent evidence, the current CASAC Panel advised that "[a] 2% biomass loss is an appropriate scientifically based value to consider as a benchmark of adverse impact for long-lived perennial species such as trees, because effects are cumulative over multiple years" and stated that in its "scientific judgment, it is appropriate to identify a range of levels of alternative W126-based standards that includes levels that aim for not greater than 2% RBL for the median tree species" (Frey, 2014, p. 14). The CASAC further states that it "considers it significant that a similar value of 1% - 2% for tree seedling biomass loss was recommended previously by a consensus meeting of experts on ecological effects of ozone (Heck and Cowling, 1997)" (Frey, 2014, p. 14).

A related uncertainty comes from the limited evidence showing that sensitivity to O_3 can vary over the lifespan of trees and that this variation in growth-stage sensitivity is species-specific. For example, some species have been shown to be more sensitive during younger growth stages (i.e., seedling/sapling) while other species may be more sensitive as adults. Though a few studies have examined tree growth beyond the seedling stage (e.g., aspen) and in some species has been measured for both seedling and mature trees within a species (e.g., red oak), for most studied tree species it remains uncertain to what degree effects observed during one growth stage can be extrapolated to other growth stages. An analysis in the WREA comparing seedling to adult tree biomass loss, discussed in 5.2.2 below, informs our consideration of this remaining uncertainty (U.S. EPA, 2014a, section 6.2.1.1).

These uncertainties are taken into account when we consider how much weight to put on predictions of risks for known effects and how precautionary it is appropriate to be in light of the potential for cumulative effects from multiple year exposures that could reasonably be anticipated to occur, based on the evidence above.

- **To what extent does currently available evidence suggest locations where the vulnerability of sensitive species, ecosystems and/or their associated services to O_3-related effects on tree growth, productivity and carbon storage would have special significance to the public welfare?**

A number of different types of locations provide services of special significance to the public welfare. These services can flow in part or entirely from the vegetation that grows there (see also discussion under section 5.1 above). With respect to forested lands, the WREA notes that there are approximately 751 million acres of forest lands in the U.S., one third of which (250 million acres) is federally owned (U.S. EPA, 2014a, p. 5-15). In order to identify what types of forest locations have special significance from a public welfare perspective, it is first useful to consider the types of services that can flow from forested areas, and more specifically, from forested areas with trees that are sensitive to O_3. Some sensitive tree species provide public welfare benefits based on their cultural significance, and some lands are important to the public welfare for their cultural value. For example, tribal lands, federally designated Class I areas, non-Class I national parks and wilderness areas, and other areas set aside to provide similar public welfare benefits, are valued for their cultural services such as outdoor recreation and aesthetics. Appendix 5A includes a table listing known O_3-sensitive species, including some trees that have been identified as having cultural importance to some tribes (U.S. EPA, 2014a, section 6.4.2). Locations where these species are growing and are used by tribes to support cultural practices would thus be potentially vulnerable to impacts from elevated cumulative O_3 exposures, which could result in the loss of those associated cultural services, including those associated with sensitive tree species. Class I areas and other parks have also been afforded special federal protection to preserve services such as a healthy natural environment that provides for the enjoyment of these resources unimpaired for current and future generations, sustainable native plant and wildlife populations, and unique recreational opportunities. As mentioned above, 66 O_3-sensitive species have been identified on NPS and U.S. Fish and Wildlife Service lands).[9] Other forested lands, both public and private, where trees are grown for timber production could also be at risk, especially in a single timber species stand that is sensitive to O_3 (i.e., Ponderosa pine) (see WREA section 6.3 and section 5.2.2 below). Urban forests provide a number of important services to the public, such as air pollution removal, cooling of the heat island effect, and beautification (U.S. EPA, 2014a, section 6.6.2). These

[9] See http://www2.nature.nps.gov/air/Pubs/pdf/flag/NPSozonesensppFLAG06.pdf

urban forests have also been recognized as important to environmental justice communities.[10] Because urban forests can include O_3-sensitive trees (e.g., black cherry), O_3 exposures have the potential to reduce the services they provide. The WREA analysis of five urban case study areas, discussed below, quantified the O_3 impacts on air pollution removal and carbon sequestration in those urban areas (WREA, sections 6.6.2 and 6.7; section 5.2.2 below). Black cherry, for example, was one of the top ten occurring species in four of the five case study areas.

The above types of forested lands have clearly designated purposes or intended uses that help define the types of services that might be recognized as important from a public welfare perspective. In addition, other services provided by trees are potentially extremely valuable, but limited information is available to quantitatively value the extent of these services. Perhaps one of the most significant of these ecosystem services is climate regulation, which provides widespread and long-lasting public welfare benefits that the ISA determined is likely being compromised by the phytotoxic effects of O_3 on tree growth, productivity and carbon storage. By reducing the amount of carbon taken up by plants, more CO_2 is allowed to remain in the atmosphere where it potentially exacerbates the effects of climate change. In contrast to the location-specific discussion of services above, this service is potentially important to the public welfare no matter in what location the sensitive trees are growing, or what their intended current or future use. In other words, the benefit exists as long as the tree is growing, regardless of what additional functions and services it provides.

In addition to identifying forested locations that provide ecosystem services that are important to the public welfare, we must also consider to what extent there is the potential for O_3 to affect sensitive tree species growing on those lands to a degree sufficient to affect the public welfare. In so doing we first note that not all tree species are equally sensitive to O_3 and thus not equally vulnerable to current ambient O_3 exposures or those anticipated under various air quality scenarios. In further considering the degree to which O_3-induced impacts to ecosystem services associated with such trees might be expected to occur, we first focused on the 12 species of trees for which we have E-R functions. While all of these species provide goods and services that are important to the public welfare, not all species are equally sensitive to O_3 under recent ambient exposure conditions or conditions projected for adjusted air quality. Table 5-1 below (modified from WREA Table 6-13), provides a more detailed description of the ecosystem services provided by each of these species that benefit the public welfare. For the purposes of this

[10] See http://www.fs.fed.us/research/urban/environmental-justice.php and Federal Interagency Working Group on Environmental Justice. (2011). Community-Based Federal Environmental Justice Resource Guide. August. Available at http://www.epa.gov/environmentaljustice/resources/publications/interagency/resource-guide.pdf

discussion we have ordered the species in the table to go in descending order from most to least sensitive (based on their predicted relative biomass loss (RBL) at a W126 of 15 ppm-hrs).

Table 5-1. O_3-Sensitive Trees, Their Uses and Relative Sensitivity

Tree Species	O_3 Effect	Role in Ecosystems and Public Welfare Uses
Eastern Cottonwood[11] ***Populus deltoides***	Biomass loss	Containers, pulp, and plywood Erosion control and windbreaks Quick shade for recreation areas Beaver dams and food
Black Cherry ***Prunus serotina***	Biomass loss, Visible foliar injury	Cabinets, furniture, paneling, veneers, crafts, toys Cough remedy, tonic, sedative Flavor for rum and brandy Wine making and jellies Food for song birds, game birds, and mammals
Eastern White Pine ***Pinus strobus***	Biomass loss	Commercial timber, furniture, woodworking, and Christmas trees Medicinal uses as expectorant and antiseptic Food for song birds and mammals Used to stabilize strip mine soils
Quaking Aspen ***Populus tremuloides***	Biomass loss, Visible foliar injury	Commercial logging for pulp, flake-board, pallets, boxes, and plywood Products including matchsticks, tongue depressors, and ice cream sticks Valued for its white bark and brilliant fall color Important as a fire break Habitat for variety of wildlife Traditional native American use as a food source
Yellow (Tulip) Poplar ***Liriodendron tulipifera***	Biomass loss, Visible foliar injury	Furniture stock, veneer, and pulpwood Street, shade, or ornamental tree – unusual flowers Food for wildlife Rapid growth for reforestation projects
Ponderosa Pine ***Pinus ponderosa***	Biomass loss, Visible foliar injury	Lumber for cabinets and construction Ornamental and erosion control use Recreation areas Food for many bird species, including the red-winged blackbird, chickadee, finches, and nuthatches

[11] The E-R function for cottonwood is considered less robust because it is based on the results of a single gradient study (Gregg et al., 2003).

Tree Species	O_3 Effect	Role in Ecosystems and Public Welfare Uses
Red Alder ***Alnus rubra***	Biomass loss, Visible foliar injury	Commercial use in products such as furniture, cabinets, and millwork Preferred for smoked salmon Dyes for baskets, hides, moccasins Medicinal use for rheumatic pain, diarrhea, stomach cramps – the bark contains salicin, a chemical similar to aspirin Roots used for baskets Food for mammals and birds – dam and lodge construction for beavers Conservation and erosion control
Red Maple^ ***Acer rubrum***	Biomass loss	One of the most abundant and widespread in eastern U.S. Used for revegetation, especially in riparian buffers and landscaping, where it is valued for its brilliant fall foliage, some lumber and syrup production. Important wildlife browse food, especially for elk and white-tailed deer in winter, also leaves important food source for some species of butterflies and moths.
Virginia Pine ***Pinus virginiana***	Biomass loss, Visible foliar injury	Pulpwood, strip mine spoil banks and severely eroded soils Nesting for woodpeckers, food for songbirds and small mammals
Sugar Maple ***Acer saccharum***	Biomass loss	Commercial syrup production Native Americans used sap as a candy, beverage – fresh or fermented into beer, soured into vinegar and used to cook meat Valued for its fall foliage and as an ornamental Commercial logging for furniture, flooring, paneling, and veneer Woodenware, musical instruments Food and habitat for many birds and mammals
Loblolly Pine*	Biomass loss, visible foliar injury	Most important and widely cultivated timber species in the southern U.S. Furniture, pulpwood, plywood, composite boards, posts, poles, pilings, crates, boxes, pallets. Also planted to stabilize eroded or damaged soils. It can be used for shade or ornamental trees, as well as bark mulch. Provides habitat, food and cover for white-tailed deer, gray squirrel, fox squirrel, bobwhite quail and wild turkey, red-cockaded woodpeckers, and a variety of other birds and small mammals. Standing dead trees are frequently used for cavity nests by woodpeckers.
Douglas Fir ***Pseudotsuga menziesii***	Biomass loss	Commercial timber Medicinal uses, spiritual and cultural uses for several Native American tribes Spotted owl habitat Food for mammals including antelope and mountain sheep
*Sensitivity categories added by EPA staff but not based on official designations.		

Sources: USDA-NRCS, 2013; Burns, 1990; Hall and Braham, 1998. ^Red maple information from http://www.na.fs.fed.us/pubs/silvics_manual/volume_2/acer/rubrum.htm. *Loblolly pine use information from http://www.ncsu.edu./project/dendrology/index/plantae/vascular/seedplants/gymnosperms/conifers/pine/pinus/australes/loblollypine/html.

While we recognized that there are important ecosystem services provided by those species that are less sensitive to O_3, those species would likely receive less benefit from additional protection below the current standard. In contrast, the other species would likely see improvements in their associated ecosystem services, some significantly, from an improvement in air quality. However, at the highest end of the known sensitivity spectrum, there are different issues that must be considered when evaluating the usefulness of this information in answering the above questions. The E-R function that is available for cottonwood is based on the results of a single gradient study (Gregg et al., 2003) and is considered less robust than the other E-R functions developed in OTCs. That combined with its apparent extreme response to O_3 prompted CASAC to advise the Administrator to not place too much emphasis on cottonwood in the review of the secondary standard (Frey, 2014, p. 10). As a result, we have decided it would not be appropriate to use the cottonwood biomass loss estimates when considering what levels of W126 should be considered protective of median species biomass loss (see Table 5C-3).

However, in this discussion of ecosystem services, we believe it is important to include cottonwood, given the many ecosystem services cottonwood provides (see Table 5-1 above), and several unique features that potentially make it and its associated ecosystem goods and services particularly vulnerable to impacts from O_3. Specifically we note that cottonwood: 1) is often found growing along streams in riparian zones under well watered conditions that make it more susceptible to injury than species growing in areas that experience drier conditions in conjunction with higher O_3 exposures; 2) can be the only tree species growing in certain types of ecosystems, thus providing important habitat for some organisms; 3) is fast growing and used commercially for pulpwood, manufacturing furniture and as a possible source for energy biomass (Burns and Hankola, 1990); 4) has provided limited, though still uncorroborated, evidence of the potential for the existence of extremely sensitive plant species which can reasonably be anticipated to exist and that could be impacted at similar cumulative exposures. With regard to the latter, we observe that CASAC also expressed the view that it "should be anticipated that there are species of vegetation that are highly sensitive to ozone that do not have E-R functions, and others that are insensitive. It is scientifically justifiable to extrapolate from the known E-R curves, assuming that they are representative of the un-sampled population" (Frey, 2014, p. 16). We also note that upon revisiting the available literature in the ISA following CASAC's review of the second draft WREA and PA, we found two studies on a related European species *(Populus nigra)* that showed that this species had an O_3 sensitivity that appears similar in magnitude to the U.S. cottonwood *(Populus deltoides)* based on its response for other growth endpoints as compared with the response of the other study species (Bortier, et al., 2000; Novak, et al., 2007) (U.S. EPA, 2006, AX9, pp. 91, 240; U.S. EPA, 2014a, Table 6-5).

This additional limited evidence of *Populus* seedling/sapling growth response, though not directly comparable to the U.S. study (Gregg et al., 2003) with respect to species, exposure methods, measurement endpoints and exposure values, does, in our judgment, lend some support to the observed magnitude of the reported U.S. cottonwood response.

In addition to the information provided here on these 12 species, we note that there are many other species of trees with known or suspected O_3-sensitive vegetation, such as those included in the 66 species identified on NPS and US Fish and Wildlife Service lands),[12] species used in the USFS biomonitoring network, and various ornamental and agricultural species (i.e., Christmas trees, fruit and nut trees) that currently provide ecosystem services important to the public welfare, but whose vulnerability to impacts from O_3 on tree growth, productivity and carbon storage has not been sufficiently characterized to allow it to directly inform our quantitative assessments (U.S. EPA, 2014a, Chapter 6; Abt Associates, 1995). However, as noted by CASAC, the anticipated impacts on these and other unstudied species should not be ignored or assumed insignificant. It is more likely that the range of O_3 sensitivities found in the studies tree species likely reflects the range of O_3 sensitivities in all tree species.

Other factors that should be taken into account when considering the potential degree to which O_3 might affect the ecosystem service flows from forested ecosystems are 1) the type of stand or community in which the sensitive species is found (i.e., single species versus mixed canopy); 2) the role or position the species has in the stand (i.e., dominant, sub-dominant, canopy, understory); 3) the O_3 sensitivity of the other co-occurring species (O_3 sensitive or tolerant); 4) environmental factors (drought or well watered conditions, other stressors).

In light of the above discussion, it is clear that there are numerous locations where the vulnerability of O_3-sensitive tree species to impacts from O_3 on tree growth, productivity and carbon storage and their associated ecosystems and services could have special significance to the public welfare. Confirmation that the American public values healthy forests is provided in the WREA, which shows that Americans are willing to pay to protect forests from the damaging effects of air pollutants (U.S. EPA, 2014a, Chapter 5, pp. 5-16). Data provided by the National Survey on Recreation and the Environment (NSRE) indicates that Americans have very strong preferences for the non-use values of existence, bequest, and option services related to forests. Studies (Haefele et al., 1991, Holmes and Kramer, 1995) assess willingness-to-pay (WTP) for spruce-fir forest protection in the southeastern U.S. from air pollution and insect damage and confirm that the non-use values held by the survey respondents were in fact greater than the use or recreation values. The results of this survey showed that median household WTP was

[12] See http://www2.nature.nps.gov/air/Pubs/pdf/flag/NPSozonesensppFLAG06.pdf

estimated to be roughly $29 (in 2007 dollars) for the minimal protection program and $44 for the more extensive program. After decomposing their value for the extensive program into use, bequest, and existence values, the results were 13 percent for use value, 30 percent for bequest, and 57 percent for existence value (See U.S. EPA, 2014a, Table 5-6). These services may be at risk in areas where O_3-sensitive trees are found.

- **To what extent does the available evidence indicate the occurrence of O_3-related effects on forest growth, productivity and carbon storage attributable to cumulative exposures lower than previously established or that might be expected to occur under the current standard?**

The evidence base available in this review, as in the previous review, indicates that O_3-induced effects on tree growth, productivity and carbon storage can occur across a range of cumulative exposures, including those lower than previously established and that would be expected to occur under the current standard. In reaching this determination, we first consider the 11 tree seedling species for which robust E-R functions have been developed from the extensive evidence base of O_3–induced growth effects that was also available and relied upon in the previous review. Each of these species were studied in OTCs, with most species studied multiple times under a wide range of exposure and/or growing conditions, with separate E-R functions developed for each species/exposure condition/growing condition scenario combination or case. Using all the information available from these multiple study cases (52 cases in all), a robust composite E-R function was developed for all species combined and separate individual composite functions were derived for each species using cases that were available on individual species. These species-specific composite E-R functions have been successfully used to predict tree seedling species biomass loss response over a range of cumulative exposure conditions. Figure 5-1A, B below, which includes the 11 robust composite E-R functions available in the last review and the E-R for cottonwood (also described in U.S. EPA 2013, section 9.6.2 and U.S. EPA, 2014a, section 6.2, Table 6-1 and Figure 6-2), illustrates the appreciable variability in sensitivity that exists across the 12 studied species, and shows that biomass loss can occur over a wide range of cumulative exposures, including those previously established. This figure further shows that for some species biomass loss would be predicted to occur at very low cumulative exposures that can occur under air quality conditions that meet or are below the current standard (see Table 5-2 below). While we put less emphasis on cottonwood (as explained above), we do note that in answering the question above, it does provide limited recent evidence of the potential for effects of a greater magnitude and at lower cumulative exposures to occur than those considered in the last review and at exposures that would be allowed by the current standard. To the extent that such effects could be anticipated,

the cumulative exposures that could be allowed by the current secondary standard would not be protective.

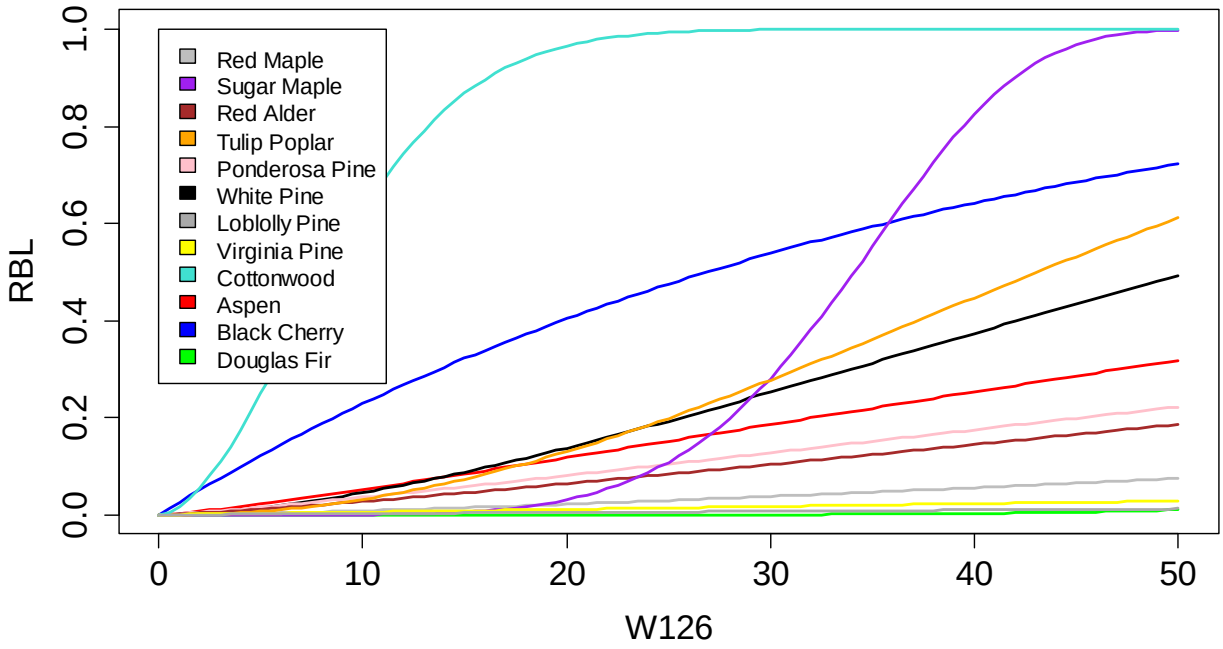
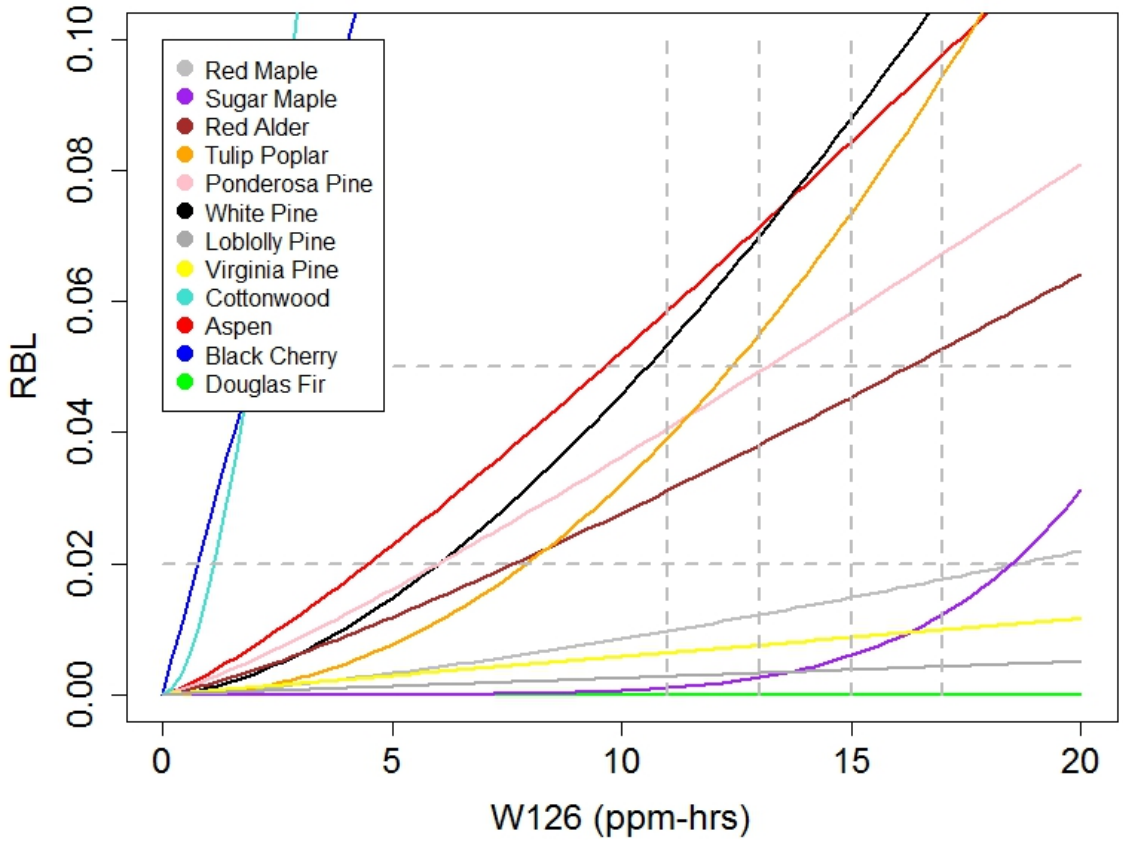


Figure 5-1. A) Relative biomass loss in seedlings for 12 studied species using composite functions in response to seasonal O_3 concentrations in terms of seasonal W126 index values, Y-axis scale for RBL values represents 0% up to 100% (U.S. EPA 2014a, Figure 6-2).



B) Expanded view of relative biomass loss in seedlings for 12 studied species using composite functions in response to seasonal O_3 concentrations in terms of lower range of seasonal W126 index values, Y-axis scale for RBL values represents 0% up to 10% (U.S. EPA 2014a, Figure 6-2).

In further answering the question above, we note CASAC's advice that a 6% median RBL is unacceptably high, and that the 2% median RBL is an important benchmark to consider. Based on the information above, the median RBL is at or below 2% at the lowest W126 level assessed, 7 ppm-hrs. As the W126 level is incrementally increased, median RBL also increases incrementally, so that at W126 index values of 9, 11, 13, 15, 17, 19 and 21, the median RBL increases to 2.4%, 3.1%, 3.8%, 4.5%, 5.3%, 6.0% and 6.8%, respectively. Based on air quality analyses of 2009-2011 (Appendix 2B), there are approximately 342, 199, 92, 43, 24, 9, 3 and 0 monitors with 3-year average W126 index values above 7, 9, 11, 13, 15, 17, 19 and 21 ppm-hrs when meeting the current standard. We note that these counts of monitors are based on those meeting the current standard and that there are many monitors for the 2009-2011 period that do not meet the current standard and also are above the W126 values of 7-21 ppm-hrs.

We also consider it informative to examine the individual species responses and RBL over the same W126 range. We first note, based on Figure 5-1(B) above that over the range of 7 to 17 ppm-hrs, 5 species maintain RBLs of less than 2%. These more tolerant species include

Douglas fir, loblolly pine, Virginia pine, sugar maple and red maple. Two of these species (red maple and sugar maple) are estimated to have RBL levels above 2% at a W126 of 21. Black cherry, the most sensitive of the remaining six species, has RBL ranging from 35.57% at W126 of 17 down to 16.67% at the W126 index value of 7 ppm-hrs.

Additional evidence of the potential for O_3-induced effects on tree seedling growth, productivity and carbon storage occurring under air quality scenarios allowed by the current standard is shown in Table 5-2 below. Specifically, all monitor sites in Table 5-2 have 3-year 8-hour average values that meet the current standard, ranging from 67 to 75 ppb, have 3-year average W126 index values that are above 15 ppm-hrs, and are located in Class I areas. Across these 22 Class I areas, the highest single-year W126 index values for these three-year periods ranged from 17.4 to 29.0 ppm-hrs. In 20 of the areas, distributed across eight states (AZ, CA, CO, KY, NM, SD, UT, WY) and four regions (west, southwest, west/north central and central), this range was 19.1 to 29.0 ppm-hrs, exposure values for which the corresponding median species RBL estimates equal or exceed 6%, which CASAC termed "unacceptably high". In addition, given that other environmental factors can influence the extent to which O_3 may have the impact predicted by the E-R functions in any given year, we also note that the highest three year periods, that include these highest annual values for the 21 areas, are at or above 19 ppm-hrs, ranging up to 22.5 ppm-hrs (which the median species RBL estimate is above 7%). Additionally, the highest three-year average W126 index value for each of the 22 areas (during periods meeting the current standard) was at or above 19 (ranging up to 22.5 ppm-hrs) in 11 areas, distributed among five states in the west and southwest regions (U.S. EPA, 2014c, Table 5-2, Appendix 5B).

In addition, as data permit, Table 5-2 shows the studied tree species that are found in each of these Class I areas. Quaking aspen and ponderosa pine are two tree species that are found in many of these 22 parks and have a sensitivity to O_3 exposure that places them near the middle of the group for which E-R functions have been established. In the areas where ponderosa pine is present, the highest single year W127 index values ranged from 18.7 to 29.0 and the highest 3-year average W126 values in which these single year values are represented ranged from 15 to 22.5, with these three-year values above 19 ppm-hrs in eight areas across five states. The ponderosa pine RBL estimates for 29 and 22.5 ppm-hrs are approximately 12% and 9%, respectively. In areas where quaking aspen is present, the highest single year W127 index values ranged from 19.2 to 26.7 ppm-hrs and the highest 3-year average W126 values in which these single year values are represented ranged from 15.0 to 22.2, with values above 19 ppm-hrs in eight areas across five states. The quaking aspen RBL estimates for 26.7 and 22.2 ppm-hrs are approximately 16% and 13%, respectively. Based on this, we note growth effects associated with

exposure concentrations occurring during periods where the current standard is met in many of these Class I areas. On the basis of such information, Table 5-2 provides evidence of the potential for significant growth loss in locations where ambient conditions meet the current standard.

Table 5-2. O_3 concentrations in Class I areas during period from 1998 to 2012 that met the current standard and where three-year average W126 index value was at or above 15 ppm-hrs.*

Class I Area	State / County	Design Value (ppb)*	3-year Average W126 (ppm-hrs)* (# ≥ 19 ppm-hrs, range)	Annual W126 (ppm-hrs)* (# ≥ 19 ppm-hrs, range)	Number of 3-year Periods
Bandelier Wilderness Area QA, DF, PP	NM / Sandoval	70-74	15.8-20.8 (2, 20.0-20.8)	12.1-25.3 (4, 19.2-25.3)	8
Bridger Wilderness Area QA, DF	WY / Sublette	69-72	15.1-17.4	9.9-19.2 (1, 19.2)	5
Canyonlands National Park QA, DF, PP,	UT / San Juan	69-73	15.0-20.5 (2, 19.8-20.5)	9.9-24.8 (5, 19.3-24.8)	9
Carlsbad Caverns National Park PP	NM / Eddy	69	15.0-15.3	8.6-26.7 (1, 26.7)	3
Chiricahua National Monument DF, PP	AZ / Cochise	69-73	15.7-18.0	13.2-21.6 (2, 19.3-21.6)	7
Grand Canyon National Park QA, DF, PP	AZ / Coconino	68-74	15.6-22.2 (7, 19.2-22.3)	11.3-26.7 (7, 19.8-26.7)	12
John Muir Wilderness Area QA, DF, PP	CA / Inyo	71-72	16.5-18.6	10.1-25.8 (2, 23.9-25.8)	3
Lassen Volcanic National Park DF, PP	CA / Shasta	75	15.3	13.6-18.7 (1, 18.7)	1
Mammoth Cave National Park BC, C, LP, RM, SM, VP, YP	KY / Edmonson	74	15.9	12.5-22.5 (1, 22.5)	1
Mesa Verde National Park DF	CO / Montezuma	67-73	15.5-21.0 (2, 19.0-21.0)	10.7-23.6 (4, 19.7-23.6)	10
Mokelumne Wilderness Area DF, PP	CA / Amador	74	17.6	14.8-22.6 (1, 22.6)	1
Petrified Forest National Park	AZ / Navajo	70	15.7	12.9-19.2 (1, 19.2)	1
Pinnacles National Monument	CA / San Benito	74	15.1	13.1-17.4	1
Rocky Mountain National Park QA, DF, PP	CO / Boulder	73-75	15.1-19.3 (1, 19.3)	9.5-25.1 (5, 20.7-25.1)	6
	CO / Larimer	74	15.0-18.3	11.1-25.8 (3, 19.1-25.8)	3
Saguaro National Park DF, PP	AZ / Pima	69-74	15.4-18.9	11.0-23.1 (3, 20.0-23.1)	6
Sierra Ancha Wilderness Area DF, PP	AZ / Gila	72-75	17.9-22.4 (3, 20.2-22.4)	14.8-27.5 (4, 20.3-27.5)	4
Superstition Wilderness Area PP	AZ / Maricopa	75	22.4 (1, 22.4)	14.5-28.6 (2, 27.4-28.6)	1

	AZ / Pinal	73-75	18.7-22.5 (2, 20.9-22.5)	14.8-29.0 (3, 22.6-29.0)	3
Weminuche Wilderness Area QA, DF, PP	CO / La Plata	70-74	15.0-19.1 (1, 19.1)	10.9-21.0 (2, 20.8-21.0)	5
West Elk Wilderness Area QA, DF	CO / Gunnison	68-73	15.6-20.1 (1, 20.1)	12.9-23.9 (3, 21.1-23.9)	8
Wind Cave National Park QA, PP	SD / Custer	70	15.4	12.2-20.6 (1, 20.6)	1
Yosemite National Park QA, DF, PP	CA / Tuolumne	73-74	20.7-20.8 (2, 20.7-20.8)	19.7-22.1 (4, 19.7-22.1)	2
Zion National Park QA, DF, PP	UT / Washington	70-73	17.8-21.1 (2, 20.3-21.1)	14.9-24.2 (5, 19.3-24.2)	4

*Based on data from http://www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm (US EPA, 2014c). W126 values are truncated after first decimal place.
Superscript letters refer to species present for which E-R functions have been developed.
QA=Quaking Aspen, BC=Black Cherry, C=Cottonwood, DF=Douglas Fir, LP=Loblolly Pine, PP=Ponderosa Pine, RM=Red Maple, SM=Sugar Maple, VP=Virginia Pine, YP=Yellow (Tulip) Poplar.
Sources for presence of species include U.S. Department of Agriculture databases in 2014 http://www.fs.fed.us/foresthealth/technology/nidrm2012.shtml, http://plants.usda.gov, http://www.wilderness.net/printFactSheet.cfm?WID=583

In answering the above question, we note that less information is available from field-based studies (e.g., FACE, gradient) due to the absence of robust E-R functions, the limited range of exposure scenarios evaluated, and unavailability of study exposures in terms of daily 8-hour averages.

Taken together, the information described above provides consistent and coherent evidence that O_3-induced impacts on tree seedling growth, productivity and carbon storage are occurring at cumulative exposures allowed by the current standard. In particular, this information provides clear evidence of the potential for significant growth loss in Class I locations where ambient conditions meet the current standard.

5.2.2 Exposure/Risk-based Considerations

The WREA presents a number of quantitative analyses of exposure and risk related to tree growth, productivity and carbon storage intended to inform our consideration of exposure and risk associated with the current and potential alternative standards (Table 5-3 below; U.S. EPA, 2014a, Chapter 6).

Table 5-3. Exposure, risk and ecosystem services analyses related to tree growth, productivity and carbon storage.

	Species Level Effects	Ecosystem Level Effects	Ecosystem Services
WREA estimates[A]	Derivation of median biomass loss values from individual species E-R functions Comparison of tree seeding growth to that of mature trees	Percent of total geographic area[B] with annual relative biomass loss above 2% Number of assessed Class I areas with annual relative biomass loss above 2%	• Economic surplus to timber producers and consumers (WREA, Table 6-12) • Carbon storage, nationally (WREA, Table 6-19) • Carbon storage, in 5 urban areas (WREA, Table 6-21) • Air pollutant removal in 5 urban areas (WREA, Table 6-22)

[A] See WREA Chapter 6 (U.S. EPA, 2014a).
[B] The total geographic area includes only the contiguous U.S.

The relevant quantitative exposure and risk analyses for tree biomass loss, productivity and carbon storage include:

1) Species-specific and median biomass loss estimates from composite functions.
2) National-scale assessments for: a) basal area weighted relative biomass loss for tree seedlings; b) timber production; c) carbon sequestration.
3) Case study-scale assessments for: a) carbon sequestration; b) air pollution removal.

- **For what air quality scenarios were exposures and risks estimated? What approaches were used to estimate W126 exposures for those conditions? What are associated limitations and uncertainties?**

Quantitative exposure and risk analyses were conducted to evaluate the effects on tree growth, productivity and carbon storage, and associated ecosystem services, that would be predicted under five air quality scenarios (recent ambient, just meeting the current standard, and W126 potential alternative standards of 15, 11, and 7 ppm-hrs). Table 5-5 summarizes the methodology used to develop the quantitative estimates for each of the five air quality scenarios. In general, this methodology involved two steps. The first is derivation of the average W126 index value (across the three years) at each monitor location. This value is based on unadjusted data for recent conditions and adjusted concentrations for the four other scenarios. The development of adjusted concentrations was done for each of 9 regions independently (see U.S. EPA, 2014a, section 4.3.4.1). In the second step, national-scale spatial surfaces (W126 index values for each 12 x 12 km^2 grid cell from the Community Multi-scale Air Quality (CMAQ) model) were created using the monitor-location values and the Voronoi Neighbor Averaging (VNA) spatial interpolation technique (details on the VNA technique are presented in U.S. EPA, 2014a, Appendix 4A).

Table 5-4. Summary of methodology by which national surface of 3-year average W126 index values was derived for each air quality scenario.

Scenario	Development of W126 index values for Each Air Quality Scenario	
	Monitor-location-specific calculations and any model-based adjustment	**Derivation of national surface of average W126 index values**
Recent Conditions (2006-2008)	An annual W126 index value is calculated for each year at each monitor location, using the highest 3-month period. A location-specific 3-year W126 was calculated by averaging annual W126 index values from 3 consecutive years which may have used different 3-month periods.	The VNA method is applied to the monitor-location average W126 index values to create a national distribution of W126 index values within model grid-cells for each scenario.
Current Standard	2006-2008 hourly O_3 concentrations at each monitor location are adjusted[A] to create a three year record of O_3 concentrations that just meets the current standard (see WREA, section 4.3.4). This results in air quality at other monitors well below the level of the controlling monitor. A seasonal W126 index value is calculated for each year at each monitor location using the same 3-month period for each year (which is the highest as a 3-yr average and is highest in at least one of the years). A location-specific average is derived from these three index values.	
Average W126 Index of 15 ppm-hrs	First, hourly O_3 concentrations were adjusted to just meet the current standard. Second, hourly O_3 concentrations at each monitor location, within each modeling region, are adjusted to create a record for which the highest location-specific average index value in the region (the controlling location) just meets the scenario target index value. A seasonal W126 index value is calculated for each year (of 2006-2008 period) at each monitor location, using the same 3-month period for each year (which is the highest in at least one of the years). A location-specific average is derived from these three index values.	
Average W126 Index of 11 ppm-hrs		
Average W126 Index of 7 ppm-hrs		

[A] The model-based adjustment approach is based on regional emission reduction scenarios at monitor sites followed by spatial interpolation for broader spatial coverage. See WREA, chapters 3 and 4, and Appendix 4A.

During the recent conditions period (2006 through 2008), the average W126 index values (across the three-year recent conditions period) at the monitor locations ranged from below 5 ppm-hrs to 48.6 ppm-hrs (U.S. EPA 2014a, Figure 4-4 and Table 4-3). Across the nine modeling regions, the maximum average W126 index values ranged from 48.6 ppm-hrs in the west region down to 6.6 ppm-hrs in the northwest region. After adjusting the 2006-2008 data to just meet the current standard in each region, the region-specific maximum values range from 18.9 ppm-hrs in the west region to 2.6 ppm-hrs in the northeast region (U.S. EPA, 2014a, Table 4-3). After application of the VNA technique to the current standard scenario monitor location values, the average W126 index values were below 15 ppm-hrs across the national surface with the

exception of a very small area of the southwest region (near Phoenix) where the average W126 index values was near or just above 15 ppm-hrs. Thus, it can be seen that application of the interpolation method to estimate W126 index values at the centroid of every 12 x 12 km^2 grid cell rather than only at each monitor location results in a lowering of the highest values.

- **What are the nature and magnitude of exposure- and risk-related estimates for tree growth, productivity, and carbon storage under recent conditions or conditions remaining upon meeting the current standard? To what extent are these exposures and risks important from a public welfare perspective?**

In answering the above question, the WREA performed a number of different assessments to estimate the exposures and risks predicted under the five air quality scenarios across a range of spatial scales. These assessments include those for individual species response as well as the median species response for studied species ranging from the county scale up to estimations of exposures and risks to ecosystem services associated with forests at the urban, park and national scales.

Before conducting the exposure and risk assessments, the WREA examined three approaches for characterizing the median response, as shown in Figure 5-2 below (U.S. EPA, 2014a, section 6.2.1.2 and Figure 6-5). These approaches use the 11 robust E-R functions for tree seedlings from the OTC research and the cottonwood E-R function. For some species, only one study was available (e.g., red maple), and for other species there were as many as 11 studies available (e.g., ponderosa pine). The first approach plotted the median (red line) of all 52 tree seedling studies available (across the 12 species). In this first approach, species with multiple studies would be represented more than once in the median. The second approach characterized the median (green line) by combining the composite E-R functions, when available for species with multiple studies, with the E-R functions for species with a single study available[13] for each of the 12 tree species. In this second approach, each species is represented only once in the median. The third approach used a stochastic sampling method to randomly select a single E-R function from the studies available for each of the 12 species. The process was repeated 1,000 times (grey lines), and the median value was plotted for biomass loss values of 1% to 7%, and 10% (red dots; the bar associated with each median point denotes the 25th and 75th percentile values). This third approach illustrates the effect of within-species variability on estimates of the median response. The median W126 index values are similar when using the first two approaches; however, the median value is higher when within-species variability is included (U.S. EPA, 2014a, section 6.2.1.2). Across these three approaches, the median seasonal W126 index value for which a two percent biomass loss is estimated in seedlings for the studied species

[13] For some species, only one study was conducted so that E-R function was used.

ranges between approximately 7 and 14 ppm-hrs. Using the green line, the seasonal W126 index value for which a two percent biomass loss is estimated in seedlings for the median of the composite functions for the 12 studied species is approximately 7 ppm-hrs. After reviewing these three approaches, the CASAC stated "[t]he Monte Carlo analysis (red dots, Figure 5-2) should not be used in evaluating the effect of ozone on RBL of tree seedlings. This analysis overemphasizes the species for which relatively few E-R functions are available, is biased toward the few less sensitive response functions available for some individual species, makes unsupported assumptions regarding the representativeness of available response functions, and confounds intra- and inter-species variability in unquantifiable ways. We favor using a measure of central tendency of the data, specifically the median across species (the green line in Figure 5-2). This analysis provides the median of best available estimates within each species, and the median across species with all species treated equally" (Frey, 2014, p. 14). Given this advice, in selecting an approach for use in later analyses, we have chosen to use the green line because the approach that generated it incorporates all the information in a way that gives equal weight to each studied species without losing any of the available data.

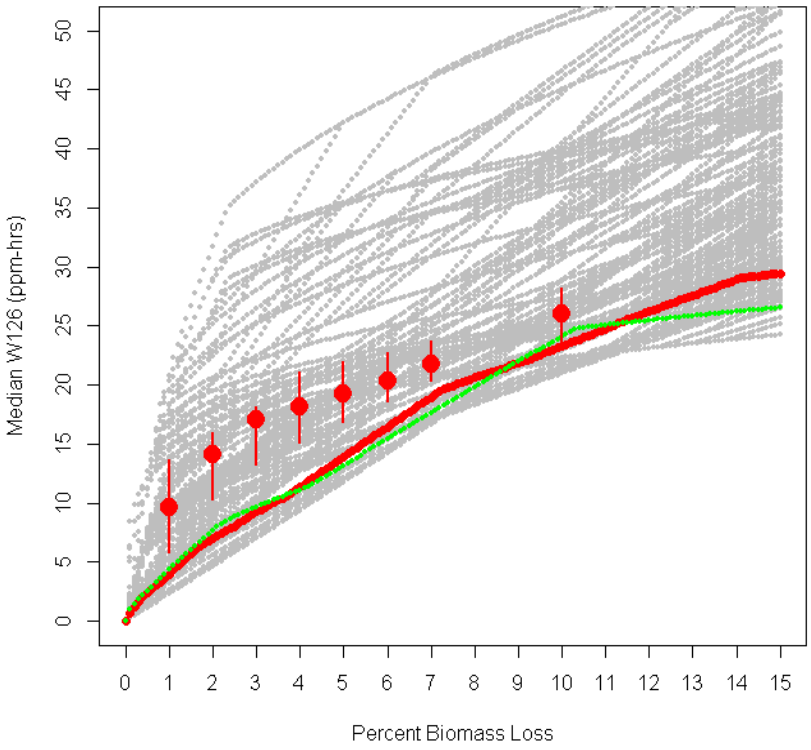


Figure 5-2. Relationship of tree seedling percent biomass loss with seasonal W126 index. (From U.S. EPA 2014a, Figure 6-5)

The WREA used the E-R functions for 12 species described above with information on the distribution of those species across the U.S., and average W126 exposure estimates to

estimate relative biomass loss for each of the studied species for each national air quality scenario (U.S. EPA, 2014a, section 6.2.1.3 and Appendix 6A). For example, the estimates of relative biomass loss of ponderosa pine for air quality adjusted to just meet the current standard are illustrated in Figure 5-3 below. While relative biomass loss below 2% is estimated for most areas where this species is found, estimates in some areas of the southwest fall above 2% biomass loss (U.S. EPA 2014a, Figure 6-8 and Appendix 6A).

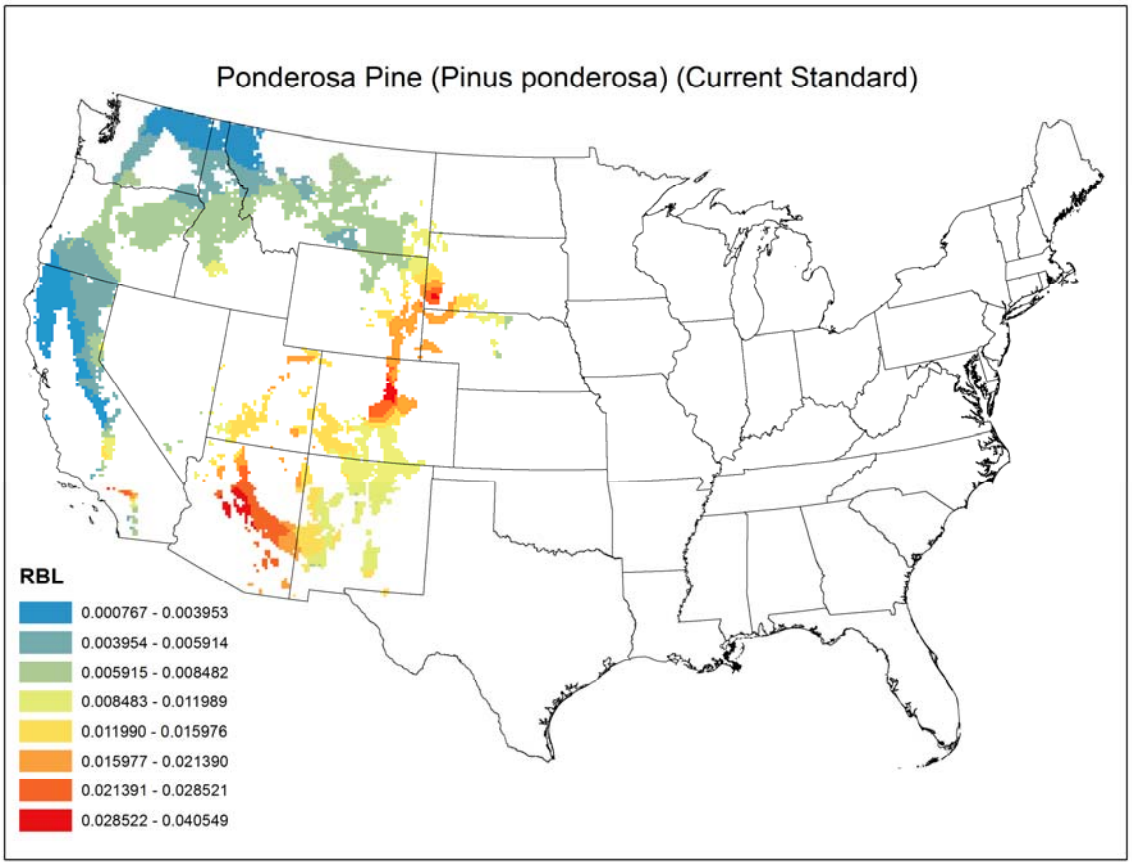


Figure 5-3. Relative biomass loss of Ponderosa Pine for air quality adjusted to just meet the current standard (U.S. EPA 2014a, Figure 6-8).

The WREA also developed national-scale estimates of O_3 biomass ecosystem-level impacts considering the 12 studied species together (U.S. EPA 2014a, section 6.8, Table 6-25). This was done using the species-specific biomass loss E-R functions, information on prevalence of the studied species across the U.S., and a weighting approach based on proportion of the basal area within each grid cell that each species contributes. The RBL values for multiple tree species were weighted by their basal area and combined into a weighted RBL value (wRBL). The wRBL is intended to inform our understanding of the potential magnitude of the ecological effect that could occur in some ecosystems. Specifically, the more basal area that is affected in a given

ecosystem, the larger the potential ecological effect. A wRBL value for each grid cell is generated by weighting the RBL value for each studied tree species found within that grid cell by the proportion of basal area it contributes to the total basal area of all tree species within the grid cell, and then summing those individual wRBLs. The percent of total basal area that exceeds a 2% weighted relative biomass loss in the recent conditions scenario is 10.1% (U.S. EPA 2014a, Table 6-25). Based on the average W126 index values estimated for the air quality scenario just meeting the current standard across the contiguous U.S., the WREA estimates 0.2% of the total geographic area to have a wRBL above 2% based on the E-R functions for the 11 tree species and 0.8% based on 12 tree species (U.S. EPA 2014a, Table 6-25). We recognize that these estimates are likely biased low as there may be other unstudied O_3-sensitive tree species in some areas that are also being impacted at those levels. Further, this analysis does not take into account the effects of competition, which could further increase biomass loss in O_3-sensitive species.

In addition, the WREA characterized the number of counties where there would be one or more studied tree species showed a 2% biomass loss (U.S. EPA, 2014a, Table 6-7), which is shown in Table 5-5 below. This is consistent with CASAC advice that "rather than focusing solely on the median relative biomass loss (RBL), the number of counties containing sensitive tree species that are expected to have growth loss of greater than 2% should be quantified." (Frey, 2014, p. 11). These data are presented as the number of U.S. counties in which any of the 12 studied tree species exceeds 2% RBL, further categorized by the number of studied species that exceed that benchmark for each of the five air quality scenarios using 3-year average W126 index values. In addition, this table provides the total number of counties (out of 3,109 total counties) for each exposure scenario with at least one species exceeding 2% RBL and the number of counties where the median of the composite functions for each species exceeds 2% RBL. The maximum number of species that exceed 2% RBL in any one county is five species, which only occurs under recent O_3 conditions. After meeting the current standard, the maximum number of species in any one county is four. Because cottonwood and black cherry are highly sensitive species and to provide a reference for the effect of these species, the data are also presented excluding cottonwood and excluding cottonwood and black cherry.

This information shows that a number of counties have more than one O_3-sensitive species growing in it, potentially together in the same forest stands, whose RBLs are above 2%. Under recent conditions, the proportion of total counties of 3,109, with 1 or more species with an RBL greater than 2% is 89% (2,761 counties) for the scenario inclusive of cottonwood and black cherry. When air quality is adjusted to just meet the current standard, that proportion dropped to 74% (2,313 counties). When air quality is adjusted to just meet a 3-year average W126 index

value of 15, 11 and 7 ppm-hrs, the proportion is 73%, 72% and 71%, respectively. For median RBL values, under recent conditions, 72% of the counties have median RBLs above 2%. When air quality is adjusted to the current standard, that proportion drops to 22% and further decreases to 20% for air quality adjusted to just meet a 3-year average W126 level of 7 ppm-hrs.

Given CASAC's advice to put less emphasis on cottonwood, we focus on the rows of this table that excluded cottonwood. Under recent air quality conditions, the proportion of counties with 1 or more species with an RBL greater than 2% is 78% (2,418 counties). As air quality is adjusted to just meet the current standard and the alternative W126 index value of 7 ppm-hrs, this number drops to 62% and 58%, respectively. In addition, under recent conditions, 52% of the counties have median RBLs above 2%. When air quality is adjusted to the current standard, that proportion drops to 8% and further decreases to 6% for air quality adjusted to just meet a 3-year average W126 level of 7 ppm-hrs.

Table 5-5 also provides information on the influence of black cherry on the estimates and shows that black cherry is a very sensitive species that is widespread in the Eastern U.S. We note that of the 1,929 counties estimated to have 1 or more species with an RBL greater than 2% when meeting the current standard, 1,805 of those counties are estimated to have black cherry as the only specie estimated to experience this level of biomass loss. With respect to median RBL values, of the 239 counties estimated to have a median RBL above 2% when meeting the current standard, 203 of those counties have a RBL above 2% because of the presence of black cherry.

Table 5-5. Number of Counties with Tree Species Exceeding 2% Relative Biomass Loss.

Number of species exceeding 2% RBL	Number of Counties (3,109 Total)				
	Recent Conditions	75 ppb	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
All 12 tree species with E-R functions					
5	134	-	-	-	-
4	387	3	3	-	-
3	765	24	22	14	5
2	882	994	981	972	924
1	593	1,292	1,273	1,238	1,277
0	348	796	830	885	903
Total counties exceeding	2,761	2,313	2,279	2,224	2,206
Counties exceeding for the median species	2,237	685	670	651	627
11 tree species with E-R functions excluding cottonwood					
5	15	-	-	-	-
4	180	-	-	-	-
3	680	3	3	-	-
2	933	46	32	14	5
1	610	1,880	1,857	1,818	1,812
0	691	1,180	1,217	1,277	1,292
Total counties exceeding	2,418	1,929	1,892	1,832	1,817
Counties exceeding for the median species	1,604	239	221	204	172
10 tree species with E-R functions excluding cottonwood and black cherry					
5	-	-	-	-	-
4	15	-	-	-	-
3	187	-	-	-	-
2	856	29	15	2	1
1	920	95	72	19	8
0	1,131	2,985	3,022	3,088	3,100
Total counties exceeding	1,978	124	87	21	9
Counties exceeding for the median species	666	36	18	6	2

We also consider WREA estimates (quantitative and qualitative) of effects on several ecosystem services. First, impacts on growth related to cumulative O_3 exposure values in federally designated Class I areas were derived from an average wRBL value (discussed above) for 145 of the 156 Class I areas (U.S. EPA 2014a, section 6.8.1). Given established objectives for Class I areas (e.g., to maintain in perpetuity), effects in Class I areas may be considered to

have the potential to adversely affect the intended use of the ecosystem, e.g., to leave them unimpaired and preserve them for the enjoyment of future generations. Under recent conditions, this analysis estimates that 13 Class I areas have wRBL values above 2%. Further, this analysis estimates that based on average W126 index values estimated for the air quality scenario just meeting the current standard, 2 of the 145 Class I areas assessed would be expected to have multiple-species, wRBL values above 2% (U.S. EPA 2014a, Table 6-26). However, we recognize that this analysis is limited to the 12 studied tree species, and therefore could underestimate other O_3-sensitive species without E-R functions.

The WREA also presents national-scale estimates of the effects of biomass loss on timber production and agricultural harvesting, as well as on carbon sequestration. The WREA used the O_3 E-R functions for tree seedlings to calculate relative yield loss (equivalent to biomass loss) across the trees' entire life spans. Because the forestry and agriculture sectors are related and trade-offs occur between the sectors, the WREA also calculated the resulting market-based welfare effects of O_3 exposure in the forestry and agriculture sectors.[14] In the analyses for commercial timber production, based on the 3-year average W126 index values estimated for the air quality scenario just meeting the existing standard, RYL estimates for timber were below one percent with the exception of the Southwest, Southeast, Central, and South regions (U.S. EPA, 2014a, section 6.3, Table 6-9) (see U.S. EPA, 2014a, Table 6-8 for clarification on region names). At the current standard the highest yield loss occurs in upland hardwood forests in the South Central and Southeast regions at over 3% per year and in Corn Belt hardwoods at just over 2% loss per year. Relative yield losses for timber remain above one percent for the 3-year average W126 scenarios for 15 and 11 ppm-hrs in parts of the Southeast, Central, and South regions, and for the 7 ppm-hrs scenario in the Southeast and South regions (U.S. EPA, 2014a, section 6.3, Table 6-9). In addition, relative yield losses for timber were above two percent in parts of the Southeast and Central U.S. after just meeting the existing standard as well as in the 15 ppm-hrs and 11 ppm-hrs scenario.

In addition to estimating changes in forestry and agricultural yields, the WREA presents estimated changes in consumer and producer/farmer surplus associated with the change in yields. Changes in biomass affect individual tree species, but the overall effect on forest ecosystem productivity depends on the composition of forest stands and the relative sensitivity of trees

[14] The WREA used the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). FASOMGHG is a national-scale model that provides a complete representation of the U.S. forest and agricultural sectors' impacts of meeting alternative standards. FASOMGHG simulates the allocation of land over time to competing activities in both the forest and agricultural sectors. FASOMGHG results include multi-period, multi-commodity results over 60 to 100 years in 5-year time intervals when running the combined forest-agriculture version of the model.

within those stands. Economic welfare impacts resulting from just meeting the existing and alternative standards were largely similar between the forestry and agricultural sectors -- consumer surplus, or consumer gains, generally increased in both sectors because higher productivity under lower O_3 concentrations increased total yields and reduced market prices. Comparisons are not straightforward to interpret due to market dynamics. For example, because demand for most forestry and agricultural commodities is not highly responsive to changes in price, there were more examples for which producer surplus (i.e., producer gains) declines.[15] In some cases, lower prices reduce producer gains more than can be offset by higher yields. The increase in consumer welfare is much larger than the loss of producer welfare resulting in net welfare gains in the forestry sector nationally. The national-scale analysis of carbon dioxide (CO_2) sequestration estimates more storage under the current standard compared to recent conditions (U.S. EPA 2014a, Appendix 6B, Table B-10). In considering the significance of the potential climate and ecosystem service impact, we also note the large uncertainties associated with this analysis (see U.S. EPA 2014a, Table 6-27).

We additionally consider the WREA estimates of tree growth and ecosystem services provided by urban trees over a 25-year period for five urban areas based on case-study scale analyses that quantified the effects of biomass loss on carbon sequestration and pollution removal (U.S. EPA 2014a, sections 6.6.2 and 6.7).[16] The urban areas included in this analysis represent diverse geography in the Northeast, Southeast, and Central regions, although they do not include an urban area in the western U.S. Estimates of the effects of O_3-related biomass loss on carbon sequestration indicate the potential for an increase of somewhat more than a million metric tons of CO_2 equivalents for average W126 index values associated with meeting for the current standard scenario as compared to recent conditions. Somewhat smaller additional increases are estimated for the three W126 scenarios in comparison to the current standard scenario (U.S. EPA 2014a, section 6.6.2 and Appendix 6D).

In addition to the quantitative assessments discussed above, qualitative assessments for some ecosystem services, were also conducted, such as commercial non-timber forest products and recreation (U.S. EPA, 2014a, section 6.4), aesthetic and non-use values (U.S. EPA, 2014a, section 6.4), increased susceptibility to insect attack and fire damage (U.S. EPA, 2014a, sections 5.3 and 5.4, respectively). Other ecological effects that are causally or likely causally associated with O_3 exposure such as terrestrial productivity, water cycle, biogeochemical cycle, and

[15] See Chapter 6, Section 6.3 of the WREA for a discussion of economic welfare and consumer and producer surplus.

[16] The WREA used the i-Tree model for the urban case studies. i-Tree is a peer-reviewed suite of software tools provided by USFS.

community composition (U.S. EPA 2013, Table 9-19) were not directly addressed in the WREA due to a lack of sufficient quantitative information.

There is substantial heterogeneity in plant responses to O_3, both within species, between species, and across regions of the U.S. The O_3-sensitive tree species are different in the eastern and western U.S. -- the eastern U.S. has far more species. Ozone exposure and risk is somewhat easier to assess in the eastern U.S. because of the availability of more data and the greater number of species to analyze. In addition, there are more O_3 monitors in the eastern U.S. but fewer national parks (U.S. EPA, 2014a, chapter 8).

- **What are the uncertainties associated with both quantitative and qualitative information?**

Several key limitations and uncertainties, which may have a large impact on both overall confidence and confidence in individual analyses, are discussed here. Despite these uncertainties, the overall body of scientific evidence underlying the ecological effects and associated ecosystem services evaluated in the WREA is strong, and the methods used to quantify associated risks are scientifically sound (Frey, 2014). Key uncertainties associated with the assessment of impacts on ecosystem services at the national and case-study scales, as well as across species, U.S. geographic regions and future years include those associated with the interpolated and adjusted O_3 concentrations used to estimate W126 exposures in the WREA air quality scenarios and those associated with the available seedling E-R functions.

The WREA identifies sources of uncertainty for the W126 estimates for each air quality scenario and qualitatively characterizes the magnitude of uncertainty and potential for directional bias (U.S. EPA, 2014a, Table 4-5). These sources of uncertainty are described in more detail in the WREA Chapter 4 and summarized below.

An important large uncertainty in the analyses is the assumed response of the W126 concentrations to emissions reductions needed to meet the existing standard (U.S. EPA, 2014a, section 8.5.1). We note that any approach to characterizing O_3 over broad geographic areas based on concentrations at monitor locations will convey inherent uncertainty. The model-based adjustments, based on U.S.-wide emissions reductions in oxides of nitrogen (NOx), do not represent air quality distributions from an optimized control scenario that just meets the current standard (or target W126 index values for other scenarios), but rather characterize one potential distribution of air quality across a region when all monitor locations meet the standard (U.S. EPA 2014a, section 4.3.4.2).[17] An additional uncertainty comes from the creation of a national

[17] Because our analyses used U.S.-wide NOx emissions reductions to simulate just meeting the existing standard independently in each region, there are broad regional reductions in O_3 even in meeting standards in urban areas when targeting a few high-O_3 urban monitors for reductions. However, the assumption of broad regional or national NOx reductions are not unreasonable given EPA regulations such as the NOx SIP Call program

W126 surface using the VNA technique to interpolate recent air quality measurements of O_3. In general, spatial interpolation techniques perform better in areas where the O_3 monitoring network is denser. Therefore, the W126 estimated in the rural areas in the West, Northwest, Southwest, and West North Central with few or no monitors (Figure 2-1) are more uncertain than those estimated for areas with denser monitoring. Additionally, the surface is created from the three-year average at the monitor locations, rather than creating a surface for each year and then averaging across years at each grid cell; the potential impact of this on the resultant estimates is considered in the WREA (U.S. EPA, 2014a, Appendix 4A).

Because the W126 estimates generated in the air quality analyses are inputs to the vegetation risk analyses for biomass loss, any uncertainties in the air quality analyses are propagated into the those analyses (U.S. EPA 2014a, section 8.5). In its letter to the Administrator following its review of the second draft WREA CASAC notes that:

> "The currently reported finding of only small differences in risk between just meeting the current standard and a W126-based level of 15 ppm-hrs must not be interpreted to mean that just meeting the current standard will be as protective as meeting a W126-based standard at 15 ppm-hrs. There are two key factors that must be considered when making this comparison. First, air quality was simulated in the Second Draft WREA based on the magnitude of across-the-board reductions in NOx emissions required to bring the highest monitor down to the target level. Meeting a target level at the highest monitor requires substantial reductions below the targeted level through the rest of the region. This artificial simulation does not represent an actual control strategy and may conflate differences in control strategies required to meet different standards and different targets. As a result, there may be a number of monitors that meet the current standard but would not meet an alternative W126 standard. Second, and equally important, the current form of the standard is much less biologically relevant for protecting vegetation than is a seasonal, peak weighted index such as the W126, which was designed to measure the cumulative effects of ozone exposure." (Frey, 2014, pp. 11-12).

With regard to the robust seedling E-R functions, the description of Figure 5-2 above provides some characterization of the variability of individual study results and the impact of that on estimates of W126 index values that might elicit different percentages of biomass loss in tree seedlings (U.S. EPA, 2014a, section 6.2.1.2). Even though the evidence shows that there are additional species adversely affected by O_3-related biomass loss, the WREA only has E-R functions available to quantify this loss for 12 tree species. This absence of information only

implemented to help areas meet the 1997 O_3 standard resulting in substantial reductions in power plant NOx emissions from states across the eastern U.S., and the multitude of onroad and offroad mobile source rules that will lead to reduction in NOx from these sources across the country in future years.

allows a partial characterization of the O_3-related biomass loss impacts in trees associated with recent O_3 index values and with just meeting the existing and potential alternative secondary standards. In addition, there are uncertainties inherent in these E-R functions, including the extrapolation of relative biomass loss rates from tree seedlings to adult trees and information regarding within-species variability. The overall confidence in the E-R function varies by species based on the number of studies available for that species. Some species have low within-species variability (e.g., many agricultural crops) and high seedling/adult comparability (e.g., aspen), while other species do not (e.g., black cherry). The uncertainties in the E-R functions for biomass loss and in the air quality analyses are propagated into the analysis of the impact of biomass loss on ecosystem services, including provisioning and regulating services (U.S. EPA, 2014a, Table 6-27). The WREA characterizes the direction of potential influence of E-R function uncertainty as unknown, yet its magnitude as high, concluding that further studies are needed to determine how accurately the assessed species reflect the larger suite of O_3-sensitive tree species in the U.S. (U.S. EPA, 2014a, Table 6-27).

Another uncertainty associated with interpretation of the WREA biomass loss-related estimates concerns the potential for underestimation of compounding of growth effects across multiple years of varying concentrations. Though tree biomass loss impacts were estimated using air quality scenarios of 3-year average W126 index values, the WREA also conducted an analysis to compare the impact of using a variable compounding rate based on yearly variations in W126 exposures to that of using a W126 index value averaged across three years. The WREA compared the compounded values for each region, except for the South. In these examples, one species was chosen that occurred within that region. Air quality values associated with just meeting the existing standard of 75 ppb were used. Within each region the WREA analysis used both the W126 index value at each monitor in the region for each year and the three-year average W126 index value using the method described in Chapter 4. The results show that the use of the three-year average W126 index value may underestimate RBL values slightly. However, it should be noted that the approach does not account for moisture levels or other environmental factors that could affect biomass loss (U.S. EPA, 2014a, section 6.2.1.4 and Figure 6-14). In considering these results, we note that in these regions and in all three years, the three-year average W126 index value is sometimes above and sometimes below the individual year W126 index value.

In the national-scale analyses of timber production, agricultural harvesting, and carbon sequestration, the WREA used the FASOMGHG model, which includes functions for carbon sequestration, assumptions regarding proxy species, and non-W126 E-R functions for three crops. However, FASOMGHG does not include agriculture and forestry on public lands, changes in exports due to O_3 into international trade projections, or forest adaptation. Despite

the inherent limitations and uncertainties, the WREA concludes that the FASOMGHG model reflects reasonable and appropriate assumptions for a national-scale assessment of changes in the agricultural and forestry sectors due to changes in vegetation biomass associated with O_3 exposure (U.S. EPA, 2014a, sections 6.3, 6.5, 6.6, and 8.5.2).

In the case study analyses of five urban areas, the WREA used the i-Tree model, which includes an urban tree inventory for each area and species-specific pollution removal and carbon sequestration functions. However, i-Tree does not account for the potential additional VOC emissions from tree growth, which could contribute to O_3 formation. Despite the inherent limitations and uncertainties, the WREA concludes that the i-Tree model reflects reasonable and appropriate assumptions for a case study assessment of pollution removal and carbon sequestration for changes in biomass associated with O_3 exposure (U.S. EPA, 2014a, sections 6.6.2, 6.7, and 8.5.2).

The overall effect of the combined set of uncertainties on confidence in the interpretation of the WREA results is difficult to quantify. Due to differences in available information, the degree to which each analysis was able to incorporate quantitative assessments of uncertainty differed. Despite these uncertainties, the overall body of scientific evidence underlying the ecological effects and associated ecosystem services evaluated in the WREA is strong, and the methods used to quantify associated risks are scientifically sound (Frey, 2014).

5.3 CROP YIELD LOSS

This section considers the current evidence and exposure/risk information to inform consideration of the adequacy of the protection provided by the current standard from known and anticipated adverse welfare effects of O_3 related to crop yield and other associated effects. Crops warrant consideration from a public welfare perspective because they provide food and fiber services to humans. This section includes a discussion of the policy-relevant science and weight-of-evidence conclusions discussed in the ISA (section 5.3.1) and the exposure/risk results (section 5.3.2) described in the final WREA. Important uncertainties and limitations in the available information are discussed under the related question below. These discussions highlight the information we consider relevant to answering the overarching question and associated policy-relevant questions included in this section.

5.3.1 Evidence-based Considerations

Ozone can interfere with carbon gain (photosynthesis) and allocation of carbon. As a result of decreased carbohydrate availability, fewer carbohydrates are available for plant growth, reproduction, and/or yield. For seed-bearing plants, these reproductive effects will culminate in

reduced seed production or yield. The detrimental effect of O_3 on crop production has been recognized since the 1960s, and current O_3 concentrations in many areas across the U.S. are high enough to cause yield loss in a variety of agricultural crops including, but not limited to, soybeans, wheat, cotton, potatoes, watermelons, beans, turnips, onions, lettuces, and tomatoes. Increases in O_3 concentration may further decrease yield in these sensitive crops while also causing yield losses in less sensitive crops (U.S. EPA 2013, section 9.4.4). The ISA concluded that the evidence is sufficient to determine that there is a causal relationship between O_3 exposure and reduced yield and quality of agricultural crops (U.S. EPA 2013, Table 2-2).

- **To what extent has scientific information become available that alters or substantiates our prior conclusions regarding O_3-related crop yield loss and of factors that influence associations between O_3 levels and crop yield loss?**

In general, the vast majority of the new scientific information has substantiated our prior conclusions regarding O_3 crop yield loss. On the whole, this evidence supports previous conclusions that exposure to O_3 decreases growth and yield of crops. The ISA describes average yield loss reported across a number of meta-analytic studies have been published recently for soybean wheat, rice, semi-natural vegetation, potato, bean and barley (U.S. EPA 2013, section 9.4.4.1). Further, several new exposure studies continue to show decreasing yield and biomass in a variety of crops with increased O_3 exposure (U.S. EPA 2013, section 9.4.4.1, Table 9-17). Research has linked increasing O_3 concentration to decreased photosynthetic rates and accelerated aging (U.S. EPA 2013, section 9.4.4) in leaves, which are related to yield. Recent research has highlighted the effects of O_3 on crop quality. Increasing O_3 concentration can also decrease nutritive quality of grasses and macro- and micro-nutrient concentrations in fruits and vegetable crops (U.S. EPA 2013, section 9.4.4). The findings of these studies did not change our understanding of O_3-related crop loss since the last review and little information has emerged on factors that influence associations between O_3 levels and crop yield loss.

- **To what extent have important uncertainties identified in the last review been reduced and/or new uncertainties emerged?**

Important uncertainties have been reduced regarding crop E-R functions, especially for soybean. In general, the ISA reports consistent results across exposure estimation techniques and across crop varieties. Figure 5-4 below illustrates the composite E-R functions for the 10 crop species assessed in the WREA (U.S. EPA, 2014a, Figure 6-3).

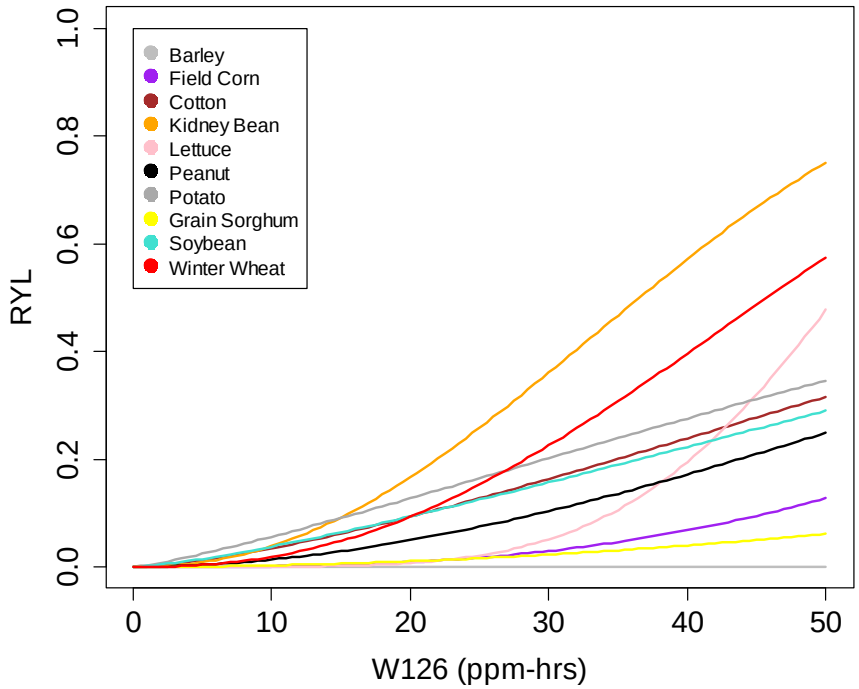


Figure 5-4. Relative yield loss in crops using the composite functions for 10 studied species in response to seasonal O_3 concentrations in terms of seasonal W126 index values, Y-axis scale for RYL values represents 0% up to 100% (U.S. EPA 2014a, Figure 6-3).

Two important uncertainties have been reduced regarding the E-R functions for yield effects of O_3 in crop species, especially for soybean. First, in the last several reviews, the extent to which E-R functions developed in OTC predicted plant responses in the field and under different exposure conditions was not clear. In this review, the ISA included an analysis comparing OTC data with field-based data for one crop and one tree species (U.S. EPA, 2013, section 9.6.3.2). The crop comparison was done using soybean OTC data from NCLAN and field-based data from SoyFACE. The NCLAN program, which was undertaken in the early to mid-1980s, assessed multiple U.S. crops, locations, and O_3 exposure levels, using consistent methods, to provide the largest, most uniform database on the effects of O_3 on agricultural crop yields (U.S. EPA 1996; U.S. EPA 2006; U.S. EPA 2013, sections 9.2, 9.4, and 9.6, Frey, 2014,

p. 9).[18] The SoyFACE experiment was a chamberless field-based exposure study in Illinois that was conducted from 2001 – 2009 (U.S. EPA 2013, section 9.2.4). Yield loss in soybean from O_3 exposure at the SoyFACE field experiment was reliably predicted by soybean E-R functions developed in NCLAN (U.S. EPA, 2013, Section 9.6). This analysis supports the robustness and use of the E-R functions developed in NCLAN to predict relative yield loss to O_3 exposure in a realistic agricultural setting.

A second area of uncertainty that was reduced is that regarding the appropriateness of applying the NCLAN E-R functions to more recent cultivars that are currently being grown. Because recent studies continue to find yield loss levels in crop species studied previously under NCLAN that reflect the earlier findings, the ISA concluded that there has been little new evidence that crops are becoming more tolerant of O_3 (U.S. EPA, 2006a; U.S. EPA 2013). This is especially evident in the research on soybean. In a meta-analysis of 53 studies, Morgan et al. (2003) found consistent deleterious effects of O_3 exposures on soybean from studies published between 1973 and 2001. Further, Betzelberger et al. (2010) recently utilized the SoyFACE facility to compare the impact of elevated O_3 concentrations across 10 soybean cultivars to investigate intraspecific variability of the O_3 response. The E-R functions derived for these 10 current cultivars were similar to the response functions derived from the NCLAN studies (Heagle, 1989), suggesting there has not been any selection for increased tolerance to O_3 in more recent cultivars. The 2013 ISA reported comparisons between yield predictions based on data from cultivars used in NCLAN studies, and yield data for modern cultivars from SoyFACE (U.S. EPA, 2013, section 9.6.3). They confirm that the average response of soybean yield to O_3 exposure has not changed in current cultivars. Thus, staff concludes that at least for soybean, uncertainties associated with use of the NCLAN generated E-R functions to estimate biomass loss in recent cultivars has been reduced.

- **To what extent does the available evidence indicate the occurrence of O_3-related effects on crop yield loss attributable to cumulative exposures at lower ambient O_3 concentrations than previously established or to exposures at or below the level of the current standard?**

Little scientific evidence has emerged to indicate a lower W126 index value for cumulative exposures that can affect crop yield than previously established. However, as

[18] The NCLAN protocol was designed to produce crop exposure-response data representative of the areas in the U.S. where the crops were typically grown. In total, 15 species (e.g., corn, soybean, winter wheat, tobacco, sorghum, cotton, barley, peanuts, dry beans, potato, lettuce, turnip, and hay [alfalfa, clover, and fescue]), accounting for greater than 85 percent of U.S. agricultural acreage planted at that time, were studied. Of these 15 species, 13 species including 38 different cultivars were combined in 54 cases representing unique combinations of cultivars, sites, water regimes, and exposure conditions. Crops were grown under typical farm conditions and exposed in open-top chambers to ambient O_3, sub-ambient O_3, and above ambient O_3.

discussed below, CASAC has provided a target benchmark protection for crop yield loss that can help better focus a discussion of the level of exposure that O_3 related effects on crops can occur (levels of concern). Currently available evidence supports effects on crop yield at cumulative exposures at and below the level of the current standard. As described above, the new evidence has strengthened the basis for using the information from the E-R functions.

Based on the 10 robust E-R functions (i.e., barley, lettuce, field corn, grain sorghum, peanut, winter wheat, cotton, soybean, potato and kidney bean) described in the ISA and additionally analyzed in the WREA (Figure 5-4), Table 5C-3 shows that for the CASAC recommended target benchmark protection level of 5% for median crop relative yield loss (RYL), W126 index values ranging from 7 to 17 ppm-hrs are protective. However, when individual species are considered over this same range, the proportion of crops protected varies from 5/10, 6/10, 7/10, 9/10, 10/10, and 10/10 at the W126 levels of 17, 15, 13, 11, 9, and 7 ppm-hrs. To the extent a given species is judged as having particular importance to the public welfare, breaking the information down by species can be helpful. For example, less than 5% yield loss was estimated for soybeans at the W126 index value of 12 ppm-hrs (U.S. EPA 2014a, Figure 6-3). Four of the studied crop species (barley, lettuce, field corn, and grain sorghum) are more tolerant, with RYL under 1% over the W126 range from 7 to 17 ppm-hrs. Peanut also remained under 4% RYL over the same W126 range. Other species differed regarding the W126 level at which RYL reached or fell below 5%. Specifically, for winter wheat, cotton, soybean, kidney bean and potato, the relevant W126 index values at which RYLs were below 5% are 15, 13, 11, 11, and 9 ppm-hrs.

Where the current evidence on crop yield loss is not in terms of parts per billion concentrations over a specific exposure period such as eight hours, assessing whether O_3 concentrations associated with meeting the current standard would allow crop yield effects is more complex. In order to characterize the O_3 exposures associated with crop yield loss in terms of seasonal W126 index and to consider the extent to which such index values might be expected to occur in agricultural locations that meet the current standard, we evaluated two agricultural counties in Kansas using O_3 monitoring data from EPA's Air Quality System (AQS) combined with the E-R function for soybeans. Sedgwick and Sumner counties both met the level of the 3-year, 8-hour standard of 75 ppb in 2009-2011, but both still had a maximum annual W126 level of 19 ppm-hours in 2011. At that annual W126 index value, soybean yield loss would be predicted to be 9% in those counties in that year.

- **To what extent does currently available evidence suggest locations where the vulnerability of sensitive species, ecosystems and/or their associated services to O_3-related crop yield loss would have special significance to the public welfare?**

During the previous NAAQS reviews, there were very few studies that estimated O_3 impacts on crop yields at large geographical scales (i.e., regional, national or global). Recent modeling studies of the historical impact of O_3 concentrations found that increased O_3 generally reduced crop yield, but the impacts varied across regions and crop species (U.S. EPA, 2013, Section 9.4.4.1). The largest O_3-induced crop yield losses were estimated to occur in high-production areas exposed to elevated O_3 concentrations, such as the Midwest and the Mississippi Valley regions of the United States. Among crop species, the estimated yield loss for wheat and soybean were higher than rice and maize. Additionally, satellite and ground-based O_3 measurements have been used to assess yield loss caused by O_3 over the continuous tri-state area of Illinois, Iowa, and Wisconsin. The results indicate that O_3 concentrations during the assessed period reduced soybean yield, which correlates well with the previous results from FACE- and OTC-type experiments (U.S. EPA 2013, section 9.4.4.1).

Thus, the recent scientific literature in the ISA continues to support the conclusions of the 1996 and 2006 CDs that ambient O_3 concentrations can reduce the yield of major commodity crops in the U.S. and to support the use of crop E-R functions based on OTC experiments. Agricultural areas that would be likely to have the most significance to the public welfare would be those high production areas for sensitive crops that also are exposed to high O_3 concentrations, such as areas in the Midwest and Mississippi Valley regions.

5.3.2 Exposure/Risk-based Considerations

Two main analyses are conducted in the WREA to estimate O_3 impacts related to crop yield. Annual yield losses are estimated for 10 commodity crops and these estimates are then additionally used to estimate O_3 impacts on producer and consumer economic surpluses (Table 5-6 below; U.S. EPA, 2014a, sections 6.2, 6.5).

Table 5-6. Exposure, risk and ecosystem services analyses related to crop yield.

	Crop-level impact[B]	Agri-Ecosystem Services[C]
WREA estimates[A]	Annual Relative Yield Loss for Corn, Cotton, Potato, Sorghum, Soybean, Winter Wheat	Economic surplus to crop producers and consumers
[A] See Chapter 4 WREA; [B] See Section 6.2 WREA; [C] See Sections 6.4 and 6.5 WREA		

- **For what air quality scenarios were exposures and risks estimated? What approaches were used to estimate W126 exposures for those conditions? What are associated limitations and uncertainties?**

The WREA crop analyses described here were performed for five air quality scenarios using the methodology summarized in Table 5-4 above. In general, this methodology is identical to the air quality scenarios for the biomass loss analyses and have the same uncertainties and limitations summarized in section 5.2.2 above. These air quality scenarios described in more detail in the WREA (U.S. EPA, 2014a, chapter 4 and Appendix 4A).

- **What is the nature and magnitude of the cumulative exposure- and risk-related estimates for crop yield loss associated with remaining upon simulating just meeting the current O_3 standard? What are the uncertainties associated this information?**

The WREA presents estimates of crop yield loss for the five air quality scenarios described above using 10 robust E-R functions for commodity crops that are grown across the U.S. (U.S. EPA, 2014a, section 6.5). The largest reduction in O_3 induced crop yield loss occurs when moving from the recent conditions scenario to that for just meeting the current standard (U.S. EPA, 2014a, section 6.5). In the analyses for agricultural harvest, the largest estimates of yield changes also occur when comparing the recent conditions scenario to that for the current standard. Under recent conditions, the West, Southwest, and Northeast regions generally have the highest yield losses. For the 3-year average W126 scenarios, relative yield losses for winter wheat[19] are less than one percent. For soybeans, yield losses for these scenarios range from just above 1 percent to below one percent (U.S. EPA 2014a, section 6.5). However, when evaluated at the county level, 99% of soybean producing counties (1,718) have greater than 5% yield loss under recent conditions, while no counties show yield loss at or above this level when air quality is adjusted to just meet the current standard (U.S. EPA, 2014a, section 6.5).

The WREA estimates of O_3-attributable percent yield loss based on 3-year average W126 index values estimated after just meeting the current standard are relatively small (0.0 – 2.72%) across the 10 crop species analyzed, U.S. EPA 2014a, section 6.5, Appendix 6B). In considering these estimates, we recognize the significant uncertainties associated with several aspects of the analyses. Because the W126 estimates generated in the air quality analyses are inputs to the vegetation risk analyses for crop yield loss, any uncertainties in the air quality analyses are propagated into the those analyses (U.S. EPA 2014a, Table 6-27, section 8.5).

[19] Among the major crops, because winter wheat and soybeans are more sensitive to ambient O_3 levels than other crops we focus on these crops for this discussion.

- **To what extent are the exposures and risks remaining upon simulating just meeting the current O_3 standard important from a public welfare perspective?**

From a public welfare prospective, the O_3 attributable risks to crops estimated for conditions that just meet the current standard are small. However, it is unclear how much weight to put on these results given the multiple areas of uncertainty associated with these estimates as discussed in the WREA and summarized above, including those associated with the model-based adjustment methodology and those associated with projection of yield loss at the estimated O_3 concentrations (U.S. EPA, 2014a, Table 6-27, section 8.5). In addition we note that while having sufficient crop yields is of high public welfare value, important commodity crops are typically heavily managed to produce optimum yields. Given all of the inputs that go into achieving these yields, such as fertilizer, herbicides, pesticides, and irrigation, it difficult to determine at what point O_3-induced yield loss creates an adverse impact for the producer in the way of requiring increased inputs in order to maintain the desired yields. In contrast, based on the economic theory of supply and demand, increases in crop yields would be expected to result in lower prices for affected crops and their associated goods, which would benefit consumers. However, due to pre-existing market forces and subsidies, it is not clear that such benefits would be realized by the consumer. Given these competing impacts on producers and consumers, it is unclear how to determine what type of effect may be adverse to the public welfare. In considering this issue, CASAC states that "calculation of consumer and producer surpluses is a useful contribution to quantification of welfare effects. However, this national-level approach does not adequately account for negative effects on individual farmers and forest owners in high-ozone areas..." (Frey, 2014, p. 10). Instead, CASAC states that "[a] county scale is appropriate for assessing crop yield loss. Calculating producer and consumer surpluses at national or large region scales does not provide adequate protection. Farmers growing sensitive crops in high ozone locations can be considered a 'sensitive population' for welfare impacts, and crop yields under these conditions should be protected." (Frey, 2014, pp. 14 – 15). The final WREA includes a county-level analysis in Appendix 6B finding that 99 percent of soybean-producing counties, for example, exceed 5% yield loss under recent conditions, while no counties have relative yield losses above 5% for any crop after adjusting air quality scenarios to just meet the current standard.

- **What are the ecosystem services potentially affected by O_3-related crop yield loss and to what extent are they important from a public welfare perspective? To what degree can the magnitude of the O_3 effect on these services be qualitatively or quantitatively characterized?**

The WREA presents national-scale estimates of the effects of biomass loss on timber production and agricultural harvesting, which supply provisioning services of food and fiber, as

well as on carbon sequestration (U.S. EPA 2014a, section 6.5). Because the forestry and agriculture sectors are related and trade-offs occur between the sectors, the WREA also calculated the resulting market-based welfare effects of O_3 exposure in the forestry and agriculture sectors. Overall effect on agricultural yields and producer and consumer surplus depends on the (1) ability of producers/farmers to substitute other crops that are less O_3 sensitive, and (2) responsiveness, or elasticity, of demand and supply (U.S. EPA, 2014a, sections 6.5, 8.2.1.3). Estimated O_3-attributable economic welfare impacts on agricultural sectors associated with air quality conditions adjusted to just meet the existing and potential alternative W126 standard levels were largely similar between the forestry and agricultural sectors. Estimates of consumer surplus, or consumer gains, were generally higher under those conditions (compared to recent conditions) in both sectors because higher productivity under lower O_3 concentrations increased total yields and reduced market prices (U.S. EPA 2014a, Table 6-18). Because demand for most forestry and agricultural commodities is not highly responsive to changes in price, generally producer surplus, or producer gains, decline. For agricultural welfare, annualized combined consumer and producer surplus gains were estimated to be $2.6 trillion for model-based adjustment to meet the current standard. Combined gains were essentially unchanged in comparisons of the current standard scenario to the average W126 scenario for 15 ppm-hrs, but gains increased by $21 million for the W126 scenario for 11 ppm-hrs and $231 million for the W126 scenario for 7 ppm-hrs. In some cases, lower prices reduce producer gains more than can be offset by higher yields (U.S. EPA, 2014a, Table 6-18).

The WREA discusses multiple areas of uncertainty associated with these estimates (also summarized above), including those associated with the model-based adjustment methodology as well as those associated with projection of yield loss at the estimated O_3 concentrations (U.S. EPA, 2014a, Table 6-27, section 8.5).

5.4 VISIBLE FOLIAR INJURY

Visible foliar injury resulting from exposure to O_3 has been well characterized and documented over several decades of research on many tree, shrub, herbaceous, and crop species (U.S. EPA, 2013, 2006, 1996, 1984, 1978). The significance of O_3 injury at the leaf and whole plant levels depends on an array of factors, and therefore, it may be difficult to quantitatively relate visible foliar injury symptoms to other vegetation effects such as individual tree growth, or effects at population or ecosystem levels (U.S. EPA, 2013, p. 9-39). Visible foliar injury by itself, however, is an indication of phytotoxicity due to O_3 exposure and can impact the public welfare through damaging or impairing the intended use of the affected entity or the service it provides. For example, ways by which O_3-induced visible foliar injury may impact the public welfare include: 1) visible damage to ornamental species used in landscaping or leafy crops

(spinach, lettuce, tobacco) that affects the economic value, yield, or usability of that plant (U.S. EPA 2007, section 7.4.1; Abt Associates, Inc., 1995); 2) visible damage to plants with special cultural significance (e.g., those used in tribal practices); 3) visible damage to species occurring in natural settings valued for their scenic beauty and/or recreational appeal, including in areas specially designated for more protection (e.g., federal Class I areas) (73 FR 16490). Given limitations in the available information pertaining to the first two categories,[20] the discussions of the evidence and exposure/risk information in sections 5.4.1 and 5.4.2 below focus primarily on what is known about visible foliar injury that has been shown to occur in natural settings valued for their scenic beauty and/or recreational appeal.

At the time of the last review, the following was known:

1) Ozone causes diagnostic visible injury symptoms on studied bioindicator species.
2) Soil moisture is a major confounding effect that can decrease the incidence and severity of visible foliar injury under dry conditions and vice versa.
3) The most extensive dataset regarding visible foliar injury incidence across the U.S. was that collected by the USFSFHM/FIA Program.
4) Visible foliar injury incidence was considered to be widespread in both the eastern and western U.S. based on staff analyses of county level air quality data and USFS biomonitoring data which showed that for each year within a four year period (2001 – 2004) the percentage of counties having a biosite with visible foliar injury ranged between 11-30% at an 8-hour average annual level of 0.074 ppm (U.S. EPA, 2007, section 7.6.3.2).

In the remainder of this section, we consider how the currently available evidence and exposure/risk information informs our understanding of the relationship that exists between visible foliar injury and exposures to O_3 in ambient air and consideration of the adequacy of protection provided by the current standard. The policy-relevant evidence and weight-of-evidence conclusions drawn from the ISA are discussed in section 5.4.1, and the exposure/risk and associated ecosystem services estimates from the WREA, are discussed in section 5.4.2. Important uncertainties and limitations in each type of available information are also discussed in these two sections.

[20] Qualitative information regarding potential cultural impacts of O_3-induced visible foliar injury is noted in section 5.5 and Appendix 5-A).

5.4.1 Evidence-based Considerations

- **To what extent has scientific information become available that alters or substantiates our previous conclusions of O_3-related visible foliar injury and of factors that influence associations between O_3 exposures or concentrations and visible foliar injury?**

Recent research continues to build and substantiate the previous conclusions and findings drawn from several decades of research on many tree, shrub, herbaceous, and crop species (U.S. EPA, 2013, 2006, 1996, 1984, 1978) that O_3-induced visible foliar injury symptoms are well characterized and considered diagnostic on certain bioindicator plant species. Diagnostic usage for these plants has been verified experimentally in exposure-response studies, using exposure methodologies such as continuous stirred tank reactors (CSTRs), open-top chambers (OTCs), and free-air fumigation (FACE). Although there remains a lack of robust exposure-response functions that would allow prediction of visible foliar injury severity and incidence under varying air quality and environmental conditions, experimental and observational evidence has clearly established a consistent association of the presence of visible injury symptoms with O_3 exposure, with greater exposure often resulting in greater and more prevalent injury (U.S. EPA 2013, section 9.4.2). This new research includes: 1) controlled exposure studies conducted to test and verify the O_3 sensitivity and response of potential new bioindicator plant species; 2) multi-year field surveys in several National Wildlife Refuges (NWR) documenting the presence of foliar injury in valued areas; 3) ongoing data collection and assessment by the USFS FHM/FIA program, including multi-year trend analysis (U.S. EPA 2013, section 9.4.2). These recent studies, in combination with the entire body of available evidence, thus form the basis for the ISA determinations of a causal relationship between ambient O_3 exposure and the occurrence of O_3-induced visible foliar injury on sensitive vegetation across the U.S. (U.S. EPA 2013, p. 9-42).

With regard to evidence from controlled exposure studies, a recent study of 28 plant species confirmed prior findings of O_3 causing predictable diagnostic visible foliar injury symptoms on some species of plants. This study selected 28 plant species, most of which grow naturally throughout the northeast and midwest US, including in national parks and wilderness areas, that were suspected of being O_3-sensitive, and exposed them to four different O_3 concentrations (30, 60, 90, and 120 ppb) in CSTR chambers (Kline et al., 2008). Two experiments were conducted in each year of the study (2003 and 2004). Plants were exposed to O_3 for 7 hours a day, five days a week over the course of each experiment. Specifically, in 2003, the first experiment lasted from July 14 to August 21 and included 29 days of O_3 exposure and the second from September 9 to 30 and included 16 exposure days. In 2004, the first experiment was conducted from July 13 to August 10 with 21 O_3 exposure days and the second from August

27 to September 24, including 21 days of O_3 exposure. Though the exposures were cumulative over the course of the study, exposures were reported only in terms of the target exposure concentration for each experiment. The study reported O_3-induced responses in 12, 20, 28 and 28 of the 28 tested species at the 30, 60, 90 and 120 ppb exposure concentrations[21], respectively. Based on their findings, the authors suggest that American sycamore, aromatic sumac, bee balm, buttonbush, common milkweed, European dwarf elderberry, New England aster, snowberry and swamp milkweed would make the most useful bioindicator species. Some of these species are native to Class 1 areas (discussed further below). The staff additionally concludes that given that the exposure protocol was designed to create a continuous exposure level, not a fluctuating one, this study shows that O_3-induced foliar injury can occur from 7-hour exposures repeated over multiple days at O_3 concentrations that are below the 75 ppb level of the current standard.[22] While this type of controlled study provides clear evidence of cause and effect, it also has limitations. The authors, recognizing this cautioned that "extrapolation of these CSTR results to the field must be done carefully, since CSTR/greenhouse conditions … are not representative of natural environmental conditions" (Kline et al., 2008).

A string of recently published multi-year field studies provide a complimentary line of field-based evidence by documenting the incidence of visible foliar injury symptoms on a variety of O_3-sensitive species over multiple years and across a range of cumulative, seasonal exposure values in several eastern and midwestern NWRs (U.S. EPA 2013, section 9.4.2.1; Davis and Orendovici, 2006; Davis, 2007a, b; Davis, 2009). Some of these studies also included information regarding soil moisture stress using the Palmer Drought Severity Index (PDSI). While environmental conditions and species varied across the four NWRs, visible foliar injury was documented to a greater or lesser degree at each site. As discussed further below, visible foliar injury incidence in these types of areas has greater significance to the public welfare.

- **To what extent have important uncertainties identified in the last review been reduced and/or new uncertainties emerged?**

The studies mentioned above also provide additional information regarding an important uncertainty identified in the previous review, i.e., the role of soil moisture in influencing visible foliar injury response (U.S. EPA 2013, section 9.4.2). These studies confirm that adequate soil moisture creates an environment conducive to greater visible foliar injury in the presence of O_3

[21] Two of the target exposure levels, 30 and 60 ppb, fall below the level of the current standard (75 ppb). The mean exposure concentrations achieved in the CTSRs for the 30 ppb target level for each year and study were 27.9, 26.3, 27.1, and 29.3 ppb and for the 60 ppb target level were 56.6, 55.8, 57.9, and 59.0 ppb, for 2003 study 1, 2003 study 2, 2004 study 1, and 2004 study 2, respectively.

[22] The current standard is met when the 3-year average of the 4th highest daily maximum 8-hour average concentrations is at or below 75 ppb.

than drier conditions. As stated in the ISA, "[a] major modifying factor for O_3-induced visible foliar injury is the amount of soil moisture available to a plant during the year that the visible foliar injury is being assessed … because lack of soil moisture generally decreases stomatal conductance of plants and, therefore, limits the amount of O_3 entering the leaf that can cause injury" (U.S. EPA, 2013, p. 9-39). As a result, "many studies have shown that dry periods in local areas tend to decrease the incidence and severity of O_3-induced visible foliar injury; therefore, the incidence of visible foliar injury is not always higher in years and areas with higher O_3, especially with co-occurring drought (Smith, 2012; Smith et al., 2003)" (U.S. EPA, 2013, p. 9-39). This "…partial 'protection' against the effects of O_3 afforded by drought has been observed in field experiments (Low et al., 2006) and modeled in computer simulations (Broadmeadow and Jackson, 2000)" (U.S. EPA, 2013, p. 9-87). In considering the extent of any protective role of drought conditions, however, the ISA also notes that other studies have shown that "drought may exacerbate the effects of O_3 on plants (Pollastrini et al., 2010; Grulke et al., 2003)" and that "[t]here is also some evidence that O_3 can predispose plants to drought stress (Maier-Maercker, 1998)". Accordingly, the ISA concludes that "the nature of the response is largely species-specific and will depend to some extent upon the sequence in which the stressors occur" (U.S. EPA, 2013, p. 9-87). Such uncertainties associated with describing the potential for foliar injury and its severity or extent of occurrence for any given air quality scenario due to confounding by soil moisture levels make it difficult to identify an appropriate degree of annual protection (as well as ambient O_3 exposure conditions that might be expected to provide that protection).

- **To what extent does the available evidence indicate the occurrence of O_3-related visible foliar injury attributable to cumulative exposures at lower ambient O_3 concentrations than previously established or to exposures at or below the level of the current standard?**

Recently available evidence confirms the evidence available in previous reviews that visible foliar injury can occur when sensitive plants are exposed to elevated O_3 concentrations in a predisposing environment (i.e., adequate soil moisture (U.S. EPA, 2013, section 9.4.2). Recent evidence also continues to indicate the occurrence of visible foliar injury at cumulative ambient O_3 exposures previously established. Since the 2006 O_3 CD, results from several multi-year field surveys and experimental screenings of O_3-induced visible foliar injury on vegetation also show that visible foliar injury can occur under conditions where the annual 8-hour average O_3 concentrations are at or below the level of the current standard, as discussed here. Limited information exists regarding the incidence of visible foliar injury occurring in areas that have design values that meet the current 3-year average 8-hour standard.

To facilitate comparison with other studies reporting foliar injury response to W126 cumulative exposures, we obtained air quality data from the EPA's AQS database for monitors in each study location and calculated the 12-hr W126 index values and obtained the maximum 4th highest 8-hour average values for a subset of the most recent years included in each study (Table 5-7). As the shaded rows in Table 5-7 below show, in the years 2002/2003 and 2004 in the Cape Romain NWR in South Carolina, and the Seney NWR in Michigan, respectively, the 4th highest daily maximum 8-hour average O_3 concentrations were at or below the level of the current standard. We additionally note that the Cape Romain site met the current standard of 75 in every 3-year period during the study and has consistently met the standard from 2001 to 2012.[23] Under these air quality conditions, three species (i.e., winged sumac, Chinese tallow tree, and wild grape) exhibited O_3-induced stipple. In 2002, 32% of the examined wild grape plants, 20% of the winged sumac plants, and 4.6% of the Chinese tallow tree plants, respectively, were symptomatic (Davis, 2009). At the same time, the 12-hour W126 index value was 20 ppm-hrs. In 2003, when air quality was somewhat improved, foliar injury declined, with only 13.3% of wild grape showing O_3 stipple at a maximum 4th highest 8-hour of 74 ppb and a W126 index value of 11 ppm-hrs. The PDSI values were 0.27 and 2.45 in 2002 and 2003, respectively. These values show that 2003 was a wetter year than 2002, though 2002 would have been considered within the normal soil moisture range.

At the Seney NWR site, by comparison, the annual W126 level was similar in 2004 to that at Cape Romain in 2003, and the annual 8-hour average level was below that of the current standard, though the 3-year average design values were above that of the current standard for that year. Not surprisingly, given the lower O_3 air quality in 2004, the Seney study reported injury ranging from about 2% on common milkweed to about 6% on spreading dogbane. Though this study does not provide the PDSI values, the authors provided some discussion of a possible relationship stating that "the incidence of ozone injury on spreading dogbane, but not other species, was weakly, but not significantly, related to the drought index (PDSI)….However this relationship was too weak to be used for predictive purposes" (Davis, 2007b). The authors then conclude that "[n]evertheless, the threshold SUM06 ozone level needed to induce stipple on sensitive plants within the Seney refuge is likely 5000 ppb-hrs under the environmental conditions of these surveys" (Davis, 2007b). On the basis of the above, the staff concludes that these studies confirm that visible foliar injury has been shown to occur in the field at W126 index values ranging down to 10 ppm-hrs and provide limited evidence that such foliar injury

[23] Design values (concentrations in the form of the standard) for this monitoring site during this period are presented in the file available at: http://www.epa.gov/airtrends/values.html (US EPA, 2014d).

can occur in areas with special public welfare significance during periods that meet the current standard.

Table 5-7. Visible foliar injury incidence in four National Wildlife Refuges.

Name/ Site #/ Ref.[A]	Year[B]	4th highest daily maximum 8-hour average	12-hour W126	% Plants with visible injury
Cape Romain NWR, South Carolina / 450190046 (Davis, 2009)	2002	0.075 ppm	20 ppm-hrs	5 - 32
	2003	0.074 ppm	11 ppm-hrs	3 - 13
Moosehorn NWR, Maine/ 230090102 (Davis, 2007a)	2002	0.1 ppm	24 ppm-hrs	0 - 17
	2003	0.083 ppm	22 ppm-hrs	0 - 13
	2004	0.082 ppm	14 ppm-hrs	3 - 10
Seney NWR, Michigan/ 261530001 (Davis, 2007b)	2002	0.083 ppm	11 ppm-hrs	0 - 13
	2003	0.076 ppm	15 ppm-hrs	1 - 6
	2004	0.074 ppm	10 ppm-hrs	2 - 6
Brigantine NWR, New Jersey / 340010005/ (Davis and Orendovici, 2006)	2001	0.095 ppm	39 ppm-hrs	0 – 45
	2002	0.092 ppm	53 ppm-hrs	0 – 4
	2003	0.085 ppm	36 ppm-hrs	0 - 4

[A] Studies (cited above) reported exposures in terms of SUM06 form. EPA staff, using AQS data for the same monitors, calculated exposures in terms of the current 8-hour and W126 forms: http://www.epa.gov/ttn/airs/airsaqs/ (US EPA, 2014b)
[B] Only recent years with available W126 data were included in the table.

By far the most extensive field-based dataset of visible foliar injury incidence is that obtained by of the USFS FHM/FIA biomonitoring network program. A trend analysis of data from the sites located in the Northeast and North Central U.S. for the 16 year period (1994-2009) (Smith, 2012) provides additional evidence of foliar injury occurrence in the field as well as some insight into the influence of changes in air quality and soil moisture on visible foliar injury and the difficulty inherent in predicting foliar injury response under different air quality/soil moisture scenarios (Smith, 2012; U.S. EPA 2013, section 9.2.4.1). In this study ambient exposures were expressed in terms of the SUM06 cumulative index coupled with a measure of the number of peak hourly concentrations above 100 ppb (N100). Soil moisture estimates were generated using both the PDSI and the plant moisture availability index (MI). Foliar injury was expressed in terms of the biosite index (BI)[24]. The authors observed that over this 16-year

[24] Biosite index (BI) is the average score (proportion of leaves with injury ["amount"] x mean severity of symptoms on injured leaves ["severity"]) for each species averaged across all species on the biosite multiplied by 1,000.

period, "injury indices have fluctuated annually in response to seasonal ozone concentrations and site moisture conditions. Sites with and without injury occur at all ozone exposures but when ambient concentrations are relatively low, the percentage of uninjured sites is much greater than the percentage of injured sites; and regardless of ozone exposure, when drought conditions prevail, the percentage of uninjured sites is much greater than the percentage of injured sites" (Smith, 2012). The authors further note that while "both site moisture and ozone exposure play a role in foliar injury expression … the interplay among these three factors is unique for each year and possibly each site. Extreme moisture deficits decrease foliar injury, … [and] … [i]n no year do high ozone exposures override the controlling effect of site moisture, although at the other end of the scale, injury severity is minimized under conditions of low ozone exposure regardless of site moisture conditions. This implies a necessary threshold of ozone exposure for injury to occur…." "In a similar analysis, Rose and Coulston (2009) reported a high percentage of biosites with injury across the Southern region in 2003, a year when SUM06 values >10 ppm-h were widespread at the same time that the land area was in moisture surplus or balance." Thus, Rose and Coulston (2009) also "found evidence that it is the co-occurrence of sufficient moisture and elevated ozone that determine whether injury occurs to bioindicator plants, not ozone exposure alone." Regarding the role of peak O_3 concentrations (>100 ppb O_3), Smith (2012) reported that over the 16-year period concentrations above 100 ppb have declined, and that this "... may account for the observed decrease in the severity of ozone-induced foliar injury to ozone sensitive bioindicator plants in eastern forests." They also note that "[t]here is no compelling evidence, however, that moderate ozone concentrations, as reflected in seasonal mean SUM06 data, are on the decline" and "[t]his may explain why injury continues to be detected on many of the same sites every year" (Smith, 2012). The authors thus conclude that, "[a]lthough it is reasonable to remain concerned about long-term impacts of ozone pollution on our forest ecosystems, the findings of this biomonitoring survey point to a declining risk of probable impact on eastern forests over the 16-year period from 1994 to 2009" (Smith, 2012).

In a similar assessment of the USFS FHM/FIA data in the West, six years (2000 to 2005) of biomonitoring data for O_3 injury were evaluated for the three coastal states of California, Oregon and Washington (Campbell et al., 2007; U.S. EPA 2013, section 9.4.2.1). Campbell et al., 2007 found that "…ozone injury occurs frequently (25 to 37 percent of sampled biosites) in California forested ecosystems demonstrating that ozone is present at phytotoxic levels." This study concluded that, "in California, an estimated 1.3 million acres of forest land and 596 million cubic feet of wood are at moderate to high risk to impacts from ozone. However, [m]ore years of data are needed to discern any trends" (Campbell et al, 2007). Though this study does not discuss the role of soil moisture in describing the results, the criteria used to select the biomonitoring sites include one that considers soil conditions. The best sites are identified as

those with low drought potential and good fertility. Thus, given the relatively high O_3 concentrations that occur in California and the likelihood that many of the biomonitoring sites occur in areas that have sufficient soil moisture, the high percentage of sampled biosites with foliar injury is not unexpected.[25]

These recent studies continue to provide evidence of O_3-induced foliar injury occurring in many areas across the U.S. and augment our understanding of O_3-related visible foliar injury and of factors that influence associations between O_3 exposures or concentrations and visible foliar injury such as soil moisture.

- **To what extent does currently available evidence suggest locations where the vulnerability of sensitive species, ecosystems and/or their associated services to O_3-related visible foliar injury would have special significance to the public welfare?**

As mentioned above, federally designated Class I areas are afforded stringent protections under the 1977 amendments to the CAA. The CAA gives federal land managers of Class I areas "the responsibility to protect all air quality related values (AQRVs)…from deterioration…. In order to determine if deterioration is occurring, baseline AQRVs must be established" (Davis, 2009). Because of this need and the significance of these areas, studies often focus on these sites. For example, a study by Kohut (2007) was undertaken to assess the risks of O_3-induced visible foliar injury on O_3-sensitive vegetation in 244 parks managed by the NPS (U.S. EPA, 2013, pp. 9-40 to 9-41, U.S. EPA, 2014a, pp. 7-19 to 7-20). Kohut (2007) concluded that the risk of visible foliar injury was high in 65 parks (27 percent), moderate in 46 parks (19 percent), and low in 131 parks (54 percent). Thus, while this study suggests that there may be a reason for concern in as much as 46% of the parks, there were a number of important limitations associated with this study (described in footnotes 8 and 9 below) that weakened this conclusion. Given the importance of this kind of assessment, the WREA used Kohut (2007) as the conceptual basis for the subsequent WREA screening-level assessment, though numerous modifications were made to the approach to make it applicable to the context of this O_3 NAAQS review (see section 5.4.2 below).

In addition, as described above, several recently published studies (U.S. EPA 2013, section 9.4.2.1; Davis and Orendovici, 2006; Davis, 2007a,b; Davis, 2009, Kohut, 2007) were conducted in federally protected areas including federally designated Class I areas such as national parks. These studies confirm that visible foliar injury has been observed in these areas under annual air quality conditions with ambient concentrations at or below the level of the

[25] Staff additionally notes that a large proportion of O_3 monitoring sites in California did not meet the current standard during the study period (see: http://www.epa.gov/airtrends/values.html) (US EPA, 2014d).

current standard and at W126 index values within the CASAC range recommended in past reviews. This evidence continues to suggest that O_3-sensitive species and their associated ecosystems and services continue to remain vulnerable to visible foliar injury incidence in areas that have been afforded special protection by Congress and that have special significance to the public welfare.

5.4.2 Exposure- and Risk-based Considerations

The WREA presents a number of analyses considering air quality conditions associated with increased prevalence of visible foliar injury and potential associated welfare impacts (see Table 5-8 below, U.S. EPA, 2014a, Chapter 7). An initial analysis included the development of benchmark criteria reflecting different prevalence of visible foliar injury in conjunction with different W126 exposures and in some cases, soil moisture conditions. These criteria were then used in a screening-level assessment to characterize potential risk of foliar injury incidence under 2006-2010 conditions in 214 national parks. The last analysis was a case study assessment on three national parks, which also provides limited characterization of the associated ecosystem services. Despite the limitations and uncertainties associated with these analyses, and recognizing that the recent air quality conditions in most cases (prior to any model-based adjustment) did not meet the current standard, we believe that they help inform our understanding of the relationship between soil moisture and foliar injury incidence, as well as provide limited support for our conclusions regarding risk of visible foliar injury incidence under air quality conditions likely to meet the current standard in areas of special significance to the public welfare.

Table 5-8. Exposure, risk and ecosystem services analyses related to visible foliar injury.

	Ecosystem Level Effects	Ecosystem Services
WREA estimates	Proportion of FHM/FIA biosites with foliar injury incidence at various W126 index values and soil moisture levels Percent of 214 national parks exceeding various W126 benchmarks derived from FHM/FIA biosite analysis [A]	Case study of 3 national parks characterized impacts using available visitor and use data, including monetary data for activities and visitor expenditures: • Utilized Willingness-to-Pay studies for scenic impairment; • Assessed the overall cover of sensitive species; • Compared sensitive species cover to trails and overlooks; and, • Estimated percent of park area with O_3 concentrations above different W126 index values averaged over three consecutive years.
[A] The screening-level assessment of 214 national parks additionally included observations based on the model-based adjustments to just meet the current standard and targets for the three W126 scenarios (discussed below) but did not conduct a full analysis using these data.		

- **For what air quality scenarios were exposures and risks estimated? What approaches were used to estimate W126 exposures for those conditions? What are associated limitations and uncertainties?**

Three types of foliar injury analyses were performed in the WREA and are considered below. They include an analysis using USFS FHM/FIA biosite data, a screening-level assessment in 214 national parks, and case studies of three national parks. The analysis of USFS biosite data was done using O_3 concentrations estimated for a national-scale surface of concentrations (at a 12 x 12 km^2 grid cell resolution in contiguous U.S.) using interpolation methodology applied to concentrations at O_3 monitor locations (U.S. EPA, 2014a, section 4.3.2, Appendix 4A). The analysis of USFS FHM/FIA data and the screening-level analysis using W126 benchmarks derived from these data used surfaces for each year from 2006 through 2010 (U.S. EPA, 2014a, Appendix 4A, section 4.2). In the National Park case study analyses, observations related to air quality were made for five air quality scenarios by the methodology summarized in Table 5-4 above.[26]

The W126 index values in the individual years from 2006 to 2010 at monitors ranged from less than 5 ppm-hrs up to above 48 ppm-hrs (U.S. EPA, 2014a, Figure 4-4 and Table 4-3).

[26] In general, this methodology involved two steps. The first is derivation of the average W126 value (across the three years) at each monitor location. This value is based on unadjusted data for recent conditions and adjusted concentrations for the 4 other scenarios. The development of adjusted concentrations was done for each of 9 regions independently (see U.S. EPA, 2014a, section 4.3.4.1). In the second step, national-scale spatial surfaces (W126 values for each model grid cell) were created using the monitor-location values and the VNA spatial interpolation technique (details on the VNA technique are presented in U.S. EPA, 2014a Appendix 4A).

Concentration estimates varied appreciably across the five years with the median index values across grid cells ranging from a low of 5.5 ppm-hrs in 2009 up to 11 ppm-hrs in 2006 (U.S. EPA, 2014a, Appendix 4A, section 4.2). During the recent conditions period (2006 through 2008), the average W126 index values (across the three-year recent conditions period) at the monitor locations ranged from below 10 ppm-hrs to 48.6 ppm-hrs (U.S. EPA 2014a, Figure 4-4 and Table 4-3). After adjusting the 2006-2008 data to just meet the current standard in each region, and subsequent application of the VNA technique to the current standard scenario monitor location values, the average W126 index values were below 15 ppm-hrs across the national surface with the exception of a very small area of the southwest region (near Phoenix) where the average W126 index values was near or just above 15 ppm-hrs. A lowering of the highest values occurred with application of the interpolation method as a result of estimating W126 index values at a 12 x 12 km^2 grid resolution rather that at the exact location of a monitor. This indicates one uncertainty associated with this aspect of the approach to estimating W126 index values for the adjusted air quality just meeting the current standard. Other uncertainties are summarized in section 5.2.2 above.

- **What are the nature and magnitude of the cumulative exposure- and risk-related estimates for visible foliar injury under recent conditions or conditions meeting the current O_3 standard?**

As an initial matter, we consider the analysis of the biomonitoring site data from the USFS FHM/FIA Network, described in section 7.2 of the WREA.[27] Using this dataset and associated data for soil moisture during the sample years along with ambient air O_3 concentrations based on monitoring data from 2006 to 2010 and spatial interpolation methodology (as described above), the proportion of biosites with any foliar injury are observed to increase with increasing annual W126 index values up to specific values after which there is little change in proportion of affected biosites with higher W126 index values (see Figure 5-5 below; U.S. EPA, 2014a, section 7.2, Figure 7-10). The proportion of biosites metric is derived by first ordering the data (across biosites and sample years) by W126 index value estimated for that biosite and year. Then for each W126 index value the proportion of biosites exceeding the selected biosite index value for all observations at or below that W126 index value is calculated. The WREA repeated this using a biosite index value greater than zero, indicating presence of any foliar injury (USFS, 2011).

When looking only at presence or absence of foliar injury ("any injury") with the exception of 2008, the proportion of biosites across all W126 index values with foliar injury

[27] Data were not available for several western states (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, Oklahoma, and portions of Texas).

exceeds 15 percent; in 2006, it exceeds 20 percent, while in 2008 the proportion of biosites with foliar injury across all W126 index values was just below 15 percent (U.S. EPA, 2014a, section 7.2.3, Figure 7-9). When categorized by moisture levels, the data demonstrate a distinct pattern. In general, the WREA concludes that the results of these foliar injury analyses demonstrate a similar pattern –the proportion of biosites showing the presence of any foliar injury (biosite index >0) increases from zero to about 20% (Figure 5-5 below). This increase occurs with increasing W126 index values up to approximately 10 ppm-hrs for any foliar injury (biosite index >0), with little change in proportion of biosites with any injury at higher W126 index values. The data for biosites during normal moisture years are very similar to the dataset as a whole, with an overall proportion of close to 18 percent for presence of any foliar injury. Among the biosites with a relatively wet season (average Palmer Z => 1), the proportion of biosites showing injury is much higher and the relationship with annual W126 index value is much steeper. Much lower proportions of biosites are reached for the any injury category at biosites with relatively dry seasons (average Palmer Z < -1.24), potentially indicating that drought may provide some protection from foliar injury as discussed in the ISA (U.S. EPA, 2014a, section 7.2.3, Figures 7-10). This information provides insight into the relationship between soil moisture and foliar injury and the issue of whether drought provides protection from foliar injury. Thus, there is relatively little change in the proportion of biosites beyond a W126 index value of 10 ppm-hrs. There are two important observations that can be made from these analyses: (1) the proportion of biosites exhibiting foliar injury rises rapidly at increasing W126 index values below approximately 10 ppm-hrs, and (2) there is relatively little change in the proportions above W126 index values of approximately 10 ppm-hrs.

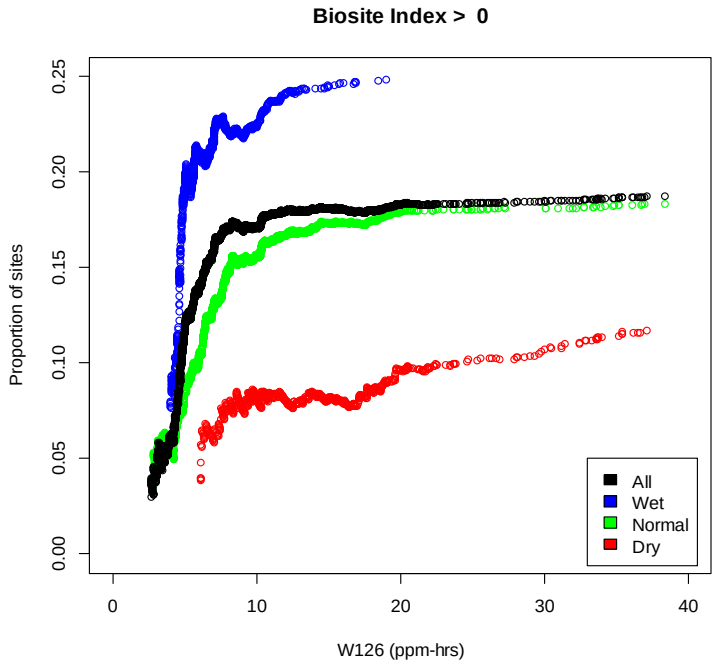


Figure 5-5. Cumulative proportion of biosites with any foliar injury present, by moisture category (U.S. EPA 2014a, Figure 7-10).

We additionally consider the WREA screening-level assessment in 214 parks in the contiguous U.S. that employed benchmark criteria developed from the above analysis (Table 5-9).[28],[29] For example, annual O_3 concentrations corresponding to a W126 index value of 10.46 ppm-hrs represents the O_3 exposure concentration where the slope of exposure-response relationship changes for FHM biosites. The WREA refers to this as the "base scenario" benchmark. Above this index value, the percentage of FHM biosites showing foliar injury remains relatively constant. The W126 benchmarks across the five scenarios range from 3.05 ppm-hrs (five percent of biosites, normal moisture, any injury) up to 24.61 ppm-hrs (10% of biosites, dry, any injury). For the scenario of 10% biosites with injury, W126 index values were approximately 4, 6, and 25 ppm-hours for wet, normal and dry years, respectively. The national-

[28] The parks assessed here include lands managed by the NPS in the continental U.S., which includes National Parks, Monuments, Seashores, Scenic Rivers, Historic Parks, Battlefields, Reservations, Recreation Areas, Memorials, Parkways, Military Parks, Preserves, and Scenic Trails.

[29] The WREA applied different foliar injury benchmarks in this assessment after further investigation into the benchmarks applied in Kohut (2007), which were derived from biomass loss rather than visible foliar injury. Kohut cited a threshold of 5.9 ppm-hrs for highly sensitive species from Lefohn et al. (1997), which was based on the lowest W126 estimate corresponding to a 10% growth loss for black cherry. For soil moisture, Kohut (2007) qualitatively assessed whether there appeared to be an inverse relationship between soil moisture and high O_3 exposure.

scale screening-level assessment includes 42 parks with O_3 monitors and a total of 214 parks with O_3 exposure estimated from the interpolated O_3 surface for individual years from 2006 to 2010 (U.S. EPA, 2014a, Appendix 7A). These data were combined with lists from the NPS of the parks containing O_3-sensitive vegetation species (NPS, 2003, 2006). Based on NPS lists, 95 percent of the parks in this assessment contain at least one O_3-sensitive species. This analysis for recent air quality conditions, estimates that 58 percent of parks exceeded the benchmark criteria corresponding to the base scenario (W126>10.46 ppm-hrs, 17.7 percent of biosites, all moisture categories, any injury) for at least three years in the period from 2006 to 2010 (U.S. EPA, 2014a, section 7.3.2). Based on model-based adjustments to meet the current standard, none of the 214 parks have average W126 index values that would exceed the annual benchmark criteria for the base scenario (W126 >10.46 ppm-hrs) (U.S. EPA, 2014a, section 7.3.3.3).

Table 5-9. Benchmark criteria for O_3 exposure and relative soil moisture used in screening-level assessment of parks (from U.S. EPA 2014a, Table 7-6).

Scenario	Description	W126 Benchmark (in ppm-hrs)		
		Wet (Palmer Z ≥1)	**Normal Moisture** (Palmer Z between -1.25 and 1)	**Dry** (Palmer Z < -1.25)
Base	17.7% of all FHM biosites showed any injury (higher W126 index values have a relatively constant percentage of FHM biosites showing injury)	10.46 (soil moisture not considered)		
5% of biosites	5% of FHM biosites showed any injury, reflects soil moisture categorization	3.76	3.05	6.16
10% of biosites	10% of FHM biosites showed any injury, reflects soil moisture categorization	4.42	5.94	24.61
15% of biosites	15% of FHM biosites showed any injury, reflects soil moisture categorization	4.69	8.18	N/A
20% of biosites	20% of FHM biosites showed any injury, reflects soil moisture categorization	5.65	N/A	N/A

Lastly, we consider the WREA case study analysis that focused on characterizing the ecosystem services potentially associated with visible foliar injury in three specific national parks (case study assessment). The parks included were Great Smoky Mountains National Park (GRSM), Rocky Mountain National Park (ROMO), and Sequoia/Kings National Parks (SEKI). For each park, the potential impact of O_3-related foliar injury on recreation (cultural services) was considered in light of information on visitation patterns, recreational activities and visitor expenditures. For example, visitor spending in 2011 exceeded $800 million, $170 million and

$97 million dollars in GRSM, ROMO and SEKI, respectively. This assessment also included percent cover of species sensitive to foliar injury and focused on the overlap between recreation areas within the park and elevated W126 concentrations. Ozone concentrations in GRSM have been among the highest in the eastern U.S. In the recent conditions scenario, the grid cells representing 44 percent of GRSM had three year average W126 index value above 15 ppm-hrs. After adjustments to just meet the current standard, no grid cell had a three-year average W126 index value above 7 ppm-hrs. In the recent conditions scenario for ROMO, three-year average W126 index values for all grid cells were above 15 ppm-hrs. In the current standard scenario, values for 59 percent of the park were below 7 ppm-hrs. For SEKI, three-year average W126 index values for all grid cells were above 15 ppm-hrs in the recent conditions scenario, but dropped below 7 ppm-hrs for the current standard scenario (U.S. EPA, 2014a, section 7.4).

In summary, these analyses indicate that O_3 concentrations in U.S. national parks in recent years correspond to W126 index values at which some foliar injury may occur, with variation associated with relative soil moisture conditions. None of the 214 parks assessed are estimated to exceed the annual benchmark criteria for the base scenario (W126 >10.46 ppm-hrs) after adjusting air quality to meet the current standard. Although adjusted scenarios to just meet the current standard indicate substantial reductions in three-year average W126 index values estimated by the VNA approach, some individual year values may range higher. The case study analysis of three parks indicates the potential for appreciable ecosystem services impact associated with foliar injury. While these analyses indicate the potential for foliar injury to occur under conditions that meet the current standard, the extent of foliar injury that might be expected under such conditions is unclear from these analyses.

- **To what extent are the exposures and risks remaining upon simulating just meeting the current O_3 standard important from a public welfare perspective?**

The screening level assessment, as described above, indicates that risk of visible foliar injury is likely to be lower in most national parks after simulating just meeting the current standard. Based on the national-scale analysis, visible foliar injury would likely continue to occur at lower O_3 exposures, including some sensitive species growing in areas (e.g., National Parks and other Class I areas) that may provide important cultural ecosystem services to the public. Staff notes that such occurrences might reasonably be considered to have some importance from a public welfare perspective, as discussed in section 5.1 above.

- **What are the ecosystem services potentially affected by visible foliar injury, to what degree can the magnitude of these effects be qualitatively or quantitatively characterized, and to what extent are they important from a public welfare perspective?**

The ecosystem services most likely to be affected by O_3-induced foliar injury are cultural services, including aesthetic value and outdoor recreation. Aesthetic value and outdoor recreation depend on the perceived scenic beauty of the environment. Many outdoor recreation activities directly depend on the scenic value of the area, in particular scenic viewing, wildlife-watching, hiking, and camping. These activities and services are of significant importance to public welfare as they are enjoyed by millions of Americans every year and generate millions of dollars in economic value (U.S. EPA, 2014a, Chapter 5, Chapter 7). These aesthetic values are at risk of impairment because of O_3-induced damage directly due to foliar injury. Other ecosystem services that have also been found to be associated with O_3-sensitive plants include those that fall under the categories of provisioning. For example, several tribes have indicated that many of the known confirmed O_3-sensitive species (including bioindicator species) are culturally significant (see Appendix 5-A). Although data are not available to explicitly quantify these negative effects on ecosystem services, several qualitative analyses conducted in the WREA are summarized below.

To assess the effects of visible foliar injury on recreation, the WREA reviewed the NSRE, as well as the 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (FHWAR) and a 2006 analysis done for the Outdoor Industry Foundation (OIF). According to the NSRE, some of the most popular outdoor activities are walking, including day hiking and backpacking; camping; bird watching; wildlife watching; and nature viewing. Participant satisfaction with these activities can depend on the quality of the natural scenery, which can be adversely affected by O_3-related visible foliar injury. According to the FHWAR and the OIF reports, the total expenditures across wildlife watching activities, trail-based activities, and camp-based activities are approximately $230 billion dollars annually. While the WREA could not quantify the magnitude of the impacts of O_3 damage to the scenic beauty and outdoor recreation, the existing losses associated with current O_3-related foliar injury are reflected in reduced outdoor recreation expenditures (U.S. EPA, 2014a, section 7.1).

The WREA also assessed O_3 impacts on cultural ecosystem services related to foliar injury at three national parks – Great Smoky Mountains National Park, Rocky Mountain National Park, and Sequoia/Kings National Parks - by considering information on visitation patterns, recreational activities and visitor expenditures. The analysis included percent cover of species sensitive to foliar injury and focused on the overlap between recreation areas within the park and elevated W126 concentrations. All three of these park units are in areas that are known

to have high ambient O_3 concentrations, have vegetation maps, and have species that are considered O_3-sensitive. Using GIS, the NPS vegetation maps were compared to the national O_3 surface to illustrate where foliar injury may be occurring, particularly with respect to park amenities such as trails (U.S. EPA, 2014a, section 7.4).

Great Smoky Mountains National Park is prized, in part, for its rich species diversity. The large mix of species includes 37 O_3-sensitive species and many areas contain several sensitive species. With 3.8 million hikers using the trails every year and hikers' WTP over $266 million for that activity, even a small benefit of reducing O_3 damage in the park could result in a significant economic value. Ozone concentrations in Great Smoky Mountains National Park have been among the highest in the eastern U.S. – at times twice as high as neighboring cities such as Atlanta (U.S. EPA, 2014a, p. 7-52). Unlike Great Smoky Mountains National Park, sensitive species cover in Rocky Mountain National Park is driven by a few O_3-sensitive species (7 species) and most notably by Quaking Aspen. This is significant in that many of the visitors to Rocky Mountain National Park visit specifically to see this tree in its fall foliage. Given 1.5 million hikers in Rocky Mountain National Park and their $70 million WTP for the hiking experience, even a small improvement in the scenic value could be economically significant (U.S. EPA, 2014a, section 7.4.2, p. 7-56). Sequoia/Kings National Parks is home to 12 identified sensitive species. Again, although the EPA is not able to quantify the impact of this scenic damage on hiker satisfaction for hikers in Sequoia/Kings National Parks and their $26 million WTP for the experience, even a small improvement in the scenic value could be economically significant ((U.S. EPA, 2014a, section 7.4.3, p. 7-63).

- **What are the uncertainties associated with this information and what is the level of confidence associated with those estimates?**

Uncertainties associated with these analyses are discussed in the WREA, sections 7.5 and 8.5.3, and in WREA Table 7-24. As discussed in the WREA (section 8.5.3), evaluating soil moisture is more subjective than evaluating O_3 exposure because of its high spatial and temporal variability within the O_3 season, and there is considerable subjectivity in the categorization of relative drought. The WREA generally concludes that the spatial and temporal resolution for the soil moisture data is likely to underestimate the potential of foliar injury that could occur in some areas. In addition, there is lack of a clear threshold for drought below which visible foliar injury would not occur. In general, low soil moisture reduces the potential for foliar injury, but injury could still occur, and the degree of drought necessary to reduce potential injury is not clear. Due to the absence of biosite injury data in the Southwest region and limited biosite data in the West and West North Central regions, the benchmarks applied may not be applicable to these regions. The WREA applied the benchmarks from the national-scale analysis to a screening-level analysis

of 214 national parks and case studies of three national parks. Therefore, uncertainties in the foliar injury benchmarks are propagated into the national park analyses.

There are also important uncertainties in the estimated O_3 concentrations for the different air quality scenarios evaluated (U.S. EPA, 2014a, section 8.5), as discussed earlier in this section. These uncertainties only apply to the national park case studies because these are the only foliar injury analyses that rely on the air quality scenarios, but any uncertainties in the air quality analyses are propagated into the those analyses. Additional uncertainties are associated with the national park case studies. Specifically, there is uncertainty inherent in survey estimates of participation rates, visitor spending/economic impacts, and willingness-to-pay. These surveys potentially double-count impacts based on the allocation of expenditures across activities but also potentially exclude other activities with economic value. In general, the national level surveys apply standard approaches, which minimize potential bias. Other sources of uncertainty are associated with the mapping, including park boundaries, vegetation species cover, and park amenities, such as scenic overlooks and trails. In general, the WREA concludes that there is high confidence in the park mapping (U.S. EPA, 2014, Table 7-24).

5.5 OTHER WELFARE EFFECTS

In addition to the welfare effects discussed in the previous sections, there is evidence of other O_3 effects, such as those related to climate impacts that we consider here. In this section, the WREA national-scale analyses of the effects of insect damage to forests related to elevated O_3 exposures are considered in section 5.5.1, and a case study-scale characterization of the effect community composition changes on forest susceptibility and fire regulation in California is considered in section 5.5.2. As above, these sections, where possible, consider the WREA information regarding risk remaining under adjusted conditions just meeting the current standard and associated uncertainties (U.S. EPA 2014a, section 8.5). Chapters 5, 6, and 7 of the WREA also qualitatively assessed additional ecosystem services, including regulating services such as hydrologic cycle and pollination; provisioning services such as commercial non-timber forest products; and cultural services with aesthetic and non-use values. The information associated with these latter effects is insufficient to inform the target protection of the standard. The effects of O_3 on climate are also considered in section 5.5.3 below, drawing primarily on the evidence presented in the ISA (U.S. EPA 2013, chapter 10).

5.5.1 Forest Susceptibility to Insect Infestation

Ozone in ambient air can contribute to increased susceptibility of some forests to infestation by some chewing insects, including the southern pine beetle and western bark beetle (U.S. EPA 2013, chapter 9; U.S. EPA 2014a, sections 5.3.3 and 5.4). These infestations can

cause economically significant damage to tree stands and the associated timber production. The WREA described the potential impacts of this effect on timber markets (U.S. EPA 2014a, section 5.4). In the short-term, the immediate increase in timber supply that results from the additional harvesting of damaged timber depresses prices for timber and benefits consumers. In the longer-term, the decrease in timber available for harvest raises timber prices, potentially benefitting producers. The USFS reports timber producers have incurred losses of about $1.4 billion (2010$), and wood-using firms have gained about $966 million, due to beetle outbreaks between 1977 and 2004. It is not possible to attribute a portion of these impacts resulting from the effect of O_3 on trees' susceptibility to insect attack; however, the losses are embedded in the estimates cited and any welfare gains from decreased O_3 would positively impact the net economic impact. However, it is important to note that CASAC clarified that spatial association is not causation, even though expert opinion relates O_3-exposure to bark beetle infestation (Frey, 2014, p. 12).

To provide some quantitative estimates related to insect infestation-related risks, the WREA reported the estimates of 3-year average W126 index values in areas estimated to be at risk of greater than 25% timber loss (high loss) due to pine beetle infestation. This was done for all six WREA air quality scenarios. For example, for the recent conditions scenario, approximately 57 percent of the at-risk area has W126 estimates above 15 ppm-hrs, with the percentage dropping to approximately five percent in the current standard scenario (U.S. EPA 2014a, section 5.4).

5.5.2 Fire Regulation

Evidence indicates that fire regime regulation may also be negatively affected by O_3 exposure (U.S. EPA 2013, chapter 9; U.S. EPA 2014a, section 5.3.3). For example, Grulke et al. (2008) reported various lines of evidence indicating that O_3 exposure may contribute to southern California forest susceptibility to wildfires by increasing leaf turnover rates and litter, increasing fuel loads on the forest floor. According to the National Interagency Fire Center, in the U.S. in 2010 over 3 million acres burned in wildland fires and an additional 2 million acres were burned in prescribed fires. From 2004 to 2008, Southern California alone experienced, on average, over 4,000 fires per year burning, on average, over 400,000 acres per fire. The California Department of Forestry and Fire Protection (CAL FIRE) estimated that losses to homes due to wildfire were over $250 million in 2007 (CAL FIRE, 2008). In 2008, CAL FIRE's costs for fire suppression activities were nearly $300 million (CAL FIRE, 2008).

The WREA developed maps that overlay the mixed conifer forest area of California with areas of moderate or high fire risk defined by CAL FIRE and with recent W126 concentrations

and surfaces adjusted to just meet existing and alternative standards. The highest fire risk and highest O_3 concentrations overlap with each other, as well as with significant portions of mixed conifer forest. In the recent concentrations scenario, over 97 percent of mixed conifer forest area has average W126 index values over 7 ppm-hrs with a moderate to severe fire risk, and 74 percent has average W126 index values over 15 ppm-hrs with a moderate to severe fire risk. The scenario for air quality adjusted to just meet the current standard, almost all of the mixed conifer forest area with a moderate to high fire risk shows a reduction in O_3 to below a W126 index value of 7 ppm-hrs (average across three years of scenario). In the scenario for an average W126 index value of 15 ppm-hrs, all but 0.18 percent of the area has average index values below 7 ppm-hrs, and for the W126 scenarios of 11 and 7 ppm-hrs, all of the moderate to high fire threat area has estimated average W126 index values below 7 ppm-hrs (U.S. EPA 2014a, section 5.3.3, Figure 5-3). However, it is important to note that CASAC clarified that spatial association is not causation, but expert opinion relates O_3-exposure to fire risk (Frey, 2014, p. 12).

5.5.3 Ozone Effects on Climate

Tropospheric O_3 is a major greenhouse gas, third in importance after carbon dioxide (CO_2) and methane (CH_4). While the developed world has successfully reduced emissions of O_3 precursors in recent decades, many developing countries have experienced large increases in precursor emissions and these trends are expected to continue, at least in the near term (U.S. EPA 2013, section 10.3.6.2). Projections of radiative forcing due to changing O_3 over the 21st century show wide variation, due in large part to the uncertainty of future emissions of source gases (U.S. EPA 2013, section 10.3.6.2). In the near-term (2000-2030), projections of O_3 radiative forcing range from near zero to +0.3 W/m^2, depending on the emissions scenario (U.S. EPA 2013, section 10.3.6.2; Stevenson et al., 2006). Reduction of tropospheric O_3 concentrations could therefore provide an important means to slow climate change in addition to the added benefit of improving surface air quality (U.S. EPA, 2013, section 10.5).

It is clear that increases in tropospheric O_3 lead to warming. However the precursors of O_3 also have competing effects on the greenhouse gas CH_4, complicating emissions reduction strategies. A decrease in CO or VOC emissions would enhance OH concentrations, shortening the lifetime of CH_4, while a decrease in NO_X emissions could depress OH concentrations in certain regions and lengthen the CH_4 lifetime (U.S. EPA, 2013, section 10.5).

Abatement of CH_4 emissions would likely provide the most straightforward means to address O_3-related climate change since CH_4 is itself an important precursor of background O_3 (West et al., 2007; West et al., 2006; Fiore et al., 2002). A set of global abatement measures identified by West and Fiore (2005) could reduce CH_4 emissions by 10% at a cost savings, decrease background O_3 by about 1 ppb in the Northern Hemisphere summer, and lead to a

global net cooling of 0.12 W/m^2. West et al. (2007) explored further the benefits of CH_4 abatement, finding that a 20% reduction in global CH_4 emissions would lead to greater cooling per unit reduction in surface O_3, compared to 20% reductions in VOCs or CO (U.S. EPA, 2013, section 10.5).

Important uncertainties remain regarding the effect of tropospheric O_3 on future climate change. To address these uncertainties, further research is needed to: (1) improve knowledge of the natural atmosphere; (2) interpret observed trends of O_3 in the free troposphere and remote regions; (3) improve understanding of the CH_4 budget, especially emissions from wetlands and agricultural sources, (4) understand the relationship between regional O_3 radiative forcing and regional climate change; and (5) determine the optimal mix of emissions reductions that would act to limit future climate change (U.S. EPA, 2013, section 10.5).

The IPCC has estimated the effect of the tropospheric O_3 change since preindustrial times on climate to be about 25-40% of the anthropogenic CO_2 effect and about 75% of the anthropogenic CH_4 effect (IPCC, 2007). There are large uncertainties in the radiative forcing estimate attributed to tropospheric O_3, making the effect of tropospheric O_3 on climate more uncertain than the effect of the long-lived greenhouse gases (U.S. EPA, 2013, section 10.5).

Radiative forcing does not take into account the climate feedbacks that could amplify or dampen the actual surface temperature response. Quantifying the change in surface temperature requires a complex climate simulation in which all important feedbacks and interactions are accounted for. As these processes are not well understood or easily modeled, the surface temperature response to a given radiative forcing is highly uncertain and can vary greatly among models and from region to region within the same model (U.S. EPA, 2013, section 10.5).

As discussed in section 5.2 above, O_3 exposure is associated with reduced forest tree growth, productivity, and carbon storage. Therefore, reducing O_3 exposure would potentially increase carbon storage in O_3-sensitive trees, which could also have climate effects.

5.5.4 Additional Effects

Recent information available since the last review considers the effects of O_3 on chemical signaling in insect and wildlife interactions. Specifically, studies on O_3 effects on pollination and seed dispersal, defenses against herbivory and predator-prey interactions all consider the ability of O_3 to alter the chemical signature of VOCs emitted during these pheromone-mediated events. The effects of O_3 on chemical signaling between plants, herbivores and pollinators as well as interactions between multiple trophic levels is an emerging area of study that may result in further elucidation of O_3 effects at the species, community and ecosystem-level (U.S. EPA, 2013, p. 9-98).

5.6 CASAC ADVICE

This section discusses CASAC advice regarding the adequacy of the existing secondary standard with respect to the 2008 review, the 2010 reconsideration of the 2008 review, and most recently its advice in this review, initiated in September 2008, in its letter to the Administrator on the second draft WREA and PA. To give an overview, following the 2008 decision to revise the secondary standard by setting it identical to the revised primary standard, CASAC conveyed additional advice to the Administrator regarding that decision. Shortly after that, several petitioners filed suit challenging the decision and in September 2009, the EPA announced its intention to reconsider the 2008 standards, issuing a notice of proposed rulemaking in January 2010 (75 FR 2938). Soon after, the EPA solicited CASAC review of that proposed rule and in January 2011 solicited additional advice. This proposal was based on the scientific and technical record from the 2008 rulemaking, including public comments and CASAC advice and recommendations. As further described in section 1.2.2 above, the EPA in the fall of 2011 did not promulgate final rulemaking in that process but decided to coordinate further proceedings on the reconsideration rulemaking with this ongoing periodic review.

More specifically, in April 2008, the members of the CASAC Ozone Review Panel sent a letter to EPA stating that "[i]n our most-recent letters to you on this subject - dated October 2006 and March 2007 - … the Committee recommended an alternative secondary standard of cumulative form that is substantially different from the primary Ozone NAAQS in averaging time, level and form — specifically, the W126 index within the range of 7 to 15 ppm-hours, accumulated over at least the 12 'daylight' hours and the three maximum ozone months of the summer growing season" (Henderson, 2008). The letter continued:

> *The CASAC now wishes to convey, by means of this letter, its additional, unsolicited advice with regard to the primary and secondary Ozone NAAQS. In doing so, the participating members of the CASAC Ozone Review Panel are unanimous in strongly urging you or your successor as EPA Administrator to ensure that these recommendations be considered during the next review cycle for the Ozone NAAQS that will begin next year … The CASAC was also greatly disappointed that you failed to change the form of the secondary standard to make it different from the primary standard. As stated in the preamble to the Final Rule, even in the previous 1996 ozone review, "there was general agreement between the EPA staff, CASAC, and the Administrator, … that a cumulative, seasonal form was more biologically relevant than the previous 1-hour and new 8-hour average forms (61 FR 65716)" for the secondary standard.....Unfortunately, this scientifically-sound approach of using a cumulative exposure index for welfare effects was not adopted…*

In response to the EPA's solicitation of their advice on the Agency's proposed rulemaking as part of the reconsideration, CASAC conveyed their support for the proposed approach as follows (Samet, 2010).

> *CASAC also supports EPA's secondary ozone standard as proposed: a new cumulative, seasonal standard expressed as an annual index of the sum of weighted hourly concentrations (i.e., the W126 form), cumulated over 12 hours per day (8am to 8pm) during the consecutive 3-month period within the ozone season with the maximum index value, set as a level within the range of 7 to [1]5 ppm-hours. This W126 metric can be supported as an appropriate option for relating ozone exposure to vegetation responses, such as visible foliar injury and reductions in plant growth. We found the Agency's reasoning, as stated in the Federal Register notice of January 19, 2010, to be supported by the extensive scientific evidence considered in the last review cycle. In choosing the W126 form for the secondary standard, the Agency acknowledges the distinction between the effects of acute exposures to ozone on human health and the effects of chronic ozone exposures on welfare, namely that vegetation effects are more dependent on the cumulative exposure to, and uptake of, ozone over the course of the entire growing season (defined to be a minimum of at least three months).*

In its advice offered early in the current review, based on the updated scientific and technical record since the 2008 rulemaking, CASAC indicated that a conclusion that the current standard is inadequate to protect vegetation and ecosystems is "warranted" although it stated that the foundation needs to be broadened beyond analysis focused on Class I areas and trees to include "effects on sensitive crops, trees in regions outside of Class I areas, and additional ecosystem impacts" (Frey and Samet, 2012, p. 2). The Panel additionally endorsed the first draft PA discussions and conclusions on biologically relevant exposure metrics, stating that "the focus on the W126 form is appropriate" and that "there is a strong justification made for using a cumulative and weighted exposure standard for welfare effects (i.e., the W126)…" (Frey and Samet, 2012, p. 2).

In its letter dated June 26, 2014, CASAC again concluded that "the current secondary standard is not adequate to protect against current and anticipated welfare effects of ozone on vegetation..." (Frey, 2014, p. iii) and that "the form of the standard should be changed from the current 8-hour form to the cumulative W126 index and... that the discussion provides an appropriate and sufficient rationale" (Frey, 2014, p. 12). CASAC then further states that

> "[t]hus, based on identification of known or anticipated ozone effects that are adverse to public welfare, taking into account the weight of evidence for causality of exposure to ozone and adverse welfare effects as given in Table 2-4 of the *Integrated Science Assessment*; results of the Second Draft WREA with regard to assessment of relative

biomass loss for tree species, foliar injury, and crop yield loss; and the breadth of adverse welfare effects for ecosystem services, foliar injury, and crop loss, the CASAC recommends that the secondary standard for ozone be revised as follows: (1) ozone should be the indicator; (2) the form and summation time of the standard should be the W126 index summed over the highest three-month interval during a year, based on accumulation over the 08:00 a.m. – 08:00 p.m. daytime 12-hour period; and (3) the level of the standard should be between 7 ppm-hrs and 15 ppm-hrs. These recommendations are based on scientific evidence of adverse effect associated with the presence of ozone in ambient air. Note that these levels are based on an annual form of the standard." (Frey, 2014, p. 15).

With respect to the averaging time, CASAC additionally states that it "does not recommend the use of a three-year averaging period. We favor a single-year averaging period, which will provide more protection for annual crops and for the anticipated cumulative effects on perennial species. The scientific analyses considered in this review, and the evidence upon which they are based, are from single-year results. If a 3-year averaging period is established, then the upper limit will need to be reduced to protect against one-year ozone peaks" (Frey, 2014, p. 13).

5.7 STAFF CONCLUSIONS ON ADEQUACY OF SECONDARY STANDARD

This section presents staff conclusions for the Administrator to consider in deciding whether the existing secondary O_3 standard is adequate and whether it should be retained or revised. Our conclusions are based on consideration of the assessment and integrative synthesis of information presented in the ISA, as well as our analyses of air quality distributions; analyses in the WREA; and the comments and advice of CASAC and public comment on earlier drafts of this document and on the ISA and WREA, as discussed above. Taking into consideration the responses to specific questions discussed above, we revisit the overarching policy question for this chapter:

- **Does the currently available scientific evidence and exposure/risk information, as reflected in the ISA and WREA, support or call into question the adequacy and/or appropriateness of the protection afforded by the current secondary O_3 standard?**

As an initial matter, we note that the CAA does not require that a secondary standard be protective of all effects associated with a pollutant in the ambient air, but only those considered adverse to the public welfare (as described in section 1.3.2 above). In helping inform the Administrator's judgments with respect to the adversity of the effects to public welfare, we have considered the scientific evidence and risk/exposure information in light of the paradigm used in the last review that takes into account the variation in public welfare significance of O_3-related

vegetation effects when evaluating the potential adversity of the currently available evidence. As discussed in Section 5.1, this paradigm recognized that the significance to the public welfare of O_3-induced effects on sensitive vegetation growing within the U.S. can vary depending on the nature of the effect, the intended use of the sensitive plants or ecosystems, and the types of environments in which the sensitive vegetation and ecosystems are located. Accordingly, any given O_3-related effect on vegetation and ecosystems (e.g., biomass loss, crop yield loss, visible foliar injury) may be judged to have a different degree of impact on the public welfare depending, for example, on whether that effect occurs in a Class I area, a city park, or commercial cropland. In the 2010 proposed reconsideration, the Administrator proposed to place the highest priority and significance on vegetation and ecosystem effects to sensitive species that are known to or are likely to occur in federally protected areas such as national parks and other Class I areas, or on lands set aside by states, tribes and public interest groups to provide similar benefits to the public welfare (75 FR 3023/24), recognizing that effects occurring in such areas would likely have the highest potential for being classified as adverse to the public welfare, due to the expectation that these areas need to be maintained in a more pristine condition to ensure their intended use is met.

In addition, there is also sufficient support to explicitly include consideration of impacts to ecosystem goods and services. Although ecosystem services were not explicitly considered in the Administrator's decision in the last review, they were recognized as an important category of public welfare effects (73 FR 16492). The CASAC letter also provides support for this approach. The inclusion of ecosystem goods and services in this paradigm brings with it a number of additional considerations. Specifically, when considering the public welfare benefits from these goods and services, it is important to note that they can accrue across a range of dimensions, including spatial, temporal, and social, and these likely will vary depending on the type of effect being characterized. For example, ecosystems can cover a range of spatial scales, and the services they provide can accrue locally or be distributed more broadly such as when crops are sold and eaten locally and/or also sold in regional, national and world markets. Ecosystem services can likewise be realized over a range of temporal scales from immediate up to long term (e.g., the removal of air pollutants that have a short-term impact on human health but are also climate forcers with long atmospheric lifetimes, which the removal of may have immediate as well as long-term benefits). The size of the societal unit receiving benefits from ecosystem services can also vary dramatically. For example, a national park can provide direct recreational services to the thousands of visitors that come each year, but also provide an indirect value to the millions who may not visit but receive satisfaction from knowing it exists and is preserved for the future (U.S. EPA, 2014a, chapter 5, section 5.5.1).

We thus recognize the usefulness of evaluating the scientific evidence regarding these effects in the context of the most recent paradigm discussed above. This paradigm integrates the concepts of: 1) variability in public welfare significance given intended use and value of the affected entity, such as individual species; 2) relevance of associated ecosystem services to public welfare; and 3) variability in spatial, temporal, and social distribution of ecosystem services associated with known and anticipated welfare effects. In so doing, we recognize that there is no bright-line rule delineating the set of conditions or scales at which known or anticipated effects become adverse to public welfare. Thus, the evidence and exposure/risk information discussed in this chapter will be further evaluated in Chapter 6 in light of the concepts incorporated in this paradigm to help inform the Administrator's judgments with respect to the potential adversity of the effects to the public welfare.

With respect to the scientific evidence, the longstanding evidence base on the phytotoxic effects of O_3 demonstrates that O_3 -induced effects that occur at the subcellular and cellular levels, at sufficient magnitudes propagate up to larger spatial scales. The ISA summarizes the coherence across the full range of effects, from the least serious to the most serious, as follows (U.S. EPA, 2013, p. 1-8):

> *The welfare effects of O_3 can be observed across spatial scales, starting at the subcellular and cellular level, then the whole plant and finally, ecosystem-level processes. Ozone effects at small spatial scales, such as the leaf of an individual plant, can result in effects along a continuum of larger spatial scales. These effects include altered rates of leaf gas exchange, growth, and reproduction at the individual plant level, and can result in broad changes in ecosystems, such as productivity, carbon storage, water cycling, nutrient cycling, and community composition.*

Many of the recent studies evaluated in this review have focused on and further increased our understanding of the molecular, biochemical and physiological mechanisms that explain how plants are affected by O_3, in the absence of other stressors, particularly in the area of genomics (U.S. EPA, 2013, Chapter 9, section 9.3). These recent studies, in combination with the extensive and long-standing evidence, have further strengthened the coherence and consistency of the entire body of research, so that our confidence in the supporting science is stronger than in the previous review.

Based on its assessment of the strength of the science, the ISA determined that the relationship that exists between exposure to O_3 in ambient air and visible foliar injury effects on vegetation, reduced vegetation growth, reduced productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops and alteration of below-ground biogeochemical cycles (U.S. EPA 2013, Table 1-2) is causal. Additionally, the ISA determined that a likely to be causal

relationship exists between exposures to O_3 in ambient air and reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial ecosystem water cycling and alteration of terrestrial community composition (U.S. EPA, 2013, Table 1-2).

Recent studies also continue to provide strong and consistent evidence that adverse vegetation effects are attributable to cumulative seasonal O_3 exposures. On the basis of the entire body of evidence in this regard, the ISA concludes that "quantifying exposure with indices that cumulate hourly O_3 concentrations and preferentially weight the higher concentrations improves the explanatory power of exposure/response models for growth and yield, over using indices based on mean and peak exposure values" (U.S. EPA, 2013, p. 2-44). Thus, as in other recent reviews, the evidence continues to provide a strong basis for concluding that it is appropriate to judge impacts of O_3 on vegetation, related effects and services, and the level of public welfare protection achieved, using a cumulative, seasonal exposure metric, such as the W126-based metric. In addition, CASAC has consistently since the 1997 review expressed support for the use of such a metric as the most appropriate form for the secondary NAAQS. In its most recent letter on the second draft PA, CASAC states that it "concurs with the justification in this section that the form of the standard should be changed from the current 8-hr form to the cumulative W126 index and finds that the discussion provides an appropriate and sufficient rationale" (Frey, 2014, p. 12). Thus, based on the consistent and well-established evidence described above, we conclude that the most appropriate and biologically relevant way to relate O_3 exposure to plant growth, and to determine what would be adequate protection for public welfare effects attributable to the presence of O_3 in the ambient air, is to characterize exposures in terms of a cumulative seasonal form, and in particular the W126 metric.

Accordingly, in considering the current evidence and exposure/risk information with regard to the adequacy of public welfare protection it affords, we have considered both the evidence of vegetation and welfare impacts in areas of the U.S. likely to have met the current standard, as well as air quality information regarding W126 index values in such areas. In evaluating the adequacy of the current secondary standard, we first considered O_3 effects on tree growth, productivity and carbon storage and associated ecosystems and services. Recent studies confirm and extend the evidence of O_3-related effects on tree growth, productivity and carbon storage. Analysis of existing data conducted by the EPA staff and discussed in the ISA has substantially reduced the uncertainty associated with using OTC E-R functions to predict tree growth effects in the field, as described in section 5.2.1 above (U.S. EPA, 2013, section 9.6.3.2). The median of the composite E-R functions (green line), (U.S. EPA, 2014a, Figure 6-5, section 6.2.1.2) shows RBL for tree seedlings. We note CASAC's advice that a 6% median RBL is unacceptably high, and that the 2% median RBL is an important benchmark to consider. The

median RBL is at or below 2% at the lowest W126 level assessed, 7 ppm-hrs. As the W126 level is incrementally increased, median RBL also increases incrementally, so that at W126 index values of 9, 11, 13, 15, 17, 19 and 21, the median RBL increases to 2.4%, 3.1%, 3.8%, 4.5%, 5.3%, 6.0% and 6.8%, respectively. Based on air quality analyses of 2009-2011 (Appendix 2B), there are approximately 342, 199, 92, 43, 24, 9, 3 and 0 monitors with 3-year average W126 index values above 7, 9, 11, 13, 15, 17, 19 and 21 ppm-hrs when meeting the current standard. We note that these counts of monitors are based on those meeting the current standard and that there are many monitors for the 2009-2011 period that do not meet the current standard and also are above the W126 values of 7-21 ppm-hrs.

We also consider it informative to examine the individual species responses and RBL over the same W126 range. We first note, based on Figure 5-1 (B) above that over the range of 7 to 17 ppm-hrs, 5 species maintain RBLs of less than 2%. These more tolerant species include Douglas fir, loblolly pine, Virginia pine, sugar maple and red maple. Two of these species (red maple and sugar maple) are estimated to have RBL levels above 2% at a W126 of 21. Black cherry, the most sensitive of the remaining six species, has RBL ranging from 35.57% at W126 of 17 down to 16.67% at the W126 index value of 7 ppm-hrs.

In addition, we also consider the growth effects associated with exposure concentrations at or below that of the current standard in Class I areas. Specifically, we found that there were 22 Class I areas that had monitor sites that have design values that meet the current standard, ranging from 67 to 75 ppb, and have 3-year average W126 index values that are above 15 ppm-hrs between the years of 1998 and 2012 (Table 5-2). Across these 22 Class I areas, the highest single-year W126 index values for these three-year periods ranged from 17.4 to 29.0 ppm-hrs. In 20 of the areas, distributed across eight states (AZ, CA, CO, KY, NM, SD, UT, WY) and four regions (west, southwest, west/north central and central), this range was 19.1 to 29.0 ppm-hrs, exposure values for which the corresponding median species RBL estimates equal or exceed 6%, which CASAC termed “unacceptably high”. In addition, given that other environmental factors can influence the extent to which O_3 may have the impact predicted by the E-R functions in any given year, we also note that the highest three year periods, that include these highest annual values for the 21 areas, are at or above 19 ppm-hrs, ranging up to 22.5 ppm-hrs (for which the median species RBL estimate is above 7%). Additionally, the highest three-year average W126 index value for each of the 22 areas (during periods meeting the current standard) was at or above 19 (ranging up to 22.5 ppm-hrs) in 11 areas, distributed among five states in the west and southwest regions (U.S. EPA, 2014c, Table 5-2, Appendix 5B).

In addition, quaking aspen and ponderosa pine are two tree species that are found in most of these 22 parks and have a sensitivity to O_3 exposure that places them near the middle of the

group for which E-R functions have been established. In the areas where ponderosa pine is present, the highest single year W127 index values ranged from 18.7 to 29.0 and the highest 3-year average W126 values in which these single year values are represented ranged from 15 to 22.5, with these three-year values above 19 ppm-hrs in eight areas across five states. The ponderosa pine RBL estimates for 29 and 22.5 ppm-hrs are approximately 12% and 9%, respectively. In the areas where quaking aspen is present, the highest single year W127 index values ranged from 19.2 to 26.7 ppm-hrs and the highest 3-year average W126 values in which these single year values are represented ranged from 15.0 to 22.2, with values above 19 ppm-hrs in eight areas across five states. The quaking aspen RBL estimates for 26.7 and 22.2 ppm-hrs are approximately 16% and 13%, respectively. Based on this, we predict growth effects associated with exposure concentrations at or below that of the current standard for most of these Class I areas. On the basis of such information, Table 5-2 provides evidence of the potential for significant growth loss in locations where ambient conditions meet the current standard. Based on this evidence, we note the occurrence in Class I areas, during periods where the current standard is met, of cumulative seasonal O_3 exposures of a magnitude that might reasonably be concluded to be important to public welfare.

Recent studies have provided additional evidence on tree biomass or growth effects associated with multiple year exposures in the field, including the potential for cumulative and carry-over effects. For example, a number of studies were conducted at a planted forest at the Aspen FACE site in Wisconsin where some researchers observed that the effects of O_3 on birch seeds (reduced weight, germination, and starch levels) could lead to a negative impact on species regeneration in subsequent years, and that the effect of reduced aspen bud size may have been related to the observed delay in spring leaf development. These effects suggest that elevated O_3 exposures have the potential to alter carbon metabolism of overwintering buds which may have subsequent effects in the following year. Other studies found that, in addition to affecting tree heights, diameters, and main stem volumes in the aspen community, elevated O_3 over a 7-year study period was reported to increase the rate of conversion from a mixed aspen-birch community to a community dominated by the more tolerant birch, leading the authors to conclude that elevated O_3 may alter intra- and inter-species competition within a forest stand (U.S. EPA, 2013, section 9.4.3).

While it is not possible at this time to identify the extent or magnitude of such effects in the field under exposures that may be associated with the current standard, their occurrence, on federal lands with special protections might reasonably be concluded to be an important public welfare consideration. We note here that the CASAC "concurs that biomass loss in trees is a relevant surrogate for damage to tree growth that affects ecosystem services such as habitat provision for wildlife, carbon storage, provision of food and fiber, and pollution removal.

Biomass loss may also have indirect process-related effects such as on nutrient and hydrologic cycles. Therefore, biomass loss is a scientifically valid surrogate of a variety of adverse effects to public welfare" (Frey, 2014, pp. 9-10).

In regard to the WREA analyses for risks for associated ecosystem services, we note that the WREA presents estimated changes in consumer and producer/farmer surplus associated with the change in forestry and agricultural yields. Changes in biomass affect individual tree species differently, and the overall effect on forest ecosystem productivity depends on the composition of forest stands and the relative sensitivity of trees within those stands. Economic welfare impacts resulting from just meeting the existing and alternative standards were largely similar between the forestry and agricultural sectors -- consumer surplus, or consumer gains, generally increased in both sectors because higher productivity under lower O_3 concentrations increased total yields and reduced market prices. Comparisons are not straightforward to interpret due to market dynamics. The national-scale analysis of carbon dioxide (CO_2) sequestration estimates more storage under the current standard compared to recent conditions, with somewhat smaller additional increases for the three W126 scenarios in comparison to the current standard scenario (U.S. EPA 2014a, Appendix 6B, Table B-10).

We additionally consider the WREA estimates of tree growth and ecosystem services provided by urban trees over a 25-year period for five urban areas based on case-study scale analyses that quantified the effects of biomass loss on carbon sequestration and pollution removal (U.S. EPA 2014a, sections 6.6.2 and 6.7).[30] The urban areas included in this analysis represent diverse geography in the Northeast, Southeast, and Central regions, although they do not include an urban area in the western U.S. Estimates of the effects of O_3-related biomass loss on carbon sequestration, for example, indicate the potential for an increase of somewhat more than a million metric tons of CO_2 equivalents for average W126 index values associated with meeting the current standard scenario as compared to recent conditions. Somewhat smaller additional increases are estimated for the three W126 scenarios in comparison to the current standard scenario (U.S. EPA 2014a, section 6.6.2 and Appendix 6D).

In considering the significance of these WREA analyses of risks for the associated ecosystem services for timber production, air pollution removal, and carbon sequestration, we note the large uncertainties associated with these analyses (see U.S. EPA 2014a, Table 6-27), and the potential to underestimate the response at the national scale. Thus, while we note that it is appropriate to consider predicted and anticipated impacts to these services in determining the adequacy of the protection afforded by the current standard, we also note that we place limited

[30] The WREA used the i-Tree model for the urban case studies. i-Tree is a peer-reviewed suite of software tools provided by USFS.

weight on the absolute magnitude of the risk results for these ecosystem service endpoints in light of these significant associated uncertainties.

In reaching conclusions regarding support for the adequacy of the current secondary standard provided by the currently available information on O_3-induced effects on trees and associated ecosystem services we note that: 1) there is robust evidence supporting the causal relationship between cumulative O_3 exposures and effects on tree growth, productivity, and carbon storage (U.S. EPA, 2013) and causal and likely to be causal relationships for several associated ecosystem services; 2) the tree seedling E-R functions evidence, which has been strengthened, demonstrates variability in sensitivity to O_3 across species; 3) estimated median RBLs are at or above 6%, a key CASAC benchmark, in several areas when air quality was at or below that of the current standard; 4) growth effects associated with exposure concentrations are predicted to occur in several Class I areas based on air quality from 1998-2012 that was at or below that of the current standard; 5) impacts from single year exposures can carry over to the subsequent year and/or cumulate over multiple years with repeated annual exposures; 6) evidence from both recent controlled chamber mechanism studies and field based exposure studies support earlier findings from OTC studies; and 7) WREA analyses show that O_3-induced biomass loss can impact ecosystem services provided by forests, including timber production, carbon storage, and air pollution removal, even when air quality is adjusted to just meet the current standard. Given the above, and noting CASAC views described above, staff concludes that the current evidence/risk information calls into question the adequacy of the public welfare protection afforded by the current standard from the known and anticipated adverse effects associated with O_3-induced impacts on tree growth, productivity and carbon storage, including the associated ecosystem services assessed in this review, and therefore it is appropriate to consider revision to provide increased protection.

With respect to crops, the detrimental effect of O_3 on crop production has been recognized since the 1960s, and recent O_3 concentrations in many areas across the U.S. are high enough that they might be expected to cause yield loss in a variety of agricultural crops including, but not limited to, soybeans, wheat, potatoes, watermelons, beans, turnips, onions, lettuces, and tomatoes (U.S. EPA, 2013, section 9.4.4). In general, the vast majority of the new scientific information confirms prior conclusions that exposure to O_3 can decrease growth and yield of crops. Recent research has highlighted the effects of O_3 on crop quality. Increasing O_3 concentration decreases nutritive quality of grasses, and decreases macro- and micro-nutrient concentrations in fruits and vegetable crops (U.S. EPA 2013, section 9.4.4). Recent studies continue to find yield loss levels in crop species studied previously under NCLAN that reflect the earlier findings. There has been little published evidence that crops are becoming more tolerant of O_3 (U.S. EPA, 2006a; U.S. EPA 2013). This is especially evident in the research on

soybean. The 2013 ISA reported comparisons between yield predictions based on data from cultivars used in NCLAN studies, and yield data for modern cultivars from SoyFACE (U.S. EPA, 2013, section 9.6.3). They confirm that the average response of soybean yield to O_3 exposure has not changed in current cultivars. In addition, satellite and ground-based O_3 measurements have been used to assess yield loss caused by O_3 over the continuous tri-state area of Illinois, Iowa, and Wisconsin. The results showed that O_3 concentrations reduced soybean yield, which correlates well with the previous results from FACE- and OTC-type experiments (U.S. EPA, 2013, section 9.4.4.1). Thus, the recently available evidence, as assessed in the ISA, continues to support the conclusions of the 1996 and 2006 CDs that ambient O_3 concentrations can reduce the yield of major commodity crops in the U.S.

The currently available evidence, as assessed in the ISA, continues to support the use of E-R functions for crops based on OTC experiments. Further, important uncertainties have been reduced regarding the E-R functions for crop yield loss, especially for soybean. In general, the ISA reports consistent results across exposure techniques and across crop varieties (U.S. EPA 2013, section 9.6.3.2). Soybean, which is the second-most planted field crop in the U.S.,[31] would be predicted to have no more than 5% RYL at a W126 index value of 12 ppm-hrs, based on the E-R function. Staff analyses of recent monitoring data (2009-2011) indicate that O_3 concentrations in multiple agricultural areas in the U.S. that meet the current standard correspond to W126 index levels above 12 ppm-hrs. With regard to crops, CASAC states that it "concurs that another important surrogate for damage that is adverse to public welfare is crop loss. Crops provide food and fiber services to humans. Evaluation of market-based welfare effects of ozone exposure in forestry and agricultural sectors is an appropriate approach to take into account damage that is adverse to public welfare" (Frey, 2014, p. 10). However, as we describe in section 5.3 above, determining at what point O_3-induced crop yield loss becomes adverse to the public welfare is still unclear, given that it is heavily managed with additional inputs that have their own associated markets and that benefits can be unevenly distributed between producers and consumers. We further note that a standard set to provide requisite protection for trees could also potentially achieve appropriate protection for commodity crops.

In reaching conclusions regarding support for the adequacy of the current secondary standard provided by the currently available information on O_3-induced effects on crops, we note that 1) there is clear and robust evidence supporting the causal relationship between cumulative O_3 exposures and effects on crop yields and quality (U.S. EPA, 2013); 2) the crop E-R functions evidence, which has been strengthened, demonstrates variability in sensitivity to O_3 across species; 3) evidence from both recent controlled chamber mechanism studies and field based

[31] http://www.ers.usda.gov/topics/crops/soybeans-oil-crops/background.aspx

exposure studies support earlier findings from OTC studies; 4) evidence continues to show that crops, and in particular soybean, has not become more tolerant of O_3 (U.S. EPA, 2013, section 9.6.3, 9.4.4.1); 5) WREA analyses show that O_3-induced crop yield loss can impact producer and consumer surpluses and the interaction between agriculture and timber production.

Given the above, and noting CASAC views described above as well as the difficulty in assessing adversity to public welfare of these effects, staff concludes that the current evidence/risk information calls into question the adequacy of the public welfare protection afforded by the current standard from the known and anticipated adverse effects associated with O_3-induced impacts on crop yields and associated services assessed in this review, and therefore, it is appropriate to consider revision to provide increased protection.

With respect to foliar injury, visible foliar injury surveys are used by the federal land managers to assess potential O_3 impacts in Class I areas (USFS, NPS, FWS, 2010). Given this focus on visible foliar injury, O_3-induced impacts have the potential to impact the public welfare in scenic and/or recreational areas on an annual basis. Visible foliar injury is associated with important cultural and recreational ecosystem services to the public, such as scenic viewing, wildlife-watching, hiking, and camping, that are of significance to the public welfare and enjoyed by millions of Americans every year, generating millions of dollars in economic value (U.S. EPA 2014a, section 7.1). In addition, several tribes have indicated that many of the known confirmed O_3-sensitive species (including bioindicator species) are culturally significant (see Appendix 5-A). We further note that CASAC "concurs that visible foliar injury can impact public welfare by damaging or impairing the intended use or service of a resource. Visible foliar injury that is adverse to public welfare can include: visible damage to ornamental or leafy crops that affects their economic value, yield, or usability; visible damage to plants with special cultural significance; and visible damage to species occurring in natural settings valued for scenic beauty or recreational appeal" (Frey, 2014, p. 10).

New research on visible foliar injury includes: 1) controlled exposure studies; 2) multi-year field surveys; and 3) USFS FHM/FIA biomonitoring program surveys and assessments. In addition to supporting the ISA causal determination, these studies also address some uncertainties identified in the previous review (i.e., influence of soil moisture on visible foliar injury development) and further show that visible foliar injury can occur under conditions where 8-hour average O_3 concentrations are or would be expected to be below the level of the current standard (e.g., Kline et al., 2008, as discussed in section 5.4.1 above). Incidence of visible foliar injury symptoms on O_3-sensitive vegetation has also been documented in the field in federally protected areas that have met the current standard. Importantly, these O_3-induced vegetation effects have been identified by the federal land managers as a diagnostic tool for informing conclusions regarding potential ozone impacts on potentially sensitive AQRVs and were found

in Class I areas that have particular public welfare significance in light of direction from Congress that these areas as merit a high level of protection (75 FR 3023/3024).

The studies mentioned above also provide additional information regarding the role of soil moisture in influencing visible foliar injury response (U.S. EPA 2013, section 9.4.2). These studies confirm that adequate soil moisture creates an environment conducive to greater visible foliar injury in the presence of O_3 than drier conditions. As stated in the ISA, "[a] major modifying factor for O_3-induced visible foliar injury is the amount of soil moisture available to a plant during the year that the visible foliar injury is being assessed … because lack of soil moisture generally decreases stomatal conductance of plants and, therefore, limits the amount of O_3 entering the leaf that can cause injury" (U.S. EPA, 2013, p. 9-39). As a result, "many studies have shown that dry periods in local areas tend to decrease the incidence and severity of O_3-induced visible foliar injury; therefore, the incidence of visible foliar injury is not always higher in years and areas with higher O_3, especially with co-occurring drought (Smith, 2012; Smith et al., 2003)" (U.S. EPA, 2013, p. 9-39). This "…partial 'protection' against the effects of O_3 afforded by drought has been observed in field experiments (Low et al., 2006) and modeled in computer simulations (Broadmeadow and Jackson, 2000)" (U.S. EPA, 2013, p. 9-87). In considering the extent of any protective role of drought conditions, however, the ISA also notes that other studies have shown that "drought may exacerbate the effects of O_3 on plants (Pollastrini et al., 2010; Grulke et al., 2003)" and that "[t]here is also some evidence that O_3 can predispose plants to drought stress (Maier-Maercker, 1998)". Accordingly, the ISA concludes that "the nature of the response is largely species-specific and will depend to some extent upon the sequence in which the stressors occur" (U.S. EPA, 2013, p. 9-87). However, such uncertainties associated with describing the potential for foliar injury and its severity or extent of occurrence for any given air quality scenario due to confounding by soil moisture levels make it difficult to identify an appropriate degree of protection (as well as ambient O_3 exposure conditions that might be expected to provide that protection).

We note the WREA analyses of the nationwide dataset (2006-2010) for USFS FHM/FIA biosites described in section 5.4.2 above, including the observation that the proportion of biosites with injury varies with soil moisture conditions and O_3 W126 index values (U.S. EPA 2014a, Chapter 7, Figure 7-10). The evidence of O_3-attributable visible foliar injury incidence occurring in USFS FHM/FIA biosites shows that the proportion of biosites showing foliar injury incidence increases steeply with W126 index values up to approximately 10 ppm-hrs. At W126 index levels greater than approximately 10 ppm-hrs, the proportion of sites showing foliar injury incidence is relatively constant. The air quality assessment discussed above identified Class I areas with recent air quality that met the current standard but were above a W126 index value of

15 ppm-hrs (Table 5-2). There were 22 Class I areas in this table and most of these areas had 3-year average W126 index values above 15 ppm-hrs for multiple 3-year periods. Given evidence of the potential occurrence of visible foliar injury at W126 index values of this magnitude, we note the ecosystem services that are at risk of impairment because of O_3-induced damage directly due to foliar injury, though data is not available to explicitly quantify these negative effects. Therefore, staff concludes that air quality levels that are at or below the level of the current standard may allow levels of visible foliar injury incidence to occur in areas of special significance to the public welfare.

In reaching conclusions regarding support for the adequacy of the current secondary standard provided by the currently available information on O_3-induced visible foliar injury we note that: 1) many species of native plants, including trees, have been observed to have visible foliar injury symptoms in both OTC and field settings, some of which have also been identified as bioindicators of O_3 exposure by the USFS; 2) visible foliar injury has been identified by the federal land managers as a diagnostic tool for informing conclusions regarding potential O_3 impacts on potentially sensitive AQRVs (USFS, NPS, FWS, 2010); 3) visible foliar injury incidence can occur for some species at very low cumulative exposures, but due to confounding by soil moisture and other factors, it difficult to predictively relate a given O_3 exposure to plant response; and 4) WREA analyses show that based on USFS biosite data, the proportion of biosites showing foliar injury incidence drops when W126 index values drop below approximately 10 ppm-hrs. However, we note that, with respect to visible foliar injury, we are unaware of any guidance for federal land managers regarding at what spatial scale or what degree of severity visible foliar injury might be sufficient to trigger protective action based on this potential impact on AQRVs. Further, there does not appear to be any consensus in the literature in this regard, and CASAC, while identifying target percent biomass loss and yield loss benchmarks for tree seedlings and commodity crops, respectively, did not provide a similar recommendation for this endpoint. Likewise, as in previous reviews, the ISA notes the difficulty in relating visible foliar injury symptoms to other vegetation effects such as individual plant growth, stand growth, or ecosystem characteristics (U.S. EPA, 2013, section 9.4.2, p. 9-39) and further noted that the full body of evidence indicates that there is wide variability in this endpoint, such that although evidence shows visible foliar injury can occur under very low cumulative O_3 concentrations, "…the degree and extent of visible foliar injury development varies from year to year and site to site…, even among co-members of a population exposed to similar O_3 levels, due to the influence of co-occurring environmental and genetic factors" (U.S. EPA 2013, section 9.4.2, p. 9-38).

Given the above, and taking note of CASAC views, we recognize foliar injury as an important O_3 effect which, depending somewhat on severity and spatial extent, may reasonably

be concluded to be of public welfare significance, especially when occurring in nationally protected areas. However, we also note the uncertainties associated with describing the potential for foliar injury and its severity or extent of occurrence for any given air quality scenario due to confounding by soil moisture levels and the difficulty in determining what degree of visible foliar injury incidence is likely to occur under different air quality conditions, and in particular on lands with special public welfare significance. We therefore conclude that the current standard may not adequately protect the public welfare from the known and anticipated adverse effects associated with O_3-induced impacts on visible foliar injury and associated services assessed in this review. Therefore, it may be appropriate to consider revising the standard to provide increased public welfare protection, though it is uncertain to what degree these O_3-induced impacts on visible foliar injury would be appropriately judged as important and adverse from a public welfare perspective.

The information for other welfare effects, including those with causal or likely causal relationships with O_3 (e.g., alteration of ecosystem water cycling, changes in climate), is limited with regard to our ability to consider potential impacts of air quality conditions associated with the current standard, although the WREA provides some perspective on this issue with regard to susceptibility to insect attack and fire regime change. We note, however, the importance of these effects categories to the public welfare.

As noted in section 1.3.2 above, our general approach to informing the Administrator's judgments recognizes that the available welfare effects evidence demonstrates a range of O_3 sensitivity across studied plant species and documents an array of O_3-induced effects that extend from lower to higher levels of biological organization. These effects range from those affecting cell processes and individual plant leaves to effects on the physiology of whole plants, species effects and effects on plant communities to effects on related ecosystem processes and services. Given this evidence, it is not possible to generalize across all studied species regarding which cumulative exposures are of greatest concern, as this can vary by situation due to differences in exposed species sensitivity, the importance of the observed or predicted O_3-induced effect, the role that the species plays in the ecosystem, the intended use of the affected species and its associated ecosystem and services, the presence of other co-occurring predisposing or mitigating factors, and associated uncertainties and limitations. At the same time, the evidence also demonstrates that though effects of concern can occur at very low exposures in sensitive species, at higher cumulative exposures those effects would likely occur at a greater magnitude and/or higher levels of biological organization and additional species would likely be impacted. It is important to note, however, due to the variability in the importance of the associated ecosystem services provided by different species at different exposures and in different locations, as well as differences in associated uncertainties and limitations, that, in addition to the magnitude of the

ambient concentrations, the species present and their public welfare significance are essential considerations in drawing conclusions regarding the significance of public welfare impact.

Therefore, in developing conclusions in this final PA, we note the complexity of judgments to be made by the Administrator regarding the adversity of known and anticipated effects to the public welfare and are mindful that the Administrator's ultimate judgments on the secondary standard will most appropriately reflect an interpretation of the available scientific evidence and exposure/risk information that neither overstates nor understates the strengths and limitations of that evidence and information.

Given all of the above, we reach the conclusion that the available evidence and exposure and risk information call into question the adequacy of public welfare protection provided by the current standard, and provides support for consideration of revisions to the current secondary standard to provide increased public welfare protection. More specifically, staff concludes that it is appropriate for the Administrator to consider revision of the current secondary O_3 standard to increase protection against O_3-attributable tree biomass loss, crop yield loss, and visible foliar injury, and their associated services, and particularly for those effects associated with cumulative, seasonal exposures that occur in Class I and similarly protected natural areas.

In reaching conclusions on options for the Administrator's consideration, we note that the final decision to retain or revise the current secondary O_3 standard is a public welfare policy judgment to be made by the Administrator, based on her judgment as to what degree of protection would be requisite (i.e., neither more nor less stringent than necessary) to protect the public welfare from any known or anticipated adverse effects. This final decision will draw upon the available scientific evidence for O_3-attributable welfare effects, and on quantitative analyses of vegetation and ecosystem exposures and associated risks to vegetation, ecosystems and their associated services, and judgments about the appropriate weight to place on the range of uncertainties inherent in the evidence and analyses. In making this decision, the Administrator will also need to weigh the importance of these effects and their associated ecosystem services in the overall context of public welfare protection.

Based on the considerations described in the sections above and summarized below, we therefore conclude that the currently available evidence and exposure/risk information call into question the adequacy of the public welfare protection provided by the current standard and provides support for considering potential alternative standards to achieve increased public welfare protection, especially for sensitive vegetation and ecosystems in federally protected Class I and similar areas. In this conclusion, we give particular weight to the evidence indicating the occurrence in Class I areas that meet the current standard of cumulative seasonal O_3 exposures associated with estimates of tree growth impacts of a magnitude that are reasonably considered important to public welfare.

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6 CONSIDERATION OF ALTERNATIVE SECONDARY STANDARDS

Chapter 5 reached the conclusion that the available evidence and exposure and risk information call into question the adequacy of public welfare protection provided by the current standard, and that it is appropriate for the Administrator to consider revising the current secondary standard to provide increased public welfare protection against O_3-attributable effects on tree biomass loss, crop yield loss, and visible foliar injury, and their associated services, particularly for those effects associated with cumulative, seasonal exposures, to the extent these effects are judged adverse to the public welfare. Given that conclusion, this chapter describes the staff evaluation of the available body of evidence, and exposure, risk and air quality information with regard to support for consideration of alternative standards, as articulated by the following overarching question:

- **What alternative secondary standards are supported by the currently available scientific evidence, exposure/risk information and air quality analyses?**

To assist us in interpreting the currently available scientific evidence and the results of recent quantitative exposure/risk analyses to address this question, we have focused on a series of more specific questions in sections 6.1, 6.2 and 6.3 below. We consider both the scientific and technical information available at the time of the last review and information newly available since the last review which has been critically analyzed and characterized in the ISA. Specifically, we consider the currently available scientific evidence and technical information in the context of decisions regarding the basic elements of the NAAQS: indicator (section 6.1); averaging time and form (section 6.2); and level (section 6.3). CASAC advice on potential alternative standards is described in section 6.4 and staff conclusions on potential alternative standards are discussed in section 6.5. Section 6.6 summarizes staff conclusions on the adequacy of the current standard and the alternative standards that are appropriate for the Administrator to consider. Key uncertainties in this review and areas in which future research and data collection would better inform the next review are identified in section 6.7.

6.1 INDICATOR

With regard to the selection of an appropriate indicator for alternative secondary standards, we consider the following question.

- **Does the information available in this review continue to support O_3 as the indicator for ambient air photochemical oxidants?**

In the last review of the air quality for O_3 and other photochemical oxidants and of the O_3 standard, as in other prior reviews, the EPA focused on a standard for O_3 as the most appropriate surrogate for ambient photochemical oxidants. Ozone is a long-established surrogate for ambient photochemical oxidants, among which it is by far the most widely studied with regard to effects on welfare and specifically on vegetation. The information available in this review adds to our understanding of the atmospheric chemistry for photochemical oxidants and O_3 in particular (as described in the ISA, sections 3.2 and 3.6, and summarized in section 2.2 in this document). The 1996 Staff Paper noted that the database on vegetation effects is generally considered to raise concern at levels found in the ambient air for O_3 and, therefore, control of ambient O_3 levels has previously been concluded to provide the best means of controlling other photochemical oxidants of potential welfare concern (U.S. EPA, 1996b, p. 277). In the current review, while the complex atmospheric chemistry in which O_3 plays a key role has been highlighted, no alternatives to O_3 have been advanced as being a more appropriate surrogate for ambient photochemical oxidants. Ozone continues to be the only photochemical oxidant other than nitrogen dioxide that is routinely monitored and for which a comprehensive database exists (U.S. EPA, 2013, section 3.6). Thus, staff concludes that O_3 remains the appropriate pollutant indicator for use in a secondary NAAQS that provides protection for public welfare from exposure to all photochemical oxidants.

6.2 FORM AND AVERAGING TIME

In considering potential forms and averaging times alternative to that of the current secondary standard (i.e., 4th highest daily maximum 8-hour average, averaged over 3 years), we address several specific questions.

- **To what extent does the currently available information provide support for considering forms different from that of the current secondary standard?**

In characterizing the current evidence, the ISA states that "[n]o recent information is available since 2006 that alters the basic conclusions put forth in the 2006 and 1996 O_3 AQCDs" with regard to biologically relevant exposure indices (U.S. EPA, 2013, section 2.6.6.1, p. 2-43). Based on the current state of knowledge and the best available data assessed in this review, the ISA therefore concludes that exposure indices that cumulate and differentially weight the higher hourly average concentrations over a season and also include the mid-level values continue to offer the most scientifically defensible approach for use in developing response functions and in defining indices for vegetation protection. Quantifying exposures with indices that cumulate hourly O_3 concentrations and preferentially weight the higher concentrations improves the

explanatory power of exposure/response models for growth and yield, over using indices based on mean and peak exposure values (U.S. EPA, 2013, section 2.6.6.1). These conclusions are based on the available body of evidence which provides a wealth of information, compiled over several decades, on the aspects of O_3 exposure that are most important in influencing plant response. As discussed in the ISA, the importance of the duration of the exposure and the relatively greater importance of higher concentrations (over lower concentrations) in determining plant response to O_3 have been well documented (U.S. EPA, 2013, section 9.5.3). Building on this research, other work has focused on developing "mathematical approaches for summarizing ambient air quality information in biologically meaningful forms for O_3 vegetation effects assessment purposes …" (U.S. EPA, 2013, section 9.5.2, p. 9-99), including those known as cumulative, concentration weighted forms (i.e., SUM06, W126). Much of this work was completed by the mid-1990s, and was summarized in the 1996 Criteria Document (CD) (U.S. EPA, 1996a, section 5.5).

On the basis of this longstanding and extensive evidence demonstrating that the risk to vegetation comes from cumulative seasonal exposures, the EPA in the 1997 and 2008 reviews, as well as in the 2010 proposed rulemaking to reconsider the 2008 decision, recognized the importance of cumulative, seasonal exposures as a primary determinant of plant responses to O_3 in ambient air (61 FR 65741-42; 62 FR 38878; 72 FR 37893, 37896, 37900, 37904; 73 FR 16488-90, 16493-94; 75 FR 3000, 3010, 3012). For example, in the 1996 notice of proposed rulemaking, the Administrator recognized that the scientific evidence supported the conclusion that "a cumulative seasonal exposure index is more biologically relevant than a single event or mean index" (61 FR 65742). In the 2008 review, CASAC recognized that an important difference between the effects of short-term exposures to O_3 on human health and the effects of O_3 exposures on welfare is that "vegetation effects are more dependent on the cumulative exposure to, and uptake of, O_3 over the course of the entire growing season" (Henderson, 2006, p. 5). In that review, the CASAC O_3 Panel members were unanimous in supporting the final Staff Paper recommendation that "protection of managed agricultural crops and natural terrestrial ecosystems requires a secondary Ozone NAAQS that is substantially different from the primary ozone standard in averaging time, level and form" (Henderson, 2007, p. 3). Accordingly, in both the 1997 and 2008 reviews as well as the 2010 reconsideration, the Administrator proposed a secondary standard with a cumulative seasonal form as an appropriate policy option (61 FR 65742-44; 72 FR 37899-905; 75 FR 3012-3027).

In considering which exposure index was best suited for use as a form for the secondary O_3 NAAQS, the 1996 CD and 1996 Staff Paper evaluated a variety of different types of forms. These documents noted that a number of forms (e.g., the one event, mean and unweighted cumulative SUM00) are unable to reliably predict plant response because they either ignore the

role of duration or ignore the disproportionate impact of higher concentrations by weighting all concentrations equally (U.S. EPA, 1996b, p. 224). Other forms that were considered at that time included multicomponent forms which take into account many other relevant factors (e.g., plant growth stage, predisposition from earlier exposures). Of all the different exposure forms, these multicomponent forms consistently predict plant response best. However, due to being species-specific and highly complex, they were not considered suitable for more general application in the context of standard setting (U.S. EPA, 1996b, pp. 224-225). On the other hand, concentration-weighted forms that take into account the role of duration and concentration perform almost as well as the multicomponent forms. These forms include several threshold forms (e.g., SUM06, AOT60) and sigmoidally weighted cumulative indices (e.g., W126[1]) (U.S. EPA, 1996a, pp. 5-84 to 5-136; U.S. EPA, 1996b, pp. 223-227). Given that these cumulative concentration-weighted forms were able to similarly predict plant response on the datasets for which they were evaluated (e.g., NCLAN), it was not possible to distinguish between them on this basis. Partly as a result, CASAC deliberations in 1995 did not produce a consensus on which cumulative concentration-weighted form would be best suited for a secondary NAAQS. As discussed further in 6.3 below, a workshop held in January of 1996 provided a consensus recommendation on the SUM06 form as appropriate for use in secondary standards, while also recognizing that a W126 form could also be appropriate (Heck and Cowling, 1997). Subsequent to this, the final 1996 Staff Paper and 1996 proposal notice both identified the SUM06 form as appropriate to consider and propose, respectively (U.S. EPA, 1996b, p. 285, 61 FR 65716). In selecting the SUM06 form that imposed a threshold despite the lack of scientific evidence for a discernible threshold for O_3-related vegetation effects across the range of studied species, the EPA noted that it had the benefit of not including concentrations that were considered at the time to be within the range of background, which was considered to be an important feature (U.S. EPA, 1996b, pp. 223-227).

In the subsequent review, the form of the standard was revisited in light of continued evidence that there remained a lack of discernible threshold for vegetation effects in general, and newer estimates of O_3 concentrations associated with background sources were lower than in the previous review such that their inclusion was less of a concern. On these bases, the 2007 Staff Paper recommended consideration of the W126 index as the basis for the form of a distinct secondary standard (U.S. EPA, 2006, pp. 9-11 to 9-15 and pp. AX9-159 to AX9-187; U.S. EPA, 2007, pp. 7-15/16). The EPA then proposed two options for the secondary standard, one of

[1] The W126 is a non-threshold approach described as the sigmoidally weighted sum of all hourly O_3 concentrations observed during a specified diurnal and seasonal exposure period, where each hourly O_3 concentration is given a weight that increases from 0 to 1 with increasing concentration (Lefohn et al, 1988; Lefohn and Runeckles, 1987; U.S. EPA, 2013, section 9.5.2).

which was to adopt a cumulative, seasonal standard based on the W126 index, while the other option was a secondary standard identical to the proposed revised primary standard (72 FR 37818). The CASAC Panel in that review expressed preference for the W126 index (Henderson, 2006). In deciding to reconsider the 2008 decision, the Administrator noted that past arguments or reasons for not moving to a cumulative, seasonal form, with appropriate exposure periods, were not based on disagreement over the biological relevance of the cumulative, seasonal form, or the recognized disadvantages of an 8-hour standard in measuring and identifying a specified cumulative, seasonal exposure pattern but were based on concerns over whether the EPA had an adequate basis to determine an appropriate level for a cumulative, seasonal secondary standard (75 FR 3019). Having reached the conclusion that such a level could be identified from within the range of levels proposed, the Agency proposed to set a secondary NAAQS in terms of a cumulative, seasonal standard form based on the W126 function (75 FR 2938). The CASAC also stated its support for this proposal, noting that it found the Agency's reasoning to be supported by the extensive scientific evidence considered in the last review (Samet, 2010).

In this review, we conclude that specific features associated with the W126 index still make it the most appropriate and biologically relevant cumulative concentration-weighted form for use in the context of the secondary O_3 NAAQS review. In particular, the W126 index does not apply an arbitrary exposure threshold below which concentrations are not included. Given the acknowledged variability in vegetation sensitivity, including evidence that some species are sensitive at very low cumulative exposures, and the continued lack of evidence of an exposure threshold for effects above a W126 index of zero, such a feature is scientifically justifiable and desirable. Thus, we conclude that the W126 form is best matched to the evidence associated with vegetation effects, as well as addressing the policy-relevant issue of how to weight exposures associated with background sources.

- **To what extent does the currently available information provide support for consideration of a cumulative seasonal form derived as a sum of weighted O_3 concentrations over daylight hours (8:00 am to 8:00 pm) and over the consecutive 3-month period having the highest sum within the O_3 season?**

As discussed in Chapter 5, mechanistic studies, including those recently assessed in this review, provide biological plausibility for the conclusions reached in the ISA that O_3-induced effects on plants are cumulative, that higher concentrations appear to be more important in eliciting a response than lower concentrations, and that plant sensitivity to O_3 can vary with time of day (U.S. EPA, 2013, p. 2-44). In particular, studies have shown that plants take up and respire gases through openings in their leaves, called stomata, which in general, are most open during daylight hours in order to allow sufficient CO_2 uptake for use in carbohydrate production

through the light-driven process of photosynthesis. Ozone, when present in sufficient amounts, is taken up along with the CO_2, where it and its derivatives can inhibit photosynthesis, leading to reduced carbohydrate production needed for growth, reproduction and repair (U.S. EPA, 2013, section 9.3.6; 75 FR 3013). Since plants are photosynthesizing during daylight hours and continue to grow throughout their growing season, the effects of repeated O_3 exposures continue to accumulate, both on a diurnal and seasonal basis. Thus, for vegetation, the element of "averaging time" has more appropriately been considered in terms of relevant exposure periods – diurnal and seasonal -- over which exposures are cumulated, or summed.

In the EPA's consideration of such exposure periods in both the 1997 and 2008 reviews, and the 2010 reconsideration, the EPA identified the 12-hour daylight period from 8:00 am to 8:00 pm as appropriately capturing the diurnal window with most relevance to the photosynthetic process (61 FR 35716; 72 FR 37900; 75 FR 2938, 3013). In so doing, the EPA recognized, as did CASAC, that in some parts of the country this period may not include all daytime hours or all exposures of importance to vegetation, thus potentially underestimating the impact of O_3 at those sites (72 FR 37900-01; 75 FR 3013-14; Henderson, 2007, p. 3, pp. C-22-23). The evidence available in this review continues to provide support for focusing on the daylight hours, since for the majority of plants, the diurnal conditions of maximum O_3 uptake occur mainly during the daytime hours (U.S. EPA, 2013, section 9.5.3.2). This evidence shows that, in general, (1) plants have the highest stomatal conductance during the daytime; (2) atmospheric turbulent mixing is greatest during the day in many areas; and (3) the high temperature and high light conditions that occur during the day and that typically promote the formation of tropospheric O_3 also promote physiological activity in vegetation (U.S. EPA, 2013, section 9.5.3.2).

In addition, as in past reviews, we have also considered the evidence available from a number of studies that have reported O_3 uptake at night in some species (U.S. EPA, 2013, section 9.5.3.2). Typically the rate of stomatal conductance at night is much lower than during the day. Across the studies discussed in the ISA, nocturnal conductance ranged from negligible to 25% of daytime values (U.S. EPA, 2013, section 9.5.3.2), and, in some studies, varied by season and drought conditions. However, many of these studies did not link the night-time flux to measured effects on plants, making it difficult to know in those studies whether the impacts on the plant from nocturnal exposures are greater or less than those from similar daytime exposures, and whether or not they should be considered as separate impacts or as additive or synergistic with impacts from the preceding or subsequent daytime exposure.

Further, there are also uncertainties associated with the extent of the occurrence of high exposure to O_3 at night. For significant nocturnal stomatal flux and O_3 effects to occur, a susceptible plant with nocturnal stomatal conductance and low defenses must be growing in an

area with relatively high nighttime O_3 concentrations (often high elevation sites) and appreciable nocturnal atmospheric turbulence. It is unclear how many areas there are in the U.S. where these atmospheric conditions occur. It may be possible that these conditions exist in mountainous areas of southern California, front-range of Colorado and the Great Smoky Mountains of North Carolina and Tennessee. However, more information is needed in locations with high nighttime O_3 to assess the local O_3 patterns, micrometeorology and responses of potentially vulnerable plant species (U.S. EPA, 2013, section 9.5.3.2).

In consideration of the uncertainties that remain regarding the importance and extent of nocturnal exposures associated with plant uptake, and whether and how they might be incorporated into a national index, we conclude that it is appropriate to continue to focus on the 12-hour daylight exposure period of 8:00 am to 8:00 pm. We note that available monitoring data indicates that the daily increase in O_3 concentrations generally does not begin until after 8:00 am (U.S. EPA, 2013, section 3.6.3.2). In regard to this staff conclusion on an appropriate diurnal exposure period, CASAC states that "[a]ccumulation over the 08:00 a.m. – 08:00 p. m. daytime 12-hour period is a scientifically acceptable and recommended means of generalizing across latitudes and seasons" (Frey, 2014a, p. 13).

With regard to identification of the seasonal period over which to cumulate exposures, we note that a plant is vulnerable to O_3 pollution as long as it has foliage and is physiologically active (U.S. EPA, 2013, section 9.5.3, p. 9-112), i.e., during its growing season. The length of vegetative growing seasons varies depending on the type or species of vegetation and where it grows. For example, as discussed in the ISA, annual crops are typically grown for periods of two to three months while perennial species may be photosynthetically active longer, up to 12 months each year for some species (U.S. EPA 2013, section 9.5.3, p. 9-112). In general, the period of maximum physiological activity and thus potential O_3 uptake for vegetation coincides with some or all of the intra-annual period defined as the O_3 season, which can vary on a state-by-state basis (U.S. EPA, 2013, Figure 3-24, p. 3-83). This is because the high temperature and high light conditions, which can vary geographically, typically promote the formation of tropospheric O_3, as well as physiological activity in vegetation (U.S. EPA, 2013, section 9.5.3, p. 9-112).

The exposure periods used in studies of O_3 effects on vegetation reflect this understanding, with crop studies typically using shorter seasonal exposure periods and studies of longer lived trees and other perennial vegetation often extending for the entire annual growing season or in some cases over multiple growing seasons. Specifically, the ISA notes that "[m]ost of the crop studies done through NCLAN had exposures less than three months with an average of 77 days. Open-top chamber studies of tree seedlings, compiled by the EPA, had an average exposure of just over three months or 99 days. In more recent FACE experiments, SoyFACE

exposed soybeans for an average of approximately 120 days per year and the Aspen FACE experiment exposed trees to an average of approximately 145 days per year of elevated O_3, which included the entire growing season at those particular sites" (U.S, EPA, 2013, section 9.5.3.2, p. 9-112). Further, the U.S. Forest Service and federal land managers have typically used the 6 months from April through September as the accumulation period (U.S, EPA, 2013, section 9.5.3.2, p. 9-112). However, despite the possibility that plants may be exposed to ambient O_3 longer than 3 months in some locations, the ISA notes that "[t]he exposure period in the vast majority of O_3 exposure studies conducted in the U.S. has been much shorter than 6 months…" and "there is generally a lack of exposure experiments conducted for longer than 3 months" (U.S. EPA, 2013, section 9.5.3.2, p. 9-112). As a result, analyses of effects in terms of the W126 exposure index have typically defined the index in terms of a 3-month exposure period or at least in terms of periods shorter than 6 months (e.g., SoyFACE, Aspen FACE) (U.S, EPA, 2013, p. 9-112).

In the current review, the EPA conducted a new analysis to further inform the consideration of the most appropriate seasonal accumulation period (U.S. EPA, 2013, section 9.5.3). This analysis calculated and compared the 3- and 6-month maximum W126 index values for over 1,200 AQS and CASTNET EPA monitoring sites for the years 2008-2009. The two accumulation periods were found to be highly correlated metrics (U.S. EPA, 2013, Figure 9-13; section 9.5.3). The analysis indicates that in the U.S., W126 cumulated over 3 months and W126 cumulated over 6 months could be proxies of one another, as long as the period in which daily W126 is accumulated corresponds to the seasonal maximum. Therefore, it is expected that either statistic will predict vegetation response equally well. Given the above information, and in particular the results of the EPA analysis showing the maximum 3-month period is highly correlated with the longer 6-month maximum period, we again conclude that it is appropriate to continue to focus on the consecutive 3-month period with the highest cumulative exposure value within the monitored O_3 season as the seasonal exposure period with most relevance to vegetation. Given its review of the available science, CASAC also expressed support for this seasonal period, stating that "[t]he Second Draft PA makes a very strong case, consistent with previous CASAC judgment, for changing the secondary metric to the W126 averaged over the highest three-month interval" (Frey, 2014a, p. 13).

6.3 LEVEL

In considering potential levels for alternative secondary standards, we again find it useful to note that the protection provided by the secondary standard derives from the combination of all elements of the standard (indicator, form, averaging time, and level). Thus, in light of the discussions in section 6.2 above, we first consider what level or range of levels can reasonably be

judged to provide a requisite degree of public welfare protection when combined with a W126 index form of cumulatively weighted concentrations from 8:00 am to 8:00 pm over a maximum consecutive 3-month period. In addition to considering the information in the context of a single growing season, we also consider it in the context of a form for this W126 metric averaged across three consecutive growing seasons for reasons discussed in section 6.2 above.

In the discussion below, we turn first to consideration of the currently available scientific evidence as assessed and characterized in the ISA. We then consider the WREA findings with regard to vegetation, ecosystem effects and services estimated for different air quality scenarios. We additionally take note of important uncertainties and limitations in the evidence and exposure/risk analyses, as well as considerations related to interpreting these impacts in light of the additional policy considerations described in the adversity paradigm. Lastly, we take note of judgments to be made by the Administrator in drawing conclusions regarding effects and risks that represent adverse effects to public welfare. In so doing, we identify key considerations with regard to the currently available evidence, exposure/risk information and associated uncertainties in identifying the range of levels that may be appropriate to consider for a cumulative seasonal secondary standard. Such levels are described in section 6.5 below, which describes staff conclusions regarding alternative secondary standards appropriate to consider in this review.

- **What does the currently available evidence indicate with regard to the range of W126-based index values that may provide protection from vegetation effects of O_3?**

In answering this question, we first consider quantitative evidence for O_3 exposure effects on plant growth, productivity and related endpoints. In so doing, we draw primarily on the robust E-R functions developed in OTC studies for tree seedling and crop species as described in the ISA (U.S. EPA 2013, section 9.6), and as used in the WREA exposure and risk analyses (U.S. EPA, 2014b, section 6.2), and discussed in Chapter 5 of this document (Figures 5-1 and 5-4). It is important to note that these functions are used to provide estimates of growth and yield reduction in tree seedlings and crops that might be expected to result from exposure over a single growing season to various O_3 concentrations expressed in terms of a W126 index. We also consider the available evidence and exposure/risk information for visible foliar injury.

As a point of clarification, we note that CASAC commented that it "concurs that relative biomass loss for tree species, crop yield loss, and visible foliar injury are appropriate surrogates of a wide range of damage that is adverse to public welfare." (Frey, 2014a, p. 10). While we agree that effects at the individual tree, crop, or other plant species level, in and of themselves, can be directly related to effects on the public welfare when they occur to a sufficient degree on lands with an intended use that can be affected by O_3-induced vegetation effects (e.g., timber

production, AQRVs in Class I areas), we also caution that not all predicted effects on vegetation occur to such a degree or occur on lands within this category. Thus, in considering the predicted effects on studied tree and crop species under various W126 exposures, we are mindful of the need to further determine under what conditions they can be considered surrogates for impacts that are important in the public welfare policy context.

Table 6-1 below presents estimates of relative biomass and yield loss for the 11 and 10 studied species of tree seedlings and crops, respectively, for which we have robust E-R functions developed in OTC studies, for a single growing season exposure to a number of W126 index values. In this table, we have included observations related to median and individual species relative biomass loss in tree seedlings and relative crop yield loss, at the target benchmark levels of 2% and 5%, respectively. These benchmarks are consistent with the 2% and 5% benchmarks for tree seedlings and crops, respectively, as advised by CASAC in this review (Frey, 2014a; section 6.4 below), and with values given focus in the 1996 expert consensus workshop. We have also included information on the number of studied species with estimates below other benchmarks that may also be of interest (i.e., 5%, 10%, and 15% for trees and 10% for crops). CASAC has placed most emphasis on the median species response in recommending a range of scientifically supportable levels. For example, CASAC noted that "[i]n our scientific judgment, it is appropriate to identify a range of levels of alternative W126-based standards that includes levels that aim for not greater than 2% RBL for the median tree species" (Frey, 2014a, p. 14)." CASAC also recognizes that as a policy matter the Administrator may find it useful to also consider information related to individual species responses, to the degree that they have special significance to the public welfare, when selecting an appropriate level or range of levels. Specifically, CASAC states that "[a]s a policy recommendation, separate from its advice above

Table 6-1. Tree seedling biomass loss and crop yield loss estimated for O_3 exposure over a season.

W126 value for exposure period	Tree seedling biomass loss[A]		Crop yield loss[C]	
	Median Value	Individual Species	Median Value	Individual Species
21 ppm-hrs	Median species w. 6.8% loss [B]	≤ 2% loss: 3/11 species ≤ 5% loss: 5/11 species ≤10% loss: 7/11 species ≤15% loss: 10/11 species >40% loss: 1/11 species	Median species w. 7.7 % loss [D]	≤ 5% loss: 4/10 species >5,<10% loss: 3/10 species >10,<20% loss: 3/10 species
19 ppm-hrs	Median species w. 6.0% loss [B]	≤ 2% loss: 3/11 species <5% loss: 5/11 species ≤10% loss: 7/11 species ≤15% loss: 10/11 species >30% loss: 1/11 species	Median species w. 6.4 % loss [D]	≤ 5% loss: 5/10 species >5, <10% loss: 3/10 species >10,<20% loss: 2/10 species
17 ppm-hrs	Median species w. 5.3% loss [B]	≤ 2% loss: 5/11 species <5% loss: 5/11 species ≤10% loss: 9/11 species ≤15% loss: 10/11 species >30% loss: 1/11 species	Median species w. 5.1 % loss [D]	≤ 5% loss: 5/10 species >5, <10% loss: 3/10 species >10,<20% loss: 2/10 species
15 ppm-hrs	Median species w. 4.5% loss [B]	≤ 2% loss: 5/11 species ≤5% loss: 6/11 species ≤10% loss: 10/11 species >30% loss: 1/11 species	Median species w.≤5% loss [D]	≤ 5% loss: 6/10 species >5, <10% loss: 4/10 species
13 ppm-hrs	Median species w. 3.8% loss [B]	≤ 2% loss: 5/11 species <5% loss: 7/11 species <10% loss: 10/11 species >20% loss: 1/11 species	Median species w.≤5% loss [D]	≤ 5% loss: 6/10 species >5, <10% loss: 4/10 species
11 ppm-hrs	Median species w. 3.1% loss [B]	≤ 2% loss: 5/11 species ≤5% loss: 8/11 species ≤10% loss: 10/11 species >20% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: 9/10 species >5, <10% loss: 1/10 species
9 ppm-hrs	Median species w. 2.4% loss [B]	≤ 2% loss: 5/11 species ≤5% loss: 10/11 species >20% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: all species
7 ppm-hrs	Median species w. ≤2% loss [B]	≤ 2% loss: 7/11 species ≤5% loss: 10/11 species >15% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: all species

A Estimates here are based on the 11 E-R functions for tree seedlings described in WREA, Appendix 6F and discussed in section 5.2.1, with the exclusion of cottonwood. See CASAC comments (Frey, 2014a).
B This median value is the median of the composite E-R functions for 11 tree species in the WREA, Appendix 6F (also discussed in section 5.2.1).
C Estimates here are based on the 10 E-R functions for crops described in Appendix 6F and discussed in section 5.3.1.
D This median value is the median of the composite E-R functions for 10 crops from WREA, Appendix 6F (also discussed in section 5.3.1).

regarding scientific findings, the CASAC advises that a level of 15 ppm-hrs for the highest 3-month sum in a single year is requisite to protect crop yield loss, but that lower levels provide additional protection against crop yield loss. Furthermore, there are specific economically significant crops, such as soybeans, that may not be protected at 15 ppm-hrs but would be protected at lower levels" (Frey, 2014a, p. iii).

From Table 6-1, we see that median tree species biomass loss is at or below 2% only at the lowest W126 index value assessed, 7 ppm-hrs. As the W126 index value is incrementally increased, median RBL also increases incrementally, so that at W126 index values of 9, 11, 13, 15, and 17, the median RBL increases to 2.4%, 3.1%, 3.8%, 4.5%, and 5.3%, respectively. Thus over the W126 range of 7 to 17 ppm-hrs, median species biomass loss ranges from approximately 2% to approximately 5%.

We also believe it is informative to examine the individual species responses and RBL over the same W126 range (7 to 17 ppm-hrs). We first note, based on Figure 5-1 (B) in chapter 5, that over this range, five species maintain RBLs of less than 2%. These more tolerant species include Douglas fir, loblolly pine, Virginia pine, sugar maple and red maple. Thus, little additional protection would be achieved for these species below the W126 index value of 17 ppm-hrs. Two of these species (red maple and sugar maple) would only exceed 2% RBL at 21 ppm-hrs. In contrast, black cherry, the most sensitive of the remaining six species, has RBL ranging from approximately 36% at 17 ppm-hrs down to approximately 17% at 7 ppm-hrs. Thus, given that the magnitude of predicted black cherry RBL could be judged adverse over this range, it is not clear to what extent this information informs the selection of an appropriate level (Table 6-1; U.S. EPA, 2014b, section 6.2, Appendix 6A), though clearly protection would be expected to be greater at lower W126 index values. We further note that CASAC based their recommendation of an appropriate W126 level by considering the median tree species RBL of no more than 2%, but some levels within CASAC's recommended range allow for the possibility for individual species RBL to go much higher.

Because Table 6-1 was updated in this final PA to deemphasize cottonwood, based on staff's understanding of CASAC advice in that regard, we note that the CASAC advice based on the numbers of species protected to no more than 2% RBL and median RBL values for tree seedlings associated with various W126 levels, as shown in the in the second draft PA table (U.S. EPA, 2014a), is no longer consistent in some cases with the revised Table 6-1. For example, in commenting on the version of Table 6-1 in the second draft PA CASAC states that "[t]able 6-1 presents the RBL results for individual species for different levels of W126. This table demonstrates that a range of 7 ppm-hrs to 15 ppm-hrs will protect against RBL of 2% for at

least 5 of the 12 species"[2] (Frey, 2014a, p. 14). In addition, CASAC states that "[t]he CASAC does not support a level higher than 15 ppm-hrs. For example, at 17 ppm-hrs, the median tree species has 6% relative biomass loss…. These levels are unacceptably high" (Frey, 2014a, p. iii). While we continue to place weight on CASAC's scientific judgments that a 6% median RBL is unacceptably high, and that the 2% median RBL is an important benchmark to consider, we also note that the updated median RBL for a W126 level of 17 ppm-hrs is now 5.3%.

We further note that CASAC does not provide additional clarification regarding its views on the acceptability of median tree species RBL levels between 2% and 6%, beyond noting that values closer to the lower end of the range (W126 index value of 7 ppm-hrs) would provide greater protection for more sensitive tree species, and that the levels within CASAC's recommended range allow for the possibility for individual species RBL to go much higher than 2% and 6%. Given the nature of this input, we then considered the RBL information available for the remaining five species (i.e., eastern white pine, aspen, tulip poplar, ponderosa pine, red alder) to further inform our evaluation of the additional protection that potentially could be achieved at different W126 levels within the range being considered. We thus note that at the W126 index value of 17 ppm-hrs, one species (eastern white pine) has RBL above 10% and one species (red alder) has RBL of 5.3% (below 6%) while the other three fall between approximately 6.7% and 9.8%. At the W126 index value of 15 ppm-hrs, two (i.e., red alder and ponderosa pine) of the five species fall below 6% RBL, while the remaining 3 species have RBLs that range from 7.4% to 8.8%. At the W126 index value of 13 ppm-hrs, three species (i.e., tulip poplar, ponderosa pine, red alder) fall below 6% RBL, while the remaining two have RBLs of 7.0% and 7.1%. At the W126 index value of 11 ppm-hrs, all five species have RBLs below 6%. Taken together with the more tolerant species, the proportion of the studied tree species with RBLs below 6% are 6/11, 7/11, 8/11, and 10/11 at W126 index values of 17, 15, 13, and 11 ppm-hrs, respectively. To the extent the focus is placed on different % RBL benchmarks and the proportion of studied trees protected at those levels, as well the expected impacts to associated ecosystem services, in regard to the identification of the appropriate level or range of levels, this information may be appropriate to consider.

With respect to crops, based on the 10 robust E-R functions (i.e., barley, lettuce, field corn, grain sorghum, peanut, winter wheat, cotton, soybean, potato and kidney bean) described in the ISA and additionally analyzed in the WREA (Figure 5-4), Table 6-1 shows that for the CASAC recommended target benchmark protection level of 5% for median crop relative yield loss (RYL), W126 index values ranging from 7 to 17 ppm-hrs are protective. However, when

[2] We note that the updated table shows that a range of 7 ppm-hrs to 17 ppm-hrs will protect against RBL of 2% for at least 5 of the 11 species.

individual species are considered over this same range, the proportion of crops protected varies from 5/10, 6/10, 7/10, 9/10, 10/10, and 10/10 at the W126 levels of 17, 15, 13, 11, 9, and 7 ppm-hrs. To the extent a given species is judged as having particular importance to the public welfare, breaking the information down by species can be helpful. For example, less than 5% yield loss was estimated for soybeans at the W126 index value of 12 ppm-hrs (U.S. EPA 2014, Figure 6-3). Four of the studied crop species (barley, lettuce, field corn, and grain sorghum) are more tolerant, with RYL under 1% over the W126 range from 7 to 17 ppm-hrs. Peanut also remained under 4% RYL over the same W126 range. Other species differed regarding the W126 level at which RYL reached or fell below 5%. Specifically, for winter wheat, cotton, soybean, kidney bean and potato, the relevant W126 index values at which RYLs were below 5% are 15, 13, 11, 11, and 9 ppm-hrs. As noted in Chapter 5, the significance of these predicted RYLs to the public welfare could be informed by the recognition that crops are heavily managed to obtain the desired yield, and the extent to which yield reductions in any specific crop in a particular location are considered adverse to public welfare could depend on a number of economic factors, including crop prices, crop substitution, and the welfare importance of relative changes in consumer and producer surplus.

With respect to considering visible foliar injury, and its ability to inform selection of an appropriate target level or range of levels for public welfare protection, we first recognize its value as a long-standing and well-established bioindicator of O_3 exposure, as described in the ISA (U.S. EPA 2013, section 9.4.2). In addition to the role of visible foliar injury as an indicator, we note that the aesthetic aspects of visible foliar injury itself have the potential to be important to public welfare (as described in section 5.4). CASAC also "concurs that visible foliar injury can impact public welfare by damaging or impairing the intended use or service of a resource. Visible foliar injury that is adverse to public welfare can include: visible damage to ornamental or leafy crops that affects their economic value, yield, or usability; visible damage to plants with special cultural significance; and visible damage to species occurring in natural settings valued for scenic beauty or recreational appeal" (Frey, 2014a, p. 10). In this regard, we first note that several tribes have identified a number of O_3 sensitive species that are important to their cultural practices (Appendix 5A). These species have many cultural uses such as food, medicines, dyes, tools/textiles, spiritual, and commercial. In addition, visible foliar injury has been identified by the federal land managers (FLMs) as a diagnostic tool for informing conclusions regarding potential ozone impacts on potentially sensitive AQRVs (USFS, NPS, FWS, 2010), and the evidence shows that injury has been documented in such areas under recent air quality conditions.

Despite its recognized importance to the public welfare as a general matter, we are unaware of any injury benchmarks or criteria that have been identified by the FLMs as to what extent and/or severity of observed foliar injury warrants protection efforts. In considering CASAC comments in this regard we note that while it states that "[a] level below 10 ppm-hrs is required to reduce foliar injury" (Frey, 2014a, p. iii), CASAC does not provide any additional information regarding the public welfare significance of this degree of injury or what an appropriate target benchmark or range of benchmarks would be for foliar injury in relation to what could be considered adverse to the public welfare. Given that there is substantial variability in this endpoint, such that "the degree and extent of visible foliar injury development varies from year to year and site to site … even among co-members of a population exposed to similar O_3 levels, due to the influence of co-occurring environmental and genetic factors" (U.S. EPA, 2013, p. 9-38), staff recognizes the lack of a consistent or generally predictable relationship between particular W126 exposures and visible foliar injury incidence. We additionally note uncertainty in what can be concluded from foliar injury in relation to plant health, productivity and ecological function as "it is not presently possible to determine, with consistency across species and environments, what degree of injury at the leaf level has significance to the vigor of the whole plant" (U.S. EPA, 2013, p. 9-39). However, we do recognize the Congressional mandate, provided in the CAA amendments of 1977 that establish additional protections for Class I areas. The 1997 Consensus Workshop Report (Heck and Cowling, 1997) discussed below, noted the potential for visible foliar injury to occur at very low levels. CASAC also stated that "[v]isible foliar injury is even more sensitive than RBL of 2%, with W126 index values below 10 ppm-hrs required to reduce the number of sites showing visible foliar symptoms" (Frey, 2014, p. 14).We further note that the information discussed here regarding incidence of visible foliar injury does not include information regarding the severity of the observed symptoms and the degree to which the public welfare impacts from different severity benchmarks might vary. Thus, there is additional uncertainty regarding the potential variability in the severity of the symptoms across species and locations and to what degree this would affect the public welfare significance of these effects so that the appropriate range of W126 index values to protect against this effect is difficult and complicated to identify.

In further considering the available information pertaining to the question above, we additionally recognize conclusions that have been drawn by expert committees with regard to these endpoints (i.e., tree seedling growth, crop yields and visible foliar injury). For example, in their review of staff documents during the O_3 NAAQS review completed in 1997, the CASAC O_3 panel members expressed a wide range of opinions on aspects of the evidence important to consider in judging the adequacy of the O_3 secondary standard and in considering the form and level that would be appropriate for a secondary O_3 standard (Wolff, 1996). Subsequent to

CASAC meetings in 1995 on this topic, a consensus-building workshop sponsored by the Southern Oxidant Study group was held on the topic of the O_3 secondary standard in January 1996 (Heck and Cowling, 1997). This workshop was attended by 16 scientists with backgrounds in agriculture, managed forest, natural systems, and air quality, all of whom were leaders in their fields and whose research formed the basis of much of the research examined in the 1996 Criteria Document. These scientists expressed their judgments on what standard level(s) would provide vegetation with protection from O_3-related adverse effects that would be adequate, in their view.[3,4] As the 1997 workshop publication indicates, the scientists at the 1996 workshop also reached consensus views regarding the types of exposures that were important in eliciting plant response and the types of metrics that were best at predicting these responses (Heck and Cowling, 1997). Before coming to agreement on daily and seasonal durations and forms pertinent to a distinct secondary standard, the participants discussed and identified endpoints to consider for natural, forest and agricultural ecosystems.[5] With regard to form of the standard, participants concurred with either the SUM06 or W126 metrics, with consensus finally reached for SUM06, with some qualification regarding implications for a threshold. The participants identified the ranges they felt should be considered for each of three endpoints. Overall, the SUM06 values ranged from 8 to 20 ppm-hrs corresponding to W126 index values ranging from 5 to 17 ppm-hrs, based on the EPA analysis focused on conditions in NCLAN studies.[6] This overall range reflected ranges for each of the three endpoints, with the following considerations (Heck and Cowling, 1997).

- Crops (yield reductions): SUM06 of 15-20 ppm-hrs (13 to 17 ppm-hrs, W126). This range was recognized to generally consider <10% yield loss in more than 75% of species.
- Trees (growth effects): SUM06 of 10-16 ppm-hrs (7 to 14 ppm-hrs, W126). This range was recognized to generally consider 1-2% per year growth reduction; in so

[3] At the time of the workshop, the secondary O_3 standard being reviewed by EPA was a 1-hour average of 0.12 ppm (identical to the primary standard at that time). In 1997, EPA concluded the review by revising both standards to a longer averaging time of 8 hours with a level of 0.08 ppm (62 FR 38856).

[4] The workshop publication describes the primary objective for the workshop as having been to assemble knowledgeable scientists to develop a group consensus on "various critical components associated with a possible revised secondary ozone standard" (Heck and Cowling, 1997).

[5] For natural ecosystems, they focused on foliar injury as an indicator. For forest ecosystems, they concluded the data did not support selection of an indicator of effects on forest structure or function. As a result, they identified two indicators pertinent to the systems: growth effects on seedlings from species of natural forest stands (1-2% per year reduction), and growth effects on seedlings and saplings from tree plantations (1-2% per year reduction). For agricultural systems, the participants focused on protection against crop yield reductions, with their acknowledgment of high uncertainties at 5% leading them to a crop yield endpoint of 10% yield reduction (Heck and Cowling, 1997).

[6] During the last review, W126 index values corresponding to the SUM06 values cited in the report were estimated using the NCLAN crop loss data, a key dataset considered by workshop participants (see Appendix 7B of 2007 Staff Paper; Appendix 6A of this document).

doing, the group identified a need to consider the potential for year-to-year compounding of impacts in long-lived perennial species.

– Visible Foliar Injury: SUM06 of 8 to 12 ppm-hrs (5 to 9 ppm-hrs, W126).

Since the publication of 1996 workshop report and conclusion of the 1997 NAAQS review, the evidence base has continued to expand as described in the 2006 CD and ISA (U.S. EPA, 2006; U.S. EPA, 2013). With regard to tree growth effects and crop yield reductions, results of additional studies conducted in the field have confirmed the tree seedling biomass loss and crop yield loss E-R relationships derived from earlier studies that used OTC (U.S. EPA 2013, section 9.6).

In the 2008 review, CASAC provided comments related to a cumulative seasonal secondary standard in the context of their comments on the draft and final Staff Papers and on the final decision (Henderson, 2006; Henderson, 2007; Henderson, 2008). In all instances, they conveyed support for establishment of a distinct secondary standard with a cumulative seasonal form. While the EPA, in the 2007 Staff Paper and 2007 notice of proposed rulemaking, recognized a broader range of W126 index values as appropriate for consideration with regard to a distinct secondary standard, the CASAC Panel focused on a range they described as approximately equivalent to that identified by the 1996 workshop participants (Henderson, 2007, pp. 3, C-27).[7] In the CASAC Panel 2006-2007 advice on levels for such a standard, their suggestion was a focus on levels for a W126 index approximately equivalent to a SUM06 range of 10 to 20 ppm-hrs (Henderson, 2006, 2007, 2008), which they estimated in 2007 to be a range from 7 (or 7.5) to 15 ppm-hrs. Based on their consideration of the information available in that review (with regard to potential magnitude of effects across multiple years), the CASAC Panel further advised that "[i]f multi-year averaging is employed to increase the stability of the secondary standard, the level of the standard should be revised downward to assure that the desired threshold is not exceeded in individual years" (Henderson, 2007, p. 3). The CASAC advice provided on the 2010 proposed reconsideration and in this review is summarized in section 6.4 below.

In considering the evidence briefly summarized above in the context of levels for a W126-based standard, we recognize that given the different types of O_3-induced effects, genetic variability within and between species, and environmental modifiers of effects that also contribute to variability, it is not feasible to identify a range of cumulative seasonal exposures from the vegetation effects evidence which would provide a consistent degree of protection for

[7] Appendix C of the March 26, 2007 CASAC letter (Henderson, 2007) used a 2001 ambient concentration dataset and other factors, rather than study data considered in the 1996 workshop, in estimating an "equivalency" between the two indices.

all species. Thus, in our consideration of the evidence, we note the importance of considering several dimensions that pertain to judgments regarding public welfare significance. For example, we take note of the usefulness of considering the cumulative seasonal exposure at which the median species response or the majority of the species' responses are expected to be below minimal response benchmarks of interest and at which only a very few species' responses are expected to exceed more substantial response benchmarks. Before articulating such considerations with regard to specific benchmarks and index values, we first consider the WREA findings in the context of the following question.

- **What are the nature and magnitude of risks to vegetation estimated for the average W126 index scenarios evaluated in the WREA, and what is the magnitude of risk reduction from risks estimated for air quality conditions estimated for the current standard?**

The WREA provides a characterization of ambient O_3 exposure and its relationship to ecological effects, and estimates of the resulting impacts to several ecosystem services. In considering the question posed above, we focus particularly on WREA estimates related to O_3 effects on plant biomass and associated ecosystem services effects. The WREA analyses provide information on the geographical extent of the effects of O_3 exposure on plant biomass for different air quality scenarios. We also note the relationships among effects on individual plants to other ecosystem components and functions, such as carbon sequestration and air pollutant removal (U.S. EPA 2013, section 9.4.3.4; U.S. EPA, 2014b, sections 6.6 and 6.7), as well as market responses to changes in timber and agricultural production (U.S. EPA, 2014b, sections 6.3 and 6.5). We additionally recognize the potential for O_3 to impact other biomass-related responses, such as the supply of non-timber forest products and other ecosystem responses for which we have primarily qualitative characterizations of impacts (U.S. EPA, 2014b, chapter 5).

We turn first to the WREA estimates for a range of effects related to biomass loss, which are based on application of the robust E-R functions for seedlings of 11 tree species described in the ISA (U.S. EPA, 2013, section 9.6.2) and the WREA (U.S. EPA, 2014b, Appendix 6F)[8]. First, we note (as considered above) the range of responses for the individual species for which robust E-R functions have been developed. These eleven species vary appreciably in sensitivity of growth reduction (in terms of relative biomass loss, or RBL) in response to O_3 exposure.

[8] There is an E-R function available for a 12th tree species (cottonwood), but this E-R function is considered less robust because it is based on the results of a single gradient study (Gregg et al., 2003). That combined with its apparent extreme response to O_3 prompted CASAC to advise the Administrator to not place too much emphasis on cottonwood in the review of the secondary standard (Frey, 2014, p. 10). As a result, while we do include cottonwood in some of the analyses, we have decided it would not be appropriate to put less weight on the cottonwood biomass loss estimates when considering what levels of W126 should be considered protective of median species biomass loss.

Based on the 11 individual tree species with robust seedling E-R functions, six of the 11 species show 2% seedling biomass loss at a W126 index value below 8 ppm-hrs and in the other five species at a W126 index value above 18 ppm-hrs. Within the group of six more sensitive species, the most sensitive is black cherry (see Figure 5-1B).

In Appendix 6F, the WREA presents individual and median response across the studied tree and crop species (U.S. EPA 2014, Appendix 6F). This appendix includes an analysis of the median of the composite exposure-response (E-R) functions for tree seedlings and crops. Specifically, Tables 6F-1 and 6F-2 provide estimates of the relative loss for trees and crops respectively at various W126 index values using the composite E-R functions for each species. The median of the composite functions is calculated for all 12 tree species as well as for the 11 tree species excluding cottonwood. The median of the composite functions for all 12 tree species and all 10 crop species is consistent with the green line shown in Figures 6-5 and 6-6 (U.S. EPA 2014, section 6.2.1.2. Tables 6F-3 and 6F-4 provide estimates of the number of species for trees and crops respectively that would be below various benchmarks (e.g., 2% biomass loss for trees) at various W126 index values. Based on the median composite E-R function developed for the 11 tree species depicted in WREA Table 6F-1, median tree species biomass loss ranges from less than 1.5% to 5.3% over the W126 index value range of 7 to 17 ppm-hrs (U.S. EPA, 2014b, Appendix 6F).

We additionally consider the WREA estimates of overall ecosystem-level effects from biomass loss considering the studied species together (U.S. EPA 2014, section 6.8). The WREA analysis used the species-specific biomass loss E-R functions, information on prevalence of the studied species across the U.S., and a weighting approach based on proportion of the basal area within each grid cell that each species contributes. The WREA analyses use information from the individual and median E-R functions for tree seedlings to provide information on the geographical extent of the effects of O_3 exposure on growth reduction for different air quality scenarios. It provides information on the location and number of species affected, as well as information about the estimated effects in Class I areas. We note that some of these analyses continue to include cottonwood and where this is the case, it is so noted. In the WREA analyses, the largest reductions in O_3 concentrations occur when air quality is adjusted from recent conditions to meeting the current standard. Smaller changes in O_3 concentrations occur when air quality is adjusted for the W126 air quality scenarios for 15, 11, and 7 ppm-hrs (average across three years), relative to meeting the current standard.

A weighted RBL value for each grid cell is generated by weighting the RBL value for each studied tree species found within that grid cell by the proportion of basal area it contributes to the total basal area of all (unstudied and studied) tree species within the grid cell, and then

summing those individual weighted RBLs. Table 6-2 below describes the percent of assessed geographic area with RBL exceeding 2% for 11 species based on the average W126 index values estimated for five air quality scenarios. Under recent conditions, 7.6 % of the total geographic area has a wRBL above 2% while just meeting the current standard across the contiguous U.S., the WREA estimates 0.2% of the total geographic area to have a weighted relative biomass loss above 2% for the 7 ppm-hrs scenario (Table 6-2 below; U.S. EPA 2014, Table 6-25). In the W126 air quality scenarios for 15, 11, and 7 ppm-hrs (average across three years), the percent of total area having weighted relative biomass loss greater than two percent was 0.2 percent, 0.1 percent and <0.1 percent, respectively (Table 6-2 below; U.S. EPA 2014, Table 6-25). In considering these estimates, however, we note that the values for percentages of basal area include many grid cells in which none of the 11 studied species are found, and thus these values are likely to be low. In addition, the ecosystem level impacts from O_3-induced effects on biomass loss in each grid cell would also depend on the interaction between the studied species with known O_3-sensitivities and the other species that are also contributing to the total basal area which have unstudied O_3-sensitivities. Given these and other potential uncertainties and limitations associated with this analysis (U.S. EPA, 2014b, section 6.8), which were also commented on by CASAC (Frey, 2014a, p. A-40), we thus conclude that this analysis does little to inform the nature and degree of risk likely to be experienced by O_3-sensitive species growing in mixed-species forests, which are wide-spread in the eastern U.S. These values may be more appropriate for western forests which more often are composed of a single species (i.e., ponderosa pine, aspen forests).

Table 6-2. Percent of assessed geographic area exceeding 2% weighted relative biomass loss in WREA air quality scenarios.

Percent of total area with wRBL>2%	----------Air Quality Scenarios ----------				
	Recent Conditions (2006-2008)	Conditions just meeting the current standard[A]	W126 index scenarios[B]		
			15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Using all 12 Species	10.8%	0.8 %	0.7 %	0.5 %	0.2 %
Using 11 species (excluding cottonwood)	7.6%	0.2%	0.2%	0.1%	<0.1%

[A] This analysis uses air quality values that are estimated per model grid cell using the W126 index value assigned to the grid cell based on application of the VNA method to the monitor-location W126 index values that are the average at that location across the 3 years of W126 index values for the adjusted dataset that just meets the current standard (4th highest daily maximum 8-hour concentration, averaged over 3 consecutive years of 75 ppb).

[B] The national distribution of W126 index values within model grid-cells for each scenario reflects model-based adjustment of 2006-2008 O_3 concentrations at monitoring sites such that the average W126 index at the controlling location in each of the modeling regions just meets the scenario target index value, followed by application of the VNA interpolation methodology (see U.S. EPA, 2014b, section 4.3.4.1 and Appendix 4A).

To further inform this issue, the WREA characterized the number of counties where the median RBLs were above 2% (U.S. EPA, 2014b, Table 6-7), as shown in Table 5-5. Given CASAC's advice to put less emphasis on cottonwood, we focus on the rows of this table that excluded cottonwood. Under recent conditions, 52% of the counties have median RBLs above 2%. When air quality is adjusted to the current standard, that proportion drops to 8% and further decreases to 6% for air quality adjusted to just meet a 3-year average W126 level of 7 ppm-hrs. With respect to median RBL values, of the 239 counties (8% of counties) estimated to have a median RBL above 2% when meeting the current standard, 203 of those counties have a RBL above 2% because of the presence of black cherry. Thus, as also discussed above in Section 6.2, given the magnitude of estimated RBL for black cherry over the entire range assessed, it is not clear to what extent the information for black cherry informs the selection of an appropriate level.

In addition, the WREA also characterized the number of counties where one or more individual studied tree species showed a 2% biomass loss (U.S. EPA, 2014b, Table 6-7), as also shown in Table 5-5. This is consistent with CASAC advice that "rather than focusing solely on the median relative biomass loss (RBL), the number of counties containing sensitive tree species that are expected to have growth loss of greater than 2% should be quantified" (Frey, 2014a, p. 11). The maximum number of species that exceed 2% RBL in any one county is five species, which only occurs under recent O_3 conditions. After meeting the current standard, the maximum number of species in any one county is four. This information shows that a number of counties have more than one O_3-sensitive species growing in it, potentially together in the same forest stands, whose RBLs are above 2%. Given CASAC's advice to put less emphasis on cottonwood, we focus on the rows of this table that excluded cottonwood. Under recent air quality conditions, the proportion of counties with 1 or more species with an RBL greater than 2% is 78% (2,418 counties). As air quality is adjusted to just meet the current standard and the alternative W126 index value of 7 ppm-hrs, this number drops to 62% and 58%, respectively. We note that of the 1929 counties estimated to have 1 or more species with an RBL greater than 2% when meeting the current standard[9], 1805 of those counties are estimated to have black cherry as the only species estimated to experience this level of biomass loss. Thus, as also discussed above in Section 6.2, given the magnitude of estimated RBL for black cherry over the entire range

[9] Excluding cottonwood, as discussed above.

assessed, it is not clear to what extent the information for black cherry informs the selection of an appropriate level. We next consider the wRBL estimates from the WREA analysis of 145 (of the 155) federally designated Class I areas for which there was sufficient information regarding O_3-sensitive species (U.S. EPA, 2014b, section 6.8.1, Table 6-26, Appendix 6E). These 145 parks had at least one O_3-sensitive tree species for which an E-R function for RBL was available. Using the E-R functions for the species found within each park, the WREA calculated an average wRBL value for each park for the 3-year average W126 index values estimated in those locations for the current standard and three W126 air quality scenarios. Under conditions adjusted to just meet the current standard, the average wRBL in 2 of the 145 parks is estimated to be above 2%, as presented in Table 6-3 below. These two parks are Badlands National Park, driven by sensitivity of cottonwood, and Wind Cave National Park, driven by sensitivity of ponderosa pine. We compare this estimate to those for the W126 scenarios. For the W126 scenarios of 15 and 11 ppm-hrs, the estimated weighted RBL is greater than 2% in these same two of the 145 parks, while it is greater than 2% in only 1 park (Wind Cave) for the 7 ppm-hrs scenario.

Table 6-3. Number of Class I areas (of 145 assessed) with weighted relative biomass loss greater than 2%.

	----------Air Quality Scenarios ----------			
		3-Year Average W126 index scenarios[B]		
	Conditions just meeting the current standard[A]	15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Number of Class I areas with wRBL>2%	2	2	2	1

[A] The wRBL is estimated per model grid cell (in which there are any of the 12 studied species) from W126 index value assigned to the grid cell based on application of the VNA method to the monitor-location W126 index values that are the average at that location across the 3 years of W126 index values for the adjusted dataset that just meets the current standard (4th highest daily maximum 8-hour concentration, averaged over 3 consecutive years of 75 ppb).

[B] The national distribution of W126 index values within model grid-cells for each scenario reflects model-based adjustment of 2006-2008 O_3 concentrations at monitoring sites such that the average W126 index at the controlling location in each of the modeling regions just meets the scenario target index value, followed by application of the VNA interpolation methodology (see U.S. EPA, 2014b, section 4.3.4.1 and Appendix 4A).

The WREA estimates of crop yield loss for the modeled air quality scenarios are summarized in Table 6-4 below (details are provided in U.S. EPA 2014, section 6.5.1 and Appendix 6B). For the recent air quality conditions scenario, the means for all crops were less than 5% loss across all states. Crop yield loss estimates for all states were also less than 5% in the air quality scenario representing conditions just meeting the current standard (U.S. EPAb, 2014, section 6.5.1 and Appendix 6B).

Table 6-4. Estimated mean yield loss (and range across states) due to O_3 exposure for two important crops.

Crop	Air Quality Scenarios				
	Recent Conditions (2006-2008)	Conditions just meeting the current standard[A]	Average W126 index scenarios[B]		
			15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
Corn	<5% [C] (0.01-0.88)	<5% (0.0-0.01)	<5% (0.0-0.01)	<5% (0.0 – 0.0)	<5% (0.0 – 0.0)
Soybean	<5% (0.69-8.30)	<5% (0.01 – 1.39)	<5% (0.01 – 1.13)	<5% (0.01 – 0.75)	<5% (0.01 – 0.59)

[A] The crop yield loss is estimated per grid cell (and per FASOMGHG region) from W126 index value assigned to the cell based on application of the VNA method to the monitor-location W126 index values that are the average at that location across the 3 years of W126 index values for the adjusted dataset that just meets the current standard (4th highest daily maximum 8-hour concentration, averaged over 3 consecutive years of 75 ppb).

[B] The national distribution of W126 index values within grid cells for each scenario reflects model-based adjustment of 2006-2008 O_3 concentrations at monitoring sites such that the average W126 index at the controlling location in each of the modeling regions just meets the scenario target index value, followed by application of the VNA interpolation methodology (see U.S. EPA 2014 section 4.3.4.1 and Appendix 4A).

[C] Mean yield loss is the mean across modeling units. The range presented in parentheses below the mean represents the minimum and maximum estimates across modeling units (U.S. EPA 2014, Appendix 6B).

The WREA also analyzes market responses to changes in timber and agricultural production (U.S. EPA, 2014b, sections 6.3 and 6.5). As explained above, however, comparisons of the WREA's air quality scenarios for the national-scale estimates of timber production and consumer and producer surpluses are not straightforward to interpret due to market dynamics. Estimates for the recent conditions and current standard scenarios are compared to the three W126 scenarios. In general, substantially greater economic surpluses (approximately $51 billion) are estimated from the comparison of the recent conditions (2006-2008) scenario to the current standard scenario. The vast majority of these economic surpluses are estimated for agricultural production. Differences of the average W126 scenarios from the current standard scenario are much smaller (U.S. EPA 2014, Appendix 6B).

Because increases in timber production represent increased tree growth and concurrent carbon sequestration, we also consider WREA estimates of the potential increase in carbon storage that potentially could occur for different air quality scenarios (U.S. EPA 2014, section 6.6.1). Comparisons of the W126 scenarios to the current standard scenario with regard to carbon sequestration estimates do not indicate an appreciable difference for the W126 scenario of 15 ppm-hrs beyond that achieved by just meeting the current standard. The majority of the enhanced carbon sequestration potential resulting from increases in forest biomass is predicted to occur for the W126 scenarios of 11 and 7 ppm-hrs. Over 30 years, the current standard scenario

projection is 89,184 million metric tons of CO_2 equivalents ($MMtCO_2e$).[10] The WREA estimates additional sequestration potential of 13, 593 and 1,600 $MMtCO_2e$, for the W126 scenarios of 15, 11 and 7 ppm-hrs, respectively, as compared to the current standard (U.S. EPA 2014, Table 6-18). We also take note of the relatively smaller estimates for carbon sequestration associated with improved crop yields (over 30 years) in the agricultural sector, which indicate little difference among the different W126 scenarios, beyond that achieved by just meeting the current standard.

We additionally consider the WREA estimates for five urban areas of how reduced growth of O_3-sensitive trees in urban forests may affect the ecosystem services of air pollutant removal and carbon sequestration (U.S. EPA, 2014b, sections 6.6.2 and 6.7 and Appendix 6D). With regard to air pollutant removal, the WREA estimated metric tons of carbon monoxide, nitrogen dioxide, ozone and sulfur dioxide removed under the W126 scenarios. In considering these estimates we note the general assumptions made to estimate order of magnitude effects of O_3 removal by trees on O_3 concentrations in the five urban areas and the associated uncertainties (U.S. EPA 2014, sections 6.7 and 6.9 and Appendix 6D). Estimates for all five case study areas indicate increased pollutant removal from the recent conditions scenario to just meeting the current standard scenario, with much smaller differences between the current standard and the three W126 scenarios (Table 6-5 below). The largest difference in carbon sequestration is between the existing conditions scenario and the current standard scenario (Table 6-5). In addition to the small differences in W126 index values among the three W126 air quality scenarios relative to the current standard for these five areas, only 2 or 3 tree species were able to be assessed in each city. Therefore, these results may underestimate the overall impacts in these areas and nationally, although other areas of uncertainty (recognized below) may tend to contribute to the opposite potential (U.S. EPA 2014, Table 6-27).

[10] 1 $MMtCO_2e$ is equivalent to 208,000 passenger vehicles or the electricity to run 138,000 homes for 1 year as calculated by the EPA Greenhouse Gas Equivalencies Calculator (updated September 2013 and available at http://www.epa.gov/cleanenergy/energy-resources/calculator.html).

Table 6-5. Estimated effect of O_3-sensitive tree growth-related impacts on the ecosystem services of air pollutant removal and carbon sequestration in five urban case study areas.

Case Study Area	Air Quality Scenarios				
	Recent Conditions (2006-2008)	Conditions just meeting the current standard[A]	Average W126 index scenarios[B]		
			15 ppm-hrs	11 ppm-hrs	7 ppm-hrs
	Air Pollutant Removal (metric tons, CO, NO_2, O_3, SO_2)				
Atlanta	33,000	35,800	35,800	36,000	36,300
Baltimore	8,500	9,200	9,200	9,200	9,200
Chicago	355,000	359,000	359,000	361,000	365,000
Syracuse	1,500	1,700	1,700	1,700	1,700
Tennessee urban	474,000	511,000	511,000	516,000	522,000
	Carbon Storage (million metric tons of CO_2 equivalents, cumulative over 25 years)				
Atlanta	1.2	1.32	1.32	1.32	1.34
Baltimore	0.5	0.57	0.57	0.57	0.57
Chicago	16.9	17.05	17.05	17.10	17.21
Syracuse	0.14	0.17	0.17	0.17	0.17
Tennessee urban	18.0	19.67	19.67	19.89	20.16

[A] Results are derived from estimates per model grid cell (in which there are any of the 12 studied species) from W126 index value assigned to the grid cell based on application of the VNA method to the monitor-location W126 index values that are the average at that location across the 3 years of W126 index values for the adjusted dataset that just meets the current standard (4th highest daily maximum 8-hour concentration, averaged over 3 consecutive years of 75 ppb).

[B] The national distribution of W126 index values within model grid-cells for each scenario reflects model-based adjustment of 2006-2008 O_3 concentrations at monitoring sites such that the average W126 index at the controlling location in each of the modeling regions just meets the scenario target index value, followed by application of the VNA interpolation methodology (see U.S. EPA, 2014b, section 4.3.4.1 and Appendix 4A).

With regard to foliar injury, we take note of the WREA analyses of the nationwide dataset (2006- 2010) for USFS/FHM biosites described in section 5.4.2 above, including the observation that the proportion of biosites with injury varies with soil moisture conditions and O_3 W126 index values (U.S. EPA 2014, Chapter 7, Figure 7-10). The evidence of O_3-attributable visible foliar injury incidence occurring in USFS/FHM biosites shows that the proportion of biosites showing foliar injury incidence increases steeply with W126 index values up to approximately 10 ppm-hrs. At W126 index levels greater than approximately 10 ppm-hrs, the proportion of sites showing foliar injury incidence is relatively constant.

In reflecting across the range of W126 index values evaluated in various WREA analyses, we first note the substantial reductions in biomass-related risks estimated for air quality

adjusted to just meet the current standard scenario. Additional incremental risk reductions are estimated across the W126 scenarios, although these risk reductions are substantially smaller.

In considering the WREA estimates here, we take note of uncertainties in the adjusted estimates. Adjustments were made to recent air quality to reflect just meeting the current standard and three W126 levels. These adjustments were based on air quality modeling simulations reflecting across-the-board reductions in NO_x emissions required to bring the highest monitor down to the target level in different regions of the country. In some areas, meeting a target level at the highest monitor in the region had the effect of substantially reducing concentrations below the targeted level in other parts of the region. This adjustment approach is not meant to represent an actual control strategy but to provide an approximation of the spatial variability of O_3 across an area when just meeting the current standard and three W126 levels.

We also note potential uncertainties in the extent to which the results for each modeled air quality scenario represent cumulative seasonal O_3 exposures that would be expected to occur across the three years represented in each scenario. In general, each scenario is represented by a dataset of 3-year average W126 index values across the national modeling area. Thus, the results estimated for the various analyses that use these scenarios do not reflect any year-to-year variability that would be expected in single year results. Rather, they reflect average estimates for the three year period modeled. Analyses in the WREA describe the potential for the WREA estimates to underestimate cumulative biomass-related effects in perennial species (as noted in sections 6.2 and 5.2.2 above and described in detail in U.S. EPA, 2014b, chapter 6, 6.2.1.4). This potential for underestimation is recognized in the context of the uncertainties associated with other aspects of the different analyses in section 6.9 of the WREA (e.g., U.S. EPA, 2014b, Table 6-27). We additionally note that the WREA compounding analyses do not take into account other variables that can affect the magnitude of these effects in the field. In considering this information discussed above in the context of identifying levels appropriate to consider for a W126-based standard, we take note of additional associated uncertainties as discussed under the following question.

- **What are important uncertainties and limitations in the evidence and exposure/risk analyses?**

In considering the evidence and exposure/risk information summarized above and the weight to place on this information, we are mindful of the uncertainties and limitations associated with several key aspects of this information. We first consider the uncertainties associated with the evidence underlying the tree seedling and crop E-R functions, given the importance of these functions for many of the ecosystem service analyses described in the

WREA. Several key uncertainties associated with this information are listed below and described in more detail in the WREA (U.S. EPA, 2014b).

- Uncertainty regarding the extent to which the subset of studied tree and crop species encompass the total number of O_3 sensitive species in the nation and to what extent it is representative of U.S. vegetation as a whole, given that information is available for only a small fraction of the number of total species of trees and crops grown in the U.S. (U.S. EPA, 2013, section 9.6, U.S. EPA, 2014b, Table 6-27).
- Uncertainties regarding intra-species variability due to the different numbers of studies that exist for different species so that the weight of evidence is not the same for each species. Those species with more than one study show variability in response and E-R functions. The potential variability in less well-studied species is, however, unknown (U.S. EPA, 2013, pp. 9-123/125, U.S. EPA, 2014b, section 6.2.1.2, and Table 6-27).
- Uncertainty regarding the extent to which tree seedling E-R functions can be used to represent mature trees since seedling sensitivity has been shown in some cases to not reflect mature tree O_3 sensitivity in the same species (U.S. EPA, 2013, section 9.6, U.S. EPA, 2014b, section 6.2.1.1 and Tables 6-5 and 6-27).
- Uncertainty in the relationship of O_3 effects on tree seedlings (e.g., relative biomass loss) in one or a few growing seasons to effects that might be expected to accrue over the life of the trees extending into adulthood (U.S. EPA, 2013, pp. 9-52/53, U.S. EPA, 2014b, section 6.2.1.4 and Table 6-27).
- Uncertainties associated with estimating the national scale ecosystem-level impacts using weighted relative biomass loss (U.S. EPA, 2014b, section 6.8, and Table 6-27).
- Uncertainties associated with potential biomass loss in federally designated Class I areas (U.S. EPA, 2014b, section 6.8. and Table 6-27).

Turning to consideration of the air quality conditions estimated for the various air quality scenarios, we take note of the following uncertainties associated particularly with estimates of O_3 exposures in rural areas nationally. These are described more completely in chapter 4 of the WREA (see for example, U.S. EPA, 2014b, section 4.4) and summarized in chapter 8 of the REA (U.S. EPA, 2014b, section 8.5).

- Uncertainties in O_3 exposures due to a lack of rural monitors, especially in the western U.S. and at high elevation sites.
- Uncertainties associated with the method (VNA) used to interpolate monitor values to estimate W126 index values in locations without monitors.
- Uncertainties in adjusted estimates of O_3 concentrations associated with meeting the current standard and potential alternative W126-based standards.

Numerous ecosystem services assessments were described in the WREA. These assessments relied heavily on models, which also relied on the inputs of the tree seedling and crop E-R functions and adjusted air quality estimates. Thus, including the uncertainties from the

first two categories discussed above, additional uncertainties associated with the ecosystem services models include the following.

- Uncertainties associated with use of the i-Tree model to estimate pollution removal and carbon storage in five urban area case studies, including uncertainties in the base inventory of city trees, the functions used for air pollution removal and carbon storage (U.S. EPA, 2014b, sections 6.6.2, 6.7, and Table 6-27).
- Uncertainties associated with use of the FASOMGHG model for national timber and crop production, including use of median E-R functions for crops in FASOM and crop proxy and forest type assumptions to fill in where there was insufficient data (U.S. EPA, 2014b, sections 6.3, 6.5, 6.6.1, and Table 6-27).
- Uncertainties associated with use of the FASOMGHG model to estimate national scale carbon sequestration, including those associated with the functions for carbon sequestration (U.S. EPA, 2014b, sections 6.2.1.1, 6.6.1, and Table 6-27).

In addition, the WREA estimates the incidence and of O_3-induced visible foliar injury, both at the national and national park scales. Numerous uncertainties are associated with these assessments and include the following.

- Uncertainties associated with our understanding of the number and sensitivity of O_3 sensitive species (U.S. EPA, 2014b, sections 7.2.1, 7.5 and Table 7-22).
- Uncertainties associated with spatial assignment of foliar injury biosite data to 12x12 km grids (U.S. EPA, 2014b, sections 7.2.1, 7.5 and Table 7-22).
- Uncertainties associated with availability of biosite sampling data in some locations in the western U.S. (U.S. EPA, 2014b, sections 7.2.1, 7.5 and Table 7-22).
- Uncertainties associated with soil moisture threshold for foliar injury (U.S. EPA, 2014b, sections 7.2.2, 7.2.3, 7.5 and Table 7-22).
- Uncertainties associated with spatial resolution of soil moisture data, time period for soil moisture data, drought categories and the combination of soil moisture and biosite data (U.S. EPA, 2014b, sections 7.3.3.2, 7.5 and Table 7-22).
- Uncertainties associated with O_3 exposure data of vegetation and recreational areas within parks (U.S. EPA, 2014b, sections 7.4, 7.5 and Table 7-22).
- Uncertainties associated with surveys of recreational activities (U.S. EPA, 2014b, sections 7.1.1.2, 7.5 and Table 7-22).

Additionally, there is uncertainty associated with the extent to which the endpoints and associated risk estimates considered above represent effects reasonably judged adverse in the context of public welfare. Despite these uncertainties, the overall body of scientific evidence underlying the ecological effects and associated ecosystem services evaluated in the WREA is strong, and the methods used to quantify associated risks are scientifically sound (Frey, 2014b).

All of these uncertainties are important to considerations below in the context of target levels of protection with regard to weight to be placed on various lines of evidence and assessment results.

- **Are there other aspects of the form that affect consideration of the welfare protection provided by the level of the cumulative seasonal standard?**

Although cumulative, seasonal exposure indices of interest for vegetation effects are often expressed in terms of a single season, we recognize that it can also be appropriate to consider a form that is evaluated over a multiple-year period, such as three years (U.S. EPA, 2007; 72 FR 37901; 75 FR 3021). The current form of the secondary standard is a 3-year average, and we recognize that the protection provided by the secondary standard derives from the combination of all elements of the standard (indicator, form, averaging time(s), and level). Thus, we find it appropriate to evaluate the protection that might be afforded by a form limited to a single year or one that is based on evaluation of exposures across multiple years. Although cumulative, seasonal exposure indices of interest for vegetation effects are often expressed in terms of a single season, we recognize that it can also be appropriate to consider a form that is evaluated over a multiple-year period, such as three years (U.S. EPA, 2007; 72 FR 37901; 75 FR 3021). Accordingly, this discussion explores the information relevant to consider in conjunction with the above identification of the W126 index form, 12-hour daylight averaging time and maximum consecutive 3-month seasonal exposure period, and the subsequent discussion on level below, when considering support in the current information for single and/or multiple-year options.

We additionally take note of advice from CASAC on this topic in the current and prior reviews. Specifically, in this review, CASAC stated that it "does not recommend the use of a three-year averaging period for the secondary standard. We favor a single-year period for determining the highest three-month summation which will provide more protection for annual crops and for the anticipated cumulative effects on perennial species. The scientific analyses considered in this review, and the evidence upon which they are based, are from single-year results. If, as a policy matter, the Administrator prefers to base the secondary standard on a three-year averaging period for the purpose of program stability, then the level of the standard should be revised downward such that the level for the highest three-month summation in any given year of the three-year period would not exceed the scientifically recommended range of 7 ppm-hrs to 15 ppm-hrs" (Frey, 2014a, p. iii).

In considering an annual form of a standard, we particularly take note of O_3-induced vegetation effects that can occur as a result of a single year's exposure. These include visible foliar injury symptoms, growth reduction in annual and perennial species, and yield loss in annual crops. The following discussion considers these effects, in the context of their potential public welfare significance, and in regard to the extent to which a W126-based standard with an

annual form or one based on evaluation across multiple years may be able to provide appropriate protection

In the case of foliar injury, the ISA notes that the full body of evidence indicates that there is wide variability in this endpoint, such that although evidence shows visible foliar injury can occur under very low cumulative O_3 concentrations, "…the degree and extent of visible foliar injury development varies from year to year and site to site… even among co-members of a population exposed to similar O_3 levels, due to the influence of co-occurring environmental and genetic factors" (U.S. EPA 2013, section 9.4.2, p. 9-38). In addition, the WREA assessment of foliar injury showed the difficulty and complexity associated with identifying W126 index values that would consistently provide appropriate protection on an annual basis for this endpoint. We thus conclude that there is limited information to discern between the level of protection provided by an annual form or a 3-year average form of a W126 standard for this endpoint, and that a multiple year form could be considered to provide a more consistent target level of protection for this endpoint, given likely fluctuations in annual O_3 and soil moisture conditions.

In the case of annual commodity crops, the overall welfare effect of annual changes in yields due to O_3 exposures is not straightforward. As noted above, determining at what point O_3-induced crop yield loss becomes adverse to the public welfare is still unclear, given that it is heavily managed with additional inputs that have their own associated markets and that benefits can be unevenly distributed between producers and consumers. We thus conclude that there is limited information to discern between the level of protection provided by an annual form or a 3-year average form of a W126 standard for this endpoint. As with foliar injury, we thus conclude that it is appropriate to consider a level of protection for annual commodity crops that would be achieved, on average, using a multiple year form, to provide a more consistent target, given likely fluctuations in environmental and economic conditions.

In contrast to impacts on annual species that accrue in the single growing season in which the O_3 exposures occur, annual effects in perennial species can be "carried over" into the subsequent year where they affect growth and reproduction (U.S. EPA, 2013, pp. 9-43 to 9-44 and p. 9-86). In addition, when these effects occur over multiple years due to elevated O_3 exposures across several years, they accumulate and potentially compound, increasing the potential for effects at the ecosystem level and associated ecosystem services that may be of significance to the public welfare.

Effects from elevated O_3 years on perennial plants, when they occur over several years, can be propagated up to higher spatial scales where they can contribute to effects on ecosystem services, e.g., alteration of below-ground biogeochemical cycles, and alteration of both above- and below- ground terrestrial community composition and terrestrial ecosystem water cycling

(U.S. EPA, 2013, Table 9-19). Ozone has also been shown to affect plant reproduction in numerous ways (U.S. EPA, 2007, 7.3.3.3; U.S. EPA, 2013, 9.4.3.1). These effects, when they occur at sufficient magnitude for a single species, may result in impaired recruitment and loss of the species from the stand or community. This has the potential to change the community composition and biodiversity. If these effects occur in multiple plant species and/or over multiple years, they can result in a reduction in the productivity and carbon sequestration of terrestrial ecosystems. Such ecosystem-related effects and others discussed in the ISA may be considered to reflect impacts of critical O_3 exposures over the longer term. We additionally note that as compared to intermittent (or single year) critical O_3 exposures, multiple years of such exposures might be expected to result in larger impacts on forested areas, e.g., increased susceptibility to other stressors such as insect pests, disease, co-occurring pollutants and harsh weather, due to the potential for compounding or carry-over effects on tree growth.

Given the above, we find it reasonable to conclude that the public welfare significance of the effects that can accumulate as a result of multiple-year O_3 exposures have the potential to be greater and more certain than those that are realized in an individual year. Thus, to the extent that the focus for public welfare protection is on long-term effects that occur in sensitive tree species in natural forested ecosystems, including in federally protected areas such as Class I areas or on lands set aside by states, tribes and public interest groups to provide similar benefits to the public welfare, a cumulative seasonal standard that evaluates exposures across multiple years (in combination with an appropriate level) might be a more appropriate match to provide the requisite protection for those O_3-related effects on vegetation that when accumulated across years, are potentially significant and adverse to the public welfare.

Additionally, we address the potential for cumulative impacts on biomass loss over a 3-year period versus a 1-year period. First it is important to note that the WREA analyses that characterize plant biomass and associated ecosystem services effects, discussed above in this section, are based on a 3-year average. The WREA analysis examined the potential for biomass loss estimates based on a 3-year average W126 index value to underestimate the cumulative impact on growth based on the biomass loss that would be predicted in each of the 3 years, based on the yearly W126 index values. The results show that the use of the three-year average W126 index value may underestimate RBL values slightly. However, it should be noted that the approach does not account for moisture levels or other environmental factors that could affect biomass loss (U.S. EPA, 2014b, section 6.2.1.4 and Figure 6-14). In considering these results, we note that in these regions and in all three years, the three-year average W126 index value is sometimes above and sometimes below the individual year W126 index value.

In addition to the vegetation effects considerations described above, there are other policy-relevant factors that can be useful to consider. For example, under a standard with a

single year form, a monitor may be judged to meet the standard based on a single year of data, while under a standard with a form requiring evaluation over a multi-year period, a monitor is not judged to have met the standard until a complete multi-year record is available. For a W126-based potential standard, the multi-year form identified for consideration in the last review was the average cumulative seasonal metric over three consecutive years (75 FR 3027). Such a multi-year form remains appropriate to consider to provide stability to an alternative secondary standard, just as the multi-year form provides for the current standard (average over three years of annual fourth-highest daily maximum 8-hour average O_3 concentrations).[11] In considering the issue of stability in the context of such a form, we first note the inter-annual variability of seasonal W126 index, which is not unexpected given the logistic weighting function and also inter-annual variability in meteorological conditions that contribute to O_3 formation (see Appendix 2C). The staff analysis in Appendix 2C describes the variability in annual W126 index values in relation to variability in the 3-year average, which indicates that a standard based on an annual W126 index would be expected to have a lower degree of year-to-year stability relative to a standard based on a form that averages seasonal indices across three consecutive years. A more stable standard can be expected to contribute to greater public welfare protection by limiting year-to-year disruptions in ongoing control programs that would occur if an area was frequently shifting in and out of attainment due to extreme year-to-year variations in meteorological conditions. This greater stability in air quality management programs thus facilitates achievement of the protection intended by a standard. In light of this relationship, we conclude that a 3-year average form has the desirable feature of providing greater stability in air quality management programs and thus facilitating the achievement of the protection intended by a standard. Thus, we recognize the public welfare benefits of having a standard of a 3-year average form.

CASAC has asked that the PA quantify the ratio of the 3-year average of the highest three-month summations in each year to the highest three-month summation in the highest year within that same 3-year average period. This information is provided in a technical memorandum titled "Relationship between W126 annual values and three-year averages" (EPA-HQ-OAR-2005-0172) and in the analyses included in Appendix 2C. In the technical memorandum, an analysis summarized the relationship between annual W126 index values and the three-year averages of the annual values based on 2007-2009 air quality data. Based on the air quality data, 79 percent of counties meeting a three-year average W126 index value of 13 ppm-hrs would also not have annual W126 index values above 15 ppm-hrs. In addition, in terms

[11] See *ATA III*, 283 F. 3d at 374-75 (recognizing programmatic stability as a legitimate consideration in the NAAQS standard-setting process).

of county-years (i.e., the number of counties times the number of years in the analysis), 93 percent of the county-years meeting a three-year average W126 index value of 13-ppm-hrs would also meet an annual W126 index value of 15 ppm-hrs.

In addition, Appendix 2C compared annual W126 index values to three-year average W126 index values for 2008-2010 air quality data. It concluded that the data analysis "shows that the inter-annual variability in the annual W126 index tends to decrease with decreasing W126 levels. Thus, it is expected that reductions in NO_x emissions will not only result in lower 3-year average W126 levels, but also result in less inter-annual variability associated with annual W126 levels." Appendix 2C also concludes that the inter-annual variability in the W126 index increases and decreases along with the three-year average.

These analyses suggest that meeting a 3-year average W126 index value of 13 ppm-hrs would mean that for most years and monitoring sites the annual W126 index value would be below 15 ppm-hrs. In addition, the relationship between 3-year average W126 index values and annual W126 index values is dynamic and varies with the three-year average W126 index value and will continue to change in the future with changing pollution levels.

Accordingly, in considering all elements for a revised standard, including level and form, we note that a standard with a form that averages across three years can also control for year-to-year variability and individual year concentrations. The appropriate level and form combination will depend on which effects endpoints are considered to warrant additional public welfare protection and what is considered to be the requisite range of target levels of protection. In articulating these objectives it may be appropriate to evaluate the nature of the O_3 induced effects and their significance or importance to the public welfare, as well as the role that year-to-year exposure variability can play in public welfare impacts.

- **What considerations may be important to the Administrator's judgments on the public welfare significance of O_3 associated vegetation effects that may be expected under air quality conditions associated with different levels for a seasonal cumulative standard?**

Our consideration of this question is intended to provide a public welfare context for consideration of the evidence and exposure/risk information discussed above, which includes the nature and magnitude of observed and predicted effects at various levels of cumulative seasonal exposures. We also note the importance of considering information in an integrated manner, rather than focusing only on results from any one analysis. For example, we find it appropriate, in considering the evidence with regard to seedling growth reduction (or biomass loss), to consider the WREA estimates of affected area based on tree basal area together with estimates of individual species responses based simply on the evidence-based E-R functions, and in light of other potential impacts summarized above. In so doing in section 6.5 below, we take into

account considerations relevant to public welfare policy judgments required of the Administrator, such as those described here.

As recognized in sections 1.3.2 and 5.1, the Clean Air Act specifies that secondary standards specify a level of air quality that is requisite to protect against known or anticipated adverse effects to public welfare. In the Administrator's judgment as to the standards that would be requisite (i.e., neither more nor less stringent than necessary) to protect the public welfare under the Act, she may consider a number of factors including 1) what should be considered to constitute an adverse effect to the public welfare; 2) the nature and magnitude of the effects and the risks that remain after meeting the level of the current standard; and, 3) what is necessary to achieve the requisite (no more and no less) degree of public welfare protection. In the 2008 decision by which the current standard was established, the Administrator considered these factors in judging the previously existing standard to not provide the requisite public welfare protection. At that time the Administrator found that the exposure- and risk-based analyses available in that review indicated that adverse effects to vegetation would be predicted to occur under air quality conditions associated with just meeting the then-current standard. The effects identified were "visible foliar injury and seedling and mature tree biomass loss in O_3-sensitive vegetation" (73 FR 16496). In so noting, the Administrator indicated that he believed that "the degree to which such effects should be considered to be adverse depends on the intended use of the vegetation and its significance to public welfare" (73 FR 16496). With regard to consideration of intended use, the Administrator took note of the specific uses of public lands set aside by Congress and intended to provide benefits to the public welfare, "including lands that are to be protected so as to conserve the scenic value and the natural vegetation and wildlife within such areas, and to leave them unimpaired for the enjoyment for future generations" such as Class I areas (73 FR 16496). The Administrator also recognized areas set aside by states, tribes and public interest groups with the intent "to provide similar benefits to the public welfare, for residents on State and Tribal lands, as well as for visitors to those areas" (73 FR 16496).[12]

In the Administrator's judgments in the 2008 review, he did not identify specific criteria or benchmarks or a specific level of protection from adverse environmental effects to public welfare judged to be requisite under the Act.[13] As noted above, the scientists at the 1996

[12] In considering areas that have not been afforded such special protection, ranging from vegetation used for residential or commercial ornamental purposes, such as land use categories that are heavily managed for commercial production of commodities such as agricultural crops, timer and ornamental vegetation, the Administrator indicated his expectation that protection of sensitive natural vegetation and ecosystems might be expected to also provide some degree of additional protection for heavily managed commercial vegetation (73 FR 16496).

[13] In remanding the 2008 decision on the secondary standard back to the EPA, the Court of Appeals for the D.C. Circuit determined that EPA did not specify what level of air quality was requisite to protect public welfare

workshop identified ranges of cumulative seasonal index values (e.g., in terms of SUM06 or W126) in the context of considering a degree of protection for vegetation effects defined in terms of relative yield loss in crops and relative biomass loss in tree seedlings. Considering this information in the context of a secondary standard entails policy judgments by the Administrator with regard to the degree that impacts exceeding these or other benchmarks and other effects should be judged adverse to the public welfare. In considering levels for a W126-based secondary standard that may be appropriate to consider, we recognize that the statute requires that a secondary standard be protective against only those known or anticipated O_3 effects that are "adverse" to the public welfare, not all identifiable O_3-induced effects. Thus, we recognize both the importance of scientific consensus statements that have been made regarding vegetation-related endpoints and O_3 exposure levels that might protect against such key endpoints and the importance of placing such conclusions in the context of consideration of the public welfare more broadly.

As discussed in section 5.1 and recognized by the EPA in prior reviews, staff recognizes the importance of a more expansive construct or paradigm that addresses what constitutes adverse effects of O_3 to public welfare. In so doing, we also recognize several aspects or dimensions of vegetation effects for consideration within this paradigm. These include the likelihood, type, magnitude, and spatial scale of the effect, as well as the potential for recovery and any uncertainties relating to these conditions (77 FR 20231). As in the last review, we also continue to recognize that the public welfare significance of O_3-induced effects on sensitive vegetation growing within the U.S. can vary, depending on the nature of the effect, the intended use of the sensitive plants or ecosystems, and the types of environments in which the sensitive vegetation and ecosystems are located. Any given O_3-related effect on vegetation and ecosystems (e.g., biomass loss, foliar injury), therefore, may be judged to have a different degree of impact on the public welfare depending, for example, on whether that effect occurs in a Class I area, a city park, or in commercial cropland. In the 2008 review, the Administrator judged it appropriate that this variation in the significance of O_3-related vegetation effects should be taken into consideration in judging the level of ambient O_3 that is requisite to protect the public welfare from any known or anticipated adverse effects (73 FR 16496). For example, in considering visible foliar injury and seedling and mature tree biomass loss in O_3-sensitive vegetation expected under alternative air quality scenarios, the Administrator noted that "the degree to which such effects should be considered to be adverse depends on the intended use of the vegetation and its significance to the public welfare" (73 FR 16496). Further, the rulemaking

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from adverse public welfare effects or explain why any such level would be requisite, as described in section 1.2.2 above. *Mississippi*, 744 F.3d at 272-73.

notice stated that "[i]n considering what constitutes a vegetation effect that is adverse from a public welfare perspective, the Administrator believes it is appropriate to continue to rely on the definition of 'adverse,' … that imbeds the concept of 'intended use' of the ecological receptors and resources that are affected, and applies that concept beyond the species level to the ecosystem level" (73 FR 16496). The notice went on to state that "[i]n so doing, the Administrator has taken note of a number of actions taken by Congress to establish public lands that are set aside for specific uses that are intended to provide benefits to the public welfare, including lands that are to be protected so as to conserve the scenic value and the natural vegetation and wildlife within such areas, and to leave them unimpaired for the enjoyment of future generations" (73 FR 16496). Such public lands that are protected areas of national interest include national parks and forests, wildlife refuges, and wilderness areas.

We also consider effects on ecosystem services in considering adversity to public welfare. For example, the WREA has evaluated the economic value of ecosystem services affected by O_3 and how those services might be expected to change under different air quality scenarios representing the current and potential alternative standards (U.S. EPA, 2014b, chapters 6 and 7).

Lastly, we recognize several important considerations in evaluating levels of protection and levels for a cumulative seasonal W126-based standard including: the extent of areas expected to be affected nationwide and the magnitude of those effects; the extent of effects in areas of national significance; the extent to which these impacts might be judged significant from a public welfare perspective and associated uncertainties in the information. Accordingly, we recognize that the range of alternative standard levels that may be appropriate to consider differs based on the weight placed on different aspects of the evidence and on different aspects of the quantitative exposure/risk information, and the associated uncertainties, as well as on public welfare policy decisions regarding the public welfare significance of the effects considered and the approaches for considering benchmarks for growth or biomass loss and other vegetation effects of O_3. As described in chapter 1, our objective is to identify the range of policy options supported by the current evidence- and exposure/risk-based information and with consideration of the role of the Administrator's public welfare judgments. In so doing, we recognize support for consideration of a broad range of W126 index values, which we discuss in section 6.5, with recognition of the different judgments that might provide support for different parts of such a range.

6.4 CONSIDERATION OF PROTECTIVENESS OF REVISED PRIMARY STANDARD

In staff consideration of the primary standard in chapter 4, staff concludes it is appropriate to consider alternative primary standards of the same form and averaging time as the current primary standard and a lower standard level within the range of 60 to 70 ppb. Thus, although the discussion in this chapter, with regard to the secondary standard, indicates the appropriateness of considering an alternative secondary standard with a cumulative, seasonal form, we also recognize that, to the extent that the Administrator may find it effective to control air quality using the same form for both the primary and secondary standards, it may be practical to consider the extent to which a standard in the form of the primary standard might be expected to also reduce and provide protection from cumulative seasonal exposures of concern. For example, if a clear and robust relationship was found to exist between 8-hour daily peak O_3 concentrations and cumulative, seasonal exposures, the averaging time and form of the current standard might be concluded to have the potential to be effective as a surrogate. In response to this, we ask the following question:

- **What does the available information indicate with regard to protection of welfare from cumulative O_3 exposures that might be afforded by alternative secondary standards based on the form of the current standard (a 3-year average of 4th highest 8-hour average concentrations)?**

Addressing this point, the ISA describes the results of a recent focus study that examined the diel[14] variability in O_3 concentrations in six rural areas between 2007 and 2009 (U.S. EPA, 2013, pp. 3-131 to 3-133). The ISA reported that "[t]here was considerable variability in the diel patterns observed in the six rural focus areas" with the three mountainous eastern sites exhibiting a "generally flat profile with little hourly variability in the median concentration and the upper percentiles", while the three western rural areas demonstrated a "clear diel pattern to the hourly O_3 data with a peak in concentration in the afternoon similar to those seen in the urban areas", which was especially obvious at the San Bernardino National Forest site, 90 km east of Los Angeles at an elevation of 1,384 meters (U.S. EPA, 2013, p. 3-132). Thus, while the western sites that are influenced by upwind urban plumes may have increased cumulative seasonal values coincident with increased daily 8-hour peak O_3 concentrations, this analysis indicates that, in sites without such an urban influence (the eastern sites in this analysis), such a relationship does not occur (U.S. EPA, 2013, section 3.6.3.2). Thus, the lack of such a relationship indicates that in some locations, O_3 air quality patterns can lead to elevated cumulative, seasonal O_3 exposures without the occurrence of elevated daily maximum 8-hour average O_3 concentrations (U.S. EPA,

[14] involving a 24-hr period

2013, section 3.6.3.2). Further, staff notes that the prevalence and geographic extent of such locations is unclear, since as in the last review, there continue to be relatively fewer monitors in the West, including in high elevation remote sites. In considering the findings of this analysis, we additionally recognize, however, that the cumulative seasonal values for the eastern rural sites, where cumulative seasonal O_3 concentrations appear to be relatively less related to daily maximum 8-hour concentrations, are lower in general than those of the western, urban-influenced sites.

In addition to the focus study described in the ISA (U.S. EPA, 2013, section 3.6.3.2), we considered analyses of air quality monitoring data and air quality modeling analyses. Chapter 2 of this document characterizes recent monitoring data on O_3 air quality in rural areas. While approximately 80% of the O_3 monitoring network is urban focused, about 120 rural monitors are divided among CASTNET, NCore, and portable ozone monitors (POMs) sites (Chapter 2, pp. 2-2 to 2-3, Figure 2.1). Specifically, as stated in chapter 2 "[a]lthough rural monitoring sites tend to be less directly affected by anthropogenic pollution sources than urban sites, rural sites can be affected by transport of O_3 or O_3 precursors from upwind urban areas and by local anthropogenic sources such as motor vehicles, power generation, biomass combustion, or oil and gas operations" (U.S. EPA, 2013, section 3.6.2.2). In addition, O_3 tends to persist longer in rural than in urban areas due to lower rates of chemical scavenging in non-urban environments. At higher elevations, increased O_3 concentrations can also result from stratospheric intrusions (U.S. EPA, 2013, sections 3.4, 3.6.2.2). As a result, O_3 concentrations measured in some rural sites can be higher than those measured in nearby urban areas (U.S. EPA, 2013, section 3.6.2.2). These known differences between urban and rural sites suggest that there is the potential for 8-hour daily peak O_3 concentrations and cumulative, seasonal exposures to not correlate well in those areas. However, while these metrics may not be directly correlated, reductions in NOx emissions that occur in urban areas to attain primary standards would also have the effect of reducing downwind, rural concentrations over the season.

In addition, as was done in both the 1997 and 2008 reviews, staff has analyzed relationships between O_3 levels in terms of the current averaging time and form and a W126 cumulative form, based on recent air quality data. One analysis describes the W126 index values and current standard design values at each monitor for two periods: 2001-2003 and 2009-2011 (e.g., Appendix 2B, Figures 2B-2 and 2B-3). This shows that between the two periods, during which broad scale O_3 precursor emission reductions occurred, O_3 concentrations in terms of both metrics were reduced. There is a fairly strong, positive degree of correlation between the two

metrics (Appendix 2B).[15] Focusing only on the latter dataset (2009-2011), it can be seen that at monitors just meeting the current standard (3-year average fourth-highest daily maximum 8-hour average concentration equal to 0.075 ppm), W126 index values (in this case 3-year averages) varied from less than 3 ppm-hrs to approximately 20 ppm-hrs (Appendix 2B, Figure 2B-3b). At sites with a 3-year average fourth-highest daily maximum 8-hour average concentration at or below a potential alternative primary standard level of 70 ppb, 3-year W126 index values were above 17 ppm-hrs at no monitors, above 15 ppm-hrs at one monitor, and above 13 ppm-hrs at 8 monitors. At sites with a 3-year average fourth-highest daily maximum 8-hour average concentration at or below a potential alternative primary standard level of 65 ppb, 3-year W126 index values were above 13 ppm-hrs at no monitors, above 11 ppm-hrs at three monitors, and above 7 ppm-hrs at 9 monitors. The majority of these monitoring sites are located in the West and Southwest and include the states of Arizona, California, Colorado, Nevada, New Mexico, and Utah. At sites with a 3-year average fourth-highest daily maximum 8-hour average concentration at or below a potential alternative primary standard level of 60 ppb, 3-year W126 index values were at or below 7 ppm-hrs at all monitors.

An additional analysis presents the data for sets of recent 3-year periods back to 2006 – 2008 and indicates that among the counties with O_3 concentrations that met the current standard, the number of counties with 3-year W126 index values above 15 ppm-hrs ranges from fewer than 10 to 24 (Appendix 2B, Figure 2B-9). In general during this longer period, W126 index values above 15 ppm-hrs and meeting the current standard were pre-dominantly in Southwest region. As the first analysis in Appendix 2B (for the 2001-2003 and 2009-2011 periods) indicates, monitors in the West and Southwest tend to have higher W126 index values relative to their design values than do monitors in other regions. This pattern is noteworthy because the Southwest region has a less dense monitoring network than regions in the Eastern U.S. (see Figure 2-1), so that the extent to which this pattern occurs throughout these regions is uncertain. Although single-year W126 index values were not separately analyzed in this analysis of the monitor data, it indicates appreciable variation in cumulative, seasonal O_3 concentrations among monitor locations meeting different levels of a standard of the current form.

Analyses of the WREA air quality scenarios indicate the potential for O_3 precursor emission reductions achieving O_3 concentrations that just meet different 8-hour standards to produce a significant reduction in 3-year W126 index values. For example, for the current standard scenario, nearly all adjusted monitors are at or below an estimated 3-year average W126 index value of 15 ppm-hrs (as summarized in section 5.2.2 and described in U.S. EPA, 2014b,

[15] Appendix 2B additionally observes that the program implemented for reducing precursor emissions, especially NOx, appears to have been an effective strategy for lowering both design values and W126 index values.

Table 4-1). Those monitors above 15 ppm-hrs would be limited to large urban areas in the southwestern U.S. (i.e., Phoenix, Los Angeles and Denver). When meeting a 4th highest 8-hour average scenario of 70 ppb averaged across 3 years, nearly all monitors in the U.S. would meet a 3-year W126 index value of 11 ppm-hrs, though some monitors in the southwest would remain between 11 and 15 ppm-hrs. At 65 ppb, all locations are at or below 11 ppm-hrs. Thus, similar to the monitoring analysis, the modeling analysis generally indicates reductions in W126 levels with reduced O_3 concentrations in terms of the current standard averaging time and form. This suggests that depending on the level for a standard of the current averaging time and form, a degree of welfare protection may be afforded. The extent to which such protection provides adequate public welfare protection additionally depends on the level of protection identified by the Administrator as requisite to protect the public welfare from any known or anticipated adverse effects. In so noting, however, we recognize the importance of also considering uncertainties in both the model-based adjustment analyses and those based on monitoring data. These uncertainties, including those related to monitor coverage, the extent to which recent data can be expected to describe future relationships, and modeling approaches[16], among others, should be kept in mind when assessing the strength of this apparent relationship.

6.5 CASAC ADVICE

In our consideration of potential alternative standards, in addition to the evidence-based, risk/exposure-based, and air quality information discussed above, we also consider the advice and recommendations of CASAC in EPA's proposed 2010 reconsideration of the 2008 decision, as well as comments received in the current review, in the context of its review of the ISA, and the WREA and PA. Some of this advice on specific aspects of the evidence and exposure/risk information has already been discussed in the relevant sections above. This section specifically considers CASAC's scientific advice on the appropriate form, averaging times and level(s) associated with a secondary standard and other related science and policy advice. We have additionally considered public comments received to date, some of which have suggested a lack of new information to support a distinct secondary standard and others that urge the consideration of a secondary standard with a cumulative seasonal form using the W126 metric and a level within the range of 7 to 15 ppm-hrs.[17]

[16] One uncertainty associated with the modeling approach, as noted in Chapter 5, relates to the lowering of the highest monitored values as a result of the application of the interpolation method used to estimate W126 index values at the centroid of every 12 X 12 km^2 grid resolution, rather than only at the exact location of a monitor.

[17] Public comment received thus far in this review are in the docket EPA–HQ–OAR-2008-0699, accessible at www.regulations.gov.

In response to the EPA's solicitation of CASAC's advice on the Agency's proposed rulemaking as part of the reconsideration,[18] CASAC conveyed their support for a secondary standard distinct from the primary standard, stating that it "also supports EPA's secondary ozone standard as proposed: a new cumulative, seasonal standard expressed as an annual index of the sum of weighted hourly concentrations (i.e., the W126 form), cumulated over 12 hours per day (8am to 8pm) during the consecutive 3-month period within the ozone season with the maximum index value, set as a level within the range of 7 to [1]5 ppm-hours. This W126 metric can be supported as an appropriate option for relating ozone exposure to vegetation responses, such as visible foliar injury and reductions in plant growth. We found the Agency's reasoning … to be supported by the extensive scientific evidence considered in the last review cycle. In choosing the W126 form for the secondary standard, the Agency acknowledges the distinction between the effects of acute exposures to ozone on human health and the effects of chronic ozone exposures on welfare, namely that vegetation effects are more dependent on the cumulative exposure to, and uptake of, ozone over the course of the entire growing season (defined to be a minimum of at least three months). In this proposal, the Agency is responding to the clear need for a secondary standard that is different from the primary standard in averaging time, level and form" (Samet, 2010, p. i-ii).

In advice offered in the current review, which considers an updated scientific and technical record since the 2008 rulemaking, the CASAC reiterated its earlier conclusions regarding the appropriate form and averaging times for a secondary O_3 NAAQS at several points in its letter to the Administrator. In stating the basis for its conclusion, CASAC notes that "[i]n reaching its scientific judgment regarding the indicator, form, summation time, and range of levels for a revised secondary standard, the CASAC has focused on the scientific evidence for the identification of the kind and extent of adverse effects on public welfare" (Frey, 2014a, p. iii), and further that "[t]hese recommendations are based on scientific evidence of adverse effect associated with the presence of ozone in ambient air" (Frey, 2014a, p. 15). On this basis, CASAC reached its conclusions on the appropriate form for the secondary standard stating "[t]he CASAC supports the scientific conclusion in the Second Draft PA that the current secondary standard is not adequate to protect against current and anticipated welfare effects of ozone on vegetation. We recommend retaining the current indicator (ozone) but establishing a revised form of the secondary standard to be the biologically relevant W126 index accumulated over a

[18] The reconsideration proposal included a proposed new cumulative, seasonal secondary standard, expressed as an index of the annual sum of weighted hourly concentrations (the W126 index), cumulated over 12 hours per day during the consecutive 3-month period within the O_3 season with the maximum index value, averaged over three years, set within a range of 7 to 15 ppm-hrs (75 FR 3027).

12-hour period (8 a.m. – 8 p.m.) over the 3-month summation period of a single year resulting in the maximum value of W126" (Frey, 2014a, p. iii).

In addition, we take note of the scientific advice provided by CASAC regarding its scientific judgments regarding appropriate target benchmarks of protection and the range of W126 index values that in its scientific judgment provides appropriate protection for these benchmarks. CASAC states that "[a] 2% biomass loss is an appropriate scientifically based value to consider as a benchmark of adverse impact for long-lived perennial species such as trees, because effects are cumulative over multiple years" and "[c]rop loss appears to be less sensitive than these other indicators, largely because of the CASAC judgment that a 5% yield loss represents an adverse impact, and in part due to more opportunities to alter management of annual crops" (Frey, 2014a, p. 14).

Given these benchmarks, CASAC provided further advice regarding an appropriate range of W126 levels that it considered appropriately protective. Specifically, "[t]he CASAC recommends that the level associated with this form be within the range of 7 ppm-hrs to 15 ppm-hrs to protect against current and anticipated welfare effects of ozone. The CASAC does not support a level higher than 15 ppm-hrs. For example, at 17 ppm-hrs, the median tree species has 6% relative biomass loss, and the median crop species has over 5% yield loss. These levels are unacceptably high" (Frey, 2014a, p. iii)[19]. CASAC further noted that "[w]ith compounding over the harvest cycle or life span of these species, this will result in considerably greater cumulative RBL as discussed above. For the more sensitive tree seedlings, a value closer to the lower end of the range (7 ppm-hrs) would be more appropriate. The level of 7 ppm-hrs is the only level analyzed for which the relative biomass loss for the median tree species is less than or equal to 2 percent. At 7 ppm-hrs, 7 of the 12 analyzed species have relative biomass loss of less than 2%" (Frey, 2014a, p. 14).

CASAC further noted that "the correlative similarity between the current standard and a level of the W126 index of 15 ppm-hrs must not be interpreted to mean that just meeting the current standard is equivalent to just meeting a W126 level of 15 ppm-hrs. Most of the analyses found effects below 15 ppm-hrs (many at 10 or even 7 ppm-hrs)" (Frey, 2014a, p. 12).

CASAC also recognized that there were policy choices left to the Administrator with respect to determining an appropriate level of protection. In so doing "[t]he CASAC acknowledges that the choice of a level within the range recommended based on scientific evidence is a policy judgment under the statutory mandate of the Clean Air Act. Specifically, the

[19] As noted in Section 6.3, the numbers for RBL for the median tree species have been updated between the second and final PA to deemphasize cottonwood, based on staff's understanding of CASAC advice in that regard. We note that CASAC advice based on what is shown in Table 6-1 is no longer consistent in some cases with the revised table, and in particular with regard to median tree seedling RBL values.

Clean Air Act grants discretion to the Administrator to specify a standard that is 'requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air'… (Frey, 2014a, p. iii). In addition, CASAC also offered its policy advice regarding selection of an appropriate level within its scientifically recommended range, stating that "[a]s a policy recommendation, separate from its advice above regarding scientific findings, the CASAC advises that a level of 15 ppm-hrs for the highest 3-month sum in a single year is requisite to protect crop yield loss, but that lower levels provide additional protection against crop yield loss. Furthermore, there are specific economically significant crops, such as soybeans, that may not be protected at 15 ppm-hrs but would be protected at lower levels. A level below 10 ppm-hrs is required to reduce foliar injury. A level of 7 ppm-hrs is protective of relative biomass loss for trees and offers additional protection against crop yield loss and foliar injury. Therefore, 7 ppm-hrs is protective of ecosystem services. Thus, lower levels within the recommended range offer a greater degree of protection of more endpoints than do higher levels within the range" (Frey, 2014a, p. iii).

Additionally, in regard to the 3-year average option discussed in the second draft PA, CASAC thus notes that "[i]f, as a policy matter, the Administrator prefers to base the secondary standard on a three-year averaging period for the purpose of program stability, then the level of the standard should be revised downward such that the level for the highest three-month summation in any given year of the three-year period would not exceed the scientifically recommended range of 7 ppm-hrs to 15 ppm-hrs. …The final Policy Assessment should quantify the ratio of the three-year average of the highest three-month summations in each year to the highest three-month summation in the highest year. This ratio should be used to determine what downward adjustment from the three-month summation in one year recommended here is needed if a three-year form is selected" (Frey, 2014a, pp. iii and iv).[20]

Finally, we note that in commenting on the significance of the uncertainties associated with the evidence and exposure and risk analyses that remain, CASAC concludes that "[w]hile these scientific research priorities will enhance future scientific reviews of the ozone primary and secondary standards, we also make clear that there is sufficient scientific evidence, and sufficient confidence in the available research results, to support the advice we have given above for this review cycle of the primary and secondary standards" (Frey, 2014a, p. iv).

[20] See Section 6.4 and Chapter 2 for more discussion on the relationship between one-year and three-year average W126 index values.

6.6 STAFF CONCLUSIONS ON ALTERNATIVE STANDARDS

Staff's consideration of alternative secondary O_3 standards builds on our conclusion from section 5.7 above that the body of evidence, in combination with the results of the WREA analyses, calls into question the adequacy of the current secondary standard and provides support for consideration of alternative standards. In sections 6.1 to 6.3 above, we consider how the currently available scientific evidence and exposure/risk information informs staff conclusions regarding the basic elements of the NAAQS: indicator (6.1), form and averaging time (6.2), and level (6.3). In so doing, we consider both the information available at the time of the last review and information newly available since the last review that has been critically analyzed and characterized in the 2013 ISA. As an initial matter, with regard to the indicator, we conclude that based on the available science it is still appropriate to continue to use measurements of O_3 in accordance with federal reference methods as the indicator to address effects associated with exposure to ambient O_3 alone or in combination with related photochemical oxidants.

In considering alternative standards, staff has considered the available body of evidence as comprehensively assessed in the ISA, the risk and exposure information presented in the WREA, and CASAC advice and public comment in this review with regard to support for consideration of options that are different from the current standard, as articulated by the following overarching question:

- **To what extent does the currently available scientific evidence- and exposure/risk-based information, as reflected in the ISA and WREA, support consideration of alternatives to the current O_3 standard to provide increased protection from ambient O_3 exposures?**

In considering potential forms alternative to that of the current standard, we note that the form for the current secondary standard is the 4th highest daily maximum 8-hour average, averaged over three years. As discussed in chapter 5 and section 6.2 above, the longstanding evidence regarding the fundamental aspects of O_3 exposure that are directly responsible for inducing vegetation response indicates that plant response to O_3 is driven by the cumulative exposure to O_3 during the growing season (U.S. EPA, 2013, section 2.6.6.1). This cumulative exposure depends on both the total duration of the exposure (from repeated O_3 episodes) and the concentrations of those exposures (higher concentrations having a disproportionate impact as compared to lower concentrations). On the basis of this longstanding and extensive evidence, the ISA concludes that exposure indices that cumulate and differentially weight the higher hourly average concentrations over a season and also include the mid-level values offer the most scientifically defensible approach for use in developing response functions and in defining indices for vegetation protection (U.S. EPA, 2013, section 2.6.6.1).

CASAC advice in the 2008 review and on the 2010 proposed reconsideration also recognized that the nature of the exposures relevant to vegetation response is well described by a cumulative seasonal form and has supported the use of such a form for a secondary O_3 standard (Henderson, 2006; Samet, 2010). The current CASAC O_3 Panel has expressed similar views. We also note that on the basis of the evidence and exposure/risk information available in the two previous reviews, and in consideration of CASAC advice, the Administrator has recognized the importance of protecting vegetation from cumulative, seasonal exposures and proposed such a form as an appropriate, reasonable policy option (61 FR 65741-44; 72 FR 37899-905; 75 FR 3012-3027).

Thus, in considering alternative forms of the standard we conclude that it is reasonable and appropriate to consider a cumulative, concentration-weighted form to provide protection against cumulative, seasonal exposures to O_3 that are known or anticipated to harm sensitive vegetation or ecosystems. Such a form is specifically designed to focus on the kind of O_3 exposures that have been shown to cause harm to vegetation and would have a distinct advantage over the form of the current standard in characterizing air quality conditions potentially of concern for vegetation and in more directly demonstrating that the desired degree of protection against those conditions was being achieved.

In considering the appropriate index for a cumulative seasonal form, we recognize that a number of different cumulative concentration weighted indices have been developed and have been evaluated in the scientific literature and in past NAAQS reviews in terms of their ability to predict vegetation response and their usefulness in the NAAQS context (U.S. EPA, 2006, pp. 9-11 to 9-15 and pp. AX9-159 to AX9-187; U.S. EPA, 2007, pp. 7-15/16). While these various forms have different strengths and limitations, as noted in the ISA (U.S. EPA, 2013, section 9.5), the W126 index[21] has some important advantages over other non-sigmoidally weighted cumulative indices. For example, given the lack of a discernible threshold for vegetation effects in general, we recognize the fact that the W126 metric does not have a cut-off in its weighting scheme (down to about 30 ppb below which the weighting factor is effectively zero), such that it includes consideration of potentially damaging lower O_3 concentrations. Additionally, the W126 metric adds increasing weight to hourly concentrations from about 40 ppb to about 100 ppb, an important feature because "as hourly concentrations become higher, they become increasingly likely to overwhelm plant defenses and are known to be more detrimental to vegetation" (U.S.

[21] The W126 is a non-threshold approach described as the sigmoidally weighted sum of all hourly O_3 concentrations observed during a specified diurnal and seasonal exposure period, where each hourly O_3 concentration is given a weight that increases from 0 to 1 with increasing concentration (Lefohn et al, 1988; Lefohn and Runeckles, 1987; U.S. EPA, 2013, section 9.5.2).

EPA, 2013, p. 9-104). We additionally take note of CASAC advice in the 2008 review and on the 2010 proposed reconsideration recommending the use of the W126 index for a cumulative seasonal form for a secondary O_3 standard (Henderson, 2006; Samet, 2010). Similarly, the current CASAC O_3 Panel has indicated that a focus on a W126 form is appropriate (Frey, 2014a, p. iii). Therefore, on the basis of the strength of the evidence and advice from CASAC, we conclude that the W126 index is the most appropriate cumulative seasonal form to consider in the context of the secondary O_3 NAAQS review.

We next turn to the exposure periods – diurnal and seasonal – over which the W126 index would be summed in any given year. As discussed in section 6.2 above, the currently available information continues to provide support for a definition of the diurnal period of interest as the 12-hour period from 8:00 am to 8:00 pm (U.S. EPA, 2013, section 9.5.3). In prior reviews, the EPA has identified the 12-hour period from 8:00 am to 8:00 pm as appropriately capturing the diurnal window with most relevance to the photosynthetic process (72 FR 37900; 75 FR 3013), and CASAC has generally supported the 12-hour daylight period (Henderson, 2006, 2007). In light of the continued support in the evidence base and no evidence on this issue differing from that in previous reviews, we again conclude that it is appropriate to use the 12-hour period from 8:00 am to 8:00 pm to cumulate daily O_3 exposures. On this basis, we conclude that the 12-hour daylight window (8:00 am to 8:00 pm) represents the portion of the diurnal exposure period that is most relevant to predicting or inducing plant effects related to photosynthesis and growth and thus is an appropriate diurnal period to use in conjunction with a W126 cumulative metric.

With regard to a seasonal period of interest, the current evidence base continues to provide support for a seasonal period with a minimum duration of three months (U.S. EPA, 2013, section 9.5.3). We note that a plant is vulnerable to O_3 pollution as long as it has foliage and is physiologically active (U.S. EPA, 2013, section 9.5.3, p. 9-112), i.e., during its growing season. The exposure periods used in studies of O_3 effects on vegetation reflect this understanding and typically focus on study periods of 3-6 months. Included in the currently available evidence is a new analysis that compared 3- and 6-month maximum W126 index values for over 1,200 AQS and CASTNET EPA monitoring sites for the years 2008-2009 that found that the two accumulation periods were highly correlated (U.S. EPA, 2013, section 9.5.3, Figure 9-13). Thus, although we recognize that the selection of a single seasonal time period over which to cumulate O_3 exposures for a national standard necessarily represents a balance of factors, given the significant variability in growth patterns and lengths of growing season among vegetative species growing within the U.S., we conclude it is appropriate to identify the seasonal W126 index value as that derived from the consecutive 3-month period within the O_3 season with the highest W126 index value. We note that such a 3-month exposure period was also

supported by CASAC in advice provided during the last review and the 2010 proposed reconsideration (Henderson, 2006; Samet, 2010).

With regard to form, we additionally consider the period of time over which a cumulative seasonal W126-based standard should be evaluated. In so doing, we have considered the support for both a single year form and a form averaged over three years (section 6.2). We note comments from CASAC on this matter, in particular their comment in the current review that "[t]he CASAC does not recommend the use of a three-year averaging period for the secondary standard. We favor a single-year period for determining the highest three-month summation which will provide more protection for annual crops and for the anticipated cumulative effects on perennial species. The scientific analyses considered in this review, and the evidence upon which they are based, are from single-year results" (Frey, 2014a, p. iii).

We recognize that there are a number of O_3-induced effects that have the potential for public welfare significance within the annual timeframe. These effects mainly include reduced crop yields and visible foliar injury, as noted in section 6.2 above. There are uncertainties associated with these effects that make it difficult to determine the degree of annual protection needed to protect the public welfare from any known or anticipated adverse effects. There are also annual effects in perennial species that may result from a single year exposure and can be "carried over" into the subsequent year where they affect growth and reproduction (U.S. EPA, 2013, pp. 9-43 to 9-44 and p. 9-86). When such annual effects due to elevated O_3 exposures occur over multiple years, they have the further potential to be compounded, increasing the potential for effects at larger scales (e.g., population, ecosystem), including effects on associated services that may be of significance to the public welfare. These ecosystem services effects can include alteration of below-ground biogeochemical cycles, and alteration of both above- and below-ground terrestrial community composition and terrestrial ecosystem water cycling (U.S. EPA, 2013, Table 9-19) and reductions in productivity and carbon sequestration in terrestrial ecosystems. We additionally note that multiple consecutive years of critical O_3 exposures might be expected to result in larger impacts on forested areas (e.g., increased susceptibility to other stressors such as insect pests, disease, co-occurring pollutants and harsh weather) than intermittent occurrences of such exposures due to the potential for compounding or carry-over effects on tree growth.

Given the above, we conclude that the public welfare significance of the effects that can occur as a result of three-year O_3 exposures are potentially greater than those associated with a single year of such exposure. Thus, to the extent that the focus for public welfare protection to be afforded by the secondary O_3 standard is on long-term effects that occur in sensitive tree species in natural forested ecosystems, including federally protected areas such as Class I areas or on lands set aside by States, Tribes and public interest groups to provide similar benefits to the

public welfare, a standard with a form that evaluates the cumulative seasonal index across multiple years might be considered to provide a more appropriate match to the nature of O_3-related effects on vegetation upon which the secondary O_3 standard is focused. In considering such forms, we focus on one that averages the W126 index values across three years, as discussed in section 6.2 above.

In addition to the vegetation effects considerations described above, there are other policy-relevant factors that can be useful to consider. For example, under a standard with a single year form, a monitor may be judged to meet the standard based on a single year of data, while under a standard with a form requiring evaluation over a multi-year period, a monitor is not judged to have met the standard until a complete multi-year record is available. For a W126-based potential standard, the multi-year form identified for consideration in the last review was the average cumulative seasonal metric over three consecutive years (75 FR 3027). Such a multi-year form remains appropriate to consider to provide stability to an alternative secondary standard, just as the multi-year form provides for the current standard (average over three years of annual fourth-highest daily maximum 8-hour average O_3 concentrations).[22] In considering the issue of stability in the context of such a form, we first note the inter-annual variability of seasonal W126 index, which is not unexpected given the logistic weighting function and also inter-annual variability in meteorological conditions that contribute to O_3 formation (see Appendix 2C). The staff analysis in Appendix 2C describes the variability in annual W126 index values in relation to variability in the 3-year average, which indicates that a standard based on an annual W126 index would be expected to have a lower degree of year-to-year stability relative to a standard based on a form that averages seasonal indices across three consecutive years. A more stable standard can be expected to contribute to greater public welfare protection by limiting year-to-year disruptions in ongoing control programs that would occur if an area was frequently shifting in and out of attainment due to extreme year-to-year variations in meteorological conditions. This greater stability in air quality management programs thus facilitates achievement of the protection intended by a standard. In light of this relationship, we conclude that a 3-year average form has the desirable feature of providing greater stability in air quality management programs and thus facilitating the achievement of the protection intended by a standard. Thus, we recognize the public welfare benefits of having a standard of a 3-year average form.

Thus, to the extent that the greater emphasis is placed on protecting against effects associated with multi-year exposures and maintaining more year-to-year stability of public

[22] See *ATA III*, 283 F. 3d at 374-75 (recognizing programmatic stability as a legitimate consideration in the NAAQS standard-setting process).

welfare protection, we conclude that it is appropriate to consider a secondary standard form that averages the seasonal W126 index values across three consecutive years. We conclude that such a form might be appropriate for a standard intended to achieve the desired level of protection from longer-term effects, including those associated with potential compounding. Further, such a form might be concluded to contribute to greater stability in air quality management programs, and thus, greater effectiveness in achieving the desired level of public welfare protection, than that that might result from a single year form.

Turning to consideration of an appropriate range of levels for a W126-based standard, we first note that our general approach to informing these judgments recognizes that the available evidence demonstrates a range of O_3 sensitivity across studied plant species and documents an array of O_3-induced effects that extend from lower to higher levels of biological organization. These effects range from those affecting cell processes and individual plant leaves to effects on the physiology of whole plants, species effects and effects on plant communities to effects on related ecosystem processes and services. Given this evidence, it is not possible to generalize across all studied species regarding which cumulative exposures are of greatest concern, as this can vary by situation due to differences in exposed species sensitivity, the importance of the observed or predicted O_3-induced effect, the role that the species plays in the ecosystem, the intended use of the affected species and its associated ecosystem and services, the presence of other co-occurring predisposing or mitigating factors, and associated uncertainties and limitations. At the same time, the evidence also demonstrates that though effects of concern can occur at very low exposures in sensitive species, at higher cumulative exposures those effects would likely occur at a greater magnitude and/or higher levels of biological organization and additional species would likely be impacted. It is important to note, however, that due to the variability in the importance of the associated ecosystem services provided by different species at different exposures and in different locations, as well as differences in associated uncertainties and limitations, that, in addition to the magnitude of the ambient concentrations, both the species present and their public welfare significance are essential considerations in drawing conclusions regarding the significance or magnitude of public welfare impact.

Therefore, in developing conclusions in this PA, we take note of the complexity of judgments to be made by the Administrator regarding the adversity of known and anticipated effects to the public welfare and are mindful that the Administrator's ultimate judgments on the secondary standard will, as appropriate, reflect an interpretation of the available scientific evidence and exposure/risk information that neither overstates nor understates the strengths and limitations of that evidence and information.

As described above in section 5.1, we employ a paradigm to assist in putting the available science and exposure/risk information into the public welfare context. This paradigm has

evolved over the course of the O_3 NAAQS reviews and has also been informed by similar constructs developed for other secondary NAAQS reviews. As discussed in Section 5.1, this paradigm recognizes that the significance to the public welfare of O_3-induced effects on sensitive vegetation growing within the U.S. can vary depending on the nature of the effect, the intended use of the sensitive plants or ecosystems, and the types of environments in which the sensitive vegetation and ecosystems are located. Accordingly, any given O_3-related effect on vegetation and ecosystems (e.g., biomass loss, crop yield loss, visible foliar injury) may be judged to have a different degree of impact on or significance to the public welfare depending, for example, on whether that effect occurs in a Class I area, a city park, or commercial cropland. In the last review, the Administrator placed the highest priority and significance on vegetation and ecosystem effects to sensitive species that are known to or are likely to occur in federally protected areas such as national parks and other Class I areas, or on lands set aside by states, tribes and public interest groups to provide similar benefits to the public welfare (75 FR 3023-24; 73 FR 16496), recognizing that effects occurring in such areas would likely have the highest potential for being classified as adverse to the public welfare, due to the expectation that these areas need to be maintained in pristine or near pristine conditions to ensure their intended use is met. This approach also includes consideration of impacts to ecosystem goods and services. Although ecosystem services were not explicitly considered in the Administrator's decision in the last review, they were explicitly recognized as an important category of public welfare effects and they have an obvious relationship to consideration of intended use (73 FR 16492). In employing this approach, we note the support for it provided by CASAC advice in this review (Frey, 2014a).

In considering potential levels for an alternative standard based on the W126 metric, we focus the discussion primarily on: 1) impacts on tree growth, productivity and carbon storage; 2) crop yield loss; and 3) visible foliar injury. With respect to tree growth, we find it useful to consider the summary of relative biomass loss estimates in Table 6-1 above and the WREA risk/exposure estimates discussed in Section 6.3 and Appendix 6F. In Table 6-1, we take note of the different index value estimates with regard to the number of studied species below different response benchmarks, as well as with regard to the median response. We additionally consider the WREA estimates regarding: (1) percent of assessed geographic area exceeding 2% weighted relative biomass (Table 6-2); (2) number of assessed Class I areas with tree seedling weighted relative biomass loss estimates above 2% (Table 6-3); and (3) the percent median biomass loss across counties for different air quality scenarios (Table 5-5). Further, we note other WREA estimates for effects on ecosystem services related to public welfare, such as carbon sequestration and air pollutant removal. With respect to crop yield loss, we note the summary of crop yield loss estimates in Table 6-1 and the WREA risk/exposure estimates discussed in

Section 6.3 and Appendix 6F, which include individual species and median response. We also note information available on visible foliar damage to species occurring in natural settings, such as federal Class I areas, and the analyses in the WREA evaluating biosite data and several benchmarks of injury as summarized in section 5.4.2.

In focusing on trees and their associated ecosystem services, we first note that the studied tree species vary widely in their sensitivity to O_3-induced relative biomass loss. We thus find it informative to consider both median species values and individual species responses and RBL over the same W126 range. We note CASAC's advice regarding RBL levels, specifically their emphasis on a benchmark of median relative tree biomass loss at or below 2% and their view that a 6% median relative biomass loss is "unacceptably high". From Table 6-1 we see that median tree species biomass loss is at or below 2% only at the lowest W126 level assessed, 7 ppm-hrs. As the W126 level is incrementally increased, median RBL also increases incrementally, so that at W126 index values of 9, 11, 13, 15, 17 and 19, the median RBL increases to 2.4%, 3.1%, 3.8%, 4.5%, 5.3% and 6.0%, respectively. Thus over the W126 range of 7 – 17 ppm-hrs, median species biomass loss ranges from approximately 2% to approximately 5%.

We next take note of the number of individual species' RBLs that fall below those same benchmarks assessed for median species values. We also note the value of additionally characterizing the RBL estimates in comparison to higher loss levels such as 10% or 15%, especially for individual tree species. Based on Figure 5-1 (B) in Chapter 5, and as shown in Table 6-1, for W126 values at or below 17 ppm-hrs, the RBLs for each of 5 species is less than 2%. Thus, over the full range of alternative levels considered, the same level of protection relative to the 2% benchmark is achieved for these species. We therefore turn our attention to the remaining 6 studied species to see if additional information might be available to help inform consideration of an appropriate degree of protection. Specifically, we consider the RBL information available for the other species (i.e., eastern white pine, aspen, tulip poplar, ponderosa pine, red alder, and black cherry) to further inform our evaluation of the additional protection that potentially could be achieved at different W126 levels within the range identified. We note that, for W126 levels of 17 to 7 ppm-hrs, biomass loss decreases for these individual species with decreasing W126 levels such that at the W126 level of 17 ppm-hrs, five species have RBL above 6% while at the W126 level of 7 ppm-hrs, one species (black cherry) has an RBL above 6%. Taken together with the more tolerant species, the proportion of the studied tree species with RBLs below 6% are 6/11, 7/11, 8/11, and 10/11 at W126 index values of 17, 15, 13, and 11 ppm-hrs, respectively.

In consideration of other benchmark levels, 9/11 studied tree species have a predicted RBL below 10% at the W126 level of 17 ppm-hrs, while 10/11 species have a predicted RBL

below 10% for W126 levels of 15 to 7 ppm-hrs. In addition, 10/11 studied tree species have a predicted RBL below 15% for W126 levels of 17 to 7 ppm-hrs. We note that black cherry, the most sensitive of the 11 species, has RBLs ranging from approximately 36% at W126 index value of 17 down to approximately 17% at the W126 index value of 7 ppm-hrs. Thus, the predicted RBL for black cherry remains above 15% for W126 levels of 17 to 7 ppm-hrs, and it is not clear to what extent those predicted RBL values might inform consideration of the level of protection achieved for different W126 exposures within this range (Table 6-1; U.S. EPA, 2014b, section 6.2, Appendix 6A).

To further inform this issue, the WREA also characterizes the number of counties where the median RBLs were greater than 2% (U.S. EPA, 2014b, Table 6-7), as shown in Table 5-5. When air quality is adjusted to the current standard, 8% of the counties have median RBLs greater than 2%. That proportion drops to 7% for air quality adjusted to just meet a 3-year average W126 level of 15 ppm-hrs and to 6% for air quality adjusted to just meet a 3-year average W126 level of 7 ppm-hrs. Of the 239 counties (8% of counties) estimated to have a median RBL above 2% when meeting the current standard, 203 of those counties have a RBL greater than 2% because of the presence of black cherry. Thus, as also discussed above in Section 6.2, given the large magnitude of estimated RBL for black cherry over the entire range assessed, it is not clear to what extent the information for black cherry informs consideration of the overall level of protection achieved across the identified range.

In considering the potential magnitude of the ecosystem impact of reduced biomass in trees, we focus on the WREA estimates of weighted RBL for the W126 air quality scenarios (U.S. EPA, 2014b, section 6.8), focusing particularly on impacts in Class I areas. For the current standard and the three W126 scenarios (15 ppm-hr, 11 ppm-hr, and 7 ppm-hr), the percent of total national land-area having weighted RBL greater than 2% was 0.2%, 0.2%, 0.1% and <0.1%, respectively (Table 6-2; U.S. EPA 2014, Table 6-25). In addition, the WREA estimates indicate weighted RBL greater than 2% in 1-2 of 145 assessed nationally protected Class I areas for the current standard and all three W126 scenarios. To the extent that emphasis is given to such estimates for nationally protected Class I areas and for appreciable percentages of forested areas nationwide, a W126 index value extending up to 17 ppm[23] may be appropriate to consider.

The WREA provides qualitative and semi-quantitative information regarding the types and potential magnitude of O_3 impacts on ecosystem services. In noting the potential ecosystem

[23] While the WREA analyses did not include an air quality scenario for 17 ppm-hrs, the data suggests that, to adjust air quality to meet a W126 index value of 17 ppm-hrs, additional emissions reductions would have been needed relative to just meeting the current standard. Therefore, because the air quality scenarios for meeting the current standard and meeting a W126 index value of 15 ppm-hrs both indicate weighted relative biomass loss less than or equal to 2% in 143 of 145 assessed nationally protected Class I areas, the same would be true for an air quality scenario for just meeting a W126 index value of 17 ppm-hrs.

services benefits related to reductions in tree biomass loss resulting from just meeting potential alternative W126-based standards, we recognize, in particular, that impacts on climate regulation can reasonably be concluded to be potentially significant from a public welfare perspective and carbon sequestration has been identified as a potentially important tool for managing anthropogenic impacts on climate. The WREA estimates the potential increase in carbon storage that potentially could occur for different air quality scenarios (U.S. EPA 2014, section 6.6.1). Comparisons of the W126 scenarios to the current standard scenario with regard to carbon sequestration estimates do not indicate an appreciable difference for the W126 scenario of 15 ppm-hrs beyond that achieved by just meeting the current standard. The majority of the enhanced carbon sequestration potential in forests over time is predicted to occur for the alternative W126 scenarios of 11 and 7 ppm-hrs. Over 30 years, the current standard scenario projection is 89,184 million metric tons of CO_2 equivalents ($MMtCO_2e$).[24] The WREA estimates additional sequestration potential of 13, 593 and 1,600 $MMtCO_2e$ for the W126 scenarios of 15, 11 and 7 ppm-hrs, respectively, as compared to the current standard (U.S. EPA 2014, Table 6-18). We additionally consider the WREA estimates for five urban areas of how reduced growth of O_3-sensitive trees in urban forests may affect air pollutant removal (U.S. EPA, 2014b, sections 6.6.2 and 6.7 and Appendix 6D). Estimates for all five case study areas indicate increased pollutant removal from the recent conditions to just meeting the current standard, with much smaller differences between the current standard and the three W126 scenarios (Table 6-5). However, we additionally take note of significant uncertainties and limitations associated with WREA estimates related to carbon sequestration and air pollution removal. Thus, we note that an identification of the requisite protection for forest trees and their associated ecosystem services would likely involve policy judgments regarding the appropriate weight to place on potential impacts to the public welfare with respect to estimated effects on the ecosystem services of carbon storage and urban air pollution removal associated with tree growth, as well as on the uncertainties associated with this information.

With respect to crops, we focus on the 10 robust E-R functions (barley, lettuce, field corn, grain sorghum, peanut, winter wheat, cotton, soybean, potato and kidney bean) described in the ISA and additionally analyzed in the WREA (Figure 5-4). We also note CASAC's advice regarding a recommended target benchmark protection level of 5% for median crop relative yield loss (RYL) and that, as shown in Table 6-1, W126 index values ranging from 7 to 17 ppm-hrs

[24] 1 million metric tons of carbon dioxide equivalents ($MMtCO_2e$) is equivalent to 208,000 passenger vehicles or the electricity to run 138,000 homes for 1 year as calculated by the EPA Greenhouse Gas Equivalencies Calculator (updated September 2013 and available at http://www.epa.gov/cleanenergy/energy-resources/calculator.html).

are estimated to have median crop RYL of less than or equal to approximately 5%. Given this, it is not clear to what extent this information informs the selection of an appropriate level.

When individual species are considered over this same range, the proportion of crops protected varies from 5/10, 6/10, 6/10, 9/10, 10/10, and 10/10 at the W126 levels of 17, 15, 13, 11, 9, and 7 ppm-hrs. To the extent a given species is judged as having particular importance to the public welfare, breaking the information down by species can be helpful. For example, less than 5% yield loss was estimated for soybeans at the W126 index value of 12 ppm-hrs (U.S. EPA 2014, Figure 6-3). Four of the studied crop species (i.e., barley, lettuce, field corn, and grain sorghum) are more tolerant, with RYL under 1% over the W126 range from 7 to 17 ppm-hrs. Peanut also remained under 4% RYL over the same W126 range. Other species differed regarding the W126 level at which RYL reached or fell below 5%. Specifically, for winter wheat, cotton, soybean, kidney bean and potato, the relevant W126 index values at which RYLs were below 5% are 15, 13, 11, 9 and 7 ppm-hrs. As noted in Chapter 5, and in early discussions in this chapter, the significance of these predicted RYLs to the public welfare could be informed by the recognition that crops are heavily managed to obtain the desired yield and the potential adversity to public welfare from yield reductions in any specific crop in a particular location would depend on a number of economic factors, including crop prices, crop substitution, and the welfare importance of relative changes in consumer and producer surplus. We also note that these crop species would likely receive some protection from a standard set, for example, to provide protection against tree biomass loss, such as in areas set aside to be maintained in a more pristine condition (75 FR 3024).

Visible foliar injury has been identified by the FLMs as a diagnostic tool for informing conclusions regarding potential ozone impacts on potentially sensitive AQRVs (USFS, NPS, FWS, 2010), indicating that such O_3-induced impacts might be considered to have the potential to impact the public welfare in scenic and/or recreational areas during years they occur. We take note of the WREA analyses of the nationwide dataset (2006-2010) for USFS/FHM biosites described in section 5.4.2 above, including the observation that the proportion of biosites with injury varies with soil moisture conditions and O_3 W126 index values (U.S. EPA 2014, Chapter 7, Figure 7-10). These analyses also show that foliar injury incidence increases steeply with W126 index values up to approximately 10 ppm-hrs. At W126 index levels greater than that, little or no further increase in proportion of sites showing foliar injury occurs.

With respect to visible foliar injury, we are unaware of any guidance for federal land managers regarding at what spatial scale or what degree of severity visible foliar injury is sufficient to trigger protective action based on this potential impact on AQRVs. Further, there does not appear to be any consensus in the literature regarding severity of foliar injury and risks to plant functions or services, and CASAC, while identifying target percent biomass loss and

yield loss benchmarks for tree seedlings and commodity crops, respectively, did not provide a similar recommendation for this endpoint. Likewise, as in previous reviews, the ISA notes the difficulty in relating visible foliar injury symptoms to other vegetation effects such as individual plant growth, stand growth, or ecosystem characteristics (U.S. EPA, 2013, section 9.4.2, p. 9-39) and further noted that the full body of evidence indicates that there is wide variability in this endpoint, such that although evidence shows visible foliar injury can occur under very low cumulative O_3 concentrations, "…the degree and extent of visible foliar injury development varies from year to year and site to site…, even among co-members of a population exposed to similar O_3 levels, due to the influence of co-occurring environmental and genetic factors" (U.S. EPA 2013, section 9.4.2, p. 9-38). Given this, it is not clear to what extent this information informs the selection of an appropriate level.

On the basis of all the considerations described above, including the evidence and exposure/risk analyses, and advice from CASAC, we conclude that a range of W126 index values appropriate for the Administrator to consider extends from 7 to 17 ppm-hrs. In so doing, however, we note, as recognized above, the role of judgments by the Administrator in such decisions. In selecting the range identified here, we primarily consider the evidence- and exposure/risk-based information for cumulative seasonal O_3 exposures represented by W126 index values (including those represented by the WREA average W126 scenarios) associated with biomass loss in studied tree species, both in and outside areas that have been afforded special protections. We note CASAC's advice that a 6% median RBL is unacceptably high, that the 2% median RBL is an important benchmark to consider, that for the lower W126 value of 7 ppm-hrs that the median tree species biomass loss is at or below 2%, and that for the upper value of 17 ppm-hrs the median tree biomass loss is below 6%[25]. We also note the estimates indicating that a W126 level of 17 ppm-hrs reduces the percent of total nationwide land-area having weighted RBL greater than 2% to 0.2% (Table 6-2) and the number of Class I areas with weighted RBL greater than 2% to 2 of the 145 assessed nationally protected Class I areas.

We also note that tree biomass loss can be an indicator of more significant ecosystem-wide effects which might reasonably be concluded to be significant to public welfare. For example, when it occurs over multiple years at a sufficient magnitude, it is linked to an array of effects on other ecosystem-level processes, such as nutrient and water cycles, changes in above and below ground communities, carbon storage and air pollution removal (U.S. EPA, 2014b, Figure 5-1), that have the potential to be adverse to the public welfare.

Thus, in staff's view, the evidence- and exposure/risk-based information relevant to tree biomass loss and the associated ecosystem services important to the public welfare support

[25] We note that a W126 index value of 19 ppm-hrs is estimated to result in a median RBL value of 6%.

consideration of a W126-based secondary standard with index values within the range of 7-17 ppm-hrs. We consider such a range for a potential alternative cumulative seasonal W126-based standard, averaged over three years, based on our analysis of the small effect of year to year variability on the cumulative biomass loss associated with multiple years of exposure, and the benefits of improved stability of the W126 standard when evaluated using the 3-year average form. Lastly, we are mindful of the policy judgments required of the Administrator with regard to the public welfare significance of identified effects and the requisite level of protection, as well as the appropriate weight to assign the range of uncertainties inherent in the evidence and analyses.

While we additionally recognize foliar injury as an important O_3 effect which, depending on severity and spatial extent, most particularly in nationally protected areas such as Class I areas, may reasonably be concluded to be of public welfare significance, we take note of the appreciable variability in this endpoint, as summarized in chapter 5 and section 6.3 above, which poses challenges to giving it primary emphasis in identifying potential alternative standard levels. Similarly, we give less emphasis to consideration of crop yield loss in our consideration of potential standard levels here and in section 6.3 above, noting the median estimates of approximately 5% or lower for W126 index levels at and below 17 ppm-hrs. We also note the range of factors affecting annual crop yields, including those related to the role of management strategies as recognized in sections 5.3 and 6.2 above which complicate the identification of a degree of impact that can be considered adverse to the public welfare.

We further recognize the role of policy judgments by the Administrator, as described above, in identifying a target level of protection for the secondary O_3 standard. For example, to the extent effects associated with cumulative multi-year exposures are judged important to the public welfare, more weight may be placed on such effects, as well as the role that year-to-year exposure variability can play in realizing the potential public welfare impacts.

Lastly, we also conclude that, to the extent the Administrator finds it useful to consider the public welfare protection that might be afforded by a revised primary standard, this is appropriately judged by evaluating how the cumulative seasonal W126-based exposure metric is affected by attainment with such a revised primary standard. For example, comparison of the air quality conditions expected to result from a revised primary standard, with those conditions expressed in terms of W126 exposures, to the W126 levels concluded to provide the desired level of public welfare protection could inform a judgment of whether a secondary standard set identical to a revised primary standard would be expected to achieve the level of public welfare protection concluded to be requisite under the Act. In this type of evaluation, such as through the overlap analyses discussed in section 6.4 above, staff further concludes it is important to take into account associated uncertainties, including those associated with the limited monitor

coverage in many rural areas, including those in the west and southwest and at high elevation sites.

6.7 SUMMARY OF CONCLUSIONS ON THE SECONDARY STANDARD

Staff conclusions are informed by our consideration of the available scientific evidence as assessed in the ISA, the air quality/exposure/risk information in the WREA, advice from CASAC in this review and in prior reviews, and public comment in this review.

Staff conclusions on policy options that are appropriate for the Administrator's consideration in making decisions on the secondary standards for O_3, together with supporting conclusions from sections 5.7 and 6.5 above, are briefly summarized below. In reaching conclusions on alternative standards to provide requisite protection for public welfare effects associated with ambient O_3 exposures, staff has considered these standards in terms of the basic elements of the NAAQS: indicator, form, averaging time, and level. In drawing these conclusions, we are mindful that the Act requires secondary standards to be set so that, in the Administrator's judgment, they are requisite to protect public welfare from known or anticipated adverse effects, such that the standards are to be neither more nor less stringent than necessary. Thus, the Act does not require that NAAQS be set at zero-risk or background levels, but rather at levels that reduce risk sufficiently to protect public welfare from adverse effects.

(1) Staff concludes, based on the combined consideration of the body of evidence and the results from the quantitative exposure/risk assessment, that the available evidence and exposure/risk information call into question the adequacy of the public welfare protection provided by the current standard and that it is appropriate to consider revising the standard to provide greater public welfare protection.

(2) With regard to indicator, staff concludes that it is appropriate to continue to use O_3 as the indicator for a standard that is intended to address welfare effects associated with exposure to O_3, alone or in combination with related photochemical oxidants. Based on the available information, staff concludes that there is no basis for considering an alternative indicator at this time.

(3) With regard to averaging time and form, staff concludes that it is appropriate to consider a revised secondary standard in terms of the cumulative, seasonal, concentration-weighted form, the W126 index. With regard to definition of the W126 index for this purpose, staff makes the additional conclusions:

   a. It is appropriate to consider the consecutive 3-month period within the O_3 season with the maximum index value as the seasonal period over which

to cumulate hourly O_3 exposures. Staff notes that the maximum 3-month period generally coincides with maximum biological activity for most vegetation, making the 3-month duration a suitable surrogate for longer growing seasons.

b. It is appropriate to cumulate daily exposures for the 12-hour period from 8:00 am to 8:00 pm, generally representing the daylight period during the 3-month period identified above.

c. It is appropriate to consider a form that averages W126 index values across three consecutive years. Staff concludes it is appropriate to consider this form in conjunction with appropriate levels in order to provide the desired degree of public welfare protection from O_3 effects across multiple years.

(4) With regard to a target level of protection for a revised standard, staff concludes that it is appropriate to give consideration to a range of levels from 17 ppm-hrs to 7 ppm-hrs, expressed in terms of the W126 index averaged across three consecutive years.

a. To the extent the Administrator finds it useful to consider the extent of public welfare protection that might be afforded by a revised primary standard, staff concludes that public welfare protection is appropriately judged through the use of the cumulative seasonal W126-based metric.

Staff additionally notes that, consideration of the support provided by the information available in this review will depend on public welfare policy judgments by the Administrator regarding the protection of public welfare. This range reflects staff judgment that a standard set within this range could provide an appropriate degree of public welfare protection.

6.8 KEY UNCERTAINTIES AND AREAS FOR FUTURE RESEARCH AND DATA COLLECTION

Staff believes it is important to highlight key uncertainties and recommendations for welfare-related research, including model development and data gathering, associated with secondary standards for O_3. Based on items highlighted in chapter 9 of the ISA, chapters 5 and 6 herein, and CASAC advice, we have identified the following areas for future research and data collection based on key uncertainties, research questions and data gaps that have been highlighted in this review of the secondary standard. The first research area addresses the key uncertainties associated with the extrapolation to plant species and environments outside of specific experimental or field study conditions. The second area of research pertains to the

assessment of the impact of O_3 on other welfare effects categories such as climate, ecosystem components, and whole ecosystem structure and function. A third area of research would support the development of approaches, tools, or methodologies useful in characterizing O_3 exposures in rural, remote, high elevation and/or complex terrain areas and in characterizing ecosystem services and their importance to the public welfare. These three areas are described below.

With regard to the first research area we note that while there have been five decades of research regarding O_3 effects on plants and much information has been compiled in previous reviews, a number of key uncertainties remain. For example, while national visible foliar injury surveys can indicate how widespread O_3 effects may be within the U.S., there remain uncertainties associated with estimating the risk to vegetation of differing amounts of O_3-induced visible foliar injury over the plant's leaf area and the relationship between relative soil moisture and the incidence and severity of foliar injury in sensitive species, as well as the extent to which different degrees of visible foliar injury can impact ecosystem services (e.g., tourism). Research to better characterize the relationship between O_3, soil moisture and foliar injury and to determine if there is an injury threshold or quantifiable relationship between these factors could help inform policy. Additionally, research to understand the connection between O_3-related foliar injury and other physiological effects and ecosystem services could also be useful. We further note that while this review relied on the robust E-R functions that are available for 11 tree and 10 crop species, there are tens of thousands of plant species in the U.S. (USDA, NRCS, 2014),[26] 66 of which have also been identified as O_3 sensitive on National Park Service and US Fish and Wildlife Service lands[27]. Research on additional tree as well as non-tree species that would support the development of robust E-R functions would improve our understanding of the full range of response of plant species to O_3 and our understanding of the overall risk to vegetation. For example, studies using large numbers of native plant species across regions where those species are indigenous, might be expected to reduce uncertainties associated with extrapolating plant response for a given level of O_3 using composite response functions across differing regions and climates. Studies focused on fruits and vegetables might assist in reducing uncertainties associated with O_3 effects on agriculture. Particular focus is suggested on organically grown vegetables that may receive less intensive management than conventionally grown crops. Recent studies indicate that watermelons may be particularly sensitive to O_3

[26] USDA, NRCS. 2014. The PLANTS Database (http://plants.usda.gov, 3 January 2014). National Plant Data Team, Greensboro, NC 27401-4901 USA.

[27] See http://www2.nature.nps.gov/air/Pubs/pdf/flag/NPSozonesensppFLAG06.pdf

exposure (U.S. EPA, 2013, section 9.4.4.1) and older studies indicate grapes, honeydew melon, lemons and oranges may also be O_3 sensitive (Abt Associates Inc., 1995).

Some new information has emerged linking effects on tree seedlings with larger trees and similarities in results between exposure techniques (U.S. EPA 2013, section 9.6). Uncertainties remain in this area as well as uncertainties in extrapolating from O_3 effects on juvenile to mature trees and from trees grown in the open versus those in a closed forest canopy in a competitive environment. The relationship between nocturnal exposures and plant uptake and response is also an important subject for further research.

With respect to the second research area pertaining to the impact of O_3 on other welfare effects categories such as climate, ecosystem components, and whole ecosystem structure and function, uncertainties that remain in extrapolating individual plant response spatially or to higher levels of biological organization, including ecosystems, could be informed by research that explores and better quantifies the nature of the relationship between O_3, plant response and multiple biotic and abiotic stressors, including those associated with the ecosystem services that would be affected (e.g., hydrology, productivity, carbon sequestration). Because these uncertainties are multiple and significant due to the complex interactions involved, new research will likely require a combination of manipulative experiments with model ecosystems, community and ecosystem studies along natural O_3 gradients, and extensive modeling efforts to project landscape-level, regional, national and international impacts of O_3.

Uncertainties associated with projections of the effects of O_3 on the ecosystem processes of water, carbon, and nutrient cycling, particularly at the stand and community levels might be addressed through research on the effects on below ground ecosystem processes in response to O_3 exposure alone and in combination with other stressors. These below-ground processes include interactions of roots with the soil or microorganisms, effects of O_3 on structural or functional components of soil food webs and potential impacts on plant species diversity, changes in the water use of sensitive trees, and if the sensitive tree species is dominant, potential changes to the hydrologic cycle at the watershed and landscape level. Research on competitive interactions under different O_3 exposures might improve our understanding of how O_3 may affect biodiversity or genetic diversity. Such research could be strengthened by modern molecular methods to quantify impacts on diversity. More tools and research would improve our understanding of relationships between O_3 exposure and stressors such as insect infestations, plant diseases, drought and potential stressors from climate change. It is also important to understand how such interactions may affect ecosystem services such as CO_2 sequestration; food and fiber production; wildlife habitat and water resources.

With respect to the research areas related to the development of approaches, tools, or methodologies useful in characterizing O_3 exposures and the relationship between O_3-induced

effects and associated ecosystem services and public welfare in a policy context, we note that one of the most important uncertainties in this review is the characterization of air quality in rural areas where there is limited monitoring. More comprehensive monitoring in these areas would reduce uncertainties associated with O_3 exposures in many rural areas. Areas of particular uncertainty include protected natural areas in the western U.S, including those at high elevation, as well as those downwind of recently expanded oil and gas development areas. Uncertainties associated with quantifying exposure in areas with and without monitors might be addressed through additional work on interpolation methods and air quality models that are tailored to estimating cumulative seasonal exposures, as well as improved model capabilities that use more refined spatial grids and are better able to handle O_3 movement in complex terrain.

Uncertainties related to characterizing the potential public welfare significance of O_3-induced effects and impacts to associated ecosystem services could also be informed by research, such as research intended to clarify the relationship between O_3 exposure and fire risk and O_3 exposure and forest susceptibility to bark beetle infestation. Research relating known O_3 ecological effects such as reproductive effects to effects on production of non-timber forest products and research to characterize public preferences including valuation related to non-use and recreation for foliar injury could also help inform consideration of the public welfare significance of these effects.

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APPENDICES

APPENDIX 2A

SUPPLEMENTAL AIR QUALITY MODELING ANALYSES OF BACKGROUND OZONE

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1. Introduction

One of the aspects of ozone that is unusual relative to the other pollutants with National Ambient Air Quality Standards (NAAQS) is that, periodically, in some locations, an appreciable fraction of the observed ozone results from sources or processes other than local and regional anthropogenic emissions of ozone precursors (Fiore *et al*., 2002). Any ozone formed by processes other than the chemical conversion of local or regional ozone precursor emissions, such as nitrogen oxides (NOx) or volatile organic emissions (VOC), is generically referred to as "background" ozone. As part of this review of the ozone NAAQS, EPA completed an extensive review of the known aspects of background ozone and summarized the findings in the Integrated Science Assessment (ISA) in March 2013 (USEPA, 2013). The purpose of this appendix is to present the results from supplemental air quality modeling analyses related to background ozone that were completed by EPA subsequent to the ISA. While these updated analyses use a recent base year (2007) and consider an alternative modeling methodology which can better account for non-linear ozone chemistry in some conditions, the results are largely consistent with previous determinations about the magnitude of background ozone contributions across the U.S.

Away from the surface, ozone can have an atmospheric lifetime on the order of weeks. As a result, background ozone can be transported long distances at heights above the boundary layer and, when meteorological conditions are favorable, be available to mix down to the surface and add to the total ozone loading from non-background sources. Generically, background ozone can originate from natural sources of ozone and ozone precursors, as well as from far upwind manmade emissions of ozone precursors. Natural sources of ozone precursor emissions such as wildfires, lightning, and vegetation can lead to ozone formation by chemical reactions with other natural sources[1]. Another important natural component of background is ozone that is naturally formed in the stratosphere through interactions of UV light with atomic oxygen (O_2). Stratospheric ozone can periodically mix down to the surface at high concentrations, especially at higher altitude locations. The manmade portion of the background includes any ozone formed due to anthropogenic sources of ozone precursors emitted far away from the local area (e.g., international emissions). Finally, both biogenic and international anthropogenic emissions of methane, which can be chemically converted to ozone over relatively long time scales, can also contribute to global background ozone levels.

The precise definition of background ozone can vary depending upon context, but it generally refers to ozone that is formed by sources or processes that cannot be influenced by actions within the jurisdiction of concern. In the first draft policy assessment document (EPA, 2012), EPA presented three specific definitions of background ozone: natural background, North American background, and U.S. background. Natural background (NB) was the narrowest definition of background and it was defined as the ozone that would exist in the absence of any manmade ozone precursor emissions. The other two previously-established definitions of background presume that the U.S. has little influence over anthropogenic emissions outside our continental or domestic borders. North American background (NAB) is defined as that ozone that would exist in the absence of any manmade ozone precursor

[1] Ozone formed through reactions between natural emissions and local anthropogenic emissions (e.g., biogenic VOC with man-made NOx) is generally not considered to be background ozone.

emissions inside of North America. U.S. background (USB) is defined as that ozone that would exist in the absence of any manmade emissions inside the United States. It is important to note that **each of these three definitions of background ozone requires photochemical modeling simulations** to estimate what the residual ozone concentrations would be were the various anthropogenic emissions to be removed.

As noted in the first draft policy assessment, EPA has revised several aspects of our methodology for estimating the change in health risk and exposure that would result from a revision to the ozone NAAQS. First, risk estimates are now based on total ozone concentrations as opposed previous reviews which only considered risk above background levels. Second, EPA is now using air quality models to estimate the spatial patterns of ozone that would result from attaining various levels of the NAAQS, as opposed to simplistic rollback techniques that required the estimation of a background ozone "floor" beyond which the rollback would not take place. Both of these revisions have had the indirect effect of obviating the need for estimating background ozone levels as part of the ozone risk and exposure assessment (REA). Regardless, EPA expects that a well-founded understanding of the fractional contribution of background sources and processes to surface ozone levels will be valuable towards informing policy decisions about the NAAQS. Section 2 of this document will describe the supplemental air quality modeling simulations that have recently been completed by EPA to bolster our understanding of background ozone. Section 3 will present the results from the updated analyses and provide estimates of average background ozone levels, and how they can vary in time and space across the U.S. Based on the same modeling, Section 4 will consider the entire spectrum of variable background ozone levels with special emphasis on areas and times in which background can approach or exceed the level of the NAAQS. Section 5 will utilize the supplemental air quality modeling estimates to determine the relative importance of specific components of background ozone. Section 6 will present estimates of the overall fraction of ozone that is estimated to result from background sources or processes in each of the 12 urban case study areas in the epidemiology study based analyses in Chapter 7 of the Risk and Exposure Assessment (REA) (EPA, 2014) based on the updated modeling. Finally, Section 7 will conclude with a limited analysis of how background ozone levels impact longer-term ozone metrics that may be important from a welfare perspective (i.e., W126).

2. Description of modeling methodologies

As noted above, air quality models are typically used to estimate background ozone as it is quite difficult to measure directly. Without special monitoring, it is impossible to determine how much of the ozone measured by a monitor originated from sources that are considered background. Even the most remote monitors within the U.S. can periodically be affected by U.S. anthropogenic emissions. Previous modeling studies have estimated what background levels would be in the absence of certain sets of emissions by simply comparing the ozone differences between a base model simulation and a control simulation in which emissions were removed. This basic approach is often referred to as "zero out" modeling or "emissions perturbation" modeling. Examples of zero out modeling include the three major studies summarized in the ISA (Zhang et al., 2011; Emery et al., 2012, Lin et al., 2013). It is important to note that the specific concepts of NB, NAB, and USB are all explicitly tied to zero-out modeling, as those definitions are based on estimating what remains *in the absence of* specific sets of man-made emissions.

EPA has conducted and will describe updated air quality modeling for a 2007 base year that employs a regional air quality model nested within a coarser-scale global chemical transport model to estimate NB, NAB, and USB levels when the respective manmade emissions are zeroed. This modeling is described in detail in section 2a.

While the zero-out approach has traditionally been used to estimate background ozone levels, the methodology has some acknowledged limitations. First, from a policy perspective, the purely hypothetical and ultimately unrealizable zero manmade emissions scenarios have limited application in this regard. Secondly, the assumption that background ozone is what is left after specific emissions have been removed within the model simulation can be misleading in locations where ozone chemistry is highly non-linear. Depending upon the local composition of ozone precursors, NOx emissions reductions can either increase or decrease ozone levels in the immediate vicinity of those reductions. For those specific urban areas in which NOx titration of ozone can be significant, zero-out modeling can result in inflated estimates of background ozone when these NOx emissions are completely and unrealistically removed. Paradoxically, in certain times and locations in a zero-out scenario there can be more background ozone than actual ozone within the model (EPA, 2014).

A separate modeling technique attempts to circumvent these limitations by apportioning the total ozone within the model to its contributing source terms. This basic approach is referred to as "source apportionment" modeling. While source apportionment modeling has not been previously used in the context of estimating background ozone levels as part of an ozone NAAQS review, it has frequently been used in other regulatory settings to estimate the "contribution" to ozone of certain sets of emissions (EPA 2005, EPA 2011). The source apportionment technique provides a means of estimating the contributions of user-identified source categories to ozone formation in a single model simulation. This is achieved by using multiple tracer species to track the fate of ozone precursor emissions (VOC and NOx) and the ozone formation caused by these emissions. The methodology is designed so that all ozone and precursor concentrations are attributed to the selected source categories at all times without perturbing the inherent chemistry. The zero out modeling attempts to determine what ozone be in the absence of background sources. The source apportionment modeling attempts to determine how much of the modeled ozone has resulted from background sources. EPA has conducted and will describe new source apportionment modeling that employs a regional air quality model nested within a coarser-scale global chemical transport model to assess the contributions of boundary conditions and other potential background sources (e.g., wildfires, biogenic emissions, and Canadian/Mexican emissions). This modeling is described in detail in section 2b.

a. 2007 GEOS-Chem/CMAQ zero-out modeling:

In order to provide estimates of the overall fraction of ozone that is estimated to result from background sources in each of the 12 REA urban study areas, EPA conducted new modeling that utilized the same model base year (2007) as was used in the ozone modeling that inform the risk and exposure analyses (EPA, 2014, Appendix 4b). The EPA modeling used a model configuration similar to that of Emery (2012), in that it nested a regional-scale (12 km) air quality model inside a global air quality model

simulation with a much coarser horizontal grid resolution (2.0 by 2.5 degrees). Figure 1a shows a map of the model domain.

The global scale simulation utilized the GEOS-Chem model, version v8-03-02, except for the chemistry package which was from version v8-02-01. The emissions estimates used in the 2007 base year modeling were aggregated from a variety of sources, starting with the global Emissions Database for Global Atmospheric Research (EDGAR) emission inventory. These initial estimates were then improved by utilizing various area-specific inventories, such as the 2005 National Emissions Inventory (NEI) for the U.S. portions of the domain, and available inventories for Asia, Canada, Europe, and Mexico. In addition to the anthropogenic estimates, emissions were specified for a variety of background sources including: lightning NO, soil NOx, wildfires, and biogenic VOC emissions. The wildfire data is from the Global Fire Emissions Database (GFED). The biogenic VOC estimates were simulated by the Model of Emissions of Gases and Aerosols from Nature (MEGAN) version 2.1. The meteorological data is based on the Goddard Earth Observing System Model, Version 5 (GEOS-5) analysis fields. More information on the global simulation is available within Henderson *et al.* (2013). This reference also provides a broad evaluation of the ability of this specific GEOS-Chem configuration to provide accurate lateral boundary conditions of ozone to finer-scale regional simulations. Using satellite retrievals from the Tropospheric Emissions Spectrometer (TES), Henderson *et al.* (2013) concluded that the GEOS-Chem ozone prediction biases and errors are generally within TES uncertainty estimates. For instance, for the ozone season month of August, model predictions are within plus or minus 20 percent of the satellite estimates between nearly 80 percent of the time, with slightly better performance along the southern boundary.

The lateral boundary conditions from the global model were then used as inputs for a 12 km horizontal resolution, CMAQ version 4.7.1, model simulation. Four scenarios were modeled: 1) a 2007 base case simulation which was the basis of the air quality modeling performed for the 2nd draft ozone REA and is described in more detail in Appendix 4b of EPA (2014), 2) a natural background run with anthropogenic ozone precursor emissions[2] removed in both the global and regional models, 3) a North American background run with anthropogenic ozone precursor emissions removed across North America (global and regional model simulations), and 4) a U.S. background run with anthropogenic ozone precursor emissions were removed over the U.S (global and regional model simulations). Detailed analyses of EPA's 2007 zero out modeling results are provided in sections 3 through 6 of this appendix.

An operational model performance evaluation was completed for surface ozone in the 2007 base simulation as described separately (EPA 2014, Appendix 4b). For the purposes of this analysis, EPA assessed the model ability to reproduce measured daily maximum 8-hour (MDA8) ozone values and seasonal mean MDA8 ozone concentrations for the period April to October 2007. As noted earlier, the base year modeling in this analysis used climatological monthly-average wildfire emissions which are not

[2] In the global model all ozone precursor species were removed (i.e., VOC, NOx, CO), except for methane which was reset to pre-industrial levels to reflect natural contributions. In the regional modeling, the methane levels were left unchanged.

intended to capture discrete events from specific fires that occurred in 2007, so perfect correlation between observations and model predictions should not be expected. Figure 1b provides a density scatterplot of the observed and predicted daily 8-hour ozone peaks paired in space and time for the 2007 CMAQ base. As can be seen, the majority of pairs line up along the 1:1 line. There is a tendency for the model to overestimate site-days with low 8-hour ozone peaks, and underestimate the site-days with higher peak ozone values. Modeled 8-hour ozone peak concentrations exhibited relatively small bias and error compared to the observations. The average bias in MDA8 ozone estimates was 3.5 ppb. Figure 1c depicts the spatial bias patterns in MDA8 ozone at all sites that measured valid ozone data for at least 100 days during the April-October period. CMAQ overestimations are greatest along the Gulf Coast region, along the Atlantic coastline, and over the central U.S. The majority of underestimated seasonal mean MDA8 occurs within southern California. The model performance for the 2007 base simulation is equivalent or better than typical state-of-the-science photochemical model performance recently reported in the literature (Simon et al, 2012).

Certainly some remote monitoring locations are more affected by background sources than other locations in the network. However, this and numerous other analyses have shown that even the most remote ozone monitoring locations in the U.S. are periodically affected by U.S. manmade emissions. In this analysis we carefully assess model performance to ensure that model error does not influence the characterization of background ozone. As noted in the recent ISA (EPA, 2013), there is greater confidence in the ability of the model to predict mean contributions from background sources rather than individual events. Beyond the statistical analyses summarized in the previous paragraph and in appendix 4b of the 2nd draft ozone REA (EPA, 2014), it is valuable to attempt to diagnose the model ability to account for background ozone within the simulation. EPA assessed whether any correlation existed between daily model biases and daily background ozone estimates. Figure 1d shows that at high-elevation sites (i.e., sites more than 1km above sea level) the highest estimates of natural background ozone tend occur on days with greatest overestimation. Conversely, the site-days with the lowest natural background estimates tend to occur when the model underestimates the observed daily peaks at these sites. This relationship between background estimates and simulation bias appears to be constrained to the mountainous portion of the Western U.S. Figure 1d also shows that estimates of natural background ozone greater than 60 ppb are associated with large over-predictions. However, based on the relatively low model bias and the general lack of correlation between daily bias values and background estimates, EPA believes that these model estimates can be used to help characterize background ozone levels over the U.S. Although the highest background estimates should be considered with caution.

Figure 1a. Modeling domain used in 2007 CMAQ and CAMx modeling.

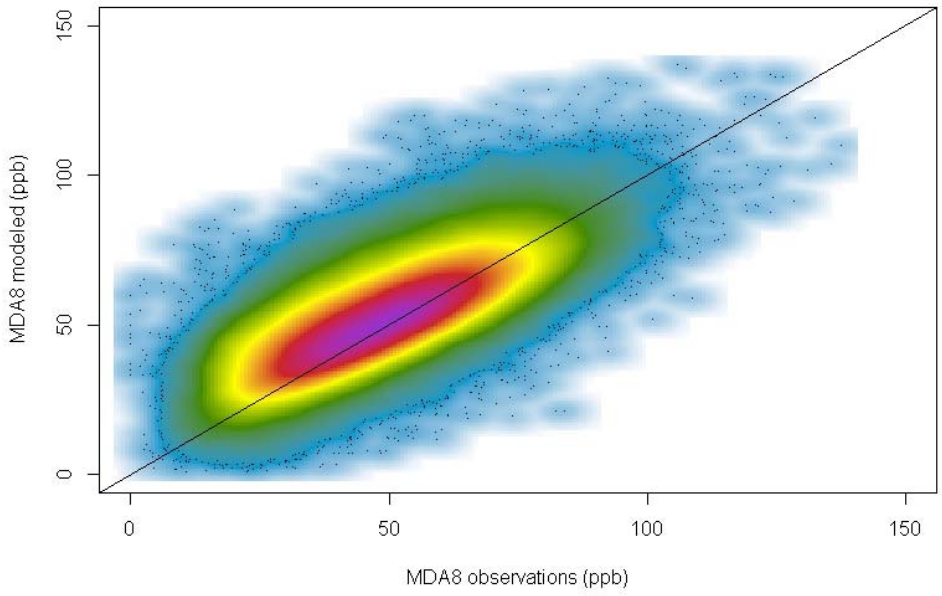

Figure 1b. Density scatterplot comparing CMAQ base daily peak 8-hour ozone predictions against observed 8-hour ozone peaks paired in space and time for all sites during April-October 2007.

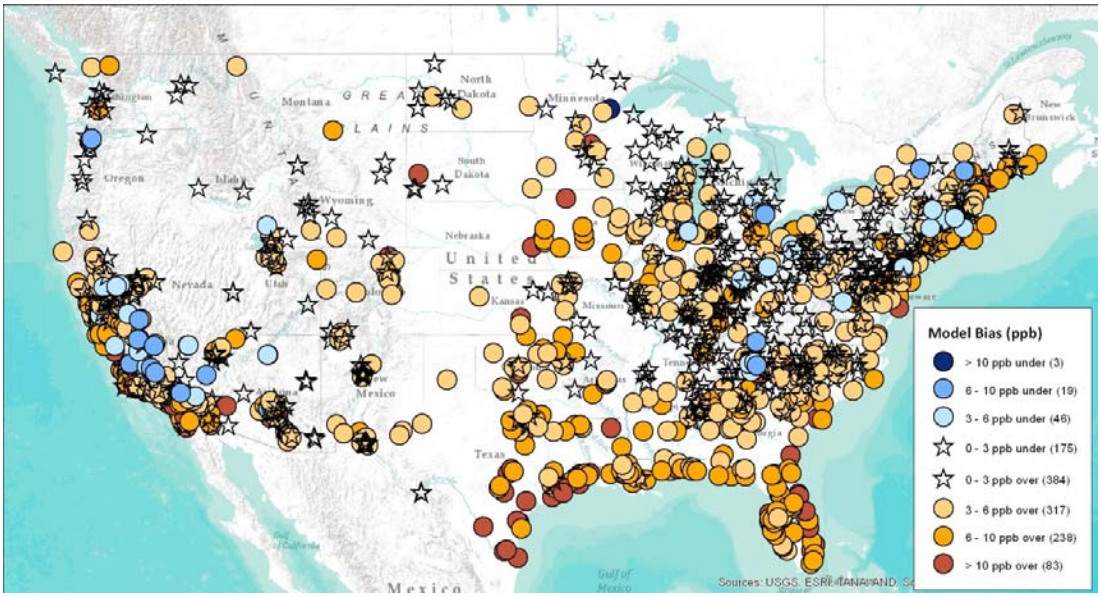

Figure 1c. Bias in seasonal mean (April-October) maximum daily 8-hour ozone predictions in the 2007 CMAQ base simulation.

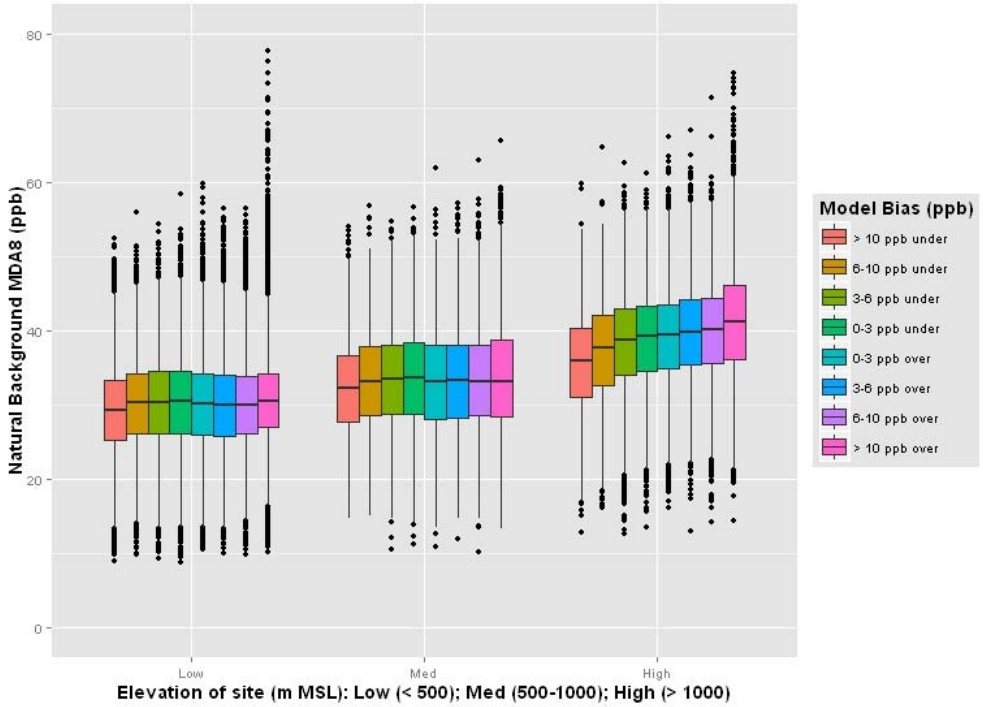

Figure 1d. Relationship between CMAQ estimations of MDA8 natural background ozone and daily model biases.

b. 2007 GEOS-Chem/CAMx source apportionment modeling:

The same global modeling described above was used to assign lateral boundary conditions to the regional-scale (12 km) CAMx v5.0 source apportionment simulations. Wherever possible, the emissions and meteorological inputs in the CAMx modeling were chosen to mimic the 2007 base CMAQ simulation described earlier. Figure 1a shows a map of the model domain.

As with the CMAQ base case, a limited operational model performance evaluation was also completed for surface ozone in the 2007 base simulation. For the purposes of this analysis, EPA assessed the model ability to reproduce measured daily maximum 8-hour (MDA8) ozone values and seasonal mean MDA8 ozone concentrations for the period April to October 2007. Figure 2a provides a density scatterplot of the observed and predicted daily 8-hour ozone peaks paired in space and time for the 2007 CAMx base simulation. As can be seen, the majority of pairs line up along the 1:1 line. Again, there is a tendency for the model to overestimate site-days with low 8-hour ozone peaks and underestimate the site-days with higher peak ozone values. Modeled 8-hour ozone peak concentrations exhibited relatively small bias and error compared to the observations. The average bias in MDA8 ozone estimates was 3.5 ppb. Figure 2b depicts the spatial bias patterns in MDA8 ozone at all sites that measured valid ozone data for at least 100 days during the April-October period. CAMx overestimations are greatest along the Gulf Coast region, along the Atlantic and Pacific coastlines, and within the southeastern U.S. The majority of underestimated seasonal mean MDA8 occurs in California away from the coastline.

The apportionment tools in CAMx utilized here to estimate the contribution of background sources are well-established and have previously been peer-reviewed (UNC, 2009). EPA used the Anthropogenic Precursor Culpability Assessment (APCA) tool in this analysis. The APCA tool attributes ozone production to manmade sources whenever ozone is determined to result from a combination of anthropogenic and biogenic emissions (Environ, 2011). The APCA methodology defines natural ozone as the production resulting from the interaction of biogenic VOC with biogenic NOx emissions. Eleven separate source categories were tracked in the source apportionment analysis, including five boundary condition terms and six in-domain sectors:

- Boundary condition terms:
    - Northern edge
    - Eastern edge
    - Southern edge
    - Western edge
    - Top boundary

- In-domain sectors:
    - U.S. anthropogenic emissions
    - Point sources located within the Gulf of Mexico
    - Category 3 marine vessels outside State boundaries
    - Climatologically-averaged wildfire emissions

- Biogenic emissions
- Canada/Mexico emissions (only those sources within the domain)

It should be noted that the source apportionment modeling conducted here does not allow for replication of natural background because of the construct of boundary conditions. The boundary conditions for our applications can include ozone and/or ozone precursors that were originally generated by natural sources, as well as ozone produced from far upstream anthropogenic emissions (e.g., Asia). It is not possible to disentangle these two terms. Instead, the source apportionment modeling is primarily used to help estimate background into the U.S., which is assumed to be the contributions from nine of the modeled sectors; that is, everything except U.S. anthropogenic emissions and point sources located within the Gulf of Mexico.

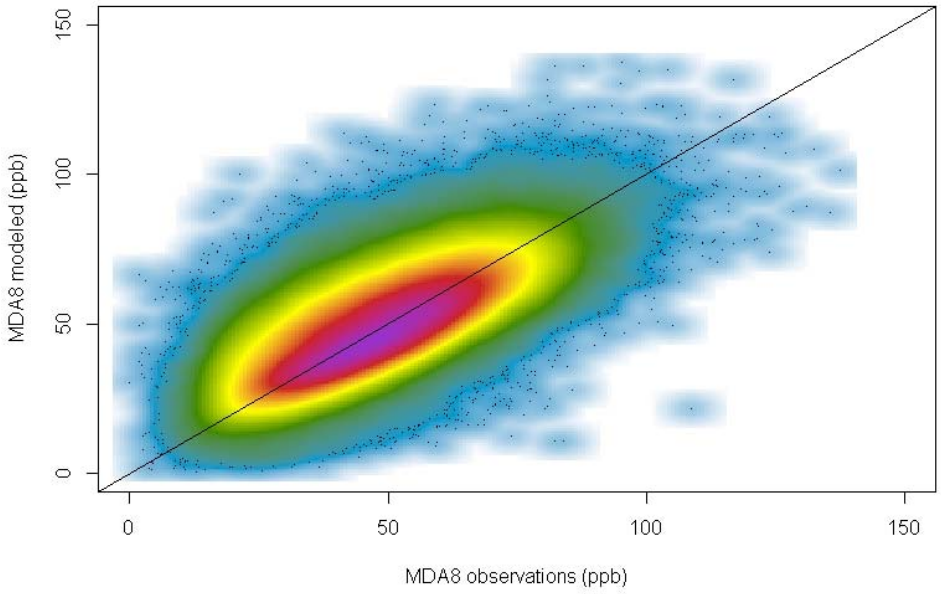

Figure 2a. Density scatterplot comparing CAMx base daily peak 8-hour ozone predictions against observed 8-hour ozone peaks paired in space and time for all sites during April-October 2007.

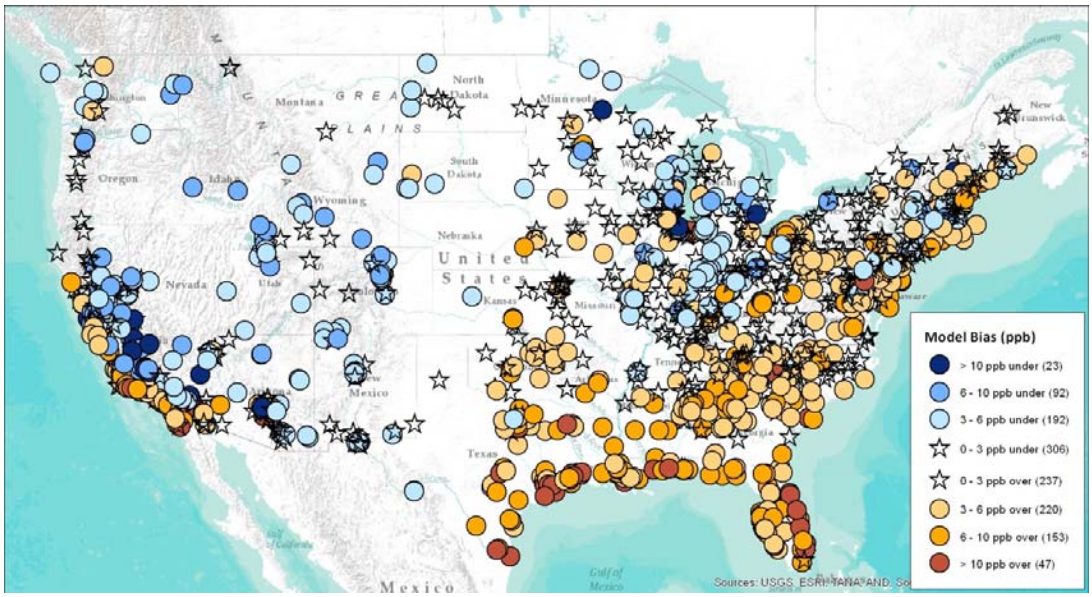

Figure 2b. Bias in seasonal mean (April-October) maximum daily 8-hour ozone predictions in the 2007 CAMx base simulation.

3. Estimates of seasonal-average background ozone levels

This section of the appendix provides estimates of seasonal average background ozone levels over the U.S. As noted in the introduction and as discussed in detail in the ISA, background ozone values can vary significantly in space and time. There can be atypical episodes of higher background ozone concentrations amidst the routine days that drive seasonal average background. The highest background episodic concentrations are typically associated with stratospheric intrusions or wildfires. These background "events" can be difficult to model as they require event-specific model inputs. The primary goal of the EPA modeling was to estimate the seasonal average background concentrations between April and October 2007. Previous analyses have shown that this is the period in which average background levels are highest (Zhang et al., 2011). This section of the appendix focuses on seasonal mean levels of background. (Section 4 will consider the upper range of possible background ozone.)

The analysis focus on the maximum daily 8-hour ozone average in ppb. This metric is referred to as MDA8. This section will first present model estimates of seasonal mean ozone levels in the base simulation. This will be followed by estimates of NB, NAB, and USB from the CMAQ zero out modeling. After discussing the magnitudes of background levels, the section switches to a consideration of the relative percentage of background to total ozone across the U.S. This portion of the text will utilize both the CMAQ zero out and CAMx source apportionment modeling.

Figure 3a displays the 2007 base case, CMAQ model-predicted, seasonal mean (April-October) MDA8 ozone concentrations in grid cells with active monitoring locations over the U.S. The model results are shown at the monitoring site level as opposed to in the default gridded format to foster subsequent site-level estimates of background magnitudes. Each grid cell containing an Air Quality System (AQS) ozone monitor that was collecting valid data in 2007 was identified and the model

background estimates were extracted for those grid cells and displayed accordingly. The base predictions are provided for context to allow easier interpretation of the following plots which isolate specific background levels. As can be seen, most of the U.S. experiences seasonal mean MDA8 ozone levels greater than 50 ppb in the base case simulation. The median value over the 1,294 monitoring locations is 52.5 ppb.

Figure 3b provides an estimate of what seasonal-average MDA8 would be in a natural background scenario, using the 2007 EPA zero out modeling. Again, in this GEOS-Chem/CMAQ simulation, all anthropogenic ozone precursor emissions were removed from both the global and regional simulations, and methane levels were adjusted to pre-industrial levels in the global simulation. As shown, natural background ozone levels range from approximately 15-35 ppb with the highest values occurring over the higher-elevation sites in the western U.S. The median value over these locations is 24.2 ppb, and more than 50 percent of the sites have natural background levels of 20-25 ppb. The highest modeled estimate of seasonal average, natural background, MDA8 ozone is 34.3 ppb at the high-elevation CASTNET site (Gothic) in Gunnison County, CO.

Figures 3c and 3d show the same information for the North American and U.S. background scenarios. In these model runs, all anthropogenic ozone precursor emissions were removed from the U.S., Canada, and Mexico (NAB scenario) and then only the U.S. (USB scenario). The figures show that there is not a large difference between the NAB and USB scenarios. Seasonal mean MDA8 NAB and USB ozone levels range from 25-50 ppb, with the most frequent values estimated in the 30-35 ppb bin. The median seasonal mean background levels are 31.5 and 32.7 ppb (NAB and USB, respectively). Again, the highest levels of background are predicted over the intermountain western U.S. Locations with NAB and USB concentrations greater than 40 ppb are confined to Colorado, Nevada, Utah, Wyoming, northern Arizona, eastern California, and parts of New Mexico. Similar to NB, the highest NAB and USB levels were modeled to occur at the Gothic CO site (46.7/47.7). This remote rural site is located 2,926 meters (9,600 feet) above mean sea level and should not be considered representative of background ozone at lower-altitude, more-populated regions. The high USB and NAB values along the Gulf Coast are most likely due to model biases.

Absolute model estimates of various background definitions are useful, but they can be influenced by any local biases and errors in the modeling. A separate way to look at the role of background in seasonal mean ozone levels is to consider the fractional contribution of NB, NAB, and USB to total ozone at each location. Considering the proportional role of background allows for an informative comparison between the two modeling approaches without having to account for the differences in base case biases and errors. Figures 4a, 4b, and 4c show the estimated fractional contribution of NB, NAB, and USB to total seasonal average MDA8 ozone levels at the monitoring locations from the CMAQ zero out modeling. The modeling estimates that approximately 35-80 percent of the seasonal average MDA8 ozone at monitoring locations is due to natural background sources. A majority sites have NB fractions between 40 and 60 percent. The mean natural background proportion over all sites is 47 percent. That is, when all global anthropogenic emissions are removed and global methane levels in GEOS-Chem are restored to pre-industrial levels, seasonal average MDA8 levels are reduced by approximately half. The fractional proportions of NAB and USB are very similar. In both

cases, most sites have background fractions that range from 50 to 80 percent. The mean NAB fraction (to seasonal mean MDA8) is 63 percent. The mean USB fraction is 66 percent.

As noted in the introduction, the advantage of the source apportionment modeling is that all of the modeled ozone is attributed to various source terms and thus this approach is not affected by the confounding occurrences of background ozone values exceeding the base ozone values as can happen in the zero out modeling (i.e., background proportions > 100%). Consequently, one would expect the fractional background levels to be lower in the source apportionment methodology as a result of removing this artifact. It is also important to remember that the terms NB, NAB, and USB are explicitly linked to the zero out modeling approach. (USB is the ozone that would exist in the absence of U.S. anthropogenic emissions.) In contrast, the source apportionment modeling performed here provides estimates the amount of MDA8 ozone that is attributable to U.S. anthropogenic emissions relative to total base model ozone. Figure 4d shows the relative contribution from ***sources other than U.S. anthropogenic emissions*** to total seasonal mean MDA8 ozone based on the 2007 source apportionment modeling. The fractional contribution fields between CMAQ zero out USB estimates and CAMx source apportionment estimates of source other than U.S. anthropogenic emissions are quite similar. The spatial patterns in Figures 4c and 4d are consistent, with the highest fractional contributions from sources other than U.S. anthropogenic emissions occurring along U.S. borders and over the intermountain western States. The source apportionment modeling estimates that approximately 40-80% of the seasonal average MDA8 ozone at monitoring locations is due to sources other than manmade ozone precursor emissions from the U.S. A majority of sites have non-U.S. fractions between 40 and 70 percent. The mean proportion attributable to international and natural sources over all sites is 59 percent. Despite the differences in the methodologies this is very similar to the mean USB estimate of 66 percent from the zero out modeling.

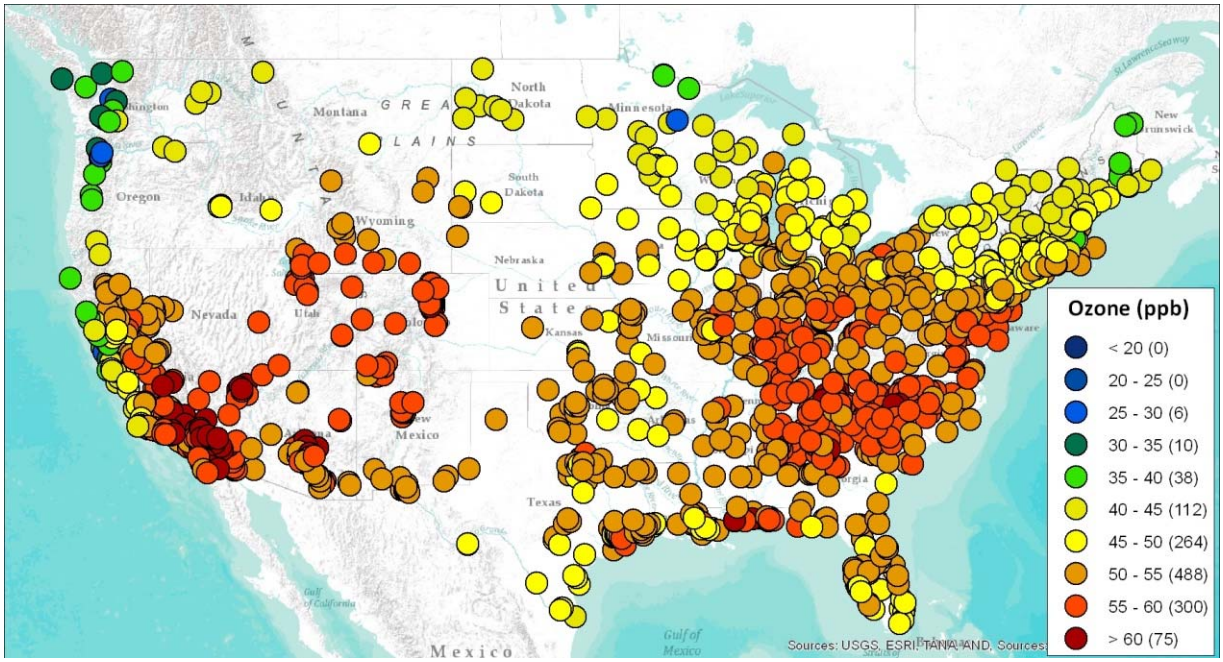

Figure 3a. April-October average MDA8 ozone (ppb) at monitoring locations across the U.S. as estimated by a 2007 CMAQ base simulation.

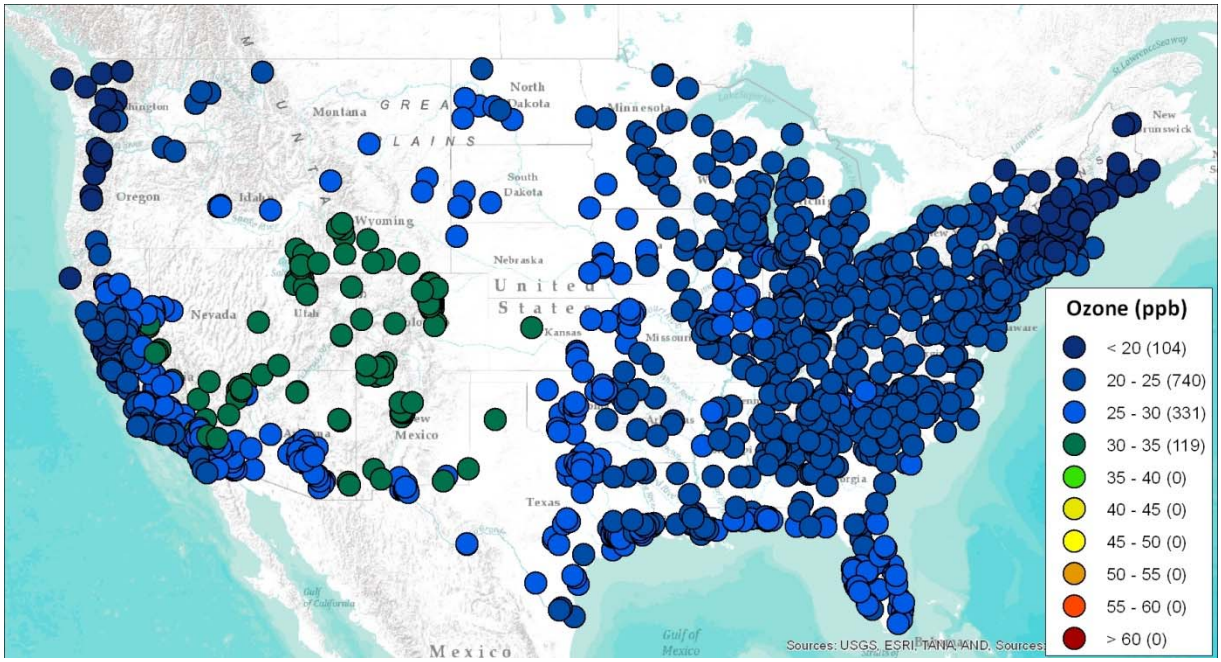

Figure 3b. April-October average *natural background* MDA8 ozone (ppb) at monitoring locations across the U.S. as estimated by a 2007 CMAQ zero out simulation.

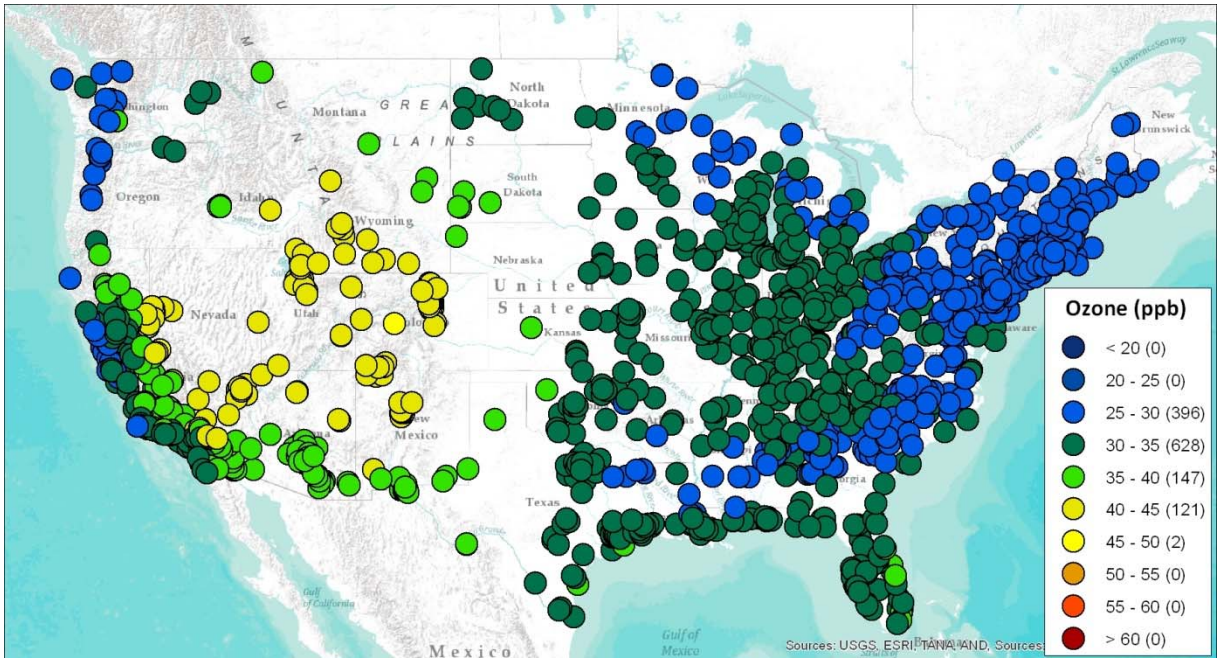

Figure 3c. April-October average *North American background* MDA8 ozone (ppb) at monitoring locations across the U.S. as estimated by a 2007 CMAQ zero out simulation.

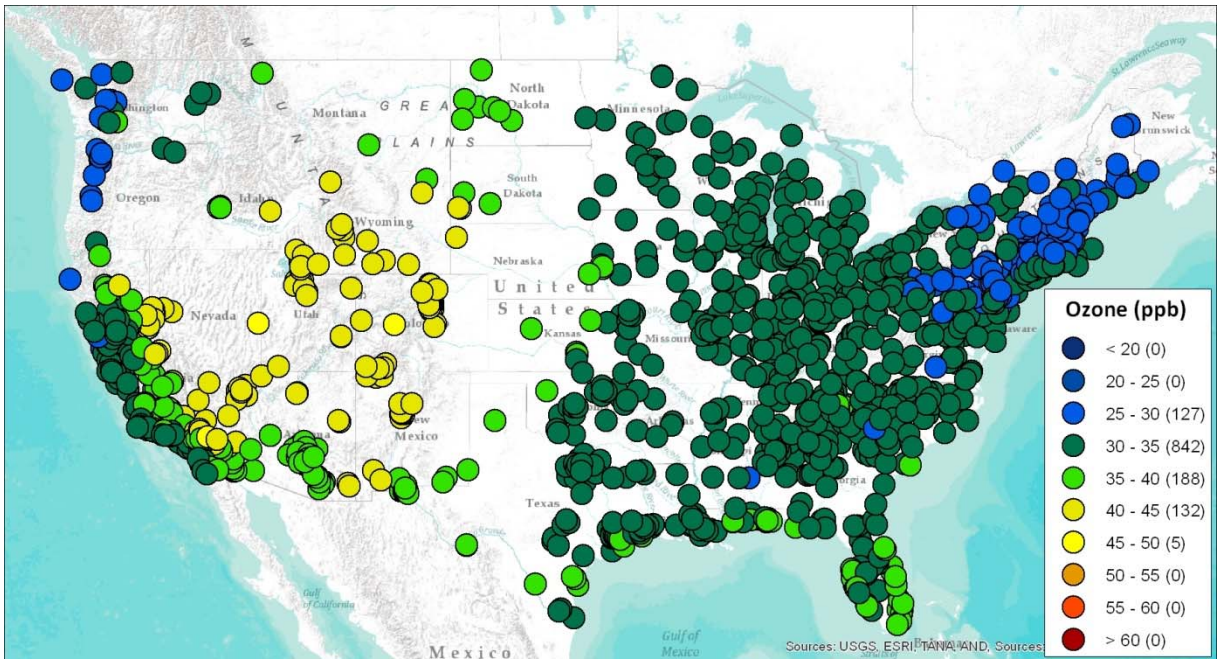

Figure 3d. April-October average *United States background* MDA8 ozone (ppb) at monitoring locations across the U.S. as estimated by a 2007 CMAQ zero out simulation.

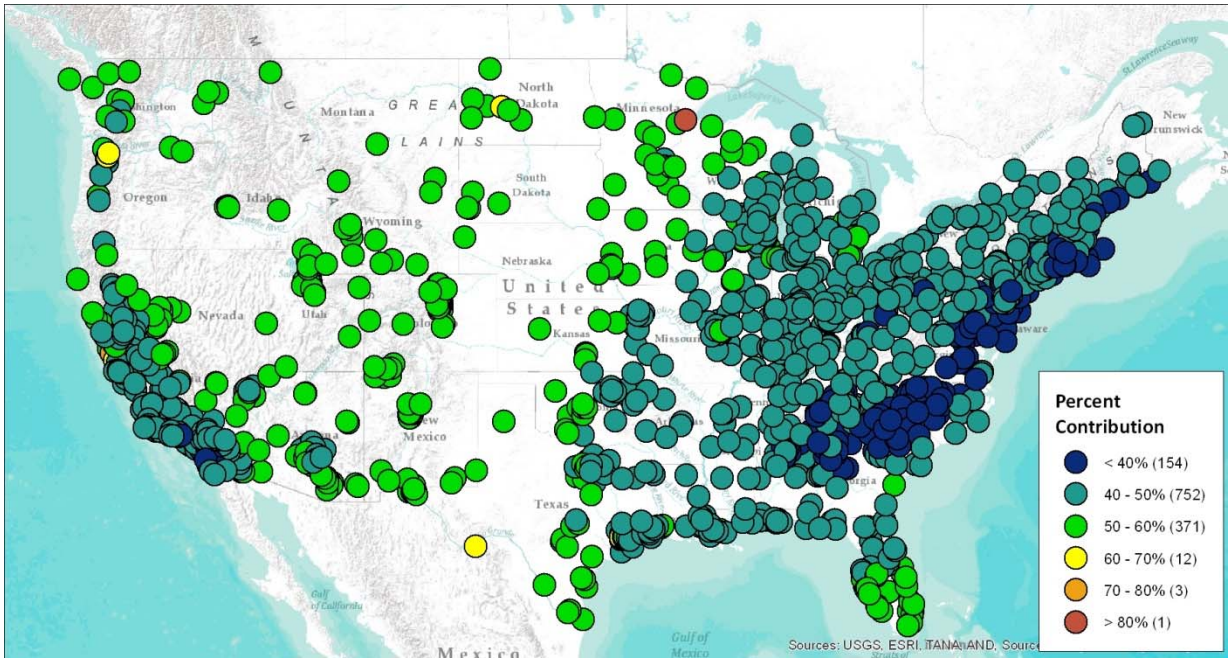

Figure 4a. Ratio of *natural background* to total April-October average MDA8 ozone at monitoring locations across the U.S. as estimated based on 2007 CMAQ simulations.

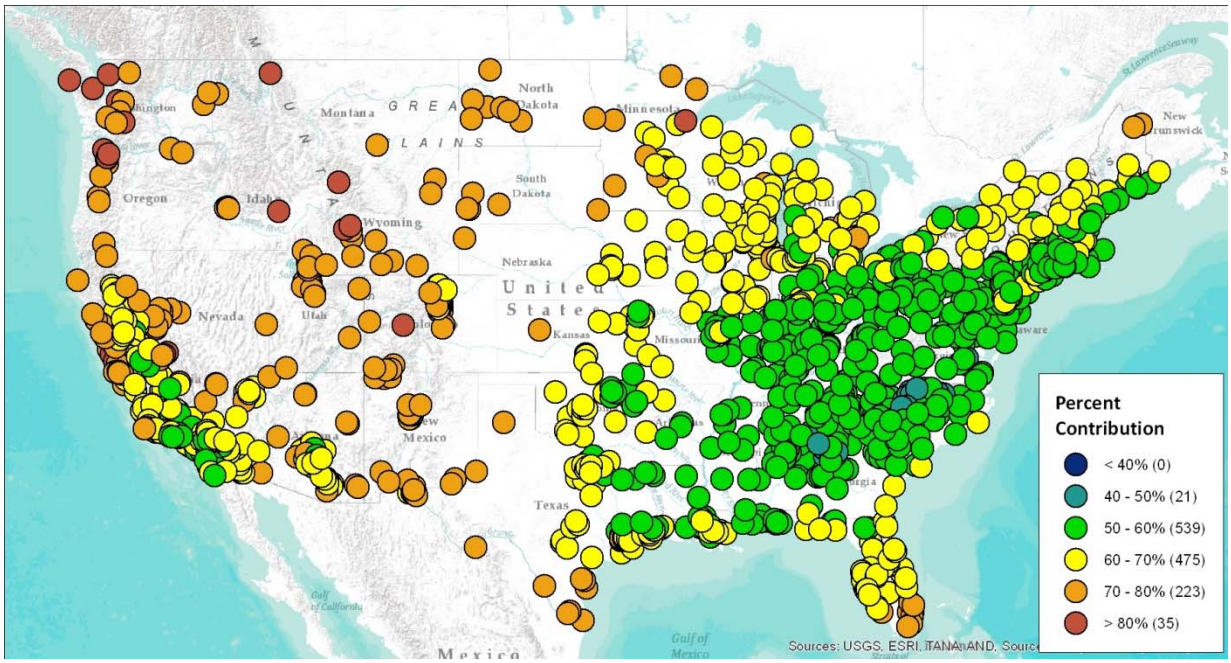

Figure 4b. Ratio of *N. American background* to total April-October average MDA8 ozone at monitoring locations across the U.S. as estimated based on 2007 CMAQ simulations.

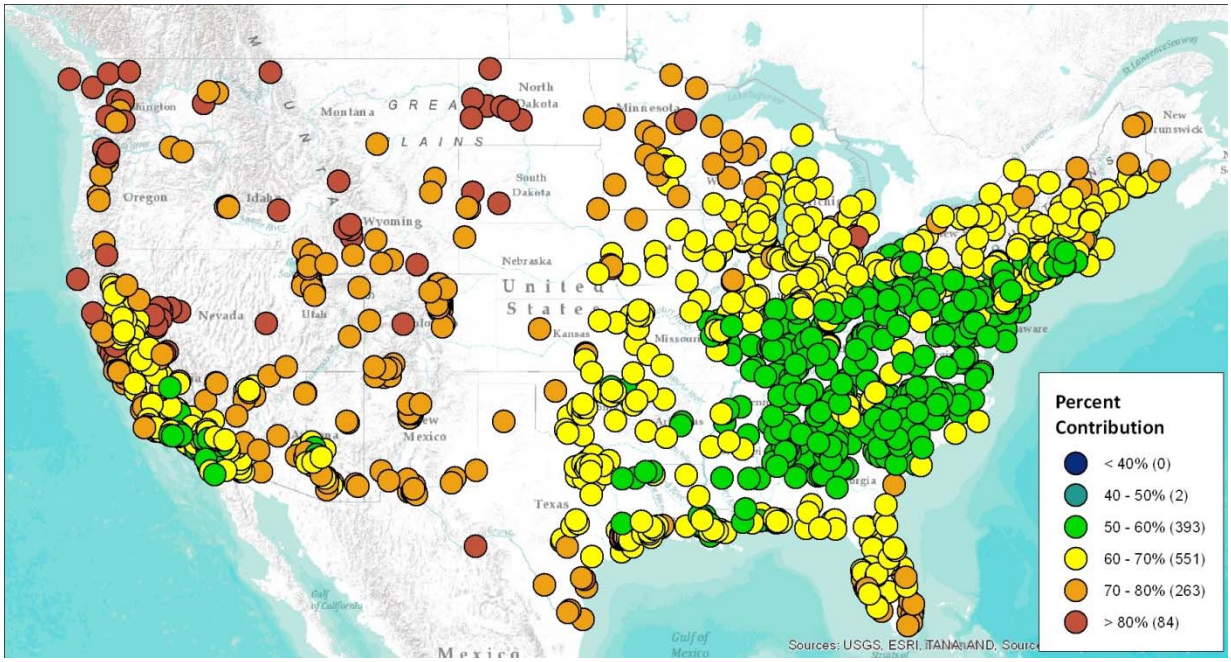

Figure 4c. Ratio of *U.S. background* to total April-October average MDA8 ozone at monitoring locations across the U.S. as estimated based on 2007 CMAQ simulations.

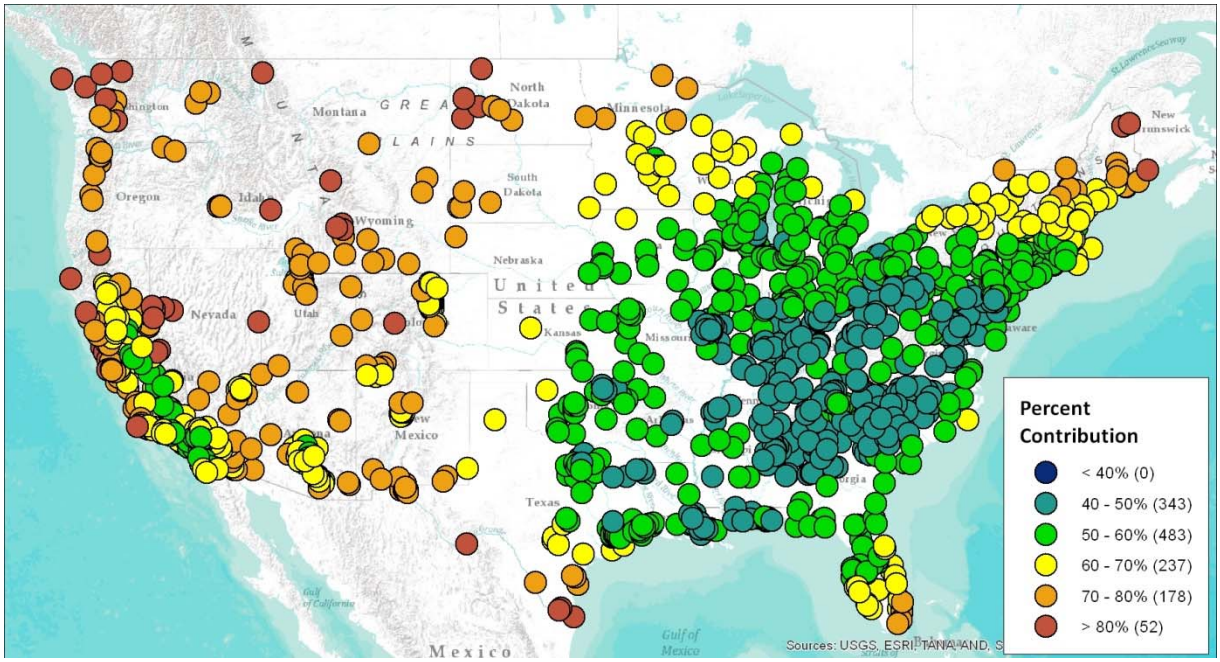

Figure 4d. Ratio of *sources other than U.S. anthropogenic emissions* to total April-October average MDA8 ozone at monitoring locations across the U.S. as estimated by a 2007 CAMx source apportionment simulation.

4. Distributions of background ozone levels

As a first-order understanding, it is valuable to be able to characterize seasonal mean levels of background ozone. However, it is well established that background levels can vary substantially from day-to-day. From an implementation perspective, the values of background ozone on possible exceedance days is a more meaningful distinction. The first draft policy assessment (EPA, 2012) considered this issue in detail, via summaries of the existing 2006 zero out modeling (Henderson et al., 2012), and concluded that "results suggest that background concentrations on the days with the highest total ozone concentrations are not dramatically higher than typical seasonal average background concentrations." Based on this finding, the 1st draft policy assessment determined that "anthropogenic sources within the U.S. are largely responsible for 4th highest 8-hour daily maximum ozone concentrations." This portion of the appendix will consider the entire spectrum of variable background ozone levels with special emphasis on days in which base model ozone concentrations approach or exceed the level of the NAAQS.

The 2007 modeling agrees with the finding from the previous 2006-based modeling analyses that the highest modeled ozone site-days tend to have background ozone levels similar to mid-range ozone days. Figures 5a-5c show the distribution of April-October MDA8 background levels (NB, NAB, and USB, respectively) from the CMAQ zero out runs. As noted in section 2, zeroing out emissions can remove the effects of local NOx titration and result in modeled background values that are higher than the base model ozone. The "box and whisker" plots shown in these figures display four key features of the distributions:

a. the median concentration (black horizontal line) per bin,

b. the inter-quartile range (blue colored box) which represents the 25th-75th percentile range in values within the distribution,

c. the "whiskers" (dark gray vertical lines with top and bottom whiskers) which represent the range of values within 1.5 times the inter-quartile range, and

d. the "outliers" (gray points) which are any values outside the whiskers.

As can be seen in Figure 5a, natural background values do not vary greatly as a function of the base modeled ozone. Recall that the seasonal average natural background MDA8 ozone values were modeled to range from 15-35 ppb across the U.S. with a median value of 24 ppb. The highest values were at the high-elevation sites in the western U.S. Based on the distributional analysis, the 75th percentile values are on the order of 30 ppb. Natural background levels exceeding 40-45 ppb are considered to be statistical outliers, due to their infrequency. Figure 5b shows the same type of distributions but for NAB instead of NB. NAB values are generally 6-12 ppb higher than their NB counterparts, due to the affect of higher global methane values and the influence of anthropogenic emissions from Asia. It was previously reported (in section 3) that the median seasonal average NAB MDA8 values were 31.5 ppb. Based on the distributions, it can be seen that 75th percentile values are

approximately 40 ppb; it is rare for NAB MDA8 values to exceed 50-55 ppb. NAB values are constant in magnitude once the base ozone exceeds 50 ppb indicating that the higher base ozone values are driven by non-NAB sources (i.e., North American emissions). Finally in Figure 5c, the USB MDA8 distributions by base model MDA8 are shown. The results are similar to NAB.

Figure 5d shows the results from the source apportionment modeling of non-U.S. anthropogenic source contributions to MDA8 ozone (i.e., the nine source apportionment categories other than U.S. anthropogenic emissions and Gulf of Mexico point sources). This non-counterfactual approach is expected to give a better indication of background levels at low concentrations. At low levels, almost all of the ozone is determined to be from background origins. The CAMx modeling shows that contributions from non-U.S. anthropogenic emissions peak when base ozone ranges from 45-55 ppb and then drop off slightly at higher base MDA8 values. The source apportionment modeling of non-U.S. impacts (similar to USB) indicates slightly lower background levels than the zero out modeling. The 75th percentile values are generally less than 35 ppb, compared to 40 ppb in the zero out modeling. It is rare to have background impacts greater than 55ppb. Interestingly, when base model MDA8 ozone exceeds 70 ppb, it is rare to have background impacts greater than 45 ppb in the CAMx source apportionment modeling.

Figures 6a-6d show the equivalent plots as 5a-5d, but use background fractions (background MDA8 / base MDA8) as the dependent variable instead of the absolute background concentrations. These plots show the same effect; that is, the proportional relative contribution of background sources and processes decreases as peak ozone increases. For natural background (Figure 6a), the median fractions drop from 50% background for values between 45-50 ppb to only 35% background for base MDA8 values between 70-75 ppb. For NAB and USB (Figures 6b and 6c), the median fractions drop from 70% background for values between 45-50 ppb to only 45% background for base MDA8 values between 70-75 ppb. The source apportionment modeling (Figure 6d) estimates less of a proportional role of non-U.S. anthropogenic emissions. In that modeling, the median fractions drop from 65% background for values between 45-50 ppb to only 35% background for base MDA8 values between 70-75 ppb. A key observation, as noted in the first draft policy assessment document, is that the relative importance of background decreases on days most likely to violate the NAAQS. An additional policy-relevant finding from the distributional analyses is that the relative role of background sources would be increased if the level of the NAAQS were lowered. At 60 ppb, the modeling suggests that the median fractional contribution from background is 45-55 percent, but there can be cases where background comprises 80-90 percent of the total ozone.

Many of the cases when background ozone is estimated to contribute in large proportions to relatively high ozone days may be eligible for consideration as exceptional events, but again, this modeling is not designed to resolve specific events that occurred in 2007. While there is greater confidence in the model's ability to predict mean contributions from background sources than from individual events, it is also useful to briefly consider the upper end of the background ozone

distributions. Figure 7 shows the 95th percentile[3] USB estimates from the zero out modeling. The 95th percentile MDA8 USB ozone levels range from 35-60 ppb, with the most frequent values residing in the 35-40 and 40-45 ppb bins. The median 95th percentile background USB ozone level is 42.0 ppb. As with the seasonal mean MDA8 USB, the highest levels of high background days (i.e., 95th percentile days) are observed over the intermountain western U.S. At these locations, 95th percentile USB levels can exceed 50 ppb. Background values at the 95th percentile end of the distribution are 4-12 ppb higher than the mean background values at the same locations.

[3] During the April-October period, there were 214 days of modeling results. Thus, the 95th percentile values represent approximately the 10th highest days from the distribution.

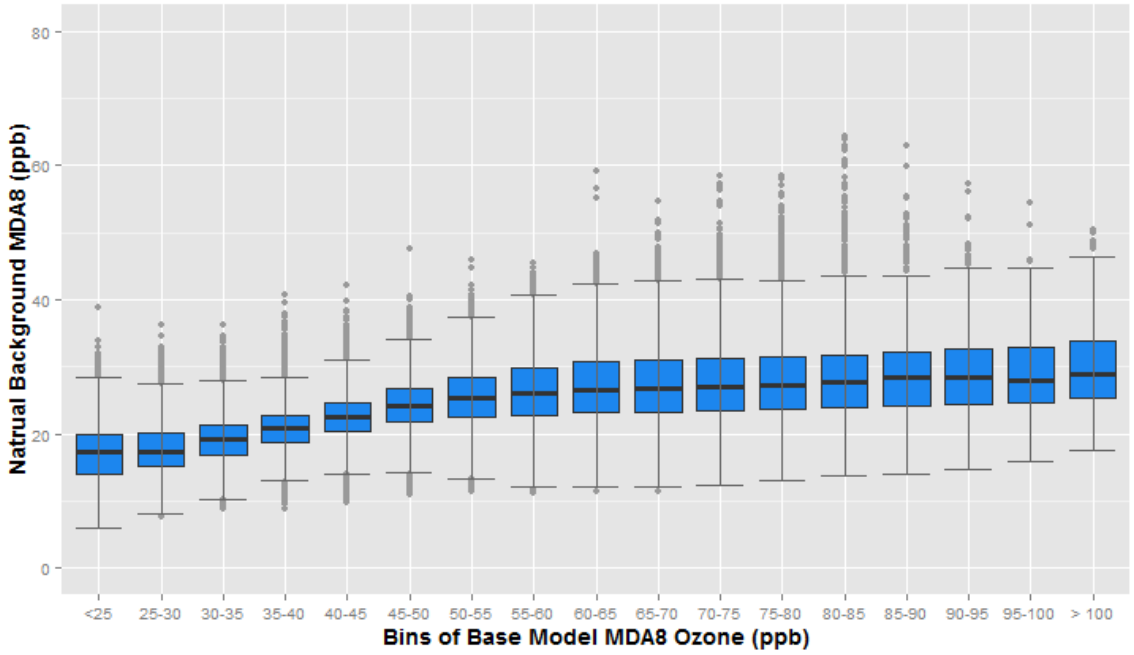

Figure 5a. Distribution of *natural background* MDA8 ozone (ppb) at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by 2007 CMAQ simulations.

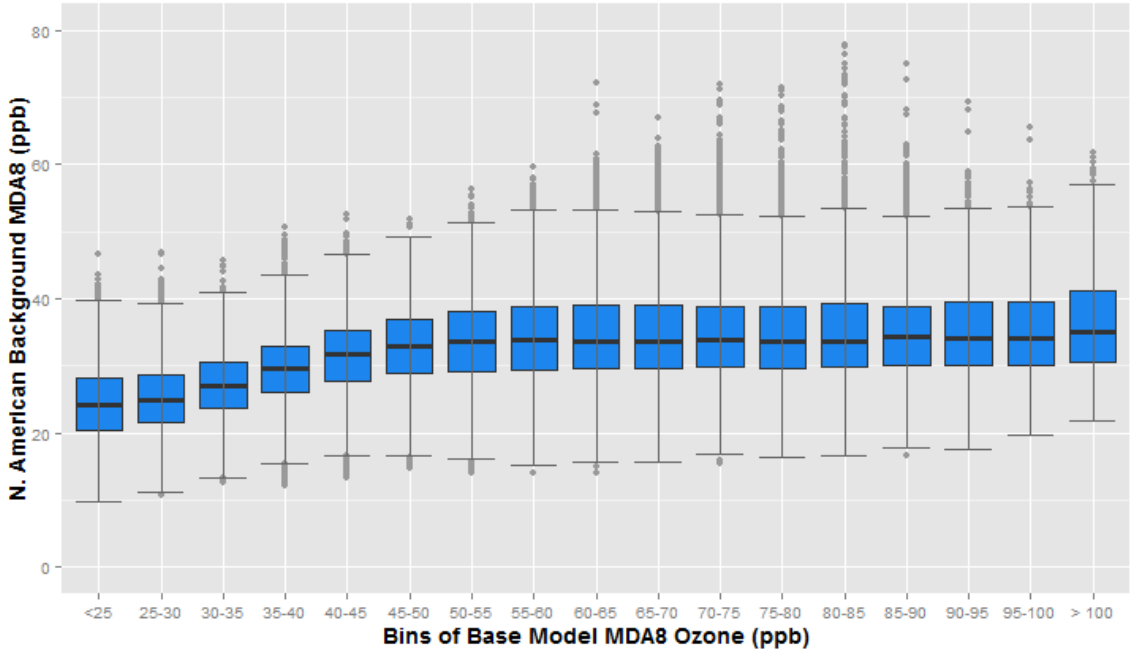

Figure 5b. Distribution of *N. American background* MDA8 ozone (ppb) at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by 2007 CMAQ simulations.

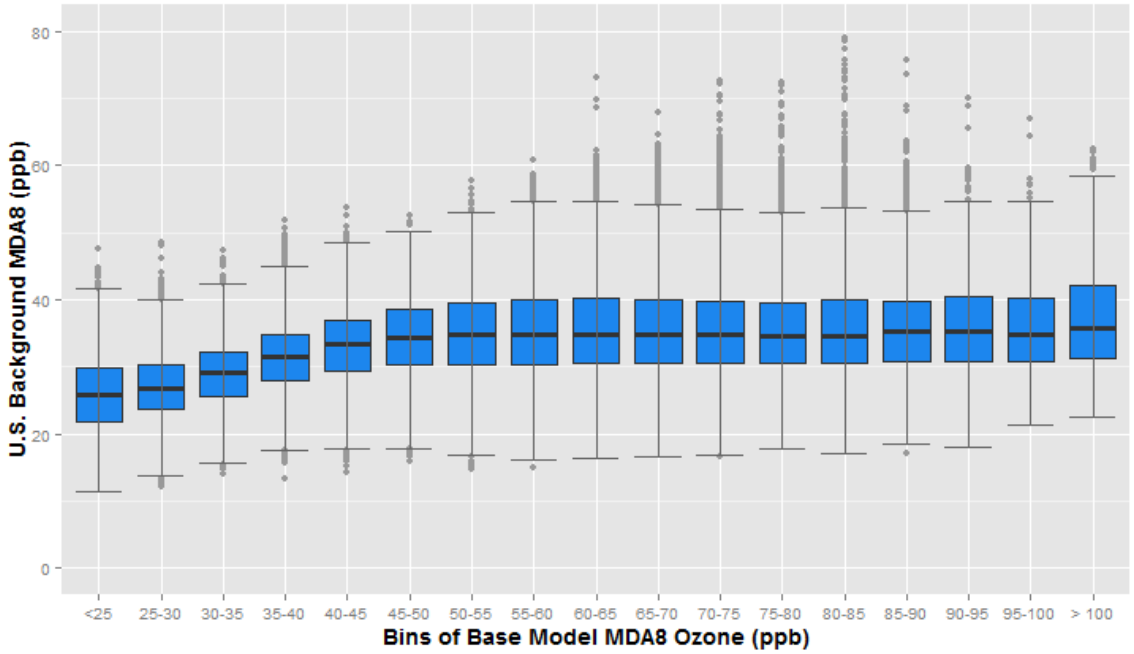

Figure 5c. Distribution of *U.S. background* MDA8 ozone (ppb) at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by 2007 CMAQ simulations.

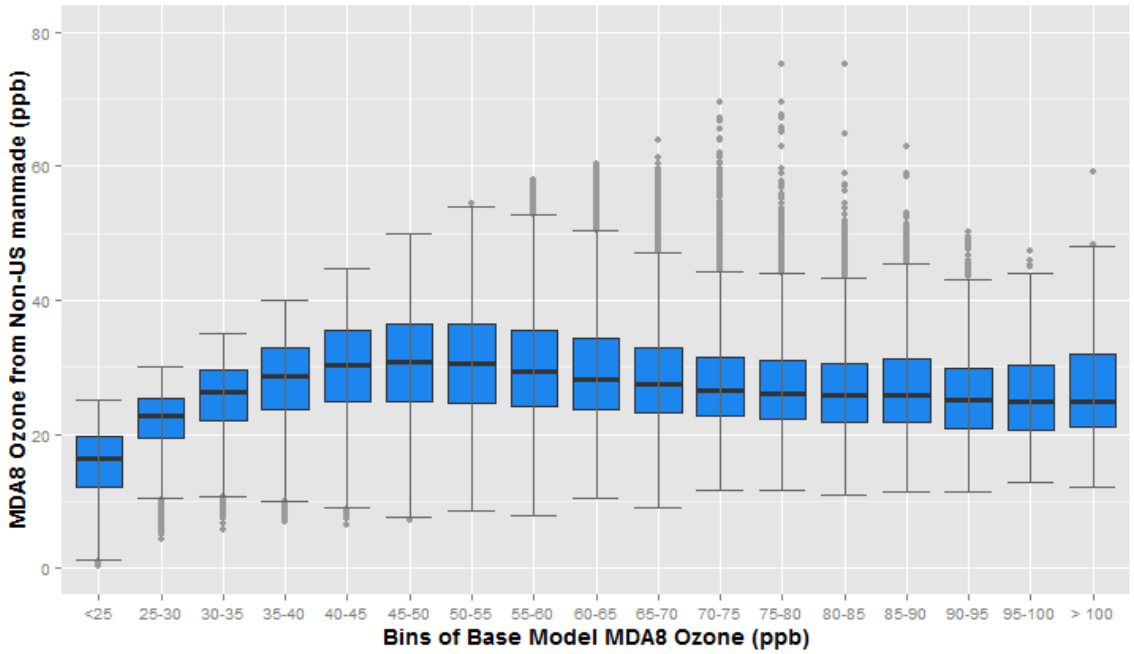

Figure 5d. Distribution of MDA8 ozone contributions from non-U.S. manmade sources (ppb) at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by 2007 CAMx simulations.

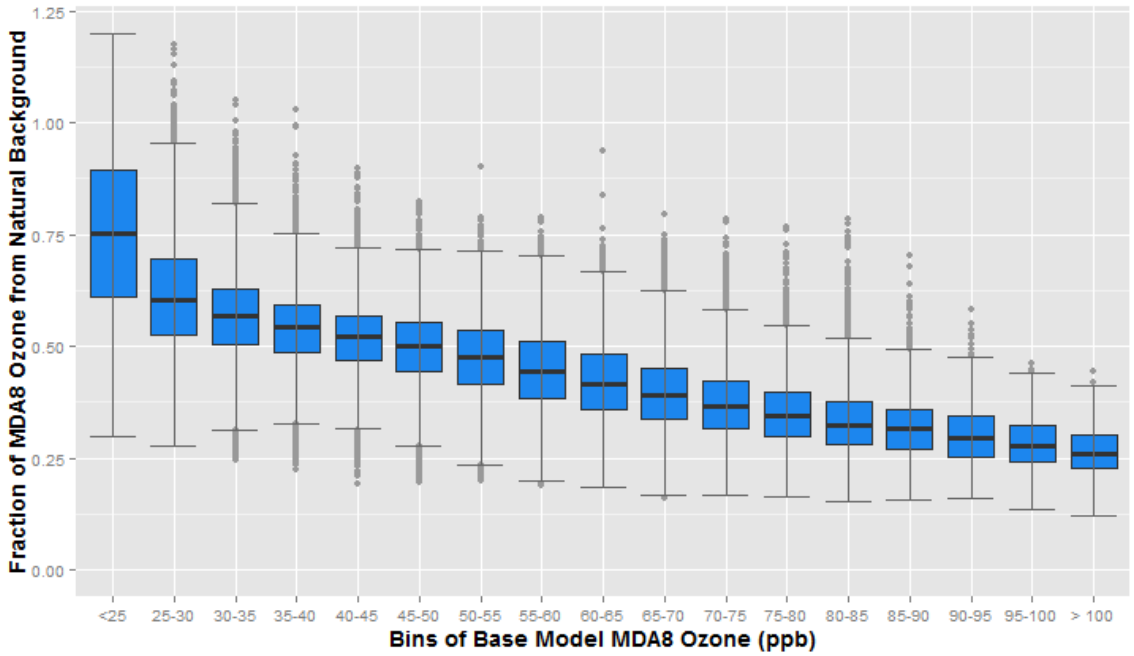

Figure 6a. Distribution of *natural background* MDA8 ozone fractions at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by 2007 CMAQ simulations.

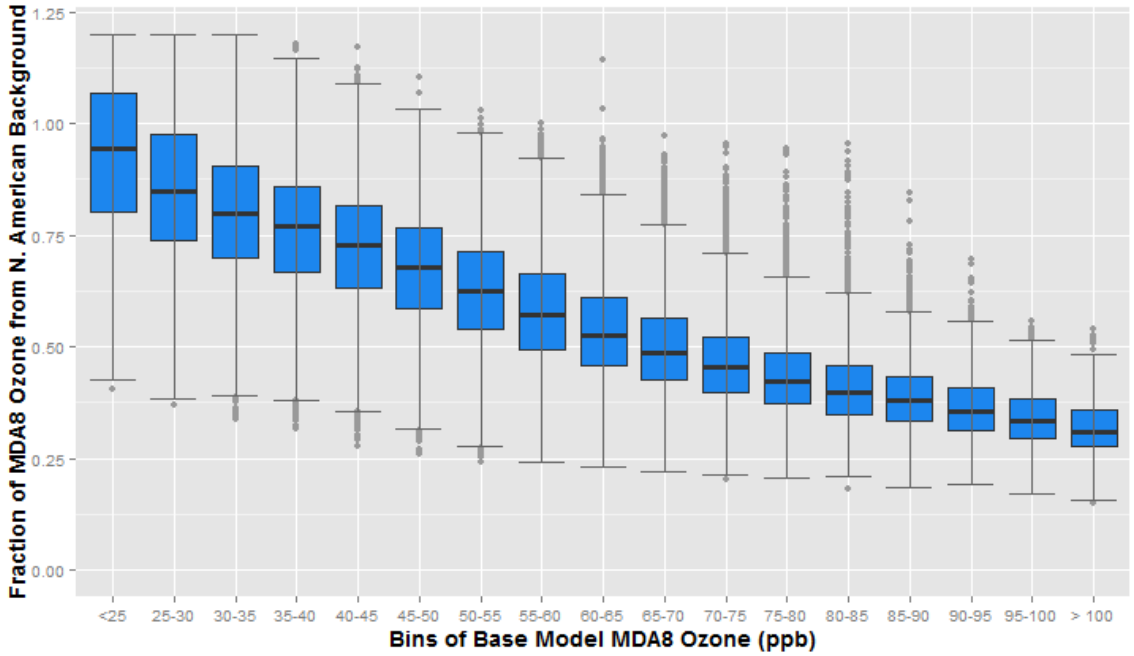

Figure 6b. Distribution of *N. American background* MDA8 ozone fractions at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by 2007 CMAQ simulations.

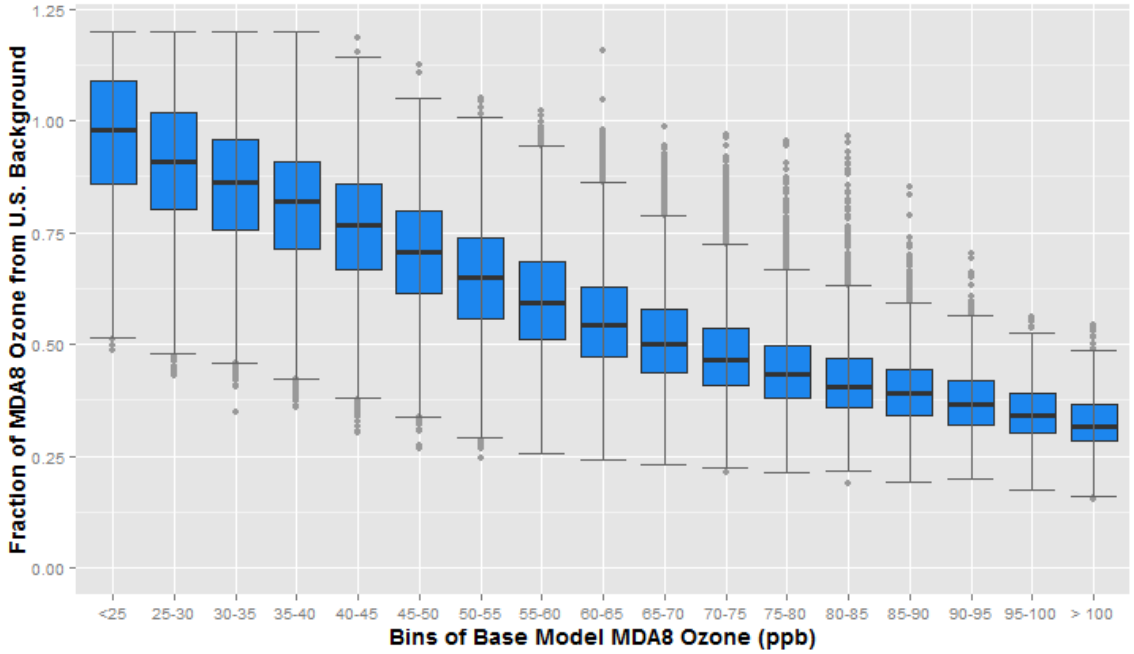

Figure 6c. Distribution of *U.S. background* MDA8 ozone fractions at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by 2007 CMAQ simulations.

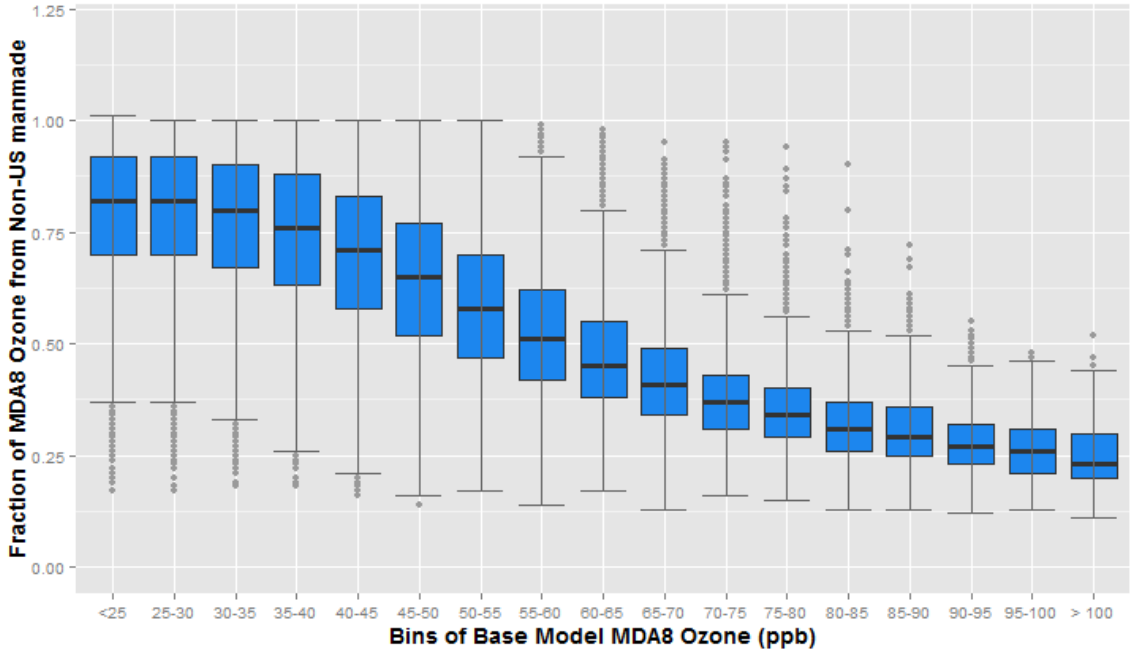

Figure 6d. Distribution of MDA8 ozone fractions *from non-U.S. anthropogenic sources* at monitoring locations across the U.S. (Apr-Oct), binned by base modeled site-day MDA8, as estimated by the 2007 CAMx simulation.

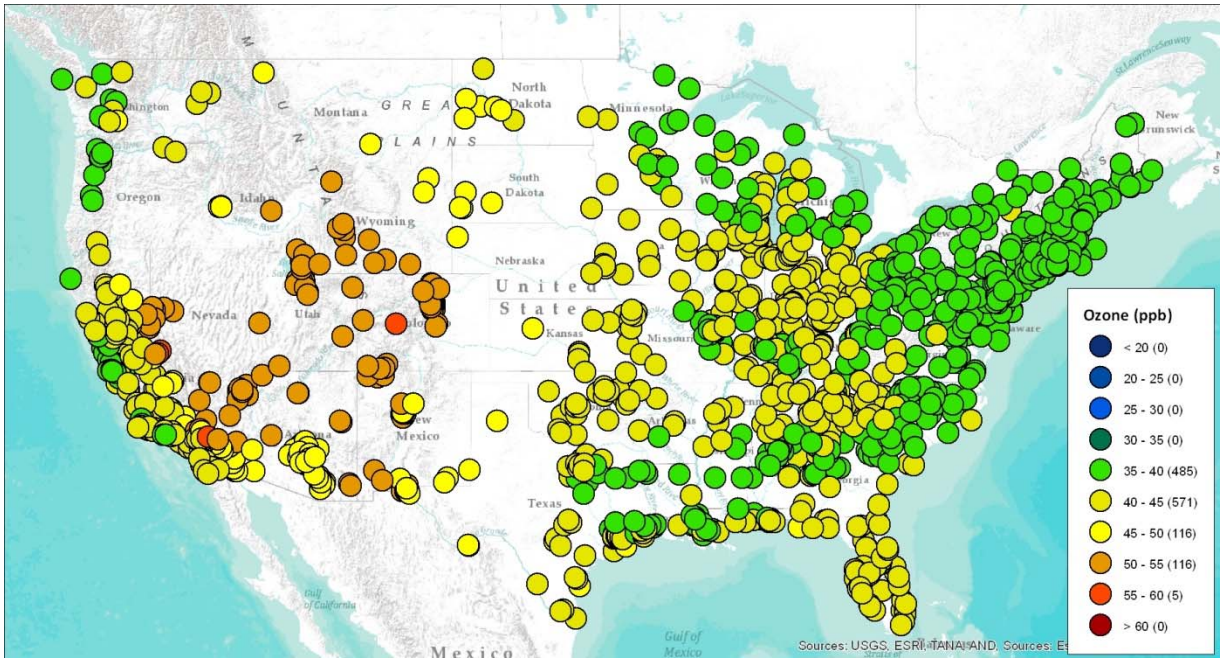

Figure 7. April-October 95th percentile *United States background* MDA8 ozone (ppb) at monitoring locations across the U.S. as estimated by a 2007 CMAQ base simulation.

5. Contribution of various processes and sources to total background ozone

This section will utilize the supplemental 2007 air quality modeling estimates to determine the relative importance of specific elements of background ozone. Comparing the differences between the three zero out scenarios can provide some information about the role of certain sets of emissions. Figure 8a compares the NAB (zero out North American manmade emissions) and USB (zero out U.S. manmade emissions) scenarios. The difference between these two runs is the inclusion of anthropogenic emissions within the Canada and Mexico portions of the modeling domain. These emissions contribute less than 2 ppb to the seasonal mean MDA8 ozone levels over most of the U.S. There are 70 sites, near an international border, where the modeling estimates Canadian/Mexican seasonal average impacts of 2-4 ppb. While not shown, the modeled peak single day impacts from these specific international emissions sources can approach 25 ppb (e.g., San Diego, Buffalo NY). Figure 8b compares the NB (zero out all manmade emissions and reset GEOS-Chem methane values to pre-industrial levels) to the NAB. The difference between these two runs is the inclusion of global methane emissions related to recent human activity as well as anthropogenic emissions outside of North America. These emissions are estimated to contribute 6-15 ppb to seasonal mean ozone levels over the U.S. The most frequent bin is the 8-10 ppb increase. It is not possible via these runs to parse out what fraction of this change is due to international emissions as opposed to methane emissions, but the ISA summarized existing modeling (Zhang *et al.*, 2011) that suggested that the rise in methane from pre-industrial levels to present-day levels led to increases in seasonal average ozone levels of 4-5 ppb. The greatest impacts from these sources occurs over the western U.S., where international emissions would be expected to have the largest impacts.

Figures 9a-9g show the fractional contribution to total seasonal mean MDA8 values of individual source sectors that were tracked in the CAMx source apportionment modeling. Figure 9a shows the impact from the regional model boundary conditions. The ozone entering the model domain via the boundary conditions could have a variety of origins including: a) natural sources of ozone and ozone precursors (including methane) emanating from outside the domain, b) anthropogenic sources of ozone precursors (including methane) from international emitters, and c) some fraction of U.S. emissions (natural and anthropogenic) which are exported and then re-imported into the domain via synoptic-scale recirculation. Thus, one should not presume that the boundary condition contribution is directly tied to any particular background definition. At most locations, boundary conditions contributed 40-60 percent of the total MDA8 seasonal mean at sites across the U.S. The highest proportional impacts from the boundary conditions (the top boundary contributes negligibly) are along the coastlines and the intermountain West.

Figure 9b shows the source apportionment contribution (to seasonal mean MDA8) from the most significant sector that was tracked: U.S. anthropogenic ozone precursor emissions. Again the most common outcome at an individual site was that 40-60% of the seasonal mean ozone values originated from U.S. anthropogenic emissions. The locations with smaller fractional contributions (e.g., 10-20 percent) from U.S. sources are generally located in places where ozone values are typically low such as the Pacific Northwest. Figures 9c-9g display the fractional contributions from the other five in-domain sectors listed in section 2. The impacts from these sectors are briefly summarized below:

- Biogenic emissions:
    - Most frequent bin: 3-5 percent
    - Highest site-specific contribution: 10-20 percent
    - Region with greatest impacts: Great Plains states where soil NOx emissions are large
- Climatologically-average fire emissions:
    - Most frequent bin: 0-1 percent
    - Highest site-specific contribution: 3-5 percent
    - Region with greatest impacts: California, Kansas/Oklahoma region
- Within-domain Canadian/Mexican manmade emissions:
    - Most frequent bin: 0-1 percent
    - Highest site-specific contribution: 10-20 percent
    - Region with greatest impacts: Sites along international borders (NY, VT, CA, AZ, TX)
- Category 3 marine vessels outside U.S. territorial waters:
    - Most frequent bin: 0-1 percent
    - Highest site-specific contribution: 10-20 percent
    - Region with greatest impacts: Coastal sites (especially southern CA)
- Gulf of Mexico point sources[4]:
    - Most frequent bin: 0-1 percent
    - Highest site-specific contribution: 1-3 percent
    - Region with greatest impacts: Sites in southeast TX and southern LA

[4] This sector was also included as part of U.S. anthropogenic source impacts in Figure 9b, but is broken out separately in Figure 9g.

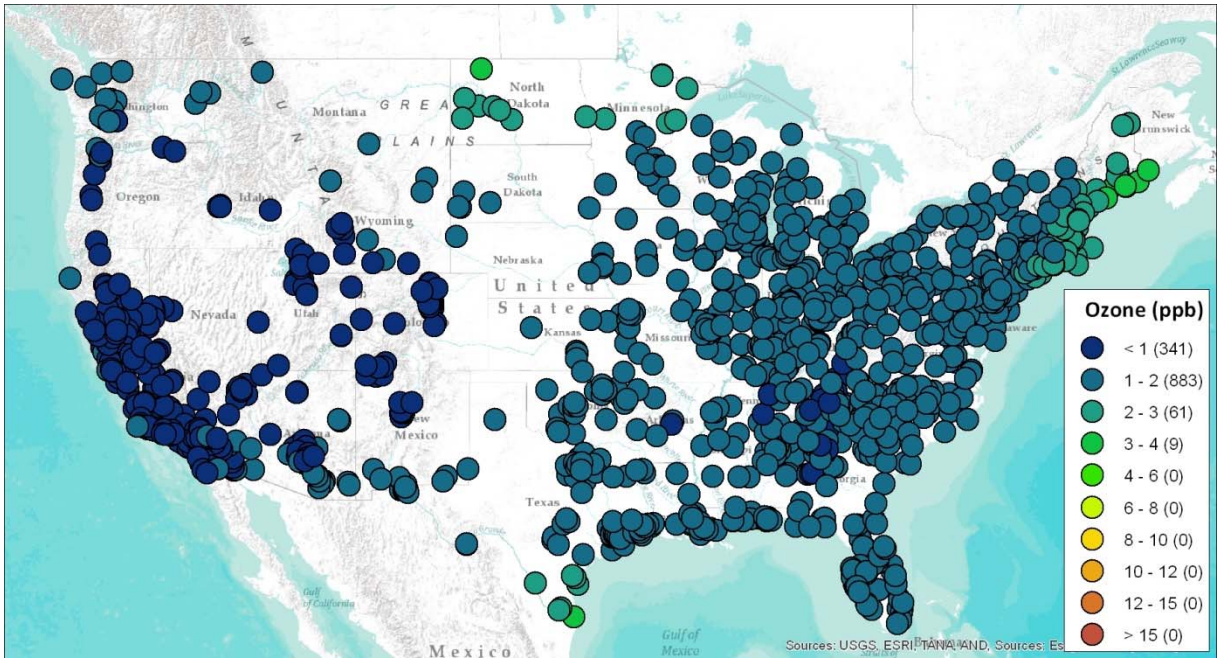

Figure 8a. Difference in April-October average MDA8 ozone (ppb) at monitoring locations across the U.S. between the USB scenario and the NAB scenario. The difference between these two runs isolates the impact of within-the-domain anthropogenic emissions from Canada and Mexico.

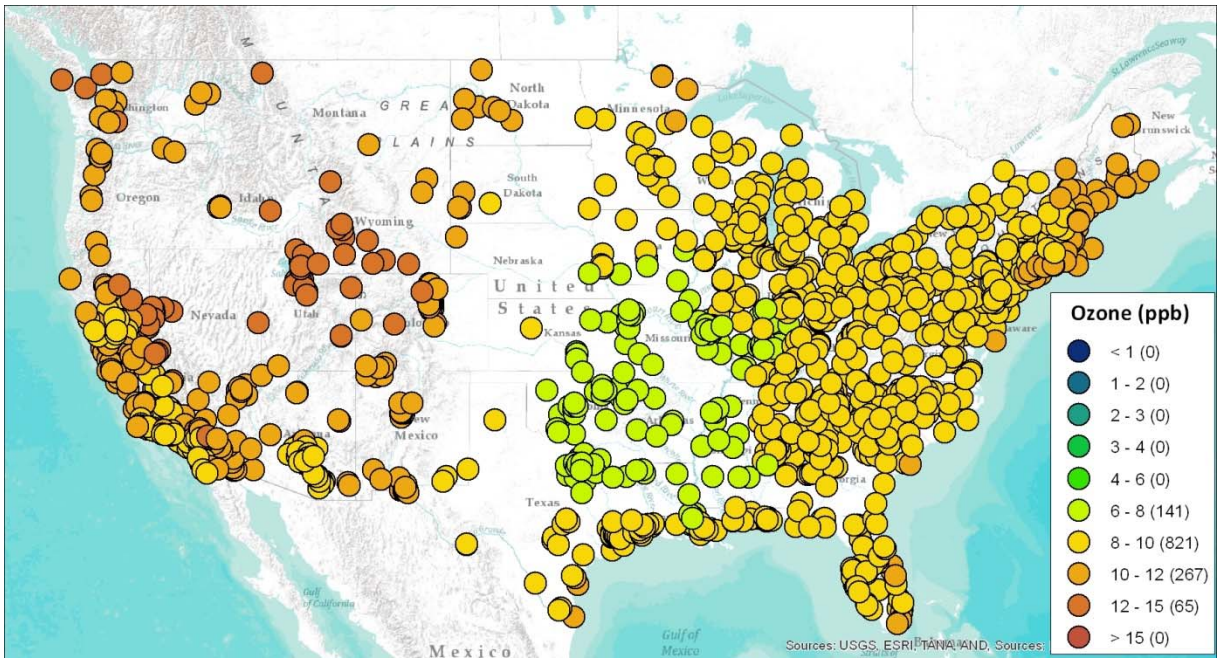

Figure 8b. Difference in April-October average MDA8 ozone (ppb) at monitoring locations across the U.S. between the NAB scenario and the NB scenario. The difference between these two runs isolates the impact of the rise in global methane emissions from the pre-industrial and anthropogenic emissions from outside North America.

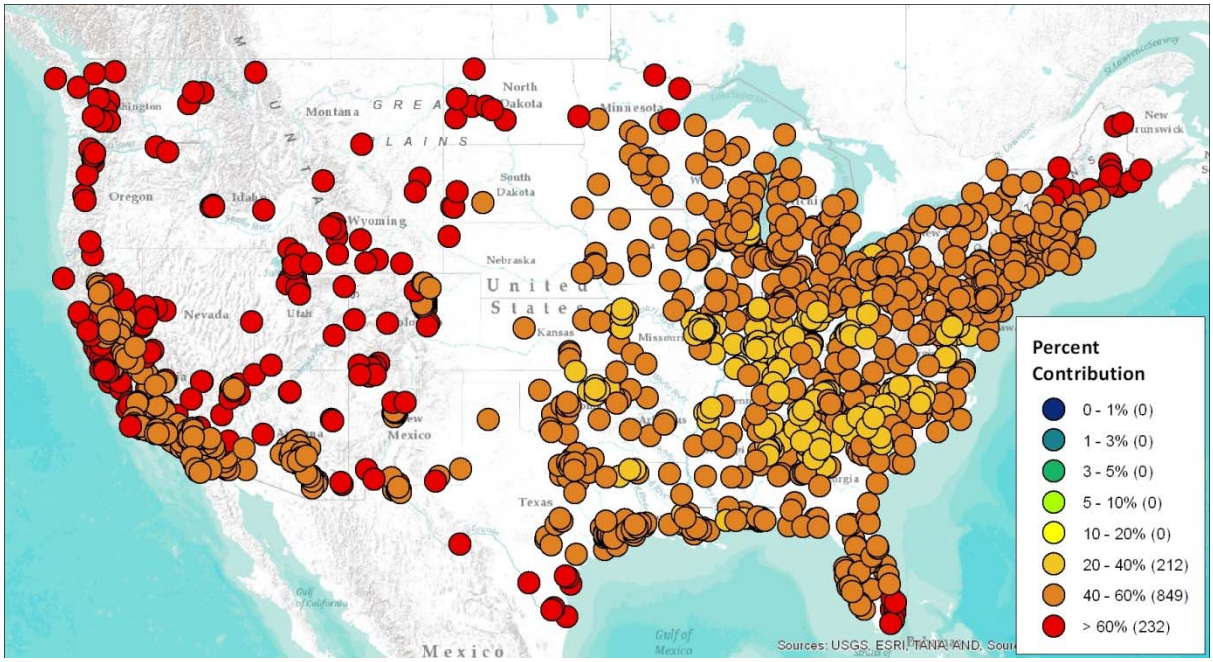

Figure 9a. Percentage of April-October average MDA8 ozone that is apportioned to *boundary conditions* as estimated at monitoring locations by a 2007 CAMx simulation.

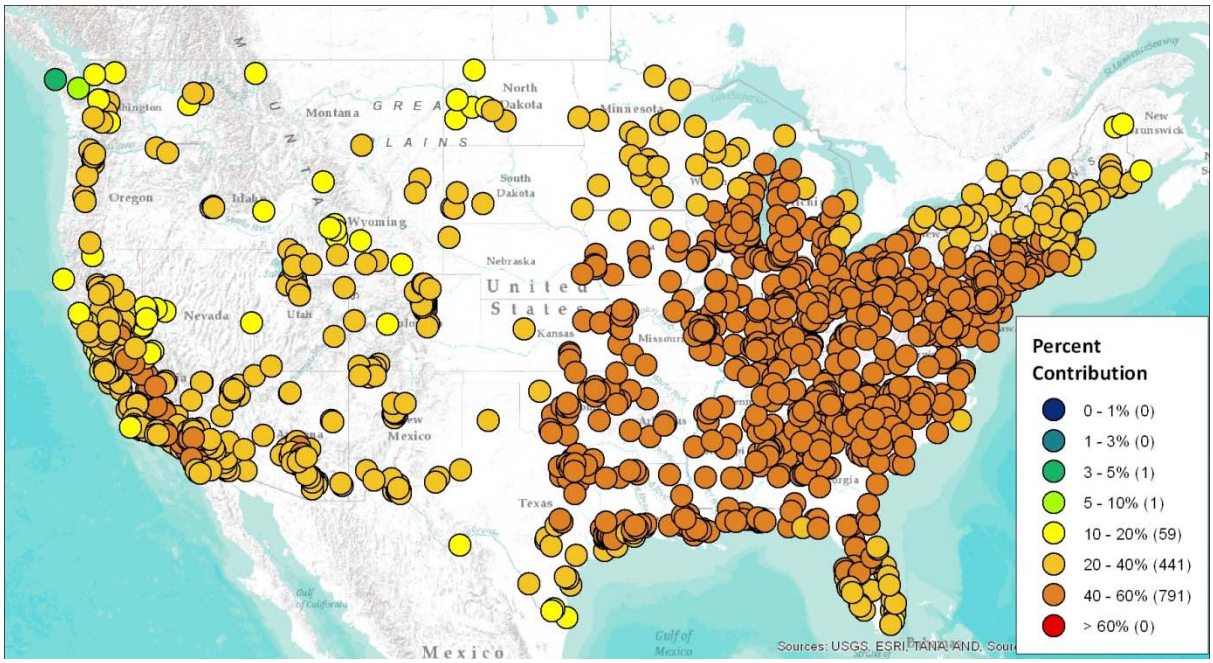

Figure 9b. Percentage of April-October average MDA8 ozone that is apportioned to *U.S. anthropogenic sources* as estimated at monitoring locations by a 2007 CAMx simulation.

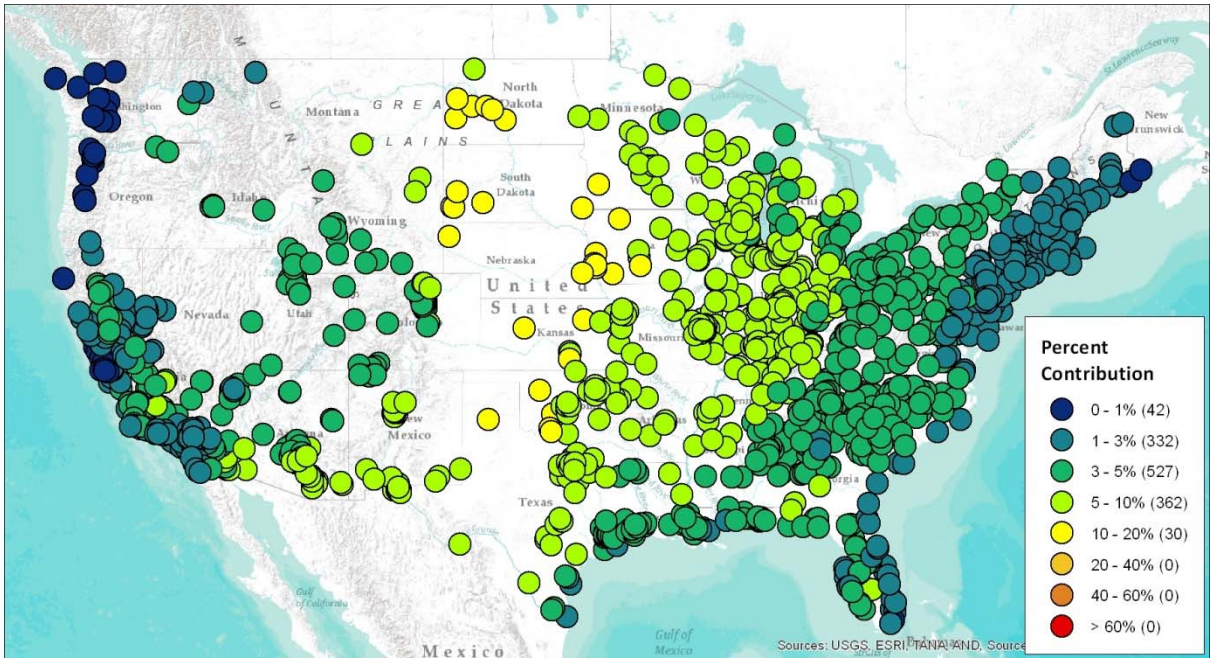

Figure 9c. Percentage of April-October average MDA8 ozone that is apportioned to *purely biogenic emissions* as estimated at monitoring locations by a 2007 CAMx simulation.

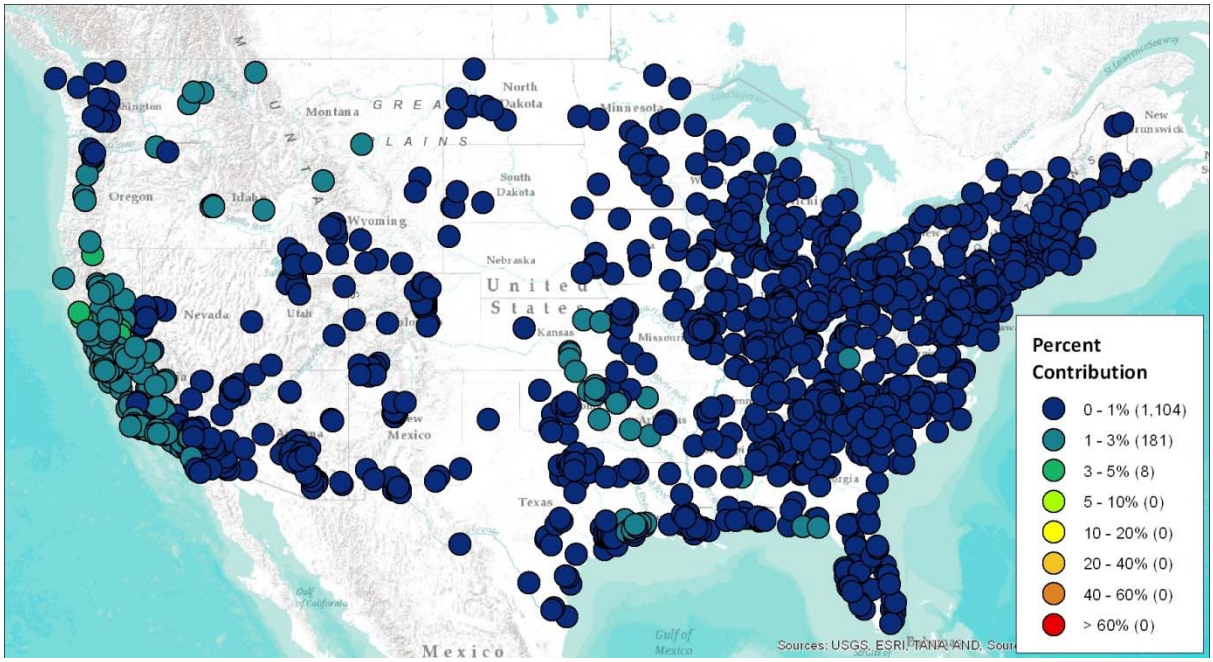

Figure 9d. Percentage of April-October average MDA8 ozone that is apportioned to *climatological fire emissions* as estimated at monitoring locations by a 2007 CAMx simulation.

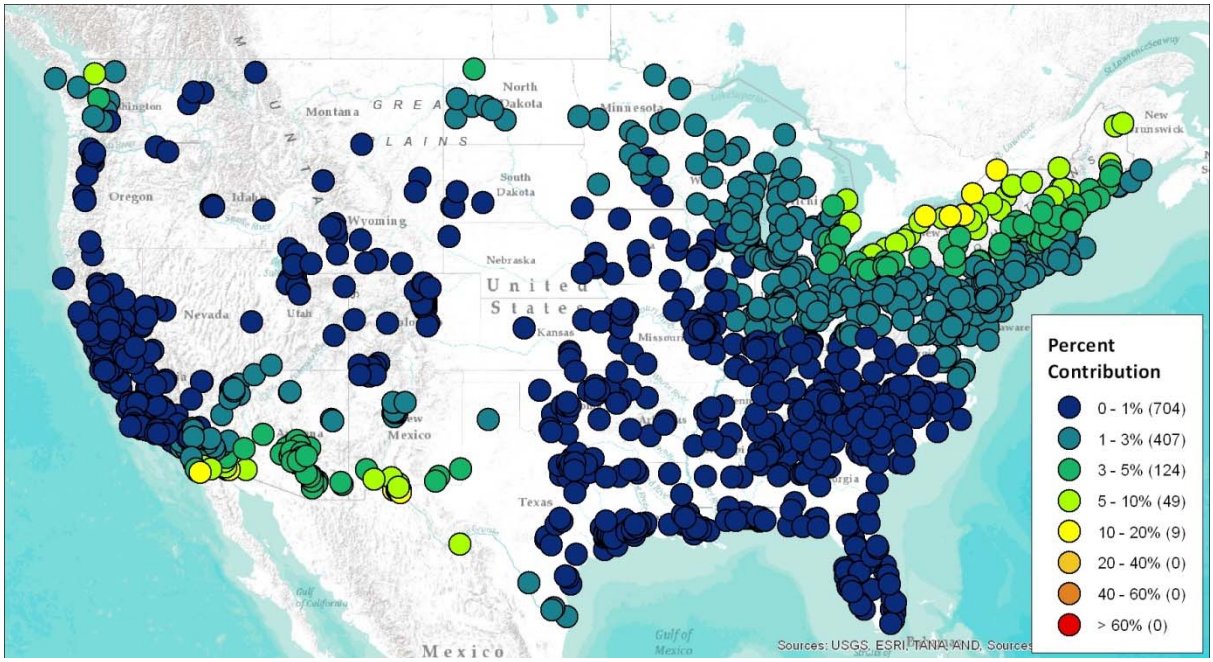

Figure 9e. Percentage of April-October average MDA8 ozone that is apportioned to *anthropogenic emissions from in-domain Canadian and Mexican sources* as estimated at monitoring locations by a 2007 CAMx simulation.

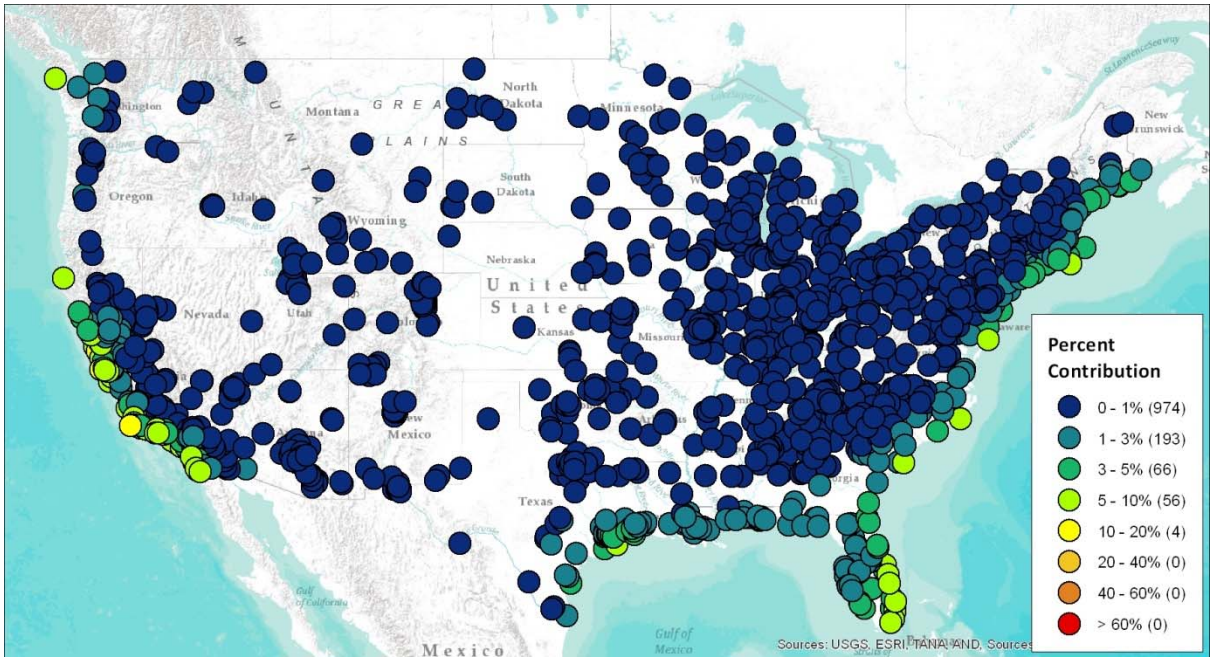

Figure 9f. Percentage of April-October average MDA8 ozone that is apportioned to *Category 3 marine vessel emissions beyond U.S. territorial waters* as estimated at monitoring locations by a 2007 CAMx simulation.

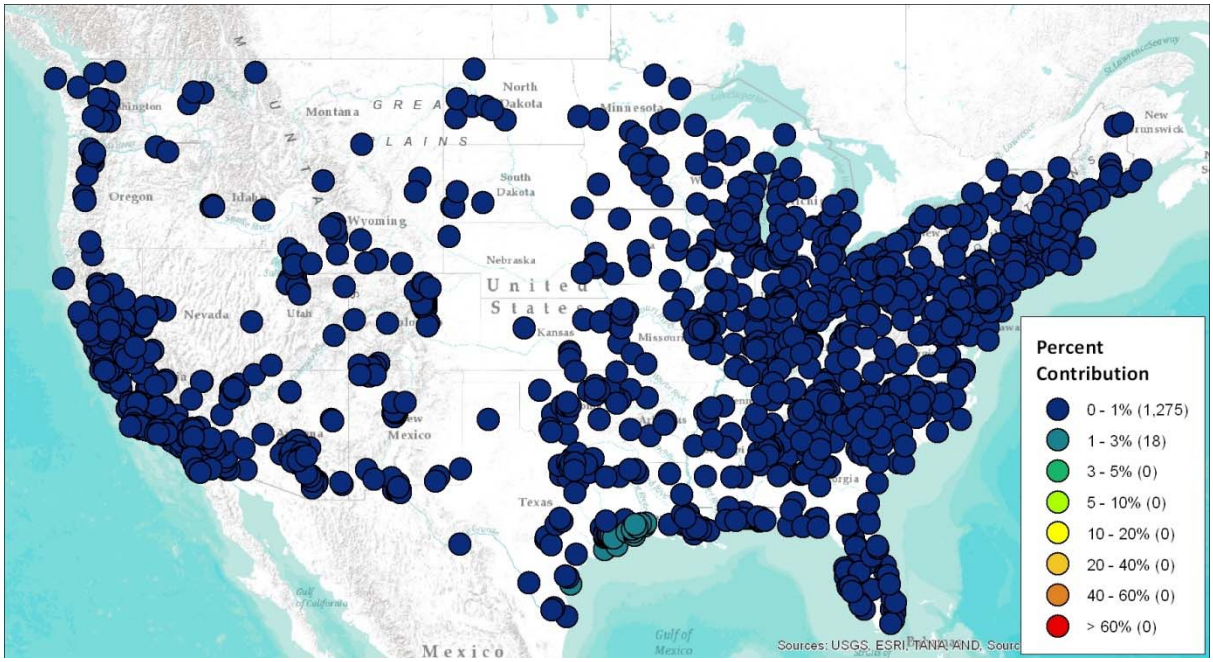

Figure 9g. Percentage of April-October average MDA8 ozone that is apportioned to *Gulf of Mexico point sources* as estimated at monitoring locations by a 2007 CAMx simulation.

6. Estimates of the fractional background contribution to total ozone in 12 specific areas

This penultimate section of the appendix presents estimates of the overall fraction of ozone that is estimated to result from background sources or processes based on the updated modeling in each of the 12 urban case study areas in the epidemiology study based analyses in Chapter 7 of the Risk and Exposure Assessment (REA). Tables 1a-1c summarize the CAMx-estimated fractional contributions of sources other than U.S. anthropogenic emissions to total ozone in each of the 12 areas. Table 1a shows that the fractional contributions from sources other than anthropogenic emissions within the U.S. to seasonal mean MDA8 levels can range from 43 to 66 percent across these 12 urban areas. These fractions are consistent with the national ratios summarized in section 3, although the urban fractions of background tend to be smaller than at rural sites. As shown in section 4, the fractional contributions from background are smaller on days with high modeled ozone (i.e., days that may exceed the level of the NAAQS). Table 1b provides the fractional contributions from these non-U.S. sources, only considering days in which base model MDA8 ozone was greater than 60 ppb. As expected, the fractional background contributions are less and range from 31 to 55 percent. Rather than taking the fractions of the seasonal means (as in Table 1a), Table 1c displays the mean and median daily MDA8 background fractions. These metrics may be more appropriate for application to health studies, but as can be seen the fractional contribution to backgrounds calculated via this approach are very similar to the Table 1a calculations. For completeness sake, although EPA expects the source apportionment results to provide a more realistic estimate of fractional background values, for completeness, we also provide USB fractions based on zero out modeling for the 12 cities (see Table 1d). The results are similar to the source apportionment findings (compare against Table 1a), but the zero out technique provides slightly higher background proportions.

All days, CAMx	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Model MDA8 seasonal mean	59.3	54.4	43.0	48.9	47.3	39.1	48.5	51.1	45.4	48.7	46.4	49.8
Model MDA8 seasonal mean from emissions other than U.S. anthropogenic sources	25.3	25.9	26.2	25.7	31.3	23.3	27.0	29.1	24.5	24.2	29.7	24.3
Fractional contribution from background	0.43	0.48	0.61	0.52	0.66	0.60	0.56	0.57	0.54	0.50	0.64	0.49

Table 1a. April-October average MDA8 ozone, average MDA8 ozone from sources other than U.S. manmade emissions, and the fractional contribution of these background sources in the 12 REA urban study areas, as estimated by a 2007 CAMx simulation.

Only days w/ base MDA8 > 60 ppb	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Model MDA8 seasonal mean	74.0	75.3	70.7	72.0	67.5	68.9	70.3	74.4	74.1	74.0	68.3	70.0
Model MDA8 seasonal mean from emissions other than U.S. anthropogenic sources	25.4	23.7	24.4	25.4	37.3	24.4	28.0	31.9	23.5	22.9	32.1	25.4
Fractional contribution from background	0.34	0.31	0.35	0.35	0.55	0.35	0.40	0.43	0.32	0.31	0.47	0.36

Table 1b. Average MDA8 ozone, average MDA8 ozone from sources other than U.S. manmade emissions, and the fractional contribution of these background sources in the 12 REA areas, as estimated by a 2007 CAMx simulation using site-days in which base MDA8 ozone exceeded 60 ppb.

	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Mean of daily MDA8 background fractions	0.46	0.53	0.68	0.58	0.69	0.64	0.59	0.61	0.61	0.56	0.67	0.52
Median of daily MDA8 background fractions	0.43	0.51	0.73	0.54	0.69	0.66	0.59	0.60	0.63	0.54	0.66	0.49

Table 1c. Fractional contribution of non-U.S. manmade emissions sources in the 12 REA urban study areas, as estimated by a 2007 CAMx simulation using means and medians of daily MDA8 fractions.

All days, CMAQ	ATL	BAL	BOS	CLE	DEN	DET	HOU	LA	NYC	PHI	SAC	STL
Model MDA8 seasonal mean	58.6	55.6	45.2	51.8	57.1	43.5	49.4	54.8	47.7	50.5	51.9	52.6
Model MDA8 seasonal mean from USB emissions	30.0	29.9	28.5	31.6	42.2	31.7	33.0	33.3	29.1	29.4	34.4	32.0
Fractional contribution from background	0.51	0.54	0.63	0.61	0.74	0.73	0.67	0.61	0.61	0.58	0.66	0.61

Table 1d. April-October average MDA8 ozone, average MDA8 ozone from USB, and the fractional contribution of these background sources in the 12 REA urban study areas, as estimated by two separate 2007 CMAQ simulations.

7. Background ozone and W126

As discussed in section 5 of the second draft policy assessment, EPA is considering the adequacy of the current secondary standard to protect against welfare effects. One metric that has been considered previously as a potential cumulative seasonal index is the W126 metric. The W126 index is a sigmoidally weighted sum of all hourly O_3 concentrations observed during a specified daily and seasonal time window, where each hourly O_3 concentration is given a weight that increases from 0 to 1 with increasing concentration (Lefohn et al, 1988). The weights are defined such that values of 0.060 ppm get a weight of ~0.3; 0.070 ppm values get a weight of ~0.6; and 0.085 ppm values get a weight of ~0.9. The remainder of this section uses the 2007 zero out modeling to conduct a limited assessment of the role of background ozone on W126 levels over the U.S.

The analysis of background influence on W126 is not as detailed as the analyses related to seasonal mean MDA8 ozone. Instead of considering impacts at every monitoring location, EPA assessed NB, NAB, and USB influences at four sample locations: Atlanta GA, Denver CO, Farmington NM, and Riverside CA. Each of these four locations had relatively high observed values of W126 in 2010-2012. Atlanta is an urban area in the Eastern U.S. with high primary ozone design values but relatively low levels of seasonal background ozone. Riverside and Denver also have high primary ozone design values but are in the Western U.S. where background ozone levels are generally higher. Farmington NM was chosen as a site that has relatively lower primary ozone design values along with its relatively high W126 levels. The varying characteristics of each of these locations perhaps allows broader national extrapolation of the 4-site results.

In previous EPA reviews of the O_3 NAAQS, the influence of background ozone was estimated according to a counterfactual (i.e., how much ozone would exist in the absence of certain sets of emissions). In the current review, EPA is supplementing the counterfactual assessment with analyses that estimate the fraction of the existing ozone that is due to background sources. This has important ramifications for assessing the influence of background on W126 concentrations, because of the non-linear weighting function used in the metric which emphasizes high ozone hours (e.g., periods in which ozone is greater than ~60 ppb). As an example, consider a sample site in the intermountain western U.S. region with very high modeled estimates of U.S background (e.g., seasonal mean USB of 45 ppb with some days as high as 65 ppb). Even at this high background location, the calculated annual W126 values in the USB scenario are quite low, on the order of 3 ppm-hrs. Most sites in the domain where background levels are lower than the location cited above will have even smaller background W126 estimates, on the order of 1 ppm-hrs, which is consistent with values mentioned in past reviews (USEPA, 2007). Using the counterfactual scenarios, background ozone has a relatively small impact on W126 levels across the U.S.

However, because of the non-linear weighting function used in the W126 calculation, the sum of the W126 from the USB scenario and the W126 resulting from US anthropogenic sources will not equal the total W126. In most cases, the sum of those two components will be substantially less than total W126. As a result, EPA believes it is more informative to estimate the fractional contribution of background ozone to W126 levels. The 5-step methodology for assessing the fractional influence of

background ozone to annual W126 levels in the four locations is described below. The fractional influence methodology essentially places higher weights on background fractions on days that are going to contribute most substantially to the yearly W126 value.

- Step 1a: Calculate the MDA8 ozone values from the base and the three zero out modeling scenarios at each grid cell containing a site in an area.
- Step 1b: Calculate the W126 daily index for the base model scenario.
- Step 2: For each site, find the three months with highest summed W126 daily indices.
- Step 3: Normalize the daily MDA8 values in the base, NB, NAB, and USB scenarios by the corresponding W126 daily index from the base scenario.
- Step 4: Calculate the average W126-weighted MDA8 values over the three month period for each of the four scenarios (base, NB, NAB, USB).
- Step 5: Calculate the NB/Base, NAB/Base, and USB/Base ratios based on step 4 outputs. These values represent an estimate of the fractional influence of background ozone on modeled W126 levels.

Figure 7a shows the estimated fractional influence of the three background definitions on W126 levels in Atlanta, Denver, Farmington, and Riverside. Based on this limited assessment, natural background sources are estimated to contribute 29-50% of the total modeled W126 with the highest relative influence in the intermountain western U.S. (e.g., Farmington NM) and the lowest relative influence in the eastern U.S. (e.g., Atlanta). U.S. background is estimated to contribute 37-65% of the total modeled W126. Figure 7b compares the relative influence of background on W126 versus seasonal mean MDA8 ozone. The proportional impacts of background are slightly less for the W126 metric than for seasonal mean MDA8 (discussed in section 2.4.2), because of the weighting function that places more emphasis on higher ozone days when background fractions are generally lower.

There are several caveats associated with this analysis. First, only the zero out modeling was used to assess the fractional influence of background sources on W126. The source apportionment approach estimated slightly smaller relative contributions for seasonal mean MDA8 levels, so from that perspective the zero out estimates could represent the high end of background influence on W126. Additionally, the methodology used for this analysis relies on daily MDA8 values as a surrogate (the data were readily available) for the 8a-8p time period relevant to the W126 metric. The key conclusion from this cursory analysis is that background ozone may comprise a non-negligible portion of current W126 levels across the U.S. This fractional influence is greatest in the intermountain western U.S. and are slightly smaller than the seasonal mean MDA8 metric. In the counterfactual cases, when non background sources are completely removed, the remaining W126 levels are low (< 3 ppm-hrs).

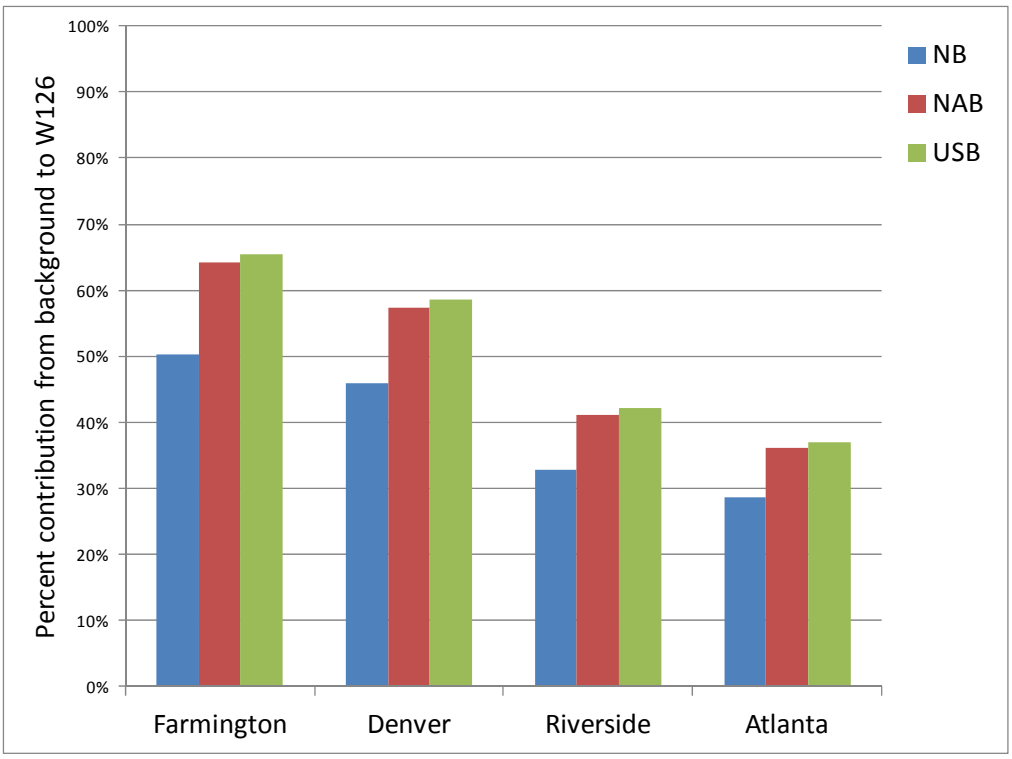

Figure 7a. Fractional contribution of background sources to W126 levels in four sample locations. Model estimates based on 2007 CMAQ zero out modeling.

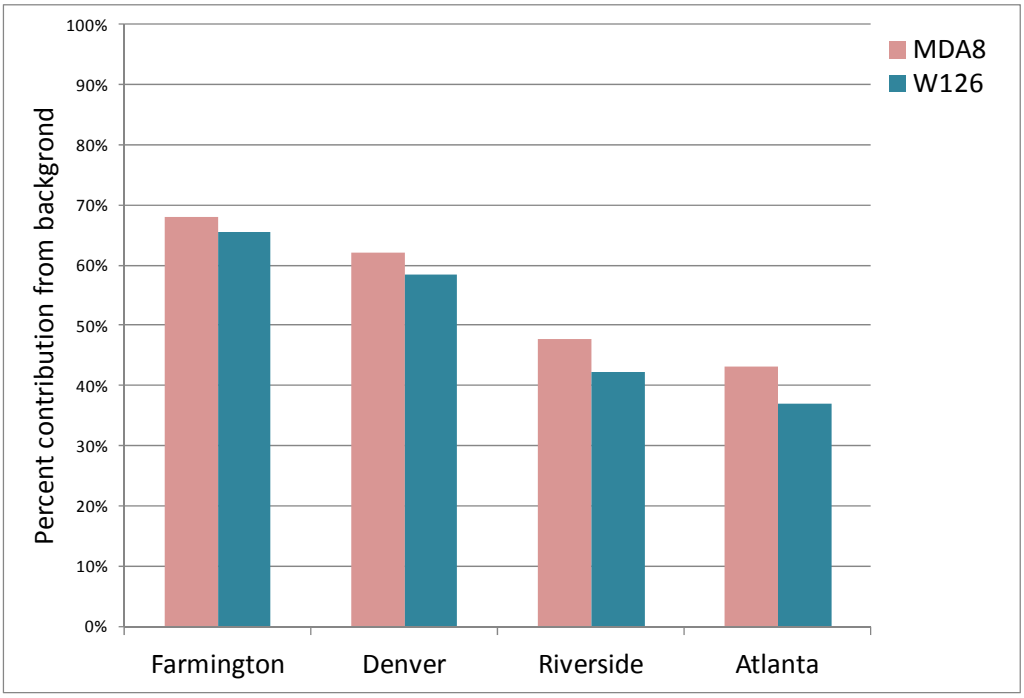

Figure 7b. Fractional contribution of U.S. background to seasonal mean MDA8 ozone and W126 levels in four sample locations. Model estimates based on 2007 CMAQ zero out modeling.

8. Summary

The precise definition of background ozone can vary depending upon context, but it generally refers to ozone that is formed by sources or processes that cannot be influenced by local control measures. Background ozone can originate from natural sources of ozone and ozone precursors, as well as from upwind manmade emissions of ozone precursors. In order to help further characterize background ozone levels over the U.S., EPA has completed additional air quality modeling analyses subsequent to the 1st-draft policy assessment. As shown above, the results are largely consistent with previous determinations about the magnitude of background ozone contributions across the U.S.

For a variety of reasons, it is challenging to present a comprehensive summary of all the components and implications of background ozone. In many forums the term "background" is used generically and the lack of specificity can lead to confusion as to what sources are being considered. Additionally, it is well established that the impacts of background sources can vary greatly over space and time which makes it difficult to present a simple summary of background ozone levels. Further, background ozone can be generated by a variety of processes, each of which can lead to differential patterns in space and time, and which often have different regulatory ramifications. Finally, background ozone is difficult to measure and thus, typically requires air quality modeling which has inherent uncertainties and potential errors and biases. Even with all of these complexities in mind, EPA believes the following concise and step-wise summary of background ozone is appropriate as based on previous modeling exercises and the more recent EPA analyses summarized herein.

- The most fundamental definition of background is "natural background" (NB). NB ozone is that which is produced by processes other than manmade emissions. Examples of sources of natural background include: stratospheric ozone intrusions, wildfire emissions, and biogenic emissions from vegetation and soils. To date, NB ozone has been estimated to be that ozone that would exist in the absence of anthropogenic ozone precursor emissions worldwide. Modeling analyses have shown that NB levels can vary in time and space. As shown in Section 3, April-October average NB levels range from approximately 15-35 ppb with the highest values in the spring and at higher-elevation sites.

- More expansive definitions of background include North American background (NAB) and U.S. background (USB). These definitions represent the ozone that originates from sources and processes other than North American or U.S. anthropogenic sources. Sources of NAB and USB include all the same sources of natural background, plus manmade ozone precursors emitted outside the North America or the U.S. Modeling analyses have shown that NAB and USB background levels can vary in time and space. As discussed in Section 3, seasonal mean NAB and USB background levels range from approximately 25-45 ppb with the highest values in the spring and at higher-elevation sites. USB levels are slightly higher than NAB, usually by less than 2 ppb.

- Estimates of seasonal mean background ozone levels are valuable in terms of a first-order characterization, however because levels can vary significantly from day-to-day, it is also instructive to consider the distribution of daily model estimates of background ozone over a season. Typically, model background is slightly higher in the April-June period than in the later portion of the ozone season (July-October) (EPA, 2012). More importantly, the modeling shows that the days with highest ozone levels, on average, have similar background levels to days with lower values. As a result, the proportion of total ozone that has background origins is smaller on high ozone days (e.g., days > 70 ppb) than the more common lower ozone days that drive seasonal means. Section 4 provides information about the distribution of background ozone fractions. Based on the source apportionment modeling, it is shown that U.S. anthropogenic emissions typically comprise the majority of the total ozone on site-days with base modeled ozone MDA8 values greater than 60 ppb.

- While it is important to recognize that most high ozone days (i.e., potential exceedance days) are estimated to be driven predominantly by non-background emissions, the recent EPA modeling also shows times and locations in which background contributions are estimated to approach 60-80 ppb. As described in Sections 4 and 6 of this document, these occurrences are relatively infrequent. While the modeling was not expressly developed to capture these types of events, ambient observations have also shown relatively rare events where background ozone sources (wildfires, stratospheric intrusions) have overwhelmingly contributed to an ozone exceedance. From a policy perspective, these background events must be viewed in the context of their relative infrequency and the existing mechanisms within the Clean Air Act (e.g., exceptional event policy, 179B international determinations) that help ensure States are not required to control for events that are inherently outside their ability to influence. While background ozone levels can approach and periodically exceed the NAAQS at some locations, these conditions are not a constraining factor in the selection of a NAAQS. The Clean Air Act requires the NAAQS to be set at a level requisite to protect public health and welfare. Case law makes it clear that attainability and technical feasibility are not relevant considerations. In previous reviews, EPA assessed the proximity of potential levels to peak background levels as a *secondary consideration* between levels where health and welfare was protected.

- Section 5 shows that the contributions to background are multi-dimensional. Daily peak 8-hour ozone values over the U.S. are a function of local and regional anthropogenic emissions, anthropogenic emissions from outside the U.S. (including shipping emissions), natural and anthropogenic methane emissions, wildfire emissions, and purely natural sources. While local and regional controls are still considered to be the most effective at reducing local ozone levels, any measures to reduce the international contributions or methane-induced background will also be valuable.

- In previous ozone NAAQS reviews, EPA estimated risk from exposure only to ozone concentrations above background. In the first drafts of the REA and PA for the current ozone

review, EPA estimated risk from exposure to total measured ozone concentrations, which include those concentrations from background sources. EPA will continue to provide estimates of risk from exposure to total ozone, consistent with CASAC advice, in the second draft policy assessment. The recent EPA modeling was completed to assist in determining, in a limited sense, the risk attributable to background ozone. The fractional values of background contributions in the 12 REA study areas (43-66 percent) could be used as first order approximations of the risk due to ozone background.

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APPENDIX 2B

MONITORING DATA ANALYSIS OF RELATIONSHIPS BETWEEN CURRENT STANDARD AND W126 METRIC

Presented here are monitoring data analyses evaluating relationship between ozone (O_3) concentrations in the averaging time and form of the current secondary standard (3-year average of the annual 4th highest daily maximum 8-hour concentrations, in parts per billion), and a three-year W126 metric (3-year average of the annual maximum 3-month sum of weighted daytime concentrations, in parts per million-hours). We also consider the responsiveness of these two metrics to historical changes in air quality related to ozone precursor emissions.

For this analysis, we chose to examine monitoring data from a base period (2001-2003) as well as a recent period (2009-2011). The base period was chosen to represent air quality conditions before the implementation of the 1997 national ambient air quality standard (NAAQS) for O_3 (0.08 ppm). In 2004, EPA designated 113 areas as nonattainment for the 1997 standard, which required many areas to begin precursor emissions control programs for the first time. At about the same time, EPA began implementation of the NOx Budget Trading Program under the NOx State Implementation Plan, also known as the "NOx SIP Call[1]," which required summertime reductions in NOx emissions from power plants and other large sources throughout the Eastern U.S. These programs were successful in reducing peak O3 concentrations, especially in the Eastern U.S., and as a result only 8 of the original 113 nonattainment areas were still violating the 1997 O3 NAAQS during the 2009-2011 period.

Hourly O3 concentration data were retrieved from EPA's Air Quality System (AQS) database[2] for both periods, and used to calculate design values for the current standard as well as 3-year average W126 values for both periods. The procedures for calculating design values for the current standard from hourly O_3 concentration data are described in 40 CFR Part 50, Appendix P, and the procedures for calculating the 3-year average W126 values are described in section 4.3.1. of the 2nd draft Welfare Risk and Exposure Assessment (WREA). There were 838 monitoring sites with sufficient data to calculate these values for both periods. In order to identify regional patterns in the relationships, these sites were grouped into the nine NOAA

[1] http://www.epa.gov/airmarkets/progsregs/nox/sip.html

[2] EPA's Air Quality System (AQS) database is a national repository for many types of air quality and related monitoring data. AQS contains monitoring data for the six criteria pollutants dating back to the 1970's, as well as more recent additions such as PM2.5 speciation, air toxics, and meteorology data. At present, AQS receives hourly O3 monitoring data collected from nearly 1,400 monitors operated by over 100 state, local, and tribal air quality monitoring agencies.

climate regions (Karl and Koss, 1984) used in the WREA. Figure 2B-1 presents a map of these regions, which are color-coded to match the scatter plots in the subsequent figures.

Figures 2B-2a, 2B-2b, 2B-3a and 2B-3b show scatter plots of the design values for the current standard (x-axis) versus 3-year average W126 values (y-axis) for the base period and recent period, respectively. Most monitors in the U.S. both exceeded the current standard of 75 ppb and a three-year average W126 value of 15 ppm-hrs during the base period. During the recent period, both the design values and 3-year average W126 values were much lower, and there also appears to be less scatter between the two metrics. In both periods, the highest design values and W126 values occurred in the West region which includes California. Finally, it is worth noting that monitors in the Southwest and West regions tend to have higher W126 values relative to their design values than in other regions.

Figure 2B-4 shows a scatter plot of the design values for the current standard for the base period (x-axis) versus for the recent period (y-axis), while Figure 2B-5 shows this same relationship based on the 3-year average W126 values. The relationship between the two periods appears to be fairly linear for both metrics, indicating that larger decreases in these metrics tended to occur at monitors with higher base values. Figures 2B-6 and 2B-7 show design values for the current standard and 3-year average W126 values, respectively, compared to the unit changes in those values between the base period and recent period. Figures 2B-6 and 2B-7 show the difference between each point and the one-to-one lines in Figures 2B-4 and 2B-5, respectively. In particular, these figures highlight that there were some monitors where design values for the current standard and/or W126 values increased. However, those monitors also tended to have lower base values, and were mostly located outside of areas subject to emissions controls under the 1997 standard.

Finally, Figure 2B-8 compares the unit change in design values (in ppb; x-axis) to the unit change in 3-year average W126 values (in ppm-hrs; y-axis). This figure shows that in most locations, the current standard metric and the W126 metric exhibit similar responses to changes in precursor emissions. In particular, the NOx SIP Call, which was implemented in the states east of the Mississippi River, was effective at reducing both design values and W126 values at nearly all monitors in the Eastern U.S. The relationship was much more variable in the remaining regions, where emissions control programs were mostly local and limited to areas which were violating the NAAQS.

Based on this analysis of ambient monitoring data, we can make the following general conclusions about the relationship between the design value metric for the current O_3 standard and the 3-year average W126 metric:

1. There is a fairly strong, positive degree of correlation between the two metrics.

2. Monitors in the West and Southwest regions tend to have higher W126 values relative to their design values than in other regions.
3. Reducing precursor emissions, especially NOx, is an effective strategy for lowering both design values and W126 values. In particular, regional control programs such as the NOx SIP call are effective at reducing both metrics over a broad area.

In addition, Figure 2B-9 examines the number of counties with 8-hour design values meeting the current standard and 3-year average W126 index values greater than 15 ppm-hrs. Most of these counties were located in the Southwest region of the country. There were no counties in any of the studied 3-year periods that had design values less than or equal to 65 ppb and 3-year average W126 index values greater than 15 ppm-hrs.

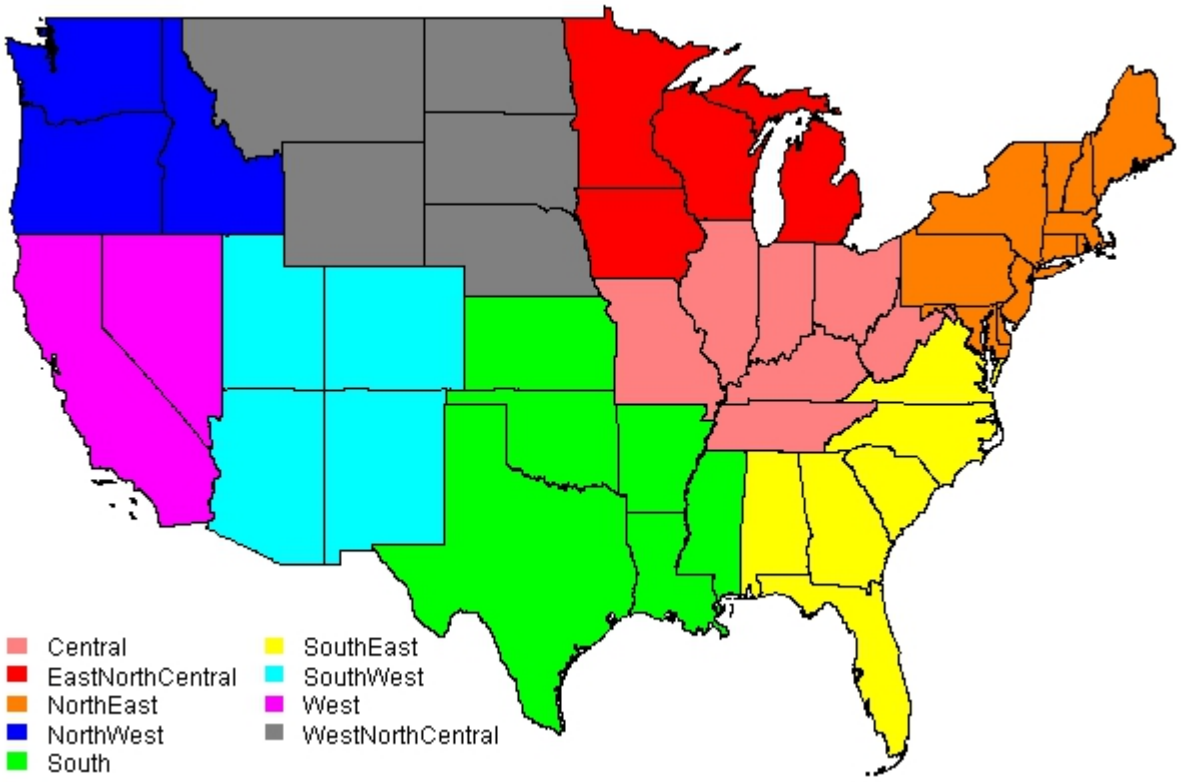

Figure 2B-1. Map of the 9 NOAA climate regions (Karl and Koss, 1984), color coded to match the subsequent scatter plots.

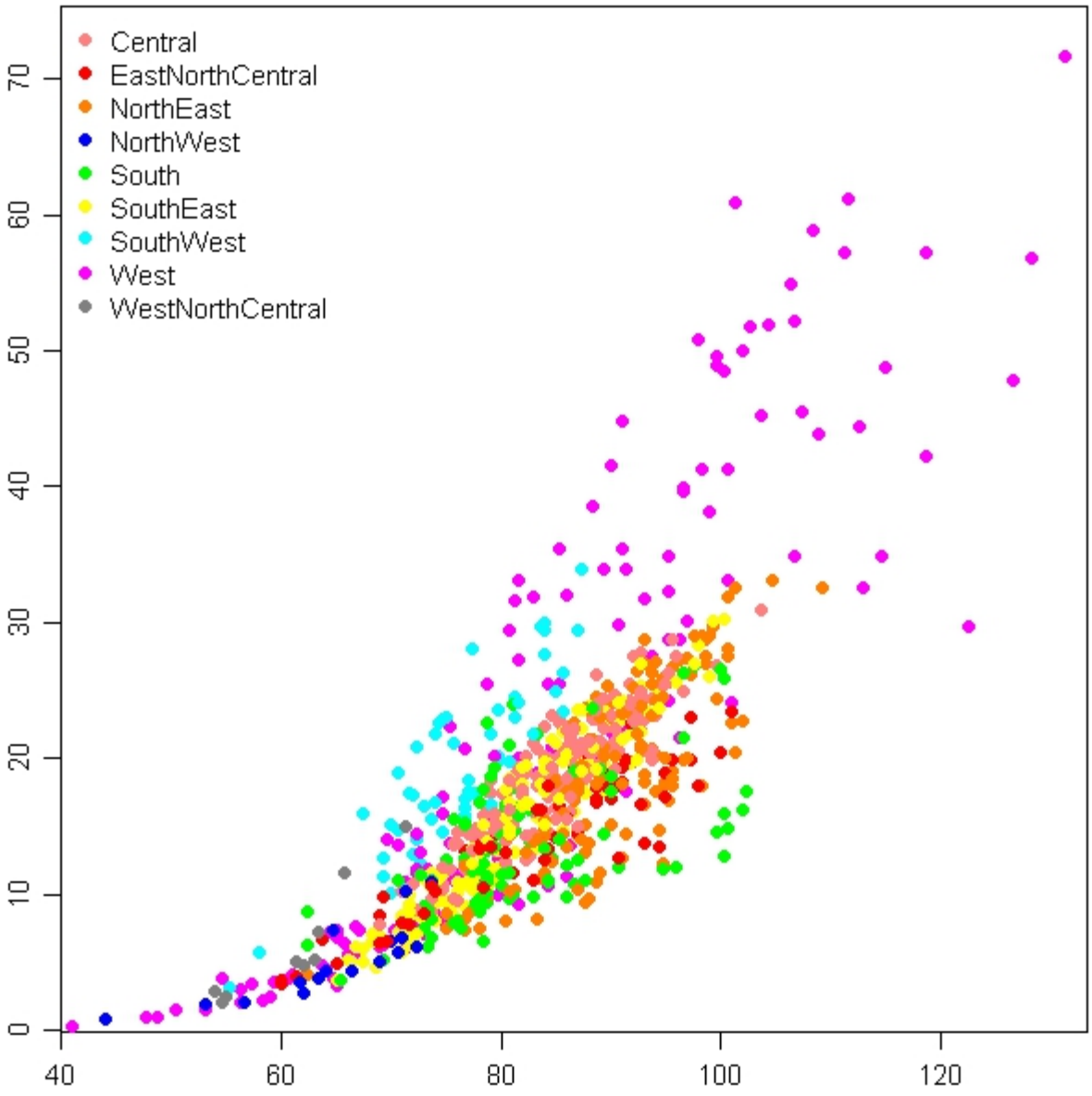

Figure 2B-2a. Design values for the current O_3 standard in ppb (x-axis) versus 3-year average W126 values in ppm-hrs (y-axis) based on ambient monitoring data for 2001-2003.

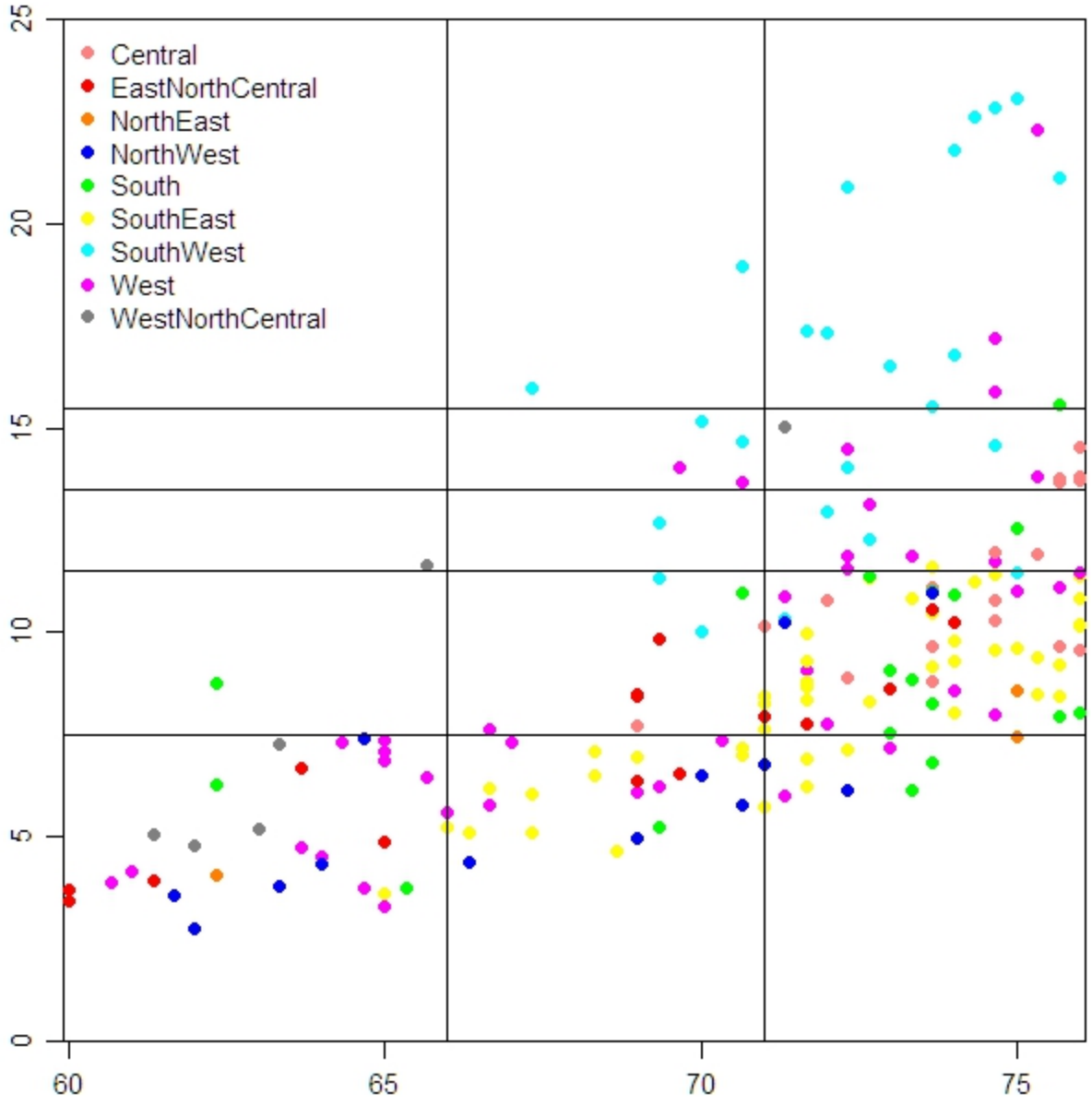

Figure 2B-2b. Design values for the current O_3 standard in ppb (x-axis) versus 3-year average W126 values in ppm-hrs (y-axis) based on ambient monitoring data for 2001-2003 with a focus on monitors with 2001-2003 design values below 75 ppb.

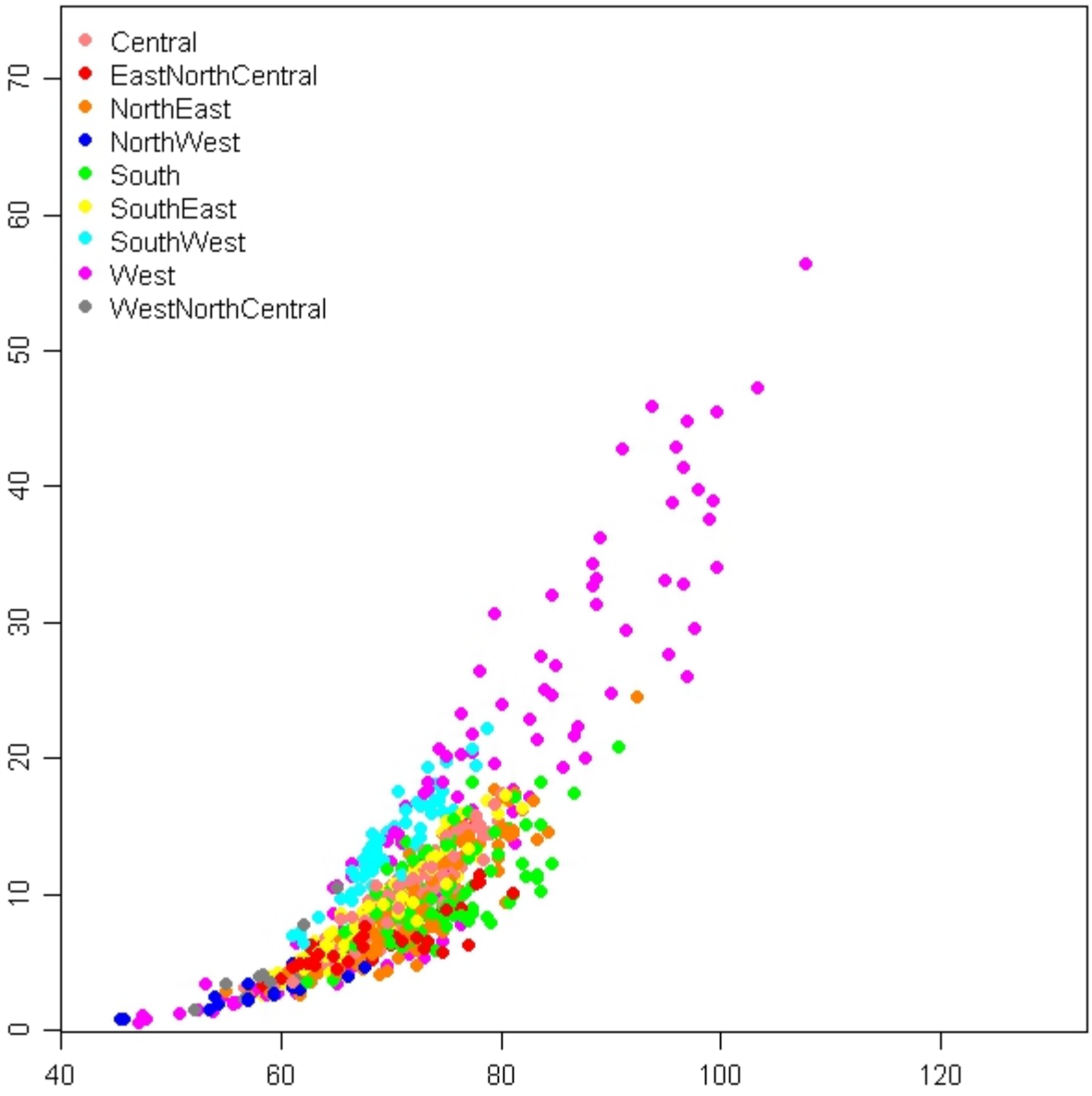

Figure 2B-3a. Design values for the current O_3 standard in ppb (x-axis) versus 3-year average W126 values in ppm-hrs (y-axis) based on ambient monitoring data for 2009-2011.

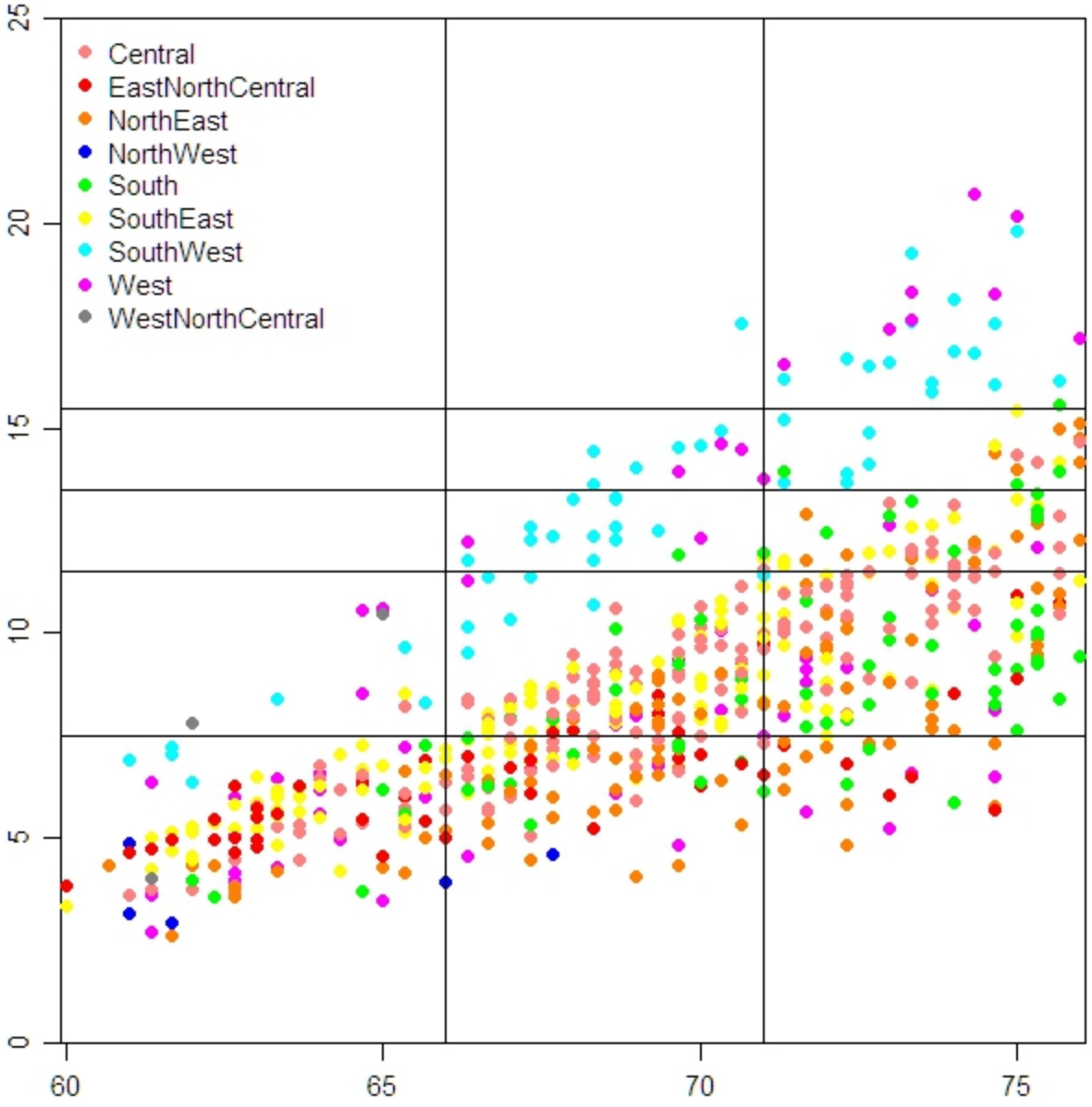

Figure 2B-3b. Design values for the current O_3 standard in ppb (x-axis) versus 3-year average W126 values in ppm-hrs (y-axis) based on ambient monitoring data for 2009-2011 with a focus on monitors with 2009-2011 design values below 75 ppb.

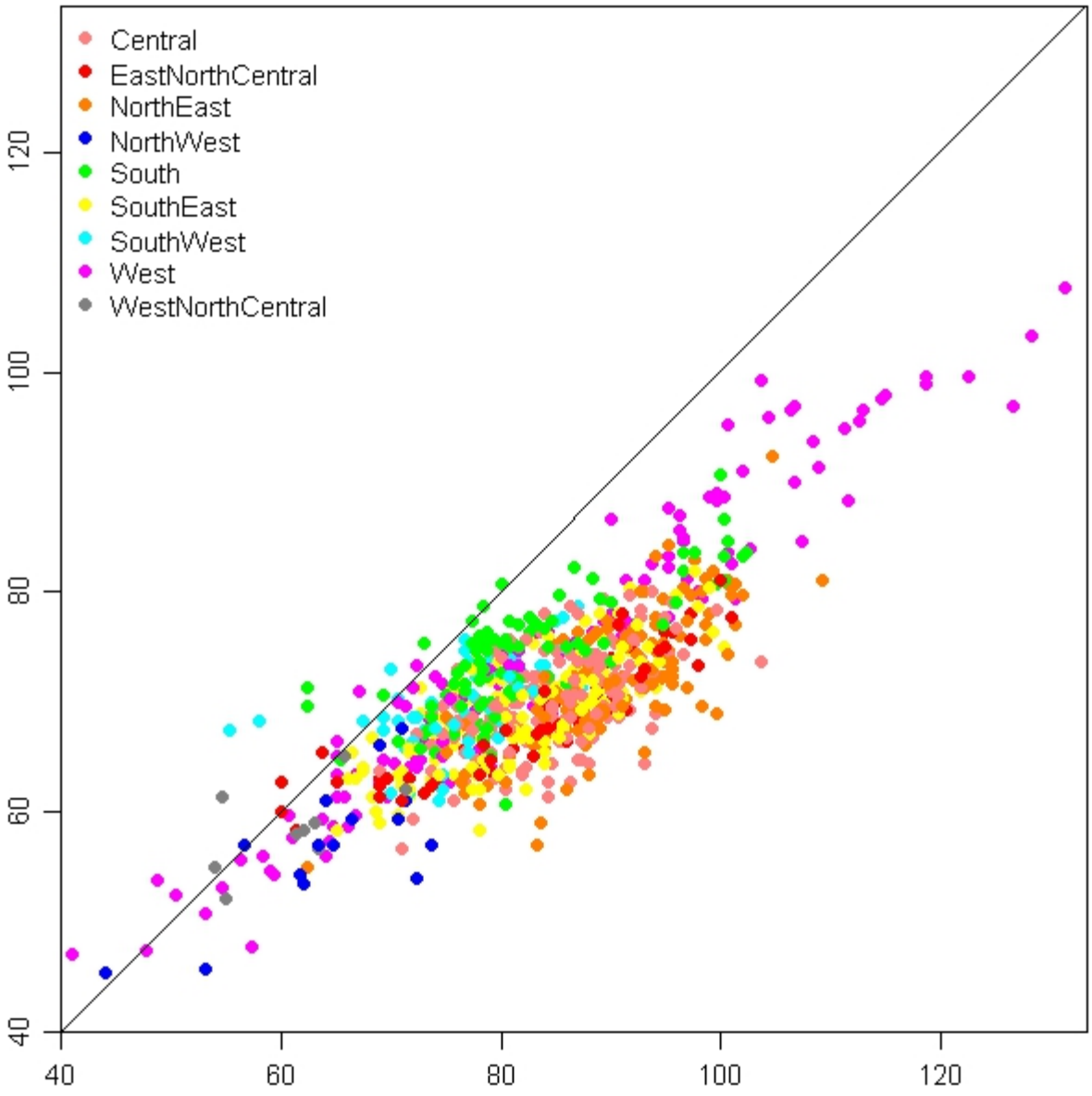

Figure 2B-4. Design values for the current O_3 standard in ppb based on ambient monitoring data for 2001-2003 (x-axis) versus 2009-2011 (y-axis).

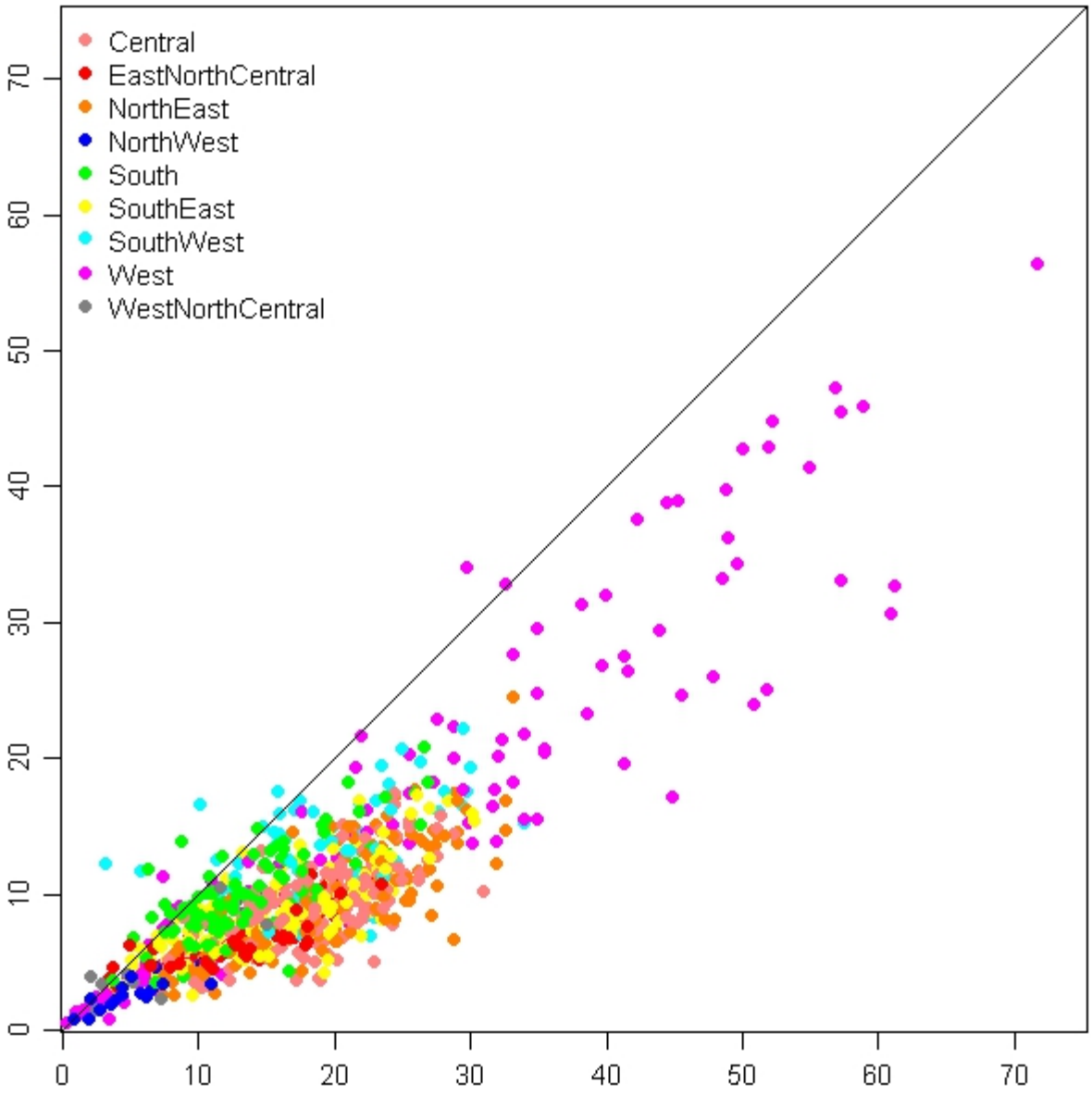

Figure 2B-5. Three-year average W126 values in ppm-hrs based on ambient monitoring data for 2001-2003 (x-axis) versus 2009-2011 (y-axis).

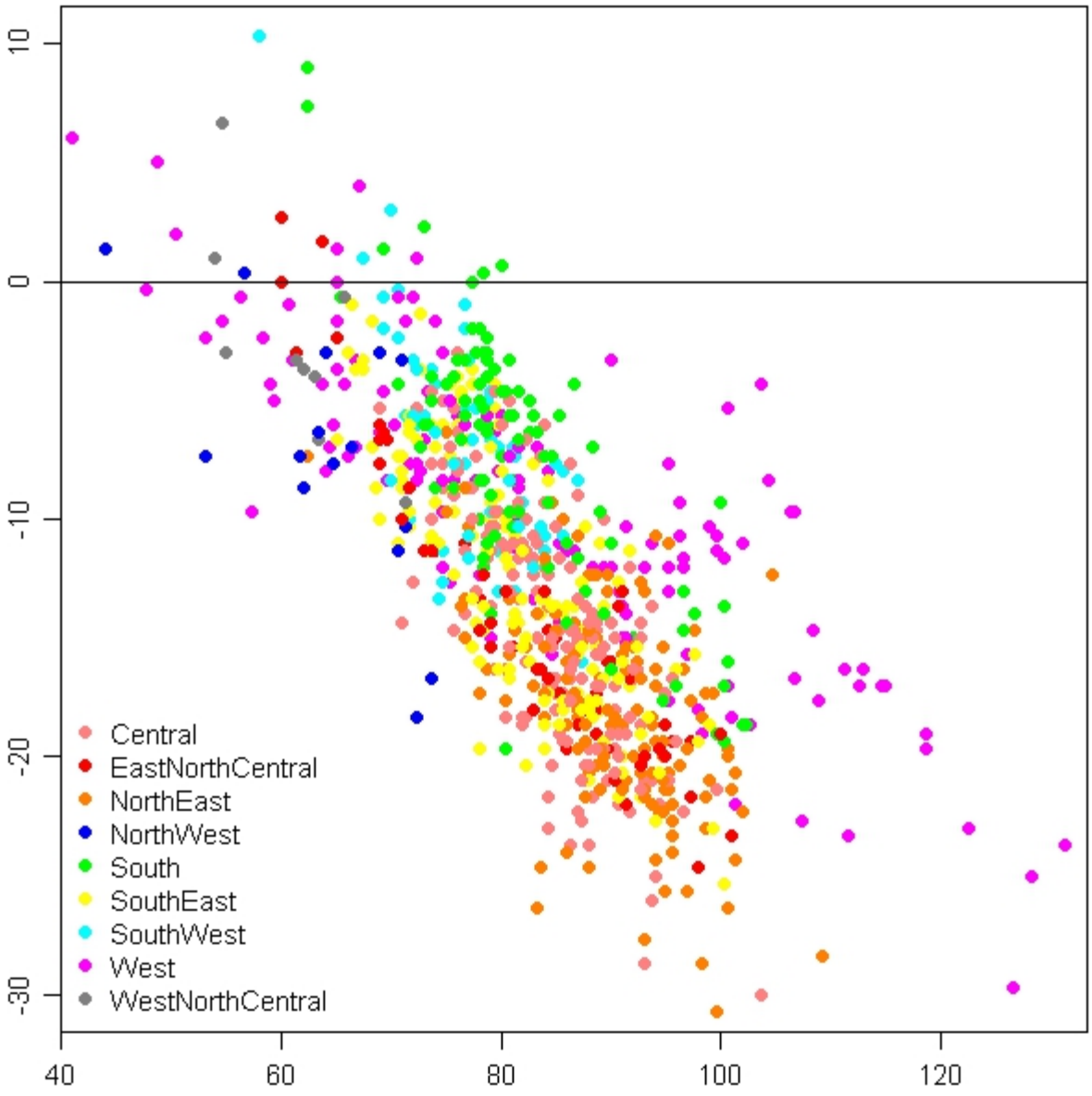

Figure 2B-6. Design values for the current O_3 standard in ppb based on ambient monitoring data for 2001-2003 (x-axis) versus unit (ppb) change in design values from 2001-2003 to 2009-2011 (y-axis).

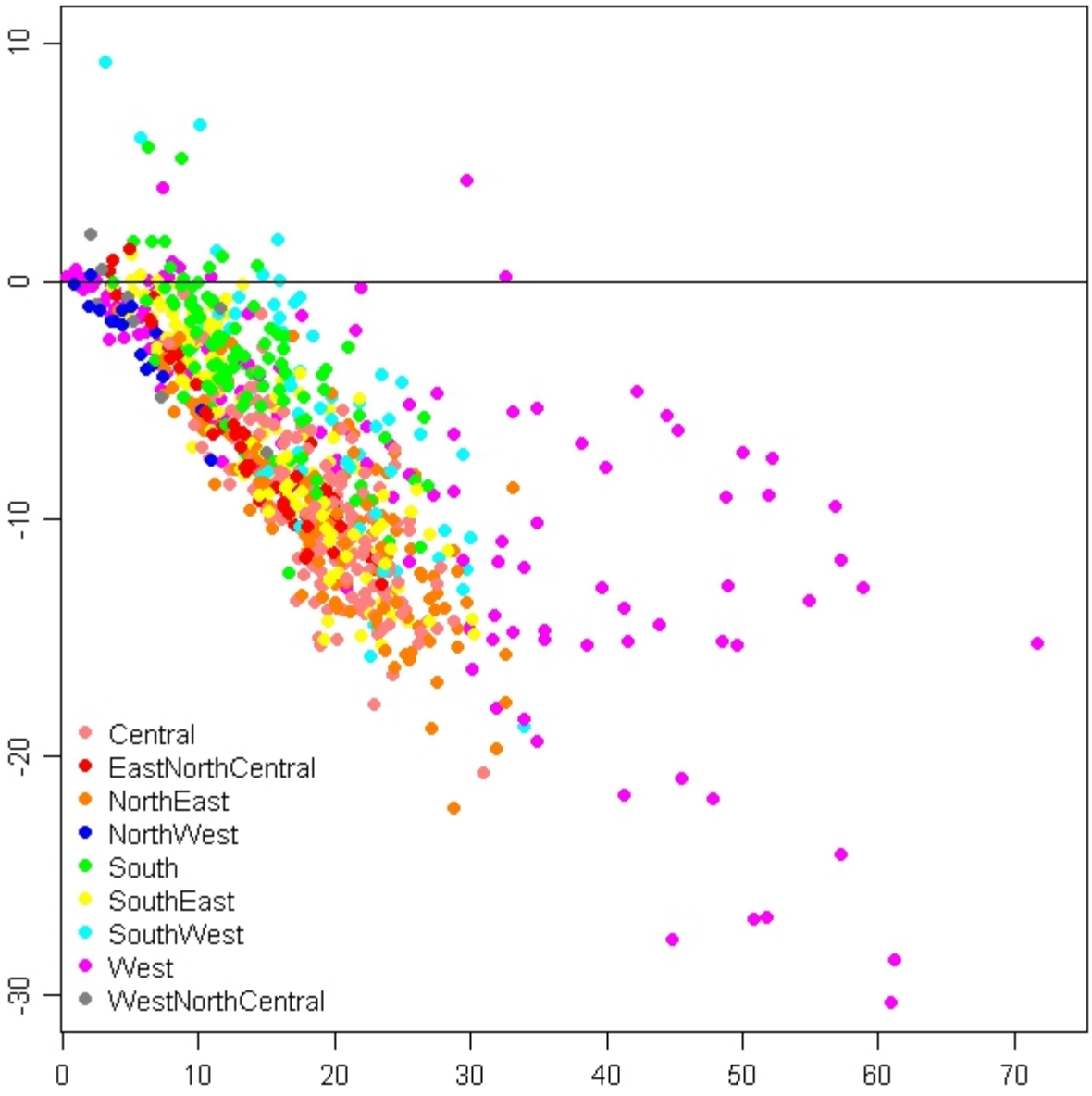

Figure 2B-7. Three-year average W126 values in ppm-hrs based on ambient monitoring data for 2001-2003 (x-axis) versus unit (ppm-hr) change in 3-year average W126 values from 2001-2003 to 2009-2011 (y-axis).

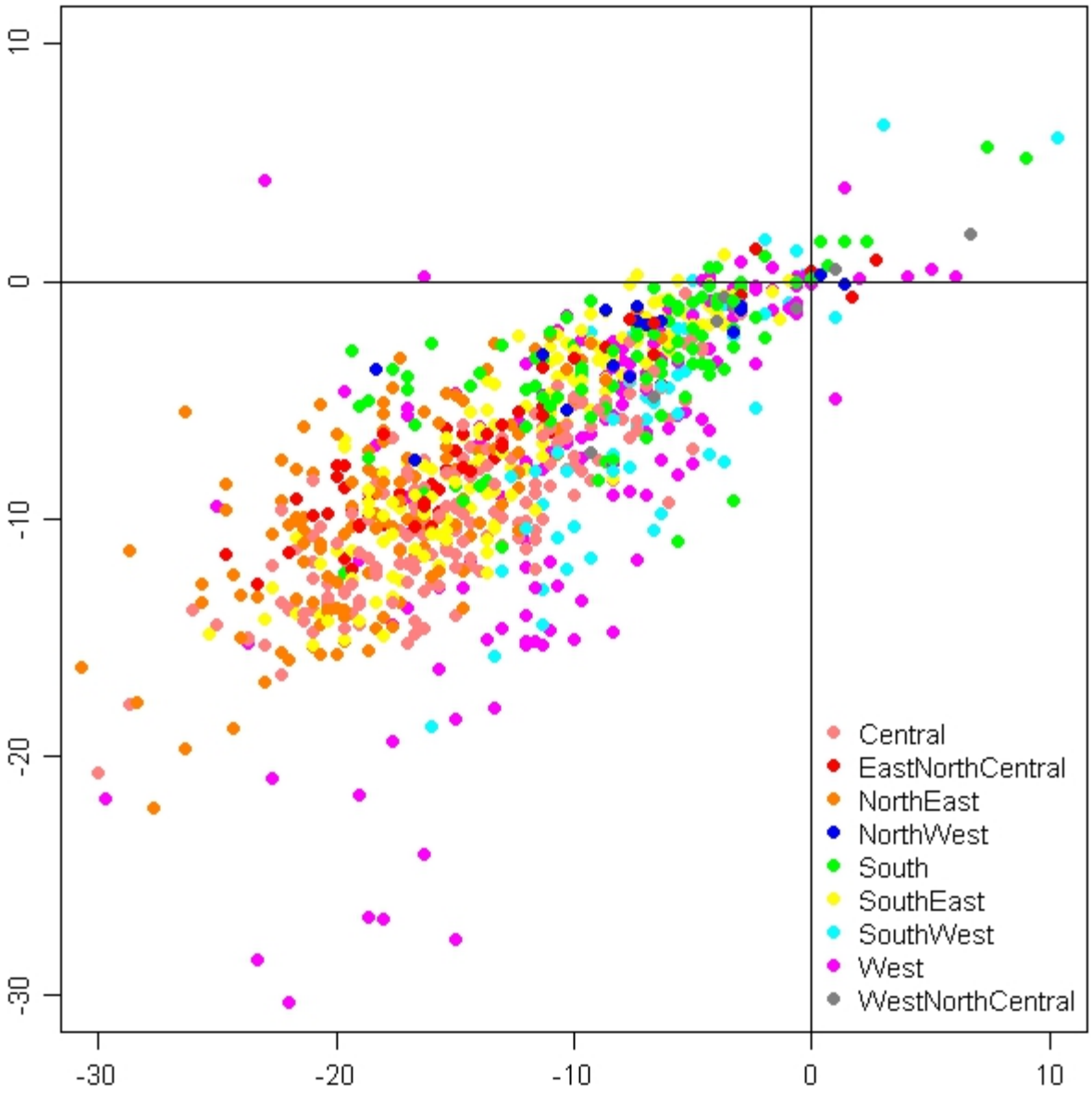

Figure 2B-8. Unit (ppb) change in design values for the current O_3 standard from 2001-2003 to 2009-2011 (x-axis) versus unit (ppm-hr) change in 3-year average W126 values from 2001-2003 to 2009-2011 (y-axis).

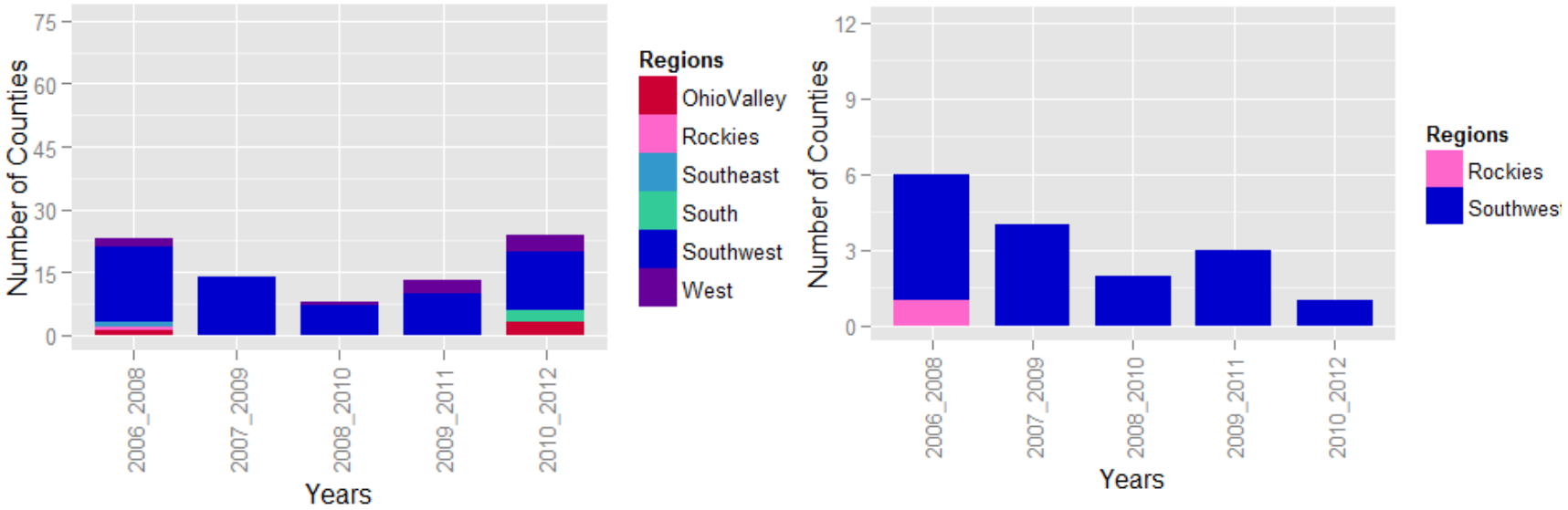

Figure 2B-9. Number of counties where the 8-hour design value is meeting the current standard and 3-year average W126 index value is greater than 15 ppm-hrs (left), and number of counties where the 8-hour design value is less than or equal to 70 ppb and 3-year average W126 index value is greater than15 ppm-hrs (right)[3].

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[3] No counties in any of the studied 3-year periods were at or below a 3-year average of 4th highest daily maximum 8-hour averages of 65 ppb and also above a 3-year W126 index value of 15 ppm-hrs.

APPENDIX 2C

INTER-ANNUAL VARIABILITY IN W126 INDEX VALUES: COMPARING ANNUAL AND 3-YEAR AVERAGE METRICS (2008-2010)

2C.1 OVERVIEW

This appendix describes an analysis comparing values for a single-year or annual W126 metric to a W126 metric averaged over three consecutive years. The purpose of this analysis is to compare values based on a 3-year average of annual W126 indices to values based on a single annual W126 index. The deviations of the annual W126 index values in 2008, 2009, and 2010 from the 2008-2010 average W126 index values are presented.

2C.2 GENERAL DATA PROCESSING

The air quality data for this analysis originated from EPA's Air Quality System (AQS) data base, the official repository of ambient air measurements. The data used in this analysis consisted of W126 index values calculated from hourly ozone concentrations measured at 1082 ozone monitors nationwide. Ozone monitors must have submitted data to AQS for at least 75% days in their required ozone monitoring season in 2008, 2009, and 2010 to be included in the analysis.

2C.3 RESULTS & CONCLUSION

The figure below shows a scatter plot of the deviations in the annual W126 index from the 3-year average by monitor. The solid curves represent the average deviation in a moving window along the x-axis for each year. From this figure, it is apparent that the highest annual W126 index value occurred in 2008 for most monitoring locations, the lowest annual W126 index value occurred in 2009 for most monitoring locations, and the 2010 W126 index value was generally somewhere in between. It is also apparent that the inter-annual variability in the W126 index increases along with the 3-year average. For monitors with 3-year average W126 values near 15 ppm-hrs, the average deviation was +3.5 ppm-hrs in 2008 and -3.8 ppm-hrs in 2009. This represents a 1-year swing of -7.3 ppm-hrs.

The model-based air quality adjustments in the 2nd draft of the O_3 Welfare REA show that reducing NOx emissions is effective for reducing 3-year average W126 levels. In Appendix 2B, the analyses based on ambient monitoring data also show that large-scale reductions in NOx emissions are associated with lower W126 levels. Finally, the data analysis presented in this appendix shows that the inter-annual variability in the annual W126 index tends to decrease with decreasing W126 levels. Thus, it is expected that reductions in NOx emissions will not only

result in lower 3-year average W126 levels, but also result in less inter-annual variability associated with annual W126 levels.

The W126 index is based on a logistic weighting function that increases the weights assigned to hourly ozone concentrations very rapidly. Hourly ozone concentrations of 50 parts per billion are given a weight of about 10% while concentrations of 80 parts per billion are given a weight of nearly 90%. The annual W126 index is calculated as a 3-month sum of weighted ozone concentrations during daylight hours, which amounts to a sum of roughly 1100 weighted hourly concentrations. Thus, even a modest change in the average daily ozone level may have a significant impact upon the annual W126 index. Since ozone formation is heavily influenced by meteorology, the inter-annual variability in meteorological conditions tends to cause a large inter-annual variability in the W126 index.

In conclusion, this evaluation indicates the extent to which a form for the secondary ozone standard that averages the annual W126 index values over three consecutive years might be expected to account for the annual variability in this index since the 3-year period would be expected to include year(s) below as well as above the 3-year average.

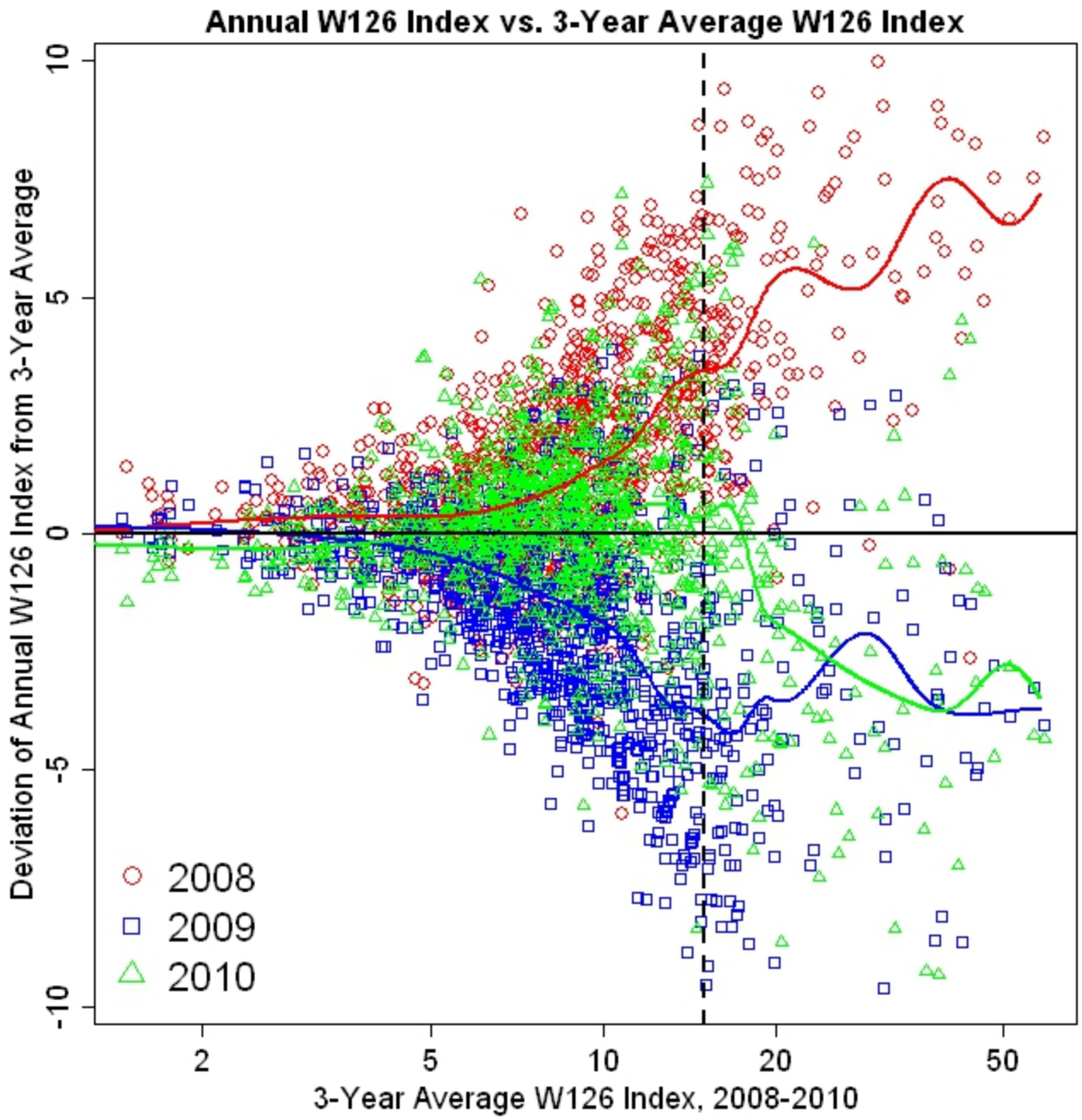

Figure 2C-1. Deviation of the annual W126 index values in 2008, 2009, and 2010 (y-axis) from the 3-year average W126 index value (x-axis).

APPENDIX 3A

RECENT STUDIES OF RESPIRATORY-RELATED EMERGENCY DEPARTMENT VISITS AND HOSPITAL ADMISSIONS

Hospital Admissions for All Respiratory Causes

The APHENA study (APHENA is for Air Pollution and Health: A European and North American Approach) analyzed air pollution and health outcome data from existing Canadian, European, and U.S. multi-city studies and examined the influence of varying model specification to control for season and weather (Katsouyanni et al., 2009). The U.S.-based portion of the APHENA study utilized the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) cohort which, for the Katsouyanni et al. (2009) analysis, comprised respiratory hospital admissions among individuals 65 years of age and older from 14 US cities with O_3 data from 1985-1994 (7 cities had summer only O_3 data). For the year round analysis, Katsouyanni et al. (2009) reported consistently positive, and statistically significant in models with 8 degrees of freedom per year (U.S. EPA, 2013, section 6.2.7.2), associations between 1-hour O_3 concentrations and respiratory hospital admissions across the datasets from the U.S., Canada, and Europe (U.S. EPA 2013, Figure 6-15).[1] In co-pollutant models adjusting for PM_{10}, O_3 effect estimates remained positive, though effect estimates were somewhat attenuated in the U.S. and European datasets, possibly due to the PM sampling schedule (U.S. EPA 2013, Figure 6-15). Effect estimates for the warm season were larger than for the year-round analysis in the Canadian dataset, but generally similar in magnitude to the year-round analysis in the U.S. and European datasets.

Several additional multicity studies examined respiratory disease hospital admissions in Canada and Europe. Cakmak et al. (2006) reported a statistically significant increase in respiratory hospital admissions in 10 Canadian cities (4.4% increase per 20 ppb increase in 24-hour average O_3, 95% CI: 2.2, 6.5%). In analyses of potential effect modifiers of the O_3-respiratory hospital admission relationship, individuals with an education level less than the 9^{th} grade were found to be at greater risk. Dales et al. (2006) reported a 5.4% (95% CI: 2.9, 8.0%) increase in neonatal respiratory hospital admissions for a 20 ppb increase in 24-hour average O_3

[1]The study by Katsouyanni et al. (2009) evaluated different statistical models. Although the investigators did not identify the model they deemed to be the most appropriate for comparing the results across study locations, they did specify that "overall effect estimates (i.e., estimates pooled over several cities) tended to stabilize at high degrees of freedom" (Katsouyanni et al., 2009). In discussing of the results of this study, the ISA focused on models with 8 degrees of freedom per year (US EPA, 2012a, section 6.2.7.2).

concentrations in 11 Canadian cities from 1986 to 2000. In contrast, Biggeri et al. (2005) did not detect an association between short-term O_3 exposure and respiratory hospital admissions in four Italian cities from 1990 to 1999.

In addition to the large multi-city studies discussed above, several smaller-scale studies have also reported associations with total respiratory hospital admissions. Specifically, Lin et al. (2008) reported a positive association between O_3 and pediatric (i.e., <18 years) respiratory admissions in an analysis of 11 geographic regions in New York state from 1991 to 2001, though results were not presented quantitatively. In co-pollutant models with PM_{10}, the authors reported that region-specific O_3 associations with respiratory hospital admissions remained relatively robust.

Cause-Specific Hospital Admissions

With regard to cause-specific respiratory outcomes, the limited evidence available in the last review indicated that the strongest findings were for ambient O_3 associated asthma and chronic obstructive pulmonary disease (COPD) respiratory hospital admissions (U.S. EPA 2013, 6.2.7.2). Since the last review, a few additional studies have investigated cause-specific respiratory admissions (i.e., COPD, asthma, pneumonia) in relation to O_3 exposure (Medina-Ramon et al, 2006; Yang et al., 2005; Zanobetti and Schwartz, 2006; Silverman and Ito, 2010).

Medina-Ramon et al. (2006) examined the association between short-term ambient O_3 concentrations and Medicare hospital admissions for COPD among individuals ≥ 65 years of age for COPD in 35 cities in the U.S. for the years 1986-1999. The authors reported an increase in COPD admissions for lag 0-1 day in the warm season for a 30 ppb increase in 8-h max O_3 concentrations. The authors found no evidence for such associations in cool season or in year round analyses. In a co-pollutant model with PM_{10}, the association between O_3 and COPD hospital admissions remained robust. In Vancouver from 1994-1998, a location with low ambient O_3 concentrations (U.S. EPA, 2013, Table 6-26), Yang et al. (2005) reported a statistically non-significant increase in COPD admissions per 20 ppb increase in 24-hour average O_3 concentrations. In two-pollutant models with every-day data for NO_2, SO_2, CO, and PM_{10}, O_3 risk estimates remained robust, though not statistically significant (U.S. EPA, 2013, Figure 6-20; Table 6-29). In addition, Wong et al. (2009) reported increased O_3-associated COPD admissions during periods of increased influenza activity in Hong Kong.

The ISA assessed a study that evaluated asthma-related hospital admissions in New York City (U.S. EPA, 2013, section 6.2.7.2) (Silverman and Ito, 2010). This study examined the association of 8-hour max O_3 concentrations with severe acute asthma admissions (i.e., those admitted to the Intensive Care Unit [ICU]) during the warm season in the years 1999 through

2006 (Silverman and Ito, 2010)). The investigators reported positive associations between O_3 and ICU asthma admissions for the 6- to 18-year age group for a 30 ppb increase in max 8-hour average O_3 concentrations, but little evidence of associations for the other age groups examined (<6 years, 19-49, 50+, and all ages). However, positive associations were observed for each age-stratified group and all ages for non-ICU asthma admissions, but again the strongest association was reported for the 6- to 18-years age group. In two-pollutant models, O_3 effect estimates for both non-ICU and ICU hospital admissions remained robust to adjustment for $PM_{2.5}$. In an additional analysis, using a smooth function, the authors examined whether the shape of the concentration-response curve for O_3 and asthma hospital admissions (i.e., both general and ICU for all ages) is linear. When comparing the curve to a linear fit line, the authors found that the linear fit was a reasonable approximation of the concentration-response relationship between O_3 and asthma hospital admissions, but the limited data density at relatively low O_3 concentrations contributes to uncertainty in the shape of the concentration-response relationship at the low end of the distribution of O_3 concentrations (U.S. EPA, 2013, Figure 6-16).

In contrast to COPD and asthma, the evidence for pneumonia-related admissions was less consistent. Medina-Ramon et al. (2006) examined the association between short-term ambient O_3 concentrations and Medicare hospital admissions among individuals ≥ 65 years of age for pneumonia. The authors reported an increase in pneumonia hospital admissions in the warm season for a 30 ppb increase in 8-hour max O_3 concentrations, with no evidence of an association in the cool season or year round. In two-pollutant models restricted to days for which PM_{10} data was available, the association between O_3 exposure and pneumonia hospital admissions remained robust. In contrast, Zanobetti and Schwartz (2006) reported a decrease in pneumonia admissions for a 20 ppb increase in 24-hour average O_3 concentrations in Boston for the average of lags 0 and 1 day.

The magnitude of associations with respiratory-related hospital admissions may be underestimated due to behavioral modification in response to forecasted air quality (U.S. EPA, 2013, section 4.6.6). Recent studies (Neidell and Kinney, 2010; Neidell, 2009) conducted in Southern California demonstrates that controlling for avoidance behavior increases O_3 effect estimates for respiratory hospital admissions, specifically for children and older adults. This study shows that on days where no public alert warning of high O_3 concentrations was issued, there was an increase in asthma hospital admissions. Although only one study has examined averting behavior and this study is limited to the outcome of asthma hospital admissions in one location and time period (i.e., Los Angeles, CA for the years 1989-1997), it does provide preliminary evidence indicating that some epidemiologic studies may underestimate associations

between O_3 and health effects by not accounting for behavioral modification when public health alerts are issued.

Emergency Department Visits for All Respiratory Causes

A large single-city study conducted in Atlanta by Tolbert et al. (2007), and subsequently reanalyzed by Darrow et al. (2011) using different air quality data and evaluating associations with different metrics, provides evidence for associations between short-term exposures to ambient O_3 concentrations and respiratory emergency department visits. Tolbert et al. (2007) reported an increase in respiratory emergency department visits for a 30 ppb increase in 8-hour max O_3 concentrations during the warm season. In copollutant models with CO, NO_2, and PM_{10}, limited to days in which data for all pollutants were available, associations between O_3 and respiratory emergency department visits remained positive, but were attenuated. Darrow et al. (2011) reported the strongest associations with respiratory emergency department visits for 8-hour daily max, 1-hour daily max, and day-time O_3 exposure metrics (all associations positive and statistically significant), while positive, but statistically non-significant, associations were reported with 24-hour average and commuting period exposure metrics. In addition, a negative association was observed when using the night-time exposure metric (U.S. EPA, 2013, Figure 6-17). The results of Darrow et al. (2011) suggest that averaging over nighttime hours may lead to smaller O_3 effect estimates for respiratory emergency department visits due to dilution of relevant O_3 concentrations (i.e., the higher concentrations that occur during the daytime); and potential negative confounding by other pollutants (e.g., CO, NO_2) during the nighttime hours (U.S. EPA, 2013, section 6.2.7.3)

Cause-Specific Emergency Department Visits

In evaluating asthma emergency department visits in an all-year analysis, a Canadian multi-city study (Stieb et al., 2009) reported that 24-hour O_3 concentrations were positively associated with emergency department visits for asthma at lag 1 and lag 2. Though the authors did not present seasonal analyses, they stated that no associations were observed with emergency department visits in the winter season, suggesting that the positive associations reported in the all-year analysis were due to the warm season (Stieb et al., 2009). In addition to asthma, the authors reported that O_3 was positively associated with COPD emergency department visits in all-year analyses, but that associations with COPD visits were statistically significant only for the warm season (i.e., April-September).

Several single-city studies have also provided evidence for positive associations between asthma emergency department visits and ambient O_3 concentrations. Ito et al. (2007) reported positive and statistically significant associations with asthma emergency department visits in New York City during the warm season, and an inverse association in the cool season, for a 30 ppb increase in 8-hour max O_3 concentrations. In two-pollutant models with $PM_{2.5}$, NO_2, SO_2, and CO, the authors found that O_3 risk estimates were not substantially changed during the warm season (U.S. EPA, 2013, Figure 6-20; Table 6-29).

Strickland et al. (2010) examined the association between O_3 exposure and pediatric asthma emergency department visits (ages 5-17 years) in Atlanta using air quality data over the same years as Darrow et al. (2011) and Tolbert et al. (2007), but using population-weighting to combine daily pollutant concentrations across monitors. Strickland et al. (2010) reported an increase in emergency department visits for a 30 ppb increase in 8-hour max O_3 concentrations in an all-year analysis. In seasonal analyses, stronger associations were observed during the warm season (i.e., May-October) than the cold season. In co-pollutant analyses that included CO, NO_2, $PM_{2.5}$ elemental carbon, or $PM_{2.5}$ sulfate, Strickland et al. (2010) reported that O_3 risk estimates were not substantially changed. The authors also examined the concentration-response relationship between O_3 exposure and pediatric asthma emergency department visits and reported that positive associations with O_3 persist at 8-hour ambient O_3 concentrations (3-day average of 8-hour daily max concentrations) at least as low as 30 ppb.

In a single-city study conducted in Seattle, WA, Mar and Koenig (2009) examined the association between O_3 exposure and asthma emergency department visits for children (< 18) and adults (≥ 18). For children, positive and statistically significant associations were reported across multiple lags, with the strongest associations observed at lag 0 and lag 3. Ozone was also found to be positively associated with asthma emergency department visits for adults at all lags, except at lag 0. The slightly different lag times for children and adults suggest that children may be more immediately responsive to O_3 exposures than adults (Mar and Koenig, 2009).

In addition to the U.S. single-city studies discussed above, a single-city study conducted in Alberta, Canada (Villeneuve et al., 2007) provides support for the findings from Stieb et al. (2009), but also attempts to identify those lifestages at greatest risk for O_3-associated asthma emergency department visits. Villeneuve et al. reported an increase in asthma emergency department visits in an all-year analysis across all ages with associations being stronger during

the warmer months. When stratified by age, the strongest associations were observed in the warm season for individuals 5-14 and 15-44. These associations were not found to be confounded by the inclusion of aeroallergens in age-specific models.

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APPENDIX 3B: AMBIENT O_3 CONCENTRATIONS IN LOCATIONS OF HEALTH STUDIES

Annual 4th highest daily maximum O_3 concentrations for all U.S. monitors operating during the 1975 – 2010 period were retrieved from EPA's AQS database. These data were used to calculate O_3 design values for the 2008 8-hour O_3 NAAQS of 0.075 parts per million (ppm) according to 40 CFR part 50, Appendix P. Design values were calculated for each O_3 monitor and each 3-year period between 1975-1977 and 2008-2010 whenever sufficient data were available.

Ozone Design Values in Study Locations

Ozone monitors were matched to 200 health study locations on a case-by-case basis, using the following guidelines:

1) Areas defined by a Metropolitan Statistical Area (MSA) were matched with O_3 monitors by incorporating all of the monitors located in within the MSA boundaries.

2) Areas not represented by a MSA were matched to monitors by incorporating all of the monitors in the county central to location of the health study area.

3) In some cases, EPA staff made judgment calls. For example, EPA staff matched the Los Angeles, CA study area to the Los Angeles-Long Beach-Santa Ana, CA MSA defined by Los Angeles County, CA and Orange County, CA, while the Long Beach, CA study area was matched to Los Angeles County, CA and the Santa Ana, CA study area was matched to Orange County, CA.

In some cases, EPA staff matched two or more study areas to the same county or MSA. In other cases, a study area was matched to a MSA and another study area was matched to a county within the same MSA. For each 3-year period, the area design value was determined by the monitor reporting the highest design value in the county or MSA. This has two implications for the design values:

1) Design values are sensitive to changes in the monitoring network. The addition or discontinuation of O_3 monitors in an area may cause increases or decreases in the design value trend.

2) Only valid design values are reported. According to 40 CFR Part 50, Appendix P, design values greater than the level of the NAAQS (0.075 ppm) are always valid, while design values less than or equal to 0.075 ppm must have 75% annual data completeness in order to be valid. This may cause anomalies in the design value trend. For example, a monitor may report a valid design value based on as few as 12 days of data, or a monitor with less than 75% annual data completeness may have valid design values in some 3-year periods and invalid design values in others.

We have identified design values for the U.S. O_3 epidemiologic studies identified in Sections 3.1.4.2 and 3.1.4.3 of the second draft Policy Assessment (see Tables 3D-1 to 3D-4). For each study, design values were identified for the cities evaluated and for the years over which the study was conducted. These design values are reported in tables A-1 to A-22 of the Wells et al, 2012 memo "Analysis of Recent U.S. Ozone Air Quality Data to Support the O_3 NAAQS Review and Quadratic Rollback Simulations to Support the First Draft of the Risk and Exposure Assessment".

Table 3B-1. Number of Study Cities from Multicity Epidemiologic Studies of Hospital Admissions and Emergency Department Visits Using Short-Term O_3 Metrics with 3-Year Averages of Annual 4th Highest Daily Maximum 8-hour O_3 Concentrations ≤ 75 ppb[1]

Study	Location	Endpoint[2]	% Increase (95% CI)[3]	# Study Cities ≤ 75 ppb over entire study period
All-year				
Medina-Ramon et al. (2006)	36 U.S. cities	COPD HA	All year: 0.24 (-0.78, 1.21) Warm season: 1.63 (0.48, 2.85)	4
		Pneumonia HA	All year: 1.81 (-0.72, 4.52) Warm Season: 2.49 (1.57, 3.47)	
Katsouyanni et al. (2009)	14 U.S. cities	Respiratory HA	All Year: 2.38 (0.00, 4.89) Warm Season: 2.14 (-0.63, 4.97)	2
	12 Canadian Cities	Respiratory HA	All year: 2.4 (0.51, 4.40) Warm Season: 4.1 (1.4, 6.8)	10
Dales et al. (2006)	11 Canadian cities	Respiratory HA	All year: 5.41 (2.88, 7.96)	7
Stieb et al. (2009)	7 Canadian cities	Asthma ED	All year: 3.48 (0.33, 6.76)	5
		COPD ED	All year: 4.03 (-0.54, 8.62) Warm season: 6.76 (0.11, 13.9)	
Cakmak et al. (2006)	10 Canadian cities	Respiratory HA	All year: 4.38 (2.19, 6.46)	7

[1] For U.S. study areas, we used EPA's Air Quality System (AQS) (http://www.epa.gov/ttn/airs/airsaqs/) to identify 8-hour O_3 concentrations. For Canadian study areas, we used publically available air quality data from the Environment Canada National Air Pollution Surveillance Network (http://www.etc-cte.ec.gc.ca/napsdata/main/aspx). We followed the data handling protocols for calculating design values as detailed in 40 CFR Part 50, Appendix P.

[2]HA stands for hospital admissions; ED stands for emergency department visits.
[3]Ozone effect estimates are taken from Table 6-28 in the ISA (U.S. EPA, 2013a).

Table 3B-2. Number of Study Cities from Multicity Epidemiologic Studies of Mortality Using Short-Term O_3 Metrics with 3-Year Averages of Annual 4th Highest Daily Maximum 8-hour O_3 Concentrations ≤ 75 ppb

Study	Location	Endpoint	% Increase (95% CI)[4]	# Study Cities ≤ 75 ppb over entire study period
All-year				
Schwartz (2005)	14 U.S. cities	Non-accidental mortality	0.76 (0.13, 1.40)	1
Bell et al. (2007)	98 U.S. communities	Non-accidental mortality	0.64 (0.34, 0.92)	6
Bell and Dominici (2008)	98 U.S. communities	Non-accidental mortality	1.04 (0.56, 1.55)	6
Katsouyanni et al. (2009)	90 U.S. cities	Non-accidental mortality	3.02 (1.10, 4.89)	6
		Respiratory mortality	2.54 (-3.32, 8.79) for <75; 1.10 (-6.48, 9.21) for 75+	
		Cardiovascular mortality	3.83 (-0.16, 7.95) for < 75; 2.30 (-1.33, 6.04) for 75+	
Bell et al. (2004)	95 U.S. communities	Non-accidental mortality	1.04 (0.54, 1.55)	6
Katsouyanni et al. (2009)	12 Canadian cities	Non-accidental mortality	0.73 (0.23, 1.20)	8
		Respiratory mortality	0.13 (-1.60, 1.90); -0.60 (-2.70, 1.60) for 75+	
		Cardiovascular mortality	0.87 (-0.35, 2.10) for <75; 1.1 (0.10, 2.20) for 75+	
Warm Season				
Schwartz (2005)	14 U.S. Cities	Non-accidental mortality	1.00 (0.30, 1.80)	1
Zanobetti and Schwartz (2008a)	48 U.S. cities	Non-accidental mortality	1.51 (1.14, 1.87)	4
Zanobetti and Schwartz (2008b)	48 U.S. cities	Non-accidental mortality	1.60 (0.84, 2.33)	4
		Respiratory mortality	2.51 (1.14, 3.89)	
		Cardiovascular mortality	2.42 (1.45, 3.43)	

[4]Ozone effect estimates are taken from Tables 6-42 and 6-53 in the ISA (U.S. EPA, 2013a).

Medina-Ramon and Schwartz (2008)	48 U.S. cities	Non-accidental mortality	1.96 (1.14, 2.82)	4
Franklin and Schwartz (2008)	18 U.S. communities	Non-accidental mortality	1.79 (0.90, 2.68)	1
Katsouyanni et al. (2009)	90 U.S. cities	Non-accidental mortality	3.83 (1.90, 5.79)	6
		Respiratory mortality	4.40 (-2.10, 11.3); 4.07 (-4.23, 13.0) for 75+	
		Cardiovascular mortality	6.78 (2.70, 11.0) for <75; 3.18 (-0.47, 6.95) for 75+	
Bell et al. (2004)	95 U.S. communities	Non-accidental mortality	0.78 (0.26, 1.30)	6
Katsouyanni et al. (2009)	12 Canadian Cities	Non-accidental mortality	0.42 (0.16, 0.67)	8

Table 3B-3. Number of Study Cities from Single-City Epidemiologic Studies Using Short-Term O_3 Metrics with 3-Year Averages of Annual 4th Highest Daily Maximum 8-hour O_3 Concentrations ≤ 75 ppb

Study	Location	Age	Endpoint	% Increase (95% CI)[5]	# Study Cities ≤ 75 ppb over entire study period
All-year					
Strickland et al. (2010)	Atlanta	Children	Asthma ED visits	6.38 (3.19, 9.57)	0
Warm season					
Ito et al. (2007)	New York City	All	Asthma ED visits	16.9 (10.9, 23.4)	0
Darrow et al. (2011)	Atlanta	All	Respiratory ED visits	2.08 (1.25, 2.91)	0
Tolbert et al. (2007)	Atlanta	All	Respiratory ED visits	3.90 (2.70, 5.20)	0
Strickland et al. (2010)	Atlanta	Children	Asthma ED visits	8.43 (4.42, 12.7)	0
Silverman and Ito (2010)	New York City	6 to 18 years	Asthma HA	28.2 (15.3, 41.5)	0
		All	Asthma HA	12.5 (8.27, 16.7)	0
Mar and Koenig (2009)	Seattle, WA	18+	Asthma ED visits	19.1 (3.00, 40.5)	1

[5]Ozone effect estimates are taken from Table 6-28 in the ISA (U.S. EPA, 2013a).

Table 3B-4 Number of Study Cities from Epidemiologic Studies Using Long-Term O_3 Metrics with 3-Year Averages of Annual 4th Highest Daily Maximum 8-hour O_3 Concentrations > 75, 70, 65, or 60 ppb

Study	Number of Cities	Study Period	Number (Percent) of Cities with Maximum conc >75	Number (Percent) of Cities with Maximum conc >70	Number (Percent) of Cities with Maximum conc >65	Number (Percent) of Cities with Maximum conc >60
Islam et al. 2008, 2009	11[6]	1994-2003	11 (100%)	11 (100%)	11 (100%)	11 (100%)
Jerrett et al. 2009	94[7]	1977-2000	91 (97%)	92 (98%)	93 (99%)	94 (100%)
Lin et al. 2008	26[8]	1991-2001	24 (92%)	24 (92%)	26 (100%)	26 (100%)
Meng et al. 2010	7	1997-2002	7 (100%)	7 (100%)	7 (100%)	7 (100%)
Moore et al. 2008	8	1980-2000	8 (100%)	8 (100%)	8 (100%)	8 (100%)
Salam et al. 2009	11[9]	1992-2005	12 (100%)	12 (100%)	12 (100%)	12 (100%)
Zanobetti & Schwartz 2011	105	1985-2006	100 (95%)	104 (99%)	104 (99%)	104 (99%)

[6] Study authors included 12 cities in their analyses, air quality data that met completeness criteria described above were available for 11 cities

[7] Study authors included 96 cities in their analyses, air quality data that met completeness criteria described above were available for 94 cities

[8] Study authors included 27 cities in their analyses, air quality data that met completeness criteria described above were available for 26 cities

[9] Study authors included 12 cities in their analyses, air quality data that met completeness criteria described above were available for 11 cities

Relationship between average 24-hour and highest 8-hour O_3 concentrations for cities analyzed by Bell et al. (2006)

Bell et al. (2006) reported associations between mortality and 24-hour average O_3 concentrations (i.e., averaged across monitors in cities with multiple monitors) in a multi-city study of 98 U.S. cities. Positive associations persisted in a series of analyses that restricted O_3 concentrations to those below various cut points (cut points ranged from 5 to 60 ppb in 5 ppb increments). To facilitate consideration of these cut point analyses for the second draft of the O_3 Policy Assessment, so as to match the form and averaging time of the existing primary standard, we evaluated the relationship between 24-hour average O_3 concentrations, averaged across monitors in cities with multiple monitors, and the highest 8-hour daily maximum O_3 concentrations among the individual monitors in each city.

EPA staff retrieved daily 24-hour average and 8-hour maximum O_3 concentrations reported to EPA by monitors in the 98 study areas defined in Bell et al. (2006) during the 1987-2012 period from EPA's Air Quality System (AQS) database. Next, EPA staff obtained the study area boundaries from the published study (Bell et al., 2006) and used them to determine which O_3 monitoring sites were associated with each study area. The 24-hour average O_3 concentrations were averaged spatially across all available monitors within each study area on each day where monitoring data were collected. Next, days where the area-wide 24-hour average concentration (i.e., averaged spatially across monitors in areas with multiple monitors) was greater than 60 ppb were removed from the data. Based on the data remaining (i.e., with 24-hour average concentrations of 60 ppb or below), the annual 4th highest 8-hour daily maximum concentrations were identified for each study area and for each year from 1987-2012 (Table 3D-3). This process was repeated by further removing days with area-wide 24-hour average concentrations greater than 55 ppb, 50 ppb, etc., down to 5 ppb, and re-calculating the same statistics after each removal. The resulting dataset consisted of the annual 4th highest 8-hour daily maximum concentrations for all study areas.

Table 3B-5 Number of Study Cities with 4th Highest 8-hour Daily Maximum Concentrations Greater Than the Level of the Current Standard and Potential Alternative Standards For Various Cut-Point Analyses Presented in Bell et al. (2006)[10]

	Cut-point for 2-day moving average across monitors and cities (24-h avg)									
	20	25	30	35	40	45	50	55	60	All
Number (%) of Cities with 4th highest >75 (any year; 1987-2000)	0 (0%)	0 (0%)	12 (12%)	52 (53%)	77 (79%)	88 (90%)	93 (95%)	94 (96%)	94 (96%)	94 (96%)
Number (%) of Cities with 4th highest >70 (any year; 1987-2000)	0 (0%)	3 (3%)	31 (32%)	77 (79%)	86 (88%)	93 (95%)	94 (96%)	94 (96%)	95 (97%)	95 (97%)
Number (%) of Cities with 4th highest >65 (any year; 1987-2000)	0 (0%)	10 (10%)	58 (59%)	84 (86%)	93 (95%)	94 (96%)	94 (96%)	94 (96%)	94 (96%)	94 (96%)
Number (%) of Cities with 4th highest >60 (any year; 1987-2000)	1 (1%)	36 (37%)	74 (76%)	93 (95%)	96 (8%)	97 (99%)	97 (99%)	97 (99%)	97 (99%)	97 (99%)

[10] Study authors included 98 cities in their analyses, air quality data only available for 95

Relationship between average and highest 8-hour daily maximum O_3 concentrations for New York City, as analyzed by Silverman and Ito (2010)

EPA staff retrieved daily maximum 8-hour O_3 concentrations for the 13 monitors in the New York City area used in the Silverman and Ito (2010) study for April-August of 1999-2006 from the AQS database. Next, EPA staff spatially averaged these concentrations across monitors for each day during this period, and then paired them with the highest 8-hour daily maximum value reported across the 13 monitors on each day.

Next, the range of observed average daily maximum 8-hour concentrations was broken into 5 ppb increments. The number of days where the area-wide average daily maximum 8-hour concentration fell within the increment and the number of days where one or more monitored 8-hour daily maximum values were greater than 75, 70, 65 and 60 ppb were recorded for each 5 ppb increment. These numbers are summarized in Table 3D-4.

Table 3B-6 Summary statistics for Observed O_3 Concentrations in the New York City Area, April – August 1999 – 2006

	2-day moving average across monitors (ppb)								
	11 to 20 (62 days)	21 to 25 (92 days)	26 to 30 (178 days)	31 to 35 (206 days)	36 to 40 (236 days)	41 to 45 (196 days)	46 to 50 (153 days)	51 to 55 (111 days)	56 to 60 (71 days)
Days > 75 ppb	0	0	1	0	1	2	9	15	20
Days > 70 ppb	0	0	1	4	1	12	17	23	30
Days > 65 ppb	0	0	1	6	5	18	37	42	45
Days > 60 ppb	0	0	2	7	12	39	67	61	53

Relationship between average and highest 8-hour daily maximum O_3 concentrations for Atlanta, as analyzed by Strickland et al. (2010)

For our assessment of the Strickland et al. (2010) study, based in the Atlanta metropolitan area, we retrieved 8-hour daily maximum concentration data for 4 of the 5 monitors used in the study during the study period (May-October, 1993-2004) from the AQS database. The 5th monitor was a part of the Southeastern Aerosol Research and Characterization (SEARCH) network, which does not report data to EPA. EPA staff calculated the area-wide average of the 8-hour daily maximum concentrations for each day, and compared to population-weighted average concentrations obtained from the author. The correlation between the arithmetic average values and the population-weighted average values was very high (R = 0.985), thus EPA staff deemed the arithmetic average to be a suitable surrogate for the population-weighted average used in the study. Finally, 3-day moving averages were calculated from the daily area-wide average values (matching the air quality metric used in the study), and paired with the highest monitored 8-hour daily maximum value occurring during each 3-day period.

Next, the range of observed average daily maximum 8-hour concentrations was broken into 5 ppb increments. The number of days where the area-wide average daily maximum 8-hour concentration fell within the increment and the number of days where one or more monitored 8-hour daily maximum values were greater than 75, 70, 65 and 60 ppb were recorded for each 5 ppb increment. These numbers are summarized in Table 3D-5.

Table 3B-7 Summary statistics for Observed O_3 Concentrations in the Atlanta Area, April – August 1999 – 2006

	3-day moving average across monitors (ppb)										
	26-30 (75 days)	31-35 (144 days)	36-40 (165 days)	41-45 (210 days)	46-50 (235 days)	51-55 (244 days)	56-60 (272 days)	61-65 (234 days)	66-70 (169 days)	71 to 75 (124 days)	76 to 80 (106 days)
Days > 75	0	0	2	2	10	24	53	80	89	87	87
Days > 70	0	0	6	6	20	49	81	111	107	96	95
Days > 65	1	0	8	19	38	75	118	147	133	106	100
Days > 60	1	2	15	33	68	115	152	173	147	116	102

Relationship between annual and highest 1-hour daily maximum O_3 concentrations for 12 study areas, as analyzed by Jerrett et al. (2009)

The Jerrett et al. (2009) study used a long-term metric based on seasonal averages of 1-hour daily maximum O_3 concentrations to evaluate associations between respiratory mortality and long-term or repeated exposures to O_3. Authors divided study cities into quartiles based on these seasonal averages of 1-hour daily O_3 concentrations. Using AQS, we identified the 3-year averages of annual 4th highest daily maximum 8-hour O_3 concentrations in study cities during the study period. Table 3D-6 presents the means and maximums of these concentrations over the study period.

In addition, for the 12 urban case study areas included in the epidemiology-based risk assessment of the 2nd draft of the Health REA we identified the seasonal averages of 1-hour daily maximum concentrations (i.e., the O_3 metric evaluated by Jerrett et al., 2009) for air quality adjusted to the current and alternative standards. Specifically, for adjusted air quality "quarterly" averages of 1-hour concentrations for April-June and July-August were calculated for each area and year. The quarterly values were considered to be valid if valid daily maximum 1-hour values were available for at least 75% of the days in the quarter. The two quarterly values were then averaged, as was done by Jerrett et al. (2009) to generate the long-term metric used in the study. This process was repeated for the various model-based adjustment scenarios in each of the 12 study areas. Summary statistics based on this seasonal average of daily O_3 concentrations are presented in Table 3D-7 for recent air quality and for air quality adjusted to just meet the current and alternative standards.

Table 3B-8 Three-Year Averages of Annual 4th Highest Daily Maximum 8-hour O_3 Concentrations in 94[11] Study Areas Examined in Jerrett et al. (2009)

	City	Mean over study period	Max over study period
Cities in the lowest quartile of average exposure[12]	Charleston, WV	81	99
	Chicago, IL	103	114
	Colorado Springs, CO	62	66
	Corpus Christi, TX	82	89
	Detroit, MI	95	103
	Flint, MI	83	91
	Ft. Lauderdale, FL	74	79
	Kansas City, MO	87	97
	Lansing, MI	81	90
	Madison, WI	82	102
	Minneapolis, MN	74	80
	New Orleans, LA	86	99
	Orlando, FL	79	82
	Portland, OR	81	91
	Providence, RI	110	124
	Salinas, CA	68	74
	San Antonio, TX	85	92
	San Francisco, CA	88	96
	San Jose, CA	91	103
	Seattle, WA	78	88
	Tacoma, WA	78	88
	Vallejo, CA	74	82
	Wichita, KS	75	81
Cities in the highest three quartiles of average exposure[13]	Charleston, SC	79	90
	Charlotte, NC	97	112
	Chattanooga, TN	90	97
	Cincinnati, OH	101	119
	Cleveland, OH	98	108
	Columbia, SC	85	109
	Columbus, OH	93	103
	Dallas/Ft Worth, TX	106	118
	Dayton, OH	95	122
	Denver, CO	83	91

[11] Jerrett et al. (2009) examined 96 MSAs; this analysis included the 94 cities that met data completeness criteria described above, after linking monitors to MSAs (see lines 10-28, above).

[12] Based on visual inspection of Figure 1 in Jerrett et al. (2009)

[13] Based on visual inspection of Figure 1 in Jerrett et al. (2009)

	El Paso, TX	85	96
	Evansville, IN	93	100
	Fresno, CA	112	123
	Gary, IN	91	105
	Greely, CO	69	75
	Greensboro, NC	89	100
	Greenville, SC	86	94
	Harrisburg, PA	94	103
	Houston, TX	121	140
	Huntington, WV	94	103
	Indianapolis, IN	93	103
	Jackson, MS	79	98
	Jacksonville, FL	81	87
	Jersey City, NJ	106	118
	Johnstown, PA	90	107
	Kenosha, WI	101	114
	Knoxville, TN	91	97
	Lancaster, PA	94	101
	Las Vegas, NV	80	85
	Lexington, KY	88	99
	Little Rock, AR	86	107
	Los Angeles, CA	193	248
	Memphis, TN	94	103
	Milwaukee, WI	103	117
	Nashville, TN	94	106
	Nassau, NY	NA[14]	NA
	New Haven, CT	116	136
	New York City, NY	118	129
	Newark, NJ	90	105
	Norfolk, VA	91	101
	Oklahoma City, OK	86	93
	Philadelphia, PA	117	136
	Phoenix, AZ	86	96
	Pittsburgh, PA	101	123
	Portland, ME	106	117
	Portsmouth, NH	92	104
	Racine, WI	102	124
	Raleigh, NC	90	104
	Reading, PA	99	114
	Richmond, VA	94	104
	Riverside, CA	196	245
	Roanoke, VA	83	95

[14] Air quality data did not meet completeness criteria described above

	Rochester, NY	89	99
	Sacramento, CA	110	118
	San Diego, CA	121	141
	Shreveport, LA	83	88
	South Bend, IN	90	102
	Springfield, MA	102	115
	St Louis, MO	105	122
	Steubenville, OH	82	99
	Syracuse, NY	85	96
	Tampa, FL	85	91
	Toledo, OH	93	108
	Trenton, NJ	112	124
	Tucson, AZ	76	82
	Ventura, CA	118	132
	Washington, DC	105	116
	Wilmington, DE	103	116
	Worcester, MA	92	102
	York, PA	95	107
	Youngstown, OH	93	103

Table 3B-9 Long-Term O_3 Concentrations in 12 Urban Case Study Areas (Using the O_3 Metric Evaluated by Jerrett et al., 2009) for Recent Air Quality and Air Quality Adjusted to Meet Standard Levels of 75, 70, 65, and 60 ppb

	Air Quality Adjusted to:	2006 (Adj Yrs 2006-2008)	2007 (Adj Yrs 2006-2008)	2008 (Adj Yrs 2008-2010)	2009 (Adj Yrs 2008-2010)	2010 (Adj Yrs 2008-2010)
Atlanta	Recent	65	63	57	50	56
	75	53	52	53	47	52
	70	50	49	49	44	49
	65	47	46	46	42	46
	60	45	44	44	40	44
Baltimore	Recent	60	59	57	52	60
	75	54	54	53	49	55
	70	52	51	51	48	53
	65	49	49	48	46	50
	60	46	46	46	44	48
Boston	Recent	49	50	46	45	49
	75	48	49	49	45	48
	70	46	47	48	44	48
	65	44	45	46	43	46
	60	43	43	44	41	44
Cleveland	Recent	51	52	53	49	54
	75	49	50	51	47	51
	70	47	48	48	45	48
	65	45	45	45	43	45
	60	41	41	41	40	42
Denver	Recent	63	63	63	58	60
	75	62	61	63	58	60
	70	60	59	62	58	58
	65	58	58	59	56	55
	60	53	53	53	51	50
Detroit	Recent	50	54	51	48	52
	75	50	52	N/A	N/A	N/A
	70	48	50	51	49	52
	65	47	49	49	47	50
	60	45	46	46	45	47
Houston	Recent	53	48	47	47	46
	75	48	46	47	48	46
	70	47	45	46	47	46
	65	46	44	45	46	45
	60	45	43	43	44	44
Los Angeles	Recent	65	61	64	62	57
	75	58	59	60	60	58
	70	55	56	57	58	56
	65	52	53	54	54	53
	60	N/A	N/A	N/A	N/A	N/A
New York City	Recent	53	54	55	48	55
	75	47	47	51	47	51
	70	N/A	N/A	N/A	N/A	N/A
	65	N/A	N/A	N/A	N/A	N/A
	60	N/A	N/A	N/A	N/A	N/A
Philadelphia	Recent	56	59	57	51	58
	75	51	52	54	49	54
	70	49	50	51	47	52
	65	47	48	49	45	49
	60	45	46	47	43	47
Sacramento	Recent	66	59	65	61	55
	75	55	50	54	51	48
	70	52	48	51	49	46
	65	50	46	49	47	44
	60	47	44	46	44	42
Saint Louis	Recent	58	58	52	51	55
	75	53	53	51	50	54
	70	50	51	50	48	52
	65	47	48	48	46	49
	60	44	45	45	43	46

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Appendix 5A

Ozone-Sensitive Plant Species[A] Used by Some Tribes* *(Based on Feedback from 3 Tribes)		
Common Name (other common names)	**Scientific Name**	**Confirmed bioindicator species**
Red alder (Oregon alder, Western alder)	*Alnus rubra*	Y
Speckled alder (Tag alder, Gray alder, Hoary alder)	*Alnus rugosa (Alnus incana)*	Y
Groundnut (Wild bean, American potato bean)	*Apios americana*	Y
Spreading Dogbane (Common dogbane)	*Apocynum androsamifolium*	Y
Common milkweed	*Asclepias syriaca*	Y
New England Aster	*Aster novae-angliae* *Symphyotrichum novae-angliae*	
Green ash	*Fraxinus pennsylvanica*	
Twinberry	*Lonicera involucrate*	Y
Bee-balm	*Monarda didyma*	
Virginia creeper	*Parthenocissus quinquefolia*	Y
Jack pine	*Pinus banksiana*	Y
Lodgepole pine	*Pinus contorta*	
White pine	*Pinus strobus*	
Black poplar (Balsam poplar)	*Populus balsamifera trichocarpa*	
Quaking aspen (Trembling aspen)	*Populus tremuloides*	Y
Black cherry	*Prunus serotina*	Y
Choke cherry	*Prunus virginiana*	
Douglas fir	*Pseudotsuga menziesii*	
Allegheny blackberry (Common blackberry)	*Rubus allegheniensis*	Y
Thimbleberry	*Rubus parviflorus*	Y
Cutleaf coneflower (Coneflower, Golden glow)	*Rudbeckia laciniata*	Y
Pussy willow	*Salix discolor*	
Shinning willow	*Salix lucida*	
American elder (White elder)	*Sambucus canadensis*	Y
Red elderberry	*Sambucus racemosa*	Y
Sassafras	*Sassafras albidum*	
Goldenrod	*Solidago altissima*	
Huckleberry	*Vaccinium membranaceum*	Y
Wild grape	*Vitis spp.*	
European wine grape	*Vitis vinifera*	Y

[A]Species included in this list are identified in one or more of the following sources:
1)SP 2007 (www.2.nature.nps.gov/air/Pubs/pdf/flag/NPSozonesensppFLAG06.pdf)
2) NPS O_3 Bioindicators 2006 (www.nature.nps.gov/air/Pubs/bioindicators/index.cfm)
3) Kline et al., 2008; 4) Davis, 2007/ 2009; 5) Flagler, et al., eds., 1998
6) USDA FS FHM/FIA: Ozone Bioindicator Sampling and Estimation (www.nrs.fs.fed.us/fia/topics/ozone/pubs/pdfs/ozone%20estimation%20document.pdf) and Ozone Injury in West Coast Forests: 6 Years of Monitoring (2007).

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APPENDIX 5B: CLASS I AREAS BELOW CURRENT STANDARD AND ABOVE 15 PPM-HRS

This appendix identifies Class I areas that might have W126 index values above 15 ppm-hrs allowed by the current standard based on an analysis of recent O_3 monitoring data. Table 5B-1 provides all monitoring sites from 1998-2002 that were at or below 75 ppb (3-year average of 4th highest maximum 8-hour average), at or above 15 ppm-hrs (3-year average), and located in counties with Class I areas. For each year that met these 3-year requirements, we also provide the maximum annual 8-hour O_3 concentration (in ppb) and W126 index value (in ppm-hrs).

Table 5B-1 Examples of Counties Containing Class I Areas where Recent 3-Year O_3 Concentrations were Below 75 ppb and 3-Year Average W126 Index Values were Above 15 ppm-hrs

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
400380011	1998-2000	1998	70	67	15.88	14.71	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	1998-2000	1999	70	72	15.88	16.57	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	1998-2000	2000	70	71	15.88	16.36	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2002-2004	2002	71	74	15.70	14.45	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2002-2004	2003	71	71	15.70	18.07	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2002-2004	2004	71	70	15.70	14.57	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2003-2005	2003	71	71	16.64	18.07	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2003-2005	2004	71	70	16.64	14.57	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2003-2005	2005	71	72	16.64	17.29	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2004-2006	2004	72	70	16.56	14.57	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2004-2006	2005	72	72	16.56	17.29	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2004-2006	2006	72	74	16.56	17.81	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2005-2007	2005	71	72	16.36	17.29	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2005-2007	2006	71	74	16.36	17.81	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2005-2007	2007	71	67	16.36	13.98	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2006-2008	2006	69	74	16.37	17.81	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2006-2008	2007	69	67	16.37	13.98	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2006-2008	2008	69	68	16.37	17.32	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2010-2012	2010	73	71	18.06	13.21	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2010-2012	2011	73	75	18.06	19.33	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400380011	2010-2012	2012	73	74	18.06	21.65	Chiricahua National Monument	AZ	Cochise	Chiricahua National Monument
400510081	2008-2010	2008	69	74	15.61	22.20	Flagstaff Middle School	AZ	Coconino	Grand Canyon National Park
400510081	2008-2010	2009	69	66	15.61	11.38	Flagstaff Middle School	AZ	Coconino	Grand Canyon National Park
400580011	2008-2010	2010	69	69	15.61	14.89	Flagstaff Middle School	AZ	Coconino	Grand Canyon National Park
400510081	2006-2008	2008	70	74	19.29	22.20	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400510081	2007-2009	2008	68	74	15.38	22.20	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400510081	2007-2009	2009	68	66	15.38	11.38	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	1998-2000	1998	73	72	18.74	18.23	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	1998-2000	1999	73	76	18.74	21.27	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	1998-2000	2000	73	71	18.74	16.74	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	1999-2001	1999	72	76	17.64	21.27	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	1999-2001	2000	72	71	17.64	16.74	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
400580011	1999-2001	2001	72	70	17.64	14.91	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2000-2002	2000	73	71	19.47	16.74	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2000-2002	2001	73	70	19.47	14.91	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2000-2002	2002	73	79	19.47	26.78	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2001-2003	2001	74	70	21.79	14.91	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2001-2003	2002	74	79	21.79	26.78	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2001-2003	2003	74	73	21.79	23.70	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2002-2004	2002	74	79	22.29	26.78	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2002-2004	2003	74	73	22.29	23.70	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2002-2004	2004	74	72	22.29	16.41	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2003-2005	2003	74	73	19.98	23.70	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2003-2005	2004	74	72	19.98	16.41	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2003-2005	2005	74	79	19.98	19.84	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2004-2006	2004	73	72	19.39	16.41	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2004-2006	2005	73	79	19.39	19.84	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2004-2006	2006	73	70	19.39	21.92	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2005-2007	2005	72	79	20.24	19.84	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2005-2007	2006	72	70	20.24	21.92	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2005-2007	2007	72	69	20.24	18.95	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2006-2008	2006	70	70	19.29	21.92	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2006-2008	2007	70	69	19.29	18.95	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2007-2009	2007	68	69	15.38	18.95	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2010-2012	2010	72	69	17.90	14.89	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2010-2012	2011	72	74	17.90	18.45	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400580011	2010-2012	2012	72	73	17.90	20.34	Grand Canyon National Park, The Abyss	AZ	Coconino	Grand Canyon National Park
400700101	2007-2009	2007	75	76	22.45	24.95	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2007-2009	2008	75	78	22.45	27.52	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2007-2009	2009	75	72	22.45	14.89	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2008-2010	2008	73	78	20.29	27.52	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2008-2010	2009	73	72	20.29	14.89	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2008-2010	2010	73	70	20.29	18.45	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2009-2011	2009	72	72	17.90	14.89	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2009-2011	2010	72	70	17.90	18.45	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2009-2011	2011	72	76	17.90	20.35	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2010-2012	2010	74	70	21.41	18.45	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
400700101	2010-2012	2011	74	76	21.41	20.35	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
400700101	2010-2012	2012	74	78	21.41	25.44	Tonto NM	AZ	Gila	Sierra Ancha Wilderness Area
401320051	2007-2009	2009	75	70	22.48	14.51	Rio Verde	AZ	Maricopa	Superstition Wilderness Area
401340081	2007-2009	2008	75	78	22.48	27.49	Rio Verde	AZ	Maricopa	Superstition Wilderness Area
401397061	2007-2009	2007	75	79	22.48	28.65	Rio Verde	AZ	Maricopa	Superstition Wilderness Area
401701191	2010-2012	2010	70	68	15.79	12.96	Petrified Forest National Park, South Entrance	AZ	Navajo	Petrified Forest National Park
401701191	2010-2012	2011	70	69	15.79	15.16	Petrified Forest National Park, South Entrance	AZ	Navajo	Petrified Forest National Park
401701191	2010-2012	2012	70	73	15.79	19.26	Petrified Forest National Park, South Entrance	AZ	Navajo	Petrified Forest National Park
401900211	1998-2000	1998	73	77	15.55	18.60	22nd & Craycroft	AZ	Pima	Saguaro National Park
401910181	1998-2000	1999	73	73	15.55	16.53	22nd & Craycroft	AZ	Pima	Saguaro National Park
401910281	1998-2000	2000	73	77	15.55	15.52	22nd & Craycroft	AZ	Pima	Saguaro National Park
401900211	2001-2003	2002	73	77	15.53	16.01	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2001-2003	2003	73	78	15.53	23.14	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2006-2008	2007	74	73	18.98	17.24	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2006-2008	2008	74	74	18.98	20.01	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2007-2009	2007	71	73	16.10	17.24	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2007-2009	2008	71	74	16.10	20.01	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2007-2009	2009	71	67	16.10	11.04	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2008-2010	2008	69	74	15.47	20.01	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2008-2010	2009	69	67	15.47	11.04	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2008-2010	2010	69	68	15.47	15.36	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2010-2012	2010	71	68	16.84	15.36	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2010-2012	2011	71	75	16.84	17.36	Saguaro Park	AZ	Pima	Saguaro National Park
401900211	2010-2012	2012	71	71	16.84	17.79	Saguaro Park	AZ	Pima	Saguaro National Park
401910111	2001-2003	2001	73	69	15.53	12.73	Saguaro Park	AZ	Pima	Saguaro National Park
401910181	2006-2008	2006	74	76	18.98	21.54	Saguaro Park	AZ	Pima	Saguaro National Park
402130011	2007-2009	2007	75	77	22.52	24.59	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2007-2009	2008	75	80	22.52	29.02	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2007-2009	2009	75	70	22.52	14.81	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2008-2010	2008	74	80	20.87	29.02	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2008-2010	2009	74	70	20.87	14.81	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2008-2010	2010	74	72	20.87	18.79	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2009-2011	2009	73	70	18.75	14.81	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2009-2011	2010	73	72	18.75	18.79	Queen Valley	AZ	Pinal	Superstition Wilderness Area
402180011	2009-2011	2011	73	78	18.75	22.66	Queen Valley	AZ	Pinal	Superstition Wilderness Area

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
600500021	2010-2012	2010	74	75	17.68	15.56	201 Clinton Road, Jackson	CA	Amador	Mokelumne Wilderness Area
600500021	2010-2012	2011	74	70	17.68	14.87	201 Clinton Road, Jackson	CA	Amador	Mokelumne Wilderness Area
600500021	2010-2012	2012	74	78	17.68	22.61	201 Clinton Road, Jackson	CA	Amador	Mokelumne Wilderness Area
602701011	2008-2010	2008	72	77	17.19	25.85	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2008-2010	2009	72	70	17.19	15.55	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2008-2010	2010	72	69	17.19	10.16	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2009-2011	2009	71	70	16.54	15.55	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2009-2011	2010	71	69	16.54	10.16	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2009-2011	2011	71	75	16.54	23.92	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2010-2012	2010	72	69	18.69	10.16	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2010-2012	2011	72	75	18.69	23.92	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
602701011	2010-2012	2012	72	73	18.69	22.00	Death Valley National Monument Near Nevares Springs Access	CA	Inyo	John Muir Wilderness Area
606900031	2005-2007	2005	74	71	15.18	13.11	Pinnacles National Monument, SW of East Entrance Station	CA	San Benito	Pinnacles National Monument
606900031	2005-2007	2006	74	78	15.18	17.44	Pinnacles National Monument, SW of East Entrance Station	CA	San Benito	Pinnacles National Monument
606900031	2005-2007	2007	74	75	15.18	14.99	Pinnacles National Monument, SW of East Entrance Station	CA	San Benito	Pinnacles National Monument
608900071	2008-2010	2009	75	74	15.31	13.66	Anderson - North Street	CA	Shasta	Lassen Volcanic National Park
608900091	2008-2010	2010	75	74	15.31	15.33	Anderson - North Street	CA	Shasta	Lassen Volcanic National Park
608930031	2008-2010	2008	75	83	15.31	18.72	Anderson - North Street	CA	Shasta	Lassen Volcanic National Park
610900051	2009-2011	2009	74	77	20.72	21.80	251 S Barretta, Sonora, CA 95370	CA	Tuolumne	Yosemite National Park
610900051	2009-2011	2010	74	72	20.72	20.58	251 S Barretta, Sonora, CA 95370	CA	Tuolumne	Yosemite National Park
610900051	2009-2011	2011	74	74	20.72	19.78	251 S Barretta, Sonora, CA 95370	CA	Tuolumne	Yosemite National Park
610900051	2010-2012	2010	73	72	20.84	20.58	251 S Barretta, Sonora, CA 95370	CA	Tuolumne	Yosemite National Park
610900051	2010-2012	2011	73	74	20.84	19.78	251 S Barretta, Sonora, CA 95370	CA	Tuolumne	Yosemite National Park
610900051	2010-2012	2012	73	75	20.84	22.14	251 S Barretta, Sonora, CA 95370	CA	Tuolumne	Yosemite National Park
801300111	2000-2002	2000	73	72	15.11	14.06	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2000-2002	2001	73	71	15.11	13.18	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2000-2002	2002	73	78	15.11	18.09	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2003-2005	2003	75	82	16.61	23.91	South Boulder Creek	CO	Boulder	Rocky Mountain National Park

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
801300111	2003-2005	2004	75	68	16.61	9.57	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2003-2005	2005	75	76	16.61	16.35	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2004-2006	2004	75	68	17.01	9.57	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2004-2006	2005	75	76	17.01	16.35	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2004-2006	2006	75	82	17.01	25.11	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2008-2010	2008	73	76	16.11	20.77	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2008-2010	2009	73	73	16.11	12.57	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2008-2010	2010	73	72	16.11	14.98	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2009-2011	2009	73	73	16.13	12.57	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2009-2011	2010	73	72	16.13	14.98	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2009-2011	2011	73	76	16.13	20.82	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2010-2012	2010	74	72	19.34	14.98	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2010-2012	2011	74	76	19.34	20.82	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
801300111	2010-2012	2012	74	76	19.34	22.20	South Boulder Creek	CO	Boulder	Rocky Mountain National Park
805199911	1998-2000	1998	73	71	20.18	21.13	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	1998-2000	1999	73	77	20.18	23.98	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	1998-2000	2000	73	73	20.18	15.43	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	1999-2001	1999	73	77	18.40	23.98	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	1999-2001	2000	73	73	18.40	15.43	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	1999-2001	2001	73	70	18.40	15.80	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2000-2002	2000	71	73	18.01	15.43	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2000-2002	2001	71	70	18.01	15.80	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2000-2002	2002	71	71	18.01	22.82	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2001-2003	2001	71	70	18.90	15.80	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2001-2003	2002	71	71	18.90	22.82	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2001-2003	2003	71	73	18.90	18.07	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2002-2004	2002	70	71	17.95	22.82	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2002-2004	2003	70	73	17.95	18.07	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2002-2004	2004	70	67	17.95	12.96	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2003-2005	2003	69	73	15.82	18.07	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2003-2005	2004	69	67	15.82	12.96	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2003-2005	2005	69	69	15.82	16.42	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2004-2006	2004	68	67	15.60	12.96	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2004-2006	2005	68	69	15.60	16.42	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2004-2006	2006	68	70	15.60	17.40	Gothic	CO	Gunnison	West Elk Wilderness Area

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
805199911	2005-2007	2005	68	69	16.38	16.42	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2005-2007	2006	68	70	16.38	17.40	Gothic	CO	Gunnison	West Elk Wilderness Area
805199911	2005-2007	2007	68	65	16.38	15.31	Gothic	CO	Gunnison	West Elk Wilderness Area
806710041	2005-2007	2005	72	75	18.78	17.93		CO	La Plata	Weminuche Wilderness Area
806710041	2005-2007	2006	72	74	18.78	20.82		CO	La Plata	Weminuche Wilderness Area
806710041	2005-2007	2007	72	69	18.78	17.58		CO	La Plata	Weminuche Wilderness Area
806710041	2006-2008	2006	70	74	18.10	20.82		CO	La Plata	Weminuche Wilderness Area
806710041	2006-2008	2007	70	69	18.10	17.58		CO	La Plata	Weminuche Wilderness Area
806710041	2006-2008	2008	70	69	18.10	15.91		CO	La Plata	Weminuche Wilderness Area
806710041	2008-2010	2008	71	69	15.07	15.91		CO	La Plata	Weminuche Wilderness Area
806710041	2008-2010	2009	71	71	15.07	10.94		CO	La Plata	Weminuche Wilderness Area
806710041	2008-2010	2010	71	74	15.07	18.36		CO	La Plata	Weminuche Wilderness Area
806710041	2009-2011	2009	74	71	16.80	10.94		CO	La Plata	Weminuche Wilderness Area
806710041	2009-2011	2010	74	74	16.80	18.36		CO	La Plata	Weminuche Wilderness Area
806710041	2009-2011	2011	74	77	16.80	21.09		CO	La Plata	Weminuche Wilderness Area
806710041	2010-2012	2010	73	74	19.16	18.36		CO	La Plata	Weminuche Wilderness Area
806710041	2010-2012	2011	73	77	19.16	21.09		CO	La Plata	Weminuche Wilderness Area
806710041	2010-2012	2012	73	69	19.16	18.02		CO	La Plata	Weminuche Wilderness Area
806900071	2008-2010	2010	74	77	18.31	19.12	Fort Collins - West	CO	Larimer	Rocky Mountain National Park
806900111	2008-2010	2008	74	76	18.31	21.63	Fort Collins - West	CO	Larimer	Rocky Mountain National Park
806900111	2008-2010	2009	74	73	18.31	14.17	Fort Collins - West	CO	Larimer	Rocky Mountain National Park
806900071	1999-2001	1999	74	74	15.05	11.16	Rocky Mountain National Park, Long's Peak	CO	Larimer	Rocky Mountain National Park
806900071	1999-2001	2000	74	78	15.05	25.82	Rocky Mountain National Park, Long's Peak	CO	Larimer	Rocky Mountain National Park
806900071	1999-2001	2001	74	70	15.05	8.16	Rocky Mountain National Park, Long's Peak	CO	Larimer	Rocky Mountain National Park
806900071	2004-2006	2004	74	73	15.57	16.23	Rocky Mountain National Park, Long's Peak	CO	Larimer	Rocky Mountain National Park
806900071	2004-2006	2006	74	76	15.57	18.53	Rocky Mountain National Park, Long's Peak	CO	Larimer	Rocky Mountain National Park
806999911	2004-2006	2005	74	78	15.57	16.20	Rocky Mountain National Park, Long's Peak	CO	Larimer	Rocky Mountain National Park
808301011	1998-2000	1998	70	68	16.37	12.90	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	1998-2000	1999	70	69	16.37	14.17	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	1998-2000	2000	70	73	16.37	22.04	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	1999-2001	1999	69	69	15.66	14.17	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	1999-2001	2000	69	73	15.66	22.04	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
808301011	1999-2001	2001	69	65	15.66	10.77	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2000-2002	2000	69	73	17.51	22.04	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2000-2002	2001	69	65	17.51	10.77	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2000-2002	2002	69	70	17.51	19.72	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2001-2003	2001	67	65	16.00	10.77	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2001-2003	2002	67	70	16.00	19.72	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2001-2003	2003	67	67	16.00	17.50	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2002-2004	2002	68	70	16.34	19.72	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2002-2004	2003	68	67	16.34	17.50	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2002-2004	2004	68	69	16.34	11.79	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2003-2005	2003	70	67	16.96	17.50	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2003-2005	2004	70	69	16.96	11.79	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2003-2005	2005	70	76	16.96	21.59	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2004-2006	2004	73	69	19.02	11.79	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2004-2006	2005	73	76	19.02	21.59	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2004-2006	2006	73	74	19.02	23.68	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2005-2007	2005	73	76	21.00	21.59	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2005-2007	2006	73	74	21.00	23.68	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2005-2007	2007	73	70	21.00	17.73	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2006-2008	2006	71	74	18.36	23.68	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2006-2008	2007	71	70	18.36	17.73	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2006-2008	2008	71	69	18.36	13.67	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
808301011	2007-2009	2007	69	70	15.58	17.73	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2007-2009	2008	69	69	15.58	13.67	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
808301011	2007-2009	2009	69	69	15.58	15.35	Mesa Verde National Park, Resource Management Area	CO	Montezuma	Mesa Verde National Park
2106105011	2006-2008	2006	74	71	15.99	12.55	Mammoth Cave National Park, Houchin Meadow	KY	Edmonson	Mammoth Cave National Park
2106105011	2006-2008	2007	74	82	15.99	22.58	Mammoth Cave National Park, Houchin Meadow	KY	Edmonson	Mammoth Cave National Park
2106105011	2006-2008	2008	74	70	15.99	12.83	Mammoth Cave National Park, Houchin Meadow	KY	Edmonson	Mammoth Cave National Park
3501510051	2004-2006	2004	69	65	15.30	8.65	5ZR on BLM Land bordering residential area outside Carlsbad	NM	Eddy	Carlsbad Caverns National Park
3501510051	2004-2006	2005	69	67	15.30	10.55	5ZR on BLM Land bordering residential area outside Carlsbad	NM	Eddy	Carlsbad Caverns National Park
3501510051	2004-2006	2006	69	76	15.30	26.71	5ZR on BLM Land bordering residential area outside Carlsbad	NM	Eddy	Carlsbad Caverns National Park
3501510051	2005-2007	2005	69	67	15.33	10.55	5ZR on BLM Land bordering residential area outside Carlsba	NM	Eddy	Carlsbad Caverns National Park
3501510051	2005-2007	2006	69	76	15.33	26.71	5ZR on BLM Land bordering residential area outside Carlsbad	NM	Eddy	Carlsbad Caverns National Park
3501510051	2005-2007	2007	69	66	15.33	8.72	5ZR on BLM Land bordering residential area outside Carlsbad	NM	Eddy	Carlsbad Caverns National Park
3501510051	2006-2008	2006	69	76	15.07	26.71	5ZR on BLM Land bordering residential area outside Carlsbad	NM	Eddy	Carlsbad Caverns National Park
3501510051	2006-2008	2007	69	66	15.07	8.72	5ZR on BLM Land bordering residential area outside Carlsba	NM	Eddy	Carlsbad Caverns National Park
3501510051	2006-2008	2008	69	67	15.07	9.78	5ZR on BLM Land bordering residential area outside Carlsbad	NM	Eddy	Carlsbad Caverns National Park
3504310011	2000-2002	2001	72	69	17.19	12.17		NM	Sandoval	Bandelier Wilderness Area
3504310011	2000-2002	2002	72	74	17.19	19.62		NM	Sandoval	Bandelier Wilderness Area
3504310011	2001-2003	2001	71	69	17.37	12.17		NM	Sandoval	Bandelier Wilderness Area
3504310011	2001-2003	2002	71	74	17.37	19.62		NM	Sandoval	Bandelier Wilderness Area
3504310031	2000-2002	2000	72	75	17.19	23.51		NM	Sandoval	Bandelier Wilderness Area
3504310031	2001-2003	2003	71	76	17.37	25.38		NM	Sandoval	Bandelier Wilderness Area
3504310011	1999-2001	2001	72	69	17.87	12.17	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310011	2002-2004	2002	74	74	20.86	19.62	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310011	2002-2004	2004	74	71	20.86	17.73	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
3504310011	2003-2005	2004	74	71	20.08	17.73	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310011	2004-2006	2004	73	71	17.75	17.73	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	1999-2001	1999	72	76	17.87	18.14	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	1999-2001	2000	72	75	17.87	23.51	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2002-2004	2003	74	76	20.86	25.38	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2003-2005	2003	74	76	20.08	25.38	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2003-2005	2005	74	75	20.08	17.03	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2004-2006	2005	73	75	17.75	17.03	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2005-2007	2005	73	75	17.50	17.03	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2005-2007	2007	73	71	17.50	17.05	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2006-2008	2007	70	71	15.87	17.05	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504310031	2006-2008	2008	70	65	15.87	12.15	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504390041	2004-2006	2006	73	72	17.75	19.26	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504390041	2005-2007	2006	73	72	17.50	19.26	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
3504390041	2006-2008	2006	70	72	15.87	19.26	2ZR Site moved from Rio Rancho City Hall to senior center	NM	Sandoval	Bandelier Wilderness Area
4603301323	2005-2007	2005	70	70	15.49	13.56	Wind Cave National Park, Visitor Center	SD	Custer	Wind Cave National Park
4603301323	2005-2007	2006	70	73	15.49	20.63	Wind Cave National Park, Visitor Center	SD	Custer	Wind Cave National Park
4603301323	2005-2007	2007	70	69	15.49	12.29	Wind Cave National Park, Visitor Center	SD	Custer	Wind Cave National Park
4903701011	1998-2000	1998	73	71	19.80	19.78	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	1998-2000	1999	73	73	19.80	20.25	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	1998-2000	2000	73	76	19.80	19.36	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2001-2003	2001	70	66	18.94	9.91	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2001-2003	2002	70	72	18.94	22.12	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2001-2003	2003	70	74	18.94	24.80	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2002-2004	2002	72	72	20.50	22.12	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2002-2004	2003	72	74	20.50	24.80	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
4903701011	2002-2004	2004	72	72	20.50	14.57	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2003-2005	2003	71	74	18.59	24.80	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2003-2005	2004	71	72	18.59	14.57	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2003-2005	2005	71	69	18.59	16.40	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2004-2006	2004	70	72	16.59	14.57	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2004-2006	2005	70	69	16.59	16.40	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2004-2006	2006	70	70	16.59	18.80	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2005-2007	2005	70	69	17.66	16.40	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2005-2007	2006	70	70	17.66	18.80	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2005-2007	2007	70	72	17.66	17.78	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2006-2008	2006	71	70	18.10	18.80	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2006-2008	2007	71	72	18.10	17.78	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2006-2008	2008	71	71	18.10	17.71	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2007-2009	2007	70	72	16.07	17.78	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2007-2009	2008	70	71	16.07	17.71	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2007-2009	2009	70	68	16.07	12.72	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2010-2012	2010	69	68	15.01	13.87	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2010-2012	2011	69	69	15.01	14.23	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4903701011	2010-2012	2012	69	72	15.01	16.93	Canyonlands National Park, Island in the Sky	UT	San Juan	Canyonlands National Park
4905301301	2006-2008	2006	71	72	21.12	24.29	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2006-2008	2007	71	71	21.12	19.37	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2006-2008	2008	71	72	21.12	19.69	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2007-2009	2007	70	71	18.01	19.37	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2007-2009	2008	70	72	18.01	19.69	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2007-2009	2009	70	68	18.01	14.96	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2008-2010	2008	70	72	18.46	19.69	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2008-2010	2009	70	68	18.46	14.96	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2008-2010	2010	70	72	18.46	20.73	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2009-2011	2009	70	68	17.85	14.96	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2009-2011	2010	70	72	17.85	20.73	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2009-2011	2011	70	72	17.85	17.86	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2010-2012	2010	73	72	20.34	20.73	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2010-2012	2011	73	72	20.34	17.86	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
4905301301	2010-2012	2012	73	75	20.34	22.42	Zion National Park, Dalton's Wash	UT	Washington	Zion National Park
5603599911	1998-2000	1998	72	71	17.25	16.02	Pinedale	WY	Sublette	Bridger Wilderness Area

Monitor ID #	Years (3-year average)	Year (annual)	Max 8-hour (ppb) (3-year average)	Max 8-hour (ppb) (annual)	W126 (3-year average)	W126 (annual)	Monitor Site Name	State	County	Name of Class I Area Located in County
5603599911	1998-2000	1999	72	72	17.25	16.88	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	1998-2000	2000	72	73	17.25	18.86	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	1999-2001	1999	71	72	16.68	16.88	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	1999-2001	2000	71	73	16.68	18.86	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	1999-2001	2001	71	69	16.68	14.31	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2000-2002	2000	71	73	17.46	18.86	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2000-2002	2001	71	69	17.46	14.31	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2000-2002	2002	71	72	17.46	19.21	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2001-2003	2001	70	69	16.63	14.31	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2001-2003	2002	70	72	16.63	19.21	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2001-2003	2003	70	70	16.63	16.36	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2002-2004	2002	69	72	15.16	19.21	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2002-2004	2003	69	70	15.16	16.36	Pinedale	WY	Sublette	Bridger Wilderness Area
5603599911	2002-2004	2004	69	65	15.16	9.93	Pinedale	WY	Sublette	Bridger Wilderness Area

APPENDIX 5C: EXPANDED EVALUATION OF RELATIVE BIOMASS AND YIELD LOSS

This appendix expands to range W126 index values evaluated for relative biomass and yield loss. Specifically, Tables 5C-1 and 5C-2 below provide estimates of the relative loss for trees and crops respectively at various W126 index values using the composite E-R functions for each species for each integer W126 index value between 7 ppm-hrs and 30 ppm-hrs. The median of the composite functions is calculated for all 11 tree species excluding cottonwood. These tables also provide estimates of the number of species for trees and crops respectively that would be below various benchmarks (e.g., 2% biomass loss for trees) at various W126 index values. Table 5C-3 provides an expansion of Table 6-1 to reflect each integer W126 index value between 7 ppm-hrs and 23 ppm-hrs.

Table 5C-1 Relative Biomass Loss for Eleven Individual Tree Seedlings and Median at Various W126 Index Values

W126	Douglas Fir	Loblolly	Virginia Pine	Red maple	Sugar maple	Red Alder	Ponderosa Pine	Aspen	Tulip Poplar	Eastern White Pine	Black Cherry	Median (11 species)	Number of Species ≤ 2%	Number of Species ≤ 5%	Number of Species ≤ 10%	Number of Species ≤ 15%
30	0.1%	0.8%	1.7%	3.8%	28.1%	10.4%	12.8%	18.6%	27.7%	25.2%	53.8%	12.8%	3	4	4	6
29	0.0%	0.7%	1.7%	3.6%	23.7%	10.0%	12.3%	17.9%	26.1%	24.0%	52.6%	12.3%	3	4	5	6
28	0.0%	0.7%	1.6%	3.5%	19.9%	9.6%	11.8%	17.2%	24.5%	22.8%	51.4%	11.8%	3	4	5	6
27	0.0%	0.7%	1.6%	3.3%	16.4%	9.2%	11.4%	16.5%	23.0%	21.6%	50.1%	11.4%	3	4	5	6
26	0.0%	0.7%	1.5%	3.1%	13.4%	8.8%	10.9%	15.8%	21.4%	20.5%	48.8%	10.9%	3	4	5	7
25	0.0%	0.6%	1.4%	3.0%	10.9%	8.4%	10.4%	15.2%	19.9%	19.3%	47.5%	10.4%	3	4	5	7
24	0.0%	0.6%	1.4%	2.8%	8.7%	8.0%	10.0%	14.5%	18.4%	18.2%	46.2%	8.7%	3	4	7	8
23	0.0%	0.6%	1.3%	2.7%	6.9%	7.6%	9.5%	13.8%	17.0%	17.1%	44.8%	7.6%	3	4	7	8
22	0.0%	0.6%	1.3%	2.5%	5.3%	7.2%	9.0%	13.1%	15.6%	15.9%	43.3%	7.2%	3	4	7	8
21	0.0%	0.5%	1.2%	2.4%	4.1%	6.8%	8.6%	12.4%	14.3%	14.9%	41.9%	6.8%	3	5	7	10
20	0.0%	0.5%	1.2%	2.2%	3.1%	6.4%	8.1%	11.8%	13.0%	13.8%	40.3%	6.4%	3	5	7	10
19	0.0%	0.5%	1.1%	2.1%	2.3%	6.0%	7.6%	11.1%	11.8%	12.7%	38.8%	6.0%	3	5	7	10
18	0.0%	0.5%	1.0%	1.9%	1.7%	5.7%	7.2%	10.4%	10.6%	11.7%	37.2%	5.7%	5	5	7	10
17	0.0%	0.4%	1.0%	1.8%	1.2%	5.3%	6.7%	9.8%	9.4%	10.7%	35.6%	5.3%	5	5	9	10
16	0.0%	0.4%	0.9%	1.6%	0.9%	4.9%	6.3%	9.1%	8.4%	9.7%	33.9%	4.9%	5	6	10	10
15	0.0%	0.4%	0.9%	1.5%	0.6%	4.5%	5.8%	8.4%	7.4%	8.8%	32.2%	4.5%	5	6	10	10
14	0.0%	0.4%	0.8%	1.4%	0.4%	4.2%	5.4%	7.8%	6.4%	7.9%	30.4%	4.2%	5	6	10	10
13	0.0%	0.3%	0.8%	1.2%	0.3%	3.8%	4.9%	7.1%	5.5%	7.0%	28.6%	3.8%	5	7	10	10
12	0.0%	0.3%	0.7%	1.1%	0.2%	3.5%	4.5%	6.5%	4.7%	6.2%	26.7%	3.5%	5	8	10	10
11	0.0%	0.3%	0.6%	1.0%	0.1%	3.1%	4.1%	5.9%	3.9%	5.4%	24.8%	3.1%	5	8	10	10
10	0.0%	0.3%	0.6%	0.9%	0.1%	2.8%	3.6%	5.2%	3.2%	4.6%	22.9%	2.8%	5	9	10	10
9	0.0%	0.2%	0.5%	0.7%	0.0%	2.4%	3.2%	4.6%	2.6%	3.9%	20.9%	2.4%	5	10	10	10
8	0.0%	0.2%	0.5%	0.6%	0.0%	2.1%	2.8%	4.0%	2.0%	3.2%	18.8%	2.0%	5	10	10	10
7	0.0%	0.2%	0.4%	0.5%	0.0%	1.8%	2.4%	3.4%	1.5%	2.6%	16.7%	1.5%	7	10	10	10

Table 5C-2 Relative Yield Loss for Ten Individual Crop Species and Median at Various W126 Index Values

W126	Barley	Lettuce	Field Corn	Grain Sorghum	Peanut	Cotton	Soybean	Winter Wheat	Potato	Kidney Bean	Median (10 species)	Number of Species ≤ 5%	Number of Species ≤ 10%	Number of Species ≤ 20%	Number of Species > 5% and ≤ 10%	Number of Species > 10% and ≤ 20%
30	0.1%	5.1%	2.9%	2.3%	10.4%	16.3%	15.7%	22.5%	20.2%	36.1%	13.0%	3	4	7	1	3
29	0.0%	4.4%	2.7%	2.1%	9.7%	15.6%	15.0%	21.0%	19.4%	34.0%	12.4%	4	5	8	1	3
28	0.0%	3.7%	2.4%	2.0%	9.1%	14.9%	14.4%	19.5%	18.7%	31.9%	11.8%	4	5	9	1	4
27	0.0%	3.1%	2.2%	1.9%	8.6%	14.1%	13.7%	18.0%	18.0%	29.8%	11.2%	4	5	9	1	4
26	0.0%	2.6%	1.9%	1.7%	8.0%	13.4%	13.1%	16.6%	17.2%	27.8%	10.6%	4	5	9	1	4
25	0.0%	2.1%	1.7%	1.6%	7.4%	12.7%	12.5%	15.3%	16.5%	25.8%	10.0%	4	5	9	1	4
24	0.0%	1.7%	1.5%	1.5%	6.9%	12.0%	11.8%	14.0%	15.7%	23.9%	9.4%	4	5	9	1	4
23	0.0%	1.4%	1.3%	1.4%	6.4%	11.3%	11.2%	12.7%	15.0%	22.0%	8.8%	4	5	9	1	4
22	0.0%	1.1%	1.2%	1.3%	5.9%	10.6%	10.6%	11.5%	14.2%	20.1%	8.2%	4	5	9	1	4
21	0.0%	0.9%	1.0%	1.1%	5.4%	10.0%	10.0%	10.4%	13.5%	18.4%	7.7%	4	7	10	3	3
20	0.0%	0.7%	0.9%	1.0%	5.0%	9.3%	9.4%	9.3%	12.7%	16.6%	7.1%	5	8	10	3	2
19	0.0%	0.6%	0.8%	0.9%	4.5%	8.7%	8.8%	8.3%	12.0%	15.0%	6.4%	5	8	10	3	2
18	0.0%	0.4%	0.7%	0.8%	4.1%	8.0%	8.2%	7.3%	11.3%	13.4%	5.7%	5	8	10	3	2
17	0.0%	0.3%	0.6%	0.8%	3.7%	7.4%	7.6%	6.4%	10.5%	11.9%	5.1%	5	8	10	3	2
16	0.0%	0.2%	0.5%	0.7%	3.3%	6.8%	7.0%	5.6%	9.8%	10.5%	4.4%	5	9	10	4	1
15	0.0%	0.2%	0.4%	0.6%	2.9%	6.2%	6.4%	4.8%	9.1%	9.2%	3.9%	6	10	10	4	0
14	0.0%	0.1%	0.3%	0.5%	2.6%	5.6%	5.9%	4.1%	8.4%	7.9%	3.3%	6	10	10	4	0
13	0.0%	0.1%	0.2%	0.5%	2.2%	5.0%	5.3%	3.5%	7.7%	6.8%	2.8%	6	10	10	4	0
12	0.0%	0.1%	0.2%	0.4%	1.9%	4.5%	4.8%	2.9%	7.0%	5.7%	2.4%	8	10	10	2	0
11	0.0%	0.0%	0.2%	0.3%	1.6%	3.9%	4.3%	2.3%	6.3%	4.7%	2.0%	9	10	10	1	0
10	0.0%	0.0%	0.1%	0.3%	1.4%	3.4%	3.8%	1.9%	5.6%	3.8%	1.6%	9	10	10	1	0
9	0.0%	0.0%	0.1%	0.2%	1.1%	2.9%	3.3%	1.5%	4.9%	3.0%	1.3%	10	10	10	0	0
8	0.0%	0.0%	0.1%	0.2%	0.9%	2.5%	2.8%	1.1%	4.3%	2.4%	1.0%	10	10	10	0	0
7	0.0%	0.0%	0.0%	0.1%	0.7%	2.0%	2.3%	0.8%	3.6%	1.8%	0.8%	10	10	10	0	0

Table 5C-3 Tree Seedling Biomass Loss and Crop Yield Loss estimated for O_3 exposure over a Season.

W126 index value for exposure period	Tree seedling biomass loss[A]		Crop yield loss[C]	
	Median Value	**Individual Species**	**Median Value**	**Individual Species**
23 ppm-hrs	Median species w. 7.6% loss [B]	≤ 2% loss: 3/11 species ≤ 5% loss: 4/11 species ≤10% loss: 8/11 species ≤15% loss: 10/11 species >40% loss: 1/11 species	Median species w. 8.8 % loss [D]	≤ 5% loss: 4/10 species >5,<10% loss: 1/10 species >10,<20% loss: 4/10 species >20: 1/10 species
22 ppm-hrs	Median species w. 7.2% loss [B]	≤ 2% loss: 3/11 species ≤ 5% loss: 4/11 species ≤10% loss: 7/11 species ≤15% loss: 10/11 species >40% loss: 1/11 species	Median species w. 8.2 % loss [D]	≤ 5% loss: 4/10 species >5,<10% loss: 1/10 species >10,<20% loss: 4/10 species >20: 1/10 species
21 ppm-hrs	Median species w. 6.8% loss [B]	≤ 2% loss: 3/11 species ≤ 5% loss: 4/11 species ≤10% loss: 7/11 species ≤15% loss: 10/11 species >40% loss: 1/11 species	Median species w. 7.7 % loss [D]	≤ 5% loss: 4/10 species >5,<10% loss: 3/10 species >10,<20% loss: 3/10 species
20 ppm-hrs	Median species w. 6.4% loss [B]	≤ 2% loss: 3/11 species ≤ 5% loss: 5/11 species ≤10% loss: 7/11 species ≤15% loss: 10/11 species >40% loss: 1/11 species	Median species w. 7.1 % loss [D]	≤ 5% loss: 5/10 species >5,<10% loss: 3/10 species >10,<20% loss: 2/10 species
19 ppm-hrs	Median species w. 6.0% loss [B]	≤ 2% loss: 3/11 species ≤5% loss: 5/11 species ≤10% loss: 7/11 species ≤15% loss: 10/11 species >30% loss: 1/11 species	Median species w. 6.4 % loss [D]	≤ 5% loss: 5/10 species >5, <10% loss: 3/10 species >10,<20% loss: 2/10 species
18 ppm-hrs	Median species w. 5.7% loss [B]	≤ 2% loss: 5/11 species ≤ 5% loss: 5/11 species ≤10% loss: 7/11 species ≤15% loss: 10/11 species >30% loss: 1/11 species	Median species w. 5.7 % loss [D]	≤ 5% loss: 5/10 species >5,<10% loss: 3/10 species >10,<20% loss: 2/10 species
17 ppm-hrs	Median species w. 5.3% loss [B]	≤ 2% loss: 5/11 species ≤5% loss: 5/11 species ≤10% loss: 9/11 species ≤15% loss: 10/11 species >30% loss: 1/11 species	Median species w. 5.1 % loss [D]	≤ 5% loss: 5/10 species >5, <10% loss: 3/10 species >10,<20% loss: 2/10 species
16 ppm-hrs	Median species w. 4.9% loss [B]	≤ 2% loss: 5/11 species ≤ 5% loss: 6/11 species ≤10% loss: 10/11 species >30% loss: 1/11 species	Median species w. 4.4 % loss [D]	≤ 5% loss: 5/10 species >5,<10% loss: 4/10 species >10,<20% loss: 1/10 species
15 ppm-hrs	Median species w. 4.5% loss [B]	≤ 2% loss: 5/11 species ≤5% loss: 6/11 species ≤10% loss: 10/11 species >30% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: 6/10 species >5, <10% loss: 4/10 species

14 ppm-hrs	Median species w. 4.2% loss [B]	≤ 2% loss: 5/11 species ≤ 5% loss: 6/11 species ≤10% loss: 10/11 species >30% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: 6/10 species >5,<10% loss: 4/10 species
13 ppm-hrs	Median species w. 3.8% loss [B]	≤ 2% loss: 5/11 species <5% loss: 7/11 species <10% loss: 10/11 species >20% loss: 1/11 species	Median species w.≤5% loss [D]	≤ 5% loss: 6/10 species >5, <10% loss: 4/10 species
12 ppm-hrs	Median species w. 3.5% loss [B]	≤ 2% loss: 5/11 species ≤ 5% loss: 8/11 species ≤10% loss: 10/11 species >20% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: 8/10 species >5,<10% loss: 2/10 species
11 ppm-hrs	Median species w. 3.1% loss [B]	≤ 2% loss: 5/11 species ≤5% loss: 8/11 species ≤10% loss: 10/11 species >20% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: 9/10 species >5, <10% loss: 1/10 species
10 ppm-hrs	Median species w. 2.8% loss [B]	≤ 2% loss: 5/11 species ≤ 5% loss: 9/11 species <10% loss: 10/11 species >20% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: 9/10 species >5,<10% loss: 1/10 species
9 ppm-hrs	Median species w. 2.4% loss [B]	≤ 2% loss: 5/11 species ≤ 5% loss: 10/11 species >20% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: all species
8 ppm-hrs	Median species w. 2.0% loss [B]	≤ 2% loss: 5/11 species ≤ 5% loss: 10/11 species >15% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: all species
7 ppm-hrs	Median species w. ≤2% loss [B]	≤ 2% loss: 7/11 species ≤5% loss: 10/11 species >15% loss: 1/11 species	Median species w. ≤5% loss [D]	≤ 5% loss: all species

A Estimates here are based on the 11 E-R functions for tree seedlings described in WREA, Appendix 6F and discussed in section 5.2.1, with the exclusion of cottonwood. See CASAC comments (Frey, 2014).
B This median value is the median of the composite E-R functions for 11 tree species in the WREA, Appendix 6F (also discussed in section 5.2.1).
C Estimates here are based on the 10 E-R functions for crops described in Appendix 6F and discussed in section 5.3.1.
D This median value is the median of the composite E-R functions for 10 crops from WREA, Appendix 6F (also discussed in section 5.3.1).

United States Environmental Protection Agency

Office of Air Quality Planning and Standards
Health and Environmental Impacts Division
Research Triangle Park, NC

Publication No. EPA-452/R-14-006
August 2014

Japan's Kansai to buy U.S. Cameron LNG from Mitsui

TOKYO, April 1 Mon Mar 31, 2014 9:23pm EDT

(Reuters) - Japan's second-biggest utility, Kansai Electric Power Co, said it had signed a 20-year contract to buy 400,000 tonnes per year of U.S. Cameron liquefied natural gas (LNG) from trader Mitsui & Co at U.S. Henry Hub-linked prices.

The Osaka-based firm said it would buy for 20 years from the project's planned launch, scheduled for late 2017.

LNG imports by Japan, the world's top buyer of the super-cooled fuel, have jumped since the Fukushima nuclear disaster, with utilities looking to boost supplies from North America to diversify supply sources and lower prices.

The deal marks Kansai's second purchase of U.S. shale gas. It has agreed to buy 800,000 tonnes per year from the U.S. Cove Point export plant in Maryland.

The U.S. Energy Department in February approved exports from Sempra Energy's Cameron LNG project as the Obama administration moves forward with its goal of expanding the global market for the fuel. (Reporting by Osamu Tsukimori; Editing by Joseph Radford)

- **UPDATE 4-Pipe explodes at Williams LNG facility in Washington state** | *31 Mar*

30-Year Fixed Jumbo	4.75%	4.35%

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phone: 713.375.5000
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March 20, 2014

Ms. Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street, N.E.
Washington, D.C. 20426

Re: Sabine Pass LNG, L.P. and Sabine Pass Liquefaction, LLC
Monthly Construction Progress Report for Sabine Pass Liquefaction Project
Docket Nos. CP11-72-000 & CP13-2-000

Dear Ms. Bose:

On April 16, 2012, the Federal Energy Regulatory Commission ("FERC") issued an Order Granting Authorization under Section 3(a) of the Natural Gas Act ("April 16 Order") in the above-captioned docket. The Order authorizes Sabine Pass LNG, L.P. and Sabine Pass Liquefaction, LLC ("Sabine Pass") to site, construct, and operate the Sabine Pass Liquefaction Project at the Sabine Pass LNG Terminal, located in Cameron Parish, Louisiana. On August 2, 2013, the FERC issued an Order Amending Section 3 Authorization ("August 2 Order") for the Sabine Pass Modification Project.

Pursuant to Condition 7 in Appendix D of the April 16 Order, and Condition 7 of the August 2 Order, Sabine Pass is herein submitting its monthly construction progress report for February 2014.

Should you have any questions about this filing, please feel free to contact the undersigned at (713) 375-5000.

Thank you,

/s/ *Karri Mahmoud*

Karri Mahmoud
Sabine Pass LNG, L.P.
Sabine Pass Liquefaction, LLC

cc: Ms. Sentho White, Federal Energy Regulatory Commission
Ms. Karla Bathrick, Federal Energy Regulatory Commission
Ms. Magdalene Suter, Federal Energy Regulatory Commission
Mr. Stephen Kusy, Federal Energy Regulatory Commission

SABINE PASS LIQUEFACTION PROJECT

Cameron Parish, Louisiana

Monthly Progress Report

February 2014

Table of Contents

1.0 Executive Summary

This report covers activities of the SPL Stage 1 and SPL Stage 2 projects occurring during the month of February 2014. Stage 1 Engineering is 94.4% complete, Procurement is 91.4%, and Subcontract and direct hire Construction work are 37.1% and 18.6% complete, respectively, for the period. Stage 1 overall project completion is 60.8% against the plan of 63.6%.

Stage 2 Engineering is now 48.1% complete, Procurement is 38.1%, and Subcontract and direct hire Construction work are 12.0% and 0.4% complete, respectively. Overall project completion for Stage 2 is 23.3% against the plan of 22.3%.

Actual project progress and current recovery plans continues to support the achievement of the scheduled Substantial Completion Dates for Trains 1 and 2, which remain as February 2016 and June 2016, respectively. Trains 3 and 4 Substantial Completion Dates are April 2017 and August 2017.

2.0 Project Highlights

In February, Stage 1 engineering is complete and is in punch list mode. For Stage 2, engineering completed the IFC of all Train 3 ISOs.

The Train 1 heavy wall vessels and the propane substation building have arrived at Site. The 1st set of refrigeration compressors are in transit and will arrive in March, as will the BOG compressors and the first shipments of air coolers for the Train 1 cryo rack. First structural steel for Train 3 was delivered to site in February. Procurement continues to support construction activities at the jobsite through delivery of piping and structural items.

During the month of February, Subcontracts managed the following major subcontracts for Trains 1 and 2: soil improvement, field erected tanks, onsite concrete batch plant, offsite equipment insulation, permanent telecommunications, and fire/gas detection. The electric heat tracing subcontract was awarded. For Trains 3 and 4, Subcontracts managed efforts for pile fabrication and installation, field erected tanks, and busing.

Construction in Train 1 continued in structural and paving concrete, structural steel erection, and installation of underground and aboveground piping, electrical grounding, cable tray and mechanical equipment. Train 2 work continued in structural and paving concrete, structural steel erection, electrical grounding, and installation of underground and aboveground pipe. Construction in the OSBL area continued with structural and paving concrete, structural steel erection, electrical grounding, installation of underground and aboveground pipe, and mechanical equipment installation. The Revamp area continued in structural concrete, structural steel erection, underground and aboveground piping, and electrical cable.

Construction in Train 3 continues with concrete works in area 233N01 and Train 3 underground piping. Seal slabs have been poured in area 233A01 and 233D01 and excavation was done for the hot oil sump.

3.0 Environmental, Safety & Health Progress

During the month of February, the project had 34 first aid, 18 near misses, and 1 OSHA recordable.

	Near Miss Cases		First Aid		OSHA Cases		LWDC Cases	
	Month	**ITD[1]**	**Month**	**ITD[1]**	**Month**	**ITD[1]**	**Month**	**ITD[1]**
Bechtel	18	106	34	267	1	8	0	0
Subcontractors	0	26	0	20	0	5	0	0
Total	**18**	**132**	**34**	**287**	**1**	**13**	**0**	**0**

[1] ITD = Project totals reflect inception to date and are combined for Stage 1 & 2.

4.0 Schedule

Overall, Train 1 & 2 project progress is 60.8% complete against a plan of 63.6%. Overall Train 3 & 4 project progress is 23.3% complete against a plan of 22.3% complete.

5.0 Construction

Area	Comments	Planned Work for Next Reporting Period
Liquefaction Stage 1 Area – Train 1	• Continued constructing foundations, erecting structural steel and installing above ground and underground piping. • Continued installing mechanical equipment. • Continued installing electrical cable tray in the propane condenser rack.	• Continue activities to support Train 1 construction.
Liquefaction Stage 1 Area – Train 2	• Continued constructing foundations, erecting structural steel and installing above ground and underground piping. • Installing mechanical equipment	• Continue activities to support Train 2 construction.
Liquefaction Stage 2 Area – Train 3	• Placement of the seal slab in the Train 3 propane Area. • Train 3 piles reached substantial completion. • Started placement of structural concrete. • Started excavation for the hot oil sump. • Started underground piping installation in the Train 3 area.	• Continue soil stabilization. • Continue pile driving. • Continue activities to support Train 3 construction.
Liquefaction Stage 2 Area – Trains 4	• Soil Stabilization • Continue pile driving activities within Train 4 and OSBL.	• Continue soil stabilization. • Continue pile driving.

Area	Comments	Planned Work for Next Reporting Period
OSBL	• Constructing pipe racks in the LNG Tank 3 and 5 areas. • Constructing the marine flare. • Continued constructing foundations and erecting structural steel.	• Continue activities to support OSBL construction.
Support Buildings Area	• Continued construction of the warehouse and control room. • Continued constructing pipe racks in the Tank 3 and 5 areas. • Continued constructing the marine flare.	• Continue warehouse and control room work.
Access Roads, Waterline	• Water trucks were operated for dust control, as necessary.	• Dust control will continue.
Laydown, Staging Areas	• Continued mixing for soil stabilization and began laying rock in the area north of Trains 3 and 4.	• Contractors will continue to mobilize personnel and equipment.
Construction Dock (Ro-Ro)	• Received and offload pile barges at the construction dock. • Receiving and offloading heavy equipment at the Ro-Ro. • Dredging occurred this period.	• Continue to receive pile barges.

6.0 Permitting and Environmental

None.

Summary of Problems, Non-Compliances, and Corrective Actions.

Date	Description
None.	

Agency Contacts/Inspections

Agency	Name	Date	Location/Activity

Proposed Changes to Schedule or Scope:
None.

7.0 Progress Pictures

Train 1 131G02 (inlet gas-seal slab for paving) (24-Feb-2014)

Train 1 131K01 (dehydration mercury removal) (24-Feb-2014)

Train 1 131N01 (propane rack accumulator set) (20-Feb-2014)

Train 1 131N02 (propane substation) (24-Feb-2014)

Train 1 131N01 (set accumulator) (24-Feb-2014)

Train 2 132A01 (compressor methane tabletop) (27-Feb-2014)

Train 2 132A02 (compressor substation) (27-Feb-2014)

Train 2 132B01 (amine storage area and thermal oxidizer) (24-Feb-2014)

Train 2 131M01 (heavies removal unit paving) (13-Feb-2014)

OSBL 135F01 (water treatment area) (24-Feb-2014)

Certificate of Service

I hereby certify that I have this day served the foregoing document upon each person designated on the official service list compiled by the Secretary in this proceeding.

Dated at Houston, Texas this 20th day of March 2014.

/s/ *Karri Mahmoud*
Karri Mahmoud
Sabine Pass LNG, L.P.
Sabine Pass Liquefaction, LLC

Document Content(s)

DOE approves Dominion Cove Point LNG exports to non-FTA countries

WASHINGTON, DC, Sept. 11
09/11/2013
By Nick Snow
OGJ Washington Editor

The US Department of Energy approved Dominion Cove Point LP's application to export LNG from its terminal in Calvert County, Md., to countries that do not have a free-trade agreement with the US.

Subject to environmental review and final regulatory approval, the facility on Chesapeake Bay received conditional authorization to export as much as 0.77 bcfd for of 20 years, DOE said on Sept. 11. The installation previously received clearance to export LNG to non-FTA countries on Oct. 7, 2011, it noted.

"We agree with DOE's decision that exports are expected to bring economic benefits to the country," said Thomas F. Farrell II, chief executive of parent Dominion Resources Inc. "It is good news on many fronts, including the thousands of jobs that will be created, the boost in government revenues that will result, and the support it provides to allied nations."

Dominion Cove Point's proposed liquefaction and export operations are expected to cost $3.4-3.8 billion. The company sought approval for them in March from the US Federal Energy Regulatory Commission. Pending receipt of regulatory approval and permits, construction is scheduled to begin in 2014, with a 2017 in-service date.

The installation already has robust infrastructure, including connections to the pipeline grid, LNG storage capacity, and an updated pier. Construction will chiefly entail adding liquefaction capability, Dominion said.

It said the facility's capacity is fully subscribed, with signed 20-year terminal service agreements. Pacific Summit Energy LLC, a US affiliate of Japanese trading company Sumitomo Corp., and GAIL Global (USA) LNG LLC, a US affiliate of GAIL (India) Ltd., each have contracted for half of the marketed capacity.

Under amendments to the 1920 Natural Gas Act, DOE is required to determine if an applicant's request to export LNG to a non-FTA country is in the national interest. In Dominion Cove Point's case, it said it considered the economic, energy security, and environmental impacts, as well as public comments for and against the application and nearly 200,000 public comments related to the associated analysis of the cumulative impacts of increased LNG exports.

Dominion Cove Point is the fourth US LNG terminal to gain DOE approval of exports to non-FTA nations. Sabine Pass Liquefaction LLC, Freeport LNG Expansion LLC, and Lake Charles Exports LLC's applications were approved earlier. DOE has another 19 non-FTA LNG export applications under review.

Contact Nick Snow at nicks@pennwell.com.

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FACTBOX-North America natural gas export plans

Fri, Mar 14 2014

March 14 (Reuters) - Freeport LNG's proposed liquefied natural gas export terminal in Texas inched closer to approval by the Federal Energy Regulatory Commission with the release of a draft report on Friday finding the project would not cause significant environmental harm.

Companies need approval from both the U.S. Department of Energy, which determines whether the proposed exports would be in the public interest, and FERC, which assesses safety and environmental effects of the projects' construction and operation.

Freeport is one of four companies waiting for a decision from FERC after receiving permission from the DOE for exports to countries without free trade agreements with the United States.

Cheniere Energy Inc's Sabine Pass project in Louisiana is the only terminal that has received permission from both agencies so far.

FERC typically sets a schedule for carrying out its environmental review of each project, with decisions on licenses usually issued 30 to 90 days after the assessments are completed.

Below is a table showing the proposed and potential LNG export plants in North America according to FERC and the release dates set for the commission's environmental reviews so far. Capacity is in billion cubic feet per day (*indicates project has received DOE, non-free trade agreement approval).

Approved by FERC

Project	State	Company	Start Up	Capacity
*Sabine Pass	Louisiana	Cheniere Energy	2015	2.6

Proposed to FERC

*Freeport LNG	Texas	Freeport LNG/FLNG Liquefaction	2015	1.8
*Lake Charles	Louisiana	Southern Union-Trunkline LNG	TBD	2
*Cove Point	Maryland	Dominion	2016	0.77
*Hackberry	Louisiana	Sempra-Cameron LNG	2018	1.7
Coos Bay	Oregon	Jordan Cove Energy Project	2017	0.9
Elba Island	Georgia	Southern LNG Company	TBD	0.35
Lavaca LNG	Texas	Excelerate Liquefaction	2017	1.38
Magnolia LNG	Louisiana	LNG Limited	2017	1.07
Sabine Pass, TX	Texas	ExxonMobil-Golden Pass	2018	2.1
Corpus Christi	Texas	Cheniere Energy	2017	2.1
Plaquemines Parish	Louisiana	CE FLNG	2018	1.07
Astoria	Oregon	Oregon LNG	2017	1.3
Sabine Pass, LA	Louisiana	Sabine Pass Liquefaction (expansion)	2017	1.3

Final environmental reviews scheduled by FERC

Freeport LNG	June 16, 2014
Cove Point	May 15, 2014
Hackberry (Cameron LNG)	April 30, 2014
Corpus Christi	Oct. 8, 2014

Potential U.S. Project Sites

Project	State	Company	Start-up	Capacity
Cameron Parish	Louisiana	Gasfin Development	TBD	0.2
Brownsville	Texas	Gulf Coast LNG Export	TBD	2.8
Pascagoula	Mississippi	Gulf LNG Liquefaction	TBD	1.5

Cameron Parish	Louisiana	Venture Global	TBD	0.7
Cameron Parish	Louisiana	Waller LNG Services	TBD	0.16
Ingleside	Texas	Pangea LNG	2018	1.09

Proposed Canadian Sites

Kitimat	British Columbia	Apache Canada	2015	0.7
Douglas Island	British Columbia	BC LNG Export Cooperative	2014	0.25
Kitimat	British Columbia	LNG Canada	2020	3.2

Potential Canadian Project Sites

Prince Rupert Island	British Columbia	BG Group	2021	4.2
Goldboro LNG	Nova Scotia	Pieridae Energy Canada	2020	0.7
Melford	Nova Scotia	H-Energy	2020	1.8
Prince Rupert Island	British Columbia	Pacific Northwest LNG	TBD	2.5
Prince Rupert Island	British Columbia	ExxonMobil-Imperial	TBD	3.8
Squamish	British Columbia	Woodfibre LNG Export	TBD	0.3

(Reporting by Ayesha Rascoe; Editing by Marguerita Choy)

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November 12, 2013

Mr. John Anderson
U.S. Department of Energy
Office of Fossil Energy
Docket Room 3F-056, FE-50
Forrestal Building
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Re: Delfin LNG LLC
FE Docket No. 13-147LNG
Application for Long-Term Authorization to Export LNG
To Non-Free Trade Agreement Countries

Dear Mr. Anderson:

Delfin LNG LLC (Delfin) hereby submits for filing with the U.S. Department of Energy, Office of Fossil Energy (DOE/FE), its application for long-term, multi-contract authorization to export domestically produced liquefied natural gas (LNG). Delfin requests this authority to export LNG of up to the equivalent of 1.8 billion cubic feet (Bcf) of natural gas per day or 657.5 Bcf per year (approximately 13 million metric tons per annum of LNG) from its planned, floating liquefaction project to be located in the West Cameron Block 167 in the Gulf of Mexico. The requested export authority would permit Delfin itself or acting as an agent for others to export LNG to any country which has or in the future develops the capacity to import LNG via ocean-going carrier and with which the United States does not prohibit trade but also does not have a Free Trade Agreement. Delfin requests authorization for exports over a twenty year period, commencing on the earlier of the date of first export or seven years from the date the requested authorization is granted.

Pursuant to 10 C.F.R. § 590.103(c), a signed opinion of legal counsel that the proposed export is within Delfin's corporate powers is attached hereto in Appendix B. Delfin is submitting this filing electronically, as well as sending a hard copy via messenger. A check in the amount of $50.00 is enclosed in payment of the applicable filing fee as required by 10 C.F.R. § 590.207. Please contact me if you have any questions regarding this application.

Respectfully submitted,

J. Patrick Nevins
Hogan Lovells US LLP
Partner
patrick.nevins@hoganlovells.com
D (202) 637-6441

Counsel to Delfin LNG LLC

Enclosures

UNITED STATES OF AMERICA BEFORE
THE DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY

In the Matter of	]	FE Docket No.
	]	
Delfin LNG LLC	]	13 - 147 - LNG

APPLICATION OF DELFIN LNG LLC FOR LONG-TERM AUTHORIZATION TO EXPORT LNG TO NON-FREE TRADE AGREEMENT COUNTRIES

Pursuant to Section 3 of the Natural Gas Act (NGA) 1/ and Part 590 of the regulations of the Department of Energy (DOE), 2/ Delfin LNG LLC (Delfin) hereby files this application (Application) with the DOE, Office of Fossil Energy, (DOE/FE) for long-term, multi-contract authorization to engage in exports of domestically produced liquefied natural gas (LNG) of up to the equivalent of 1.8 billion cubic feet (Bcf) of natural gas per day or 657.5 Bcf per year (approximately 13 million metric tons per annum (mtpa) of LNG). Delfin requests authorization to export the LNG over a twenty year term commencing on the date of the first LNG export or seven years from the date that the authorization is issued, whichever is sooner. Delfin proposes to export the LNG from its planned, newly constructed floating liquefaction project to be located in West Cameron Block 167 ("WC 167") of the Gulf of Mexico, offshore Cameron Parish, Louisiana, near the terminus of an existing thirty-mile pipeline. The authorization requested here would allow Delfin to export the LNG to any country that has or in the future develops the capacity to import LNG via ocean-going carrier and with which the United States does not have a Free Trade Agreement but does not prohibit trade. Delfin is requesting this authorization for itself as well as to allow it to act as agent on behalf of other entities who themselves hold title to the LNG, after registering each such entity with DOE/FE.

1/ 15 U.S.C. § 717 (b).

2/ 10 C.F.R. Part 590 (2013).

This Application represents the second part of Delfin's two-part request for DOE/FE authorization to export domestic natural gas in the form of LNG from its liquefaction project. On October 7, 2013, Delfin filed in FE Docket No. 13-129-LNG its application requesting long-term, multi-contract authorization to export domestically produced LNG to any country (1) with which the United States has, or in the future enters into, an FTA requiring national treatment for trade in natural gas or its legal equivalent and (2) which has or in the future develops the capacity to import LNG via ocean-going carrier. Through the combination of its two applications, Delfin requests authorization to export domestic natural gas as LNG to any country with which trade is not prohibited by U.S. law or policy. Delfin requests authorization for the same volumes of up to the equivalent of 1.8 Bcf of natural gas per day or 657.5 Bcf per year in each application: the volumes to be exported under the two requested authorizations are *not* additive.

In support of this Application, Delfin respectfully submits as follows:

I. DESCRIPTION OF THE APPLICANT

The exact legal name of Delfin is Delfin LNG LLC. Delfin is a limited liability company organized and existing under the laws of the State of Louisiana with its principal place of business at:

Toombs, Hall & Foster, LLP
5949 Sherry Lane, Suite 950
Dallas, Texas 75225

Delfin has been formed for purposes of owning this project. The company currently is a wholly-owned subsidiary of Fairwood Peninsula Energy LLC ("Fairwood Peninsula"), a Delaware-registered limited liability company, formed by a group of experienced oil and gas and project management executives from both the Fairwood Group, based in India and Singapore, and the U.S.-based Peninsula Group. Fairwood Peninsula is owned by FWNR Energy Holdings (USA) Corporation ("Fairwood USA") and the Peninsula Group.

Fairwood USA is a Delaware-registered corporation formed for purposes of holding assets in the United States, and is a subsidiary of Fairwood Welbeck Natural Resources Pte. Ltd. ("FWNRL"). FWNRL is a company organized and existing under the laws of the Singapore with its principal place of business at 112 Middle Road, #07-03 Midland House, Singapore 188970. FWNRL is engaged in developing natural gas activities within the U.S. and Asia, including natural gas production and LNG liquefaction within the U.S. and regasification facilities and offtake contracts in Asia. FWNRL, in turn, is part of the Fairwood Group, an India-based group of companies with investments in energy, transportation and urbanization, with offices in six countries that has completed projects with a value of over $3 billion, is currently working on other projects valued at approximately $800 million, and has a further approximately $2 billion of projects under consideration.

The Peninsula Group is a privately owned, Texas-based group of companies with interests in land development, construction projects and oil and gas. The Peninsula Group has completed projects in these areas worth over $500 million.

Principals of FWNRL and of the Peninsula Group have been working on the development of the LNG export project described herein for over three years. They are engaged in advanced negotiations with major strategic partners that are likely to participate in the project and to obtain equity in Delfin in the future. Delfin will notify the DOE/FE of future changes in its ownership structure when they occur.

II. COMMUNICATIONS AND CORRESPONDENCE

The names, titles and mailing addresses of the persons to whom correspondence and communications concerning this Application, including all service of pleadings and notices, are to be addressed are:

J. Patrick Nevins
Hogan Lovells USA LLP
555 Thirteenth Street, NW
Washington, D.C. 20004
Telephone: (202) 637-6441
Email: Patrick.Nevins@hoganlovells.com

and

Randy Foster
Toombs, Hall & Foster, LLP
5949 Sherry Lane, Suite 950
Dallas, Texas 75225
Telephone: 214-369-5695
Email: RF@THFCPA.com

These persons are designated to receive service on behalf of Delfin and should be placed on the official service list for this proceeding.

III. DESCRIPTION OF THE DELFIN PROJECT

Delfin's request for LNG export authorization here is part of its plan to develop, own and operate a floating liquefaction facility in WC 167 of the Gulf of Mexico, offshore Cameron Parish, Louisiana. The facility will be a "deepwater port" within the meaning of the Deepwater Port Act (DWPA). 3/ As such, the facility shall require a license to be issued by the Department of Transportation's Marine Administration (MARAD), working in conjunction with the U.S. Coast Guard.

Liquefaction at the new Delfin deepwater port will utilize floating liquefaction and storage vessels (FLNGV) to be moored near an existing platform located in WC 167, approximately 30 miles off-shore Cameron Parish, Louisiana. The platform is the terminus and metering point of the existing Enbridge Offshore Pipelines (UTOS) ("UTOS") natural gas pipeline system, and is connected to the shore via an existing 42-inch diameter, 30-mile long gas pipeline. The pipeline system commenced operation in 1978 and previously

3/ 33 U.S.C. § 1501 *et seq.* The DWPA authorizes the ownership, construction and operation of marine terminals in federal waters of the Outer Continental Shelf. The DWPA originally applied only to oil import terminals, but was amended in 2002 to include LNG import terminals. Section 312 of the Coast Guard and Maritime Transportation Act of 2012 (H.R. 2838) further amended the DWPA to include facilities for the export of oil and natural gas.

was utilized for the purpose of transporting off-shore natural gas production to onshore connections with Transcontinental Gas Pipe Line (Transco), Natural Gas Pipeline Company of America (NGPL), and ANR Pipeline Company (ANR), as well as to nearby gas processing plants. Given the significantly decreased flow volumes from off-shore production over the years, this gas pipeline could no longer be economically operated for that original purpose. As a result, the Federal Energy Regulatory Commission (FERC) in 2011 authorized the pipeline to abandon its services and certificates while deferring the final disposition of its facilities.4/ The system has been idled since that time and is currently filled with nitrogen.

FWNRL entered into an agreement with the owner of UTOS on August 14, 2013, that provides it, subject to the satisfaction of certain conditions including regulatory approvals, the exclusive right to acquire the pipeline system. FWNRL will contribute the UTOS system once it is acquired to Delfin. The agreement sets forth a three-stage process for the acquisition of UTOS. The first stage (which is now underway) required an initial payment and provides for preliminary feasibility assessments and certain meetings and filings with regulatory agencies. The second stage requires an additional payment by FWNRL, more advanced due diligence activities, and the negotiation of a contemplated sales and purchase agreement. The third and final stage involves the final purchase payment and the closing of the transaction, subject to requisite regulatory approvals. 5/

Delfin intends to recommission and to reverse the flow on the existing 42-inch pipeline for purposes of delivering feed gas to its project. The existing pipeline is

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4/ Enbridge Offshore Pipelines (UTOS) LLC, 136 FERC ¶ 62,269 (2011).

5/ Delfin and the pipeline owner consider the terms of their agreement to be confidential. The agreement contains commercially valuable and proprietary information the disclosure of which would cause competitive and financial harm to the parties. Accordingly, Delfin submitted the agreement under seal for purposes of review by DOE/FE along with its prior, FTA application in FE Docket No. 13-129-LNG, while requesting that that agreement be treated and maintained as confidential to the greatest extent permitted by law, in accordance with 10 C.F.R. § 1004.11 (2013). Delfin has summarized the material terms of the agreement for the public record above.

anticipated to have capacity to transport up to 1.8 Bcf per day from the Louisiana coastline to the new deepwater port facility near the existing WC 167 platform. Following the reactivation of its previous on-shore interconnections with major interstate pipelines (Transco, NGPL and ANR) and modification to reverse flow, the pipeline will provide access for Delfin's project to the domestic natural gas interstate pipeline system. A map showing the location of WC 167 and the existing pipeline is attached as Appendix C.

Delfin's planned liquefaction will be provided on FLNGVs that will be moored at purpose-built single point moorings located as near the terminus of the existing pipeline in WC 167 as operationally and safely possible (expected to be within approximately 2000 feet). The FLNGVs will have the capability to export LNG to off-taking LNG carriers utilizing a proven ship-to-ship, side transfer process. The precise location and spacing of the FLNGV's around the existing WC 167 platform will depend on further detailed design work, as well as consultation with MARAD and the Coast Guard. Delfin has begun the process of consultation with MARAD and the Coast Guard concerning the licensing of its planned deep water port.

Delfin also has retained the engineering firm of Moffatt and Nichol to prepare its marine studies, including evaluation of the location, metocean analysis, navigation assessment, development of the mooring lay-out, and dynamic mooring analysis. Moffatt and Nichol is a leading global infrastructure advisor that, for decades, has been an industry-leading consultancy addressing the offshore and near-shore marine terminal needs of the oil and gas industry.6/ While the final design remains under development, a simplified presentation of the basic site plan for the Delfin mooring system, as well as a conceptual depiction of a vessel attached to a tower mooring, is included in Appendix D.

The Delfin floating liquefaction project, as currently planned, will be constructed in four trains. Delfin has entered into a memorandum of understanding with one of the world's

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6/ Moffatt and Nichol offers a full range of engineering consulting services for the design and construction management of LNG facilities. Its engineers and scientists have participated in nearly every aspect of planning and engineering of LNG facilities -- from pre-FEED and FEED engineering to vessel traffic analysis, dredging and structural design. The firm has provided these services for more than twenty major LNG projects throughout Asia, Africa, Canada, Mexico, and the United States.

leading midstream LNG companies to provide at least the first two FLNGVs. The focus of the MOU is to develop fast track, modular, mid-scale liquefaction solutions of approximately 2.5 million mtpa per train based on existing technology and using completed Front-End Engineering and Designs.

Delfin anticipates that its third and fourth trains will be provided by new-build FLNGV(s) ordered and constructed for purposes of this project. Delfin is in engaged in advanced discussions with one of the world's largest ship builders, and a particular leader in LNG carriers, concerning these later trains. Delfin anticipates contracting with the ship-builder for the construction of a new FLNGV(s) for its third and fourth trains, which will provide liquefaction capacity of 4.0 million mtpa each, bringing the project's total capacity to approximately 13 million mtpa.

Delfin will proceed with the commissioning of its four trains scheduled and sequenced as appropriate to meet contracted customer demand. The FLNGVs will be constructed in the controlled environment of a shipyard and fast track option are available, allowing Delfin to avoid much of the long lead time of land-based LNG export projects. Accordingly, Delfin anticipates that, subject to all regulatory approvals, it will begin operation of at least its first train in 2017 and its second train in 2018. Delfin anticipates beginning operation of its third and fourth trains in 2019 and 2021, following the longer period needed for construction of the new-build FLNGV(s).

Delfin plans to export domestically produced natural gas, sourced from both conventional and non-conventional production, available from the interstate pipeline grid and delivered through the connection to its dedicated, existing pipeline to the new deepwater port in WC 167. Delfin's connection through its dedicated pipeline with the interstate pipeline systems will provide access to abundant and diverse domestic supplies across the US including Texas and Louisiana, where significant volumes of gas are currently being flared at zero value, specifically in the nearby Eagle Ford Shale.

Delfin is engaged in commercial negotiations with numerous potential customers. Based

on those discussions, Delfin anticipates that it will contract some of its capacity (in particular, portions of its first and possibly second trains) with customers located in countries with which the U.S. has an FTA already in place. Delfin also expects, however, to contract with companies seeking to export LNG to nations that do not currently have an FTA in place with the U.S. To maximize its ability to market the project, and to provide the project's full economic benefit to all the stakeholders, Delfin needs to expand its potential customer pool in this way. For that reason, Delfin respectfully requests this authorization to export LNG to non-FTA countries.

IV. REQUESTED AUTHORIZATION

Delfin proposes to engage in the export of LNG of up to the equivalent of 1.8 Bcf of natural gas per day or 657.5 Bcf per year (approximately 13 million mtpa of LNG) 7/ from its new deep water port to be located in WC 167 of the Gulf of Mexico, offshore Cameron Parish, Louisiana. As noted above, Delfin previously requested in FE Docket No. 13-129-LNG the long-term, multi-contract authorization to export those volumes of domestically produced LNG to any country that has or in the future develops the capacity to import LNG via ocean-going carrier and with which the United States has, or in the future enters into, an FTA requiring national treatment for trade in natural gas or its legal equivalent. Here, Delfin requests authorization to export these same volumes of LNG to any country with which the United States does not have a Free Trade Agreement but does not prohibit trade.

Delfin anticipates entering into one or more long-term (more than two years and up to 20 years) contractual agreements with customers for natural gas liquefaction and LNG

7/ Section 590.202(b)(1) of the DOE's regulations requires that applications for export or import authority set forth "the volumes of natural gas involved, expressed either in Mcf or Bcf and their Bcf equivalents." DOE/FE recently reaffirmed its intention to authorize LNG export in annual quantities equivalent to natural gas volumes set forth in volumetric units (typically Bcf). In recent orders authorizing LNG exports to FTA countries, DOE/FE has authorized levels set forth in Bcf of natural gas. *E.g.*, Freeport LNG Expansion, L.P. and FLNG Liquefaction, LLC, DOE/FE Order No. 3282, at pages 119-120 (May 17, 2013). Delfin similarly requests authorization for the amount of natural gas of up to equivalent of 657.5 Bcf per year. For purposes of conversion of its planned 13 million mtpa of liquefaction capacity, Delfin has utilized a conversion factor of 50.58 Bcf per metric ton of LNG, but the actual conversion factor will depend on the composition of the natural gas and other conditions.

export services. Long-term authorization by DOE/FE to export LNG is required for contracts with potential customers. Consistent with the terms of prior DOE/FE orders, Delfin will file under seal all relevant long-term commercial agreements with its customers once they are executed.

Delfin requests long-term, multi-contract authorization for the export of domestically produced LNG for a term of twenty years commencing on the date of the first LNG export of each train or seven years 8/ from the date that the authorization is issued, whichever is sooner. In light of the planned phased development of its project (with successive trains expected to become operational from 2017 through 2021), Delfin respectfully requests that the "date of first export" for purposes of the beginning of its export authorization be determined on a train-specific basis. For example, exports from the first train, if placed in operation in 2017 as planned, would extend for twenty years from that first export from Delfin's facility; but if the third train were placed in operation in 2020, exports from it also would be authorized for twenty years from the start of *that train's* export operations (rather than only approximately seventeen years, based on the original date of first export). Delfin submits that this phased approach, while not previously adopted by DOE/FE, will facilitate the orderly, phased development of its facility and its customer contracting. 9/

The structure of the contracts between Delfin and its customers is not yet definitely known. Depending on that structure, either Delfin or its customer may own the LNG at the time of export. Accordingly, Delfin requests authorization to export LNG both on its own

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8/ Delfin anticipates commencing exports in 2017, but proposes that the requested authorization commence within seven years of the date of authorization in recognition of the planned phasing of its project, as well as to allow for some potential delay in that schedule. DOE/FE has authorized similar conditions in previous export orders. For instance, in each of its recent orders authorizing LNG exports to non-FTA countries, DOE/FE concluded that a seven-year operations commencement date is a reasonable limitation. Freeport LNG, Order No. 3282 at page 115; Lake Charles Exports, LLC, DOE/FE Order No. 3324 at page 128 (Aug. 7, 2013); Dominion Cove Point LNG, LP, DOE/FE Order No. 3331 at 145 (Sept. 11, 2013).

9/ Of course, the export authorization for all trains would commence no later than seven years from the date of the Order authorizing the exports. Thus, for example, were the requested order issued sometime in 2014, the authorization for all Delfin's trains would commence no later than that same date in 2021. So, if Delfin's fourth train were placed in-service after that date, the export authorization for volumes exported from that train would still be less than the full twenty years.

behalf and acting as an agent for other entities who themselves hold title to the LNG. Consistent with the terms established by DOE/FE for an LNG terminal operator receiving export authorization in its role as agent for others, 10/ Delfin will register each LNG title holder for whom Delfin seeks to export LNG with DOE/FE. As required in prior DOE/FE orders, the registration will include a written statement by the title holder acknowledging and agreeing to comply with all applicable requirements included in Delfin's export authorization and to include those requirements in any subsequent purchase or sale agreement entered into for the exported LNG by that title holder.

Delfin respectfully submits that, for the reasons detailed below, its planned export of natural gas to non-free trade countries is "not inconsistent with the public interest." Accordingly, DEO/FE should grant the requested authorization.

V. CONSISTENCY WITH THE PUBLIC INTEREST

A. The Applicable Legal Standard

Section 3(a) of the NGA, 15 USC 717b(a), sets forth the following statutory standard for the review of this Application:

> [N]o person shall export natural gas from the United States to a foreign country or import any natural gas from a foreign country without first having secured an order of the [Secretary of Energy 11/] authorizing it to do so. The [Secretary] shall issue such order upon application, unless after opportunity for hearing, [he] finds that the proposed exportation or importation will not be consistent with the public interest. The [Secretary] may by [the Secretary's] order grant such application, in whole or in part, with such modification and upon such terms and conditions as the [Secretary] may find necessary or appropriate.

This provision establishes a rebuttal presumption that a proposed export of natural gas is in the public interest. The DOE/FE must grant an export application unless opposing parties (if any)

10/ *See, e.g.*, Freeport LNG Development, LP, DOE/FE Order No. 2913 (February 10, 2011); Gulf Coast LNG Export, LLC, DOE/FE Order No. 3163 (October 16, 2012).

11/ The Secretary's authority was established by the DOE Organization Act of 1977, which transferred jurisdiction over gas import and export authorizations from the Federal Power Commission.

overcome that presumption by making an affirmative showing of inconsistency with the public interest. 12/

While section 3(a) establishes a broad public interest standard and a presumption favoring export authorizations, the statute does not define "public interest" or identify the criteria that must be considered. In its prior decisions, however, DOE/FE has identified a range of factors that it evaluates when reviewing an application for export authorization. These factors include economic impacts, international impacts, security of natural gas supply, and environmental impacts, among others.13/ DOE/FE also has explained that its review of export applications focuses on: (i) the domestic need for the natural gas proposed to be exported, (ii) whether the proposed exports pose a threat to the security of domestic natural gas supplies, (iii) whether the arrangement is consistent with DOE/FE's policy of promoting market competition, and (iv) any other factors bearing on the public interest.14/

The nation's policy of promoting market competition in natural gas is reflected in the DOE/FE policy guidelines for implementing NGA Section 3 established in 1984, 15/ which the agency has continued to rely upon in each of its recent decisions evaluating the public interest in LNG exports. 16/ The Policy Guidelines were "designed to establish natural gas trade on a

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12/ *E.g.,* Phillips Alaska Natural Gas Corp. and Marathon Oil Co., DOE/FE Order No. 1473 at page 13 (April 2, 1999), *citing* Panhandle Producers and Royalty Owners Assoc. v. ERA, 822 F.2d 1105, 1111 (D.C. Cir. 1987); Sabine Pass Liquefaction LLC, DOE/FE Order No. 2961 at page 28 (May 20, 2011); Freeport LNG, Order No. 3282 at page 6; Lake Charles Exports, Order No. 3324 at page 7; Dominion Cove Point LNG, Order No. 3331 at 7.

13/ Freeport LNG, Order No. 3282 at page 6; Lake Charles Exports, Order No. 3324 at page 7; Dominion Cove Point LNG, Order No. 3331 at page 7.

14/ Sabine Pass Liquefaction, Order No. 2961 at page 29; Freeport LNG, Order No. 3282 at page 7; Lake Charles Exports, Order No. 3324 at page 8; Dominion Cove Point LNG, Order No. 3331 at pages 8-9.

15/ "New Policy Guidelines and Delegation Orders Relating to the Regulation of Natural Gas," 49 Fed. Reg. 6684-01 (Feb. 22, 1984)(hereinafter the "Policy Guidelines"),

16/ Freeport LNG, Order No. 3282 at page 6; Lake Charles Exports, Order No. 3324 at page 7; Dominion Cove Point LNG, Order No. 3331 at page 7. As DOE/FE held in each of those orders, while the Policy Guidelines are nominally applicable to natural gas import cases, the same policies should be applied to natural gas export applications.

market-competitive basis and to provide immediate as well as long-term benefits to the American economy from this trade." 17/ The Guidelines provide that:

> The market, not government, should determine the price and other contract terms of imported [or exported] gas. U.S. buyers [sellers] should have full freedom – along with the responsibility – for negotiating the terms of trade arrangements with foreign sellers [buyers]....
>
> [T]he guidelines establish a regulatory framework for buyers and sellers to negotiate contracts based on traditional competitive and market considerations, with minimal regulatory constraints and conditions. The government, while ensuring that the public interest is adequately protected, should not interfere with buyers' and sellers' negotiation of the commercial aspects of import [export] arrangements. The thrust of this policy is to allow the commercial parties to structure more freely their trade arrangements, tailoring them to the markets served....
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> * * *
>
> The policy cornerstone of the public interest standard [of NGA Section 3] is competition. Competitive import [export] arrangements are an essential element of the public interest, and natural gas imported [exported] under arrangements that provide for the sale of gas in volumes and at prices responsive to market demands largely meets the public interest test....
>
> This policy approach presumes that buyers and sellers, if allowed to negotiate free of constraining governmental limits, will construct competitive import [export] agreements that will be responsive to market forces over time. The specific commercial terms and conditions of a particular arrangement should be negotiated by the parties pursuant to discrete requirements of the buyer's [and seller's] market and not directed by government regulators.18/

DOE/FE recently has explained that it "continues to subscribe to the principle set forth in our 1984 Policy Guidelines that, under most circumstances, the market is the most efficient means of allocating natural gas supplies." 19/ The agency has promoted the competitive, free-trade policies embodied in the Policy Guidelines in its decisions to date authorizing LNG exports

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17/ Policy Guidelines at 6684.

18/ *Id.* at 6685 and 6687. The parenthetical references to exports are added in the above quotation to reflect the applicability of the Policy Guidelines to exports. *See* note 16, *supra.*

19/ Freeport LNG, Order No. 3282 at page 112; Lake Charles Exports, Order No. 3324 at page 125; Dominion Cove Point LNG, Order No. 3331 at page 141.

to non-FTA nations in each of the four recent cases where it has considered the issue. It should continue to follow this course in approving Delfin's application here.

B. Delfin's Proposed LNG Exports Will Promote the Public Interest

Granting Delfin's requested authorization to allow LNG exports will be consistent with, and indeed advance, the public interest. Allowing Delfin and its customers to freely negotiate contracts to respond to market conditions and utilize Delfin's planned deep water port in WC 167 for LNG exports will be consistent with the pro-competition focus of the Policy Guidelines. And North American gas reserves are more than adequate to satisfy U.S. demand, even under the most aggressive demand projections including a large domestic LNG export industry. The exports proposed by Delfin could not possibly pose a threat to domestic gas supply security. Indeed, by providing a steady, incremental demand for gas, LNG exports from the Delfin facility will help support natural supply development, with resulting economic and employment benefits. Other benefits of LNG exports include reducing the U.S. trade imbalance, complying with the Nation's long-standing support of free-trade, and promoting positive consequences in international relations.

The general benefits of LNG exports are well known to DOE/FE. Faced with the prospect (and, now, the reality) of numerous LNG export proposals, DEO/FE undertook an in-depth two party study of the cumulative economic impact of LNG exports. The first part of the study was conducted by the Energy Information Agency (EIA) and evaluated the potential impact of additional LNG exports on domestic energy consumption, production and prices under several export scenarios. The second part of the study, performed by NERA Economic Consulting (NERA), assessed the potential macroeconomic impact of LNG exports using its energy-economy model. The two studies, as well as the results of the extensive notice and comment process undertaken by DOE/FE seeking public comments on them, are summarized

in detail in each of the recent DOE/FE orders authorizing LNG exports to non-FTA countries. 20/ As DOE/FE has summarized, two of the key findings of the NERA study are the following:

- Across all the scenarios studied, NERA projected that the United States would gain net economic benefits from allowing LNG exports. For every market scenario examined, net economic benefits increased as the level of LNG exports increased. Scenarios with unlimited exports had higher net economic benefits than corresponding cases with limited exports. In all cases, the benefits that come from export expansion outweigh the losses from reduced capital and wage income to U.S. consumers, and hence LNG exports have net economic benefits in spite of higher domestic natural gas prices.

- U.S. natural gas prices would increase if the United States exports LNG. However, the global market limits how high U.S. natural gas prices can rise under pressure of LNG exports because importers will not purchase U.S. exports if U.S. wellhead price rises above the cost of competing supplies. Natural gas price changes attributable to LNG exports remain in a relatively narrow range across the entire range of scenarios. 21/

DOE/FE has held that the NERA study is fundamentally sound and supports the proposition that proposed exports of LNG are not inconsistent with the public interest. 22/ Moreover, NERA's fundamental findings that the United States will benefit from the export of domestically produced LNG are confirmed by numerous other persuasive studies, including but not limited to: Charles Ebinger *et. al.*, "Liquid Markets: Assessing the case for U.S. Exports of Liquefied Natural Gas," Brookings Institution (May 2012)(hereinafter, "Ebinger/Brookings"); Michael Levi, "A Strategy for U.S. Natural Gas Exports," The Hamilton Project, Brookings Institution (June 2012) (hereinafter, "Levi/Brookings"); Kenneth B. Medlock II, Ph.D., "U.S. LNG Exports: Truth and Consequences," Energy Forum at the James A. Baker Institute for Public Policy, Rice University (August 2012)(hereinafter, "Medlock/Baker"); Deloitte, "Exploring the

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20/ Freeport LNG, Order No. 3282 at pages 30-109; Lake Charles Exports, Order No. 3324 at pages 42-121; Dominion Cove Point LNG, Order No. 3331 at pages 56-134.

21/ Freeport LNG, Order No. 3282 at pages 40-41; Lake Charles Exports, Order No. 3324 at pages 52-53; Dominion Cove Point LNG, Order No. 3331 at pages 66-67. These findings are also set forth in the Executive Summary of NERA Study itself at pages 1-2.

22/ Freeport LNG, Order No. 3282 at page 110; Lake Charles Exports, Order No. 3324 at p. 123; Dominion Cove Point LNG, Order No. 3331 at page 140.

American Renaissance: Global Impacts of LNG Exports from the United States" (October 2012) (hereinafter "Deloitte"); ICF International, "U.S. LNG Exports: Impacts on Energy Markets and the Economy" (May 2013) (hereinafter "ICF").23/ Delfin hereby incorporates these studies into the record here as supporting of the public interest supporting its proposed LNG exports.

The public and political appreciation for the benefits of LNG exports is growing. For instance, the Energy and Commerce Subcommittee on Energy and Power of the House of Representatives recently hosted a forum entitled "Geopolitical Implications and Mutual Benefits of U.S. LNG Exports." In announcing the summit, full committee Chairman Fred Upton explained: "Innovative technological advancements have dramatically changed the energy landscape of America, and this new energy reality has game-changing potential both domestically and abroad. Such a summit with our global friends would have been unthinkable just a few short years ago. Our natural gas boom is creating jobs and revitalizing manufacturing here at home, but it also offers an opportunity for us to help our allies and trading partners fuel their economy and reduce the world's reliance on unstable regions of the world." 24/ At that forum, representatives from several foreign countries and the Commonwealth of Puerto Rico expressed international perspectives on U.S. LNG exports, the current policies governing these exports, and the potential impacts increasing exports would have on global markets.

Given the extensive evidence of the benefits of LNG exports as demonstrated by the studies noted above and previously recognized by DOE/FE itself in its previous orders, Delfin is not submitting any additional studies of its own. Delfin instead will note some of the unique,

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23/ These studies are all publicly available: Edinger/Brookings at http://www.brookings.edu/~/media/Research/Files/Reports/2012/5/02%20lng%20exports%20ebinger/0502_lng_exports_ebinger.pdf; Levi/Brookings at http://www.brookings.edu/research/papers/2012/06/13-exports-levi; Medlock/Baker at http://bakerinstitute.org/publications/US%20LNG%20Exports%20-%20Truth%20and%20Consequence%20Final_Aug12-1.pdf; Deloitte at http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/Energy_us_er/us_er_GlobalImpactUSLNGExports_AmericanRenaissance_Jan2013.pdf; ICF at http://www.api.org/~/media/Files/Policy/LNG-Exports/API-LNG-Export-Report-by-ICF.pdf.

24/ *See* http://energycommerce.house.gov/event/geopolitical-implications-and-mutual-benefits-us-lng-exports

public interest benefits of its project and then summarize more general factors showing the public interest in LNG exports.

1. Unique Benefits of Delfin's Project

Unlike most of the projects with LNG export applications pending before DOE/FE, Delfin's project will be located off-shore. The off-shore location enables Delfin to avoid certain environmental and land-owner concerns that frequently arise concerning shore-based facilities. The off-shore location also avoids seaway congestion by limiting the number of LNG tankers entering our crowded port terminal system: an issue which may prove problematic for some of the proposed terminals on the nearby Gulf coast. Moreover, Delfin's FLNGVs will be powered and mobile, so that they can move away from the mooring location to escape an expected hurricane or other storm that could pose a threat or cause interruptions in service from damaged facilities of fixed, on-short LNG terminals. Furthermore, Delfin's liquefaction trains on the FLNGVs will be constructed in the controlled environment of a shipyard, a significant advantage over the potentially challenging construction environment of other projects. The controlled construction environment also will result in improved quality controls and promote increased safety in operations.

Delfin's first two FLNGVs will be converted using existing LNG carriers incorporating proven technology with gas as the only fuel for power generation and propulsion. The liquefaction trains are modular, proven designs and the Front End Engineering Design for the conversion of the initial FLNGs is complete. The vessels will meet or exceed all environmental and certification standards. Delfin expects to be among the most environmentally friendly LNG liquefaction facilities in the world, burning only natural gas and using air cooling and closed loop cooling, with no sea-water used, for all systems. Delfin's approach provides certainty, cost advantages, and relatively speedy construction time – allowing it to place its first train into operation in 2017.

In addition to converting existing carriers into FLNGVs, Delfin also will utilize existing American gas infrastructure. The use of the existing UTOS gas pipeline both avoids the need for new construction (with the attendant environmental issues) and provides a new use for infrastructure that was otherwise slated for abandonment. Existing gas processing facilities located near where UTOS comes ashore will both provide ready processing capability for the LNG feed gas and create an important new use for existing facilities that are currently significantly under-utilized as a result of declining Gulf production in the area. Thus, Delfin's project will stimulate not only new production in the area but also utilize processing services, resulting in economic benefits to the Louisiana coast region.

2. Projected Gas Supplies Are More Than Sufficient To Support Exports

The main focus of the DOE/FE's public interest analysis for gas export authorizations traditionally has been the projected domestic need for the gas. DOE has historically determined whether there is a domestic need for the gas proposed for export by comparing the total volume of natural gas reserves expected to be available to produce with the expected gas demands during the proposed period of exports. 25/ In light of the dramatic recent successes of domestic gas exploration and production, such an analysis clearly demonstrates that sufficient reserves now exist to satisfy domestic demand as well as the proposed LNG exports.

In its recent orders approving LNG exports to non-free trade countries, DOE/FE consistently has found that adequate natural gas supplies exist to meet demand associated with those authorizations. All available data continues to confirm this conclusion. As both DOE/FE and the leader of the NERA study have explained, using more recent data than that available at the time of that study only strengthens NERA's conclusions concerning the benefits to the economy of LNG exports. While EIA's projected gas consumption for 2035 increased by 6 Bcf

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25/ *E.g.*, Yukon Pacific Corp., ERA Docket No. 87-68-LNG, Order No. 350 (Nov. 16, 1989); Phillips Alaska, Order No. 1473, *supra.*; Conoco Phillips Alaska Natural Gas Corp. and Marathon Oil Co., Order No. 2500 at 43 (June 3, 2008).

per day between the 2011 Annual Energy Outlook ("AEO") utilized by NERA and the 2013 AEO (from 72.7 to 78.7 Bcf per day), the projected 2035 production increased by more than twice that amount (from 72.1 to 85.9 Bcf per day), while the projected 2035 Henry Hub price declined from $7.07/MMBtu to $6.32/MMBtu. 26/ "The implication of the latest EIA projections is that a greater quantity of natural gas is projected to be available at a lower cost than estimated just two years ago." 27/ Thus, as the leader of the NERA study explained in Congressional testimony:

> The current natural gas outlook has changed dramatically for the better since 2011. According to the U.S. Energy Information Administration's current projection, in every future year more natural gas will be available for the same price than it projected in its 2011 forecast. Our analyses show clearly that the net benefits to the U.S. would be larger if more natural gas were available for domestic use at the same level of LNG exports. Hence, if we used the current EIA projections which include greater natural gas supply at every price, we would find even larger net benefits. 28/

DOE/FE has recognized in its recent orders that proved reserves of domestic natural have been increasing dramatically. Specifically, those orders explain that EIA's estimates of proved reserves increased from 177,427 Bcf in 2000 to 304,625 Bcf in 2010, a 72 percent increase, compared to increased production of 16 percent over that period. 29/ Once again,

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26/ *See* Freeport LNG, Order No. 3282 at pages 62-63; Lake Charles Exports, Order No. 3324 at pages 74-75; Dominion Cove Point LNG, Order No. 3331 at pages 88-89.

27/ Freeport LNG, Order No. 3282 at page 81; Lake Charles Exports, Order No. 3324 at page 93; Dominion Cove Point LNG, Order No. 3331 at page 106.

28/ Prepared Testimony of W. David Montgomery, Senior Vice President of NERA Economic Consulting, Submitted to the Committee on Foreign Affairs, Subcommittee on Terrorism, Nonproliferation, and Trade, U.S. House of Representatives, Natural Gas Exports: Economic and Geopolitical Opportunities, April 25, 2013 (hereinafter, "Montgomery Testimony"), available at: http://docs.house.gov/meetings/FA/FA18/20130425/100776/HHRG-113-FA18-Wstate-MontgomeryW-20130425.pdf

29/ Freeport LNG, Order No. 3282 at page 82; Lake Charles Exports, Order No. 3324 at page 94; Dominion Cove Point LNG, Order No. 3331 at page 107.

more recent data only further strengthens the conclusion. EIA's calculation of proved reserves of dry natural gas increased by another 10 percent from 2010 to 2011, to 334,067 Bcf. 30/

EIA's estimates of the nation's technically recoverable reserves ("TRR") have also sky-rocketed over the past decade, with some relatively minor fluctuation in the most recent years as EIA continues to refine its estimates of shale resources. DOE/FE's recent LNG export orders have recognized the estimated TRR of 2,335 Tcf set forth in AEO 2013. 31/ This latest EIA reserve estimate compares to EIA's 2005 TRR estimate of about 1,600 Tcf 32/ -- just over 70 percent of the current level. Similarly, the latest study by the Potential Gas Committee of the Colorado School of Mines estimated that the recoverable natural gas resource in North America is 2,384 Tcf, compared to its 2004 estimate of just 1,119 Tcf – an astounding more than doubling of the estimate.33/ The most recent estimates of TRR equate to over 90 years of supply at the 2012 domestic consumption level of 25.63 Tcf.

The tremendous success of the American development of shale gas reserves cannot be questioned. As Dr. Daniel Yergin (a leading expert on energy markets and a member of the Secretary of Energy's Advisory Board) has explained: "Our view is that, owing to the very large [natural gas] resource base, the market in the U.S. is demand-constrained, rather than supply-constrained. Larger markets – whether they be in electric power, industrial consumption,

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30/ EIA, *U.S. Crude Oil and Natural Gas Proved Reserves*, Table 11 (Dry Natural Gas Proved Reserves) (Aug. 2, 2013), available at http://www.eia.gov/naturalgas/crudeoilreserves/?src=Natural-f4

31/ Freeport LNG, Order No. 3282 at page 82; Lake Charles Exports, Order No. 3324 at page 95; Dominion Cove Point LNG, Order No. 3331 at page 108.

32/ *See* Newell, EIA, *Shale Gas and the Outlook for U.S. Natural Gas Markets and Global Gas Resources*, presentation to the Organization for Economic Cooperation and Development (OECD), June 21, 2011, available at http://www.eia.gov/pressroom/presentations/newell_06212011.pdf (comparing 2005 AEO to 2011 AEO).

33/ Potential Gas Committee press release, April 9, 2013, and summary of the report, available at http://potentialgas.org/ and http://potentialgas.org/download/pgc-press-release-april-2013-slides.pdf

transportation or exports – are required to maintain the investment flow into the development of the resources." 34/

Importantly, increased demand for gas to be exported as LNG will stimulate additional natural gas production. ICF International has studied this issue in depth and concluded that 79-88% of LNG export volumes will be offset by increasing domestic natural gas production. 35/ This increased gas production will have the added benefit of increased associated natural gas liquids ("NGL"). ICF estimated that LNG exports will increase NGL volumes by 2035 by 138,000 barrels per day (for a low LNG export case of 4 Bcf per day) to 550,000 barrels per day (in the high, 16 Bcf per day export case). 36/ The increased gas and NGL production are important public benefits of LNG exports.

All available evidence and projections show that current gas reserves are ample to support all expected demand, including LNG exports, at least through 2040. Accordingly, there is no "domestic need" for the gas that Delfin proposes to export. Certainly, the proposed exports do not pose any possible threat to the security of domestic natural gas supplies. Therefore, Delfin's proposal is consistent with the public interest.

3. Any Effect of Delfin's LNG Exports On Domestic Prices Would Be Minor

The Policy Guidelines establish that the federal government's policy is not to manipulate energy prices by approving or disapproving import or export applications. Rather, the Nation's policy is that markets, and not the government, should allocate resources and set prices, and that free trade in natural gas on a market-competitive basis benefits consumers and promotes

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34/ Prepared Testimony of Dr. Daniel Yergin, Submitted to the Energy and Commerce Committee, Subcommittee on Energy and Power Foreign Affairs, for Hearings on "America's Energy Security and Innovation," February 5, 2013 (hereinafter "Yergin testimony"), available at: http://danielyergin.com/daniel-yergin-testimony/

35/ The ICF study is cited above at [note 23]. See also the ICF International presentation, summarizing the study, provided to the U.S. House of Representatives LNG Working Group at page 5 (May 15, 2013), available at: http://www.api.org/~/media/Files/Policy/LNG-Exports/ICF-Key-Findings-for-API.pdf

36/ *Id.*

the public interest. Nevertheless, DEO/FE has explained that it views very seriously the economic impacts of higher natural gas prices and any potential increases in gas price volatility that could result from LNG exports.

Economic analysis by the Baker Institute at Rice University concluded:

> [T]he more salient question for U.S. policymakers regards the U.S. price response to U.S. LNG exports. This question is best answered in understanding the elasticity of the domestic supply curve. In particular, we estimate that domestic elasticity of supply is roughly 1.52 between a price of $4 and $6 per mcf, which represents a five-fold increase since the emergence of shale gas. In other words, a one percent increase in price will result in a one-and-a-half increase in domestic production. This means that the export of LNG in any reasonable volume from the U.S. should not have a significant impact on price at the margin. 37/

The EIA and NERA studies commissioned by DOE/FE confirmed that the impact of LNG exports on domestic gas prices will be relatively minor. As noted above, the key conclusion as explained in the NERA Study was:

> U.S. natural gas prices increase when the U.S. exports. But the global market limits how high U.S. natural gas prices can raise under pressure of LNG exports because importers will not purchase U.S. exports if U.S. wellhead price rises above the cost of competing supplies. In particular, the U.S. natural gas price does not become linked to oil prices in any of the cases examined. Natural gas price changes attributable to LNG exports remain in a relatively narrow range across the entire range of scenarios. 38/

Moreover, it is important to recognize, as NERA did, that more significant price impacts (at the high end of the "narrow range") occur "only under conditions of ample U.S. supplies and low domestic natural gas prices, with smaller price increases when U.S. supplies are more costly and domestic prices higher." 39/ This conclusion makes sense, of course: LNG exports from this country will be significant only if domestic prices remain low compared to elsewhere in the

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37/ Medlock / Baker at page 33.

38/ NERA Study, Executive Summary, page 2.

39/ *Id.*

world. If domestic gas prices increase too much, LNG exports will no longer be economically attractive.

Other economic studies of the likely price effects of LNG exports have reached conclusions generally similar to NERA's. The recent ICF study includes a comparison of various studies of the price impact of LNG exports and explains that the variation in results generally is caused by different assumptions about the price elasticity of domestic gas supply. 40/ With any reasonable assumptions, however, the expected price effect of even very significant LNG exports is modest.

When assessing the impact of any projected cost increases from LNG exports, one must recognize the historically low gas prices constituting the current base line. Historical price data from before the shale boom emphasize the current low price environment: annual average Henry Hub spot prices per MMBtu were $7.91 in 2005, $6.62 in 2006, $6.20 in 2007, and $8.25 in 2008.41/ At that time, expectations were that gas prices would continue to rise. Thus, the EIA as recently as its 2009 AEO reference case projected that prices would be $6.96 in 2010, $7.77 in 2020, and $9.68 in 2030 (adjusted to 2010 dollars for purposes of comparison). 42/ In comparison, the 2013 AEO, even with its assumptions of much greater gas demand including from LNG exports, projects a price in 2035 of just $6.32 (in 2011$).

Gas consumers have enjoyed tremendous savings as a result of the success of the shale gas revolution. For instance, the EIA recently announced, based data from the 2010 Manufacturing Energy Consumption Survey, that the average natural gas price paid by manufacturers decreased by 36% in between 2006 and 2010 from $7.59 to $4.83 per million

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40/ ICF at pages 99-105.

41/ *Platt's Inside FERC.*

42/ Annual Energy Outlook 2009 with Projections to 2030, Table 13, U.S. Energy Information Administration, available at http://www.eia.gov/oiaf/archive/aeo07/aeoref_tab.html.

Btu, adding that natural gas prices have fallen further since that survey was conducted.43/ And the American Gas Association has found that all natural gas consumers have benefited from lower gas prices, calculating as an illustration that the bills of northern residential natural gas consumers in January 2011 would have been some 40 to 70 percent higher (roughly $97 to $125 more for the month) had they reflected the higher prices from the supply-constrained January of 2006. 44/

Incremental demand from new uses like LNG exports is needed to spur on the production boom that has so benefitted consumers. Even if LNG exports increase gas prices marginally, U.S. gas prices will remain attractively priced, and far below the levels expected prior to the shale revolution. And, of course, American manufacturers and other consumers will continue to enjoy the competitive advantage of inexpensive domestic supplies, as overseas consumers of US-sourced LNG will necessarily bear the significant added costs associated with liquefaction, tanker transportation and regasification.

With respect to the related concern of potential increases in natural gas volatility, DOE/FE has consistently explained that it is not persuaded that LNG exports will substantially increase volatility. 45/ Delfin believes that DOE/FE has correctly analyzed this issue. Indeed, the new baseload demand associated with LNG export projects actually should reduce price volatility.

43/ EIA, Cost of Natural Gas Used in Manufacturing Sector Has Fallen," released Sept. 13, 2013, available at: http://www.eia.gov/consumption/manufacturing/reports/2010/ng_cost/?src=Natural-f1

44/ American Gas Association, "THE POSITIVE NATURAL GAS SUPPLY SITUATION BENEFITS CONSUMERS – A LOOK AT JANUARY, 2011" (March 8, 2011), available at: http://www.aga.org/Kc/analyses-and-statistics/studies/demand/Documents/EA1102Positive-Gas-Supply-Situation-Benefits-Consumers.pdf

45/ Freeport LNG, Order No. 3282 at page 99; Lake Charles Exports, Order No. 3324 at page 112; Dominion Cove Point LNG, Order No. 3331 at page 125.

4. LNG Exports Will Significantly Benefit America

The NERA study decisively concluded that LNG exports will be a net benefit to the U.S. economy, regardless of the supply and demand scenario studied and regardless of the level of exports.

> Across all the scenarios that we examined in which the global market would take exports from the U.S., there were net economic benefits to the U.S. from allowing LNG exports. Moreover, for every one of the market scenarios examined, net economic benefits increased as the level of LNG exports increased. In particular, scenarios with unlimited exports always had higher net economic benefits than corresponding cases with limited exports. 46/

DOE/FE has held that the conclusion of the study it sponsored that the U.S. will experience net economic benefits from LNG exports is "fundamentally sound and supports the proposition that the proposed exports will not be inconsistent with the public interest." 47/ This conclusion remains true *regardless of the level of exports.* Indeed, when testifying to Congress on this issue, the leader of the NERA study repeated the conclusion quoted above at the opening of his Congressional testimony and then added: "There was no 'sweet spot,' and no point where any 'balance' was required to gain the greatest benefits." 48/

The fundamental conclusion that LNG exports will benefit the nation has been confirmed by other studies, including those by the Brookings Institute and ICF. ICF quantified the likely benefits and found even stronger support for LNG exports than indicated in the NERA study. ICF projected an increase in gross domestic product (GDP, in 2010 dollars) ranging from $15.6 to $22.8 billion assuming just 4 Bcf per day of exports, and up to $50.3 to $73.6 billion with 16 Bcf per day of exports. 49/ Furthermore, ICF estimated net job gains of 73,100 to 145,100 in

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46/ NERA Study, Executive Summary, page 1.

47/ Freeport LNG, Order No. 3282 at page 110; Lake Charles Exports, Order No. 3324 at page 123; Dominion Cove Point LNG, Order No. 3331 at page 140.

48/ Montgomery Congressional Testimony, note 28 *supra.* at page 3.

49/ ICF at page 2.

the low export case and up to 220,100 to 452,300 in the high export case. 50/ In each case, both the GDP expansion and the job growth increase with more exports.

The increased jobs associated with LNG exports certainly are an important part of the public interest consideration, and supportive of the Administration's 2010 National Export Initiative (NEI). 51/ The NEI is intended "to improve conditions that directly affect the private sector's ability to export. The NEI will help meet [the] Administration's goal of doubling exports over the next 5 years by working to remove trade barriers abroad, by helping firms -- especially small businesses -- overcome the hurdles to entering new export markets, by assisting with financing, and in general by pursuing a Government-wide approach to export advocacy abroad, among other steps." 52/ In announcing the NEI, President Obama explained:

> Creating jobs in the United States and ensuring a return to sustainable economic growth is the top priority for my Administration. A critical component of stimulating economic growth in the United States is ensuring that U.S. businesses can actively participate in international markets by increasing their exports of goods, services, and agricultural products. Improved export performance will, in turn, create good high-paying jobs. 53/

The International Trade Administration of the Department of Commerce issued a report as an "analytical complement to the NEI, demonstrating the fundamental role that exports already play in the U.S. economy." 54/ That report found that in 2008 (the most recent year studied), exports represented 12.7% of the U.S. GDP and supported jobs for other 10 million Americans. 55/ The total value of American exports that year was about $1,693 billion and supported nearly 10.3 million jobs – meaning that each $1 billion of exports supported about

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50/ *Id.*

51/ NEI, Executive Order No. 13534, 75 Fed. Reg. 12433 (March 11, 2010).

52/ NEI, Section 1.

53/ *Id.*

54/ International Trade Administration, Department of Commerce, "Exports Support American Jobs" (2010), available at: http://trade.gov/publications/pdfs/exports-support-american-jobs.pdf

55/ *Id.* at page 1.

6,000 jobs. 56/ The importance of exports to the U.S. economy continues to grow, as exports as a share of U.S. GDP were a record 13.9 percent in both 2011 and 2012. 57/ The advent of LNG exports worth billions of dollars will add tens of thousands of additional jobs to the U.S. economy.

Furthermore, LNG exports also will help realign the U.S. balance of trade. The U.S. has experienced large balance of trade deficits for more than decade (although the rise in U.S. exports in recent years has somewhat realigned the trade balance). In 2012, the U.S. trade deficit was $541.5 billion (an improvement of $19.5 billion compared to 2011). Authorizing the export of LNG will help redress this balance, by allowing the U.S. to export some of its abundant and valuable natural gas.

Beyond these economic factors, allowing LNG exports will have positive international consequences, as DOE/FE has previously recognized. 58/ "[T]o the extent U.S. exports can counteract concentration within global LNG markets, thereby diversifying international supply options and improving energy security for many of this country's allies and trading partners, authorizing U.S. exports may advance the public interest for reasons that are distinct from and additional to the economic benefits." 59/ Export of LNG from the U.S. has the potential to fundamentally alter the world's energy and economic map and benefit the Nation's allies around the globe. Asian LNG prices have been more than four-times the U.S. prices, driven by Japan's need for power fuel following the shut-down of most of its nuclear plant and growing economies elsewhere, as well as the traditional oil-linked LNG prices. High gas prices in Europe

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56/ *Id.*, Appendix A.

57/ Statement from U.S. Deputy Secretary of Commerce Rebecca Blank on Record International Trade in Goods and Services in 2012, submitted Feb. 12, 2013, available at: http://www.commerce.gov/news/press-releases/2013/02/08/statement-us-deputy-secretary-commerce-rebecca-blank-record-internati

58/ Freeport LNG, Order No. 3282 at page 111; Lake Charles Exports, Order No. 3324 at page 124; Dominion Cove Point LNG, Order No. 3331 at page 140".

59/ *Id.*

(compared to the U.S. though not Asia) threaten the Continent's economic recovery after the financial crisis, and have caused a shift to coal (including that exported from the U.S.) for power generation, retarding progress there on reducing greenhouse gas emissions. Closer to the U.S., export of LNG to Caribbean nations could reduce reliance on more expensive, and carbon-intensive, fuel oil and diesel. Increased access to U.S. gas would not only provide new supplies to America's allies around the world, it would also position the country as an alternative to traditional suppliers in Russia and the Middle East.

The international and geopolitical benefits of increased U.S. domestic gas production – which will be fostered by LNG exports – are further explained in the report by the James A. Baker III Institute for Public Policy at Rice University. 60/ That report highlights the broad effects that new shale discoveries are having on our Nation's energy security, and explains the added security and stability that increased American natural gas reserves will bring around the world, lessening the entanglements that our dependence on foreign energy sources brings. The report also details the numerous benefits that shale gas will have on a global scale, from eliminating demand for imports of foreign LNG to the U.S., to reducing the possibility of a "natural gas OPEC," weakening the energy stranglehold held by certain countries, and helping curb America's dependence on Middle East oil.

Conversely, any American limitations on LNG exports could cause foreign relations problems. As Dr. Yergin observed in Congressional testimony:

> While markets and economics will eventually determine the realistic scale of U.S. exports, one also has to take into account wider considerations in assessing policy regarding future LNG exports. For decades, the United States has made the free flow of energy supplies one of the cornerstones of foreign policy. It is a principle we have urged on many other nations. How can the United States, on the one hand, say to a close ally like Japan, suffering energy shortages from Fukashima, please reduce your

---

60/ "Shale Gas and U.S. National Security," Medlock, Myers Jaffe, and Hartley, published by the James A. Baker III Institute for Public Policy (July 19, 2011), available at: http://www.bakerinstitute.org/publications/EF-pub-DOEShaleGas-07192011.pdf

> oil imports from Iran, and yet turn around and, on the other, say new natural gas exports to Japan are prohibited. 61/

Moreover, any limitation on the level of LNG exports wound run counter not only to the competitive framework of DOE/FE's Policy Guidelines but U.S. trade policy. Imposing restrictions on trade in natural gas would be contrary to the United States' longstanding policy and international trade rules disfavoring export restraints (see the General Agreement on Tariffs and Trade, Article XI). Indeed, the U.S. has led the way in *challenging* export restraints when adopted by other nations. For instance, in 2012, the World Trade Organization agreed with the United States' challenge to China's export restraints on several industrial raw materials: a victory heralded by U.S. Trade Representative Ron Kirk's proclamation that "The Obama Administration will continue to ensure that China and every other country play by the rules so that U.S. workers and companies can compete and succeed on a level playing field." 62/ Later in 2012, the United States challenged China's export restrictions on rare earths, with Ambassador Kirk decrying export restraints "resulting in massive distortions and harmful disruptions in supply chains for these materials throughout the global marketplace." 63/ Thus, were DOE/FE to impose quantitative limits on LNG exports, it would not only hurt the US economically, it would undermine the country's own international trade policies and perhaps also violate its international obligations.

The National Association of Manufacturers (the largest manufacturing association in the country) recognized this point in their initial comments to DOE/FE on the NERA study, explaining:

61/ Yergin Testimony at page 7.

62/ "U.S. Trade Representative Ron Kirk Announces U.S. Victory in Challenge to China's Raw Materials Export Restraints," January 2012 press release, available at: http://www.ustr.gov/about-us/press-office/press-releases/2012/january/us-trade-representative-ron-kirk-announces-us-vict

63/ "United States Challenges China's Export Restraints on Rare Earths," March 2012 press release, available at: http://www.ustr.gov/about-us/press-office/press-releases/2012/march/united-states-challenges-china%E2%80%99s-export-restraints-r

> With 95 percent of the world's consumers outside the United States, export bans on any product, including LNG, can be expected to have far-reaching negative effects, including on domestic economic opportunities, employment and ultimately economic growth....
> The United States' ability to challenge other countries' existing exports restraints on agricultural, forestry, mineral and ferrous scrap products – just to name a few – will be virtually non-existent if the United States itself begins imposing its own export restrictions. Even worse, as the world's largest economy and largest trading country, U.S. actions are often replicated by our trading partners to our own dismay. If the U.S. were to go down the path of export restrictions, even more countries would quickly follow suit and could easily limit U.S. access to other key natural resources or inputs that are not readily available in the United States. 64/

Finally, exporting LNG also will have significant environmental benefits because natural gas is a much cleaner-burning fuel than other fossil fuels. The Environmental Protection Agency has estimated that compared to the average air emissions from coal-fired generation, natural gas-fired generation produces half as much carbon dioxide, less than a third as much nitrogen oxides, and one percent as much sulfur oxides. 65/ Energy Secretary Moniz reportedly has recognized how the natural gas boom has helped reduce America's greenhouse gas emissions, noting that about half of the progress that has been made toward reducing greenhouse gases to 17 percent below 2005 levels by 2020 has been due to substitution of gas for coal in electric generation. 66/ LNG exports from the U.S. may similarly substitute for coal, or fuel oil, usage overseas, thereby sharing the environmental benefits of natural gas with other nations in the quest to reduce global greenhouse gas emissions.

64/ Comments of Ross Eisenberg, Vice President, Energy and Resources Policy, on behalf of the National Association of Manufacturers filed with DOE/FE on Jan. 24, 2013, and available at: http://www.fossil.energy.gov/programs/gasregulation/authorizations/export_study/ross_eisenberg_em01_24_13.pdf

65/ *See* http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html

66/ *See* "Energy secretary: Natural gas helps battle climate change – for now," *By Ben Geman, The Hill (08/01/13), available at: http://thehill.com/blogs/e2-wire/e2-wire/315009-energy-secretary-natural-gas-helps-battle-climate-change-for-now* (quoting Secretary Moniz's comments to reporters).

5. Conclusion: the Requested Authorization Should Be Granted

Given the ample domestic natural gas supply, the economic and other benefits of LNG exports, and the nation's free-trade policies, the DOE/FE has no reason to restrict, by regulatory fiat, the level of LNG exports. Of course, not all projects that receive export authorizations will actually be built. EIA's latest International Energy Outlook projects that LNG will account for a growing share of world natural gas trade, more than doubling from about 10 trillion cubic feet in 2010 to around 20 trillion cubic feet in 2040 (in the Reference Case). 67/ Yet, there is strong competition to serve this growing market, not only among the myriad of proposed export projects in the United States but further among suppliers in Australia, Canada, east Africa, the eastern Mediterranean, the Middle East, and elsewhere.

Given this competition, the speed with which DOE/FE processes and approves non-FTA export authorizations like this one is crucial. As the White Paper entitled "The Narrowing Window: America's Opportunity To Join The Global Gas Trade," issued by Senator Lisa Murkowski explained:

> The analytical debate about whether exports are in the national interest is settled.... The risks of building out LNG capacity are manageable, particularly for the government, while the potential gains to the nation's economy are enormous....
>
> The window for the United States to join the global gas trade will not be open indefinitely. In fact, it is narrowing, and there is the real possibility that the nation will miss out on a historic opportunity. 68/

For all the reasons set forth above, Delfin submits that its proposed export of LNG is "not inconsistent with" the public interest. Moreover, while recognizing the many other export

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67/ EIA, 2013 International Energy Outlook, released July 25, 2013, available at: http://www.eia.gov/forecasts/ieo/more_highlights.cfm

68/ "The Narrowing Window: America's Opportunity To Join The Global Gas Trade," issued by Senator Lisa Murkowski, at page 14 (Aug. 6, 2013), available at: http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=986351eb-316d-4dc9-9d1a-b75abcf4b5fc

applications previously filed with DOE/FE, Delfin respectfully urges DOE/FE to grant this application as soon as possible.

VI. ENVIRONMENTAL IMPACT

Delfin plans to file an application with MARAD and the Coast Guard for the necessary licensing of its deepwater port and authorization for the facilities to allow for the liquefaction of domestically produced natural gas and export of LNG from the offshore facilities. Those facilities will be designed to minimize or mitigate any environmental or other adverse impacts. The authorization requested here, as a practical matter, will not be actionable until MARAD grants Delfin authorization for the facilities needed for the liquefaction of natural gas and the export of LNG.

An environmental review under the National Environmental Policy Act ("NEPA") will be completed by MARAD and the Coast Guard, together with the participation of DOE and other consulting agencies, prior to granting the required authorizations. Accordingly, consistent with the approach taken with prior (FERC-jurisdictional) non-FTA export authorizations, Delfin requests that DOE/FE issue a conditional order authoring the export of LNG, conditioned on completion of the environmental review by MARAD and the Coast Guard.

VII. APPENDICES

The following appendices are attached hereto and incorporated by reference herein:

Appendix A: Verification

Appendix B: Opinion of Counsel

Appendix C: Map of Existing Pipeline and the WC 167 Area

Appendix D: Conceptual Site Plan and Depiction of Mooring System

VIII. CONCLUSION

Based on the reasons set forth above, Delfin respectfully requests that the DOE/FE grant Delfin authority for its proposal to engage in long-term, multi-contract exports of domestically produced LNG for a term of twenty years for up to the equivalent of 1.8 Bcf of natural gas per day or 657.5 Bcf per year (approximately 13 million mtpa of LNG) to any country which has or in the future develops the capacity to import LNG via ocean-going carrier and with which the U.S. has not entered into an FTA or the legal equivalent but also does not prohibit trade.

Respectfully submitted,

Frederick Jones
Founder Director
Fairwood Welbeck Natural Resources Pte. Ltd.
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Singapore 188970
Telephone: +65 63384608
Email: f.jones@iegag.com

Dated: November 12, 2013

APPENDIX A

VERIFICATION

STATE OF TEXAS)

COUNTY OF KERR)

William R. Nichols, being first duly sworn on his oath deposes and says: that he is a Member of Fairwood Peninsula Energy, LLC. and an Authorized Representative of Delfin LNG LLC; that he is duly authorized to make this Verification; that he has read the foregoing submittal and is familiar with the contents thereof; that all the statements and matters contained therein are true and correct to the best of his information, knowledge and belief; and that he is authorized to execute and file the same with the U.S. Department of Energy.

Sworn to and subscribed before me this 22 day of October, 2013

BILL O. BULL
MY COMMISSION EXPIRES
July 23, 2015

Notary Public
In and For Kerr County, Texas

APPENDIX B

THOMPSON & KNIGHT LLP

ATTORNEYS AND COUNSELORS

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October 6, 2013

Office of Fuels Program, Fossil Energy
U.S. Department of Energy
Docket Room 3F-056, FE-50, Forrestal Building
1000 Independence Avenue SW.
Washington, DC 20585

Ladies and Gentlemen:

We have acted as special counsel for Delfin LNG LLC, a Louisiana limited liability company (the "***Company***"), and are furnishing this opinion letter pursuant to 10 C.F.R. 590.202(c) of the Department of Energy administrative procedures for purposes of complying with the requirements of the Company's application seeking authorization to export natural gas out of the United States (the "***Application***").

In connection with this opinion letter, we have examined the following:

(i) a certified copy of the articles of organization of the Company, certified as being complete, true and correct by the Secretary of State of the State of Louisiana;

(ii) a certified copy of the certificate of formation of Fairwood Peninsula Energy, LLC, a Delaware limited liability company and the sole member of the Company (the "***Sole Member***"), certified as being complete, true and correct by the Secretary of State of the State of Delaware;

(iii) a certified copy of the limited liability company agreement of the Company, certified as being complete, true and correct by the Sole Member; and

(iv) a certified copy of the resolutions of the Sole Member authorizing (a) the execution and delivery of the Application and (b) the export of domestically produced natural gas by the Company pursuant to the filing of the Application, certified as being complete, true and correct by the Sole Member.

In rendering the opinions expressed below, we have assumed:

(i) The genuineness of all signatures.

(ii) The authenticity of the originals of the documents submitted to us.

(iii) The conformity to authentic originals of any documents submitted to us as copies.

We have not independently established the validity of the foregoing assumptions.

Based upon the foregoing, and subject to the qualifications and limitations herein set forth, we are of the opinion that:

1. The Company is a limited liability company that is validly existing and in good standing under the laws of its state of organization.

2. The Company (i) has the requisite limited liability company power and authority to execute and deliver the Application and, pursuant to the filing of the Application, export domestically produced natural gas and (ii) has taken all limited liability company action necessary to authorize the execution and delivery of the Application and export domestically produced gas upon the filing of the Application.

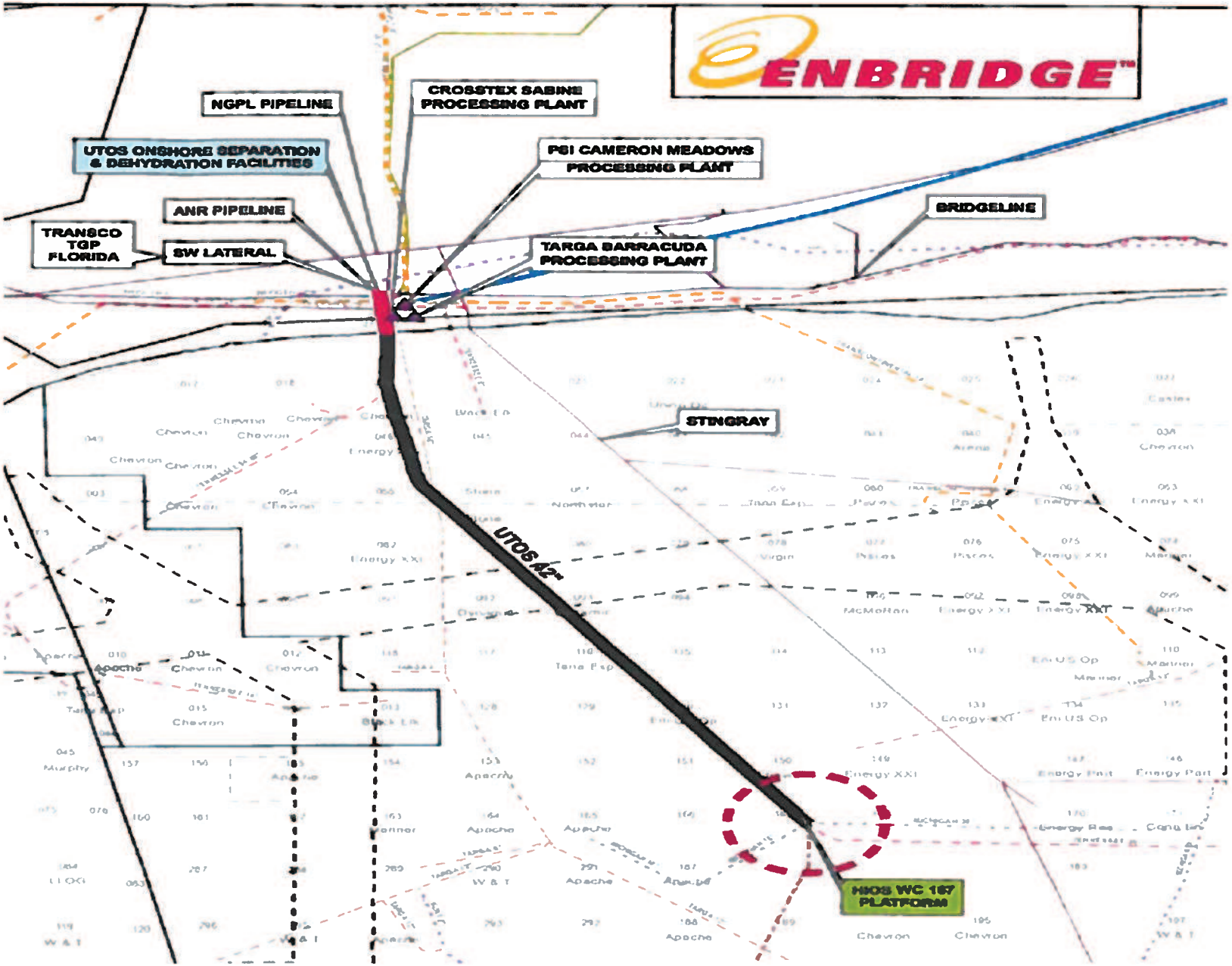
This opinion letter has been prepared, and is to be understood, in accordance with customary practice of lawyers who regularly give and lawyers who regularly advise recipients regarding opinions of this kind, is limited to the matters expressly stated herein and is provided solely for purposes of complying with the requirements of the Application, and no opinions may be inferred or implied beyond the matters expressly stated herein. The opinions expressed herein are rendered and speak only as of the date hereof and we specifically disclaim any responsibility to update such opinions subsequent to the date hereof or to advise you of subsequent developments affecting such opinions. This letter may be relied upon only by the addressee hereof. Without our prior written consent, this letter may not be quoted in whole or in part or otherwise used or referred to in connection with any other transactions and may not be furnished to or filed with any governmental agency or other person or entity.

Respectfully submitted,

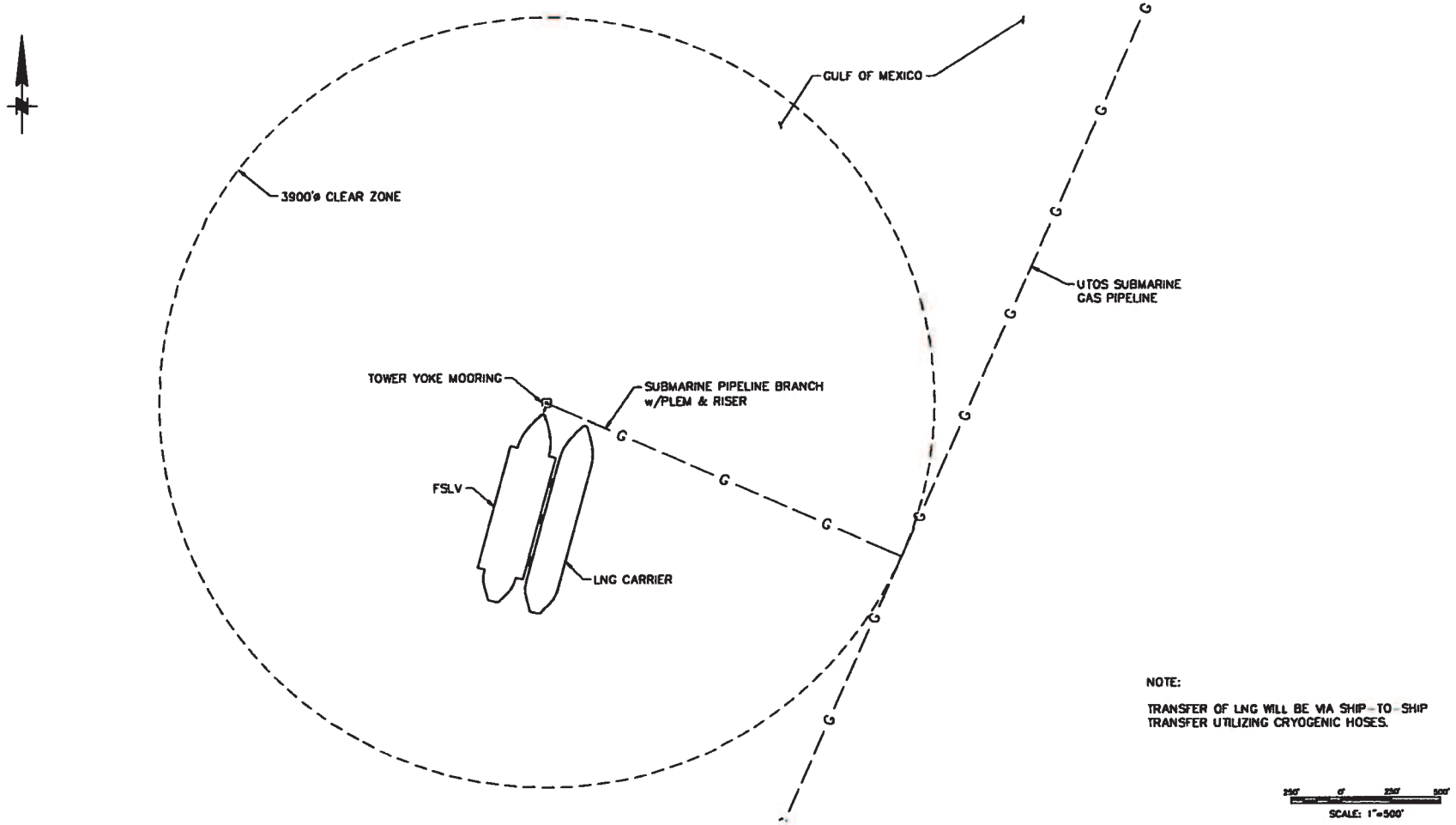
Thompson & Knight LLP

DP/BS/HL/jc

APPENDIX C


ENBRIDGE™
NGPL PIPELINE
CROSSTEX SABINE PROCESSING PLANT
UTOS ONSHORE SEPARATION & DEHYDRATION FACILITIES
PSI CAMERON MEADOWS PROCESSING PLANT
ANR PIPELINE
BRIDGELINE
TRANSCO TGP FLORIDA
SW LATERAL
TARGA BARRACUDA PROCESSING PLANT
STINGRAY
UTOS42"
HIOS WC 167 PLATFORM

APPENDIX D

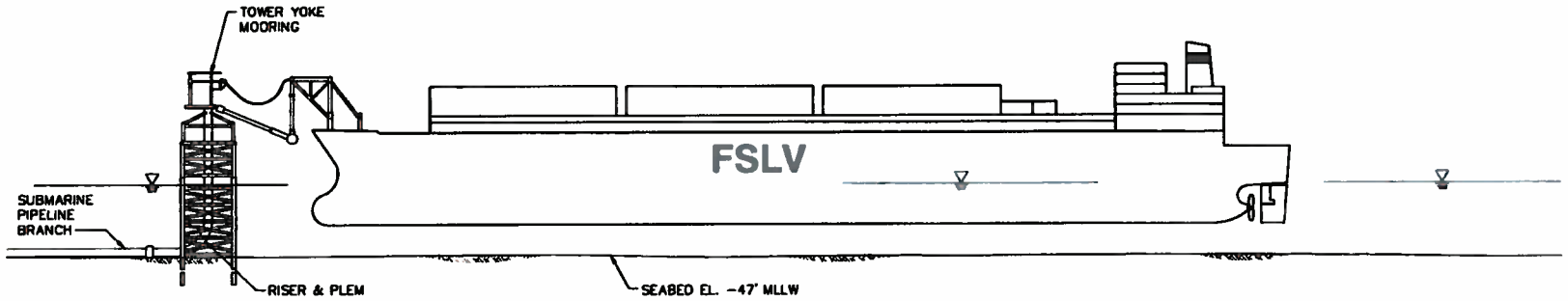


moffatt & nichol

FSLV SITE LAYOUT
FSLV SITE PLAN
FIGURE 6

FAIRWOOD

* **Final Design Under Development**



NOTE:
LNG CARRIER NOT SHOWN FOR CLARITY.

SCALE: 1"=100'

moffatt & nichol

FSLV SITE LAYOUT
ELEVATION
FIGURE 7

FAIRWOOD

* Final Design Under Development

* Final Design Under Development

MAGNOLIA LNG fact sheet

PROJECT	Magnolia LNG, LLC, proposes to construct, own and operate a mid-scale liquefied natural gas (LNG) export facility that will use a thermally efficient LNG process technology.
LOCATION	108 acres of industrial land on Industrial Canal South Shore (PLC Tract 475), through a long-term lease with the Lake Charles Harbor and Terminal District (Port of Lake Charles). The Project site is located on an existing LNG shipping channel and the facility will be accessible by road, near the intersection of Henry Pugh Boulevard and Big Lake Road (Conceptual Layout and Site Map on reverse side).
PROCESS	It is proposed that the Project will receive natural gas via an existing pipeline. The natural gas will be treated, liquefied, and stored onsite. The LNG will be loaded onto LNG vessels for delivery to domestic and export markets and into trucks for domestic distribution in Louisiana and surrounding states.
CAPACITY	At full plant capacity, the Project will consist of four LNG trains (gas liquefaction units), each with a nominal LNG production capacity of 2 million tonnes per annum (mtpa).
TECHNOLOGY	Optimized Single Mixed Refrigerant (OSMR®) liquefaction process has the following main features, which contribute to its high efficiency and 30% less emissions: • Aeroderivative gas turbines and efficient compressors. • Combined heat and power plant, which minimizes plant fuel gas use. • Steam-driven ammonia refrigeration system. OSMR® is 100% developed and owned by Magnolia LNG, LLC's parent company, Liquefied Natural Gas Limited.
OWNER	Magnolia LNG, LLC, a wholly owned subsidiary of Liquefied Natural Gas Limited (www.lnglimited.com.au), GPO Box 920, West Perth WA 6872 Australia
INITIAL INVESTMENT	$2.2 billion, for Phase 1 of the Project comprising two LNG Trains, each of 2 mtpa LNG production capacity.
JOBS	Based on estimates by Magnolia LNG, LLC and the Louisiana Department of Economic Development Phase 1 of the Project will generate approximately 1,000 construction jobs, 45 permanent direct jobs and an additional 175 indirect jobs, and provide significant economic benefits for the State of Louisiana and the United States of America.
SCHEDULE	Magnolia LNG, LLC, is targeting commencement of construction in 2015 and initial start-up of operations in late 2017.

CONTACT

Ernie Megginson
VP–Project Management
Magnolia LNG, LLC
Email: emegginson@lnglimited.com.au
616 Broad Street | Lake Charles, LA 70601


MAGNOLIA
LNG
MAGNOLIA LNG PROJECT
CONCEPTUAL LAYOUT - 8 MTPA

MAGNOLIA LNG

PROJECT OVERVIEW

Total Capital Cost (Phase 1)
US$ 2.2 Billion

Estimated Construction Jobs 1,000

Estimated Direct Employment 45

Estimated Indirect Employment 175

Phase 1 (4 mtpa) focused on Domestic and FTA Markets

Construction Start
Mid-2015

Operations Start
Late 2017

MAGNOLIA**LNG**.COM

MAGNOLIA LNG

FREQUENTLY ASKED QUESTIONS

What is LNG?

- Liquefied natural gas (LNG) is natural gas in its liquid form.
- Cooled to –260°F, LNG is a clear, colorless, odorless, non-corrosive, non-toxic liquid.
- Primarily methane, with low concentrations of other hydrocarbons, water, carbon dioxide, nitrogen and some sulphur compounds.
- Sometimes confused with LPG (liquefied petroleum gas), which is used for domestic and commercial applications. LPG is kept liquid by confining under high pressure; LNG is kept liquid at normal atmospheric pressure by maintaining a very low temperature.

How is LNG used?

- Before LNG can be used, it must be converted back into a gas (regasification).
- After regasification, supplied to households, power stations and other industrial consumers through pipelines.
- LNG in liquid form used as cleaner alternative transportation fuel.

Why use LNG?

- Natural gas is the cleanest-burning fossil fuel, producing less emissions and pollutants than coal or oil.
- Occupies only 1/600th of the volume of natural gas; more economical to transport; can be stored in larger quantities.

How is LNG stored?

- Stored in large insulated tanks consisting of an inner tank and outer tank, with a special insulating layer between.

How is LNG transported?

- Transported in double-hulled ships designed specifically to handle the low temperature of LNG.
- LNG weighs less than half the weight of water so it will float if spilled on water, quickly boiling off and dissipating into the atmosphere, leaving no residue. No environmental clean-up is needed for an LNG spill on water.

Is LNG flammable?

- As a liquid, LNG is not flammable. Vaporized LNG is only flammable if its concentration is within 5%–15% natural gas with air.

Is LNG explosive?

- As a liquid, LNG is not explosive. LNG vapors (methane) mixed with air are not explosive in an unconfined environment. LNG vapor will explode only if in a confined space, and only if within the flammable range of 5% to 15% natural gas with air.

How safe are LNG ships and LNG terminals?

- The LNG industry has an excellent safety record thanks to the safe properties of LNG and the stringent enforcement of standards, codes and guidelines applying to LNG.
- To date there have been more than 50,000 transported shipments by LNG tankers, covering more than 70 million nautical miles, without a single significant accident or safety problem, neither in a port nor at sea.

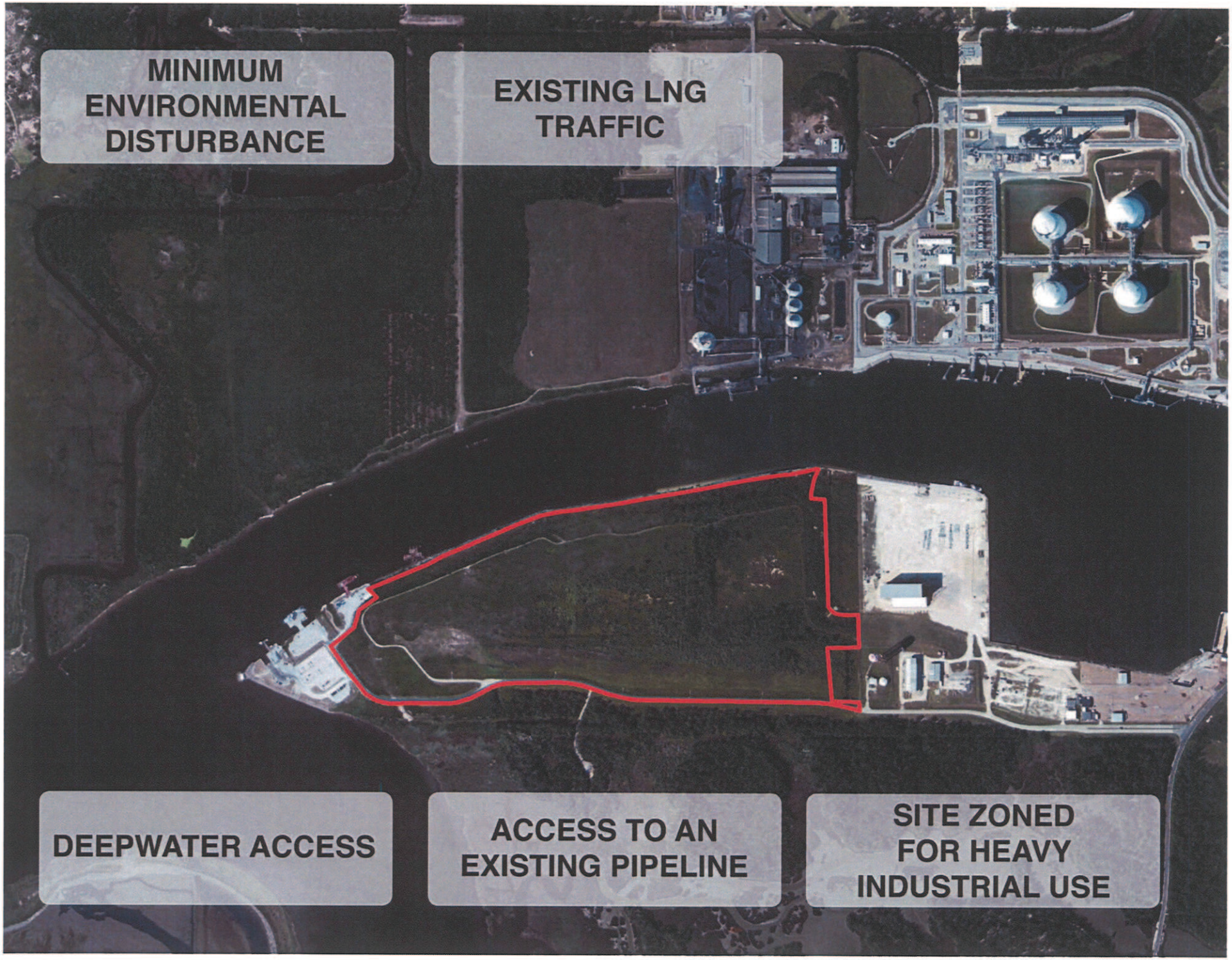
How secure are LNG ships and LNG facilities?

- The LNG industry adheres to stringent security procedures for its ships and facilities. The industry carefully follows requirements set forth by the International Maritime Organization, Federal Energy Regulatory Commission, Department of Transportation, and the U.S. Coast Guard and works closely with the Department of Homeland Security to ensure that its operations are safe and secure.

Source: www.LNGFacts.org

The LNG Industry in General

- This industry has an excellent safety record spanning many decades.
- LNG terminals (export and import) are located all over the world.
- There are over 80 LNG reception terminals and approximately 30 LNG liquefaction plants in operation worldwide, with over 40 planned new and expanded LNG terminals, and more than 30 planned liquefaction plants and expansions.


MINIMUM ENVIRONMENTAL DISTURBANCE
EXISTING LNG TRAFFIC
DEEPWATER ACCESS
ACCESS TO AN EXISTING PIPELINE
SITE ZONED FOR HEAVY INDUSTRIAL USE

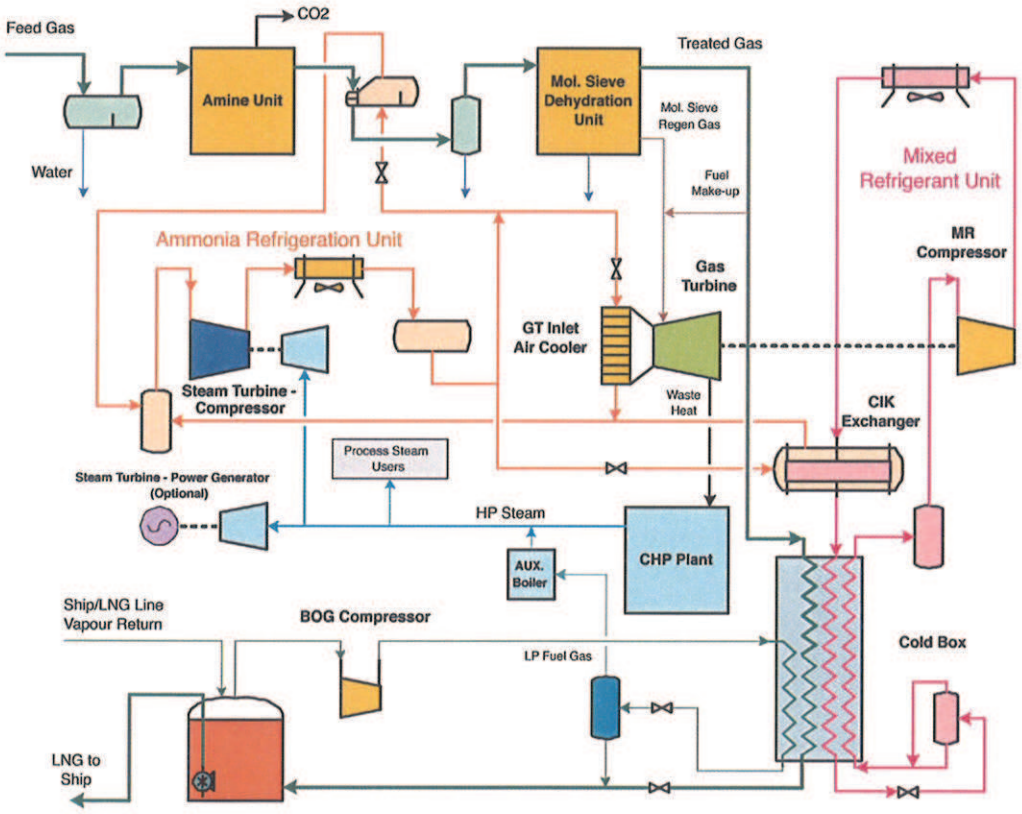
LIQUEFACTION TECHNOLOGIES

Large Scale Liquefaction Technology (>3 mtpa)
ConocoPhillips – Cascade Process
API – C3MR Process
Shell – Dual MR

Medium Scale Liquefaction Technology (1-3 mpta)
LNG Limited – OSMR® Process

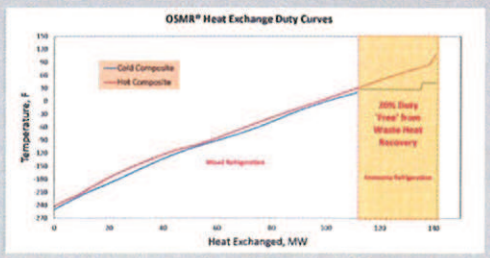
Small Scale Liquefaction Technology (< 1 mtpa)
Black & Veatch – PRICO – SMR Process
Hamworthy – N2 Expansion

OSMR® PROCESS SCHEMATIC



MAGNOLIA LNG

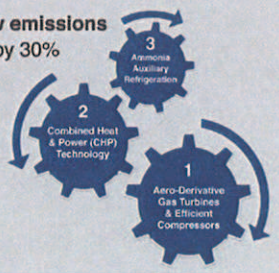
OSMR® COOLING CURVE



OSMR® BENEFITS

Simplicity in design, construction and operation
- Faster construction
- Proven technology
- Reduced capital requirement
- Location flexibility
- Less footprint required
- Simple start-up & operation
- Low turndown

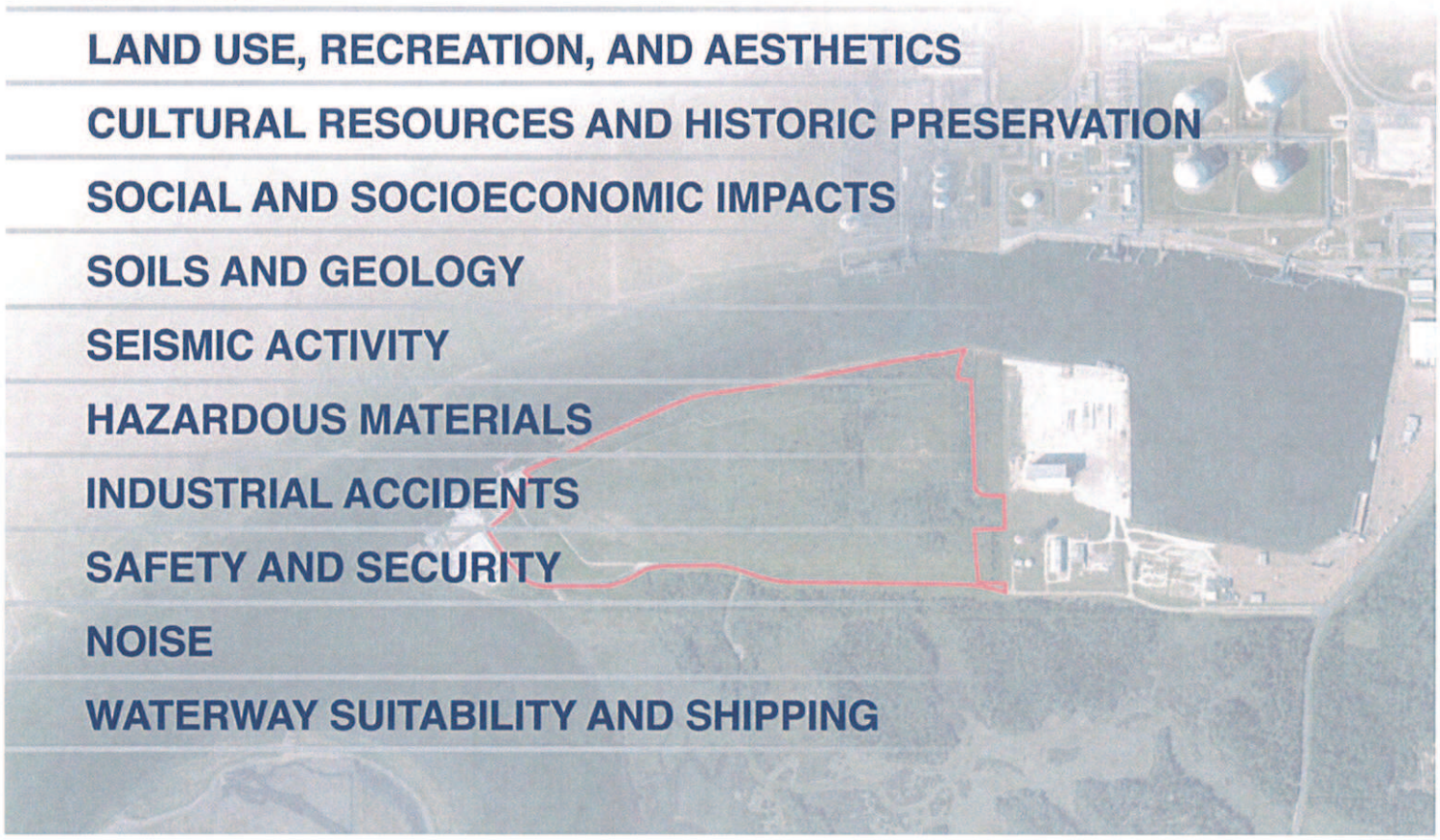
High efficiency and low emissions
- Improved efficiency by 30%
- Better economics
- Reduced emissions



MAGNOLIA LNG

PARTIAL LIST OF SUBJECTS IN ENVIRONMENTAL STUDY

- AIR EMISSIONS
- WATER DISCHARGES
- WATER USE
- WATER QUALITY
- STORM WATER RUN OFF
- WETLANDS IMPACTS
- DREDGING AND SPOIL PLACEMENT
- WILDLIFE AND PROTECTED SPECIES
- FISHERIES
- LAND USE, RECREATION, AND AESTHETICS
- CULTURAL RESOURCES AND HISTORIC PRESERVATION
- SOCIAL AND SOCIOECONOMIC IMPACTS
- SOILS AND GEOLOGY
- SEISMIC ACTIVITY
- HAZARDOUS MATERIALS
- INDUSTRIAL ACCIDENTS
- SAFETY AND SECURITY
- NOISE
- WATERWAY SUITABILITY AND SHIPPING



MAGNOLIA LNG

MAJOR AGENCY ROLES IN ENVIRONMENTAL AND SAFETY REVIEW

FEDERAL AGENCIES

Federal Energy Regulatory Commission
Order Granting Section 3 Authorization

National Oceanic & Atmospheric Administration: National Marine Fisheries Service
Consultation on essential fish habitat, sea turtles in the water, marine mammals, marine fisheries and other protected marine species under agency jurisdiction

U.S. Army Corps of Engineers
Section 10/404 Dredge and Fill Permit

U.S. Coast Guard
Letter of Recommendation for suitability of waterway for LNG marine traffic

U.S. Department of Interior, Fish and Wildlife Service
Consultation on migratory birds, bald and golden eagles, sea turtles on the beach, and other protected species under agency jurisdiction

U.S. Department of Transportation: Pipeline and Hazardous Materials Safety Administration
Applies and enforces federal safety regulations related to LNG facilities

STATE AGENCIES

Louisiana Department of Environmental Quality
Process air emissions permits, water discharge permits, storm water control permits

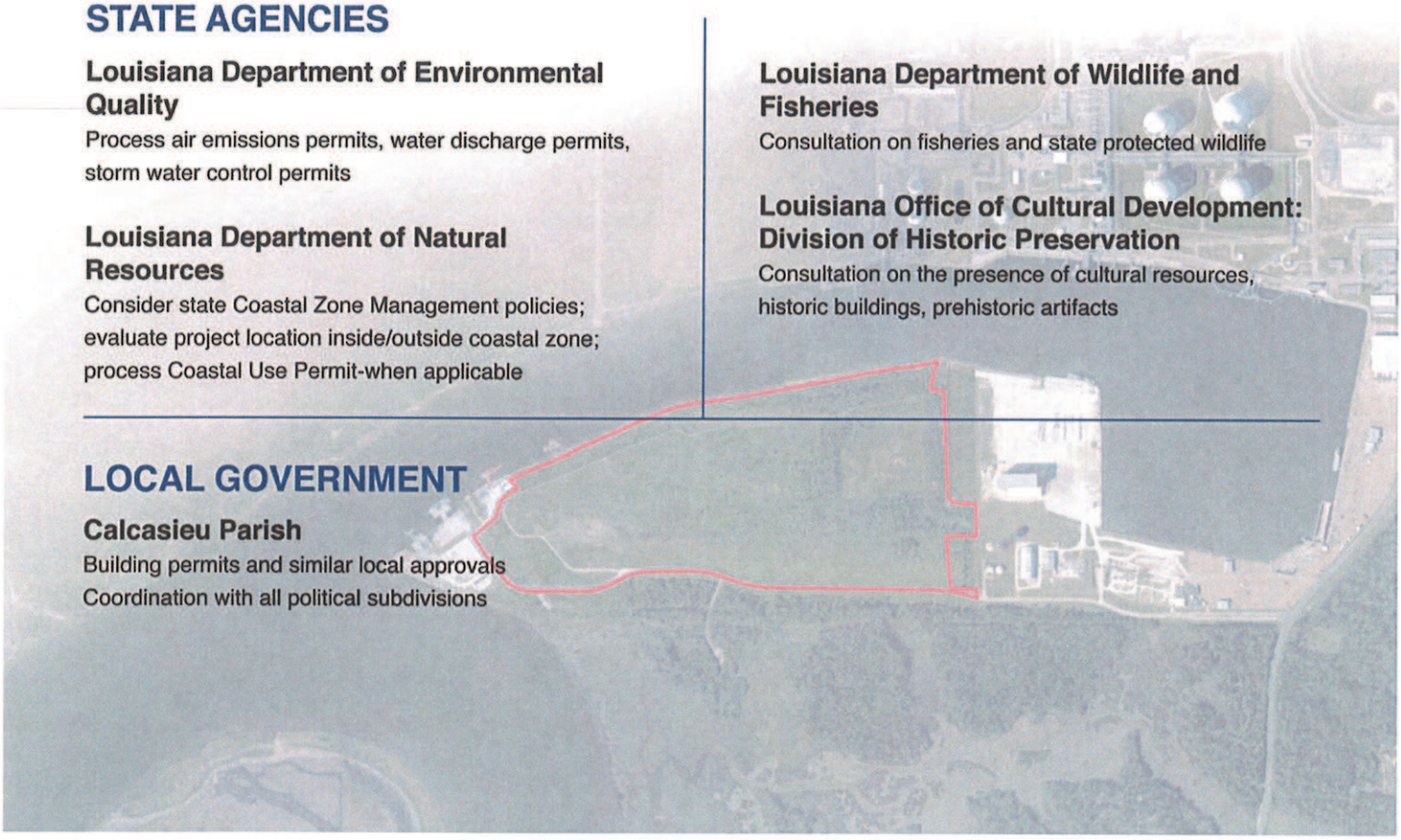
Louisiana Department of Natural Resources
Consider state Coastal Zone Management policies; evaluate project location inside/outside coastal zone; process Coastal Use Permit-when applicable

Louisiana Department of Wildlife and Fisheries
Consultation on fisheries and state protected wildlife

Louisiana Office of Cultural Development: Division of Historic Preservation
Consultation on the presence of cultural resources, historic buildings, prehistoric artifacts

LOCAL GOVERNMENT

Calcasieu Parish
Building permits and similar local approvals
Coordination with all political subdivisions



Endesa Buys More LNG from Cheniere

Posted on Apr 8th, 2014 with tags Buys, Cheniere, Endesa, LNG, News .

Cheniere Energy's unit Corpus Christi Liquefaction has entered into an LNG sale and purchase agreement with Endesa under which the Spanish company has agreed to purchase approximately 0.75 million tonnes per annum of LNG. The SPA is in addition to the previously signed SPA under which Endesa will purchase approximately 1.5 mtpa of LNG, bringing the total quantity of LNG sold to Endesa under the two agreements to approximately 2.25 mtpa.

The Corpus Christi Liquefaction project is being designed and permitted for up to three trains, with aggregate design production capacity of 13.5 mtpa of LNG.

Under the SPA, Endesa will purchase LNG on an FOB basis for a purchase price indexed to the monthly Henry Hub price plus a fixed component. LNG will be loaded onto Endesa's vessels. The SPA has a term of twenty years commencing upon the date of first commercial delivery and an extension option of up to ten years. Deliveries are expected to occur as early as 2018.

"Endesa has agreed to purchase an additional 0.75 mtpa from the Corpus Christi Liquefaction Project for use by their Italian parent company Enel," said **Charif Souki, Chairman and CEO.** "*We have nowentered into a total of approximately 3 mtpa of SPAs at the project, completing the SPAs for Train 1. We continue to work towards finalizing additional agreements and expect*

to complete all necessary steps to reach a final investment decision and begin construction by early 2015."

Press Release, April 08, 2014; Image: Cheniere

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THE GLOBE AND MAIL

March 24, 2014

U.S. approves Veresen's LNG project in Oregon

By BRENT JANG

Terminal in Oregon will be supplied with Canadian natural gas to ship to Asia

The U.S. Department of Energy has approved an application to export liquefied natural gas from a proposed Oregon terminal that would tap into resources that originate in Canada.

The Jordan Cove LNG project, owned by an arm of Calgary-based Veresen Inc., will rely heavily on natural gas supplies to be transported through an existing pipeline network from Western Canada to Oregon.

Plans also call for building the 370-kilometre Pacific Connector feeder pipeline, co-owned by Veresen and Williams Companies Inc. of Tulsa, Okla., in an effort to bring in natural gas from suppliers in Wyoming and Colorado.

Veresen wants to export LNG to Asian customers in a fierce energy race on North America's West Coast. Rivals include one other U.S. Pacific Northwest project, Oregon LNG Marketing Co. LLC, and at least 14 B.C. LNG proposals. There is also global competition to export LNG to Asia, including from Qatar, Australia and Nigeria.

So far, Cheniere Energy Inc.'s Sabine Pass LNG project in Louisiana is the only LNG export project under construction in North America. Jordan Cove and five other U.S. proposals are awaiting approval from the U.S. Federal Energy Regulatory Commission.

Several B.C. LNG projects have been spending millions of dollars on site preparation and other costly preliminary planning, but none of the proponents have made final investment decisions.

Environmentalists and local residents oppose the Jordan Cove project in southern Oregon, but its backers point to economic benefits. Veresen chief executive officer Don Althoff said Monday that Jordan Cove will generate much-needed jobs and provide tax revenue to the Oregon government.

Last month, Canada's National Energy Board approved Jordan Cove's 25-year licence application to export up to 1.55 billion cubic feet a day of natural gas from Western Canada to the U.S.

Veresen said the Canadian natural gas will help supply the Oregon terminal to be constructed at Coos Bay. The LNG production launch is slated for early 2019.

The U.S. Department of Energy's 20-year authorization allows Jordan Cove to export nearly six million tonnes annually of LNG, subject to final regulatory approval. The department said it "considered the economic, energy security and environmental impacts" before giving its blessing Monday for Jordan Cove to export LNG to countries that do not have free-trade agreements with the United States. Jordan Cove needs to secure Asian customers to take delivery of LNG.

The Globe and Mail, Inc.

Lake Charles LNG export project partners file FERC application

HOUSTON, Mar. 26
03/26/2014
By OGJ editors

Trunkline LNG Co. LLC and Trunkline LNG Export LLC, both wholly owned subsidiaries of Energy Transfer Equity LP and Energy Transfer Partners LP, have submitted an application with the US Federal Energy Regulatory Commission seeking its authorization for the siting, construction, ownership, and operation of the proposed Lake Charles LNG export project.

The FERC filing represents the culmination of significant front-end engineering and design (FEED) work and pre-filing consultations with FERC and other federal, state, and local agencies that have been under way since mid-2012, said BG Group, which will oversee the construction and operation of the proposed facility under a long-term agreement with Energy Transfer.

Pending final investment decisions and the receipt of all necessary approvals expected in 2015, construction is planned to start shortly afterwards, with first LNG exports expected in second-quarter 2019.

The US Department of Energy in August 2013 conditionally granted authorization to export as much as 2 bcfd of LNG from the existing Trunkline LNG import terminal to non-free trade agreement nations (OGJ Online, Aug. 8, 2013).

The proposed project will include the construction of three liquefaction trains and use the existing LNG storage and marine berthing facilities owned by Trunkline LNG Co. LLC. Energy Transfer has secured all property rights required for the site of the proposed liquefaction facility.

Energy Transfer will own and finance the proposed facility while BG Group will be responsible for the offtake. Trunkline Gas will provide pipeline transportation services to supply gas to the proposed facility.

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Large scale export of East Coast Australia natural gas: Unintended consequences

A study of the national interest effects of the structure of the Australian gas industry.

A report to
The Australian Industry Group and the Plastics and Chemicals Industries Association

Prepared by the
National Institute of Economic and Industry Research
ABN: 72 006 234 626
416 Queens Parade, Clifton Hill, Victoria, 3068

October 2012

While the National Institute endeavours to provide reliable forecasts and believes the material is accurate it will not be liable for any claim by any party acting on such information.

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Contents (cont.)

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Executive summary

"*One molecule of natural gas is chemically the same as another, but where it is found has enormous implications for global politics.*

The price of gas in the US following the shale drilling boom is now a third of that in western Europe and a fifth of that in Asia."

Financial Times, 17 July 2012

"Gas prices on the eastern seaboard will follow the big rises already hitting downstream industrial users in Western Australia, says Santos chief executive David Knox.

At a Sydney forum on the future of gas, Mr Knox stated that prices in the east of between $3 and $4 a gigajoule would rise to between $6 and $9 for new domestic customers as increasing volumes were exported.

That is the range we are talking about for anyone coming to us now," he said. "We are actively negotiating with a number of buyers … and you are going to see an increase in prices."

Australian Financial Review, 23 August 2012

Natural gas is a fundamental source of energy for power generation, industry, consumers, hospitals and institutions generally. In today's world of transition to greater use of renewable energy it plays an important role in facilitating cost effective peaking power to fill the gaps when renewable supply is not available. It is both an efficient relatively clean fuel source and a critical feedstock for conversion by industry into value-added consumer products. Its value to the domestic economy is very significant as the alternatives are less efficient and, in the case of coal and oil, have significantly higher greenhouse gas emissions.

Many major projects to export Liquefied Natural Gas from Eastern Australia have been approved and will start to operate over the next several years. This will significantly impact the domestic supply of natural gas. In this report we do not argue against the export of LNG but emphasise that the benefits from exporting LNG should be weighed against the benefits of ensuring competitive supply to the domestic gas-dependent manufacturing sector. In a market where there are sufficient reserves of the resource, as appears to be the case in Australia, the typical response would be for additional supply to be made available to meet domestic demand. However, due to the nature of the gas resources, their location, limitations in infrastructure and the way in which we manage these resources, there is a serious risk that this will not be the case. Even a temporary period without secure access to domestic gas would have significant unintended consequences, as would a shift to LNG-linked gas pricing. As such, it is prudent to look at the implications of these developments for consumers and industry.

The National Institute of Economic and Industry Research (NIEIR) has made such an assessment, reviewing the literature and conducting its own assessment of the sectoral and macroeconomic implications of these developments. The findings are concerning.

NIEIR has found that:

- if existing plans proceed, gas exports from eastern Australia will rise from 2 million tonnes in 2015 to 20 million tonnes in 2018, and possibly 24 million tonnes in 2023;

- the current policy framework and market settings for the Australian gas industry favour export of LNG without a subsequent assurance of reliable, competitively priced supplies of gas for domestic industry. Such supplies have historically been a competitive advantage for Australian industry, and gas export revenue is insufficient to compensate Australia for the loss of this advantage;

- natural gas is essential to a range of industries, particularly non-ferrous metals and basic chemicals, but also plastics, pharmaceuticals, paints and cosmetics. Secure local supply at competitive prices is a fundamental requirement for the continuation of a significant part of production and the development of new investment in these industries;

- contracts for the long term supply of gas to domestic industry have 'evaporated' as a consequence of export commitments;

- Australia has only a few years before significant economic loss is likely to be felt from the failure to secure an affordable supply of natural gas to domestic users;

- domestic gas users are increasingly being offered "surplus" gas volumes and prices that do not reflect domestic supply, demand or extraction costs, but are instead linked to East Asia's LNG market – the highest-priced gas in the world. This is a radical reshaping of the domestic gas market, constraining supply (in the near term at least) and driving prices to high (and for many industries uneconomic) levels;

- current gas production and proven reserves will need to expand dramatically in order to support the LNG expansion without significant large scale suppression of gas use on the domestic economy. While the total gas resource is thought to be very large, proving up additional resources and developing them will take time and faces community opposition and other barriers. To ensure gas availability for domestic users, the management of reserves and their supply to market needs attention if domestic needs are not to be overlooked in the rush to export this valuable resource;

- there are important opportunities to expand use of gas in industrial production and electricity generation, but even so domestic consumers cannot make use of the whole gas resource. There are worthwhile benefits to pursue from exporting gas production beyond these needs. But each petajoule of natural gas that is shifted **away** from industrial use **towards** export, whether because of tight supply or uneconomic pricing, means giving up $255 million in lost industrial output for a $12 million gain in export output. That is, for every dollar gained $21 is lost. This increases to $24 when economy-wide impacts are taken into account;

- the dramatic shift in the domestic gas market will have wider impacts well beyond the gas intensive industries:

    - increased operating costs for gas-fired electricity generators due to high gas prices. Such generators would see cost increases three times greater than those currently resulting from the carbon tax. Wholesale electricity prices would thus rise, and the viability of new gas-fired generation would suffer. These plants already play an important role in the electricity market for both peak power and

base load. That role is expected to grow to meet emissions reduction targets and provide backup for expanding renewable generation;

- some substitution away from gas towards electricity by business and households, to reduce their exposure to rising gas prices. This would still leave their costs higher than at present, and would raise greenhouse emissions;

- a slow-down of general economic activity resulting from impacts of the tighter gas supply and higher costs for gas and electricity;

- the expected economic response to the East Coast LNG expansion will involve a combination of the adjustments above. As a result, modelling indicates that, by 2040 the gross production benefit for East Coast LNG expansion will be $15 billion annually, in 2009 prices. However, taking into account the negative effects of adjustment on other sectors, annual GDP will be $22 billion lower than it would be with secure and affordable gas. An alternative 'benefit indicator' used for this study, which combines private consumption, tax receipts and net national product, will be reduced by $46 billion;

- under current policy settings and market structures, the unwanted consequences of the significant boom in LNG exports will persist even if, as is likely, adequate natural gas reserves exist and are brought to market; and

- there are substantial further risks that would lead to even greater costs if realised. These risks include:

  (i) LNG prices may be lower than currently expected. While this would reduce the extent of domestic price rises, it would also reduce gross export benefits while leaving domestic supply constrained in the short-to-medium term by contracted export commitments; and

  (ii) industry will likely be unable to grow without secure affordable gas supplies, leading to additional damage.

The rules of thumb developed in this study for these additional effects are:

- for every 1 per cent reduction in the LNG price the economy-wide benefits from LNG exports will be reduced by approximately 2 percentage points. This stems mainly from the fact that tax receipts and domestic profits will be disproportionately impacted. Foreign interest payments and repayment of debt will still have to be paid; and

- for every $1m of existing chemical industry output that is saved by increased natural gas supply there is another $1m of output that can be obtained by using the competitive advantages for domestic natural gas availability in general, and natural gas liquids in particular.

The likely consequences of the current policy and industry settings on natural gas export are serious for both industry and households. There is an urgent need for more recognition of these impacts, and for a debate on how they can be prevented, alleviated or adapted to. LNG export is a positive for Australia as long as it proceeds without significant harm to the domestic sector and with confident assurance of domestic supply.

1. Background and study objective

1.1 Background

Natural gas is an essential input to value creation and productivity in many of Australia's key industries. If the supply of natural gas is threatened or, short of this, confidence in its ready availability at competitive prices is weakened, so too are the industries that use the gas as a raw material or fuel. Current developments in Queensland, focusing on LNG exports, are threatening Eastern Australia's gas-dependent industries by weakening confidence that gas will be available at competitive cost.

In this report we do not argue against the export of LNG but emphasise that the benefits from exporting LNG should be weighed against the benefits of ensuring competitive supply to the domestic gas-dependent manufacturing sector. Our work indicates that the national benefit from the supply of gas to the many industries that are involved is many times the gain due to export of the same quantity of gas.

Taking these benefits into account, from the beginning the Western Australian Government was active in ensuring that domestic use of the offshore North West Shelf gas resource was to be protected. The Government explicitly committed to actively ensuring that this would be the case. The provisions of the original LNG Act drafted in the 1970s to pave the way for Australia's first LNG export project are specific in the way the reserves are to be used for both export and domestic users. Two sections of the Act indicate this.

> *"**Notification of additional reserves of natural gas***
>
> *20. If the Joint Venturers discover reserves of natural gas additional to those required for their commitments contemplated in recitals (c) and (d) of this Agreement during their exploration programme in the offshore Dampier region (carried out under the provision of the Petroleum (Submerged Lands) Acts), which in the opinion of the Joint Venturers are capable of commercial development the Joint Venturers shall –*
>
> *(a) notify the Minister of the extent and nature of such additional reserves;*
>
> *(b) having regard to the State's desire for the petrochemical industry to be established in Western Australia, investigate the processing of all or part of such natural gas for use as petrochemical feedstock; and*
>
> *(c) enter into discussions with the Minister concerning the utilisation of such natural gas."*
>
> ***"Marketing authorisation***
>
> *42. The State authorises the Joint Venturers and each of them subject to the provisions of this Agreement and pursuant to recital (c) hereof to sell gas to the State Energy Commission and pursuant to such gas agreements with the State Energy Commission –*
>
> *(a) to market gas in the Pilbara to each of their affiliated companies and to major industrial customers who use more than 28 000 cubic metres of gas per day;*

(b) to sell or supply gas to each of their affiliated companies anywhere in Western Australia;

(c) to construct, finance and operate gas transmission pipelines to each of their customers in the Pilbara."

The benchmark price for domestic sales from the Joint Venture was set with a high weight given to domestic cost levels and competitiveness.

In terms of new fields in this century, the Western Australian Government has imposed a reservation policy where 15 per cent of the natural gas reserves are required to be used for domestic purposes.

The case is very different for Queensland. As of 2012 three major LNG plants are under construction in Gladstone on the Queensland central coast. These projects have been approved to proceed without any conditions or arrangements being put in place to generate supply at competitive prices to domestic gas users, whether they are heavy industrial users, commercial business, electricity generators or households.

With the advent of LNG projects the situation changed quickly for Queensland domestic gas customers and increasingly for large users across the east coast. Previously users were offered long-term contracts with predictable price settings. They could undertake long-term investments underpinned by a secure and cost-stable energy supply.

Currently, long-term contracts have "evaporated" as the first priority of gas producers is to secure supply for their LNG plants. Domestic customers feel the domestic market is now the residual sector, allocated what is surplus to requirements for the LNG plants, a reality which will become obvious once existing gas contracts end. Medium-term, let alone long-term, security of supply is no longer guaranteed. Domestic customers are now faced with the expectation having to pay the "net back" LNG price for natural gas, involving most probably a significant increase in price and, more importantly, the introduction of considerable price uncertainty derived from the unpredictability of the world gas market.

Admittedly, it is difficult to be precise about the calculation of 'net back' prices. Because of the variation in contract arrangements between LNG projects, the concept of a world LNG price is difficult to apply and actual prices will be determined by specific contract provisions. The provisions may or may not relate to LNG prices from other sources, either in Australia or overseas.

However, the concept of a domestic gas price based on a 'net back' price for LNG may not be the only factor leading to increased and more variable prices. Domestic consumers expect that the large impact of LNG demand on reserves will force domestic supply to be sourced from fields with higher extraction costs and, therefore, higher domestic cost. Since the majority of gas reserves are leased by interested parties focussed on LNG, it now appears likely that the domestic customers will be matched to the marginal increment in gross supply costs.

This is an extraordinary state of affairs given the scale of the projects and scale of the impact on the existing Australian identified reserves of natural gas. In the application of the national interest test to the projects which governments are obliged to do as manager of the resource on behalf of the community, it appears unlikely that the impacts of the LNG projects on domestic gas using industries have been considered to any great extent. This has been done in private sector reports, such as "*Carbon Market Economics – The Impact of Liquefied Natural Gas on Queensland Gas markets and Gas Users*", March 2010, with to date little impact in changing arrangements.

Australian natural gas (identified and potential) reserves are owned by the Crown which obliges the government of the day to determine when and how the resources are to be used. In exercising this duty, the government has a responsibility to optimise the benefit which current and future generators obtain from the extraction of the resources. Under the Australian constitution there are Federal/State Government jurisdiction issues as to who is responsible, but the reality is that all areas of Government need to cooperate to solve the problem.

1.2 Study objective

Accordingly, the study objective is to:

(i) outline a framework for testing the national interest benefit of Eastern Australian LNG projects that should be applied by the responsible Governments;

(ii) apply the framework to assess the net benefits that are likely to be obtained from the current projects under the current terms and conditions of their approval; and

(iii) evaluate the impact of alternative terms and conditions, in terms of assessing whether or not the net benefits assessed in (ii) can be significantly increased.

In short, this report complements the *Carbon Market Economics* (CME) report by quantifying the macroeconomic costs of a less than satisfactory (that is deficient) national interest evaluation and appropriate complementary policy design.

1.3 The LNG industry evaluated by this study

The LNG industry evaluated by this national interest evaluation is LNG exports from Queensland. The question at issue is whether Australia will obtain a net benefit from expected exports of LNG from Queensland. The expansion profile assumed in the quantitative analysis of the issue is:

Exports of LNG from Queensland
(million tonnes)

2015	2
2016	15
2017	18
2018	20
2019	20
2020	20
2021	20
2022	20
2023	24

In simple terms, therefore, the study will attempt to answer the question of whether or not Australia will obtain a net benefit from 24 million tonnes per annum of natural gas export from Queensland.

1.4 Why the focus on East Coast LNG?

The focus on East Coast LNG is because:

(i) the Western Australian market is not connected to the integrated gas market of the Eastern Australian states (which for this purpose include South Australia but not the Northern Territory) and

(ii) Western Australia has a domestic reservation policy for natural gas and the eastern states do not.

Because of the inter-connection between the eastern states' markets, the East Coast LNG plants will affect the majority of the Australian economy.

In short, given the conditions under which the Queensland projects were allowed to proceed, it is these projects that are most likely to fail a comprehensive national interest test.

1.5 Construction impacts

This study focuses on the production impacts on the economy. The construction impacts of new capacity required to support the changes is ignored as there is no suggestion that the LNG projects should not proceed but the focus should be on ensuring there is ample gas for the domestic sector.

2. The national interest evaluation framework, indicators and methodology

Under Australian law, Australia's petroleum (including natural gas) resources (and mineral resources) are owned by the Crown, in some cases in the right of the states and territories and in some cases in the right of the Commonwealth. In the words of the Productivity Commission, governments should exercise stewardship over Crown resources, managing them to achieve maximum overall benefits for the community. As the Productivity Commission notes, management should not simply be focussed on economic benefits but should also take into account objectives such as the protection of health, the environment and heritage. In general terms, the governance requirement is expressed as the Government's responsibility to make decisions on:

- how;
- when; and
- on what terms,

the petroleum resources are extracted, in terms of maximising the national interest.

Although the national interest test is required in legislation, for example, for assessing foreign investment proposals, Australian Governments have not explicitly stated what guidelines should be applied in balancing the economic, environment, strategic or social interests that constitute the national interest. While this allows regulatory bodies to operate with maximum flexibility, it also shields their decisions from evaluation in terms of explicit criteria.

2.1 The national interest test

The latest statement on the national interest test was made on behalf of the Australian Government by the Treasurer.[1] The statement applies to foreign investment but would be equally relevant to resource management decisions, and not only for the reason that most resource management decisions have a foreign investment component. The statement runs as follows.

2.1.1 What are the characteristics of investment proposals that are likely to be approved

The Government is making sure investments are not contrary to the national interest. If an investment is contrary to the national interest, the Government will intervene. This occurs infrequently.

What is contrary to the national interest cannot be answered with hard and fast rules. Attempting to do so can prohibit beneficial investments and that is not the intention of our regime. Australia's case-by-case approach maximises investment flows while protecting Australia's national interest.

[1] The Treasurer of Australia, "*Australian Foreign Investment Policy*", January 2012.

2.1.2 What are the national interest considerations

Assessing the national interest allows the Government to balance potential sensitivities against the benefits of foreign investment.

The Government determines national interest concerns case-by-case. We look at a range of factors and the relative importance of these can vary depending upon the nature of the target enterprise. Investments in enterprises that are large employers or that have significant market share may raise more sensitivities than investments in smaller enterprises. However, investments in small enterprises with unique assets or in sensitive industries may also raise concerns.

The impact of the investment is also a consideration. An investment that enhances economic activity – such as by developing additional productive capacity or new technology – is less likely to be contrary to the national interest.

The Government typically considers the following factors when assessing foreign investment proposals.

National Security

The Government considers the extent to which investments affect Australia's ability to protect its strategic and security interests. The Government relies on advice from the relevant national security agencies for assessments as to whether an investment raises national security issues.

Competition

The Government favours diversity of ownership within Australian industries and sectors to promote healthy competition. The Government considers whether a proposed investment may result in an investor gaining control over market pricing and production of a good or service in Australia. For example, the Government will carefully consider a proposal that involves a customer of a product gaining control over an existing Australian producer of the product, particularly if it involves a significant producer.

The Government may also consider the impact that a proposed investment has on the make-up of the relevant global industry, particularly where concentration could lead to distortions to competitive market outcomes. A particular concern is the extent to which an investment may allow an investor to control the global supply of a product or service.

The Australian Competition and Consumer Commission (ACCC) also examines competition issues in accordance with Australia's competition policy regime. Any such examination is independent of Australia's foreign investment regime.

Other Australian Government Policies (Including Tax)

The Government considers the impact of a foreign investment proposal on Australian tax revenues. Investments must also be consistent with the Government's objectives in relation to matters such as environmental impact.

Impact on the Economy and the Community

The Government considers the impact of the investment on the general economy. The Government will consider the impact of any plans to restructure an Australian enterprise following an acquisition. It also considers the nature of the funding of the acquisition and what level of Australian participation in the enterprise will remain after the foreign investment occurs, as well as the interests of employees, creditors and other stakeholders.

The Government considers the extent to which the investor will develop the project and ensure a fair return for the Australian people. The investment should also be consistent with the Government's aim of ensuring that Australia remains a reliable supplier to all customers in the future.

Though the national interest is defined broadly, possible negative spillover effects of any specific investment on other industries are not explicitly considered.

2.2 A qualification of the national interest test: The guidelines used for this study

(i) Net economic benefit

The project should make a significant net benefit to cumulative economic activity over its life including the construction phase.

(ii) Significant medium-term benefits

In order to ensure that the benefits are not delayed beyond the living spans of a significant proportion of the current living population, at least one third of the net benefits should be achieved within the first 10 years of the life of the operations of the project.

(iii) Strengthening the skill base of the economy

The project should, net, strengthen the skills base of the economy as measured by the skill intensity of demand for labour.

(iv) There is a significant net impact on Government revenues

In order for the benefits of resources to be distributed to the broader community, Governments need a significant revenue base to distribution. Therefore, a necessary requirement would be that the discounted Government revenue from the project be greater than what would be achieved from an expansion in the general economy.

(v) Australia's economic security

One requirement here, in general terms, would be for the economy to be able to withstand negative economic shocks better than would have been the case in the absence of the project. Australia's relatively secure open economy is subject to shocks in the form of sudden and adverse movements in terms of trade (commodity prices) and the exchange rate. It is desirable, therefore, that the project should reduce the economic costs of adverse commodity prices and exchange rates.

(vi) Australian political security is enhanced

It is desirable that the project should not promote economic dependence on any particular trade partner or closely-allied group of partners.

2.3 The national interest evaluation: Its importance in optimising national benefits

The decision to allow an individual LNG project to proceed or not, in terms of the national interest test, would depend on whether or not the expected net economic, environmental and security outcomes are significantly positive. The project would only be allowed to proceed if it was deemed likely to yield greater national benefit compared to denial of approval.

In most cases, however, it will not be a simple case of a go/no go decision. The national interest evaluation process will frequently identify negative outcomes which can be remedied either by changes in the particular project or by more general policy changes, unrelated to the particular project, which will increase the benefits generated by the project. These complementary policies or other changes may change the status of a project from 'no go' to a strong positive national interest return, and will frequently include strategies to minimise the costs which the project imposes on other industries. A rigorous national interest evaluation process is therefore in itself an instrument to maximise national benefit.

2.4 The benefit indicator

After the design of the national interest evaluation framework, the next most important decision is the selection of the core indicator for evaluating net benefits. In general terms the benefit indicator selected should measure that part of the flow of production that is available to support expenditures in the national economy that directly contribute to welfare/happiness. In the absence of direct measures of welfare, it is usual to concentrate on the flows of funds available to citizens for expenditure on meeting their needs and wants. We are therefore seeking within the constraints of available data for a benefit indicator of sustainable consumption.

A range of indicators is commonly used when measuring the impact of an investment on economic activity, including:

- gross domestic product;
- gross national product (gross domestic income); and
- net national product (net domestic income).

The bracketed name is what the series is now called in the Australian National Accounts. The original names are retained in this study because they clearly signal that the indicators have the same status as GDP whereas the new names imply a lower status. Gross domestic product is the value added generated in a given jurisdiction, irrespective of where the income is distributed. Gross national product (gross domestic income) is GDP less that part of GDP that is distributed to foreign residents or companies in the form of interest, dividends and undistributed income. Net national product is gross national product less that part of value added that is allocated to depreciation expenses. The last is the most appropriate to use in evaluating the benefits of investments in the gas industry for two reasons.

- high foreign ownership in the industry (one of the three LNG export terminals currently under construction at Gladstone is wholly overseas owned and the other two are joint ventures with substantial overseas participation); and

- very high depreciation charges (the bulk of depreciation expense occurs in the first half of the project life and much of it is returned overseas to repay debt).

Because of overseas ownership and high depreciation, the GDP indicator gives a very misleading indication of the benefits of LNG plants.

Given a regard for national welfare, the benefit indicator on which all national interest evaluations should be based should be either net national product (net disposable income) or direct estimates of sustainable private and public consumption expenditure impacts, which can be approximated by consumption expenditure plus total taxation revenue. Both NNP and consumption plus tax revenue are reasonably good proxies for sustainable consumption. Accordingly, for this study, the benefit indicator is taken to be an average of the two measures, that is, the sum of NNP plus private consumption expenditure plus taxation revenue divided by two.

2.5 A probability approach needs to be built into the evaluation framework

A probability approach is required for this study and for testing the implications of a project's approval by regulators. For this study a range of parameters have to be quantified with values around which there is a great deal of uncertainty not only in terms of current settings but also what the values may be over a 20 to 30 year time horizon.

Regulators are able to assess more accurately current information in regard to particular projects if only for the reason that it will be contained in the supporting documentation required for the approval process. In terms of the future values of required parameters, this will require judgement based on the best available current information. In this case, it would be useful for regulators to adopt a probability approach which requires the explicit setting of the characteristics of the probability distribution around key parameters.

This also fits into the general bottom line reality of assessments. Because of uncertainty, the best that any national interest assessment can conclude is that "*on the balance of probabilities it is concluded that .....*". By specifying probability distributions of the key parameters that determine the overall outcomes, the degree of uncertainty surrounding a decision for a project to proceed or not, or surrounding the conditions imposed on project approval, can be communicated to the general public. This eliminates the need for regulators to have a non-transparent and flexible definition of how the national interest is to be assessed.

Further, it can be more difficult to interrogate modelling results, and minor differences in assumptions can lead to big differences in outcomes. This worry is blunted if a probabilistic framework is adopted since, if results are sensitive to certain parameter specifications, this will be indicated by a high probability distribution range around the bottom line evaluation indicators.

In the present study, all relevant data and relationships used in the calculations for the national interest evaluation are included to readers to cross check the conclusions.

2.6 The quantification of risk – the Trigen distribution

For this study the probability distribution selected to quantify risk is the Trigen distribution. This distribution is selected because its parameters are easily related to the conditions that the probability distribution is describing.

To apply a Trigen probability distribution five parameters have to be specified. They are:

(i) the lower bound of the parameter/indicator;

(ii) the mode value of the parameter/indicator;

(iii) the upper bound value of the parameter/indicator;

(iv) the probability that values less the lower bound values will be taken; and

(v) the probability that values less than the upper bound value will be taken.

The approach will be illustrated for perhaps the most important input indicator for this study which has a high level of uncertainty. This indicator is the total remaining identified and undiscovered reserves of natural gas. As shorthand, these reserves are often referred to as remaining reserves. Chapter 6 below nominates the lower bound and upper bound values based on the estimates of others.

Figure 2.1: Trigen probability distribution for remaining reserves

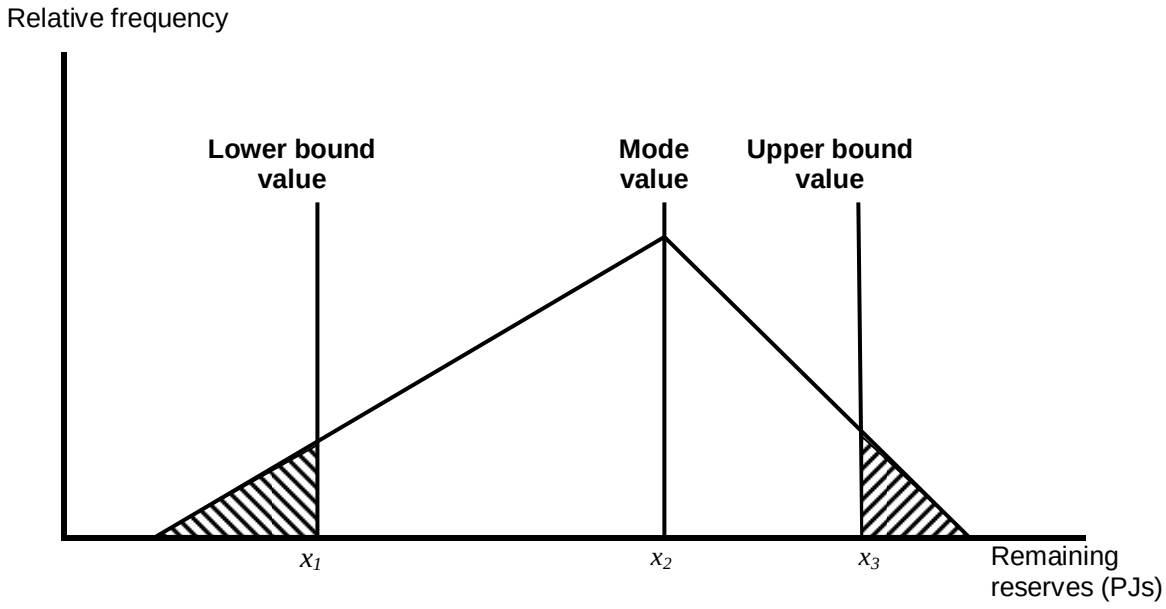


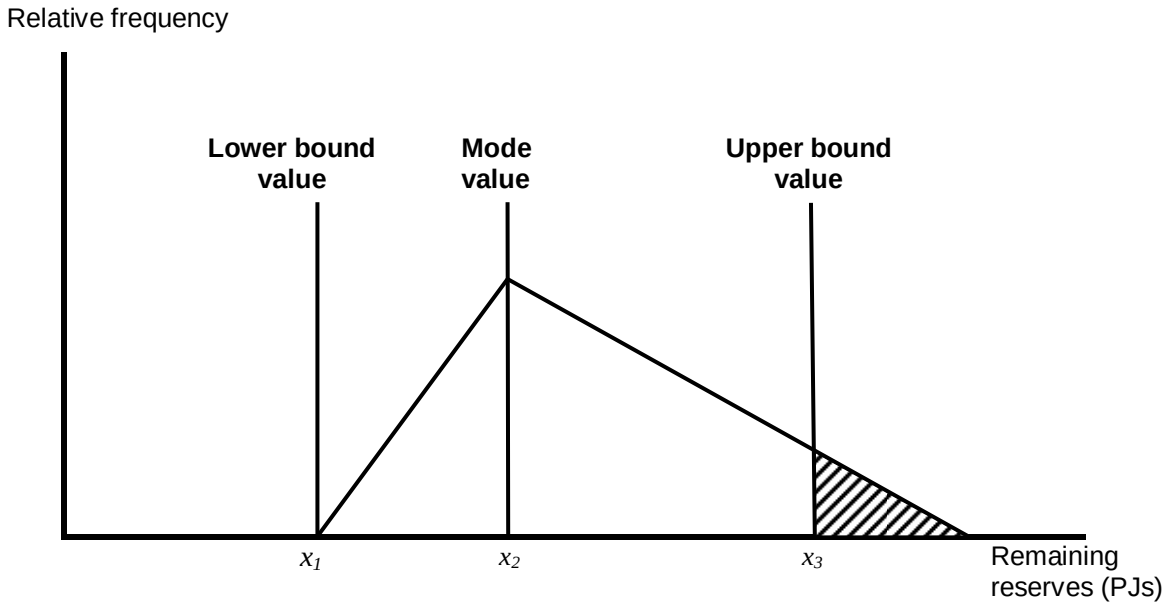
Figure 2.1 illustrates this case. Remaining reserves are measured in petajoules (PJs). The remaining reserves, in terms of lower bound (x_1), mode (x_2) and upper bound values (x_3) are selected on the best available information. If the upper bound probability is set at 100, then there will be no shaded area for the upper bound value. However, if it was considered that the probability of finding more reserves than the upper bound value, then the upper bound probability might be set at 80 per cent with the shaded area in the figure representing a probability of 20 per cent.

The same concepts apply to the lower bound values. For this study the lower bound probability is set at zero, meaning that there is no probability of the lower bound value taking lower values.

The mode can be selected on the basis of whether an upward or downward bias is to be imposed after consideration of upside and downside risks.

Figure 2.2 illustrates the case where the downside risks are considered dominant. Also, the lower bound probability is set at zero.

Figure 2.2: Trigen probability distribution for remaining reserves



2.7 The spillover impacts on other industries

A deficient national interest test would focus on the value of a project with little or no testing of the implications for other industries.

Comprehensive economic national interest testing examines how the project will impact other industries both positively and negatively. Comprehensive national interest testing, therefore, focuses not on the gross benefit of a project but the net impact after taking into account both negative and positive impacts on other industries.

3. LNG export expansion – channels of costs imposed on non-resource industries

LNG expansion can impose costs on other industries. Although a range of transmission channels may be relevant, the costs generally take the form of reductions in the level of output in other industries, sometimes referred to as crowding out. In a fully-employed economy some level of crowding out is inevitable if new projects are to proceed; the question is then whether the benefits from the new project exceed those lost through crowding out. In economies which are less than fully employed opportunities may exist to resource the new project without crowding out, in which case the potential benefits are considerable. However, there is also a possibility that projects will be implemented in ways which cause unnecessary crowding-out.

The discussion here is in qualitative terms and takes LNG expansion as a particular case of resource industry expansion. Although agriculture is also a resource industry, in the context of this chapter the term exclusively applies to the resource extraction industry. In ABS terminology the resource extraction industry is called mining and includes all activities which extract subsurface mineral resources other than water.

3.1 Macroeconomic resource (labour) constraints: Non-resource industry crowding out

Macroeconomic resource constraints apply to any LNG project planned for an economy which would otherwise be operating with full utilisation of resources, or which would reach full resource utilisation in the event of the project proceeding. Full utilisation can apply in both the construction and production phases of the project, and may apply to the economy as a whole or to particular inputs or geographic areas. If the project is to divert inputs from other uses the following tests must return positive answers if the project is to yield net benefits at the national level. (The tests are specified in terms of labour, but can be re-phrased to apply to any other diverted inputs such as office space). The first test is relatively simple: gross product, real wages and Government tax per hour worked by marginal workers transferred into the project are greater than gross product, real wages and taxes per hour worked by marginal workers in the industries from which they are displaced. The second test recognises that labour displacement will be accompanied by a gradual process of capital displacement, particularly during the construction phase, during which capacity-enhancing investment in the non-resource industries will be crowded out by resource project investment. The second test requires that the foregone productivity-enhancing effects of the crowded out investment does not reverse the first test.

Though these tests are conveniently specified in terms of labour, it should be remembered that Australia has a long history of alleviation of labour shortages through increased immigration. The chief concern, therefore, has to be crowded-out investment.

3.2 The drivers of manufacturing expansion

Relative costs are important in the sense that manufacturing will contract if there is too great a gap between domestic and foreign costs of production. However, even if relative costs are comparable and Australian products have a price edge (as when the actual $A/$US exchange rate is below its Purchasing Power Parity level) manufacturing expansion still depends on producers' ability to gain a competitive edge by product differentiation in terms of the design, functionality, durability, etc. of their products. This requires years of lead time in research and development and marketing efforts and also requires time to finance innovation and new capacity involving the latest technology and so on. The efforts of a firm to adopt best practice production technology, innovate via research and development expenditures and develop new markets are all part of either achieving competitive edge product differentiation or identifying opportunities for greater exploitation of existing advantages.

In the typical manufacturing industry the individual producer creates or maintains a market while in the resource extraction industry the producer responds to the market. This is why differentiated product manufacturing is riskier than most other industries. An important aspect of this higher level of risk is that differentiated product manufacturers have to create their own finance for expansion whereas in resource extraction industries this finance is delivered by the market.

At the macroeconomic level the different drivers of the resource extraction industry versus manufacturing expansion can lead to a conflict between manufacturing expansion and equivalent resource extraction industry expansion that is unrelated to issues of national resource availability. This is because the higher terms of trade effect associated with resource extraction industry expansion crowds out manufacturing activity through exchange rate impacts. The converse negative impact on the resource extraction industry from manufacturing expansion is much weaker because manufacturing expansion does not influence the terms of trade.

The most important dynamic is one of cumulative causation. Success in sustained manufacturing expansion depends on an uninterrupted sequence of steps that are resourced adequately and are consistent with market requirements.

Periods of highly over-valued exchange rates associated with elevated resource extraction industry activity intensity are very destructive for manufacturing. This is because high relative costs, in conjunction with already high risks, lead producers to curtail or end new development initiatives. Research and development (R&D) is scaled back and capacity expansion and replacement decisions are postponed, which leads to producers falling further behind their competitors in other countries. When the period of elevated resource extraction investment ends and the exchange rate falls back to cost parity levels domestic competitors are too far behind to restart R&D programs or even, in some cases, to undertake the replacement investment required to ensure long term business sustainability. The same adjustment process occurs, though less severely in terms of the long run negative outcomes, for other trade-exposed industries such as differentiated agriculture, high value business services industries, tourist industries and export-oriented segments of the health and education industries.

In general, a floating exchange rate protects the resource extraction industry in both the expansion and stability phase of the resource price cycle. For manufacturing and other trade exposed industries, positive stimulus to growth mainly comes in periods of low resource prices and hence low exchange rates. However the strength of this positive stimulus to growth is likely to be weak under the following conditions:

(i) if the period of low commodity prices corresponds to a period of relatively low world growth and low expectations of future growth; and

(ii) if a history of high exchange rates during past mining booms has generated expectations of future episodes, leading potential investors to discount the benefits of a current relatively low exchange rate heavily when they calculate the expected future returns on investment. They will not expect the exchange to remain low for very long.

Repeated episodes of resource extraction industry expansion lead to expectations of increasing volatility and the requirement of high short-term returns on investment.

National interest testing of a project's impact on economic security should cover a number of components, including, inter alia trade dependency and resilience to economic shocks.

3.2.1 Economic security: Trade dependency

It is not in an exporting country's national interest to become over-dependent for its exports on any other country. Over-dependence means that if the importing country's economic prospects decline rapidly it will force a significant decline in economic activity on the exporting country. There is also a risk that such trade dependency might be used by the importing country to force political and economic decisions on the exporting country even when they are costly in terms of the latter's national interest.

3.2.2 Economic security and the national interest: Resilience to economic shocks

One of the economic security components of national interest evaluation is the resilience to economic shocks test. If project proceeds, the project should not increase the security risk of the economy to a negative economic shock and, in particular, an exchange rate shock.

The one thing that is certain about any period of strong expansion in resource development is that it will end. More often than not the ending will be characterised by a rapid fall in commodity prices, closely followed by a fall in the exchange rate. This will lead to a widening of the current account deficit which in the Australian case is likely to be unsustainable given that, even with relatively high terms of trade, Australia's current account deficit is likely to be around 5-8 per cent of GDP circa 2016-2020.

The national interest evaluation would require that the following questions be answered.

(i) What is a plausible lower limit for commodity prices at the end of the current resource extraction industry expansion?

(ii) Assuming that the exchange rate falls in proportion to the commodity price fall, what would be the direct impact on:

- domestic inflation rates; and
- the current account deficit?

(iii) How much will national economic activity have to contract to return the inflation rate to desired levels? (The assumption here is that increases in unemployment rates are required to reduce the rate of growth of nominal wages and hence of costs and prices.)

(iv) In terms of (iii), does the project under consideration increase or reduce the contraction in economic activity necessary to bring inflation under control during a period of falling exchange rates?

(v) To what extent are import and export responses to the exchange rate devaluation likely to reduce the initial current account deficit after a reasonable time, say three years? What will be the contribution of the project to these responses?

(vi) Given the outcome of (v), what is the contraction in output required to restore the current account deficit to sustainable levels?

(vii) Given the outcome of (vi) does the go-ahead of the project under evaluation add to or reduce the contraction in economic activity required to restore the current account deficit to acceptable levels?

The national interest test would then compare the calculations from (iv) and (vii). If one or both answers were negative the project would fail the national interest test because it reduced the resilience of the economy to economic shocks. Failure of these tests means that the project could increase the contractions in the level of general economic activity required to achieve satisfactory inflation or balance of payments outcomes during the last phase of an episode of elevated resource expansion, the period of the return to stability.

3.3 Microeconomic resource constraints: Industry crowding out

As distinct from macroeconomic resource constraints, microeconomic resource constraints, resulting from projects proceeding, can impose costs on specific industries by limiting the growth in, or reducing the availability of, key resource inputs which cannot be effectively substituted with other inputs. In this case the industries affected have no option but to reduce actual or planned output in proportion with the actual or expected reduction in key input supply – a process which can easily lead to unemployment of other inputs.

For the case of LNG projects requiring large scale access to natural gas reserves, the impact on the future availability of gas will affect actual and expected investment, output and employment decisions in directly affected industries, especially heavy industry and electricity generation.

The chemical and alumina industries depend on the availability of gas at competitive prices. One or two LNG projects may not undermine confidence in the future availability of gas provided that expected gas reserves are adequate. However, with three and perhaps four additional LNG plants to come online over the next few years, along with projected expansion in the capacity of these plants, it is becoming clear that the combined claims on gas resources may lead to gas supply constraints in the eastern Australian gas market which will almost certainly lead to increasing expectations of real gas cost rises as higher costs of extraction are encountered in exploiting Australia's remaining resources of natural gas. The expectation of rising gas prices will reduce the willingness of producers in the chemical and alumina industries both to maintain the competitiveness of their current plants and to invest in additional capacity. This change in expectations could trigger a long-term decline in these industries which will be accelerated if expectations of gas shortages to domestic users take hold.

Because of the importance of the downstream gas-user industries in Australia's industrial structure and their recent growth performance, the impact of LNG export proposals on domestic users would have to be at the centre of any national interest evaluation for any

valid determination of net project benefits. The critical indicator to focus on in this component of the national interest test is the ratio of annual natural gas demand (including all approved LNG plans) to estimated remaining reserves. If this ratio falls below acceptable levels then substantial microeconomic crowding out is likely to eventuate at some point over the project's life.

Microeconomic crowding out is analysed in Chapters 4 to 7 below.

3.4 Electricity price impacts

A further avenue of impact from LNG expansion lies in the implications for wholesale electricity prices that result from greatly elevated natural gas prices. Gas powered generation already plays a significant role in the electricity market, particularly in meeting peak demand, and its role is expected to grow both to provide backup to variable renewable generation and to provide relatively low-emissions base load. At peak times highly responsive Open Cycle Gas Turbines (OCGT) frequently set the wholesale price in the National Electricity Market and increased fuel costs can be expected to flow directly through to higher prices in that market. A 2010 AGL study found a $35 per megawatt hour difference in the marginal running costs of OCGT between a gas price scenario of $3.60 per GJ and one at $6.75.[2] These increases will flow through to almost all consumers, while those businesses who have moved to insulate themselves from rising electricity prices by installing highly efficient gas-fired cogeneration systems in recent years will find themselves subject to the same fuel price pressures.

[2] Paul Simshauser, Tim Nelson and Thao Doan, *The Boomerang Paradox, Part 1* (October 2010) http://www.aglblog.com.au/wp-content/uploads/2010/10/No.17-Boomerang-Paradox-Final-Oct-20101.pdf.

4. The natural gas usage trade-off: Domestic allocation versus export use – the case of natural gas dependent industries

Central to the application of the national interest test will be the direct economic value of a given quantity of natural gas from LNG exports versus the economic value of the same quantity of gas produced from domestic use. The net value of this comparison is a key estimate because:

(i) it indicates the cost of supply shortages if the export of gas has supply preference over domestic users; and

(ii) a high economic value for gas for domestic use entails that it is in the national interest that confidence in the adequacy of future domestic gas supplies at competitive prices ought not to be undermined by inappropriate exports.

The value of the trade-off will be assessed from two perspectives, namely:

(i) gas dependent industries; and

(ii) the non-resource economy excluding agriculture and mining.

The case of natural gas dependent industries is considered in this chapter and the broader economy-wide industry effects will be considered in the next chapter.

Natural gas dependent industries are industries where a large part of total output depends on the availability of natural gas at relatively low prices. These industries are the chemical sector and the non-ferrous basic metals industries (particularly alumina production).

To calculate the net value trade off for a given quantity of natural gas we estimate the value of current output of these industries that, in the long-term, would be curtailed if the supply of natural gas to these industries ended, or alternatively if supply was available only at such prohibitive prices that the industries became uncompetitive and retreated offshore.

4.1 Natural gas dependent industries: The direct value of natural gas availability

The chemical sector consists of the following major industries:

- basic chemicals;
- paints;
- pharmaceuticals;
- soap and detergents;
- cosmetics;
- other chemicals;
- rubber products; and
- plastic products.

There are other industries where the dependency on natural gas is high enough to justify the assumption that a substantial part of these industries, in the current environment, would not exist without reliable supplies of natural gas at competitive prices. These industries include glass and cement. The electricity sector is also becoming dependent on natural gas for peak power generation and increasingly for base load; this dependence will likely increase with the growth of renewables. The concentration of the present study on non-ferrous metals and chemicals to assess the cost of diversion of gas to LNG exports does not imply that other industries are unaffected. As long as the other affected industries have smaller economic values for gas the marginal cost of gas diversion is determined by the analysed industries.

The assumption in this study is that if natural gas was no longer available, the bulk of the basic chemicals industry would cease to operate, not necessarily overnight, but over time. The basic chemical industry was established in Australia before adequate supplies of natural gas became available. However, this was driven by factors including security objectives arising during and from World War II and high levels of tariff protection and subsidies. These no longer exist. More importantly, it was established at a time when other countries with large scale chemical industries also had limited or no supply of natural gas. The widespread availability of natural gas over the last half century has meant that the technological base of the industry has changed radically so that now a world competitive industry perforce relies on natural gas.

Other industries in the chemical sector rely on the presence of a local basic chemicals industry at the head of their supply chain and part of these industries would not exist without the availability of domestic basic chemical products. Accordingly the basic chemical industry generates a supply multiplier through the rest of the chemical sector. The question is how big is this multiplier effect? This multiplier effect was estimated by the following steps:

(i) using input-output table $m flows to calculate the share of product from the basic chemical industry used in the other seven chemical industries listed above as a percentage of output of each industry;

(ii) find the industry with the highest share of basic chemical products and nominate that share of this industry that would not exist in the long-run without the local availability of supply from the basic chemical industry. This nomination is termed the maximum basic chemical industry dependency ratio;

(iii) extend this nomination to the other chemical industries dependent on the basic chemical industry as the maximum basic chemical industry dependency rate multiplied by the basic chemical input share of the industry being estimated, divided by the basic chemical industry input share from (ii), or for that industry with the maximum basic chemical industry dependency ratio;

(iv) divide the results from (ii) for each industry by the basic chemical sector industry; and

(v) sum the results of (iv) across all the chemical industries to give the basic chemical industry multiplier, with a multiplier of unity for the basic chemical industry itself.

Table 4.1 gives the results of the calculation for Australia in 2008-09. The highest input ratio is for the plastics industry and the maximum basic chemical dependency ratio for this industry is nominated at 60 per cent. From this flows the multiplier estimates by industry shown in the second column of the table. The total multiplier value is 1.6.

Table 4.1 The chemical industry basic chemical multiplier		
	Input from basic chemicals – ratio of output	**Basic chemical sector – output multiplier**
Basic chemicals	0.12	1.00
Paints	0.05	0.02
Pharmaceutical products	0.01	0.04
Soap and detergents	0.06	0.01
Cosmetics	0.06	0.01
Other chemicals	0.07	0.07
Rubber products	0.02	0.01
Plastic products	0.13	0.44
Total	**–**	**1.60**

4.1.1 The importance of the local supply chain

It may be asserted that Australia's non-basic chemical enterprises would be best served by securing basic chemical inputs from anywhere in the world so long as they are at lowest cost and that a local basic chemicals industry is therefore not important. This view is wrong. The benefits of the local supply chain come from:

(i) just-in-time manufacturing capability;

(ii) manufacture of product that is required by the particular production technologies and product types produced by the local industry (these are not fully available elsewhere in the world);

(iii) security of supply; and

(iv) mutual dependency placing upper limits on price settings.

In this context, the multiplier value of Table 4.1 could be considered as being too low.

4.1.2 The non-ferrous metals industry

The non-ferrous metals industry consists of the alumina, aluminium and other processing industries, such as zinc, nickel, etc. Most certainly the alumina industry would not exist without the availability of natural gas, and almost certainly part of the aluminium industry would not exist without the availability of a strong local supply chain extending from bauxite to alumina and finally to aluminium.

Accordingly, the assumption adopted here is that half the Australian non-ferrous basic metals industry would not exist without the availability of plentiful natural gas supplies at reasonable prices.

4.1.3 Natural gas dependent industries: The direct value estimates

Given the above methodology, Table 4.2 profiles the direct benefit Australia receives from the supply of natural gas to the local gas-dependent industries. The estimates are in terms of $m of output per petajoule (PJ) of natural gas input.

Table 4.2	The direct benefit to Australia per PJ of natural gas – natural gas dependent industries (2008-09)
	$m
Non-ferrous metals	
Output per PJ	476
Adjusted output per PJ	238
Chemical sector ($m per PJ)	
Basic chemicals	168
Paints	3.9
Pharmaceuticals	4.0
Soaps and detergents	6.4
Cosmetics	2.2
Other chemical products	11.6
Rubber products	1.6
Plastic products	73.9
Total	**271.6**
LNG exports	**11.5**

The total value of a PJ of natural gas into the basic chemical industry, given the spillover benefits from the other industries, comes to $271 million per PJ. This is in accordance with the 1.6 multiplier developed above for the chemical sector.

The PJ value for LNG exports over the fiscal years from 2009 to 2011 has averaged $11.5 million. It is extremely important to recognise that this exported gas was sourced without affecting supply to domestic industrial users. The trade-off ratio means that if 1 PJ is instead shifted from local use by gas-dependent industries to export, the result is a direct loss of gross output of (averaging the basic metals and chemical sector estimates) of $255 million, compared to a $12 million gain from export revenues. The direct net loss in Australian value added is $243 million, or a loss/benefit ratio of 21 to 1.

This by itself would justify a national interest evaluation methodology which investigates whether local industry has an adequate supply of gas for the next two to four decades and approves LNG plants only when they can be supplied without affecting supply and price to domestic users. The fact that this evaluation is so compelling suggests that no such evaluation has been applied in national interest assessment to date. However, to be secure in this conclusion a further analysis needs to be undertaken, placing the direct estimates in the context of an input-output framework for the total national economy, incorporating into the analysis parameters reflecting differentials in the depreciation rates, tax rates and foreign ownership rates between industries, and assessing the net impact on the indicators selected as appropriate for national interest evaluations.

4.2 The input-output modelling framework

To evaluate the issue further, it is necessary to adopt a mixed demand-supply constrained input-output framework. This is because the existence of gas dependent industries means that these industries' activity levels are determined not simply by demand, but by whether or not there is an adequate supply of natural gas at reasonable prices to support domestic supply expansion where this is required to accommodate an increase in demand.

Let x_i represent (gross) output of industry i.

The economy consists of n industries, of which m industries are supply constrained by the availability of natural gas. By supply constrained is meant that they cannot automatically respond to demand changes unless the natural gas industry decides to provide the required inputs of (in this case) natural gas without major price increases.

The input-output relationship for the case where no industry is constrained is:

$$\begin{pmatrix} x_1 \\ \vdots \\ x_m \\ \cdots\cdots \\ x_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ x_n \end{pmatrix} = \begin{pmatrix} a_1 & \cdots\cdots & a_{1,m} \\ \vdots & & \vdots \\ a_{m,1} & \cdots\cdots & a_{m,n} \\ \cdots\cdots & & \cdots\cdots \\ a_{m+1,1} & \cdots\cdots & a_{m+1,n} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ a_{n,1} & \cdots\cdots & a_{m,n} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ x_m \\ \\ x_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ x_n \end{pmatrix}$$

$$+ \begin{pmatrix} c_1 & \cdots\cdots & c_{1,n} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ c_{m,1} & & c_{m,n} \\ c_{m+1,1} & & c_{m+1,n} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ c_{n,1} & \cdots\cdots & c_{m,n} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ \vdots \\ x_m \\ x_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ x_n \end{pmatrix}$$

$$+ \begin{pmatrix} f_1 \\ \vdots \\ \vdots \\ f_m \\ f_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ f_n \end{pmatrix}$$

Given that x_1 to x_m are constrained, the (4.1) can be rewritten as:

$$\begin{pmatrix} x_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ x_n \end{pmatrix} = \begin{pmatrix} a_{m+1,1} & \cdots & a_{m+1,m} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ a_{n,1} & \cdots & a_{n,m} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ \vdots \\ \vdots \\ x_m \end{pmatrix}$$

$$+ \begin{pmatrix} a_{n+1,m+1} & \cdots & a_{m+1,m} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ a_{n,m+1} & \cdots & a_{n,n} \end{pmatrix} \begin{pmatrix} x_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ x_m \end{pmatrix}$$

$$+ \begin{pmatrix} c_{m+1,1} & \cdots & c_{m+1,m} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ c_{m,1} & \cdots & c_{n,m} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ \vdots \\ \vdots \\ x_m \end{pmatrix}$$

$$+ \begin{pmatrix} c_{m+1,m+1} & \cdots & c_{m+1,n} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ c_{n,m+1} & \cdots & c_{n,n} \end{pmatrix} \begin{pmatrix} x_1 \\ \vdots \\ \vdots \\ \vdots \\ x_m \end{pmatrix}$$

$$+ \begin{pmatrix} f_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ f_n \end{pmatrix}$$

Or in matrix form:

$$\boldsymbol{x^u} = \boldsymbol{A^c x^c + C^c x^c + A^u x^u + C^u x^u + f^u}$$

Where:

$$\boldsymbol{x^u} = \begin{pmatrix} x_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ x_n \end{pmatrix}$$

$$\boldsymbol{x^c} = \begin{pmatrix} x_1 \\ \vdots \\ \vdots \\ \vdots \\ x_m \end{pmatrix}$$

$$\boldsymbol{f^u} = \begin{pmatrix} f_{m+1} \\ \vdots \\ \vdots \\ \vdots \\ f_n \end{pmatrix}$$

A^c = $(n - m) * m$ matrix of coefficient of inter-industry input-output coefficients.

A^u = $(n - m) * (n - m)$ coefficients of inter-industry input-output coefficients.

C^c = $(n - m) * m$ matrix of consumption output coefficients for constrained industries.

C^u = $(n - m) * (n - m)$ matrix of consumption output coefficients for unconstrained industries.

Unconstrained industry output is, therefore, given by:

$$\boldsymbol{x^u} = \boldsymbol{[I - A^u - C^u]^{-1}\,[A^c + C^c]} + \boldsymbol{[I - A^u - C^u]^{-1}\,f^u}$$

Other indicators

Other indicators are given by the general form:

$$i_{o,j} = va_j \,.\, i^c_o\, x_j$$

Where:

$i_{o,j}$ = other indicator value (net national product, wage, salaries and mixed income, etc.) for industry j.

va_j = share of value added at factor cost to total gross output for industry j.

i^c_o = ratio of indicator o to value added (or gross surplus) for industry j.

x_j = total gross output for industry j.

The aggregate value across industries is given by:

$$i^t = \sum_{j-1}^{n} i_j$$

The key coefficients, i^c_o, are presented in Appendix B.

4.3 The input-output tables

The direct allocation of imports input-output table used for this study for 2008-09 is given in Appendix B. Other associated tables used are:

(i) the flow table with indirect allocation of imports;

(ii) the indirect tax flow table;

(iii) the import flow table as the difference between the Appendix B table and the indirect import table described in (i).

The key coefficients, tax, income, etc. by industry are also given in the table in Appendix B.

Adjustments are made to the coefficients given in Appendix B to better reflect the East Coast LNG industry as distinct from the offshore Western Australian industry, which is the only LNG industry reflected in the 2008-09 input-output tables. The main adjustment is to employment. The East Coast LNG industry is likely to be more labour intensive in operation due, in part, to its reliance on a land-based, dispersed natural gas collection and distribution system. As a result, the employment to output ratio is set at 0.19 or 60 per cent greater than the Western Australian average. Appropriate adjustments are made to other related parameters.

The foreign ownership ratio is also likely to be lower than for Western Australian projects. The average foreign ownership ratio for Queensland projects is set at 30 per cent.

The other issue is the tax rate. Once the Resource Rent Tax (RRT) becomes operational the ratio of direct tax to gross surplus will approach 50 per cent. However, this will not occur until towards 2030. In the early years, the tax rate will be negligible, rising to around 15 to 20 per cent once company tax rates become applicable. One way to account for this is to adjust the tax rates year by year, requiring all results to be presented in cumulative discounted terms only rather than as yearly average impacts. Accordingly, the tax rate is set at its average project level of around 35 cents in the dollar of gross surplus, which gives a significant upward bias to the benefits of LNG in the first half of a project's life.

4.4 The impact on the economy of LNG exports – a 50 PJ expansion

The model framework developed above will be used to assess the impact on the economy of a 50 PJ (approximately one million tonnes) LNG export expansion supplied at the expense of supply to domestic gas-dependent industries. The construction impacts are not considered.

In 2008-09 dollars, the additional gross output of LNG (and exports) comes to $620 million. Table A.1 indicates that GDP at market prices increases by $729 million, implying a standard multiplier of 1.2. However, the increase in net national product is half the increase in GDP. The increase in the benefit indicator is $401 million annually.

4.5 A 50 PJ contraction in natural gas supply to natural gas dependent industries

The second column in Table A.2 assumes that the 50 PJ expansion allocated to the LNG project is diverted from natural gas dependent industries. The reduction in gross output for the constrained industries given in Table A.2 runs to $12.8 billion in 2009 prices. This follows directly from the calculations given above on the assumption that 25 PJ is withdrawn from the non-ferrous metal industry and 25 PJ from the basic chemicals industry.

In this case the annual average loss in GDP at market prices is $11.0 billion, while total employment falls by 203,000 from what otherwise would have been the case. From column three of Table A.2 the gross negative from the natural gas withdrawal from natural gas dependent industries so overwhelms the positive impacts of LNG expansion that the net change between the two cases is close to the negative impacts of the gas withdrawal case for gas dependant industries.

The net (LNG plus gas dependant industry) cumulative discounted benefit indicator outcome is -$100 billion. The cost benefit ratio for gas withdrawal increases to 24.2 to 1, which may be compared with the preliminary estimate of 21 to 1 calculated in Section 4.1.3 above. Far from reducing the burden, placing the two cases in the broader context of the national economy increases the net cost of shifting gas from gas-dependent industries compared to LNG export expansion.

4.6 Conclusion

When natural gas is reallocated to exports from domestic use in gas-dependent industries, for every $1 of benefit gained from exports $24 of benefits is lost in contraction of the gas-dependent industries. This can be stated in discounted terms. In 2009 140 PJ of natural gas was allocated to Australian gas-dependent industries. It would have taken 3,400 PJ of LNG exports to deliver this benefit. If, at full development, the Australian east coast LNG industry is supplied at the expense of domestic gas-dependent industry, it will deliver less than a third of the benefit required to offset the loss of domestic industry.

On the other hand, the domestic gas using industrial sector does not put a significant claim on the supply options for Australian LNG and thus the growth options for LNG are not significantly constrained by domestic needs at present. However, this will change if large demands are made on gas as a transitional fuel to renewables.

The core issue is whether the large scale export of gas will constrain the ability of the domestic industry to expand or even maintain existing production levels. This will be considered in Chapter 6. In Chapter 5 we generalise the calculations of the present chapter.

5. The net benefits: LNG exports versus domestic gas use – the case of the general economy

One way to assess the impact of switching natural gas from domestic to export sales on the general economy, that is the non-resource sector of the economy, would be to use a large scale multi-sector model of the economy with detailed industry energy demand equations. Energy prices in general and natural gas prices in particular could then be adjusted until domestic natural gas use was reduced to required levels and the impact on the macroeconomic indicators assessed.

NIEIR has such a model and has used it for similar exercises many times. However, the model results are highly sensitive to model closure conditions. The final outcomes depend on which sector bears the cost adjustment for whatever the changed energy capacity arrangements have to be put in place to maintain overall demand/supply balance. From experience, the quantitative impact of the optimum strategy is approximated by a simple approach, which is adopted here.

The approach requires the direct estimation of a production function for the non-resource economy with capital, labour, gas and electricity as factor inputs. The estimated production function coefficients are then used to calculate the elasticity of substitution between gas and electricity. These two fuels are sufficient to specify the production function since, after the adjustment from the oil price shocks of the 1970s and early 1980s, the substitutability between natural gas and oil has been reduced to low levels. Effectively, gas now mainly competes with electricity.

A quantitative estimate of the elasticity of substitution between gas and electricity will enable the calculation of the quantity of electricity that must be supplied to leave economic activity unchanged after the withdrawal of domestic gas.

However, the economic adjustment does not end there. If the additional electricity supply can only be secured at significant additional cost, the additional costs on the economy will have to be taken into account. If these costs are allowed to flow into the industry structure of the economy there will be a whole range of flow-on effects, including loss of exports, increased imports and reduced real incomes. The least cost option (in terms of the fall in economic activity) is to channel the costs into the household sector with the major burden of adjustment being via real household incomes rather than by reduction in investment, exports, employment, and so on.

An alternative strategy would assume that there is no attempt to compensate for the loss of gas supply and non-resource gross product falls in line with the production function coefficient implications. This channel will also be evaluated in this chapter.

There is a third possible approach. This involves suppressing natural gas supply into the electricity sector which would force electricity production to exploit alternative and higher cost sources of supply. This lies outside the production function approach since natural gas input into electricity is included in the electricity input into the general economy.

These three alternative approaches are evaluated in turn.

5.1 The Australian production function

The task is to estimate a production function to determine directly the role of gas and electricity in driving Australia's economic activity. By definition it takes a supply side approach to economic activity.

A general production function can be written in the form:

$$Y = ae^{rt}(K, L, E, G) \quad (5.1)$$

Where:

Y = output, which may be defined as gross product of the economy, gross product of the private sector, or gross product of a combination of industries.

L = labour employed.

t = transport or total general government capital stock.

r = rate of exogenous technological change.

If a Cobb-Douglas production function is specified, then (4.1) becomes:

$$\ln Y = \ln a + rt + \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln TE + \alpha_4 \ln G \quad (5.2)$$

where ln denotes natural logarithms.

The key estimate is for the a coefficient, or the elasticity of output with respect to gas input.

However, the Cobb-Douglas production function is restrictive in terms of the implied returns to scale for individual factors and the elasticity of substitution between factors. The latter is important for this study because of the requirement to use the elasticity of substitution between gas and electricity to obtain estimates of the costs of gas demand suppression.

To circumvent this, a flexible, that is, unrestricted, transcendental production function is estimated. This takes the form:

$$Y = Ae^{rt} \ln^{\alpha 1} e^{b,L} . K^{\alpha 2} e^{b2K} . E^{\alpha 3} e^{b3E} . G^{\alpha 4} e^{b4G} \quad (5.3)$$

The two estimated coefficients which are of particular interest to this study are α_4 and b^4.

5.1.1 The data

Pooled time series cross section data are used to estimate the coefficients. The data is for the five mainland states. The period of estimation is from 1980 to 2011.

The output variable is state gross non-resource product (total state gross product at factor cost less gross product of agriculture and mining and ownership of dwellings. The annual data over recent years is from the Australian Bureau of Statistics (ABS) "*Australian National Accounts*", Cat. no. 5202.0. These estimates are spliced back to 1980 using estimates by NIEIR.

The labour input variable is total hours of work of the non-resource sector by state obtained from ABS "*Labour Force Australia*", Cat. no. 6203.0.

The methodology of estimating capital stock input by state for business capital stock and transport infrastructure capital stock is outlined in NIEIR's "*Transport Infrastructure Investment: An Instrument for Sustainable Debt Financed Fiscal Policy*", April 2012.

The energy data is taken from the Bureau of Resources and Energy "*Economics – data base for energy consumption by state and industry*". The electricity sector energy input is excluded from the non-resource sector totals for electricity and natural gas.

To remove cyclical effects a five year moving average is passed through the data.

5.1.2 The production function: Coefficient estimates and implications

The estimated coefficients are given in Table 5.1. Ignoring the constraints, non-zero coefficients are of the correct sign and, bar one, strongly significant.

A sensitivity analysis was used to calculate the elasticity of substitution between gas and electricity input and the elasticity of non-resource gross product for the four Eastern Australian mainland states. The elasticity of substitution, as at 2011, was calculated as -0.67. This means that if one PJ of natural gas is withdrawn from Eastern Australian markets, it will require an increase in supply of 0.67 PJ of electricity to maintain a constant level of non-resource gross product.

The elasticity of non-resource gross product at factor cost, with respect to natural gas input for the four Eastern Australian mainland states, was found to be 0.082.

Table 5.1 Estimated coefficients of the transcendental production function

Parameters	Coefficient	t-value
α_1	0.455	9.9
b_1	0.00000015	1.4
α_2	0.483	10.6
b_2	-0.0000067	10.1
α_3	0.011	0.6
b_3	0.103	3.2
α_4	0.0	–
b_4	0.00088	7.6
NSW constant	-0.428	0.8
VIC constant	-0.609	1.1
QLD constant	-0.653	1.2
SA constant	-0.615	1.2
WA constant	-0.803	1.6
$R^2 = 0.985$		

5.2 General economy adjustment to domestic suppression of 50 PJ of natural gas – the electricity substitution case

The three self-contained cases for the adjustment of the general economy to the suppression of 50 PJ of natural gas will be examined in terms of their impact on the economy using the framework applied in the previous chapter.

The elasticity of substitution between natural gas and electricity estimated above suggests that if 50 PJ of natural gas are withdrawn from the domestic market, 34 PJ of electricity will be required to maintain production capacity. The substitution would be partially focussed on space and water heating and process heat involving drying and melting.

Table 5.2 indicates that a considerable cost differential currently exists between electricity and gas, depending on the market and the carbon price. This means that total direct costs of adjustment will depend on the carbon price and a scenario analysis is therefore needed. This will be undertaken in Chapter 7 below. To illustrate the impact on the economy, in terms of the analysis of the previous section, a $50 price of carbon will be assumed. The data in Table 5.2 includes all transmission and distribution costs. The analysis here is for ex-plant costs.

Table 5.2 Current electricity and gas prices in Australia: The impact of carbon prices

	Electricity price	Gas price
No carbon pricing		
Industrial	$100/MWh = $28/GJ	$10/GJ
Residential/commercial	$250/MWh = $69/GJ	$16/GJ
Carbon pricing – $25/t CO_2e		
Industrial	$125/MWh = $35/GJ	$11.8/GJ
Residential/commercial	$275/MWh = $76/GJ	$17.8/GJ
Carbon pricing – $50/t CO_2e		
Industrial	$145/MWh = $40/GJ	$13.3/GJ
Residential/commercial	$295/MWh = $82/GJ	$19.3/GJ

5.2.1 The net cost of electricity substitution

It is critical that the same model framework be used for all evolutions of the possible adjustment paths for gas suppression. The framework developed in the previous section is ideal in terms of transparency and assessing the plausible impact of the contraction in gas dependent industries. For the more general adjustment paths of this chapter, other evaluation approaches are possible, but these would result in unacceptably different methodologies for quantifying impacts. Accordingly, the methodology used for calculating impacts in the electricity substitution case has been designed so that the modelling framework of the previous chapter can be employed. This framework also allows the straightforward introduction of probability analysis. The result is that the shock which is imposed on the model structure becomes a direct adjustment to real household disposable income.

It should be noted that no allowance has been made for the impact on distribution margins. It is assumed that the same total margins have to be recouped to support the distribution infrastructure installed, irrespective of throughput. In any case, the reduction in gas distribution margin would be offset to some extent by the increase in electricity margins.

These preliminaries out of the way, we proceed to model the full electricity substitution case. In the absence of the East Coast LNG plants, the industrial gas price will be taken to be $6/GJ. For each $10 of carbon price the cost of natural gas increases by $0.72/GJ, so the alternative gas price is $9.6/GJ. Therefore, the forgone cost of natural gas will be 9.6 x 50, or $480 million in 2009 prices.

Assuming that between 2012 and the 2020s there is increasing public and international anxiety about the baleful consequences if CO_2 emissions are not curbed, and therefore increasing political and economic pressure to reduce CO_2 emissions, the alternative electricity substitution cost will be taken to be an average of renewable options, for which recent cost estimates range from wind at $110 MWh to solar at over $200 MWh, with other renewables such as geothermal between the two polar cases. The average will be set at $150 MWh. This translates into $42 million additional cost per PJ, or $1.43 billion for the 34 PJ of electricity required.

The net cost is, therefore, 1.43 – 0.48 = $0.95 billion in 2009 prices annually.

To minimise the loss of employment and economic activity, the optimum cost allocation strategy would be to channel the impact into additional cost imposts on the household sector. This would hypothetically be done by:

(i) increasing direct taxes on households to pay for subsidies to shelter industry from the additional energy costs;

(ii) increasing residential electricity prices more than prices for non-household users; and

(iii) increasing the costs of electricity for those commercial sectors that service the household and Government sectors rather than trade-exposed industries.

The results of doing this for the full electricity substitution case are given in Table A.4 to Table A.6.

For the gross product indicators the impact is positive being about two thirds of the LNG overall impact. The combined total impact is a strong $1199m at factor cost. For net national product the increase is much less because of the high depreciation rate for the electricity sector. More importantly private consumption expenditure falls by $810m, or a net $646m if the LNG impact is included. The benefit indicator falls by $423m, more than cancelling out the gain from LNG exports. Full electricity substitution therefore results in no net benefit from LNG exports. The strong response for gross product is due to the fact that the drivers of this growth are dominated by factors (foreign income and depreciation allowances) which cannot be used to support domestic consumption and tax growth.

5.3 General economy adjustment to domestic suppression of 50 PJ of natural gas: The decline in economic activity case

Rather than release gas for export by switching to electricity, it would be possible to release the gas by reducing industrial activity. It is implausible to assume that all the natural gas suppression will involve reductions to industry; part will come from reductions in allocation to households. In the case here it is assumed to be 30 per cent of the total reduction impacts directly on households at a cost similar to the electricity substitution.

This still leaves 35 PJ to be suppressed from the non-resource industries. For the Eastern Australian market this will represent a 7.6 per cent reduction in supply. Using the elasticity estimated above, this will generate a 0.6 per cent reduction in gross non-resource product which translates into a $4.68 billion reduction in non-resource gross product at factor cost for the four Eastern Australian states. Using the relationship between direct reductions in household income and gross product at factor cost (see the model sensitivity results in the previous section) this indicates a direct reduction in household income of $3.58 billion. To this has to be added the reduction in real household incomes due to the transfer of 15 PJ of natural gas from the household sector to exports and its replacement with electricity. Using the full substitution case as the benchmark this will add $0.3 billion, bringing the total to $3.9 billion in 2009 prices.

Table A.4 shows the impact on the general economy for the general reduction in economic activity case. In terms of gross and net product, the decline in activity is six times the LNG benefit. The benefit indicator declines by 17 times the LNG benefit. Even if we make no particular allowance for gas-dependent industries and instead base the calculations on the non-resource sector as a whole, the outcome is decidedly unattractive.

5.4 General economy adjustment to suppression of 50 PJ of natural gas: The electricity sector gas substitution case

We now consider the case where gas is switched from the electricity sector to LNG exports. In this case, before the need for gas suppression, the 50 PJ of gas would have been used in the electricity sector to generate electricity. The scenario is that, in the absence of East Coast LNG exports, large scale gas-fired electricity plants would have been built near major CSM deposits and these exports require that the electricity sector will have to substitute other sources of electricity generation.

The two key determinants of the cost of this response are the cost of electricity generated from natural gas and the cost of the alternatives.

The cost of natural gas derived electricity will be a function of the natural gas price and the carbon price. Table 5.3 indicates a range of responses depending on the gas price and the carbon price. Assessing the effect of the carbon price involves modelling probabilities, because of the range of possibilities both for a given year and across time. This is carried out in Chapter 6 below. To illustrate the impact on the economy that is comparable to the approach taken for other adjustment paths above specific assumptions have to be made. The assumptions are:

- a price per gigajoule of $4; and
- a carbon price of $50.

From Table 5.3 this indicates an electricity price of $78 MWh.

As before, the alternative electricity price will be renewables at an average rate of $150 MWh. To complete the cost estimates it is necessary to know how much electricity can be generated from 1 PJ of natural gas. 1 PJ of electricity is 278 GWh. If a conversion factor of 0.45 is assumed, then 1 PJ of natural gas will generate 125 GWh of electricity. Hence, 50 PJ will generate 6,250 GWh or $489 million. If the alternative 6,250 GWh comes from renewables, then the cost will be 6.25 x 150, or $938 million, giving a net cost of $457 million.

Table 5.3 Natural gas based electricity – cost of supply by input costs

Combinations	Natural gas price ($/GJ)	Carbon price ($/tonne of CO_2)	Long-run marginal cost CCGT ($/MWh)
1	3	0	49
2	4	0	55
3	5	0	61
4	6	0	67
5	3	50	69
6	4	70	83
7	5	80	93
8	6	100	107
Alternative			**150**

Note: CCGT denotes combined cycle gas turbine. Assume 65 per cent capacity factor. For every $10 increase – carbon price a $/tonne of CO_2, the price will increase by $4/MWh. For every $1/GJ increase in the natural gas input price the $/MWh price increases by approximately $6 in 2009 prices.

The impact on the general economy of the gas suppression case is given in Table A.4. This is a low cost case compared to the decline in economic activity case but comes at a higher cost than the full electricity substitution case. For the gross product indicators, the decline is a little under 40 percent of the LNG benefit. However, there is a deterioration compared to the net product indicator with the loss from the gas suppression case almost cancelling out the gain from the LNG expansion. However for the benefit indicator the loss from gas suppression in electricity use is nearly 30 percent more than the LNG benefit.

It should also be noted that the suppression of gas supply to the electricity sector, or if suppression is avoided the increase in gas prices that will result from LNG netback pricing and production from higher-cost reserves, would ultimately have implications for the costs of all existing gas-fired generators. Operating costs for both peaking plants and CCGT would increase, driving higher spot and contract prices in the National Electricity Market.

The electricity sector gas suppression case is a relatively low cost option. Nevertheless the net costs are still significant.

5.5 Conclusion

Analysis which abstracts from the position of the gas-dependent industries concludes that natural gas can be switched from domestic sales to LNG export sales using a number of strategies, the best of which yields little benefit to the economy and the worst substantial net costs. In this worst case, the costs approach those calculated when concentrating on the position of the gas dependant industries. To minimise cost, the following factors would have to be put in place, namely:

(i) the natural gas dependent industries were quarantined from any impact of LNG expansion on available gas supplies and costs;

(ii) the electricity sector would have to plan to carry the full cost of adjustment including higher quantitative targets for renewable energy; and

(iii) the household sector would have to accept that it and not industry would have to directly accept the full costs of adjustment.

Historical experience, the current design of the policy for the introduction of carbon taxes and the political debate over carbon pricing give no grounds for businesses to expect that the minimum cost path would be adopted if it becomes necessary to withdraw domestic natural gas supply to meet export contracts.

How the four options may be combined to determine an overall gas suppression response is outlined in Chapter 7 below.

6. The Australian gas market: Resources, prices and risk of supply shortage by 2040

The prime objective of this chapter is to assess the risks of supply shortages in the Eastern Australian gas market by 2040. This is a critical final step to assessing the likelihood that the costs of natural gas supply withdrawal assessed in the previous two chapters will be realised. The risk of gas supply shortages emerging in turn depends on estimates of natural gas reserves remaining to be discovered.

6.1 The Australian natural gas market: Background

The Australian natural gas industry has three distinct components:

1. the domestic Eastern Australian system;
2. the domestic west/north coast systems; and
3. the LNG export industry (currently only on the west coast fed mainly from off-shore fields, with plants proposed for Eastern Australia based on coal seam methane).

As with electricity, there is no transmission connection between the east and west coasts (Tasmania is connected to the eastern gas and electricity transmission systems).

In 2012-13 total Australian gas production will be about 2,500 PJ, about 35 per cent of which will be exported as LNG. The main producing basins are: in the East, the Gippsland, Cooper-Eromanga and Otway (conventional); and the Bowen and Surat (coal seam gas); and in the West, the Carnarvon, Bonaparte and Browse.

In the domestic markets, east coast demands are about 800 PJs and west/north coast demands 650 PJs. The major domestic markets are for gas-powered electricity generation (GPG), industrial and residential consumption. The GPG market is growing most rapidly but future GPG increases depend significantly on carbon pricing policies.

The current CO_2e price of \$23/t CO_2e is not high enough to stimulate substantial growth in GPG for combined cycle gas turbine (CCGT) base load plants. Gas peaking plants are relatively unaffected by carbon pricing, being mainly responsive to growing summer peak loads where gas plants (open cycle gas turbines, OCGTs) have distinct quick response advantages. Growth in GPG base load will depend on carbon tax levels, gas prices, coal prices and any policy initiatives that directly favour gas (such as the Queensland gas generation policy).

In the industrial sector gas is used for process heat (drying, etc. such as alumina production), water heating, steam raising and for production of petrochemicals (such as ammonia). Metal products, petroleum and chemicals and non-metallic mineral products account for about 85 per cent of industrial gas consumption in Australia.

The alumina industry, a major use of gas for drying (often with cogeneration), is concentrated in south-west Western Australia (Kwinana region) and Gladstone in Queensland. In Western Australia, industrial gas prices have increased substantially (from \$4/GJ to \$8/GJ) due to domestic market supply/demand constraints and reliance (65 per cent) on the North West Shelf project (LNG predominantly) supply. In eastern Australia industrial gas prices are in the \$4 to \$6/GJ range, including network costs as well as wholesale gas costs. At higher prices (>\$10/GJ) some industrial gas users could lose competitiveness to competitors based

in gas rich regions, such as the Middle East. Fertiliser and other chemical plants would be at risk, as would alumina.

Over 2011-25 NIEIR estimates (July 2012) growth in industrial gas use will average 2.91 per cent per year, residential 1.48 per cent, commercial 2.4 per cent and electricity generation 4.48 per cent per annum.

The major industrial market is in Western Australia (alumina, direct reduced iron and ammonium nitrate), 55 per cent of national industrial market. The major residential market is in Victoria (space and water heating), 65 per cent of national residential market. GPG is strongest in Queensland and Western Australia.

6.2 Estimates of reserves

Category 1 reserves (commonly referred to as 'Proven' or 'P1' reserves) include recoverable reserves that have been declared commercially viable. **Category 2** reserves (commonly referred to as "Probable' or 'P2' reserves) comprise estimates of recoverable reserves that have not yet been declared commercially viable, although they have been geologically proved or are awaiting further appraisal. Geoscience Australia (GSA) are now **mainly** using the McKelvey classification of economic and sub-economic demonstrated resources (EDR, SDR), but do not precisely define (for example, $/G) EDR and SDR. In addition, P3 possible/potential reserve estimates are sometimes estimated. Also, inferred resources are mentioned. These arise from recent discoveries and finds that require further appraisal.

While there is always some uncertainty associated with any reserves estimates, GSA's estimates are often regarded as conservative. These estimates should perhaps be seen as a lower bound estimate of actual reserves. Due to this conservatism, NIEIR formulates its own estimates of reserve levels in the eastern basins by supplementing official data with information recently published by operators and other basin participants. Over the years (1980s on) we have observed significant increases in GSA reserves towards NIEIR estimates.

West Coast (Western Australia/Northern Territory) reserves are mainly in off-shore basins (Carnarvon, Browse, Bonaparte) and amount to about (2009 data, no recent update) 165,000 PJ in P1 and P2 reserves (not including CSM or shale gas). Source: Geoscience Australia, Oil and Gas Resources of Australia 2008.

Eastern Australian reserves, from the same source, P1 and P2 reserves were about 11,000 PJ (excluding CSM and shale reserves); and P3 at 28,000 PJ. CSM reserves (P1, P2) were estimated at 37,000 PJ (P3 at 60,000 PJ).

McKelvey classification reserve estimates are outlined below. Source: Australian Gas Resource Assessment, 2012.

Table 6.1 Australian conventional gas resource represented as McKelvey classification estimates as of 1 January 2011

Conventional gas resources	PJ	tcf
Economic demonstrated resources	113,400	111
Sub-economic demonstrated resources	59,600	53
Inferred resources	11,000	20
Total	**184,000**	**184**

Table 6.2 McKelvey classification estimates by basin as at 1 January 2011			
		Gas	
McKelvey class.	**Basin**	**PJ**	**tcf**
EDR	Carnarvon	74,700	68
EDR	Browse	17,900	16
EDR	Bonaparte	10,100	9
EDR	Gippsland	7,000	6
EDR	Other	3,600	0
Total EDR		**113,400**	**103**
SDR	Carnarvon	26,800	24
SDR	Browse	17,900	16
SDR	Bonaparte	11,900	11
SDR	Gippsland	2,300	2
SDR	Other	1,200	1
Total SDR		**59,600**	**54**
Total (EDR + SDR)		**173,000**	**157**

CSM/G reserve estimates, not included above are presented below.

Table 6.3 CSG resources at January 2011		
CSG resources	**PJ**	**tcf**
Economic demonstrated resources	35,905	33
Sub-economic demonstrated resources	65,529	60
Inferred resources	122,020	111
Total	**223,454**	**203**

Table 6.4 Total Australian gas resources

Resource category	Conventional gas		Coal seam gas		Tight gas		Shale gas		Total gas	
	PJ	**tcf**	**PJ**	**tcf**	**PJ**	**tcf**	**PJ**	**tcf**	**PJ**	**tcf**
EDR	113,400	103	35,905	33	–	–	–	–	149,305	136
SDR	59,600	54	65,529	60	–	–	2,200	2	127,329	116
Inferred	11,000	10	122,020	111	22,052	20	–	–	155,072	141
All identified resources	**184,000**	**167**	**223,454**	**203**	**22,052**	**20**	**2,200**	**2**	**431,706**	**392**
Potential in ground resource	Unknown	Unknown	258,888	235	Unknown	Unknown	435,600	396	694,488	631
Resources – identified, potential and undiscovered	184,000	167	258,888	235	22,052	20	435,600	396	900,540	819

Note: Conventional gas demonstrated resources as of January 2011; CSG demonstrated resources as of January 2012. Note CSG 2P reserves and 2C resources are used as proxies for EDR and SDR respectively.

Tight gas and shale gas resources

Currently Australia has no proven reserves of tight or shale gas. The in-place resources of tight gas are estimated at around 22,000 PJ (20 tcf) but together with shale gas could be considerably higher. The largest known resources of tight and shale gas are in low permeability sandstone reservoirs in the Perth, Canning, Cooper and Gippsland basins with APPEA's estimates at 440,000 PJ of total possible reserves

6.3 Total Australian reserves (identified, potential and undiscovered)

What is important for this study is not total Australian reserves, but reserves that can supply the integrated Eastern Australian market. This is the market that the East Coast LNG projects will impact. The situation would be different if the Western Australian market was integrated with the Eastern Australian market.

6.3.1 Two estimates of Eastern Australian case reserves

One recent attempt to estimate Eastern Australian reserves was carried out by **Core Energy Group** (COE): gas (Eastern Australian) resource studies, 2012. This study included a section on the distribution of gas reserves by gas production costs (COE page 24).

Core estimated a total of 143,066 PJs potential resource at 1 January 2012 at up to $6/GJ and about 161,000 PJs at up to $8/GJ.

In the report (Table 7.1) **conventional** resources were estimated to be 13,000 PJ at up to $7.37/GJ at a 10 per cent rate of return. In Table 7.2, **coal seam gas** reserves were estimated to be 96,000 PJ at up to $5.58/GJ at a 10 per cent return. In Table 7.3 estimates for total Eastern Australian **prospective** resources were given as 190,000 PJ at up to $9.27/GJ at a 10 per cent return.

The study also gave estimates of gas transmission costs as at April 2012. Indicative tariffs for **existing** pipelines are provided in this report in Table 6.4, page 12.

For **new** pipelines estimated tariffs are presented in **Figure 10.4** for a range of pipelines. For example, an estimated tariff of $0.0018/GJ/km for a 1,000 kilometre hypothetical pipeline would result in a tariff of $1.8/GJ for the full 1,000 kilometres of gas transmission. Estimated tariffs are also presented in **Figure 10.4** for a range of existing pipelines such as $0.0014/GJ/km for the Eastern Gas Pipeline. Tariff components (WACC, taxation, etc.) are also provided for several pipelines.

Another study which also estimates remaining gas reserves was by **ACIL Tasman**: draft report, December 2011, Fuel cost projections. This report was prepared for Worley Parsons to provide natural gas and coal outlooks for AEMO modelling.

ACIL Tasman estimated (page 6, Figure 3) that around 90,000 PJ of potential (reserves and resource) could be developed on the East Australian seaboard at up to A$8/GJ (of which 50,000 PJ is Queensland CSM); and 60,000 PJ (about 40,000 PJ of CSM) at up to $6/GJ. **Note** that in the same report ACIL Tasman estimated that in addition to these reserve estimates 25,000 PJ of Eastern Australian shale gas could be available at $9/GJ.

These estimates are much lower than the COE estimates outlined above. The reasons for estimate differences are difficult to discern from the two sets of reports, though COE allows for sales of liquids from gas projects, thus improving project economics.

Potential use of Eastern Australian reserves over 2012-2040 are presented below.

Table 6.5 Potential domestic use of Eastern Australian natural gas reserves

		2015 (NIEIR)	2025 (NIEIR)
Gas (2011, 1,300 PJ)	**Total**	1,400 PJ	2,300 PJ
	GPG use	416 PJ	986 PJ
	Excluding gas for power generation (GPG)	≈ 950 PJ	≈ 1,300 PJ
Electricity consumption	Total in NEM	200,000 GWhs	256,000 GWhs
	Australia	236,000 GWhs	311,000 GWhs

Potential GPG (electricity) use

A 400 MW CCGT	at 90 per cent capacity factor requires about	22 PJ/a
A 10,000 MW CCGT	at 90 per cent capacity factor requires about	550 PJ/a

Potential LNG export use

LNG	4 Mt plant requires	200 PJ/a	1 train
	20 Mt plant requires	1,000 PJ/a	5 trains

28 years (2012-2040) potential use

End use	Approximate average	1,700 PJ/a	= 47,600 PJ
10,000 MW GPG by 2040	Approximate average	300 PJ/a	= 8,400 PJ
LNG (6 trains by 2040)	Approximate average	800 PJ/a	= 22,400 PJ
			78,400 PJ

This suggests adequate availability at up to $8/GJ on the above assumptions: LNG use could be higher but GPG and end-use could be lower. Table 6.5 is the basis for the Eastern Australian market's natural gas projections for the case of no LNG plants outlined below.

6.3.2 Western Australia/Northern Territory

Domestic gas use

In 2012 Western Australia's total gas use is estimated at 617 PJ and Northern Territory at 43 PJ. Western Australia's gas use is dominated by industrial use (442 PJ) and GPG (145 PJ), growing respectively over 2012-25 at 2.65 per cent and 3.44 per cent average per year. Total use in 2025 is estimated to be 905 PJ, the increase mainly through alumina, direct reduced iron, ammonium nitrate and GPG expansion.

In the Northern Territory industrial (24 PJ) and GPG (19 PJ) dominate gas use, growing respectively over 2011-25 at an average per year of 8.4 and 7.0 per cent. Total use in 2025 is projected to be 122 PJ through increases in industrial use (Gove Alumina conversion to gas from fuel oil) and GPG.

Potential domestic use over 2012-2040

At an average annual use in the region (Western Australia/Northern Territory) at the 2025 level of 1,027 PJ, regional gas use over 2012-40 would be about 30,000 PJ. Use could be higher depending on GPG economics (carbon and gas prices) and industrial use (regional competitiveness in global markets).

Potential LNG use over 2012-40

LNG use of gas in the region (Western Australia/Northern Territory) will depend on global demands for LNG and competitiveness of regional LNG plants.

Global LNG demand is projected to increase significantly over the period depending on global climate change policies: aggressive policies could constrain global gas demands. Regional LNG competitiveness could be constrained by high regional costs for new LNG plants and global LNG competition from the Middle East, East Africa, North America and Europe. The strength of this competition will depend considerably on the success of Middle East and Russian gas export strategies and on global shale gas developments. At regional (Western Australia/Northern Territory) average LNG exports over 2012-2040 of 100 Mtpa (about 5,000 PJ per year) LNG exports would total 140,000 PJ.

Total requirements, reserves and prices: Western Australia/Northern Territory

On the basis of the above estimates, 170,000 PJ of regional gas would be consumed (domestic, LNG) over 2012-40, about the current estimates (P1, P2/EDR, SDR) of regional reserves (excluding CSM and shale, which are not yet prominent in the region).

No costs of reserve estimates for the region are available as far as we are aware. Based on net back estimates required for existing and proposed LNG projects, we consider the requirements could be met at <A$8/GJ (ex-processing plant) and <A$10/GJ delivered to customers.

6.4 Proposed LNG plants, 2012-18

Over the period to 2018, 12 LNG plants are proposed: 8 on the west coast (output 70 mtpa) and 4 on the Eastern Australian (30 mtpa). If all proposed plants proceed, gas use by the plants over the period to 2040 would be about 3,400 PJ/a and about 84,000 PJ in total on the west coast; and 1,500 PJ/a and 36,000 PJ in total on the Eastern Australian. (ABARE/BREE, 2010; 5,930 PJ **total** exports in 2029-30.)

Given the prices of gas from LNG in export markets and the cost of liquefaction, transport, regasification and transmission to pricing hubs, to be profitable we judge LNG exporters must be able to access gas at $6-8/GJ (the net back price) for existing and proposed LNG plants.

6.5 Gas prices: weighted average, 2007-08 to 2039-40 – the current view

Gas prices have not been historically transparent whether at the well-head, ex-processing plant or delivered, particularly for large users.

Preliminary estimates for weighted average gas prices (ex-processing plant) are set out below.

Table 6.6 Projection of natural gas prices

Year	Prices (2011-12 $/GJ)	
2007-08	$4	
2011-12	$5	
	Conventional view	**Alternative (optimistic) view**
2019-20	$9	$7
2029-30	$13	$10
2039-40	$15	$11

The alternative optimistic view is based on potential global trends in gas supplies and demands (climate change policies and gas technology improvements for exploration and development).

Traded gas prices, for example those used by ACIL Tasman for the AEMO scenarios, continue to be mainly based on the oil price/gas export price relationship which could be loosened resulting in lower gas prices as global gas competition increases. That is, we believe that despite its continued use in gas trade pricing, there is no longer a logical basis for this concept. Gas and oil are no longer significant substitutes in energy markets for electricity generation, space and water heating, etc. Exploration, development and marketing of the two commodities have diverged over the past 20 years.

6.6 Shale gas: A global gas revolution

The production of gas from low permeability gas rich structures has led to a transformation of the USA gas industry. Gas production from this source in the USA has risen from 4 per cent of total USA gas production in 2004 to 25 per cent in 2011, a total in 2011 of 5,650 PJ (twice Australia's 2011 production) with a reserve estimate (USA EIA) of 4.8 x 10^6 PJs. The flood of shale gas has dropped wholesale gas prices in the USA from >US$10/GJ in 2006 to >US$3/GJ in 2011-12 and stimulated investment in USA LNG export plants.

There is potential for the North American (Canada also has shale gas reserves) experience with shale gas to be repeated elsewhere, but caution is advised as conditions (geologic, development costs, environmental, infrastructure, politics) for shale gas development can vary widely.

In Australia there appears to be significant shale gas potential in the Cooper, Galilee, Perth and Canning Basins.

In North America viable/profitable wellhead prices for shale gas appear to be >US$5/GJ, so the industry is currently not profitable leading to a write-down of shale gas assets by companies (including BHPB). Of the majors, Chevron appears to be shale gas positive with Exxon-Mobil less so.

In a report on Fuel Cost Projections to provide outlooks/inputs for AEMO modelling, ACIL-Tasman in December 2011 estimated an aggregate shale gas resource of 25,000 PJs in eastern Australia at a cost of around A$9/GJ (2012-13 $'s). The report noted that this would tend to limit upward pressures on gas prices. It should be noted, however, that this upper limit, if realised, would still be twice to three times as high as previous wholesale prices.

6.7 The specification of the probability distributions

The above analysis for Eastern Australia needs to be incorporated into the analysis by the specification of probability distributions for two key parameters, namely the remaining reserves and the percentage of remaining gas reserves discovered by 2040.

Table 6.7 gives Trigen probability estimates for the two parameters. The lower bound estimate is the ACIL Tasman estimate. The upper bound estimate is the Core Energy Growth estimate plus the tight and shale gas reserves estimate. There is considerable upside in terms of shale gas availability. This is incorporated into the analysis by setting the upper bound probability relatively low at 85 per cent. This ensures that the maximum upper bound will be higher than the estimate set in the table.

The specification of the estimates of the per cent of remaining reserves at 2011 discovered by 2040 is straightforward and given in Table 6.7.

The reserve production trigger ratio requires explanation. It is one of the most important parameters in the analysis. The central assumption is that there is a minimum identified reserve to production ratio which, if attained, will render prohibitive the risks of investing in gas-intensive projects. This applies equally to new projects as it does to the investment to maintain the competitiveness of existing facilities. This trigger's value will vary from project to project and industry to industry. It is unlikely to be much lower than 15. Below 15 means that the risks are high that there will not be enough gas to feed the gas-using capacity currently installed. For large scale gas-using projects, the realised reserves to production ratio would have to be significantly above 15 given a three year construction period and a 20 to 30 plant life. Hence, the upper boundary is set at a reserve to production ratio of 25 in Table 6.7.

Table 6.7	The specification of the Trigen probability distribution parameters						
		Unit	Lower bound	Mode	Upper bound	Lower bound probability	Upper bound probability
1	Reserves remaining as at 2011	PJ	90,000	163,000	237,000	0	85
2	Per cent of reserves remaining as at 2011 discovered by 2040	Per cent	55	70	80	0	95
3	Reserves – production ratio trigger for suppressing gas demand	No.	15	20	25	0	100

In the model, if Eastern Australia's gas reserve to production ratio falls below the trigger level, the new growth in demand ceases and normal replacement investments are not made, meaning that underlying demand will fall by 2 per cent per annum. The level of demand falls to regain the benchmark reserve to production ratio. If more gas suppression is required gas is suppressed in the electricity sector and finally, in the case of severe restrictions, there will be plant closures.

6.8 The outcomes for the Trigen distribution

Probability estimates from the Trigen distribution parameters specified in Table 6.7 are presented in Table 6.8. The table indicates that the maximum estimate for discovered and undiscovered reserves, as at 2012, is 263,400 PJ. There is a 75 per cent probability that 147,000 PJ will be discovered and a 25 per cent probability that at least 200,000 PJs will be discovered.

The extraction ratio by 2040 of discovered reserves rises from a 5 percentile rate of 60 per cent through a mean of 70 per cent to a 95 percentile level of 80 per cent.

Table 6.8 Reserves and extraction probabilities		
	Ultimately recoverable reserves (PJs)	**Per cent of reserves discovered by 2040 (%)**
Aggregate indicators		
Minimum	91288.86	55.35
Maximum	263437.80	84.62
Mean	173481.80	69.89
Std Deviation	36426.91	6.06
Distribution		
5% Percentile	115200.30	59.67
10% Percentile	125942.10	61.64
15% Percentile	134066.20	63.15
20% Percentile	140810.00	64.43
25% Percentile	146886.90	65.53
30% Percentile	152278.00	66.55
35% Percentile	157293.80	67.46
40% Percentile	161965.70	68.33
45% Percentile	166397.90	69.14
50% Percentile	171161.40	69.90
55% Percentile	176066.50	70.66
60% Percentile	181323.10	71.46
65% Percentile	186829.00	72.32
70% Percentile	192840.70	73.23
75% Percentile	199367.60	74.23
80% Percentile	206442.70	75.32
85% Percentile	214675.40	76.58
90% Percentile	224387.30	78.05
95% Percentile	236890.60	79.99

6.9 The cost of natural gas ex-plant

A price constraint is also inserted into the model. If prices exceed a benchmark level new growth in demand (including replacement demand) will cease. The price formula in the model is given by:

$$Pg = 5 + 0.15 \,.\, RD$$

Where:

Pg = price of gas ex-processing plant.

RD = per cent of reserves extracted as a per cent of remaining reserves, as at 2012.

The schedule has an upper limit of $15/GJ as the extraction ratio of estimated 2012 remaining reserves approaches its upper limit.

6.10 The base case: No Eastern Australian LNG plants

Given the model developed above, the base case will be the case of no Eastern Australian LNG plants to 2040. This will indicate the risk of suppressed demand for gas in the absence of the LNG projects proceeding. The results are given in Table A.7.

If there were no East Coast LNG plants, there is no chance of suppressed demand by 2020.

In the absence of the LNG exports from Queensland, there is only a very small chance, at the 95 percentile level, of the need for gas suppression in the 2020s.

In the 2030s there is a mean risk of the need for natural gas suppression but it is small, at 25 PJ per annum. This is on the basis that between 2025 and 2040 the Eastern Australian domestic natural gas demand grows at 2 per cent per annum for non-electricity sector gas use. The electricity sector case stays constant at the 2025 level to 2040.

6.11 The case of LNG exports

The alternative case is of the impact of 24 million tonnes of East Coast LNG exports on the Eastern Australian demand-supply balance. For the 2012-2020 period there is a mean expected outcome that the Eastern Australian domestic demand will be suppressed by an average of 40 PJ a year. For the 2020s the mean expectation is for a suppression of 600 PJs, with the 25 to 75 per cent probability range being between 165 and 952 PJs. By the 2040s the expectation (that is, the mean) is that there will be a suppression of natural gas equal to 40 per cent of the unconstrained demand case. The 25 to 75 per cent probability range is for a 2040 natural gas suppression rate of between 24 and 58 per cent.

Overall the mean expectation is that a cumulative 15,000 PJs of natural gas demand will be suppressed.

Table A.9 gives the net impact of the East Coast LNG exports on the domestic demand supply balance. As the results in Table A.8 demonstrate, there is little difference between the results in the two tables.

The tables enable readers to apply their own judgement. If one wanted to be optimistic, then the 30 per cent percentile case could be made equal to the expected case. In this case there is still a cumulative shortfall by 2040 of suppressed domestic natural gas demand of 7,640 PJs, with severe supply shortages appearing in the 2020s and the expectation that by 2040 the suppressed demand as a per cent of base case demand is 27 per cent.

6.12 Conclusion

The results are very significant. The results indicate that either the national interest evaluation of the LNG plants was deficient or that confidential knowledge of the gas resources available confirmed that these resources are considerably greater than what is in the public domain. Even if the latter is the case, impacts will not be avoided. There may well be adequate reserves but businesses make decisions on what they know and what they know would indicate that gas is likely to be transferred from domestic to LNG export sales. In this case the net economic cost of the East Coast LNG plants having preferred access to supply will involve very large costs on the economy.

The exact costs will be quantified in the next chapter.

7. The net benefit of East Coast LNG expansion in the context of Eastern Australian demand/supply balance

This chapter takes the results of the last three chapters and assesses the net national benefits and costs of the East Coast LNG expansion. In the event of limited supply to domestic users, the burden of adjustment will be divided between:

- gas dependent industries;
- general economy adjustment – decline in activity;
- general economy adjustment – full electricity substitution; and
- electricity sector gas suppression.

The key task in preparing input to the analysis is to specify the distribution of the burden of adjustment.

7.1 Domestic industrial gas demand suppression in the allocation of the burden of adjustment

The allocation of the share each adjustment path will play is critical in driving the overall net benefits or costs. The reason for this, as Chapter 6 indicated, is that there is a wide range in the net costs of adjustment per channel with the highest being for gas dependent industries and the lowest for the full electricity substitution case.

One approach would simply be to assume the lowest cost outcome. The full electricity substitution case may be appropriate for an efficiently planned state like China which would incorporate the strategy into its five year planning guidelines and more often than not achieve the desired result. In Australia, the mechanism for adjustment is via price changes which, in this case, will have a negative impact on economic activity and real incomes, and increase inflationary pressures via loss of competitiveness.

The fact of the matter is that adopting the full electricity substitution strategy would require a large scale investment in the electricity sector where prices would need to rise to finance it. Given the current reaction to price movements driven by large investments in electricity distribution it would appear that further rises to substitute electricity for gas would be very difficult to achieve.

The second-best course of action, the suppression of gas usage in electricity production, would also be difficult to achieve as it would require increases in the share of renewable production. As the reliance on renewables increases, the stability of the electricity system will decline in that variations in climatic conditions (perhaps aggravated by climate change) will result in greater volatility in supply. The need to have gas fired generating capacity as a back-up supply source can only increase. The reality is that by the 2020s and certainly by the 2030s, there may well be severe constraints on the ability to suppress gas usage in electricity production.

While the costs of a choice to suppress supply to gas-dependent industries are extremely high, this scenario should not be ignored without study. The reality is that it is already happening. Major domestic natural gas users in Queensland (Rio Tinto and Incitec Pivot) are already forecasting natural gas shortages by 2015. This must affect their incentive to expand in Australia and even to maintain their Australian assets at a level that would prevent medium-term closure.

The only way to ensure that gas-dependent industries do not atrophy is to ensure that they have new and guaranteed supply sources for the next three to four decades at prices that can be projected with a degree of confidence. To guarantee supplies to gas-dependent industry will require substantial interventions in the existing regime. However, the need for intervention should be put in perspective: the gas-dependent industries' entire consumption (4 million tonnes a year) is less than the allocation of gas required to keep one LNG train supplied.

Because of the uncertainty surrounding the adjustment paths, a probability approach is adopted. Table 7.1 gives the Trigen probability distribution parameter settings. The burden of the adjustment of the gas-dependent industries is biased downwards compared to their share of overall gas demand. However, the setting of the upper bound probability at 0.85 allows for cases where the burden of adjustment may well be greater.

The resulting distribution of the adjustment share of gas-dependent industries is given in Table 7.2. The mean is a 10 per cent adjustment burden with the 25th percentile at 8 per cent and the 75th percentile at 12 per cent.

For the other channels of adjustment the means are:

- suppression of gas usage in electricity production – 22 per cent; and
- a general fall in economic activity – 16 per cent.

The remaining share would be borne by the residential sector and, at the mean, would be 100 less 22 less 16 less 10, or 52 per cent. This allocation imposes a conservative bias on the analysis, as the above discussion implies that the decline in economic activity should perhaps have a greater weight than it has been accorded.

Table 7.1 Trigen probability distribution parameters – domestic natural gas suppression of the adjustment burden by sector

		Maximum lower bound	Mode	Maximum upper bound	Lower bound probability	Upper bound probability
1	Gas dependent industries – share in gas suppression	0.05	0.09	0.13	0	0.85
2	Electricity gas usage – share in gas suppression	0.15	0.20	0.25	0	1.00
3	General economy – actual decline of electricity substitution – residual given the above three outcomes	0.08	0.15	0.25	0	1.00
4	Carbon price 2040 ($/tonne)	60	100	200	0	0.9
5	Alternative natural gas input price into electricity production ($/GJ)	3	4	5	0	0.9

Table 7.2 Reserves and extraction probabilities		
	Carbon price (2009 $/tonne)	Share of natural gas dependent industries in total gas suppression (%)
Aggregate indicators		
Minimum	15.18	5.35
Maximum	219.78	16.35
Mean	119.98	10.22
Std Deviation	44.41	2.42
Distribution		
5% Percentile	45.67	6.54
10% Percentile	59.50	7.13
15% Percentile	71.17	7.65
20% Percentile	79.88	8.05
25% Percentile	88.31	8.42
30% Percentile	95.00	8.74
35% Percentile	102.51	9.03
40% Percentile	108.53	9.33
45% Percentile	114.59	9.65
50% Percentile	119.88	9.96
55% Percentile	125.38	10.33
60% Percentile	131.42	10.65
65% Percentile	137.94	11.08
70% Percentile	144.24	11.48
75% Percentile	151.91	11.93
80% Percentile	159.74	12.39
85% Percentile	168.84	12.99
90% Percentile	179.75	13.66
95% Percentile	194.48	14.57

7.2 The distribution of CO_2 price outcomes

A probability approach was taken for the determination of the CO_2 price with the probability distribution parameters given in Table 7.1. The resulting distribution for the CO_2 price is also given in Table 7.1. The mean over the project period is $120 and the 25 to 75 per cent probability benchmarks are $88 to $152 a tonne.

The operating cost of natural gas for electricity in the absence of East Coast LNG also is determined by a probability distribution with the parameters given in Table 7.1.

7.3 The impact of East Coast LNG exports on the national economy: The expected outcome

Expected outcomes from the mean settings of the various inputs are determined by the probability distributions. This applies whether the input variable is carbon prices or estimates of natural gas reserves to be discovered. The expected results are given in Tables A.11 to A.13.

From Table A.8 there is some risk of gas shortages by 2020, though the risk is not large. What is significant is the inability to secure long-term contracts for gas at competitive rates as gas producers see the opportunity of LNG exports as a windfall, particularly since some LNG plants have yet to secure all their needs. This is the real driver of the crowding out of domestic supply which will have a very significant negative impact on downstream production, jobs and overall economic benefit.

The GDP increase at market prices is initially greater than the direct impact of the LNG exports. Employment increases by 82,000 compared to what would have otherwise been the case. From Table A.8, however, over the 2020s, the expectation is that domestic gas demand will be suppressed by 592 PJ on an average annual basis. This means that by 2020 the positive stimulus from the LNG exports is fully offset by the negative stimulus of the crowding out by gas suppression. All the production series are negative with the greatest decline being for NNP.

The decline continues but at a slower rate in the outcomes for the 2020-2025 period. By 2040 the decline is $22 billion for gross domestic product at market prices, while the net national product is $34 billion lower in 2040 compared to what otherwise would have been the case. The decline by 2040 is 775,000 in employment, while the benefit indicator declines by $46 billion, compared to the disallowance of East Coast LNG exports. This represents about 1.6 to 1.8 per cent below what national baseline GDP would be expected to be by 2040.

The employment loss may appear implausibly large. However, it is likely that the main response to a decline in employment will be via reduction in immigration. The employment loss over 30 years implies a net average annual reduction in immigration of some 35,000. The response to this may be that there is no national loss if the cost is borne by residents who will not be in Australia. The risk is, however, that the decline in employment may be so great that the required level of immigration will fall below the “bedrock” 170,000 to 200,000 level. In this case there will be increases in the effective unemployment rate. There is a limit to the size of a negative shock which can be imposed on the economy without considerable eventual economic pain.

The cumulative decline of the net benefit indicator is $160 billion. If the probability distribution for the expected reserves is near reality, the only strategy to minimise costs is to reduce LNG exports by the amount of the expected supply shortage. By 2040 the expected supply shortage equals the LNG requirement. This is, of course, when the plants are near the end of their expected life. The critical time is in the mid-2020s when the supply shortage is half the LNG demand.

In this context a prudent strategy would have been to perhaps approve one project and delay the approval of other projects until:

(i) the local industry was protected by identified reserves which are allocated to domestic use with a minimum headline reserve to production rate of 20 to 1 by 2040 given expected demand growth; and

(ii) identified available reserves support any new projects over there complete life.

7.4 The range of possible outcomes

Table A.10 shows the distribution of expected outcomes around the mean outcomes for 2020 and 2040. High negative outcomes would result if the ACIL Tasman estimates of remaining natural gas reserves are anywhere near the mark. The low negative and marginally positive outcomes would occur if the alternative estimates of reserves by COE are near the mark, at least in terms of reserves that can be extracted at $10/GJ.

The point about the results is that even if the reserves remaining are at the upper end of the range, the benefit of the East Coast LNG projects are marginal in that costs and benefits are in balance. This is clearly shown in Table A.10 where, if eventually recoverable reserves are near 240,000 PJ, the value of the net benefit indicator in 2040 is $2.4 billion.

7.5 Conclusion

The most important point of all is that even if ultimately recoverable reserves are in fact near the upper range currently assessed, or indeed in excess of the upper range, if these reserves are not identified and they cannot be quickly extracted to meet shortfalls at reasonable costs, the negative consequences in the table are likely to be realised. This is because:

(i) the natural gas dependent industries will not expand and would most likely go into decline;

(ii) gas using electricity plants will not be built; and

(iii) unnecessary costs will be imposed on the economy because businesses and Governments in the main will base demand on realised outcomes with an allowance for future supply security.

To illustrate the issue, assume that the ultimate recoverable reserves are 300,000 PJ. If gas producers continue their practice of allocating resources to export the reserves will not be identified and extracted for domestic use unless Governments force them to do so. The negative results of this analysis would remain, albeit reduced by the additional benefits of another LNG train or two. The only certain way to prevent the negative outcomes of this chapter is the identification and allocation of sufficient reserves for domestic use to cater for their needs for the next 30 to 40 years. In this context the estimates of overall remaining reserves are irrelevant. In any case, given the conservative allocation of weights in this study (that is, biased to low cost options), the benefits of additional potential reserves are likely to be neutralised by increasing the weight towards the higher cost adjustment options.

A related issue is the ownership structure of the enterprises which control the identification of reserves. If their interests are in “just-in-time” identification of reserves, a significant proportion of the negative consequences identified above will still be realised, even if the actual level of eventually recoverable reserves is much greater. Unfortunately, on the estimates presented here, future reserve estimates will affect domestic investment decisions even if they turn out to be too low.

Under the current reserves management practice and with the pipeline infrastructure limitations, Australia does not seem to have enough available reserves of gas to be able to avoid the negative effects of large increases in demand or of falls in the headline reserve/production ratio on business decision making.

8. East Coast LNG expansion: Additional downside risks

Three additional areas could add to the net cost over and above those identified in the previous chapters. These include:

(i) lower prices for LNG than expected;

(ii) higher alternative benefits from the use of the gas domestically; and

(iii) balance of payments adjustment costs to a rapid decline in the terms of trade.

8.1 East Coast LNG expansion: The impact of lower LNG prices

On the world stage, identified recoverable shale gas reserves, together with the extraction of the resource, are now growing strongly, particularly in the United States. United States reserves are large, estimated currently at 865 Tcf with relative low cost investment and production costs at around $4 to $6 per GJ. As a result, shale gas currently constitutes one quarter of United States total gas production and this is expected to increase to 50 per cent by 2035.

Once the United States authorities are satisfied that there is sufficient gas to satisfy domestic requirements for the foreseeable future, large scale LNG exports may be encouraged. Initially this will be done at low cost, converting LNG import infrastructure (currently unused because of the rapid expansion of shale gas production) to LNG export plants.

Given the analysis of the previous section, where the extraction costs are expected to rise to the $7 to $10 per GJ range because of resource depletion, the export of lower cost gas from the United States could force a $2 to $4 reduction in the export LNG price from the East Coast which would be a reduction of between 14 and 28 per cent. Even if LNG prices for East Coast Australia are linked, in part, to the price of oil, downward price pressure will not be avoided. The United States will not allow large scale export of gas until the gas has been fully utilised domestically to maximise the reduction in its dependence on oil imports. Other countries with substantial shale gas resources will also apply the same policies which, combined, will put significant downward pressure on oil prices and hence LNG prices.

If it is assumed that world-wide expansion of shale gas extraction reduces LNG prices by, in real terms, 20 per cent by the latter part of this decade, the effect of the decrease per PJ of output is:

- contribution to gross domestic product reduced by 25 per cent;
- tax receipts down by 66 per cent;
- domestic distributed income reduced by 28 per cent; and
- net national product reduced by 34 per cent.

These are average declines over the first 20 years of the project. The decline in tax revenue occurs because the collection of PRRT revenue is delayed until towards the end of the life of the project.

Table 8.1 shows the economy-wide impact given the above assumed price changes. The base case price is the 2011 level. The alternative case is a 20 per cent reduction in this level.

From the table, the reduction in net benefits is proportional to the reduction in the input parameters. The reduction in the net benefit indicator is $171 million for 50 PJ of exports, or a 43 per cent reduction to $229 million from the base case of $401 million.

This result provides the rule of thumb that:

- **for every 1 per cent reduction in the LNG price the economy-wide benefits from LNG exports will be reduced by approximately 2 percentage points. This stems mainly from the fact that tax receipts and domestic profits will be disproportionately impacted. Interest owed overseas will still have to be paid and debt repaid.**

Table 8.1 The impact of lower LNG prices

		Case study: 50 PJ of natural gas allocated to LNG exports – base case prices	Case study: 50 PJ of natural gas allocated to LNG exports – 20% reduction in base case prices	Net benefit of 50 PJ of LNG exports with 20% reduction in base case prices
Macroeconomic aggregates				
Gross domestic product at factor cost	$2009m	729.56	-186.22	543.34
Gross domestic product at market prices	$2009m	767.76	-198.23	569.53
Gross national product at market prices	$2009m	538.64	-187.21	351.43
Net national product at market prices	$2009m	355.40	-132.73	222.67
Total imports of goods and services	$2009m	75.85	-21.53	54.33
Total employment	**ths.**	**4.28**	**-1.25**	**3.03**
Household activity				
Wages and mixed income	$2009m	170.21	-48.13	122.08
Property income	$2009m	128.49	-54.30	74.20
Direct taxes paid	$2009m	67.21	-23.05	44.16
Household consumption	$2009m	184.68	-63.33	121.36
Government revenue				
Direct taxes on households	$2009m	67.21	-23.05	44.16
Direct taxes on business	$2009m	156.55	-112.19	44.36
Indirect taxes	$2009m	38.21	-12.01	26.19
Total tax revenue	$2009m	261.96	-147.24	114.72
Other indicators				
Income paid overseas	$2009m	229.12	-11.03	218.10
Benefit indicator	$2009m	401.02	-171.65	229.37

8.2 Foregone growth benefits from expansion of the chemicals sector

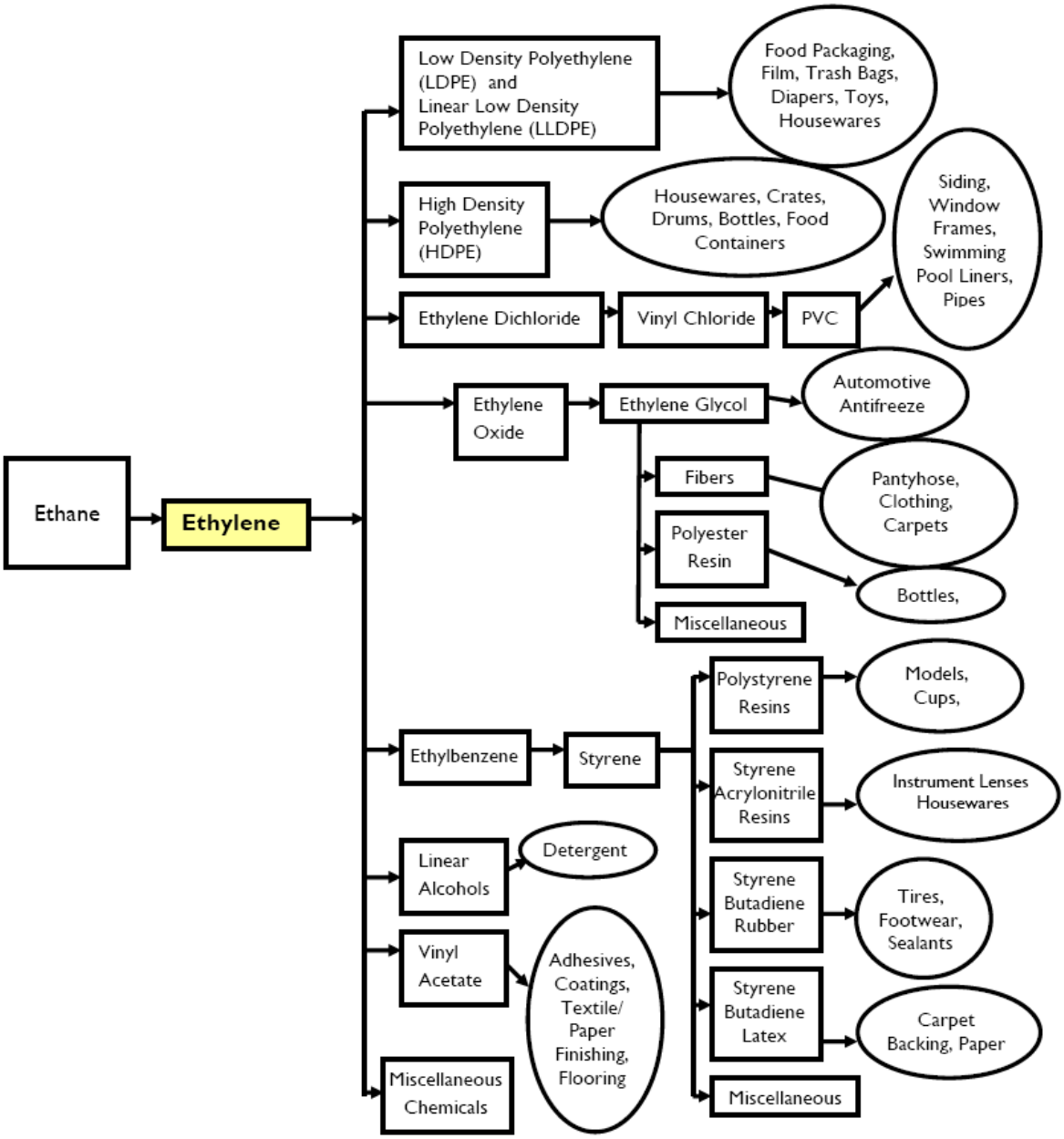
The analysis of Chapters 4 to 7 above were in the context of the existing chemicals sector being crowded out by natural gas shortages. This analysis provided minimum estimates which made no allowance for the foregone ability to grow the chemicals sector as a strategic industry – not only the gas-intensive chemicals industry (fertilizers, explosives) but also that part of the chemicals industry which uses natural gas liquids in general, and ethane in particular. Ethane is the next largest component of natural gas after methane. Its concentration varies from negligible levels to up to 6 per cent of a natural gas deposit. As Figure 8.1 shows, ethane is used to produce ethylene, which is an essential input into a wide range of chemical products.

A 2011 study by the American Chemistry Council (ACC) examined the benefits to the United States of an expansion in the chemicals industry enabled by expanded supply of natural gas. The American study had an indirect (that is inter-industry) effect of $US36 billion from a hypothetical but plausible 25 per cent increase in ethane supply. The ACC study used a completely unconstrained input output framework whereas for this study the chemical sector is treated as a constrained set of industries because of the methodology assuming it is constrained by gas supply. Therefore for this study it was necessary to estimate the indirect inter-industry effect on the rest of the chemical sector by the methodology outlined in developing the data in Table 4.2 which underlies the multiplier of 1.6 for the chemical sector as a whole. The induced multiplier for this study in the context of the Australian economy is of the order of 1.4. This represents the employment income, household consumption expenditure induced plus the non-chemical inter-industry effects which are identical to the Chemical Council study in methodology and concept. Thus if the Australian basic chemical value of $168 million per PJ is multiplied by 1.60 and 1.4 the result is $376 million per PJ which is less than the $415 million per PJ for the American study. The American total multiplier would be expected to be bigger because of the lower import content of the American economy and the greater complexity of the inter-industry supply chains.

Once this adjustment is taken into account the two studies are extremely similar in their quantitative conclusions.

If the investment effects are taken into account an interesting conclusion emerges. While the investment to output ratio for LNG is between 4.0 and 4.5 times the annual value of output, the equivalent ratio for the chemical sector is 0.5 because of the greater value extracted from the chemical sector use of natural gas. The value of output per PJ of natural gas used by the chemicals sector is 2.7 times that for the LNG sector. There is no validity in the argument that LNG should be promoted simply because of its investment intensity.

Figure 8.1: Ethane/Ethylene and the chemical industry flow chart



Source: American Chemistry Council, "*Shale Gas and New Petrochemicals Investment: Benefits for the Economy, Jobs and US Manufacturing*", March 2011.

8.3 The costs of adjustment when the mining boom ends

When the mining boom ends, the terms of trade will decline, the exchange rate will fall and the current account deficit will expand rapidly to double digit levels as a percentage of GDP. The current account deficit circa 2016 to 2020 at least will be around 5 to 6 per cent of GDP with terms of trade near current levels, and given Australia's existing high net international debt any fall in the terms of trade will increase the measured debt and require that the current account deficit be closed rapidly back to the 5 per cent of GDP mark.

Normally the exchange rate decline would be expected to carry some of the burden by facilitating an export expansion/import replacement response to cushion the impact on economic activity. However Australia is destroying capacity in its non-resource trade-exposed industries from a combination of natural gas suppression and the investment-discouraging effects of the loss of competitiveness due to the high exchange rate which has accompanied the boom in mining investment. (Admittedly the iron ore export industry bears major responsibility for the high exchange rate, but LNG exports have played a role.) The high prices for iron ore, coal and other mineral exports are bound to subside, if only because of current investment in expanding capacity in Australia, Africa and elsewhere, and when the high prices fall the Australian dollar exchange rate is likely to fall with them. At this point the loss of capacity in manufacturing, tourism and other trade-exposed industries will have two unpleasant consequences:

(i) the current account deficit will be considerably worse than what would have been the case; and

(ii) most of the adjustment required to bring the current account deficit back to sustainable levels will have to come from demand suppression via contractionary monetary and fiscal policies.

To illustrate, from Table A.11, the expected benefit from East Coast LNG exports would lead to a $6 billion increase in imports. At an average 20 per cent share of imports in GDP to neutralise the impact of the import increase of the balance of payments will require a loss in GDP of $30 billion. However, normal income elasticity effects will reduce this to around $15 billion. This is because imports are highly elastic with respect to GDP change. Even so, it is two to four times the expected GDP loss from Table A.11 from East Coast LNG exports in the 2020s.

Hence, the following rule of thumb.

- **For every $1m of lost GDP from the absence of effective policies to neutralise the impact of domestic gas suppression costs on the economy, at least an additional $2 million will be lost from the current damage being done to the Australian non-resource tradeable industries from the general effects of the currently high exchange rate and potentially from domestic gas suppression.**

This analysis has only been done in terms of the marginal case of Table A.11. The risks for the national economy in the period 2016-2020 appear to require careful analysis. The inference from the above calculations is that a sharp end to the mining boom and a return of the terms of trade to near pre 2005 levels would risk severe economic instability.

9. A review of current policy is urgent

It is not the task of this study to outline the appropriate policy regime. This study goes no further than demonstrating that, unless an appropriate policy regime is put in place, the cost of East Coast LNG exports from Australia is likely to be a net negative for the national economy.

In order to avoid the likelihood of net negative consequences to the economy, a policy review is urgent that considers the impacts and risks discussed in this report and develops policies which gave continuity to existing and potential large scale uses of natural gas in regard to:

(i) adequate supply availability over a 40 year horizon;

(ii) benchmarks for the determination of costs of supply; and

(iii) institutional arrangements which would ensure that domestic customers' long-term interests are protected.

In relation to (iii), the CME study, "*The Impact of Liquefied Natural Gas on Queensland Gas Markets and Gas Users*", March 2010, points to a number of factors which will contribute to negative outcomes from the East Coast LNG exports.

Firstly, as noted in Chapter 1, the interest of gas producers in LNG plants is giving foreign customers first preference in the supply of gas in part because sales on foreign markets are expected to be more profitable than sales to domestic customers. However, as the CME report notes, even if domestic gas sales had higher margins once the LNG plant came into production the domestic sales would become small compared to foreign sales. Higher margins on domestic sales will, therefore, make a small contribution to overall profits.

The drive to secure large scale supply for export markets has driven consolidation in the gas supply industry in Queensland and greatly reduced competition. Second, the control of gas producers over pipelines and, therefore, access is also contributing to a decline in competition. This discourages smaller scale producers from expanding or commencing production. The volume of gas going through pipelines to service export markets will make it easier for pipeline owners to apply for exemptions from pipeline access on the grounds of capacity constraints.

There will indeed be producers who will be willing to supply the local market. However, as the larger producers become increasingly export focussed, these producers are likely to be small scale and, therefore, inefficient and under-capitalised, which will not assist in increasing the confidence of local gas users in long-run prospects.

In this environment the required policy regime to optimise the national interest and to avoid the costs quantified in Chapter 7 is self-evident.

Appendix A: Tables related to chapters of this report

Table A.1	Natural gas dependent industries response to 50 PJ suppression of domestic natural gas demand – macroeconomic implications of different adjustment paths			
		Case study: 50 PJ of natural gas allocated to LNG exports	Case study: 50 PJ of natural gas withdrawn from natural gas dependent industries	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export
Macroeconomic aggregates				
Gross domestic product at factor cost	$2009m	729.56	-11004.69	-10275.13
Gross domestic product at market Prices	$2009m	767.76	-12289.23	-11521.46
Gross national product at market prices	$2009m	538.64	-10994.01	-10455.37
Net national product at market prices	$2009m	355.40	-9112.42	-8757.02
Total imports of goods and services	$2009m	75.85	5680.81	5756.67
Total employment	**ths.**	**4.28**	**-203.34**	**-199.06**
Household activity				
Wages and mixed income	$2009m	170.21	-6441.65	-6271.45
Property income	$2009m	128.49	-2169.01	-2040.51
Direct taxes paid	$2009m	67.21	-1937.40	-1870.19
Household consumption	$2009m	184.68	-5323.87	-5139.19
Government revenue				
Direct taxes on households	$2009m	67.21	-1937.40	-1870.19
Direct taxes on business	$2009m	156.55	-706.87	-550.32
Indirect taxes	$2009m	38.21	-1284.54	-1246.33
Total tax revenue	**$2009m**	**261.96**	**-3928.81**	**-3666.85**
Other indicators				
Income paid overseas	$2009m	229.12	-1295.22	-1066.09
Benefit indicator	$2009m	401.02	-9182.55	-8781.53
Cumulative discounted (at 5%) benefit indicator 2016-2040	$2009m	4629.63	-104509.34	-99879.72

Table A.2 Gross output formation by industry ($2009m)			
	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: 50 PJ of natural gas withdrawn from natural gas dependent industries	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export
Constrained industries			
Basic chemicals	0.00	-4202.24	-4202.24
Paints	0.00	-98.17	-98.17
Medicinal and pharmaceutical products, pesticides	0.00	-98.77	-98.77
Soap and detergents	0.00	-159.09	-159.09
Cosmetics and toiletry preparations	0.00	-55.37	-55.37
Other chemical products	0.00	-288.82	-288.82
Rubber products	0.00	-40.00	-40.00
Plastic products	0.00	-1847.01	-1847.01
Basic non-ferrous metal and products	0.00	-5951.61	-5951.61
LNG	620.73	0.00	620.73
Unconstrained industries			
Sheep	0.70	-28.13	-27.43
Grains	1.06	-47.17	-46.11
Beef cattle	1.94	-87.10	-85.15
Dairy cattle	1.08	-33.71	-32.62
Pigs	0.27	-10.67	-10.40
Poultry	0.60	-22.74	-22.14
Other agriculture	3.94	-135.46	-131.52
Services to agriculture, hunting and trapping	0.92	-39.85	-38.94
Forestry and logging	0.50	-23.60	-23.11
Commercial fishing	0.63	-18.96	-18.34
Coal	1.79	-80.86	-79.07
Gas	5.80	-83.10	-77.30
Oil	1.47	-65.27	-63.81
Iron ores	0.20	-5.91	-5.71
Non-ferrous metal ores	0.31	-2448.79	-2448.48
Other mining	0.45	-69.09	-68.64
Services to mining	15.45	-281.93	-266.48
Meat and meat products	4.60	-191.72	-187.12
Dairy products	3.54	-110.34	-106.80
Fruit and vegetable products	1.12	-33.81	-32.69
Oils and fats	0.44	-19.27	-18.83
Flour mill products and cereal foods	1.83	-72.38	-70.55
Bakery products	1.51	-45.15	-43.64
Confectionery	1.15	-35.13	-33.98
Other food products	2.69	-100.96	-98.27

Table A.2 Gross output formation by industry ($2009m) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: 50 PJ of natural gas withdrawn from natural gas dependent industries	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export
Soft drinks, cordials and syrups	1.48	-46.55	-45.07
Beer and malt	1.26	-37.46	-36.20
Wine, spirits and tobacco products (a)	1.44	-45.56	-44.12
Textile fibres, yarns and woven fabrics	0.12	-6.26	-6.14
Textile products	0.37	-11.76	-11.38
Knitting mill products	0.26	-8.45	-8.19
Clothing	0.57	-18.84	-18.27
Footwear	0.12	-3.97	-3.85
Leather and leather products	0.09	-3.46	-3.36
Sawmill products	0.54	-16.20	-15.65
Other wood products	1.09	-38.72	-37.63
Pulp, paper and paperboard	0.30	-13.32	-13.01
Paper containers and products	0.90	-47.09	-46.20
Printing and services to printing	2.88	-101.92	-99.04
Publishing, recorded media, etc.	3.29	-122.30	-119.01
Petroleum and coal products	6.35	-282.82	-276.47
Glass and glass products	0.67	-27.41	-26.74
Ceramic products	0.12	-4.41	-4.30
Cement, lime and concrete slurry	0.83	-29.53	-28.70
Plaster and other concrete products	0.43	-15.83	-15.40
Other non-metallic mineral products	0.23	-7.38	-7.16
Iron and steel	4.24	-122.60	-118.36
Structural metal products	2.92	-73.11	-70.19
Sheet metal products	0.91	-37.26	-36.35
Fabricated metal products	2.23	-73.55	-71.32
Motor vehicles and parts, other transport equipment	4.75	-137.15	-132.41
Ships and boats	0.40	-13.72	-13.31
Railway equipment	1.21	-13.28	-12.06
Aircraft	1.39	-21.41	-20.02
Photographic and scientific equipment	0.91	-27.53	-26.62
Electronic equipment	0.83	-24.03	-23.20
Household appliances	1.37	-38.35	-36.98
Other electrical equipment	1.34	-41.45	-40.12
Agricultural, mining, etc. machinery	1.79	-36.27	-34.49
Other machinery and equipment	1.60	-44.46	-42.87
Prefabricated buildings	0.85	-8.07	-7.22
Furniture	1.26	-36.77	-35.51
Other manufacturing	1.07	-57.35	-56.28

Table A.2 Gross output formation by industry ($2009m) – continued			
	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: 50 PJ of natural gas withdrawn from natural gas dependent industries	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export
Electricity supply	10.97	-460.21	-449.24
Gas supply	1.10	-65.39	-64.29
Water supply, sewerage and drainage services	4.06	-157.67	-153.62
Residential building	1.94	-47.42	-45.48
Other construction	3.52	-78.84	-75.32
Construction trade services	19.47	-418.47	-399.00
Wholesale trade	25.88	-1231.10	-1205.22
Wholesale mechanical repairs	2.89	-22.17	-19.28
Other wholesale repairs	5.51	-111.48	-105.97
Retail trade	32.74	-984.54	-951.80
Retail mechanical repairs	7.63	-229.35	-221.72
Other retail repairs	0.44	-13.03	-12.59
Accommodation, cafes and restaurants	16.97	-515.86	-498.90
Road transport	9.58	-489.81	-480.23
Rail, pipeline and other transport	10.02	-111.10	-101.09
Water transport	1.13	-54.45	-53.32
Air and space transport	4.99	-155.51	-150.52
Services to transport, storage	13.62	-496.68	-483.06
Communication services	15.22	-500.67	-485.44
Finance	47.38	-1319.57	-1272.19
Ownership of dwellings	4.72	-135.99	-131.27
Other property services	31.27	-739.24	-707.97
Scientific research, technical and computer services	11.85	-445.16	-433.31
Legal, accounting, marketing and business management services	18.85	-766.52	-747.67
Other business services	11.10	-478.61	-467.51
Government administration	2.21	-99.62	-97.42
Defence	0.03	-1.39	-1.36
Education	9.51	-282.15	-272.63
Health services	9.29	-271.61	-262.32
Community services	1.16	-33.37	-32.21
Motion picture, radio and television services	4.08	-139.92	-135.84
Libraries, museums and the arts	1.11	-36.41	-35.30
Sport, gambling and recreational services	7.78	-192.15	-184.37
Personal services	3.71	-108.00	-104.28
Other services	3.99	-119.36	-115.37
Total	**1082.81**	**-29840.57**	**-28757.76**

Table A.3 Total employment formation (ths)			
	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: 50 PJ of natural gas withdrawn from natural gas dependent industries	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export
Constrained industries			
Basic chemicals	0.00	-11.20	-11.20
Paints	0.00	-1.00	-1.00
Medicinal and pharmaceutical products, pesticides	0.00	-0.80	-0.80
Soap and detergents	0.00	-0.92	-0.92
Cosmetics and toiletry preparations	0.00	-0.37	-0.37
Other chemical products	0.00	-2.81	-2.81
Rubber products	0.00	-0.35	-0.35
Plastic products	0.00	-16.88	-16.88
Basic non-ferrous metal and products	0.00	-32.47	-32.47
LNG	0.12	0.00	0.12
Unconstrained industries			
Sheep	0.01	-0.47	-0.46
Grains	0.01	-0.41	-0.40
Beef cattle	0.03	-1.24	-1.21
Dairy cattle	0.01	-0.45	-0.43
Pigs	0.01	-0.26	-0.25
Poultry	0.01	-0.20	-0.20
Other agriculture	0.04	-1.28	-1.24
Services to agriculture, hunting and trapping	0.01	-0.29	-0.28
Forestry and logging	0.00	-0.17	-0.16
Commercial fishing	0.00	-0.12	-0.12
Coal	0.00	-0.10	-0.10
Gas	0.00	-0.07	-0.06
Oil	0.00	-0.03	-0.03
Iron ores	0.00	-0.01	-0.01
Non-ferrous metal ores	0.00	-5.15	-5.15
Other mining	0.00	-0.26	-0.25
Services to mining	0.10	-1.88	-1.78
Meat and meat products	0.07	-2.82	-2.75
Dairy products	0.04	-1.17	-1.13
Fruit and vegetable products	0.01	-0.20	-0.19
Oils and fats	0.00	-0.08	-0.08
Flour mill products and cereal foods	0.01	-0.51	-0.50
Bakery products	0.03	-0.97	-0.94
Confectionery	0.01	-0.24	-0.23
Other food products	0.02	-0.63	-0.61

Table A.3 Total employment formation (ths) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: 50 PJ of natural gas withdrawn from natural gas dependent industries	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export
Soft drinks, cordials and syrups	0.01	-0.19	-0.18
Beer and malt	0.00	-0.12	-0.11
Wine, spirits and tobacco products (a)	0.01	-0.17	-0.16
Textile fibres, yarns and woven fabrics	0.00	-0.04	-0.04
Textile products	0.01	-0.16	-0.16
Knitting mill products	0.00	-0.07	-0.07
Clothing	0.01	-0.33	-0.32
Footwear	0.00	-0.04	-0.04
Leather and leather products	0.00	-0.02	-0.02
Sawmill products	0.00	-0.12	-0.12
Other wood products	0.02	-0.58	-0.56
Pulp, paper and paperboard	0.00	-0.05	-0.05
Paper containers and products	0.01	-0.35	-0.34
Printing and services to printing	0.03	-1.01	-0.98
Publishing, recorded media, etc.	0.03	-0.94	-0.92
Petroleum and coal products	0.01	-0.64	-0.63
Glass and glass products	0.01	-0.26	-0.25
Ceramic products	0.00	-0.04	-0.03
Cement, lime and concrete slurry	0.00	-0.12	-0.11
Plaster and other concrete products	0.00	-0.08	-0.08
Other non-metallic mineral products	0.00	-0.09	-0.09
Iron and steel	0.04	-1.10	-1.07
Structural metal products	0.02	-0.45	-0.43
Sheet metal products	0.00	-0.17	-0.16
Fabricated metal products	0.02	-0.78	-0.76
Motor vehicles and parts, other transport equipment	0.05	-1.53	-1.48
Ships and boats	0.00	-0.05	-0.05
Railway equipment	0.00	-0.05	-0.05
Aircraft	0.01	-0.09	-0.08
Photographic and scientific equipment	0.01	-0.29	-0.28
Electronic equipment	0.01	-0.26	-0.25
Household appliances	0.01	-0.33	-0.32
Other electrical equipment	0.01	-0.41	-0.40
Agricultural, mining, etc. machinery	0.02	-0.40	-0.38
Other machinery and equipment	0.02	-0.49	-0.47
Prefabricated buildings	0.01	-0.06	-0.05
Furniture	0.03	-0.89	-0.86
Other manufacturing	0.01	-0.71	-0.70

Table A.3 Total employment formation (ths) – continued			
	Case study: 50 PJ of natural gas allocated to LNG exports	**Case study: 50 PJ of natural gas withdrawn from natural gas dependent industries**	**Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export**
Electricity supply	0.03	-1.38	-1.35
Gas supply	0.01	-0.55	-0.54
Water supply, sewerage and drainage services	0.02	-0.68	-0.67
Residential building	0.01	-0.23	-0.22
Other construction	0.02	-0.56	-0.53
Construction trade services	0.29	-6.23	-5.94
Wholesale trade	0.19	-9.03	-8.84
Wholesale mechanical repairs	0.02	-0.15	-0.13
Other wholesale repairs	0.05	-0.94	-0.90
Retail trade	0.56	-16.80	-16.24
Retail mechanical repairs	0.20	-6.06	-5.86
Other retail repairs	0.01	-0.28	-0.27
Accommodation, cafes and restaurants	0.25	-7.51	-7.26
Road transport	0.10	-4.86	-4.77
Rail, pipeline and other transport	0.08	-0.89	-0.81
Water transport	0.01	-0.28	-0.28
Air and space transport	0.04	-1.10	-1.07
Services to transport, storage	0.07	-2.57	-2.50
Communication services	0.09	-3.10	-3.01
Finance	0.19	-5.40	-5.20
Ownership of dwellings	0.00	0.00	0.00
Other property services	0.11	-2.51	-2.41
Scientific research, technical and computer services	0.13	-4.86	-4.73
Legal, accounting, marketing and business management services	0.17	-6.95	-6.78
Other business services	0.08	-3.64	-3.55
Government administration	0.03	-1.18	-1.16
Defence	0.00	-0.01	-0.01
Education	0.12	-3.66	-3.54
Health services	0.11	-3.31	-3.20
Community services	0.02	-0.50	-0.48
Motion picture, radio and television services	0.03	-1.08	-1.05
Libraries, museums and the arts	0.02	-0.77	-0.74
Sport, gambling and recreational services	0.11	-2.77	-2.66
Personal services	0.10	-2.77	-2.68
Other services	0.05	-1.43	-1.38
Total	**4.28**	**-203.34**	**-199.06**

Table A.4	General economy responses to 50 PJ suppression of domestic natural gas demand – macroeconomic implications of different adjustment paths							
		Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Macroeconomic aggregates								
Gross domestic product at factor cost	$2009m	729.56	469.54	1199.10	-4658.41	-3928.85	-206.25	523.31
Gross domestic product at market Prices	$2009m	767.76	402.91	1170.67	-5697.53	-4929.77	-282.58	485.18
Gross national product at market prices	$2009m	538.64	211.60	750.23	-5492.32	-4953.68	-296.18	242.45
Net national product at market prices	$2009m	355.40	-3.10	352.30	-4966.96	-4611.56	-307.24	48.16
Total imports of goods and services	$2009m	75.85	-64.14	11.72	-1521.38	-1445.52	-113.45	-37.60
Total employment	**Ths**	**4.28**	**-0.50**	**3.78**	**-92.67**	**-88.39**	**-5.72**	**-1.44**
Household activity								
Wages and mixed income	$2009m	170.21	-1.13	169.07	-3130.00	-2959.80	-209.59	-39.39
Property income	$2009m	128.49	264.86	393.36	-922.44	-793.95	16.41	144.90
Direct taxes paid	$2009m	67.21	59.34	126.55	-911.80	-844.59	-43.47	23.74
Household consumption	$2009m	184.68	-831.59	-646.91	-6410.88	-6226.20	-576.70	-392.02

Table A.4	General economy responses to 50 PJ suppression of domestic natural gas demand – macroeconomic implications of different adjustment paths (continued)							
		Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Government revenue								
Direct taxes on households	$2009m	67.21	59.34	126.55	-911.80	-844.59	-43.47	23.74
Direct taxes on business	$2009m	156.55	-4.20	152.34	-248.23	-91.68	-26.12	130.42
Indirect taxes	$2009m	38.21	-66.63	-28.43	-1039.13	-1000.92	-76.33	-38.13
Total tax revenue	**$2009m**	**261.96**	**-11.50**	**250.46**	**-2199.15**	**-1937.19**	**-145.92**	**116.04**
Other indicators								
Income paid overseas	$2009m	229.12	191.31	420.44	-205.21	23.91	13.60	242.73
Benefit indicator	$2009m	401.02	-423.10	-22.07	-6788.50	-6387.47	-514.93	-113.91
Cumulative discounted (at 5%) benefit indicator 2016-2040	$2009m	4629.63	-6154.42	-1524.79	-90767.69	-86138.06	-6995.04	-2365.42

Table A.5 Gross output formation by industry ($2009m)

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Constrained industries							
Basic chemicals	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paints	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medicinal and pharmaceutical products, pesticides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soap and detergents	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cosmetics and toiletry preparations	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other chemical products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rubber products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Basic non-ferrous metal and products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LNG	620.73	0.00	620.73	0.00	620.73	0.00	620.73
Unconstrained industries							
Sheep	0.70	-2.63	-1.93	-22.11	-21.41	-1.95	-1.25
Grains	1.06	-4.28	-3.22	-34.66	-33.60	-3.08	-2.03
Beef cattle	1.94	-7.93	-5.98	-64.11	-62.17	-5.70	-3.76
Dairy cattle	1.08	-4.48	-3.40	-36.09	-35.01	-3.21	-2.13
Pigs	0.27	-1.06	-0.79	-8.69	-8.43	-0.77	-0.50
Poultry	0.60	-2.48	-1.88	-19.94	-19.34	-1.77	-1.17
Other agriculture	3.94	-16.22	-12.27	-130.01	-126.06	-11.61	-7.66
Services to agriculture, hunting and trapping	0.92	-3.57	-2.65	-29.49	-28.58	-2.61	-1.70
Forestry and logging	0.50	-0.11	0.39	-5.70	-5.20	-0.50	0.00

Table A.5 Gross output formation by industry ($2009m) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Commercial fishing	0.63	-2.68	-2.06	-21.17	-20.54	-1.89	-1.27
Coal	1.79	127.25	129.04	15.40	17.19	38.71	40.50
Gas	5.80	-129.56	-123.77	-201.86	-196.06	-181.74	-175.94
Oil	1.47	0.52	1.98	-32.29	-30.82	-1.75	-0.28
Iron ores	0.20	0.17	0.37	-1.74	-1.54	-0.12	0.08
Non-ferrous metal ores	0.31	0.32	0.64	-3.73	-3.42	-0.20	0.11
Other mining	0.45	1.11	1.57	-4.96	-4.51	-0.08	0.38
Services to mining	15.45	-0.63	14.82	-13.67	1.78	-9.15	6.30
Meat and meat products	4.60	-18.91	-14.32	-152.31	-147.71	-13.56	-8.96
Dairy products	3.54	-14.68	-11.13	-118.18	-114.63	-10.51	-6.96
Fruit and vegetable products	1.12	-4.74	-3.62	-37.59	-36.47	-3.36	-2.24
Oils and fats	0.44	-1.80	-1.36	-14.62	-14.18	-1.30	-0.85
Flour mill products and cereal foods	1.83	-7.51	-5.68	-60.59	-58.75	-5.39	-3.56
Bakery products	1.51	-6.14	-4.63	-49.72	-48.21	-4.42	-2.91
Confectionery	1.15	-4.77	-3.62	-38.27	-37.12	-3.41	-2.26
Other food products	2.69	-10.64	-7.95	-86.71	-84.02	-7.72	-5.03
Soft drinks, cordials and syrups	1.48	-6.47	-4.99	-50.51	-49.04	-4.53	-3.05
Beer and malt	1.26	-5.01	-3.75	-40.88	-39.62	-3.63	-2.37
Wine, spirits and tobacco products (a)	1.44	-5.69	-4.25	-45.81	-44.37	-4.11	-2.67
Textile fibres, yarns and woven fabrics	0.12	-0.31	-0.19	-3.21	-3.09	-0.27	-0.15
Textile products	0.37	-1.33	-0.96	-11.30	-10.93	-1.00	-0.63
Knitting mill products	0.26	-0.99	-0.73	-8.17	-7.91	-0.73	-0.47
Clothing	0.57	-1.75	-1.18	-16.00	-15.43	-1.40	-0.83
Footwear	0.12	-0.31	-0.19	-3.63	-3.50	-0.29	-0.17

Table A.5 Gross output formation by industry ($2009m) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Leather and leather products	0.09	-0.19	-0.09	-2.23	-2.13	-0.19	-0.09
Sawmill products	0.54	0.69	1.23	-8.10	-7.56	-0.36	0.18
Other wood products	1.09	0.98	2.07	-15.03	-13.94	-0.81	0.28
Pulp, paper and paperboard	0.30	-0.54	-0.23	-7.04	-6.73	-0.57	-0.27
Paper containers and products	0.90	-2.32	-1.42	-25.71	-24.82	-2.09	-1.19
Printing and services to printing	2.88	-4.72	-1.84	-67.72	-64.84	-5.35	-2.47
Publishing, recorded media, etc.	3.29	-10.22	-6.93	-95.69	-92.40	-8.23	-4.94
Petroleum and coal products	6.35	2.25	8.60	-139.89	-133.54	-7.58	-1.23
Glass and glass products	0.67	-1.21	-0.54	-15.11	-14.43	-1.26	-0.59
Ceramic products	0.12	0.45	0.57	-1.83	-1.71	0.01	0.13
Cement, lime and concrete slurry	0.83	5.82	6.65	-6.45	-5.62	1.11	1.94
Plaster and other concrete products	0.43	5.95	6.38	-2.71	-2.28	1.50	1.93
Other non-metallic mineral products	0.23	0.52	0.75	-1.92	-1.69	-0.03	0.20
Iron and steel	4.24	3.06	7.29	-35.80	-31.57	-2.61	1.62
Structural metal products	2.92	4.69	7.60	-17.79	-14.87	-0.77	2.15
Sheet metal products	0.91	-0.80	0.11	-15.64	-14.73	-1.28	-0.37
Fabricated metal products	2.23	2.09	4.31	-19.85	-17.62	-1.26	0.97
Motor vehicles and parts, other transport equipment	4.75	-13.68	-8.93	-127.96	-123.21	-11.19	-6.45
Ships and boats	0.40	-0.91	-0.51	-9.75	-9.34	-0.84	-0.43
Railway equipment	1.21	0.70	1.91	-6.24	-5.03	-0.67	0.55
Aircraft	1.39	-1.44	-0.04	-15.97	-14.57	-1.75	-0.36
Photographic and scientific equipment	0.91	-2.04	-1.13	-23.19	-22.28	-1.92	-1.01
Electronic equipment	0.83	-0.42	0.41	-16.44	-15.61	-1.15	-0.32

Table A.5 Gross output formation by industry ($2009m) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Household appliances	1.37	-4.11	-2.74	-38.44	-37.07	-3.33	-1.96
Other electrical equipment	1.34	16.53	17.87	-17.25	-15.92	3.76	5.10
Agricultural, mining, etc. machinery	1.79	0.47	2.26	-10.42	-8.64	-1.19	0.59
Other machinery and equipment	1.60	0.55	2.15	-14.76	-13.16	-1.21	0.39
Prefabricated buildings	0.85	-0.05	0.80	-1.29	-0.44	-0.53	0.32
Furniture	1.26	-4.00	-2.74	-36.28	-35.03	-3.16	-1.91
Other manufacturing	1.07	-0.92	0.14	-21.80	-20.73	-1.62	-0.55
Electricity supply	10.97	1617.38	1628.35	245.05	256.02	500.12	511.09
Gas supply	1.10	22.25	23.35	-21.68	-20.58	5.50	6.60
Water supply, sewerage and drainage services	4.06	-6.94	-2.89	-106.27	-102.21	-8.00	-3.94
Residential building	1.94	9.08	11.02	-18.08	-16.15	1.11	3.05
Other construction	3.52	12.53	16.05	-30.01	-26.49	0.90	4.42
Construction trade services	19.47	134.00	153.47	-124.52	-105.05	26.28	45.75
Wholesale trade	25.88	-26.98	-1.10	-528.97	-503.09	-40.62	-14.74
Wholesale mechanical repairs	2.89	1.57	4.47	-9.40	-6.51	-1.43	1.47
Other wholesale repairs	5.51	3.25	8.76	-44.94	-39.43	-3.57	1.94
Retail trade	32.74	-133.41	-100.67	-1078.70	-1045.95	-95.95	-63.20
Retail mechanical repairs	7.63	-5.42	2.21	-149.57	-141.94	-10.97	-3.35
Other retail repairs	0.44	-1.49	-1.06	-13.13	-12.69	-1.15	-0.71
Accommodation, cafes and restaurants	16.97	-61.52	-44.56	-533.81	-516.84	-46.52	-29.55
Road transport	9.58	-16.59	-7.00	-228.91	-219.32	-18.20	-8.62
Rail, pipeline and other transport	10.02	6.02	16.03	-52.46	-42.45	-5.45	4.57
Water transport	1.13	0.88	2.01	-13.55	-12.41	-0.82	0.32

Table A.5 Gross output formation by industry ($2009m) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Air and space transport	4.99	-13.85	-8.86	-140.33	-135.34	-11.81	-6.81
Services to transport, storage	13.62	-8.85	4.77	-172.10	-158.48	-16.09	-2.47
Communication services	15.22	-24.74	-9.52	-384.41	-369.19	-29.13	-13.90
Finance	47.38	-42.08	5.30	-1081.89	-1034.51	-75.99	-28.61
Ownership of dwellings	4.72	-21.24	-16.52	-163.75	-159.04	-14.73	-10.01
Other property services	31.27	0.18	31.44	-386.50	-355.23	-30.34	0.92
Scientific research, technical and computer services	11.85	7.43	19.28	-139.34	-127.49	-8.99	2.86
Legal, accounting, marketing and business management services	18.85	-4.21	14.63	-349.65	-330.81	-23.61	-4.76
Other business services	11.10	-1.27	9.83	-207.63	-196.53	-13.59	-2.49
Government administration	2.21	-2.87	-0.66	-41.08	-38.87	-3.50	-1.29
Defence	0.03	-0.03	0.00	-0.51	-0.48	-0.04	-0.01
Education	9.51	-30.06	-20.55	-297.24	-287.73	-24.65	-15.13
Health services	9.29	-41.36	-32.08	-320.54	-311.25	-28.80	-19.51
Community services	1.16	-5.21	-4.05	-40.18	-39.02	-3.61	-2.46
Motion picture, radio and television services	4.08	-8.30	-4.21	-101.00	-96.91	-8.25	-4.17
Libraries, museums and the arts	1.11	-1.05	0.06	-29.01	-27.90	-1.92	-0.82
Sport, gambling and recreational services	7.78	-27.59	-19.80	-216.58	-208.80	-20.18	-12.39
Personal services	3.71	-16.27	-12.56	-127.06	-123.35	-11.39	-7.68
Other services	3.99	-16.76	-12.78	-135.57	-131.58	-11.99	-8.00
Total	**1082.81**	**1156.34**	**2239.14**	**-9213.92**	**-8131.11**	**-344.93**	**737.88**

Table A.6 Total employment formation (ths)

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Constrained industries							
Basic chemicals	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paints	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Medicinal and pharmaceutical products, pesticides	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soap and detergents	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cosmetics and toiletry preparations	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other chemical products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rubber products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plastic products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Basic non-ferrous metal and products	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LNG	0.12	0.00	0.12	0.00	0.12	0.00	0.12
Unconstrained industries							
Sheep	0.01	-0.04	-0.03	-0.37	-0.36	-0.03	-0.02
Grains	0.01	-0.04	-0.03	-0.30	-0.29	-0.03	-0.02
Beef cattle	0.03	-0.11	-0.09	-0.91	-0.89	-0.08	-0.05
Dairy cattle	0.01	-0.06	-0.05	-0.48	-0.46	-0.04	-0.03
Pigs	0.01	-0.03	-0.02	-0.21	-0.20	-0.02	-0.01
Poultry	0.01	-0.02	-0.02	-0.18	-0.17	-0.02	-0.01
Other agriculture	0.04	-0.15	-0.12	-1.23	-1.19	-0.11	-0.07
Services to agriculture, hunting and trapping	0.01	-0.03	-0.02	-0.21	-0.21	-0.02	-0.01
Forestry and logging	0.00	0.00	0.00	-0.04	-0.04	0.00	0.00

Table A.6 Total employment formation (ths) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Commercial fishing	0.00	-0.02	-0.01	-0.14	-0.14	-0.01	-0.01
Coal	0.00	0.16	0.17	0.02	0.02	0.05	0.05
Gas	0.00	-0.11	-0.10	-0.16	-0.16	-0.15	-0.14
Oil	0.00	0.00	0.00	-0.02	-0.01	0.00	0.00
Iron ores	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-ferrous metal ores	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Other mining	0.00	0.00	0.01	-0.02	-0.02	0.00	0.00
Services to mining	0.10	0.00	0.10	-0.09	0.01	-0.06	0.04
Meat and meat products	0.07	-0.28	-0.21	-2.24	-2.17	-0.20	-0.13
Dairy products	0.04	-0.16	-0.12	-1.25	-1.21	-0.11	-0.07
Fruit and vegetable products	0.01	-0.03	-0.02	-0.22	-0.21	-0.02	-0.01
Oils and fats	0.00	-0.01	-0.01	-0.06	-0.06	-0.01	0.00
Flour mill products and cereal foods	0.01	-0.05	-0.04	-0.43	-0.42	-0.04	-0.03
Bakery products	0.03	-0.13	-0.10	-1.07	-1.03	-0.09	-0.06
Confectionery	0.01	-0.03	-0.02	-0.26	-0.25	-0.02	-0.02
Other food products	0.02	-0.07	-0.05	-0.54	-0.53	-0.05	-0.03
Soft drinks, cordials and syrups	0.01	-0.03	-0.02	-0.20	-0.20	-0.02	-0.01
Beer and malt	0.00	-0.02	-0.01	-0.13	-0.12	-0.01	-0.01
Wine, spirits and tobacco products (a)	0.01	-0.02	-0.02	-0.17	-0.16	-0.02	-0.01
Textile fibres, yarns and woven fabrics	0.00	0.00	0.00	-0.02	-0.02	0.00	0.00
Textile products	0.01	-0.02	-0.01	-0.15	-0.15	-0.01	-0.01
Knitting mill products	0.00	-0.01	-0.01	-0.07	-0.07	-0.01	0.00
Clothing	0.01	-0.03	-0.02	-0.28	-0.27	-0.02	-0.01
Footwear	0.00	0.00	0.00	-0.04	-0.04	0.00	0.00

Table A.6 Total employment formation (ths) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Leather and leather products	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Sawmill products	0.00	0.01	0.01	-0.06	-0.06	0.00	0.00
Other wood products	0.02	0.01	0.03	-0.22	-0.21	-0.01	0.00
Pulp, paper and paperboard	0.00	0.00	0.00	-0.02	-0.02	0.00	0.00
Paper containers and products	0.01	-0.02	-0.01	-0.19	-0.18	-0.02	-0.01
Printing and services to printing	0.03	-0.05	-0.02	-0.67	-0.64	-0.05	-0.02
Publishing, recorded media, etc.	0.03	-0.08	-0.05	-0.74	-0.71	-0.06	-0.04
Petroleum and coal products	0.01	0.01	0.02	-0.32	-0.30	-0.02	0.00
Glass and glass products	0.01	-0.01	-0.01	-0.14	-0.14	-0.01	-0.01
Ceramic products	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Cement, lime and concrete slurry	0.00	0.02	0.03	-0.03	-0.02	0.00	0.01
Plaster and other concrete products	0.00	0.03	0.03	-0.01	-0.01	0.01	0.01
Other non-metallic mineral products	0.00	0.01	0.01	-0.02	-0.02	0.00	0.00
Iron and steel	0.04	0.03	0.07	-0.32	-0.28	-0.02	0.01
Structural metal products	0.02	0.03	0.05	-0.11	-0.09	0.00	0.01
Sheet metal products	0.00	0.00	0.00	-0.07	-0.07	-0.01	0.00
Fabricated metal products	0.02	0.02	0.05	-0.21	-0.19	-0.01	0.01
Motor vehicles and parts, other transport equipment	0.05	-0.15	-0.10	-1.43	-1.38	-0.12	-0.07
Ships and boats	0.00	0.00	0.00	-0.04	-0.03	0.00	0.00
Railway equipment	0.00	0.00	0.01	-0.03	-0.02	0.00	0.00
Aircraft	0.01	-0.01	0.00	-0.07	-0.06	-0.01	0.00
Photographic and scientific equipment	0.01	-0.02	-0.01	-0.25	-0.24	-0.02	-0.01
Electronic equipment	0.01	0.00	0.00	-0.18	-0.17	-0.01	0.00

Table A.6 Total employment formation (ths) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Household appliances	0.01	-0.04	-0.02	-0.33	-0.32	-0.03	-0.02
Other electrical equipment	0.01	0.16	0.18	-0.17	-0.16	0.04	0.05
Agricultural, mining, etc. machinery	0.02	0.01	0.02	-0.11	-0.09	-0.01	0.01
Other machinery and equipment	0.02	0.01	0.02	-0.16	-0.14	-0.01	0.00
Prefabricated buildings	0.01	0.00	0.01	-0.01	0.00	0.00	0.00
Furniture	0.03	-0.10	-0.07	-0.88	-0.85	-0.08	-0.05
Other manufacturing	0.01	-0.01	0.00	-0.27	-0.26	-0.02	-0.01
Electricity supply	0.03	4.84	4.88	0.73	0.77	1.50	1.53
Gas supply	0.01	0.19	0.20	-0.18	-0.17	0.05	0.06
Water supply, sewerage and drainage services	0.02	-0.03	-0.01	-0.46	-0.44	-0.03	-0.02
Residential building	0.01	0.04	0.05	-0.09	-0.08	0.01	0.02
Other construction	0.02	0.09	0.11	-0.21	-0.19	0.01	0.03
Construction trade services	0.29	1.99	2.28	-1.85	-1.56	0.39	0.68
Wholesale trade	0.19	-0.20	-0.01	-3.88	-3.69	-0.30	-0.11
Wholesale mechanical repairs	0.02	0.01	0.03	-0.06	-0.04	-0.01	0.01
Other wholesale repairs	0.05	0.03	0.07	-0.38	-0.33	-0.03	0.02
Retail trade	0.56	-2.28	-1.72	-18.40	-17.84	-1.64	-1.08
Retail mechanical repairs	0.20	-0.14	0.06	-3.95	-3.75	-0.29	-0.09
Other retail repairs	0.01	-0.03	-0.02	-0.28	-0.27	-0.02	-0.02
Accommodation, cafes and restaurants	0.25	-0.90	-0.65	-7.77	-7.52	-0.68	-0.43
Road transport	0.10	-0.16	-0.07	-2.27	-2.18	-0.18	-0.09
Rail, pipeline and other transport	0.08	0.05	0.13	-0.42	-0.34	-0.04	0.04
Water transport	0.01	0.00	0.01	-0.07	-0.06	0.00	0.00

Table A.6 Total employment formation (ths) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports	Case study: impact of withdrawing 50 PJ of natural gas – general economy impact full electricity substitution	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – full substitution effect	Case study: impact of withdrawing 50 PJ of natural gas – decline in economic activity	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – decline in economic activity	Case study: impact of withdrawing 50 PJ of natural gas – gas substitution in electricity production	Net benefit of reallocating 50 PJ of natural gas from natural gas dependent industries to export – general economy effect – gas substitution in electricity production
Air and space transport	0.04	-0.10	-0.06	-0.99	-0.96	-0.08	-0.05
Services to transport, storage	0.07	-0.05	0.02	-0.89	-0.82	-0.08	-0.01
Communication services	0.09	-0.15	-0.06	-2.38	-2.29	-0.18	-0.09
Finance	0.19	-0.17	0.02	-4.43	-4.23	-0.31	-0.12
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	0.11	0.00	0.11	-1.31	-1.21	-0.10	0.00
Scientific research, technical and computer services	0.13	0.08	0.21	-1.52	-1.39	-0.10	0.03
Legal, accounting, marketing and business management services	0.17	-0.04	0.13	-3.17	-3.00	-0.21	-0.04
Other business services	0.08	-0.01	0.07	-1.58	-1.49	-0.10	-0.02
Government administration	0.03	-0.03	-0.01	-0.49	-0.46	-0.04	-0.02
Defence	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Education	0.12	-0.39	-0.27	-3.86	-3.73	-0.32	-0.20
Health services	0.11	-0.50	-0.39	-3.91	-3.79	-0.35	-0.24
Community services	0.02	-0.08	-0.06	-0.60	-0.58	-0.05	-0.04
Motion picture, radio and television services	0.03	-0.06	-0.03	-0.78	-0.75	-0.06	-0.03
Libraries, museums and the arts	0.02	-0.02	0.00	-0.61	-0.59	-0.04	-0.02
Sport, gambling and recreational services	0.11	-0.40	-0.29	-3.12	-3.01	-0.29	-0.18
Personal services	0.10	-0.42	-0.32	-3.26	-3.16	-0.29	-0.20
Other services	0.05	-0.20	-0.15	-1.62	-1.57	-0.14	-0.10
Total	**4.28**	**-0.50**	**3.78**	**-92.67**	**-88.39**	**-5.72**	**-1.44**

Table A.7	Eastern Australian estimates of suppressed gas demand – No East Coast LNG							
	Cumulative suppressed gas demand 2011-2040 – petajoules (PJ)	Average annual suppressed gas demand 2011-2020 – petajoules (PJ)	Average annual suppressed gas demand 2021-2030 – petajoules (PJ)	Average annual suppressed gas demand 2031-2040 – petajoules (PJ)	Average annual ex-plant gas cost $2011 per gigajoule 2011-2020 – petajoules ($/GJ)	Average annual ex-plant gas cost $2011 per gigajoule 2021-2030 – petajoules ($/GJ)	Average annual ex-plant gas cost $2011 per gigajoule 2031-2040 – petajoules ($/GJ)	Suppressed demand as per cent of base case domestic Eastern Australian demand (%)
Aggregate indicators								
Minimum	0	0.0	0.0	0.0	5.4	6.4	7.7	0.0
Maximum	16894	0.0	522.3	1167.1	6.0	8.4	11.4	51.6
Mean	1193	0.0	11.6	107.7	5.6	7.0	9.1	9.5
Std Deviation	2269	0.0	49.1	184.0	0.1	0.4	0.8	9.3
Distribution								
5% Percentile	0	0.0	0.0	0.0	5.4	6.5	8.0	0.0
10% Percentile	0	0.0	0.0	0.0	5.4	6.6	8.1	0.0
15% Percentile	0	0.0	0.0	0.0	5.5	6.6	8.2	0.0
20% Percentile	0	0.0	0.0	0.0	5.5	6.7	8.4	0.0
25% Percentile	0	0.0	0.0	0.0	5.5	6.7	8.4	0.0
30% Percentile	86	0.0	0.0	8.6	5.5	6.8	8.5	3.2
35% Percentile	86	0.0	0.0	8.6	5.5	6.8	8.6	3.2
40% Percentile	254	0.0	0.0	25.4	5.5	6.9	8.7	6.3
45% Percentile	254	0.0	0.0	25.4	5.5	6.9	8.8	6.3
50% Percentile	259	0.0	0.0	25.9	5.6	6.9	8.9	6.3
55% Percentile	499	0.0	0.0	49.9	5.6	7.1	9.1	9.3
60% Percentile	499	0.0	0.0	49.9	5.6	7.1	9.2	9.3
65% Percentile	817	0.0	0.0	81.7	5.6	7.2	9.4	12.2
70% Percentile	817	0.0	0.0	81.7	5.7	7.3	9.5	12.2
75% Percentile	1206	0.0	0.0	120.6	5.7	7.3	9.6	15.0
80% Percentile	1432	0.0	0.0	143.2	5.7	7.4	9.8	15.0
85% Percentile	1661	0.0	0.0	166.1	5.7	7.5	9.9	17.7
90% Percentile	3067	0.0	0.0	304.2	5.8	7.7	10.3	21.2
95% Percentile	6403	0.0	77.6	578.6	5.8	7.8	10.5	28.4

Table A.8 Eastern Australian estimates of suppressed gas demand – East Coast LNG

	Cumulative suppressed gas demand 2011-2040 – petajoules (PJ)	Average annual suppressed gas demand 2011-2020 – petajoules (PJ)	Average annual suppressed gas demand 2021-2030 – petajoules (PJ)	Average annual suppressed gas demand 2031-2040 – petajoules (PJ)	Average annual ex-plant gas cost $2011 per gigajoule 2011-2020 – petajoules ($/GJ)	Average annual ex-plant gas cost $2011 per gigajoule 2021-2030 – petajoules ($/GJ)	Average annual ex-plant gas cost $2011 per gigajoule 2031-2040 – petajoules ($/GJ)	Suppressed demand as per cent of base case domestic Eastern Australian demand (%)
Aggregate indicators								
Minimum	68.9	0.0	0.0	6.9	5.4	6.9	8.9	2.6
Maximum	43585.1	319.9	1752.8	2317.8	6.2	9.2	12.2	94.3
Mean	15170.8	40.2	597.5	883.4	5.7	7.7	10.1	40.8
Std Deviation	10525.2	59.9	450.0	562.1	0.1	0.4	0.6	19.5
Distribution								
5% Percentile	929.1	0.0	0.0	64.1	5.5	7.0	9.2	11.9
10% Percentile	1556.5	0.0	0.0	155.6	5.5	7.2	9.4	15.7
15% Percentile	2148.3	0.0	0.0	187.4	5.5	7.2	9.5	19.3
20% Percentile	2824.3	0.0	52.4	255.5	5.5	7.3	9.6	22.8
25% Percentile	5071.4	0.0	165.3	345.5	5.6	7.4	9.7	24.3
30% Percentile	7641.6	0.0	252.8	494.9	5.6	7.5	9.8	27.0
35% Percentile	9767.5	0.0	361.8	612.4	5.6	7.5	9.9	31.0
40% Percentile	11838.2	0.0	455.0	727.0	5.6	7.6	10.0	33.8
45% Percentile	13520.0	0.0	529.8	811.2	5.6	7.6	10.1	37.2
50% Percentile	15089.4	0.0	609.6	885.4	5.6	7.7	10.1	39.7
55% Percentile	16447.8	8.9	669.9	979.8	5.7	7.7	10.2	42.4
60% Percentile	17998.8	24.6	744.7	1030.2	5.7	7.8	10.3	44.6
65% Percentile	19676.0	38.2	824.7	1112.7	5.7	7.8	10.4	47.6
70% Percentile	21718.6	50.2	888.4	1209.7	5.7	7.9	10.4	51.2
75% Percentile	23340.6	63.7	952.3	1324.2	5.8	8.0	10.5	55.1
80% Percentile	25130.9	82.2	1031.1	1413.9	5.8	8.0	10.6	58.5
85% Percentile	27283.7	110.0	1113.1	1540.5	5.8	8.2	10.7	63.7
90% Percentile	29833.6	136.4	1222.5	1659.1	5.9	8.3	10.9	68.3
95% Percentile	33126.2	169.5	1339.2	1826.5	6.0	8.5	11.2	75.1

Table A.9	Eastern Australian estimates of suppressed gas demand – Impact of East Coast LNG							
	Cumulative suppressed gas demand 2011-2040 – petajoules (PJ)	Average annual suppressed gas demand 2011-2020 – petajoules (PJ)	Average annual suppressed gas demand 2021-2030 – petajoules (PJ)	Average annual suppressed gas demand 2031-2040 – petajoules (PJ)	Average annual ex-plant gas cost $2011 per gigajoule 2011-2020 – petajoules ($/GJ)	Average annual ex-plant gas cost $2011 per gigajoule 2021-2030 – petajoules ($/GJ)	Average annual ex-plant gas cost $2011 per gigajoule 2031-2040 – petajoules ($/GJ)	Suppressed demand as per cent of base case domestic Eastern Australian demand (%)
Aggregate indicators								
Minimum	68.9	0.0	0.0	6.9	0.0	0.5	1.1	2.6
Maximum	26691.3	319.9	1230.5	1150.7	0.2	0.8	0.8	42.7
Mean	13977.5	40.2	585.9	775.7	0.1	0.7	1.1	31.3
Std Deviation	8255.9	59.9	400.9	378.1	0.0	0.0	-0.2	10.2
Distribution								
5% Percentile	929.1	0.0	0.0	64.1	0.0	0.5	1.2	11.9
10% Percentile	1556.5	0.0	0.0	155.6	0.1	0.6	1.3	15.7
15% Percentile	2148.3	0.0	0.0	187.4	0.1	0.6	1.3	19.3
20% Percentile	2824.3	0.0	52.4	255.5	0.1	0.6	1.3	22.8
25% Percentile	5071.4	0.0	165.3	345.5	0.1	0.7	1.3	24.3
30% Percentile	7555.6	0.0	252.8	486.3	0.1	0.7	1.3	23.8
35% Percentile	9681.5	0.0	361.8	603.8	0.1	0.7	1.3	27.8
40% Percentile	11584.7	0.0	455.0	701.7	0.1	0.7	1.3	27.4
45% Percentile	13266.5	0.0	529.8	785.8	0.1	0.7	1.3	30.9
50% Percentile	14830.2	0.0	609.6	859.5	0.1	0.7	1.2	33.4
55% Percentile	15949.2	8.9	669.9	930.0	0.1	0.7	1.1	33.0
60% Percentile	17500.2	24.6	744.7	980.4	0.1	0.7	1.1	35.3
65% Percentile	18858.7	38.2	824.7	1031.0	0.1	0.6	1.0	35.4
70% Percentile	20901.2	50.2	888.4	1128.0	0.1	0.6	0.9	39.0
75% Percentile	22134.6	63.7	952.3	1203.6	0.1	0.6	0.9	40.1
80% Percentile	23698.6	82.2	1031.1	1270.6	0.1	0.6	0.8	43.5
85% Percentile	25622.9	110.0	1113.1	1374.5	0.1	0.7	0.8	46.0
90% Percentile	26767.1	136.4	1222.5	1354.9	0.1	0.6	0.6	47.1
95% Percentile	26723.0	169.5	1261.6	1247.8	0.1	0.7	0.7	46.7

Table A.10 Eastern Australian estimates of suppressed gas demand – No East Coast LNG

	Gross domestic product at market prices (2009 $m) – 2020	Gross domestic product at market prices (2009 $m) – 2040	Total employment (ths) – 2020	Total employment (ths) – 2020	Benefit indicator (2009 $m) – 2020	Benefit indicator (2009 $m) – 2040	Cumulative discounted net benefit indicator (5% rate) (2009 $m) 2012 – 2040	Ultimately recoverable reserves (2009 $m)	Estimates of eventually recoverable reserves as at 2012 (PJ)
Aggregate indicators									
Minimum	-26636	-109626	-672	-2161	-40493	-127105	-797201	94208	91288.9
Maximum	15118	18445	82	103	7744	9647	101184	265838	263437.8
Mean	8339	-33424	-47	-837	-319	-49917	-196062	173479	173481.8
Std Deviation	9292	28332	174	505	10880	31851	212661	36543	36426.9
Distribution									
5% Percentile	-10823	-79109	-391	-1647	-21041	-98005	-561368	115734	115200.3
10% Percentile	-3839	-69326	-279	-1477	-16162	-89901	-492412	125386	125942.1
15% Percentile	-1816	-65155	-243	-1409	-12573	-84793	-433361	133987	134066.2
20% Percentile	-75	-56463	-213	-1263	-10853	-78436	-382385	140845	140810.0
25% Percentile	1720	-52830	-179	-1208	-8621	-73908	-342773	147117	146886.9
30% Percentile	3493	-49945	-131	-1131	-5658	-69629	-313076	151931	152278.0
35% Percentile	5639	-44308	-94	-1038	-3384	-66274	-292924	157163	157293.8
40% Percentile	10072	-41612	-20	-1002	1577	-61076	-263167	161852	161965.7
45% Percentile	13688	-40193	54	-940	5990	-55411	-227867	166430	166397.9
50% Percentile	15118	-35602	82	-869	7744	-52388	-197998	170863	171161.4
55% Percentile	15118	-32403	82	-824	7744	-47911	-168263	176278	176066.5
60% Percentile	15118	-28204	82	-758	7744	-44830	-130813	181130	181323.1
65% Percentile	15118	-21513	82	-637	7744	-37388	-92761	186871	186829.0
70% Percentile	15118	-15515	82	-518	7744	-30791	-39563	192865	192840.7
75% Percentile	15118	-10561	82	-428	7744	-23149	-14712	199282	199367.6
80% Percentile	15118	-5415	82	-331	7744	-18460	25583	206500	206442.7
85% Percentile	15118	593	82	-221	7744	-10114	85246	214882	214675.4
90% Percentile	15118	6777	82	-108	7744	-3718	94371	223848	224387.3
95% Percentile	15118	12600	82	-13	7744	2518	98438	237320	236890.6

Table A.11 Queensland natural gas expansion – the expected net benefit on the national economy (with year benchmarks)							
		2015	**2020**	**2025**	**2030**	**2035**	**2040**
Macroeconomic aggregates							
Gross domestic product at factor cost	$2009m	0.0	14395.9	-3791.9	-6697.9	-8918.8	-22009.2
Gross domestic product at market prices	$2009m	0.0	15117.7	-7326.3	-10834.4	-13496.1	-29253.7
Gross national product at market prices	$2009m	0.0	10544.6	-12045.5	-15406.3	-17962.4	-33181.2
Net national product at market prices	$2009m	0.0	6903.3	-14433.9	-17458.7	-19785.0	-33728.5
Total imports of goods and services	$2009m	0.0	1455.2	6083.9	5781.5	6262.0	9284.3
Total employment	**ths.**	**0.0**	**81.8**	**-375.2**	**-434.3**	**-482.8**	**-774.6**
Household activity							
Wages and mixed income	$2009m	0.0	3275.8	-11437.0	-13396.2	-14975.8	-24450.8
Property income	$2009m	0.0	2528.8	352.4	-179.0	-480.5	-2156.4
Direct taxes paid	$2009m	0.0	1306.0	-2494.0	-3054.4	-3477.7	-5986.6
Household consumption	$2009m	0.0	3436.6	-22827.7	-26451.1	-29099.2	-45299.7
Government revenue							
Direct taxes on households	$2009m	0.0	1306.0	-2494.0	-3054.4	-3477.7	-5986.6
Direct taxes on business	$2009m	0.0	3121.2	2176.4	2004.9	1841.8	860.5
Indirect taxes	$2009m	0.0	721.8	-3534.3	-4136.5	-4577.3	-7244.5
Total tax revenue	**$2009m**	**0.0**	**5149.0**	**-3851.9**	**-5186.0**	**-6213.2**	**-12370.6**
Other indicators							
Income paid overseas	$2009m	0.0	4573.1	4719.2	4571.9	4466.3	3927.6
Benefit indicator	$2009m	0.0	7744.4	-20556.8	-24547.9	-27548.7	-45699.4
Cumulative discounted (at 5%) benefit indicator 2016-2040	$2009m	0.0	0.0	0.0	0.0	0.0	-160043.6

Table A.12 The impact of East Coast LNG exports on the national economy: Gross output formation by industry ($2009m)						
	2015	2020	2025	2030	2035	2040
Constrained industries						
Basic chemicals	0.0	0.0	-5867.8	-6185.3	-6801.4	-10581.1
Paints	0.0	0.0	-137.1	-144.5	-158.9	-247.2
Medicinal and pharmaceutical products, pesticides	0.0	0.0	-137.9	-145.4	-159.9	-248.7
Soap and detergents	0.0	0.0	-222.1	-234.2	-257.5	-400.6
Cosmetics and toiletry preparations	0.0	0.0	-77.3	-81.5	-89.6	-139.4
Other chemical products	0.0	0.0	-403.3	-425.1	-467.5	-727.2
Rubber products	0.0	0.0	-55.9	-58.9	-64.7	-100.7
Plastic products	0.0	0.0	-2579.1	-2718.6	-2989.4	-4650.7
Basic non-ferrous metal and products	0.0	0.0	-8310.6	-8760.2	-9632.7	-14985.9
LNG	0.0	12414.5	14897.5	14897.5	14897.5	14897.5
Unconstrained industries						
Sheep	0.0	13.0	-89.1	-102.3	-112.7	-176.2
Grains	0.0	19.7	-146.0	-167.0	-183.8	-286.9
Beef cattle	0.0	36.3	-270.2	-308.9	-340.1	-530.7
Dairy cattle	0.0	20.2	-131.1	-151.8	-167.1	-260.7
Pigs	0.0	5.0	-34.8	-40.0	-44.0	-68.8
Poultry	0.0	11.2	-78.2	-89.9	-98.9	-154.4
Other agriculture	0.0	73.7	-491.7	-567.1	-624.4	-974.7
Services to agriculture, hunting and trapping	0.0	17.1	-122.9	-140.7	-154.9	-242.1
Forestry and logging	0.0	9.7	-34.2	-38.7	-43.5	-72.3
Commercial fishing	0.0	11.7	-76.5	-88.5	-97.4	-151.9
Coal	0.0	34.9	1028.6	1061.6	1150.7	1749.2
Gas	0.0	115.1	-2135.4	-2272.8	-2519.9	-4005.1
Oil	0.0	28.0	-117.6	-137.5	-153.1	-246.0
Iron ores	0.0	4.0	-5.8	-7.0	-8.2	-14.9
Non-ferrous metal ores	0.0	6.1	-3417.2	-3603.8	-3963.4	-6168.9
Other mining	0.0	8.8	-87.0	-94.3	-104.6	-167.1

Table A.12 The impact of East Coast LNG exports on the national economy: Gross output formation by industry ($2009m) – continued						
	2015	2020	2025	2030	2035	2040
Services to mining	0.0	308.8	-97.0	-125.1	-175.6	-479.9
Meat and meat products	0.0	85.8	-621.9	-712.7	-784.6	-1224.3
Dairy products	0.0	66.1	-429.4	-496.9	-547.1	-853.6
Fruit and vegetable products	0.0	20.9	-135.5	-156.9	-172.7	-269.4
Oils and fats	0.0	8.2	-60.8	-69.5	-76.6	-119.5
Flour mill products and cereal foods	0.0	34.2	-241.8	-277.6	-305.6	-476.9
Bakery products	0.0	28.2	-178.2	-206.5	-227.4	-355.1
Confectionery	0.0	21.5	-138.3	-160.1	-176.3	-275.1
Other food products	0.0	50.3	-340.0	-391.0	-430.7	-673.1
Soft drinks, cordials and syrups	0.0	27.6	-185.1	-214.0	-235.5	-366.9
Beer and malt	0.0	23.5	-146.3	-169.6	-186.8	-291.9
Wine, spirits and tobacco products (a)	0.0	27.0	-168.9	-195.3	-215.2	-336.7
Textile fibres, yarns and woven fabrics	0.0	2.3	-14.9	-17.0	-18.8	-29.6
Textile products	0.0	7.0	-41.4	-47.9	-52.9	-82.9
Knitting mill products	0.0	4.8	-30.3	-35.0	-38.6	-60.4
Clothing	0.0	10.7	-59.7	-69.1	-76.3	-120.3
Footwear	0.0	2.3	-12.6	-14.6	-16.2	-25.4
Leather and leather products	0.0	1.8	-8.7	-10.0	-11.1	-17.8
Sawmill products	0.0	10.6	-20.8	-25.6	-29.1	-49.8
Other wood products	0.0	21.1	-51.5	-61.3	-69.3	-117.1
Pulp, paper and paperboard	0.0	5.8	-30.2	-34.6	-38.4	-61.2
Paper containers and products	0.0	16.9	-115.6	-131.9	-145.5	-228.7
Printing and services to printing	0.0	54.8	-250.9	-291.6	-323.5	-516.7
Publishing, recorded media, etc.	0.0	62.0	-370.7	-427.5	-471.8	-741.9
Petroleum and coal products	0.0	121.2	-509.4	-596.0	-663.2	-1066.0
Glass and glass products	0.0	12.8	-63.2	-72.7	-80.6	-128.8
Ceramic products	0.0	2.2	-3.4	-4.4	-5.1	-8.9
Cement, lime and concrete slurry	0.0	16.3	13.1	9.3	8.0	3.1
Plaster and other concrete products	0.0	8.4	32.1	31.1	32.7	45.6

Table A.12 The impact of East Coast LNG exports on the national economy: Gross output formation by industry ($2009m) – continued						
	2015	2020	2025	2030	2035	2040
Other non-metallic mineral products	0.0	4.4	-4.8	-6.1	-7.2	-13.7
Iron and steel	0.0	83.3	-124.1	-149.5	-173.2	-314.2
Structural metal products	0.0	57.6	-34.7	-47.5	-58.9	-125.3
Sheet metal products	0.0	17.6	-69.4	-79.8	-89.0	-145.0
Fabricated metal products	0.0	43.7	-75.9	-90.2	-103.8	-184.8
Motor vehicles and parts, other transport equipment	0.0	89.8	-451.6	-525.6	-581.1	-919.4
Ships and boats	0.0	7.7	-37.0	-42.8	-47.4	-75.6
Railway equipment	0.0	24.0	1.2	-2.6	-5.6	-23.1
Aircraft	0.0	27.3	-43.0	-52.5	-60.2	-106.6
Photographic and scientific equipment	0.0	17.3	-80.8	-94.3	-104.4	-166.0
Electronic equipment	0.0	15.9	-51.0	-60.7	-67.8	-110.6
Household appliances	0.0	25.9	-132.9	-154.9	-171.1	-270.0
Other electrical equipment	0.0	25.8	76.9	69.8	73.0	100.4
Agricultural, mining, etc. machinery	0.0	35.3	-28.7	-36.2	-43.8	-88.7
Other machinery and equipment	0.0	31.4	-51.8	-62.0	-71.3	-127.3
Prefabricated buildings	0.0	17.0	3.9	2.7	0.9	-9.9
Furniture	0.0	23.7	-128.0	-148.8	-164.3	-258.8
Other manufacturing	0.0	20.5	-107.0	-121.8	-135.3	-216.7
Electricity supply	0.0	209.5	13710.6	14196.4	15426.2	23620.7
Gas supply	0.0	20.8	78.2	68.7	72.1	103.4
Water supply, sewerage and drainage services	0.0	76.8	-396.4	-460.1	-509.2	-806.9
Residential building	0.0	37.9	16.9	7.0	3.1	-15.5
Other construction	0.0	69.1	12.9	-4.1	-12.7	-57.7
Construction trade services	0.0	382.9	721.2	664.5	677.3	822.6
Wholesale trade	0.0	496.1	-2411.8	-2760.3	-3066.7	-4922.9
Wholesale mechanical repairs	0.0	57.5	25.7	20.0	15.1	-12.7
Other wholesale repairs	0.0	108.4	-97.4	-126.2	-150.3	-292.6
Retail trade	0.0	611.5	-3874.5	-4489.3	-4943.5	-7719.1
Retail mechanical repairs	0.0	146.5	-490.9	-579.9	-647.6	-1054.8

Table A.12 The impact of East Coast LNG exports on the national economy: Gross output formation by industry ($2009m) – continued						
	2015	**2020**	**2025**	**2030**	**2035**	**2040**
Other retail repairs	0.0	8.2	-46.7	-54.2	-59.8	-94.0
Accommodation, cafes and restaurants	0.0	317.8	-1903.2	-2208.5	-2434.2	-3811.9
Road transport	0.0	182.4	-1059.5	-1208.2	-1337.7	-2124.3
Rail, pipeline and other transport	0.0	198.3	7.8	-23.9	-48.9	-194.1
Water transport	0.0	22.1	-70.6	-80.9	-91.0	-152.1
Air and space transport	0.0	94.2	-497.3	-578.4	-639.1	-1008.3
Services to transport, storage	0.0	265.5	-809.1	-929.8	-1045.8	-1747.7
Communication services	0.0	288.8	-1322.0	-1546.7	-1714.2	-2727.7
Finance	0.0	903.3	-3266.8	-3885.7	-4324.4	-6963.1
Ownership of dwellings	0.0	87.8	-583.1	-675.6	-743.3	-1157.1
Other property services	0.0	609.7	-1108.0	-1345.8	-1535.6	-2671.3
Scientific research, technical and computer services	0.0	231.3	-574.5	-671.9	-761.0	-1294.2
Legal, accounting, marketing and business management services	0.0	362.6	-1376.3	-1599.8	-1785.5	-2903.2
Other business services	0.0	213.5	-841.6	-975.7	-1088.4	-1766.6
Government administration	0.0	42.5	-195.3	-222.8	-247.9	-400.1
Defence	0.0	0.5	-2.6	-2.9	-3.2	-5.2
Education	0.0	178.2	-1015.8	-1184.4	-1306.1	-2047.0
Health services	0.0	172.9	-1146.0	-1327.5	-1460.6	-2274.4
Community services	0.0	21.5	-143.1	-165.8	-182.4	-283.9
Motion picture, radio and television services	0.0	77.6	-372.4	-432.5	-479.2	-762.5
Libraries, museums and the arts	0.0	20.9	-91.8	-108.4	-120.2	-191.1
Sport, gambling and recreational services	0.0	147.0	-751.3	-874.5	-966.0	-1525.0
Personal services	0.0	69.1	-453.0	-524.9	-577.6	-899.9
Other services	0.0	74.3	-483.5	-560.5	-616.8	-961.4
Total	**0.000**	**21268**	**-25534**	**-31834**	**-37239**	**-69242**

Table A.13 The impact of East Coast LNG exports on the national economy: Total employment formation (ths)						
	2015	**2020**	**2025**	**2030**	**2035**	**2040**
Constrained industries						
Basic chemicals	0.000	0.000	-15.639	-16.485	-18.127	-28.201
Paints	0.000	0.000	-1.390	-1.465	-1.611	-2.506
Medicinal and pharmaceutical products, pesticides	0.000	0.000	-1.115	-1.175	-1.292	-2.010
Soap and detergents	0.000	0.000	-1.288	-1.358	-1.493	-2.322
Cosmetics and toiletry preparations	0.000	0.000	-0.523	-0.551	-0.606	-0.943
Other chemical products	0.000	0.000	-3.920	-4.133	-4.544	-7.069
Rubber products	0.000	0.000	-0.485	-0.512	-0.563	-0.875
Plastic products	0.000	0.000	-23.566	-24.841	-27.315	-42.495
Basic non-ferrous metal and products	0.000	0.000	-45.336	-47.789	-52.549	-81.751
LNG	0.000	2.359	2.831	2.831	2.831	2.831
Unconstrained industries						
Sheep	0.000	0.217	-1.483	-1.702	-1.875	-2.933
Grains	0.000	0.170	-1.260	-1.441	-1.587	-2.477
Beef cattle	0.000	0.517	-3.850	-4.401	-4.845	-7.561
Dairy cattle	0.000	0.268	-1.740	-2.014	-2.217	-3.460
Pigs	0.000	0.120	-0.834	-0.958	-1.055	-1.648
Poultry	0.000	0.101	-0.704	-0.810	-0.892	-1.391
Other agriculture	0.000	0.697	-4.652	-5.365	-5.907	-9.222
Services to agriculture, hunting and trapping	0.000	0.124	-0.891	-1.019	-1.123	-1.754
Forestry and logging	0.000	0.069	-0.244	-0.276	-0.310	-0.515
Commercial fishing	0.000	0.077	-0.503	-0.582	-0.641	-0.999
Coal	0.000	0.045	1.330	1.373	1.488	2.262
Gas	0.000	0.094	-1.743	-1.855	-2.057	-3.269
Oil	0.000	0.013	-0.055	-0.064	-0.072	-0.115
Iron ores	0.000	0.004	-0.006	-0.007	-0.008	-0.014
Non-ferrous metal ores	0.000	0.013	-7.191	-7.584	-8.340	-12.981
Other mining	0.000	0.033	-0.323	-0.350	-0.388	-0.620

Table A.13 The impact of East Coast LNG exports on the national economy: Total employment formation (ths) – continued						
	2015	2020	2025	2030	2035	2040
Services to mining	0.000	2.059	-0.647	-0.834	-1.171	-3.200
Meat and meat products	0.000	1.262	-9.148	-10.484	-11.542	-18.009
Dairy products	0.000	0.701	-4.549	-5.264	-5.796	-9.043
Fruit and vegetable products	0.000	0.120	-0.782	-0.905	-0.996	-1.554
Oils and fats	0.000	0.036	-0.267	-0.306	-0.337	-0.526
Flour mill products and cereal foods	0.000	0.242	-1.712	-1.965	-2.164	-3.377
Bakery products	0.000	0.605	-3.822	-4.429	-4.877	-7.616
Confectionery	0.000	0.146	-0.940	-1.088	-1.198	-1.870
Other food products	0.000	0.315	-2.127	-2.447	-2.695	-4.212
Soft drinks, cordials and syrups	0.000	0.112	-0.750	-0.867	-0.954	-1.486
Beer and malt	0.000	0.074	-0.459	-0.532	-0.586	-0.915
Wine, spirits and tobacco products (a)	0.000	0.100	-0.626	-0.724	-0.798	-1.248
Textile fibres, yarns and woven fabrics	0.000	0.014	-0.089	-0.102	-0.113	-0.178
Textile products	0.000	0.096	-0.565	-0.654	-0.722	-1.133
Knitting mill products	0.000	0.041	-0.256	-0.295	-0.326	-0.510
Clothing	0.000	0.186	-1.036	-1.199	-1.324	-2.087
Footwear	0.000	0.024	-0.130	-0.152	-0.168	-0.264
Leather and leather products	0.000	0.011	-0.051	-0.059	-0.065	-0.104
Sawmill products	0.000	0.081	-0.159	-0.197	-0.224	-0.382
Other wood products	0.000	0.315	-0.766	-0.911	-1.031	-1.742
Pulp, paper and paperboard	0.000	0.020	-0.105	-0.120	-0.133	-0.212
Paper containers and products	0.000	0.126	-0.861	-0.982	-1.084	-1.703
Printing and services to printing	0.000	0.542	-2.480	-2.883	-3.198	-5.107
Publishing, recorded media, etc.	0.000	0.478	-2.861	-3.299	-3.641	-5.726
Petroleum and coal products	0.000	0.275	-1.155	-1.352	-1.504	-2.418
Glass and glass products	0.000	0.121	-0.598	-0.688	-0.763	-1.219
Ceramic products	0.000	0.018	-0.027	-0.036	-0.042	-0.072
Cement, lime and concrete slurry	0.000	0.064	0.052	0.037	0.032	0.012
Plaster and other concrete products	0.000	0.042	0.159	0.155	0.163	0.227

Table A.13 The impact of East Coast LNG exports on the national economy: Total employment formation (ths) – continued						
	2015	**2020**	**2025**	**2030**	**2035**	**2040**
Other non-metallic mineral products	0.000	0.055	-0.060	-0.076	-0.090	-0.170
Iron and steel	0.000	0.749	-1.117	-1.345	-1.559	-2.828
Structural metal products	0.000	0.357	-0.215	-0.294	-0.365	-0.776
Sheet metal products	0.000	0.079	-0.312	-0.359	-0.400	-0.652
Fabricated metal products	0.000	0.463	-0.803	-0.955	-1.099	-1.956
Motor vehicles and parts, other transport equipment	0.000	1.002	-5.043	-5.868	-6.488	-10.266
Ships and boats	0.000	0.028	-0.136	-0.157	-0.174	-0.277
Railway equipment	0.000	0.097	0.005	-0.011	-0.023	-0.093
Aircraft	0.000	0.113	-0.179	-0.219	-0.250	-0.444
Photographic and scientific equipment	0.000	0.186	-0.864	-1.009	-1.117	-1.776
Electronic equipment	0.000	0.174	-0.560	-0.665	-0.744	-1.212
Household appliances	0.000	0.223	-1.146	-1.335	-1.475	-2.329
Other electrical equipment	0.000	0.255	0.761	0.690	0.722	0.992
Agricultural, mining, etc. machinery	0.000	0.387	-0.315	-0.398	-0.480	-0.973
Other machinery and equipment	0.000	0.343	-0.566	-0.678	-0.780	-1.393
Prefabricated buildings	0.000	0.129	0.030	0.020	0.007	-0.075
Furniture	0.000	0.575	-3.104	-3.609	-3.985	-6.276
Other manufacturing	0.000	0.255	-1.333	-1.517	-1.685	-2.700
Electricity supply	0.000	0.627	41.056	42.510	46.193	70.731
Gas supply	0.000	0.175	0.659	0.578	0.607	0.871
Water supply, sewerage and drainage services	0.000	0.333	-1.717	-1.992	-2.205	-3.494
Residential building	0.000	0.187	0.083	0.035	0.016	-0.077
Other construction	0.000	0.489	0.091	-0.029	-0.090	-0.409
Construction trade services	0.000	5.699	10.736	9.891	10.081	12.245
Wholesale trade	0.000	3.638	-17.687	-20.242	-22.490	-36.102
Wholesale mechanical repairs	0.000	0.393	0.176	0.137	0.103	-0.087
Other wholesale repairs	0.000	0.917	-0.824	-1.068	-1.272	-2.476
Retail trade	0.000	10.433	-66.102	-76.590	-84.339	-131.692
Retail mechanical repairs	0.000	3.870	-12.971	-15.323	-17.111	-27.872

Table A.13 The impact of East Coast LNG exports on the national economy: Total employment formation (ths) – continued						
	2015	**2020**	**2025**	**2030**	**2035**	**2040**
Other retail repairs	0.000	0.178	-1.011	-1.174	-1.295	-2.034
Accommodation, cafes and restaurants	0.000	4.627	-27.705	-32.149	-35.435	-55.489
Road transport	0.000	1.811	-10.521	-11.998	-13.284	-21.095
Rail, pipeline and other transport	0.000	1.595	0.062	-0.192	-0.393	-1.562
Water transport	0.000	0.115	-0.367	-0.420	-0.473	-0.790
Air and space transport	0.000	0.667	-3.522	-4.097	-4.527	-7.142
Services to transport, storage	0.000	1.374	-4.185	-4.810	-5.410	-9.041
Communication services	0.000	1.790	-8.192	-9.585	-10.622	-16.902
Finance	0.000	3.695	-13.364	-15.896	-17.690	-28.485
Ownership of dwellings	0.000	0.000	0.000	0.000	0.000	0.000
Other property services	0.000	2.074	-3.768	-4.577	-5.223	-9.085
Scientific research, technical and computer services	0.000	2.527	-6.278	-7.342	-8.316	-14.143
Legal, accounting, marketing and business management services	0.000	3.290	-12.487	-14.514	-16.199	-26.339
Other business services	0.000	1.622	-6.394	-7.413	-8.270	-13.423
Government administration	0.000	0.504	-2.316	-2.643	-2.941	-4.746
Defence	0.000	0.004	-0.020	-0.022	-0.025	-0.040
Education	0.000	2.312	-13.176	-15.362	-16.941	-26.552
Health services	0.000	2.107	-13.971	-16.184	-17.807	-27.729
Community services	0.000	0.322	-2.138	-2.478	-2.726	-4.243
Motion picture, radio and television services	0.000	0.599	-2.876	-3.341	-3.701	-5.890
Libraries, museums and the arts	0.000	0.441	-1.935	-2.286	-2.534	-4.029
Sport, gambling and recreational services	0.000	2.120	-10.832	-12.609	-13.928	-21.989
Personal services	0.000	1.774	-11.621	-13.467	-14.819	-23.087
Other services	0.000	0.889	-5.786	-6.707	-7.381	-11.505
Total	**0.000**	**81.816**	**-375.199**	**-434.261**	**-482.785**	**-774.619**

Table A.14 East Coast LNG expansion: Gross output formation by industry ($2009m)			
	Case study: 50 PJ of natural gas allocated to LNG exports – base case prices	Case study: 50 PJ of natural gas allocated to LNG exports – 20% reduction in base case prices	Net benefit of 50 PJ of LNG exports with 20% reduction in base case prices
Constrained industries			
Basic chemicals	0.00	0.00	0.00
Paints	0.00	0.00	0.00
Medicinal and pharmaceutical products, pesticides	0.00	0.00	0.00
Soap and detergents	0.00	0.00	0.00
Cosmetics and toiletry preparations	0.00	0.00	0.00
Other chemical products	0.00	0.00	0.00
Rubber products	0.00	0.00	0.00
Plastic products	0.00	0.00	0.00
Basic non-ferrous metal and products	0.00	0.00	0.00
LNG	620.73	-124.15	496.58
Unconstrained industries			
Sheep	0.70	-0.23	0.47
Grains	1.06	-0.35	0.70
Beef cattle	1.94	-0.65	1.29
Dairy cattle	1.08	-0.37	0.72
Pigs	0.27	-0.09	0.18
Poultry	0.60	-0.20	0.40
Other agriculture	3.94	-1.32	2.62
Services to agriculture, hunting and trapping	0.92	-0.30	0.61
Forestry and logging	0.50	-0.12	0.37
Commercial fishing	0.63	-0.21	0.41
Coal	1.79	-0.45	1.34
Gas	5.80	-1.24	4.55
Oil	1.47	-0.43	1.03
Iron ores	0.20	-0.05	0.16
Non-ferrous metal ores	0.31	-0.08	0.24
Other mining	0.45	-0.11	0.34
Services to mining	15.45	-3.11	12.34
Meat and meat products	4.60	-1.55	3.05
Dairy products	3.54	-1.20	2.35
Fruit and vegetable products	1.12	-0.38	0.74
Oils and fats	0.44	-0.15	0.29
Flour mill products and cereal foods	1.83	-0.62	1.22
Bakery products	1.51	-0.51	1.00
Confectionery	1.15	-0.39	0.76
Other food products	2.69	-0.90	1.79
Soft drinks, cordials and syrups	1.48	-0.50	0.98
Beer and malt	1.26	-0.42	0.84
Wine, spirits and tobacco products (a)	1.44	-0.48	0.96
Textile fibres, yarns and woven fabrics	0.12	-0.04	0.08
Textile products	0.37	-0.12	0.25
Knitting mill products	0.26	-0.09	0.17

Table A.14 East Coast LNG expansion: Gross output formation by industry ($2009m) – continued			
	Case study: 50 PJ of natural gas allocated to LNG exports – base case prices	Case study: 50 PJ of natural gas allocated to LNG exports – 20% reduction in base case prices	Net benefit of 50 PJ of LNG exports with 20% reduction in base case prices
Clothing	0.57	-0.18	0.39
Footwear	0.12	-0.04	0.08
Leather and leather products	0.09	-0.03	0.07
Sawmill products	0.54	-0.14	0.40
Other wood products	1.09	-0.28	0.81
Pulp, paper and paperboard	0.30	-0.09	0.21
Paper containers and products	0.90	-0.29	0.61
Printing and services to printing	2.88	-0.86	2.02
Publishing, recorded media, etc.	3.29	-1.05	2.24
Petroleum and coal products	6.35	-1.87	4.48
Glass and glass products	0.67	-0.20	0.47
Ceramic products	0.12	-0.03	0.08
Cement, lime and concrete slurry	0.83	-0.20	0.63
Plaster and other concrete products	0.43	-0.10	0.33
Other non-metallic mineral products	0.23	-0.05	0.17
Iron and steel	4.24	-1.00	3.24
Structural metal products	2.92	-0.66	2.26
Sheet metal products	0.91	-0.25	0.66
Fabricated metal products	2.23	-0.53	1.70
Motor vehicles and parts, other transport equipment	4.75	-1.48	3.27
Ships and boats	0.40	-0.12	0.28
Railway equipment	1.21	-0.27	0.95
Aircraft	1.39	-0.34	1.05
Photographic and scientific equipment	0.91	-0.28	0.64
Electronic equipment	0.83	-0.23	0.59
Household appliances	1.37	-0.43	0.94
Other electrical equipment	1.34	-0.36	0.98
Agricultural, mining, etc. machinery	1.79	-0.40	1.39
Other machinery and equipment	1.60	-0.38	1.22
Prefabricated buildings	0.85	-0.17	0.68
Furniture	1.26	-0.40	0.86
Other manufacturing	1.07	-0.30	0.76
Electricity supply	10.97	-3.21	7.76
Gas supply	1.10	-0.34	0.76
Water supply, sewerage and drainage services	4.06	-1.26	2.80
Residential building	1.94	-0.47	1.46
Other construction	3.52	-0.84	2.68
Construction trade services	19.47	-4.56	14.91
Wholesale trade	25.88	-7.38	18.50
Wholesale mechanical repairs	2.89	-0.61	2.28
Other wholesale repairs	5.51	-1.29	4.22
Retail trade	32.74	-10.99	21.75

Table A.14 East Coast LNG expansion: Gross output formation by industry ($2009m) – continued			
	Case study: 50 PJ of natural gas allocated to LNG exports – base case prices	**Case study: 50 PJ of natural gas allocated to LNG exports – 20% reduction in base case prices**	**Net benefit of 50 PJ of LNG exports with 20% reduction in base case prices**
Retail mechanical repairs	7.63	-2.15	5.48
Other retail repairs	0.44	-0.14	0.30
Accommodation, cafes and restaurants	16.97	-5.60	11.37
Road transport	9.58	-2.87	6.72
Rail, pipeline and other transport	10.02	-2.21	7.80
Water transport	1.13	-0.28	0.85
Air and space transport	4.99	-1.58	3.41
Services to transport, storage	13.62	-3.43	10.19
Communication services	15.22	-4.65	10.57
Finance	47.38	-14.02	33.36
Ownership of dwellings	4.72	-1.62	3.10
Other property services	31.27	-7.86	23.41
Scientific research, technical and computer services	11.85	-2.96	8.89
Legal, accounting, marketing and business management services	18.85	-5.24	13.61
Other business services	11.10	-3.10	8.01
Government administration	2.21	-0.61	1.60
Defence	0.03	-0.01	0.02
Education	9.51	-3.13	6.38
Health services	9.29	-3.18	6.11
Community services	1.16	-0.40	0.76
Motion picture, radio and television services	4.08	-1.24	2.85
Libraries, museums and the arts	1.11	-0.34	0.76
Sport, gambling and recreational services	7.78	-2.45	5.34
Personal services	3.71	-1.27	2.45
Other services	3.99	-1.36	2.63
Total	**1082.81**	**-256.45**	**-28757.76**

Table A.15 East Coast LNG expansion: Total employment formation (ths)			
	Case study: 50 PJ of natural gas allocated to LNG exports – base case prices	Case study: 50 PJ of natural gas allocated to LNG exports – 20% reduction in base case prices	Net benefit of 50 PJ of LNG exports with 20% reduction in base case prices
Constrained industries			
Basic chemicals	0.00	0.00	0.00
Paints	0.00	0.00	0.00
Medicinal and pharmaceutical products, pesticides	0.00	0.00	0.00
Soap and detergents	0.00	0.00	0.00
Cosmetics and toiletry preparations	0.00	0.00	0.00
Other chemical products	0.00	0.00	0.00
Rubber products	0.00	0.00	0.00
Plastic products	0.00	0.00	0.00
Basic non-ferrous metal and products	0.00	0.00	0.00
LNG	0.12	-0.02	0.09
Unconstrained industries			
Sheep	0.01	0.00	0.01
Grains	0.01	0.00	0.01
Beef cattle	0.03	-0.01	0.02
Dairy cattle	0.01	0.00	0.01
Pigs	0.01	0.00	0.00
Poultry	0.01	0.00	0.00
Other agriculture	0.04	-0.01	0.02
Services to agriculture, hunting and trapping	0.01	0.00	0.00
Forestry and logging	0.00	0.00	0.00
Commercial fishing	0.00	0.00	0.00
Coal	0.00	0.00	0.00
Gas	0.00	0.00	0.00
Oil	0.00	0.00	0.00
Iron ores	0.00	0.00	0.00
Non-ferrous metal ores	0.00	0.00	0.00
Other mining	0.00	0.00	0.00
Services to mining	0.10	-0.02	0.08
Meat and meat products	0.07	-0.02	0.04
Dairy products	0.04	-0.01	0.02
Fruit and vegetable products	0.01	0.00	0.00
Oils and fats	0.00	0.00	0.00
Flour mill products and cereal foods	0.01	0.00	0.01
Bakery products	0.03	-0.01	0.02
Confectionery	0.01	0.00	0.01
Other food products	0.02	-0.01	0.01
Soft drinks, cordials and syrups	0.01	0.00	0.00
Beer and malt	0.00	0.00	0.00
Wine, spirits and tobacco products (a)	0.01	0.00	0.00
Textile fibres, yarns and woven fabrics	0.00	0.00	0.00
Textile products	0.01	0.00	0.00
Knitting mill products	0.00	0.00	0.00

Table A.15 East Coast LNG expansion: Total employment formation (ths) – continued			
	Case study: 50 PJ of natural gas allocated to LNG exports – base case prices	Case study: 50 PJ of natural gas allocated to LNG exports – 20% reduction in base case prices	Net benefit of 50 PJ of LNG exports with 20% reduction in base case prices
Clothing	0.01	0.00	0.01
Footwear	0.00	0.00	0.00
Leather and leather products	0.00	0.00	0.00
Sawmill products	0.00	0.00	0.00
Other wood products	0.02	0.00	0.01
Pulp, paper and paperboard	0.00	0.00	0.00
Paper containers and products	0.01	0.00	0.00
Printing and services to printing	0.03	-0.01	0.02
Publishing, recorded media, etc.	0.03	-0.01	0.02
Petroleum and coal products	0.01	0.00	0.01
Glass and glass products	0.01	0.00	0.00
Ceramic products	0.00	0.00	0.00
Cement, lime and concrete slurry	0.00	0.00	0.00
Plaster and other concrete products	0.00	0.00	0.00
Other non-metallic mineral products	0.00	0.00	0.00
Iron and steel	0.04	-0.01	0.03
Structural metal products	0.02	0.00	0.01
Sheet metal products	0.00	0.00	0.00
Fabricated metal products	0.02	-0.01	0.02
Motor vehicles and parts, other transport equipment	0.05	-0.02	0.04
Ships and boats	0.00	0.00	0.00
Railway equipment	0.00	0.00	0.00
Aircraft	0.01	0.00	0.00
Photographic and scientific equipment	0.01	0.00	0.01
Electronic equipment	0.01	0.00	0.01
Household appliances	0.01	0.00	0.01
Other electrical equipment	0.01	0.00	0.01
Agricultural, mining, etc. machinery	0.02	0.00	0.02
Other machinery and equipment	0.02	0.00	0.01
Prefabricated buildings	0.01	0.00	0.01
Furniture	0.03	-0.01	0.02
Other manufacturing	0.01	0.00	0.01
Electricity supply	0.03	-0.01	0.02
Gas supply	0.01	0.00	0.01
Water supply, sewerage and drainage services	0.02	-0.01	0.01
Residential building	0.01	0.00	0.01
Other construction	0.02	-0.01	0.02
Construction trade services	0.29	-0.07	0.22
Wholesale trade	0.19	-0.05	0.14
Wholesale mechanical repairs	0.02	0.00	0.02
Other wholesale repairs	0.05	-0.01	0.04
Retail trade	0.56	-0.19	0.37

Table A.15 East Coast LNG expansion: Total employment formation (ths) – continued

	Case study: 50 PJ of natural gas allocated to LNG exports – base case prices	Case study: 50 PJ of natural gas allocated to LNG exports – 20% reduction in base case prices	Net benefit of 50 PJ of LNG exports with 20% reduction in base case prices
Retail mechanical repairs	0.20	-0.06	0.14
Other retail repairs	0.01	0.00	0.01
Accommodation, cafes and restaurants	0.25	-0.08	0.17
Road transport	0.10	-0.03	0.07
Rail, pipeline and other transport	0.08	-0.02	0.06
Water transport	0.01	0.00	0.00
Air and space transport	0.04	-0.01	0.02
Services to transport, storage	0.07	-0.02	0.05
Communication services	0.09	-0.03	0.07
Finance	0.19	-0.06	0.14
Ownership of dwellings	0.00	0.00	0.00
Other property services	0.11	-0.03	0.08
Scientific research, technical and computer services	0.13	-0.03	0.10
Legal, accounting, marketing and business management services	0.17	-0.05	0.12
Other business services	0.08	-0.02	0.06
Government administration	0.03	-0.01	0.02
Defence	0.00	0.00	0.00
Education	0.12	-0.04	0.08
Health services	0.11	-0.04	0.07
Community services	0.02	-0.01	0.01
Motion picture, radio and television services	0.03	-0.01	0.02
Libraries, museums and the arts	0.02	-0.01	0.02
Sport, gambling and recreational services	0.11	-0.04	0.08
Personal services	0.10	-0.03	0.06
Other services	0.05	-0.02	0.03
Total	**4.28**	**-1.25**	**3.03**

Appendix B: Input-output flow table with direct allocation of imports – Australia

Table B.1(a) Australia input-output flow table with direct allocation of imports – $2009m

	Sheep	Grains	Beef cattle	Dairy cattle	Pigs	Poultry	Other agriculture	Services to agriculture, hunting and trapping	Forestry and logging	Commercial fishing
Sheep	2.82	2.66	4.46	1.74	1.64	2.28	2.14	1.15	0.00	0.00
Grains	46.57	1725.26	95.11	50.94	15.51	35.12	29.84	2.74	0.03	0.02
Beef cattle	0.00	0.00	11.30	2.89	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	1.19	1.14	0.00	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	0.00	0.00	0.00	13.34	0.00	0.00	0.00	0.00
Other agriculture	161.23	0.34	527.58	122.40	23.88	0.28	359.74	1194.95	4.39	0.07
Services to agriculture, hunting and trapping	555.44	612.63	1295.55	295.68	11.84	46.84	1405.10	32.09	10.57	0.00
Forestry and logging	4.17	0.08	133.48	6.99	0.02	0.07	95.67	0.00	381.55	0.00
Commercial fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal	0.28	0.27	1.10	0.29	0.03	0.03	0.62	0.30	0.02	0.02
Gas	2.56	2.71	4.34	2.23	0.71	6.67	4.98	2.09	1.24	0.28
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.03	0.04	0.13	0.03	0.00	0.01	0.06	0.09	0.00	0.01
Non-ferrous metal ores	1.07	0.94	4.01	1.14	0.13	0.07	2.44	0.39	0.06	0.01
Other mining	0.04	0.06	0.08	0.03	0.02	0.03	0.50	0.02	0.00	0.00
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	1.22	0.78	10.83	16.71	2.77	12.27	11.05	8.39	0.14	4.55
Dairy products	5.76	1.32	47.85	64.06	34.55	25.38	14.81	1.41	0.26	8.64
Fruit and vegetable products	0.49	0.98	1.07	0.74	0.51	0.48	1.25	0.45	0.17	0.46
Oils and fats	1.67	0.35	7.66	6.88	8.39	5.10	4.16	0.31	0.12	1.86
Flour mill products and cereal foods	7.86	2.93	39.92	57.05	25.76	43.30	12.99	1.81	4.31	25.16
Bakery products	0.32	0.91	0.59	0.31	0.05	0.61	1.44	0.41	0.36	0.63
Confectionery	2.47	0.70	20.51	43.20	7.62	30.55	19.36	14.31	0.12	11.03
Other food products	26.80	3.52	199.02	379.30	65.82	275.07	108.87	67.11	0.45	98.05
Soft drinks, cordials and syrups	0.63	2.30	1.04	0.89	0.05	0.11	3.33	0.42	0.04	0.12
Beer and malt	0.40	1.16	0.61	0.51	0.07	0.07	0.51	0.30	0.09	0.17
Wine, spirits and tobacco products	3.90	1.30	34.84	4.61	0.71	0.55	15.33	3.88	2.74	5.34
Textile fibres, yarns and woven fabrics	0.20	0.64	0.45	0.21	0.06	0.09	1.00	0.28	0.13	0.34

Table B.1(a) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Sheep	Grains	Beef cattle	Dairy cattle	Pigs	Poultry	Other agriculture	Services to agriculture, hunting and trapping	Forestry and logging	Commercial fishing
Textile products	0.27	0.57	0.73	0.13	0.03	0.11	0.73	0.17	0.27	1.24
Knitting mill products	0.18	0.49	0.42	0.14	0.04	0.07	0.50	0.16	0.16	0.91
Clothing	0.88	2.27	1.66	1.91	0.13	0.32	2.66	0.81	0.94	1.72
Footwear	0.14	0.36	0.24	0.31	0.04	0.08	0.45	0.16	0.23	0.32
Leather and leather products	0.25	0.57	0.97	1.44	0.24	1.03	1.32	0.24	0.15	0.67
Sawmill products	0.95	0.71	0.94	0.73	0.18	0.12	0.82	0.36	0.22	0.42
Other wood products	1.08	1.61	1.77	0.75	0.47	0.73	1.95	1.13	3.42	9.37
Pulp, paper and paperboard	0.21	0.45	0.40	0.13	0.09	0.29	2.43	0.19	0.18	0.18
Paper containers and products	0.67	1.09	1.08	0.24	0.12	6.29	18.56	0.25	0.21	0.30
Printing and services to printing	1.17	3.55	12.87	0.71	0.34	0.17	10.47	1.24	0.69	0.93
Publishing, recorded media, etc.	2.18	6.47	5.55	1.67	0.20	0.33	6.84	0.78	0.81	0.87
Petroleum and coal products	91.55	138.70	61.52	43.43	3.65	17.52	193.32	8.72	33.48	82.31
Basic chemicals	93.73	263.20	226.97	66.85	4.32	4.86	557.99	63.41	2.47	3.19
Paints	1.15	2.24	4.33	0.66	0.33	0.67	3.91	1.15	0.75	3.30
Medicinal and pharmaceutical products, pesticides	30.50	38.54	81.04	25.36	3.29	6.01	80.92	20.16	6.45	0.52
Soap and detergents	0.59	1.31	0.67	0.14	0.06	0.10	1.57	1.78	0.54	0.28
Cosmetics and toiletry preparations	0.15	0.21	0.35	0.12	0.02	0.04	0.35	0.10	0.05	0.03
Other chemical products	1.95	7.03	12.74	1.73	0.91	0.39	3.21	0.90	2.89	0.85
Rubber products	0.59	2.90	0.85	0.26	0.05	0.10	7.98	0.17	0.16	0.87
Plastic products	2.10	3.07	2.21	2.09	0.27	5.51	26.56	1.32	1.01	10.00
Glass and glass products	0.86	1.28	0.83	0.18	0.03	0.11	1.04	0.25	0.37	0.65
Ceramic products	0.04	0.12	0.08	0.04	0.01	0.02	0.60	0.07	0.24	0.52
Cement, lime and concrete slurry	0.19	0.53	0.35	0.17	0.05	0.11	0.62	0.23	6.75	0.96
Plaster and other concrete products	0.20	0.39	0.37	0.15	0.09	0.14	0.44	0.16	4.24	0.84
Other non-metallic mineral products	0.20	0.72	0.28	0.09	0.02	0.02	2.26	0.09	2.49	1.25
Iron and steel	0.76	1.92	2.51	1.10	0.21	0.46	35.39	0.68	2.21	4.07
Basic non-ferrous metal and products	1.40	3.34	2.60	1.13	0.38	0.94	6.49	1.35	0.95	2.55
Structural metal products	1.39	3.70	4.32	1.92	0.55	2.12	36.34	1.28	6.03	13.18
Sheet metal products	0.71	2.25	1.10	1.35	0.12	0.51	8.94	0.25	0.80	3.05
Fabricated metal products	11.57	9.52	7.27	1.48	0.49	1.62	26.11	0.86	9.47	18.76
Motor vehicles and parts, other transport equipment	3.43	7.64	5.95	2.28	1.34	1.86	7.00	1.97	4.09	10.82
Ships and boats	0.21	0.37	0.40	0.16	0.08	0.14	0.32	0.68	0.35	27.97
Railway equipment	0.10	0.21	0.20	0.09	0.03	0.06	0.20	0.08	0.12	0.29

Table B.1(a) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Sheep	Grains	Beef cattle	Dairy cattle	Pigs	Poultry	Other agriculture	Services to agriculture, hunting and trapping	Forestry and logging	Commercial fishing
Aircraft	0.50	1.63	1.08	0.19	0.03	0.02	0.92	5.86	0.22	0.21
Photographic and scientific equipment	1.38	1.40	3.96	2.47	0.16	0.27	2.74	0.67	0.60	2.83
Electronic equipment	0.93	4.53	2.31	1.29	0.23	0.51	1.84	0.61	1.68	4.20
Household appliances	0.51	1.52	2.49	1.11	0.13	0.23	2.09	0.60	0.58	2.31
Other electrical equipment	1.17	2.31	4.21	1.72	0.44	0.69	4.74	1.07	4.97	9.83
Agricultural, mining, etc. machinery	5.53	44.16	14.67	3.79	0.74	2.85	12.72	1.89	9.33	13.23
Other machinery and equipment	2.04	6.54	4.21	2.07	0.42	0.79	26.54	1.35	11.87	20.01
Prefabricated buildings	0.07	0.21	0.16	0.07	0.01	0.04	0.31	0.09	0.20	0.16
Furniture	0.63	1.41	0.92	0.45	0.11	0.26	2.83	0.70	0.94	3.28
Other manufacturing	2.08	4.30	5.27	6.29	1.12	4.10	11.63	0.90	1.32	6.63
Electricity supply	10.55	21.13	49.89	28.06	4.27	13.19	36.49	3.04	1.14	4.92
Gas supply	1.89	2.12	2.43	1.37	0.65	0.83	2.76	1.46	0.07	0.24
Water supply, sewerage and drainage services	14.08	218.43	132.27	87.66	22.22	24.67	160.91	4.23	0.74	2.34
Residential building	3.14	5.66	12.95	2.90	0.98	1.80	6.26	7.46	0.92	0.78
Other construction	9.67	15.68	34.82	9.65	2.05	4.11	14.92	10.50	1.71	1.06
Construction trade services	70.44	73.77	130.75	41.79	35.60	58.35	60.89	23.77	10.08	10.21
Wholesale trade	244.23	673.79	345.56	163.55	28.07	68.28	658.64	206.46	118.43	193.82
Wholesale mechanical repairs	14.22	47.95	22.30	11.29	1.57	1.78	19.10	0.22	24.73	6.42
Other wholesale repairs	4.70	33.98	15.64	4.75	0.33	2.18	12.51	1.01	2.37	17.89
Retail trade	15.84	42.37	27.49	9.11	1.79	4.53	51.27	14.81	12.29	15.43
Retail mechanical repairs	56.64	54.78	85.84	28.03	1.99	7.60	82.55	3.38	61.81	41.48
Other retail repairs	2.24	1.15	4.09	1.34	1.22	1.87	1.67	0.71	0.00	0.00
Accommodation, cafes and restaurants	19.05	36.23	30.64	12.01	0.21	1.20	38.72	0.82	1.95	6.89
Road transport	119.31	418.02	299.53	173.54	28.86	74.05	280.38	64.63	23.19	36.93
Rail, pipeline and other transport	4.88	18.24	5.65	2.37	0.80	1.44	4.40	1.92	0.30	0.28
Water transport	0.38	0.61	0.08	0.02	0.02	0.02	0.44	0.04	0.13	6.35
Air and space transport	4.38	4.54	11.79	3.01	0.49	0.54	9.35	6.36	0.65	1.46
Services to transport, storage	28.65	233.79	52.43	12.99	2.77	43.73	38.93	0.55	2.37	12.67
Communication services	45.20	45.85	93.11	20.87	5.61	9.36	46.04	4.14	3.88	6.87
Finance	117.26	344.08	258.25	93.21	15.26	43.71	345.73	56.95	39.53	79.69
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	41.04	100.35	104.40	21.11	4.63	10.92	61.60	96.31	3.89	4.68
Scientific research, technical and computer services	21.93	68.65	109.25	6.27	2.01	2.08	114.97	8.49	0.39	0.84

Table B.1(a) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Sheep	Grains	Beef cattle	Dairy cattle	Pigs	Poultry	Other agriculture	Services to agriculture, hunting and trapping	Forestry and logging	Commercial fishing
Legal, accounting, marketing and business management services	99.12	160.64	212.32	40.35	29.62	28.86	104.69	15.28	1.72	9.14
Other business services	4.14	10.81	41.27	0.04	0.01	0.50	5.69	0.38	1.80	2.88
Government administration	3.75	5.03	3.55	0.41	0.06	0.20	9.21	0.73	1.25	3.69
Defence	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Education	0.40	2.58	2.79	0.53	0.11	0.70	4.09	0.83	0.28	1.90
Health services	1.65	0.01	21.78	8.45	0.61	2.68	0.97	2.43	0.16	1.01
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.55	0.86	0.00
Libraries, museums and the arts	0.57	0.80	12.64	0.07	0.01	0.02	0.31	0.08	7.27	0.12
Sport, gambling and recreational services	14.31	0.09	14.59	7.06	0.86	0.01	0.12	0.01	0.01	0.02
Personal services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1.97
Other services	0.06	0.36	0.35	0.02	0.00	0.05	0.12	0.01	0.00	0.00
Total intermediate usage including imports	**2342**	**5978**	**5544**	**2265**	**450**	**1040**	**6109**	**2085**	**1024**	**1250**
Wages and salaries	541	466	914	439	131	163	2168	843	657	326
Gross surplus	1968	3614	4137	1699	390	847	5741	2200	517	560
Indirect taxes on production	185	393	267	179	29	50	407	117	63	114
Total gross output	**5035**	**10451**	**10861**	**4582**	**1000**	**2101**	**14424**	**5244**	**2262**	**2250**
Value added at factor cost to output ratio	0.53	0.43	0.49	0.51	0.55	0.50	0.58	0.60	0.55	0.44
Share of wages and mixed income in value added	0.81	0.76	0.82	0.82	0.84	0.80	0.79	0.77	0.80	0.68
Employment to gross output ratio	16.64	8.63	14.25	13.27	23.95	9.01	9.46	7.25	7.13	6.58
Foreign ownership ratio	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Direct tax rate on surplus	0.01	0.01	0.01	0.01	0.08	0.09	0.02	0.06	0.06	0.06
Indirect tax rate on production	0.06	0.08	0.04	0.07	0.04	0.04	0.04	0.03	0.04	0.11
Foreign income payout ratio	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Replacement depreciation to value added ratio	0.08	0.07	0.18	0.05	0.12	0.13	0.08	0.06	0.13	0.13
Net national product ratio	0.91	0.92	0.81	0.94	0.87	0.86	0.91	0.93	0.86	0.86
Domestic income distribution ratio	0.17	0.20	0.16	0.16	0.14	0.17	0.19	0.20	0.16	0.25

Table B.1(b) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Coal	Gas	LNG	Oil	Iron ores	Non-ferrous metal ores	Other mining	Services to mining	Meat and meat products	Dairy products
Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1575.79	0.00
Grains	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7479.29	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4062.56
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	651.23	0.00
Poultry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1165.84	0.00
Other agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	16.01
Services to agriculture, hunting and trapping	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forestry and logging	41.01	7.77	2.99	7.53	0.11	60.12	1.00	0.00	0.00	0.00
Commercial fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal	150.92	30.29	11.64	29.36	9.67	19.88	0.52	0.07	0.89	0.79
Gas	12.69	215.70	77.95	49.97	35.18	19.79	1.67	2.00	37.95	58.04
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	299.82	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	1.35	0.30	0.12	0.29	804.22	0.74	0.14	0.08	0.15	0.03
Non-ferrous metal ores	16.35	3.22	1.24	3.12	55.08	1108.46	5.87	16.40	0.43	0.08
Other mining	31.61	1.99	0.77	1.93	4.23	6.85	687.19	0.03	0.07	0.01
Services to mining	3243.55	622.23	239.13	603.08	4941.65	4236.04	38.20	147.94	0.00	0.00
Meat and meat products	2.44	0.42	0.16	0.41	1.57	1.97	0.12	0.64	1320.25	13.31
Dairy products	1.81	0.30	0.11	0.29	16.44	1.46	0.10	0.59	13.06	1983.16
Fruit and vegetable products	3.05	0.46	0.18	0.45	1.77	2.79	0.18	0.97	15.34	23.80
Oils and fats	1.20	0.18	0.07	0.18	0.61	1.11	0.06	0.42	3.03	11.30
Flour mill products and cereal foods	2.67	0.43	0.16	0.42	1.66	2.32	0.14	0.73	24.60	25.99
Bakery products	11.19	0.98	0.38	0.95	9.70	7.78	0.55	9.58	17.24	69.52
Confectionery	1.91	0.31	0.12	0.30	1.09	1.67	0.10	0.49	2.43	162.09
Other food products	8.22	1.43	0.55	1.39	8.55	6.93	0.61	2.34	62.32	154.13
Soft drinks, cordials and syrups	0.81	0.17	0.07	0.16	1.46	0.62	0.07	0.14	5.16	9.04
Beer and malt	3.35	0.77	0.30	0.75	6.29	7.01	0.20	0.89	0.75	4.96
Wine, spirits and tobacco products	6.11	2.67	1.03	2.59	6.92	6.10	0.43	1.20	20.50	2.34
Textile fibres, yarns and woven fabrics	3.00	0.45	0.17	0.44	3.36	2.35	0.16	1.02	0.59	2.59
Textile products	4.23	1.05	0.40	1.02	3.09	3.38	0.09	0.74	1.10	7.38
Knitting mill products	1.94	0.40	0.15	0.39	2.73	1.50	0.14	0.29	0.37	0.97
Clothing	12.11	2.01	0.77	1.95	5.19	10.11	0.47	1.35	2.67	6.60

Table B.1(b) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Coal	Gas	LNG	Oil	Iron ores	Non-ferrous metal ores	Other mining	Services to mining	Meat and meat products	Dairy products
Footwear	1.59	0.30	0.12	0.29	1.22	1.31	0.10	0.23	0.51	1.32
Leather and leather products	1.68	0.30	0.11	0.29	1.09	1.49	0.10	0.37	3.18	1.36
Sawmill products	7.21	1.20	0.46	1.16	3.24	3.17	0.15	0.70	0.79	1.60
Other wood products	45.06	9.02	3.47	8.74	38.76	30.52	1.83	4.59	1.76	9.42
Pulp, paper and paperboard	4.62	0.84	0.32	0.82	2.14	3.26	0.13	18.01	15.65	37.75
Paper containers and products	7.43	1.75	0.67	1.70	5.51	5.01	0.31	3.10	97.82	201.03
Printing and services to printing	42.11	10.63	4.09	10.31	16.72	26.74	2.34	24.95	11.38	34.98
Publishing, recorded media, etc.	17.68	5.35	2.06	5.19	6.92	13.45	0.52	9.91	3.64	11.51
Petroleum and coal products	537.32	47.85	18.39	46.38	293.63	524.75	25.50	159.67	13.20	62.35
Basic chemicals	116.48	20.45	7.86	19.82	57.52	140.73	4.45	17.00	8.64	44.15
Paints	7.93	1.46	0.56	1.41	5.00	6.73	0.23	1.05	0.30	1.14
Medicinal and pharmaceutical products, pesticides	13.72	3.09	1.19	2.99	6.13	12.85	0.45	3.45	2.67	6.70
Soap and detergents	5.00	0.64	0.24	0.62	3.72	6.47	0.20	1.37	3.41	11.10
Cosmetics and toiletry preparations	0.59	0.16	0.06	0.15	1.13	0.39	0.05	0.10	0.16	0.45
Other chemical products	259.85	43.36	16.67	42.03	144.63	142.80	10.53	3.50	0.96	4.31
Rubber products	36.17	6.30	2.42	6.10	7.49	29.41	1.01	2.19	0.18	0.46
Plastic products	33.95	6.02	2.31	5.84	16.80	32.65	1.16	10.20	23.31	503.84
Glass and glass products	17.17	2.26	0.87	2.20	13.10	13.08	0.50	4.56	0.43	0.68
Ceramic products	2.14	0.25	0.10	0.24	1.46	4.15	0.15	1.65	0.18	1.47
Cement, lime and concrete slurry	15.39	3.13	1.20	3.04	14.24	31.92	0.80	20.99	0.56	1.62
Plaster and other concrete products	15.00	1.98	0.76	1.92	14.91	18.14	0.28	2.72	0.26	1.13
Other non-metallic mineral products	13.54	4.02	1.54	3.89	15.59	8.21	0.63	4.59	0.17	0.95
Iron and steel	289.72	47.23	18.15	45.77	182.16	156.23	5.20	257.88	1.57	5.78
Basic non-ferrous metal and products	66.79	24.27	9.33	23.53	86.94	78.09	4.24	25.55	3.11	27.85
Structural metal products	223.84	45.85	17.62	44.44	217.37	259.69	8.55	175.22	1.29	3.41
Sheet metal products	48.38	8.77	3.37	8.50	24.99	56.76	1.06	17.95	2.75	134.96
Fabricated metal products	224.89	46.10	17.72	44.68	108.22	159.01	7.40	34.13	5.09	8.81
Motor vehicles and parts, other transport equipment	75.23	16.94	6.51	16.42	47.72	57.85	5.26	18.40	3.39	9.02
Ships and boats	10.01	1.89	0.73	1.83	9.32	6.03	0.38	1.93	1.58	1.00
Railway equipment	13.92	4.83	1.85	4.68	4.55	2.23	0.26	0.26	0.20	0.39
Aircraft	147.12	27.85	10.70	26.99	15.03	8.71	2.38	16.06	0.10	0.69
Photographic and scientific equipment	26.28	5.97	2.29	5.78	14.45	18.45	0.86	3.19	1.28	7.04
Electronic equipment	11.94	5.30	2.04	5.14	16.43	10.19	0.61	8.83	1.41	7.74

Table B.1(b) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Coal	Gas	LNG	Oil	Iron ores	Non-ferrous metal ores	Other mining	Services to mining	Meat and meat products	Dairy products
Household appliances	17.61	5.55	2.13	5.38	7.82	13.58	1.12	4.44	0.81	4.37
Other electrical equipment	58.14	11.45	4.40	11.10	34.89	38.15	3.04	5.61	3.63	21.19
Agricultural, mining, etc. machinery	287.42	51.61	19.84	50.03	118.37	259.25	18.44	11.49	1.56	7.78
Other machinery and equipment	215.63	34.76	13.36	33.69	95.87	196.27	10.31	26.31	8.81	16.57
Prefabricated buildings	132.33	32.96	12.67	31.95	82.80	92.89	8.32	2.66	0.24	0.53
Furniture	21.86	4.28	1.64	4.15	16.11	18.75	0.97	4.09	1.60	5.18
Other manufacturing	38.29	8.53	3.28	8.27	39.40	39.55	1.94	11.30	9.26	29.74
Electricity supply	410.33	79.29	30.47	76.85	224.80	481.93	2.50	4.01	130.75	193.52
Gas supply	6.83	1.50	0.58	1.46	19.79	14.87	0.35	0.03	2.32	4.22
Water supply, sewerage and drainage services	70.33	8.70	3.34	8.43	275.95	179.62	13.38	1.85	28.91	32.02
Residential building	99.82	24.67	9.48	23.91	211.46	77.86	18.28	44.79	4.57	3.00
Other construction	274.01	59.39	22.82	57.56	842.41	194.27	85.23	60.64	6.18	4.05
Construction trade services	1221.53	304.97	117.20	295.59	5167.95	1003.91	192.47	326.54	15.09	49.52
Wholesale trade	1677.97	237.85	91.41	230.53	925.22	1582.16	88.21	468.73	383.49	1162.12
Wholesale mechanical repairs	176.85	95.04	36.53	92.12	138.95	67.05	9.24	246.94	9.08	6.96
Other wholesale repairs	454.67	140.62	54.04	136.29	138.12	100.77	15.69	157.33	25.01	8.61
Retail trade	171.55	30.07	11.56	29.14	107.04	107.94	9.37	45.46	212.50	128.82
Retail mechanical repairs	175.58	86.96	33.42	84.28	103.17	146.53	34.47	113.23	18.62	14.28
Other retail repairs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accommodation, cafes and restaurants	124.71	33.37	12.83	32.35	89.35	64.64	7.67	113.50	3.50	2.61
Road transport	405.57	65.09	25.02	63.09	152.81	281.41	49.11	92.31	1064.24	483.67
Rail, pipeline and other transport	1926.32	342.66	131.69	332.12	119.70	55.36	0.52	3.80	11.79	15.80
Water transport	45.69	10.00	3.84	9.69	8.07	21.98	1.75	359.92	1.05	3.44
Air and space transport	93.25	17.14	6.59	16.61	86.89	72.95	4.55	89.98	2.22	1.99
Services to transport, storage	1169.62	225.91	86.82	218.96	231.79	173.66	8.91	98.91	93.79	164.35
Communication services	191.90	49.15	18.89	47.64	74.33	367.76	13.30	127.98	44.48	101.62
Finance	1141.70	295.41	113.53	286.32	723.89	952.44	176.74	327.21	80.25	81.10
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	1721.27	407.16	156.47	394.63	1083.64	533.21	30.22	72.19	338.34	54.20
Scientific research, technical and computer services	165.77	17.00	6.53	16.47	55.03	229.07	3.40	3668.41	39.03	69.18
Legal, accounting, marketing and business management services	1028.24	120.96	46.49	117.24	302.53	844.39	15.18	312.48	41.33	208.89
Other business services	334.76	36.58	14.06	35.45	106.82	545.69	10.51	314.49	128.55	96.96

Table B.1(b) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Coal	Gas	LNG	Oil	Iron ores	Non-ferrous metal ores	Other mining	Services to mining	Meat and meat products	Dairy products
Government administration	121.14	24.00	9.22	23.26	175.98	98.03	6.49	13.19	9.75	3.59
Defence	0.11	0.02	0.01	0.02	0.11	0.08	0.00	1.30	0.14	0.13
Education	67.21	18.04	6.93	17.48	33.97	47.21	4.40	34.85	14.91	34.45
Health services	0.03	0.00	0.00	0.00	0.03	0.02	0.00	1.51	29.60	0.11
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	5.68	2.29	0.88	2.22	20.81	54.46	0.55	18.65	7.15	48.76
Libraries, museums and the arts	0.00	0.00	0.00	0.00	0.05	1.38	0.03	49.17	0.00	0.00
Sport, gambling and recreational services	75.46	52.34	20.11	50.73	8.84	39.30	0.03	94.28	0.00	0.00
Personal services	0.23	0.00	0.00	0.00	0.00	0.00	0.00	6.79	0.00	0.00
Other services	44.27	0.00	0.00	0.00	10.11	11.83	0.11	0.00	3.36	0.38
Total intermediate usage including imports	**23076**	**4822**	**1848**	**4815**	**20960**	**19037**	**1820**	**9326**	**15582**	**11555**
Wages and salaries	4373	1486	211	1225	967	3249	769	5376	3644	1384
Gross surplus	29574	3761	7998	8488	11711	16205	1574	511	134	108
Indirect taxes on production	9	74	28	74	513	599	37	293	451	282
Total gross output	**57032**	**10143**	**10086**	**14601**	**34152**	**39091**	**4200**	**15506**	**19811**	**13329**
Value added at factor cost to output ratio	0.60	0.52	0.82	0.67	0.39	0.51	0.57	0.40	0.21	0.13
Share of wages and mixed income in value added	0.13	0.31	0.05	0.14	0.08	0.17	0.37	0.93	0.92	0.85
Employment to gross output ratio	1.29	0.82	0.19	0.47	0.95	2.10	3.71	6.67	14.71	10.59
Foreign ownership ratio	0.50	0.80	0.70	0.80	0.55	0.60	0.30	0.40	0.45	0.55
Direct tax rate on surplus	0.18	0.21	0.30	0.21	0.25	0.23	0.26	0.22	0.58	0.16
Indirect tax rate on production	-0.01	0.00	0.00	0.00	0.02	0.02	0.01	0.03	0.07	0.09
Foreign income payout ratio	0.36	0.46	0.46	0.50	0.35	0.36	0.15	0.03	0.03	0.07
Replacement depreciation to value added ratio	0.13	0.30	0.24	0.30	0.11	0.26	0.17	0.15	0.13	0.23
Net national product ratio	0.51	0.24	0.29	0.21	0.54	0.38	0.68	0.83	0.84	0.70
Domestic income distribution ratio	0.36	0.11	0.15	0.14	0.28	0.24	0.34	0.04	0.04	0.05

Table B.1(c) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Fruit and vegetable products	Oils and fats	Flour mill products and cereal foods	Bakery products	Confectionery	Other food products	Soft drinks, cordials and syrups	Beer and malt	Wine, spirits and tobacco products	Textile fibres, yarns and woven fabrics
Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	418.17
Grains	12.80	153.60	1693.59	4.85	13.04	598.87	10.87	522.89	74.14	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	0.00	12.44	0.00	3.63	0.00	0.00	0.00	0.00
Other agriculture	573.50	22.99	3.66	40.84	49.84	1567.91	214.38	6.88	583.85	0.01
Services to agriculture, hunting and trapping	0.00	7.13	0.00	0.00	0.00	3.20	0.00	0.00	0.00	21.06
Forestry and logging	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial fishing	0.00	25.76	0.63	1.58	0.30	356.64	0.00	0.00	0.00	0.00
Coal	3.55	0.67	4.31	0.56	0.92	8.32	0.04	0.49	0.14	0.38
Gas	21.46	7.47	19.29	15.73	5.25	57.53	26.17	10.15	2.78	0.03
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.00	0.00	0.02	0.00	0.00	0.02	0.01	0.00	0.00	0.00
Non-ferrous metal ores	0.01	0.00	0.05	0.01	0.01	0.07	0.02	0.01	0.01	0.00
Other mining	0.01	0.46	0.03	0.29	0.04	169.98	0.00	0.00	0.00	0.00
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	34.85	70.59	7.46	362.52	5.93	446.80	0.34	0.92	1.07	0.07
Dairy products	34.16	33.63	132.74	235.56	598.75	170.25	7.65	0.27	4.42	0.03
Fruit and vegetable products	128.50	3.73	27.11	35.38	19.77	38.17	1.51	0.78	7.84	0.04
Oils and fats	6.94	82.49	31.14	31.27	7.98	53.45	0.66	0.14	2.59	0.02
Flour mill products and cereal foods	133.22	19.05	1009.40	526.35	110.04	150.15	2.33	2.18	5.51	0.05
Bakery products	3.88	0.51	6.94	59.80	122.06	103.56	0.39	0.24	1.42	0.04
Confectionery	15.34	2.03	90.71	66.75	99.57	75.05	0.55	0.74	1.82	0.04
Other food products	90.65	71.26	166.24	178.23	183.51	570.49	53.45	13.58	26.97	0.15
Soft drinks, cordials and syrups	33.79	3.48	16.07	11.31	25.99	21.26	1.18	2.96	133.27	0.01
Beer and malt	1.82	0.19	2.86	1.78	3.93	15.37	9.99	234.75	6.81	0.01
Wine, spirits and tobacco products	3.23	1.31	4.26	1.79	79.11	6.21	1.61	1.32	244.34	0.07
Textile fibres, yarns and woven fabrics	0.28	0.52	0.63	1.20	0.36	3.79	0.21	0.15	0.45	4.32
Textile products	0.59	0.36	1.38	0.83	1.41	3.50	0.60	1.29	0.84	2.29
Knitting mill products	0.20	0.11	0.43	0.20	0.13	0.72	0.14	0.11	0.14	3.06
Clothing	1.14	0.80	2.01	1.83	1.09	5.33	0.83	0.68	0.85	0.13

Table B.1(c) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Fruit and vegetable products	Oils and fats	Flour mill products and cereal foods	Bakery products	Confectionery	Other food products	Soft drinks, cordials and syrups	Beer and malt	Wine, spirits and tobacco products	Textile fibres, yarns and woven fabrics
Footwear	0.25	0.14	0.46	0.21	0.29	0.77	0.21	0.16	0.19	0.03
Leather and leather products	0.23	0.16	0.26	0.70	0.24	1.67	0.18	0.18	0.18	0.15
Sawmill products	0.38	0.16	0.63	0.26	0.33	1.00	0.28	0.25	0.40	0.04
Other wood products	2.33	1.05	1.34	0.54	0.58	2.09	4.72	1.17	1.36	0.11
Pulp, paper and paperboard	6.84	2.90	7.94	2.35	7.38	11.63	5.87	6.60	7.99	0.04
Paper containers and products	56.92	20.46	60.93	18.29	36.17	123.75	49.01	41.07	67.57	0.04
Printing and services to printing	3.67	1.41	24.82	4.44	4.21	12.32	5.68	4.77	4.52	1.28
Publishing, recorded media, etc.	1.62	0.45	2.86	1.38	3.39	7.49	1.15	1.55	1.56	0.14
Petroleum and coal products	34.01	3.68	18.87	6.87	3.14	34.42	15.63	6.35	5.13	0.39
Basic chemicals	10.15	9.92	11.82	12.47	9.17	45.74	37.50	2.30	3.68	1.83
Paints	0.16	0.06	0.30	0.20	0.14	1.35	0.15	0.09	0.13	0.03
Medicinal and pharmaceutical products, pesticides	1.17	0.62	1.99	1.03	1.59	4.09	1.15	0.88	2.51	0.15
Soap and detergents	0.26	0.10	0.52	0.32	0.41	1.56	0.35	0.19	0.23	0.18
Cosmetics and toiletry preparations	0.21	0.19	0.16	0.21	0.15	0.51	0.31	0.03	0.03	0.01
Other chemical products	0.39	0.27	0.91	0.49	1.02	1.75	0.70	1.59	0.62	0.07
Rubber products	0.15	0.12	0.33	0.12	0.54	0.67	0.09	0.07	0.09	0.02
Plastic products	82.06	44.77	42.29	35.78	34.92	142.44	189.32	6.47	8.94	0.69
Glass and glass products	100.47	0.71	0.29	0.16	1.26	14.66	98.97	35.95	53.67	0.02
Ceramic products	0.08	0.25	0.19	0.11	0.11	0.45	0.07	0.05	0.09	0.01
Cement, lime and concrete slurry	0.41	0.31	0.70	0.33	0.57	2.36	0.28	0.23	0.27	0.05
Plaster and other concrete products	0.17	0.12	0.26	0.12	0.39	0.83	0.15	0.12	0.15	0.02
Other non-metallic mineral products	0.23	0.29	0.58	0.30	1.24	0.86	0.04	0.03	0.08	0.04
Iron and steel	2.35	0.48	1.84	1.12	0.90	7.58	3.15	3.29	0.51	0.10
Basic non-ferrous metal and products	3.74	1.40	3.34	1.91	4.67	24.99	4.23	2.40	1.17	0.55
Structural metal products	6.55	0.31	0.75	0.35	0.71	4.18	6.43	4.59	3.27	0.06
Sheet metal products	89.94	5.36	4.63	0.90	1.05	30.39	176.01	90.57	3.02	0.03
Fabricated metal products	2.46	0.67	1.86	1.14	3.22	5.69	4.11	4.58	1.63	0.11
Motor vehicles and parts, other transport equipment	1.98	1.01	3.14	1.66	3.04	5.26	4.58	1.91	1.87	0.14
Ships and boats	0.18	0.14	0.71	0.26	0.75	2.57	0.91	0.24	0.25	0.01
Railway equipment	0.09	0.03	0.13	0.06	0.28	0.28	0.08	0.05	0.08	0.01
Aircraft	0.03	0.01	0.08	0.05	0.04	0.13	0.07	0.06	0.06	0.00
Photographic and scientific equipment	0.73	0.39	1.25	0.67	0.54	3.24	0.68	0.61	0.56	0.07
Electronic equipment	0.82	0.45	1.38	0.91	1.70	7.70	20.92	1.94	1.40	0.08

Table B.1(c) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Fruit and vegetable products	Oils and fats	Flour mill products and cereal foods	Bakery products	Confectionery	Other food products	Soft drinks, cordials and syrups	Beer and malt	Wine, spirits and tobacco products	Textile fibres, yarns and woven fabrics
Household appliances	0.49	0.26	0.83	0.40	0.47	1.70	0.32	1.00	0.31	0.04
Other electrical equipment	1.11	0.58	2.81	1.67	2.07	5.12	3.02	2.70	2.23	0.11
Agricultural, mining, etc. machinery	1.13	0.44	1.28	0.63	0.61	2.96	1.04	2.24	0.57	0.08
Other machinery and equipment	5.08	1.15	3.64	4.66	3.44	15.66	14.74	2.45	1.17	0.12
Prefabricated buildings	0.11	0.04	0.17	0.07	0.08	0.32	0.07	0.09	0.10	0.01
Furniture	1.11	0.35	1.17	1.33	3.72	2.56	3.45	0.89	0.56	0.16
Other manufacturing	4.51	7.92	10.19	30.80	8.80	39.44	5.72	3.53	3.83	0.83
Electricity supply	25.55	13.35	67.09	22.19	22.46	74.60	14.75	27.84	7.75	4.56
Gas supply	17.52	6.39	16.22	13.33	3.92	44.98	21.97	8.72	1.54	0.05
Water supply, sewerage and drainage services	14.97	3.53	15.91	3.49	7.89	29.42	6.99	26.34	1.87	4.92
Residential building	1.25	0.98	2.70	1.10	2.29	5.53	1.78	0.70	2.27	0.04
Other construction	1.69	1.32	3.65	1.49	3.09	7.35	2.39	0.94	2.99	0.05
Construction trade services	14.06	13.28	28.53	13.61	33.90	32.89	14.25	11.72	13.02	0.84
Wholesale trade	256.71	87.05	352.17	188.32	181.41	663.59	168.97	148.98	180.63	25.90
Wholesale mechanical repairs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other wholesale repairs	0.52	0.84	5.56	36.21	2.09	24.87	11.47	3.89	2.64	1.20
Retail trade	28.66	7.13	74.95	223.70	161.67	269.10	11.64	9.31	53.03	1.73
Retail mechanical repairs	27.40	13.85	52.14	13.81	17.75	72.46	65.97	11.19	3.51	1.05
Other retail repairs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accommodation, cafes and restaurants	6.22	4.72	15.34	26.09	22.38	66.55	158.16	111.28	80.09	0.34
Road transport	196.62	78.00	379.00	96.47	62.86	535.91	80.28	177.23	67.85	21.73
Rail, pipeline and other transport	8.36	2.12	29.22	5.66	2.17	24.52	7.07	21.73	3.97	2.78
Water transport	1.46	1.97	2.00	0.88	2.02	33.02	1.17	0.53	2.38	0.20
Air and space transport	9.85	5.40	17.88	3.84	5.24	17.40	2.68	2.09	2.97	0.21
Services to transport, storage	15.49	43.50	122.16	42.28	46.19	411.25	133.92	113.20	51.45	1.73
Communication services	12.81	5.59	77.64	13.57	11.80	52.85	26.60	10.13	13.77	1.56
Finance	37.33	29.99	103.52	36.09	19.16	259.28	26.98	129.33	31.77	8.61
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	6.76	4.37	18.42	22.97	5.11	37.14	24.47	3.29	6.25	0.39
Scientific research, technical and computer services	40.07	2.83	50.28	32.61	11.23	149.39	41.25	1.24	28.04	1.24
Legal, accounting, marketing and business management services	34.60	22.22	175.27	26.56	90.05	220.34	64.42	54.79	54.79	2.01
Other business services	122.36	6.77	42.08	35.94	9.25	120.98	49.70	5.45	62.61	0.75

Table B.1(c) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Fruit and vegetable products	Oils and fats	Flour mill products and cereal foods	Bakery products	Confectionery	Other food products	Soft drinks, cordials and syrups	Beer and malt	Wine, spirits and tobacco products	Textile fibres, yarns and woven fabrics
Government administration	0.78	0.89	9.81	2.34	3.87	36.77	14.61	2.84	2.40	0.03
Defence	0.21	0.02	0.29	0.15	0.03	1.13	0.37	0.00	0.13	0.00
Education	3.94	4.36	8.35	8.00	6.74	12.70	9.58	6.39	3.40	0.10
Health services	0.10	0.06	0.31	0.21	0.42	0.84	0.87	0.14	4.33	0.00
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	9.19	0.00	10.63	5.93	18.76	55.10	24.27	5.85	5.50	0.00
Libraries, museums and the arts	0.00	0.00	0.00	0.00	1.57	0.00	0.00	0.23	0.31	0.00
Sport, gambling and recreational services	0.14	0.01	0.04	0.08	0.06	2.33	0.50	0.36	7.06	0.00
Personal services	0.22	0.14	0.33	0.61	0.27	1.35	1.21	0.13	0.12	0.01
Other services	2.20	0.19	4.75	1.01	1.36	3.26	0.68	0.33	1.17	0.00
Total intermediate usage including imports	**2832**	**1291**	**5581**	**3002**	**2710**	**9080**	**2184**	**2011**	**2229**	**558**
Wages and salaries	440	71	578	1135	948	2329	632	442	1352	405
Gross surplus	776	345	442	364	236	821	1401	1407	2827	109
Indirect taxes on production	96	55	133	124	105	292	94	74	384	144
Total gross output	**4144**	**1762**	**6734**	**4625**	**4000**	**12522**	**4312**	**3933**	**6791**	**1216**
Value added at factor cost to output ratio	0.32	0.27	0.17	0.35	0.32	0.27	0.49	0.49	0.67	0.54
Share of wages and mixed income in value added	0.35	0.17	0.54	0.78	0.78	0.73	0.31	0.24	0.31	0.62
Employment to gross output ratio	5.77	4.40	7.08	21.45	6.80	6.26	4.05	3.14	3.71	5.99
Foreign ownership ratio	0.37	0.42	0.43	0.23	0.32	0.10	0.50	0.29	0.15	0.14
Direct tax rate on surplus	0.02	0.01	0.06	0.09	0.07	0.19	0.15	0.15	0.03	0.02
Indirect tax rate on production	0.05	0.09	0.06	0.06	0.06	0.05	0.03	0.03	0.08	0.27
Foreign income payout ratio	0.22	0.31	0.18	0.05	0.06	0.02	0.28	0.18	0.09	0.04
Replacement depreciation to value added ratio	0.13	0.10	0.17	0.22	0.21	0.14	0.13	0.05	0.11	0.09
Net national product ratio	0.65	0.59	0.66	0.74	0.73	0.84	0.59	0.77	0.80	0.87
Domestic income distribution ratio	0.38	0.42	0.23	0.15	0.13	0.21	0.28	0.43	0.52	0.24

Table B.1(d) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Textile products	Knitting mill products	Clothing	Footwear	Leather and leather products	Sawmill products	Other wood products	Pulp, paper and paperboard	Paper containers and products	Printing and services to printing
Sheep	0.01	0.00	0.08	0.00	41.29	0.00	0.00	0.00	0.00	0.00
Grains	0.02	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other agriculture	1.93	0.07	0.22	0.14	6.11	0.00	0.00	0.00	0.00	0.61
Services to agriculture, hunting and trapping	0.28	8.99	3.91	0.04	42.09	0.00	0.00	0.00	0.00	0.00
Forestry and logging	0.00	0.00	0.00	0.00	0.00	747.20	164.62	74.11	13.12	3.76
Commercial fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal	9.00	0.43	0.01	0.00	0.01	0.21	1.70	2.02	1.50	0.38
Gas	7.69	1.01	0.86	0.42	0.22	12.29	21.49	34.76	39.60	14.18
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.01	0.02	0.08
Non-ferrous metal ores	0.01	0.01	0.01	0.00	0.01	1.12	0.36	0.02	0.07	0.26
Other mining	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.01	0.03
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	12.93	0.11	18.95	0.02	325.32	0.27	0.47	0.09	0.21	0.70
Dairy products	0.07	0.07	0.11	0.03	0.05	0.24	0.37	0.06	0.17	0.41
Fruit and vegetable products	0.14	0.09	0.26	0.03	1.71	0.26	0.42	0.08	0.19	0.63
Oils and fats	0.08	0.04	0.06	0.01	0.02	0.13	0.16	0.06	0.07	0.30
Flour mill products and cereal foods	0.10	0.11	0.19	0.04	0.08	0.34	0.51	0.09	0.25	0.78
Bakery products	0.08	0.09	0.16	0.03	0.07	0.24	0.41	0.07	0.18	0.62
Confectionery	0.07	0.08	0.14	0.03	0.06	0.22	0.37	0.06	0.16	0.55
Other food products	0.94	0.25	0.75	0.13	4.19	1.16	2.55	0.37	0.81	2.03
Soft drinks, cordials and syrups	0.08	0.02	0.03	0.01	0.01	0.07	0.10	0.14	0.23	2.15
Beer and malt	0.07	0.06	0.03	0.01	0.01	0.32	0.24	0.04	0.12	0.49
Wine, spirits and tobacco products	0.51	0.43	0.05	0.01	0.02	1.31	1.79	0.31	0.44	4.40
Textile fibres, yarns and woven fabrics	22.20	14.29	20.17	0.65	0.34	0.23	0.71	0.06	1.06	2.29
Textile products	3.07	6.05	11.20	0.22	0.51	0.26	3.53	0.05	1.12	1.55
Knitting mill products	7.17	45.85	39.29	0.14	0.11	0.17	0.24	0.04	1.52	0.86
Clothing	1.38	3.37	37.10	3.23	3.23	0.81	1.49	0.20	0.69	6.20

Table B.1(d) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Textile products	Knitting mill products	Clothing	Footwear	Leather and leather products	Sawmill products	Other wood products	Pulp, paper and paperboard	Paper containers and products	Printing and services to printing
Footwear	0.10	0.12	3.21	11.62	2.69	0.23	0.41	0.04	0.12	0.99
Leather and leather products	2.02	0.58	5.40	8.52	77.73	0.30	0.31	0.06	0.20	0.56
Sawmill products	0.16	0.12	0.18	0.08	0.11	318.93	539.16	25.54	1.34	1.04
Other wood products	1.24	0.34	1.91	0.24	0.39	38.14	397.97	0.68	1.80	15.12
Pulp, paper and paperboard	0.51	0.35	0.61	0.21	0.06	4.88	4.98	5.40	28.76	148.32
Paper containers and products	0.73	2.52	3.16	0.91	0.28	4.85	6.75	1.81	71.55	69.79
Printing and services to printing	23.16	24.62	10.76	0.88	0.74	7.45	17.03	6.35	35.87	373.65
Publishing, recorded media, etc.	0.93	0.84	10.90	0.28	2.44	1.94	10.72	19.85	34.30	43.88
Petroleum and coal products	1.89	0.36	0.60	0.12	0.22	11.84	8.63	5.93	2.31	10.66
Basic chemicals	17.21	25.93	4.83	0.89	5.79	22.06	47.29	15.10	63.39	126.17
Paints	0.19	0.25	0.10	0.04	0.06	1.18	19.87	0.21	1.55	5.27
Medicinal and pharmaceutical products, pesticides	0.95	0.56	0.78	0.58	0.56	4.80	4.15	3.59	3.96	7.58
Soap and detergents	1.34	0.11	0.13	0.05	0.12	2.02	1.68	1.29	2.14	4.85
Cosmetics and toiletry preparations	0.03	0.01	0.02	0.01	0.01	0.13	0.09	0.04	0.09	0.08
Other chemical products	6.00	0.44	0.28	1.50	0.29	6.15	64.21	2.09	13.11	79.28
Rubber products	0.31	0.02	0.10	0.39	0.04	0.16	0.85	0.22	2.03	4.73
Plastic products	14.14	9.45	4.81	1.67	0.93	4.73	26.62	2.35	31.08	265.05
Glass and glass products	1.59	0.07	4.21	1.59	0.55	7.69	15.00	0.08	1.15	3.48
Ceramic products	0.08	0.02	0.18	0.08	0.02	0.17	0.62	0.55	0.86	0.48
Cement, lime and concrete slurry	0.15	0.17	0.18	0.08	0.08	1.74	1.88	0.42	0.98	1.00
Plaster and other concrete products	0.08	0.05	0.10	0.05	0.04	0.92	29.72	0.46	0.79	1.97
Other non-metallic mineral products	0.44	0.21	0.05	0.01	0.01	2.47	5.53	0.72	0.64	0.99
Iron and steel	1.66	0.43	0.29	0.15	0.15	3.93	41.36	2.48	2.66	6.72
Basic non-ferrous metal and products	5.84	2.62	1.34	0.77	0.77	13.21	71.81	2.40	13.28	72.79
Structural metal products	5.47	0.16	0.30	0.06	0.19	1.92	112.06	29.03	0.59	2.47
Sheet metal products	0.42	0.07	0.19	0.06	0.07	0.52	16.76	0.21	1.63	6.76
Fabricated metal products	3.10	7.68	0.51	0.26	0.25	10.98	53.45	6.47	4.73	16.28
Motor vehicles and parts, other transport equipment	0.96	0.39	0.56	0.21	0.23	1.94	9.09	0.54	2.16	8.09
Ships and boats	0.04	0.04	0.05	0.02	0.03	1.20	1.33	0.43	1.29	3.36
Railway equipment	0.02	0.03	0.03	0.01	0.02	0.10	0.17	0.02	0.11	0.25
Aircraft	0.01	0.01	0.02	0.00	0.01	0.03	0.05	0.23	0.18	0.09
Photographic and scientific equipment	0.20	0.14	0.85	0.14	0.18	10.90	12.85	0.34	1.14	12.35
Electronic equipment	0.18	0.20	0.33	0.17	0.20	10.04	11.69	0.34	0.93	8.86

Table B.1(d) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Textile products	Knitting mill products	Clothing	Footwear	Leather and leather products	Sawmill products	Other wood products	Pulp, paper and paperboard	Paper containers and products	Printing and services to printing
Household appliances	0.08	0.09	0.15	0.03	0.07	8.07	9.27	0.09	0.24	6.48
Other electrical equipment	0.43	0.24	0.39	0.09	0.16	10.95	14.51	4.89	4.24	12.69
Agricultural, mining, etc. machinery	0.16	0.17	0.67	0.06	0.14	10.35	13.11	0.16	0.46	8.63
Other machinery and equipment	0.30	0.25	1.18	0.34	0.29	11.64	16.73	4.10	1.10	10.57
Prefabricated buildings	0.14	0.05	0.12	0.04	0.02	0.25	2.36	0.02	0.13	0.30
Furniture	0.79	0.67	1.09	0.31	0.30	0.74	11.01	0.20	0.67	1.60
Other manufacturing	12.83	6.13	37.44	1.00	0.63	5.36	36.53	1.67	11.09	19.99
Electricity supply	10.21	12.10	3.22	1.44	2.02	85.97	130.66	57.67	80.66	109.78
Gas supply	6.23	0.64	0.68	0.12	0.18	6.15	11.92	25.50	31.94	11.61
Water supply, sewerage and drainage services	4.28	11.64	1.12	0.25	1.49	3.29	12.55	11.18	13.54	17.38
Residential building	0.85	0.62	0.18	0.09	0.21	4.79	5.08	0.37	2.70	8.08
Other construction	1.14	0.83	0.24	0.12	0.28	9.05	9.46	0.57	3.90	11.12
Construction trade services	3.57	4.14	2.42	1.29	1.51	63.01	54.18	4.43	14.29	28.23
Wholesale trade	50.85	53.40	98.73	20.51	40.23	226.90	323.00	45.86	117.14	375.61
Wholesale mechanical repairs	0.00	0.00	0.00	0.00	0.00	12.32	8.92	0.70	3.16	0.00
Other wholesale repairs	10.15	3.19	0.82	6.35	4.71	57.68	67.89	6.87	24.56	47.52
Retail trade	9.64	118.90	57.37	2.74	3.24	14.68	25.55	8.39	24.97	69.28
Retail mechanical repairs	15.54	11.50	0.00	8.90	5.31	25.33	14.96	4.27	37.01	147.03
Other retail repairs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accommodation, cafes and restaurants	8.95	7.55	7.30	0.13	3.10	14.68	20.64	2.06	14.21	84.91
Road transport	20.91	17.58	19.76	13.54	52.95	237.59	128.80	36.86	58.35	126.20
Rail, pipeline and other transport	2.14	16.41	0.25	0.49	0.51	8.73	3.08	6.72	5.98	4.82
Water transport	3.11	1.14	2.58	1.09	0.33	8.66	3.05	9.27	10.32	5.49
Air and space transport	2.70	4.94	7.03	0.40	1.02	2.24	9.69	0.50	5.20	79.96
Services to transport, storage	5.36	3.40	21.75	3.52	3.32	279.77	261.89	26.22	217.09	126.76
Communication services	8.58	6.94	8.93	1.96	1.96	30.36	77.84	3.43	16.84	190.35
Finance	20.83	11.03	12.49	2.42	5.80	45.67	75.02	15.47	33.21	167.58
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	2.69	1.93	8.64	1.67	4.18	244.87	190.88	2.13	19.76	153.39
Scientific research, technical and computer services	42.99	24.21	8.26	1.44	5.98	27.55	42.09	1.71	28.75	226.54
Legal, accounting, marketing and business management services	37.53	18.85	19.13	5.26	8.00	98.48	170.73	9.10	174.78	425.72
Other business services	6.66	14.71	31.08	7.57	8.61	103.11	154.47	8.98	93.05	409.15

Table B.1(d) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Textile products	Knitting mill products	Clothing	Footwear	Leather and leather products	Sawmill products	Other wood products	Pulp, paper and paperboard	Paper containers and products	Printing and services to printing
Government administration	0.58	0.60	0.07	0.01	0.06	7.82	7.34	1.47	13.86	34.27
Defence	0.08	0.19	0.03	0.01	0.02	0.11	0.13	0.00	0.12	0.42
Education	1.91	1.35	16.06	0.28	0.79	5.13	9.23	1.56	6.27	26.60
Health services	0.02	0.06	5.31	5.53	0.01	4.79	7.61	0.18	1.73	8.84
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	0.72	0.18	1.02	0.19	0.00	1.50	31.55	0.00	0.62	1.51
Libraries, museums and the arts	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.76	2.22
Sport, gambling and recreational services	0.03	0.02	0.02	0.00	0.01	0.04	0.06	0.01	0.04	0.25
Personal services	0.39	0.07	0.00	0.00	0.00	0.40	0.32	0.07	0.55	2.26
Other services	0.00	0.00	0.68	0.04	0.20	1.33	1.37	1.75	6.48	9.71
Total intermediate usage including imports	**725**	**740**	**999**	**245**	**728**	**3232**	**4258**	**717**	**2046**	**5934**
Wages and salaries	672	81	732	111	151	448	1626	240	1481	3227
Gross surplus	145	51	418	77	191	768	608	473	610	1743
Indirect taxes on production	51	30	83	16	24	93	120	57	125	251
Total gross output	**1594**	**902**	**2232**	**449**	**1094**	**4542**	**6612**	**1488**	**4262**	**11154**
Value added at factor cost to output ratio	0.54	0.18	0.55	0.45	0.33	0.29	0.36	0.52	0.52	0.47
Share of wages and mixed income in value added	1.01	0.65	0.79	0.64	0.50	0.39	0.87	0.32	0.69	0.69
Employment to gross output ratio	13.65	8.43	17.35	10.39	5.84	7.68	14.87	3.47	7.45	9.88
Foreign ownership ratio	0.03	0.09	0.02	0.15	0.22	0.05	0.15	0.29	0.27	0.05
Direct tax rate on surplus	0.25	0.04	0.08	0.08	0.02	0.06	0.13	0.02	0.03	0.06
Indirect tax rate on production	0.05	0.15	0.06	0.07	0.04	0.04	0.03	0.07	0.05	0.03
Foreign income payout ratio	0.00	0.03	0.00	0.05	0.11	0.02	0.02	0.16	0.08	0.01
Replacement depreciation to value added ratio	0.15	0.09	0.06	0.09	0.06	0.09	0.18	0.54	0.13	0.13
Net national product ratio	0.85	0.89	0.93	0.87	0.83	0.88	0.80	0.29	0.79	0.86
Domestic income distribution ratio	0.00	0.26	0.18	0.27	0.36	0.49	0.10	0.39	0.20	0.27

Table B.1(e) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Publishing, recorded media, etc.	Petroleum and coal products	Basic chemicals	Paints	Medicinal and pharmaceutical products, pesticides	Soap and detergents	Cosmetics and toiletry preparations	Other chemical products	Rubber products	Plastic products
Sheep	0.00	0.00	4.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grains	0.00	0.00	8.95	2.30	90.72	10.00	1.85	5.74	0.01	0.03
Beef cattle	0.00	0.00	23.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	2.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	4.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other agriculture	1.98	0.00	0.52	0.68	0.05	0.25	0.04	0.20	3.14	55.40
Services to agriculture, hunting and trapping	0.00	0.00	7.66	3.90	0.00	8.89	5.40	2.86	0.00	0.00
Forestry and logging	0.66	0.00	17.31	0.12	10.12	0.00	1.57	9.86	0.00	0.00
Commercial fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal	0.10	316.26	101.18	0.01	0.38	0.01	0.01	0.45	0.01	0.12
Gas	4.58	-4821.55	75.97	0.82	8.15	2.17	0.35	5.61	0.30	14.04
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	5844.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.02	0.35	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.02
Non-ferrous metal ores	0.10	10.72	118.82	1.20	0.05	0.02	0.00	0.09	0.01	0.11
Other mining	0.01	3.98	75.39	0.03	0.03	0.40	0.07	4.16	0.03	0.14
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	0.20	0.47	104.51	6.50	17.95	103.67	6.38	16.42	0.05	0.77
Dairy products	0.12	0.36	9.41	0.19	5.17	2.10	0.79	1.27	0.03	0.65
Fruit and vegetable products	0.17	0.60	2.05	0.18	1.04	0.48	0.12	0.45	0.04	0.68
Oils and fats	0.07	5.05	12.35	3.36	13.17	6.68	1.07	0.92	0.06	0.35
Flour mill products and cereal foods	0.20	0.57	39.21	1.48	3.03	2.69	0.75	3.45	0.05	0.83
Bakery products	0.16	0.44	1.86	0.06	0.57	0.14	0.04	0.19	0.04	0.66
Confectionery	0.14	0.39	2.13	0.08	0.51	0.14	0.04	0.21	0.03	0.59
Other food products	0.73	2.53	39.63	8.03	23.49	15.11	5.40	15.19	0.14	2.37
Soft drinks, cordials and syrups	0.38	0.40	8.32	0.02	0.97	1.41	0.51	2.57	0.01	0.28
Beer and malt	1.69	0.47	0.47	0.04	0.16	0.07	0.02	0.07	0.02	0.27
Wine, spirits and tobacco products	9.72	2.35	10.79	0.48	2.87	0.53	0.17	0.60	0.18	1.14
Textile fibres, yarns and woven fabrics	1.94	0.67	3.77	0.07	1.81	0.11	0.33	0.58	1.03	5.44
Textile products	0.70	0.44	1.81	0.13	0.33	0.31	0.21	0.34	0.16	2.26
Knitting mill products	0.98	0.54	0.66	0.03	0.26	0.07	0.03	0.09	0.02	2.95
Clothing	3.31	1.43	4.49	0.17	1.66	0.49	0.28	0.69	0.73	5.89

Table B.1(e) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Publishing, recorded media, etc.	Petroleum and coal products	Basic chemicals	Paints	Medicinal and pharmaceutical products, pesticides	Soap and detergents	Cosmetics and toiletry preparations	Other chemical products	Rubber products	Plastic products
Footwear	0.40	0.34	0.74	0.05	0.37	0.12	0.03	0.18	0.10	0.76
Leather and leather products	0.13	0.26	0.73	0.07	0.30	0.13	0.04	0.16	0.21	0.74
Sawmill products	1.24	0.83	1.90	0.07	1.11	0.20	0.09	1.34	0.06	1.87
Other wood products	1.56	6.56	17.79	0.56	3.63	2.08	0.47	3.47	0.71	19.22
Pulp, paper and paperboard	176.63	1.64	2.90	0.15	10.87	2.32	0.45	1.27	0.40	8.86
Paper containers and products	8.72	1.20	22.54	2.66	110.93	19.01	3.94	9.79	0.37	28.04
Printing and services to printing	135.08	5.43	18.01	2.06	16.55	2.52	1.31	4.91	1.15	24.69
Publishing, recorded media, etc.	203.77	10.17	31.72	1.88	34.52	1.73	1.65	16.43	3.43	44.21
Petroleum and coal products	10.34	399.46	200.51	14.46	5.59	3.59	2.39	18.96	6.99	29.97
Basic chemicals	4.97	351.43	1388.08	58.61	58.97	94.98	33.06	172.44	23.88	1102.74
Paints	0.21	4.82	45.64	2.58	1.21	0.95	0.14	2.96	0.13	5.58
Medicinal and pharmaceutical products, pesticides	0.29	4.10	710.67	2.07	98.70	2.47	0.60	6.97	1.29	9.31
Soap and detergents	0.14	10.01	35.63	1.77	2.17	3.16	0.70	5.24	0.39	3.65
Cosmetics and toiletry preparations	0.03	0.91	2.64	0.03	0.44	0.04	0.04	0.19	0.02	0.22
Other chemical products	9.13	26.59	81.52	1.60	6.34	2.93	1.77	102.90	0.74	40.42
Rubber products	1.07	1.48	5.63	0.18	0.61	0.09	0.04	0.70	13.79	18.05
Plastic products	11.49	17.83	133.65	4.36	135.75	72.31	24.31	39.88	5.55	259.92
Glass and glass products	0.51	1.65	5.14	0.11	35.39	8.30	0.28	7.18	0.15	14.59
Ceramic products	0.52	0.63	1.12	0.08	1.95	0.22	0.08	1.25	0.02	1.30
Cement, lime and concrete slurry	0.48	5.42	7.03	0.54	1.98	1.76	0.24	2.30	0.28	2.64
Plaster and other concrete products	0.40	1.30	8.10	0.56	0.71	0.17	0.06	0.50	0.17	5.92
Other non-metallic mineral products	0.59	0.46	3.00	1.14	0.84	0.60	0.21	1.02	0.51	6.18
Iron and steel	1.46	3.13	17.51	0.71	3.82	0.90	0.34	2.84	0.72	9.35
Basic non-ferrous metal and products	4.66	55.07	131.31	6.08	12.95	16.92	1.88	12.09	2.99	185.01
Structural metal products	1.00	1.67	6.04	0.95	3.16	0.77	0.13	1.42	0.19	23.38
Sheet metal products	0.87	7.93	14.61	13.98	35.89	1.83	2.17	9.49	0.12	13.24
Fabricated metal products	16.74	3.46	52.10	2.78	24.60	4.51	1.31	14.62	7.68	29.18
Motor vehicles and parts, other transport equipment	1.30	3.18	5.11	0.37	2.85	0.87	0.33	1.35	0.78	9.03
Ships and boats	6.30	4.66	3.65	0.16	0.44	0.29	0.07	0.43	0.04	0.50
Railway equipment	0.09	0.87	0.30	0.01	0.19	0.03	0.02	0.05	0.04	0.87
Aircraft	0.08	0.34	0.10	0.00	0.05	0.01	0.00	0.01	0.00	0.26
Photographic and scientific equipment	13.22	29.51	6.80	0.11	3.31	0.32	0.11	0.51	0.10	2.45
Electronic equipment	10.98	26.58	5.73	0.12	0.98	0.30	0.09	1.26	0.23	1.97

Table B.1(e) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Publishing, recorded media, etc.	Petroleum and coal products	Basic chemicals	Paints	Medicinal and pharmaceutical products, pesticides	Soap and detergents	Cosmetics and toiletry preparations	Other chemical products	Rubber products	Plastic products
Household appliances	8.72	21.70	4.39	0.08	0.91	0.22	0.05	0.28	0.07	2.13
Other electrical equipment	12.74	28.32	9.02	0.21	2.75	0.55	0.18	0.98	4.86	9.36
Agricultural, mining, etc. machinery	11.02	27.82	9.39	0.15	1.97	0.48	0.12	0.72	0.09	1.70
Other machinery and equipment	11.16	28.36	14.38	0.75	4.46	1.37	0.37	2.85	0.37	6.50
Prefabricated buildings	0.08	0.19	0.36	0.01	0.18	0.04	0.01	0.08	0.01	0.54
Furniture	0.66	0.93	2.94	0.16	1.41	0.29	0.09	0.58	0.27	1.78
Other manufacturing	2.55	5.99	17.62	1.09	11.44	4.27	1.64	7.89	0.52	32.11
Electricity supply	21.64	84.85	164.76	2.61	40.78	6.38	3.07	20.08	7.53	154.35
Gas supply	3.68	24.68	41.45	0.59	6.46	1.60	0.23	4.01	0.10	8.72
Water supply, sewerage and drainage services	5.75	62.36	54.44	0.86	16.99	3.20	3.06	20.94	1.52	10.52
Residential building	5.46	39.76	5.17	0.44	5.70	0.76	0.25	0.91	0.90	5.33
Other construction	7.72	164.87	6.97	0.59	7.68	1.02	0.34	1.23	1.22	7.19
Construction trade services	14.56	735.40	32.56	5.16	21.22	10.55	3.16	11.44	8.01	35.76
Wholesale trade	107.35	606.03	845.70	35.16	385.31	80.88	23.92	111.75	23.11	395.23
Wholesale mechanical repairs	0.00	0.00	1.87	0.53	1.01	1.03	0.31	1.12	0.00	0.00
Other wholesale repairs	94.95	2.84	48.42	3.02	4.31	1.71	0.28	1.05	7.00	78.60
Retail trade	51.50	42.31	69.81	2.81	52.62	11.12	2.38	13.11	2.44	45.36
Retail mechanical repairs	76.80	33.13	72.66	4.04	24.56	7.79	1.82	15.81	0.46	23.16
Other retail repairs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accommodation, cafes and restaurants	89.46	131.70	63.86	3.18	76.70	7.31	5.36	20.12	0.65	19.13
Road transport	43.72	126.10	363.08	12.71	160.72	41.78	11.39	51.06	8.02	178.81
Rail, pipeline and other transport	4.66	17.14	25.23	0.42	6.58	1.48	0.37	2.49	0.21	66.14
Water transport	5.22	191.07	16.16	0.16	2.17	0.66	0.29	6.16	1.11	9.22
Air and space transport	55.06	17.51	18.53	1.61	17.28	3.68	1.19	3.17	0.65	10.11
Services to transport, storage	356.83	135.90	383.77	7.33	232.04	10.43	2.87	103.22	4.72	67.35
Communication services	170.76	135.89	50.37	8.69	41.24	7.65	2.16	18.39	3.56	65.56
Finance	295.24	77.38	116.25	5.88	101.67	15.98	4.36	16.14	10.52	79.55
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	553.54	204.32	22.22	5.35	32.66	4.29	2.72	11.95	1.85	42.95
Scientific research, technical and computer services	157.07	23.54	126.68	6.73	340.76	24.98	5.38	14.23	18.84	126.30
Legal, accounting, marketing and business management services	442.18	780.98	317.70	15.51	335.97	10.69	4.32	28.98	21.79	294.02
Other business services	392.91	583.24	134.30	2.75	510.35	38.26	12.74	32.26	109.60	256.18

Table B.1(e) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Publishing, recorded media, etc.	Petroleum and coal products	Basic chemicals	Paints	Medicinal and pharmaceutical products, pesticides	Soap and detergents	Cosmetics and toiletry preparations	Other chemical products	Rubber products	Plastic products
Government administration	114.98	25.43	98.31	5.44	2.85	7.27	1.75	5.60	0.51	9.02
Defence	0.35	0.10	0.77	0.04	1.18	0.09	0.03	0.06	0.10	0.51
Education	8.05	51.17	19.34	2.44	14.48	0.77	1.25	4.75	1.19	14.17
Health services	38.08	1.18	4.83	1.66	76.87	0.16	0.03	0.17	0.10	0.77
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	113.70	14.89	6.54	4.43	32.56	4.13	9.07	0.00	0.05	11.86
Libraries, museums and the arts	51.32	0.00	0.24	1.11	0.00	14.16	1.14	1.82	0.00	0.00
Sport, gambling and recreational services	9.12	0.17	1.77	0.01	0.22	0.83	0.18	0.06	1.76	1.96
Personal services	8.33	0.00	0.75	0.15	0.53	0.11	0.08	0.09	0.22	0.87
Other services	9.41	1.47	4.75	0.15	8.76	0.97	0.37	0.88	0.44	4.86
Total intermediate usage including imports	**5559**	**22850**	**8908**	**462**	**4088**	**1019**	**278**	**1488**	**432**	**5880**
Wages and salaries	3639	618	1642	532	1671	261	164	727	374	1963
Gross surplus	2523	2022	1242	82	711	259	115	145	195	776
Indirect taxes on production	369	364	235	34	173	36	21	53	44	192
Total gross output	**12090**	**25854**	**12027**	**1111**	**6644**	**1575**	**578**	**2413**	**1046**	**8810**
Value added at factor cost to output ratio	0.54	0.12	0.26	0.58	0.38	0.35	0.52	0.38	0.59	0.33
Share of wages and mixed income in value added	0.59	0.24	0.56	0.85	0.68	0.49	0.57	0.82	0.63	0.70
Employment to gross output ratio	7.72	2.27	2.67	10.14	8.08	5.80	6.76	9.72	8.69	9.14
Foreign ownership ratio	0.03	0.80	0.50	0.48	0.65	0.60	0.45	0.28	0.90	0.20
Direct tax rate on surplus	0.04	0.02	0.12	0.06	0.41	0.21	0.21	0.34	0.06	0.13
Indirect tax rate on production	0.05	0.02	0.04	0.05	0.05	0.04	0.06	0.04	0.07	0.04
Foreign income payout ratio	0.01	0.58	0.19	0.07	0.16	0.24	0.16	0.04	0.30	0.05
Replacement depreciation to value added ratio	0.01	0.23	0.24	0.14	0.15	0.13	0.15	0.37	0.09	0.20
Net national product ratio	0.98	0.19	0.58	0.79	0.69	0.63	0.70	0.59	0.61	0.75
Domestic income distribution ratio	0.37	0.15	0.19	0.08	0.09	0.16	0.19	0.11	0.03	0.21

Table B.1(f) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Glass and glass products	Ceramic products	Cement, lime and concrete slurry	Plaster and other concrete products	Other non-metallic mineral products	Iron and steel	Basic non-ferrous metal and products	Structural metal products	Sheet metal products	Fabricated metal products
Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grains	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.21	0.14
Services to agriculture, hunting and trapping	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forestry and logging	0.00	0.00	0.00	0.00	0.00	0.65	8.80	0.00	0.00	0.00
Commercial fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal	0.00	0.00	9.65	0.19	0.00	263.70	8.85	0.54	0.17	3.23
Gas	102.59	97.20	550.65	7.25	22.22	162.42	212.82	8.77	5.21	12.14
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.01	0.00	0.04	0.01	0.00	837.81	1.93	30.04	0.03	16.00
Non-ferrous metal ores	0.05	0.00	0.12	72.63	14.97	24.75	25675.69	0.27	0.10	10.53
Other mining	40.68	0.00	683.28	184.78	19.97	582.95	220.53	2.72	0.07	2.67
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	0.19	0.00	0.46	0.26	0.03	1.58	1.40	1.11	0.42	0.60
Dairy products	0.11	0.00	0.28	0.15	0.02	0.91	1.17	0.63	0.17	0.51
Fruit and vegetable products	0.19	0.00	0.41	0.23	0.03	1.14	1.25	0.93	0.24	0.47
Oils and fats	0.08	0.00	0.17	0.21	0.01	0.58	0.49	0.34	0.11	0.22
Flour mill products and cereal foods	0.20	0.00	0.50	0.30	0.04	1.42	1.50	1.13	0.29	0.59
Bakery products	0.16	0.00	0.40	0.22	0.02	1.23	1.25	0.92	0.23	0.47
Confectionery	0.14	0.00	0.36	0.20	0.02	1.04	1.09	0.81	0.21	0.41
Other food products	0.49	0.00	1.19	1.26	0.10	3.75	3.29	4.52	1.52	2.41
Soft drinks, cordials and syrups	0.06	0.00	0.10	0.06	0.01	0.36	0.28	0.20	0.06	0.11
Beer and malt	0.08	0.00	0.26	0.09	0.01	0.45	0.34	0.31	0.14	0.18
Wine, spirits and tobacco products	1.10	0.00	2.21	0.95	0.13	1.29	0.92	1.17	0.70	0.87
Textile fibres, yarns and woven fabrics	0.20	0.00	0.28	0.51	0.04	2.55	1.05	1.08	0.65	0.83
Textile products	0.46	0.00	0.72	1.17	0.04	2.40	1.74	7.43	0.34	4.98
Knitting mill products	0.10	0.00	0.19	1.54	0.02	0.97	0.64	0.61	1.29	0.39
Clothing	0.59	0.00	1.14	1.10	0.11	4.06	3.51	5.74	1.86	3.39

Table B.1(f) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Glass and glass products	Ceramic products	Cement, lime and concrete slurry	Plaster and other concrete products	Other non-metallic mineral products	Iron and steel	Basic non-ferrous metal and products	Structural metal products	Sheet metal products	Fabricated metal products
Footwear	0.19	0.00	0.30	0.26	0.03	0.76	0.73	0.71	0.27	0.86
Leather and leather products	1.63	0.00	0.46	0.36	0.06	0.44	0.64	1.04	0.19	4.43
Sawmill products	1.05	0.00	0.47	1.75	0.07	7.58	1.81	91.38	2.25	8.48
Other wood products	9.78	0.00	1.34	4.78	0.34	37.23	8.99	48.45	4.54	22.32
Pulp, paper and paperboard	0.85	0.00	5.03	2.30	0.10	1.96	0.79	1.86	0.44	1.56
Paper containers and products	3.83	0.00	52.97	9.97	0.84	4.12	2.47	5.31	1.24	11.82
Printing and services to printing	4.80	0.00	13.08	10.07	1.09	21.59	9.47	34.81	7.19	16.39
Publishing, recorded media, etc.	1.18	0.00	13.15	4.33	0.33	17.26	10.98	56.89	6.85	9.02
Petroleum and coal products	13.83	5.79	196.84	16.09	8.60	116.62	51.87	33.91	15.22	26.73
Basic chemicals	82.80	0.00	5.64	29.24	11.55	51.37	77.78	58.12	13.67	48.82
Paints	3.53	0.00	0.25	0.88	0.22	36.81	1.34	2.98	3.20	5.93
Medicinal and pharmaceutical products, pesticides	2.33	0.00	0.79	1.57	0.36	6.20	5.39	1.96	1.14	3.52
Soap and detergents	4.13	0.00	0.36	2.26	0.50	3.42	2.06	0.54	0.49	2.15
Cosmetics and toiletry preparations	0.38	0.00	0.05	0.08	0.01	0.32	0.21	0.25	0.04	0.09
Other chemical products	3.57	0.00	2.00	5.55	2.40	11.27	3.04	6.60	1.43	8.14
Rubber products	0.20	0.00	0.09	0.48	0.11	1.75	7.01	1.85	1.51	6.76
Plastic products	12.24	0.00	4.58	10.39	3.54	19.14	18.96	47.13	11.77	16.74
Glass and glass products	309.44	0.00	0.90	1.63	0.81	1.67	2.91	170.33	1.84	8.03
Ceramic products	0.90	0.00	74.46	33.96	1.45	6.29	2.23	7.34	0.17	5.99
Cement, lime and concrete slurry	8.55	0.00	1038.10	481.95	18.61	64.79	42.79	8.56	1.61	5.11
Plaster and other concrete products	9.49	0.00	92.16	112.04	9.88	10.25	6.57	19.57	1.24	1.99
Other non-metallic mineral products	22.40	0.00	20.86	13.75	3.54	5.17	6.06	12.31	2.06	9.35
Iron and steel	20.12	0.00	29.12	71.25	3.04	2416.38	237.64	1992.57	334.37	750.88
Basic non-ferrous metal and products	129.53	0.00	8.90	31.74	2.84	2125.18	15296.53	1395.96	1131.20	955.96
Structural metal products	22.62	0.00	8.62	115.15	14.35	65.54	74.88	1299.37	39.11	258.57
Sheet metal products	0.69	0.00	0.31	3.40	1.31	42.47	12.46	60.17	43.16	22.04
Fabricated metal products	5.86	0.00	3.47	12.61	1.71	117.47	47.28	406.52	64.17	153.78
Motor vehicles and parts, other transport equipment	20.52	0.00	4.03	4.74	1.07	21.71	11.71	18.57	8.25	13.76
Ships and boats	0.66	0.00	3.62	0.74	0.08	2.60	1.14	3.99	0.54	1.87
Railway equipment	0.06	0.00	0.12	0.38	0.02	3.32	0.71	0.41	0.22	0.45
Aircraft	0.04	0.00	0.06	0.05	0.00	0.34	0.19	0.11	0.03	0.05
Photographic and scientific equipment	0.34	0.00	0.85	1.08	0.06	6.67	5.93	2.76	0.88	1.69
Electronic equipment	0.90	0.00	1.16	0.82	0.12	5.26	3.13	18.81	1.76	3.31

Table B.1(f) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Glass and glass products	Ceramic products	Cement, lime and concrete slurry	Plaster and other concrete products	Other non-metallic mineral products	Iron and steel	Basic non-ferrous metal and products	Structural metal products	Sheet metal products	Fabricated metal products
Household appliances	2.42	0.00	0.57	0.50	0.06	2.61	1.92	2.39	0.96	1.40
Other electrical equipment	1.67	0.00	2.73	2.75	0.25	18.56	9.25	21.83	8.12	13.51
Agricultural, mining, etc. machinery	0.65	0.00	5.25	6.38	0.21	15.15	14.28	14.24	1.54	19.84
Other machinery and equipment	3.70	0.00	2.94	10.83	0.50	27.15	42.17	22.37	9.54	13.60
Prefabricated buildings	0.11	0.00	0.22	0.93	0.21	1.31	1.30	38.54	0.63	1.34
Furniture	0.86	0.00	0.93	1.44	0.51	11.75	7.69	13.57	2.58	8.53
Other manufacturing	3.79	0.00	2.53	5.40	1.48	71.17	160.88	27.82	6.45	8.91
Electricity supply	80.90	44.40	204.79	33.97	42.42	995.46	529.79	67.54	26.89	80.18
Gas supply	77.97	74.03	431.96	3.31	14.81	104.62	133.25	6.52	4.08	9.14
Water supply, sewerage and drainage services	7.92	0.00	16.50	9.61	0.80	94.92	20.66	6.46	1.71	5.88
Residential building	1.58	0.00	3.88	1.99	0.14	32.21	11.77	8.28	3.11	3.51
Other construction	2.18	0.00	6.11	2.77	0.19	43.55	15.94	11.18	4.20	4.73
Construction trade services	12.25	0.00	17.65	10.16	1.67	133.17	92.10	32.09	14.03	19.06
Wholesale trade	97.80	0.00	238.06	133.43	15.24	735.32	1176.60	551.40	164.68	290.43
Wholesale mechanical repairs	0.17	0.00	12.99	5.60	0.23	6.29	0.80	0.00	0.00	0.00
Other wholesale repairs	13.48	0.00	92.41	11.09	0.38	53.79	4.93	53.51	17.17	21.53
Retail trade	8.84	0.00	35.61	16.07	1.21	87.69	56.82	54.39	19.77	29.19
Retail mechanical repairs	3.44	0.00	24.00	7.02	0.29	15.88	5.30	15.52	6.74	5.24
Other retail repairs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accommodation, cafes and restaurants	18.38	0.00	36.90	16.33	3.02	48.15	23.82	93.37	25.15	39.18
Road transport	73.46	0.00	564.22	181.37	22.43	620.55	415.74	186.63	48.57	94.16
Rail, pipeline and other transport	27.11	0.00	180.51	4.10	2.20	244.25	307.80	13.20	3.90	9.73
Water transport	2.44	0.00	25.05	5.94	1.51	44.38	220.56	31.51	4.77	8.24
Air and space transport	2.34	0.00	11.48	3.18	0.69	22.74	10.36	20.31	6.55	9.58
Services to transport, storage	30.96	0.00	131.37	56.99	3.37	282.86	148.82	217.46	139.14	130.69
Communication services	17.40	0.00	72.26	63.93	10.18	78.62	23.53	138.63	23.62	69.10
Finance	49.33	0.00	112.88	32.56	7.39	128.52	215.90	129.79	31.38	66.35
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	15.82	0.00	34.83	11.67	0.73	1530.66	476.80	191.93	60.43	101.44
Scientific research, technical and computer services	45.33	0.00	238.43	32.76	2.47	277.10	114.57	218.39	70.27	63.88
Legal, accounting, marketing and business management services	37.71	0.00	107.18	205.19	11.96	163.92	57.77	235.96	77.37	151.19
Other business services	37.22	0.00	210.38	126.04	2.25	247.53	81.02	312.32	76.43	182.20

Table B.1(f) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Glass and glass products	Ceramic products	Cement, lime and concrete slurry	Plaster and other concrete products	Other non-metallic mineral products	Iron and steel	Basic non-ferrous metal and products	Structural metal products	Sheet metal products	Fabricated metal products
Government administration	2.32	0.00	11.23	3.49	0.18	35.22	3.79	12.85	8.37	6.70
Defence	0.16	0.00	0.53	0.16	0.01	0.50	0.26	1.02	0.47	0.31
Education	5.68	0.00	26.22	9.97	0.46	34.30	16.51	24.02	4.27	7.23
Health services	0.19	0.00	0.78	0.31	0.02	0.70	0.38	0.99	0.22	0.30
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	1.31	0.00	1.22	11.85	0.58	0.94	0.01	9.12	0.29	4.99
Libraries, museums and the arts	0.32	0.00	0.43	0.47	0.00	0.00	0.00	0.00	0.00	0.00
Sport, gambling and recreational services	0.06	0.00	0.11	0.05	0.01	0.14	0.08	0.28	0.07	0.11
Personal services	0.13	0.00	0.33	0.18	0.01	0.94	0.05	0.49	0.32	0.36
Other services	0.52	0.00	2.81	3.09	0.03	2.16	1.07	8.32	2.56	3.51
Total intermediate usage including imports	**2034**	**230**	**6099**	**2622**	**356**	**15381**	**58564**	**10198**	**3063**	**5178**
Wages and salaries	609	507	1330	1254	536	3079	2786	2201	1078	2703
Gross surplus	246	238	483	157	266	2064	3315	1341	464	702
Indirect taxes on production	66	-121	194	83	32	338	945	268	114	195
Total gross output	**2954**	**853**	**8106**	**4115**	**1191**	**20862**	**65611**	**14008**	**4719**	**8777**
Value added at factor cost to output ratio	0.31	0.73	0.25	0.36	0.70	0.26	0.11	0.27	0.35	0.41
Share of wages and mixed income in value added	0.72	0.75	0.71	0.88	0.88	0.61	0.47	0.64	0.74	0.84
Employment to gross output ratio	9.47	8.14	3.93	4.97	12.42	9.00	5.46	6.20	4.50	10.59
Foreign ownership ratio	0.37	0.08	0.42	0.22	0.22	0.25	0.52	0.22	0.32	0.20
Direct tax rate on surplus	0.07	0.14	0.22	0.22	0.05	0.15	0.04	0.18	0.15	0.16
Indirect tax rate on production	0.05	0.07	0.06	0.03	0.03	0.03	0.03	0.04	0.05	0.04
Foreign income payout ratio	0.09	0.02	0.09	0.02	0.03	0.08	0.25	0.07	0.08	0.03
Replacement depreciation to value added ratio	0.27	0.19	0.23	0.14	0.11	0.14	0.32	0.07	0.10	0.08
Net national product ratio	0.63	0.79	0.67	0.84	0.87	0.77	0.43	0.86	0.83	0.89
Domestic income distribution ratio	0.16	0.20	0.13	0.08	0.09	0.25	0.23	0.24	0.16	0.12

Table B.1(g) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Motor vehicles and parts, other transport equipment	Ships and boats	Railway equipment	Aircraft	Photographic and scientific equipment	Electronic equipment	Household appliances	Other electrical equipment	Agricultural, mining, etc. machinery	Other machinery and equipment
Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grains	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other agriculture	0.00	0.00	0.00	0.00	0.25	0.04	0.04	0.17	0.00	0.21
Services to agriculture, hunting and trapping	0.00	0.00	0.00	0.00	0.03	1.11	0.00	6.68	0.00	0.00
Forestry and logging	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Commercial fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal	1.88	0.06	0.01	0.04	0.21	0.35	0.08	0.09	0.07	1.17
Gas	24.14	4.36	1.41	25.75	6.21	3.26	4.51	4.91	9.62	4.83
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.54	0.02	0.00	0.01	0.05	0.10	0.01	0.02	0.02	0.03
Non-ferrous metal ores	1.51	0.05	0.24	0.02	0.62	0.29	3.10	38.76	6.98	0.99
Other mining	0.15	0.06	0.03	0.20	0.35	0.05	0.17	1.61	0.10	0.18
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	4.02	0.58	0.14	1.47	0.74	0.65	1.54	0.74	1.05	0.92
Dairy products	5.17	2.00	0.08	1.68	1.26	0.78	1.01	0.66	0.78	1.05
Fruit and vegetable products	3.65	0.88	0.28	1.68	0.55	0.59	0.76	0.58	0.69	1.58
Oils and fats	1.46	0.40	0.06	0.32	0.21	0.21	0.25	0.21	0.25	0.28
Flour mill products and cereal foods	4.18	0.66	0.16	0.89	0.68	0.72	0.84	0.71	0.84	0.92
Bakery products	3.84	0.75	0.13	0.73	0.59	0.68	0.80	0.67	0.81	1.11
Confectionery	3.65	1.05	0.12	0.82	0.48	0.52	0.60	0.51	0.60	0.66
Other food products	9.71	1.90	0.47	2.26	17.70	1.90	2.60	2.06	3.25	3.42
Soft drinks, cordials and syrups	0.71	0.10	0.03	0.17	0.13	0.11	0.12	0.11	0.12	0.14
Beer and malt	0.95	0.16	0.03	4.17	0.11	0.12	0.16	0.15	0.18	0.23
Wine, spirits and tobacco products	1.51	0.61	0.17	2.83	0.96	0.38	0.63	0.49	0.66	0.88
Textile fibres, yarns and woven fabrics	7.82	1.63	0.42	0.74	1.12	0.53	1.32	0.70	1.53	1.48
Textile products	1.76	2.37	0.41	0.73	1.45	1.47	1.44	3.16	1.57	3.13
Knitting mill products	1.78	0.47	0.07	0.35	0.34	0.27	0.34	0.27	0.32	0.35

Table B.1(g) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Motor vehicles and parts, other transport equipment	Ships and boats	Railway equipment	Aircraft	Photographic and scientific equipment	Electronic equipment	Household appliances	Other electrical equipment	Agricultural, mining, etc. machinery	Other machinery and equipment
Clothing	12.80	1.91	0.66	2.25	2.41	1.85	2.93	2.30	3.87	2.25
Footwear	1.80	0.42	0.16	0.86	0.53	0.32	0.43	0.32	0.40	0.46
Leather and leather products	3.18	0.32	0.29	0.48	1.73	0.37	0.52	0.49	0.70	0.39
Sawmill products	5.86	4.58	0.21	0.70	1.32	1.03	1.38	1.65	1.83	1.54
Other wood products	24.60	97.68	2.72	5.61	4.78	2.07	6.75	3.90	8.07	10.59
Pulp, paper and paperboard	2.41	0.81	0.28	1.08	2.13	0.74	2.16	0.76	0.55	1.67
Paper containers and products	12.95	1.51	0.50	3.04	12.77	4.21	20.71	3.78	3.86	4.82
Printing and services to printing	50.86	7.41	1.20	3.84	12.58	6.04	17.92	16.38	24.78	29.08
Publishing, recorded media, etc.	32.09	4.19	0.63	4.08	6.44	15.20	11.66	10.68	10.68	9.64
Petroleum and coal products	27.81	22.80	4.39	5.92	6.61	3.07	6.01	6.28	15.33	28.85
Basic chemicals	124.74	15.74	4.41	6.05	71.67	10.16	51.58	128.17	6.90	11.55
Paints	57.09	14.75	0.55	3.69	1.29	0.55	8.07	1.94	4.29	5.98
Medicinal and pharmaceutical products, pesticides	6.18	0.82	0.22	1.19	2.44	0.92	1.12	0.96	1.03	1.12
Soap and detergents	2.11	0.26	0.16	0.35	0.88	0.23	0.32	0.45	0.30	0.37
Cosmetics and toiletry preparations	0.40	0.08	0.02	0.11	0.06	0.05	0.10	0.06	0.07	0.08
Other chemical products	9.65	1.75	2.04	2.34	13.39	0.79	3.33	1.63	2.80	3.37
Rubber products	31.70	2.38	1.58	0.30	3.66	1.29	6.95	2.53	3.01	10.66
Plastic products	105.54	5.66	5.41	4.57	83.76	30.27	48.17	32.41	20.32	33.64
Glass and glass products	157.23	16.62	6.72	4.84	3.07	1.31	26.92	9.47	7.08	6.73
Ceramic products	2.46	0.18	0.86	0.99	0.83	0.50	1.79	1.94	2.78	1.62
Cement, lime and concrete slurry	11.86	2.05	1.18	2.50	4.50	1.26	10.13	1.39	6.24	12.87
Plaster and other concrete products	6.48	1.98	1.88	2.08	2.57	0.90	1.44	1.66	2.64	3.81
Other non-metallic mineral products	9.03	6.27	3.14	3.23	6.12	1.53	2.44	1.62	3.96	3.32
Iron and steel	948.29	292.57	84.49	14.28	158.91	35.60	586.40	158.45	731.01	881.53
Basic non-ferrous metal and products	537.71	254.17	27.41	73.46	616.39	124.15	142.68	1588.34	93.03	219.09
Structural metal products	79.40	68.70	139.13	5.66	26.86	12.54	27.47	104.41	117.13	243.02
Sheet metal products	88.41	15.79	6.97	38.12	13.27	4.83	97.24	18.68	58.35	105.25
Fabricated metal products	161.52	49.43	20.71	67.42	26.92	14.68	56.20	49.59	76.60	96.91
Motor vehicles and parts, other transport equipment	1240.96	15.20	6.98	41.18	17.34	6.47	27.51	9.68	45.91	18.04
Ships and boats	6.46	10.35	0.49	3.11	0.71	0.42	0.55	0.82	2.39	1.22
Railway equipment	13.22	0.44	322.99	0.40	0.73	0.94	3.39	2.21	1.44	3.39
Aircraft	1.59	1.70	0.03	489.32	0.05	0.05	0.06	0.07	0.39	0.06

Table B.1(g) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Motor vehicles and parts, other transport equipment	Ships and boats	Railway equipment	Aircraft	Photographic and scientific equipment	Electronic equipment	Household appliances	Other electrical equipment	Agricultural, mining, etc. machinery	Other machinery and equipment
Photographic and scientific equipment	9.98	123.04	1.22	15.01	9.09	7.43	14.52	8.85	11.72	10.24
Electronic equipment	16.57	10.64	3.46	24.05	30.63	50.23	26.67	21.99	17.50	24.86
Household appliances	28.78	9.50	1.18	2.80	3.20	2.57	95.48	5.43	8.45	6.61
Other electrical equipment	33.79	14.76	10.17	16.47	69.07	59.28	230.96	255.74	74.23	114.12
Agricultural, mining, etc. machinery	58.58	87.82	8.11	9.96	4.20	6.41	7.18	9.84	47.25	31.18
Other machinery and equipment	84.61	74.84	14.15	15.36	10.12	14.33	40.88	27.46	71.17	83.36
Prefabricated buildings	1.86	1.38	1.63	0.26	0.31	0.28	0.63	1.51	1.43	2.58
Furniture	10.42	30.87	1.22	2.29	1.61	1.94	2.58	2.89	5.19	5.37
Other manufacturing	28.78	12.29	7.04	5.85	9.58	5.36	19.14	12.26	12.24	22.09
Electricity supply	238.06	32.64	13.41	1.60	27.95	116.63	52.53	54.39	67.84	98.40
Gas supply	16.27	2.36	1.15	18.71	3.55	2.88	3.75	3.93	4.66	3.93
Water supply, sewerage and drainage services	40.68	3.17	0.92	0.00	4.26	7.85	9.31	5.34	12.15	18.66
Residential building	19.38	2.50	1.02	0.07	4.84	1.78	2.94	1.63	2.20	2.46
Other construction	26.22	3.39	1.38	0.10	6.54	2.41	3.97	2.21	2.98	3.33
Construction trade services	62.24	37.43	17.35	7.77	47.69	16.13	26.56	17.54	23.10	29.43
Wholesale trade	1976.45	321.92	77.63	422.63	335.53	352.18	407.21	392.76	411.13	448.39
Wholesale mechanical repairs	129.75	0.00	0.00	0.00	0.09	0.07	0.07	0.22	0.59	0.97
Other wholesale repairs	61.14	7.46	0.83	0.00	5.16	4.54	1.78	5.01	44.00	42.61
Retail trade	208.36	22.50	4.85	31.59	41.52	27.29	27.63	27.87	31.23	31.47
Retail mechanical repairs	13.58	3.96	0.07	0.00	1.39	1.15	1.09	3.43	9.31	15.47
Other retail repairs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Accommodation, cafes and restaurants	81.73	9.50	2.63	0.00	28.36	21.44	17.06	8.30	18.18	17.31
Road transport	186.29	43.54	12.71	30.17	63.53	30.76	90.79	56.60	74.37	87.08
Rail, pipeline and other transport	18.77	1.63	0.55	4.89	4.01	1.69	4.87	2.85	13.80	28.89
Water transport	6.26	0.44	0.38	0.26	3.56	0.70	3.57	3.40	9.43	7.03
Air and space transport	33.98	6.90	0.32	0.99	13.89	10.51	18.55	14.24	30.57	25.43
Services to transport, storage	276.44	61.10	11.35	2.81	18.45	10.63	16.45	25.22	28.25	50.17
Communication services	137.83	31.82	8.41	0.00	60.22	33.99	67.30	60.93	102.34	165.98
Finance	229.53	29.86	13.91	18.11	38.92	40.23	38.08	42.80	55.57	49.08
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	1179.65	36.93	2.08	13.01	38.31	28.13	20.76	28.56	47.95	70.37
Scientific research, technical and computer services	738.74	19.33	13.09	0.00	155.22	226.63	310.89	165.78	165.05	108.54

Table B.1(g) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Motor vehicles and parts, other transport equipment	Ships and boats	Railway equipment	Aircraft	Photographic and scientific equipment	Electronic equipment	Household appliances	Other electrical equipment	Agricultural, mining, etc. machinery	Other machinery and equipment
Legal, accounting, marketing and business management services	254.06	51.78	7.33	0.00	189.08	33.45	72.99	55.18	93.65	176.05
Other business services	740.23	43.30	1.30	0.00	121.42	87.01	204.31	93.89	197.87	139.98
Government administration	57.69	6.57	0.73	0.00	4.11	1.84	4.91	3.02	6.07	4.29
Defence	0.80	0.03	0.02	0.00	0.30	0.20	0.20	0.10	0.17	0.13
Education	43.85	5.05	1.60	0.00	13.28	12.56	15.67	9.25	17.18	16.36
Health services	29.00	0.65	0.01	0.00	0.36	0.55	0.41	0.40	0.52	0.65
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	178.76	0.00	0.00	0.00	5.41	1.98	17.85	9.19	3.87	1.85
Libraries, museums and the arts	2.39	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sport, gambling and recreational services	0.24	0.03	0.01	0.00	0.09	0.06	0.05	0.02	0.05	0.05
Personal services	3.64	1.20	0.01	0.00	2.49	2.51	0.46	0.25	0.31	0.45
Other services	17.45	1.59	0.28	0.00	3.04	1.56	3.41	1.26	2.76	2.68
Total intermediate usage including imports	**14123**	**3107**	**1520**	**2799**	**3590**	**2244**	**4368**	**4814**	**4151**	**5181**
Wages and salaries	3199	1020	642	1196	1637	1614	642	1303	1748	2023
Gross surplus	2743	127	22	-31	60	296	441	649	477	589
Indirect taxes on production	532	94	45	119	104	138	110	159	153	147
Total gross output	**20597**	**4349**	**2229**	**4083**	**5390**	**4293**	**5562**	**6925**	**6529**	**7940**
Value added at factor cost to output ratio	0.31	0.29	0.32	0.31	0.33	0.48	0.21	0.30	0.36	0.35
Share of wages and mixed income in value added	0.54	0.96	1.06	1.09	1.03	0.82	0.59	0.67	0.80	0.80
Employment to gross output ratio	11.17	3.67	4.05	4.16	10.70	10.96	8.62	9.89	10.97	10.94
Foreign ownership ratio	0.50	0.40	0.50	0.50	0.30	0.20	0.18	0.13	0.80	0.42
Direct tax rate on surplus	0.07	0.75	0.75	-0.03	1.98	0.42	0.07	0.15	0.31	0.28
Indirect tax rate on production	0.06	0.05	0.04	0.07	0.03	0.06	0.05	0.05	0.04	0.03
Foreign income payout ratio	0.19	0.01	0.00	0.00	0.00	0.03	0.07	0.04	0.14	0.08
Replacement depreciation to value added ratio	0.24	0.07	0.05	0.27	0.12	0.08	0.09	0.07	0.07	0.08
Net national product ratio	0.57	0.91	0.95	0.73	0.88	0.89	0.85	0.89	0.80	0.85
Domestic income distribution ratio	0.19	0.02	0.00	0.00	0.00	0.12	0.31	0.25	0.03	0.11

Table B.1(h) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Pre-fabricated buildings	Furniture	Other manufacturing	Electricity supply	Gas supply	Water supply, sewerage and drainage services	Residential building	Other construction	Construction trade services	Wholesale trade
Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	77.64
Grains	0.05	0.05	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	63.83
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.55
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.55
Poultry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.20
Other agriculture	0.17	0.53	19.27	0.88	0.00	6.51	23.93	93.58	15.49	9.17
Services to agriculture, hunting and trapping	0.00	0.25	34.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forestry and logging	0.03	19.34	0.65	1.90	0.00	0.00	1.61	56.86	6.77	0.00
Commercial fishing	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.18	0.00	0.00
Coal	0.00	0.00	0.00	3017.38	5.90	0.99	2.82	8.51	2.49	10.64
Gas	2.43	7.18	9.06	1797.48	0.00	0.00	2.76	8.63	2.43	3624.98
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.00	0.00	0.01	0.93	0.27	0.04	1.22	3.57	1.07	4.06
Non-ferrous metal ores	0.00	0.21	0.03	6.07	0.73	0.60	3.41	11.35	2.98	554.21
Other mining	0.03	0.02	6.24	0.47	0.12	12.02	107.66	336.14	159.21	1.96
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	0.10	0.56	7.73	0.93	0.11	2.55	7.36	23.41	8.19	222.65
Dairy products	0.26	1.36	1.43	2.33	0.10	10.10	12.03	21.75	6.20	55.82
Fruit and vegetable products	0.08	0.51	0.50	0.93	0.15	0.78	4.60	8.17	4.10	7.00
Oils and fats	0.03	0.21	0.20	0.72	0.10	1.23	2.96	5.12	2.04	5.53
Flour mill products and cereal foods	0.10	0.62	0.61	1.04	0.12	0.80	4.42	7.35	4.66	4.61
Bakery products	0.08	0.48	0.48	2.43	1.40	3.20	3.95	6.56	3.92	11.00
Confectionery	0.08	0.52	0.46	1.18	0.08	2.13	6.61	11.39	4.53	9.06
Other food products	1.15	2.37	5.46	3.61	0.85	3.47	26.15	41.32	16.31	32.21
Soft drinks, cordials and syrups	0.02	0.09	0.13	0.19	0.02	0.14	4.33	6.01	0.86	1.79
Beer and malt	0.02	0.12	0.12	0.20	0.02	0.36	2.63	3.77	1.69	9.00
Wine, spirits and tobacco products	0.24	0.47	1.32	0.45	0.13	3.92	5.44	7.99	3.92	20.32
Textile fibres, yarns and woven fabrics	0.12	10.11	1.78	0.75	0.31	0.96	10.50	19.36	12.88	11.86
Textile products	0.77	7.75	11.13	0.86	0.12	0.47	34.10	55.24	23.28	9.22
Knitting mill products	0.06	7.08	2.85	0.54	0.06	0.28	5.44	8.70	2.74	9.93
Clothing	0.50	3.32	2.82	3.71	0.42	1.70	10.06	18.05	9.97	18.81

Table B.1(h) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Pre-fabricated buildings	Furniture	Other manufacturing	Electricity supply	Gas supply	Water supply, sewerage and drainage services	Residential building	Other construction	Construction trade services	Wholesale trade
Footwear	0.13	0.41	1.44	3.01	0.13	0.51	2.66	7.36	2.98	5.19
Leather and leather products	0.13	5.63	51.53	0.55	0.99	0.42	3.46	7.31	4.71	6.00
Sawmill products	23.87	500.93	44.41	0.81	0.15	1.53	804.82	137.05	742.35	16.37
Other wood products	38.01	351.66	49.68	3.91	0.56	29.34	1664.80	423.85	1350.10	231.96
Pulp, paper and paperboard	0.47	6.60	4.24	1.81	0.09	0.30	35.44	55.15	10.19	34.50
Paper containers and products	0.84	6.38	5.18	12.81	1.32	5.73	126.54	198.98	33.05	244.40
Printing and services to printing	2.31	13.23	18.84	33.90	8.51	14.66	152.72	375.26	55.19	1021.94
Publishing, recorded media, etc.	1.74	6.49	8.76	13.30	2.81	11.55	56.53	116.62	23.66	469.77
Petroleum and coal products	2.16	7.18	8.13	390.97	3.70	188.32	186.34	398.33	360.74	512.03
Basic chemicals	2.73	30.44	55.10	35.94	15.30	96.86	241.00	635.34	404.98	86.63
Paints	1.84	23.84	18.84	8.53	0.93	15.20	112.63	121.71	155.04	11.54
Medicinal and pharmaceutical products, pesticides	0.49	1.71	3.10	6.10	3.36	41.43	10.87	45.50	30.44	44.04
Soap and detergents	0.08	0.90	2.20	3.19	0.98	6.01	2.65	10.35	6.32	23.04
Cosmetics and toiletry preparations	0.03	0.14	0.14	0.17	0.04	0.24	0.90	2.24	1.26	2.61
Other chemical products	1.39	15.09	7.13	4.12	1.07	3.93	82.64	215.26	169.33	28.68
Rubber products	0.23	5.93	10.52	10.85	1.22	1.40	16.05	37.38	16.07	15.23
Plastic products	3.17	68.41	163.38	11.69	29.03	44.59	686.62	910.51	528.20	221.76
Glass and glass products	6.74	34.95	7.38	2.46	0.47	3.09	122.26	143.77	75.18	264.14
Ceramic products	0.42	0.92	0.87	5.61	0.40	5.64	286.71	28.46	183.62	5.26
Cement, lime and concrete slurry	0.77	1.10	3.95	40.19	1.02	85.20	1442.16	2268.57	2051.67	10.39
Plaster and other concrete products	2.14	13.15	4.87	98.02	0.30	4.95	1247.73	776.93	1203.20	22.04
Other non-metallic mineral products	1.17	3.11	6.80	7.12	1.37	8.30	207.53	228.09	230.54	26.17
Iron and steel	104.17	168.01	274.12	30.05	13.26	44.24	837.47	2236.45	1161.22	147.99
Basic non-ferrous metal and products	83.51	249.01	598.38	20.57	6.98	24.57	636.73	492.96	278.11	63.46
Structural metal products	55.00	42.51	93.36	44.35	7.41	84.69	3027.96	3216.94	1450.53	77.75
Sheet metal products	5.96	15.01	22.42	3.73	21.00	7.43	275.29	433.92	189.19	135.96
Fabricated metal products	23.09	63.61	45.23	58.40	36.72	118.84	495.20	1184.73	479.64	123.63
Motor vehicles and parts, other transport equipment	2.80	13.78	55.27	14.92	1.46	11.82	122.76	214.53	155.03	159.31
Ships and boats	0.17	0.32	0.49	1.26	0.39	0.83	72.79	108.94	34.95	80.95
Railway equipment	0.02	0.91	0.87	2.98	0.08	0.22	5.84	9.57	4.07	4.02
Aircraft	0.01	0.03	0.24	0.48	0.02	0.11	14.87	23.23	7.02	121.36
Photographic and scientific equipment	0.24	1.44	3.68	14.80	0.35	4.32	16.23	88.40	20.88	39.01
Electronic equipment	1.42	1.93	4.70	22.15	1.06	9.75	45.82	271.54	137.05	23.66

Table B.1(h) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Pre-fabricated buildings	Furniture	Other manufacturing	Electricity supply	Gas supply	Water supply, sewerage and drainage services	Residential building	Other construction	Construction trade services	Wholesale trade
Household appliances	0.18	1.68	2.85	5.79	0.37	2.12	462.97	263.01	230.32	15.50
Other electrical equipment	1.73	5.10	12.07	399.50	1.61	13.97	170.77	1299.73	401.27	110.60
Agricultural, mining, etc. machinery	0.69	1.35	5.59	22.96	0.92	4.25	72.54	131.66	144.71	36.96
Other machinery and equipment	1.62	7.68	7.79	30.62	5.03	22.57	126.39	444.89	150.03	78.97
Prefabricated buildings	1.03	0.74	0.82	0.43	0.06	0.59	49.86	142.46	36.62	3.93
Furniture	7.00	21.66	3.91	2.42	0.39	14.88	279.97	214.42	231.97	41.11
Other manufacturing	4.20	18.39	35.76	19.02	7.90	10.00	201.35	413.32	364.40	143.34
Electricity supply	1.47	23.17	33.57	4827.31	5.92	282.16	104.04	510.88	83.52	629.05
Gas supply	1.92	5.55	7.33	585.29	0.00	0.99	28.27	6.10	10.87	241.42
Water supply, sewerage and drainage services	0.26	3.91	5.28	97.68	19.28	436.75	304.70	173.35	72.58	251.48
Residential building	0.18	0.68	1.24	160.25	82.17	62.56	1426.15	1976.41	2201.08	271.33
Other construction	0.25	0.91	1.67	230.25	111.09	86.27	2060.11	2681.58	2984.62	434.89
Construction trade services	2.31	6.96	13.39	2220.62	815.06	950.43	11408.93	13437.05	34415.77	1814.01
Wholesale trade	52.88	297.28	306.59	550.84	49.44	449.78	2181.57	3724.59	2502.70	2741.35
Wholesale mechanical repairs	0.09	0.42	0.18	67.54	31.76	36.10	101.58	216.97	59.17	58.03
Other wholesale repairs	4.90	30.34	19.14	147.54	163.60	52.18	130.66	178.25	65.25	579.01
Retail trade	4.94	44.43	94.23	70.91	12.16	39.88	243.68	626.68	275.68	1132.59
Retail mechanical repairs	6.25	24.39	29.37	234.72	47.87	61.64	178.14	502.70	895.85	983.25
Other retail repairs	0.00	0.00	0.00	0.00	0.00	0.00	13.53	22.77	13.07	30.94
Accommodation, cafes and restaurants	4.84	16.71	24.36	122.48	11.67	33.58	38.76	49.67	12.43	579.98
Road transport	13.32	105.45	102.28	164.16	11.44	100.55	947.47	1437.57	1065.81	1141.59
Rail, pipeline and other transport	0.78	3.03	5.29	271.92	2.07	1.07	62.45	115.20	28.30	119.07
Water transport	0.33	1.36	10.01	48.19	13.87	0.29	2.68	6.36	4.19	85.85
Air and space transport	1.47	4.65	5.44	58.93	19.46	29.85	88.59	94.80	23.54	960.80
Services to transport, storage	1.93	20.57	51.35	51.73	2.77	24.67	340.74	3216.56	388.10	9969.41
Communication services	5.48	39.23	76.67	348.59	86.62	143.56	644.46	1482.10	251.68	3116.56
Finance	9.81	43.71	38.38	1313.33	197.77	722.21	3454.88	3401.09	4318.10	3141.12
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	1.55	18.79	39.26	391.96	312.37	5.11	2745.85	6598.09	2147.70	8405.65
Scientific research, technical and computer services	8.79	25.09	17.42	248.89	51.90	28.04	253.43	6225.46	746.88	1398.42
Legal, accounting, marketing and business management services	3.99	76.50	97.04	316.29	971.67	693.63	1794.49	5040.22	2410.66	5356.98
Other business services	13.98	101.11	74.39	223.77	369.80	101.27	954.49	2917.96	1293.09	1504.10

Table B.1(h) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Pre-fabricated buildings	Furniture	Other manufacturing	Electricity supply	Gas supply	Water supply, sewerage and drainage services	Residential building	Other construction	Construction trade services	Wholesale trade
Government administration	0.43	3.28	2.62	19.07	1.65	38.65	263.71	480.88	83.84	121.97
Defence	0.01	0.07	0.07	0.09	0.00	0.00	0.67	0.73	0.14	8.58
Education	0.48	3.35	3.31	160.64	26.71	25.69	46.29	42.02	10.32	33.03
Health services	0.08	0.27	0.59	1.17	0.00	3.61	0.21	7.13	0.05	12.91
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	1.97	8.26	1.78	13.38	17.43	20.31	46.26	28.59	15.71	285.24
Libraries, museums and the arts	0.50	12.85	1.19	38.49	56.88	50.38	40.11	7.05	0.88	51.48
Sport, gambling and recreational services	0.01	0.05	0.07	0.37	0.03	0.09	227.26	349.43	126.74	158.71
Personal services	0.03	0.60	0.28	0.76	0.00	1.60	15.15	56.23	6.02	18.62
Other services	0.26	1.36	1.26	8.80	0.00	4.59	141.07	448.76	62.11	13.91
Total intermediate usage including imports	**698**	**3597**	**4012**	**20752**	**3980**	**6704**	**48434**	**83660**	**74435**	**62975**
Wages and salaries	194	1447	872	4350	182	3434	4084	13387	21745	30714
Gross surplus	136	485	49	12228	922	6065	7436	19748	17410	18696
Indirect taxes on production	20	125	75	1012	106	20	1053	1768	1902	4578
Total gross output	**1048**	**5654**	**5009**	**38342**	**5189**	**16223**	**61006**	**118564**	**115491**	**116963**
Value added at factor cost to output ratio	0.33	0.36	0.20	0.46	0.23	0.59	0.21	0.29	0.36	0.46
Share of wages and mixed income in value added	0.61	0.94	1.30	0.25	0.16	0.39	0.43	0.48	0.97	0.64
Employment to gross output ratio	7.58	24.25	12.46	2.99	8.42	4.33	4.93	7.08	14.89	7.33
Foreign ownership ratio	0.03	0.05	0.07	0.40	0.30	0.01	0.05	0.15	0.05	0.35
Direct tax rate on surplus	0.16	0.10	0.16	0.01	0.02	0.01	0.07	0.06	0.08	0.23
Indirect tax rate on production	0.03	0.04	0.02	0.04	0.05	-0.01	0.05	0.03	0.02	0.08
Foreign income payout ratio	0.01	0.00	0.00	0.27	0.23	0.01	0.03	0.07	0.00	0.10
Replacement depreciation to value added ratio	0.21	0.08	0.07	0.35	0.35	0.29	0.03	0.02	0.06	0.08
Net national product ratio	0.78	0.92	0.93	0.38	0.42	0.71	0.95	0.91	0.94	0.82
Domestic income distribution ratio	0.32	0.05	0.00	0.41	0.53	0.59	0.49	0.42	0.03	0.19

Table B.1(i) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Wholesale mechanical repairs	Other wholesale repairs	Retail trade	Retail mechanical repairs	Other retail repairs	Accommodation, cafes and restaurants	Road transport	Rail, pipeline and other transport	Water transport	Air and space transport
Sheep	0.00	0.00	502.50	0.00	0.00	181.44	0.00	0.00	0.00	0.00
Grains	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Beef cattle	0.00	0.00	413.05	0.00	0.00	149.45	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	3.59	0.00	0.00	1.31	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	236.53	0.00	0.00	85.58	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	310.29	0.00	0.00	134.42	0.00	0.00	0.00	0.00
Other agriculture	0.00	0.86	318.37	2.96	0.36	482.42	0.77	1.27	0.00	0.00
Services to agriculture, hunting and trapping	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forestry and logging	0.00	0.00	1.34	0.00	0.00	0.65	3.47	14.34	0.00	0.00
Commercial fishing	0.00	0.00	190.81	0.00	0.00	142.71	0.00	0.00	0.00	0.00
Coal	0.04	1.90	9.97	0.49	0.02	2.40	1.97	9.87	0.99	0.99
Gas	0.84	5.34	115.00	7.57	1.16	167.93	12.48	34.52	0.00	2.86
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.02	0.81	1.90	0.21	0.01	1.01	0.56	0.89	0.01	0.29
Non-ferrous metal ores	0.05	2.10	5.64	0.57	0.02	2.99	4.49	25.51	0.33	0.98
Other mining	0.01	0.39	0.46	0.09	0.00	3.67	0.26	0.92	0.00	0.14
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	0.38	1.56	2613.99	7.05	0.21	1837.30	3.77	1.40	0.05	1.36
Dairy products	1.54	3.07	739.73	13.59	0.92	703.01	6.83	3.32	0.12	6.46
Fruit and vegetable products	0.39	1.69	213.73	3.12	0.20	215.58	3.13	0.32	0.09	1.53
Oils and fats	0.31	0.72	134.36	2.25	0.12	82.00	1.66	0.31	0.03	0.60
Flour mill products and cereal foods	0.44	1.80	719.60	3.72	0.24	383.44	3.73	0.36	0.06	1.62
Bakery products	0.37	1.53	430.33	3.09	0.20	401.24	3.68	1.25	1.50	3.98
Confectionery	0.55	1.65	175.99	4.38	0.28	225.87	3.41	0.73	0.04	1.28
Other food products	1.17	4.30	376.52	9.25	0.60	305.00	13.24	2.35	0.22	7.69
Soft drinks, cordials and syrups	0.07	0.28	423.16	0.55	0.05	99.17	0.86	0.35	0.01	0.33
Beer and malt	0.06	0.62	4.89	1.53	0.19	1550.84	2.28	0.69	0.01	1.84
Wine, spirits and tobacco products	0.10	1.40	5.17	3.09	1.14	902.16	4.61	1.52	0.04	4.36
Textile fibres, yarns and woven fabrics	0.44	1.15	19.88	7.24	0.14	6.36	4.70	0.69	0.08	0.75
Textile products	0.06	0.84	17.71	0.76	0.20	7.75	5.40	0.96	0.13	0.23
Knitting mill products	0.16	0.72	44.33	1.79	0.13	2.02	3.16	0.63	0.03	0.62
Clothing	17.02	5.17	18.56	51.44	1.16	10.84	8.55	2.27	0.20	3.78

Table B.1(i) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Wholesale mechanical repairs	Other wholesale repairs	Retail trade	Retail mechanical repairs	Other retail repairs	Accommodation, cafes and restaurants	Road transport	Rail, pipeline and other transport	Water transport	Air and space transport
Footwear	0.16	4.97	2.76	1.50	1.35	1.62	1.76	0.30	0.03	0.80
Leather and leather products	0.60	1.17	5.20	10.14	0.29	2.08	4.16	0.69	0.29	3.37
Sawmill products	0.29	1.37	28.60	2.43	0.17	2.98	12.12	2.10	0.39	1.82
Other wood products	2.62	3.03	143.12	9.63	0.50	15.76	36.78	5.08	1.17	4.82
Pulp, paper and paperboard	0.08	0.87	21.63	1.17	0.26	24.61	13.86	3.25	1.91	16.27
Paper containers and products	1.10	6.41	192.83	6.22	2.20	93.60	10.62	10.11	1.85	19.39
Printing and services to printing	4.35	6.96	1664.05	36.44	1.56	205.04	44.97	31.26	3.66	13.65
Publishing, recorded media, etc.	3.47	6.39	820.06	28.11	1.31	103.76	22.61	36.72	3.32	12.08
Petroleum and coal products	11.11	81.63	392.69	70.68	16.25	168.35	1466.79	146.92	58.79	2002.78
Basic chemicals	3.31	8.90	49.75	20.90	1.53	56.47	16.54	11.58	0.53	8.51
Paints	4.51	8.94	5.63	19.39	1.20	4.25	1.32	1.09	0.27	0.51
Medicinal and pharmaceutical products, pesticides	0.62	2.20	23.36	5.12	0.34	10.99	5.26	2.02	0.07	2.88
Soap and detergents	0.47	1.49	11.89	2.58	0.27	25.61	4.62	1.44	0.04	0.58
Cosmetics and toiletry preparations	0.06	0.14	1.27	0.37	0.03	0.85	0.31	0.29	0.01	0.13
Other chemical products	1.37	3.91	17.17	4.09	0.82	5.19	4.32	1.38	0.27	3.29
Rubber products	1.38	6.43	4.63	15.69	0.74	4.96	20.27	0.70	0.01	0.22
Plastic products	2.48	11.20	121.51	37.34	1.35	124.50	57.90	12.38	1.88	70.53
Glass and glass products	16.56	2.32	31.70	92.26	0.28	20.45	12.81	5.64	0.02	0.47
Ceramic products	0.06	0.52	5.09	0.63	0.09	1.66	1.34	0.20	0.01	0.21
Cement, lime and concrete slurry	0.34	1.35	22.66	2.14	0.36	1.85	2.43	0.63	0.08	1.05
Plaster and other concrete products	0.33	0.90	9.80	1.59	0.10	3.96	1.36	2.90	0.08	0.51
Other non-metallic mineral products	0.16	0.54	16.12	1.20	0.07	1.74	1.05	0.55	0.02	0.19
Iron and steel	4.78	13.41	75.88	44.09	2.19	9.40	16.60	84.05	0.36	1.62
Basic non-ferrous metal and products	2.97	9.16	90.75	23.58	2.15	30.98	22.03	17.62	0.41	6.80
Structural metal products	10.34	12.96	42.54	42.59	1.01	10.74	18.20	287.25	0.55	2.37
Sheet metal products	2.44	3.40	93.18	21.33	3.15	5.46	181.07	33.52	0.91	4.19
Fabricated metal products	17.19	44.45	137.20	69.57	9.33	36.40	35.98	36.89	1.43	13.74
Motor vehicles and parts, other transport equipment	66.20	18.73	167.17	1582.32	4.39	35.59	680.59	12.00	0.51	6.40
Ships and boats	4.49	1.87	3.41	3.81	0.31	3.28	2.09	1.64	203.12	0.78
Railway equipment	1.55	2.05	4.48	4.53	0.13	1.78	6.04	1156.96	0.04	0.41
Aircraft	0.11	1.49	43.00	2.58	0.35	2.88	0.97	0.55	0.04	1368.70
Photographic and scientific equipment	3.24	27.49	16.77	13.05	2.47	12.76	8.64	4.11	0.79	17.10
Electronic equipment	4.83	101.24	11.21	15.96	5.61	18.32	13.67	4.41	0.81	15.73

Table B.1(i) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Wholesale mechanical repairs	Other wholesale repairs	Retail trade	Retail mechanical repairs	Other retail repairs	Accommodation, cafes and restaurants	Road transport	Rail, pipeline and other transport	Water transport	Air and space transport
Household appliances	4.07	41.41	28.73	17.89	108.99	43.90	16.05	8.17	0.59	12.31
Other electrical equipment	8.63	87.19	57.42	47.66	12.39	27.00	110.44	6.60	0.96	17.51
Agricultural, mining, etc. machinery	54.10	50.63	17.77	162.41	4.48	22.29	11.58	18.75	0.81	16.82
Other machinery and equipment	37.03	128.97	66.75	130.15	12.25	81.40	40.18	16.04	1.72	17.94
Prefabricated buildings	0.10	0.54	3.01	1.15	0.05	1.07	1.47	4.79	0.03	0.40
Furniture	0.89	3.27	39.80	6.32	0.39	38.34	18.10	3.57	0.12	2.86
Other manufacturing	3.69	31.46	136.75	75.26	5.92	85.95	17.01	15.98	0.42	5.53
Electricity supply	38.96	137.13	1018.69	228.00	44.40	780.66	194.40	360.15	52.31	39.47
Gas supply	0.89	3.07	115.31	7.28	1.23	147.08	6.91	12.83	2.96	2.96
Water supply, sewerage and drainage services	17.05	24.71	303.83	76.85	4.96	314.12	309.03	89.19	25.10	20.71
Residential building	10.35	69.98	123.85	21.14	1.12	78.29	46.82	40.52	1.16	14.90
Other construction	14.02	94.38	168.36	28.52	1.52	233.75	72.29	131.16	2.19	21.74
Construction trade services	144.95	185.97	598.79	119.23	16.06	793.76	112.48	781.56	5.83	30.93
Wholesale trade	210.08	913.10	1680.96	1765.04	118.91	1237.11	2245.13	167.52	42.01	1195.34
Wholesale mechanical repairs	1.06	0.00	326.59	0.00	0.00	0.50	34.92	8.08	15.45	0.00
Other wholesale repairs	0.00	0.00	715.52	0.00	0.00	26.65	125.69	32.81	51.54	77.35
Retail trade	13.15	55.31	2399.89	122.04	7.97	2584.89	330.52	43.24	3.03	383.65
Retail mechanical repairs	0.00	81.23	1145.36	0.00	13.68	37.94	3448.50	47.01	58.83	43.87
Other retail repairs	0.00	0.00	56.33	0.00	0.00	19.91	51.45	28.90	21.11	14.70
Accommodation, cafes and restaurants	1.41	9.76	345.67	22.33	4.91	54.01	160.29	15.26	6.35	39.00
Road transport	6.99	63.43	614.95	43.79	19.40	455.43	1310.11	69.91	6.06	223.35
Rail, pipeline and other transport	0.29	2.97	50.96	2.18	0.55	41.98	4.38	5.76	0.05	13.13
Water transport	0.09	3.65	35.73	0.46	0.03	4.95	4.40	0.32	136.02	0.14
Air and space transport	1.50	26.49	188.04	8.40	1.23	38.43	28.04	3.43	2.09	608.78
Services to transport, storage	17.07	28.68	819.74	89.70	7.58	309.37	657.77	55.87	779.88	1687.35
Communication services	59.06	238.08	3093.64	295.78	25.91	673.89	1010.35	54.95	16.80	136.18
Finance	88.29	224.03	2444.20	452.59	35.99	806.72	608.75	268.15	23.86	201.81
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	16.70	752.39	3732.50	209.30	3.70	1624.62	1239.53	867.32	5.98	586.77
Scientific research, technical and computer services	2.20	15.87	437.73	1.50	0.03	337.05	940.88	52.59	82.82	311.62
Legal, accounting, marketing and business management services	112.86	257.39	6658.34	694.83	54.60	1109.93	2188.96	54.30	63.35	400.34
Other business services	112.29	647.25	3867.83	82.14	1.25	582.84	263.14	83.77	10.10	148.54

Table B.1(i) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Wholesale mechanical repairs	Other wholesale repairs	Retail trade	Retail mechanical repairs	Other retail repairs	Accommodation, cafes and restaurants	Road transport	Rail, pipeline and other transport	Water transport	Air and space transport
Government administration	8.41	8.76	180.14	54.25	2.72	12.60	488.72	16.75	0.91	1.62
Defence	0.00	0.00	2.55	0.00	0.00	3.08	7.92	0.39	0.11	0.67
Education	0.95	2.43	59.27	70.61	0.69	58.23	50.30	18.41	3.38	18.39
Health services	1.02	1.74	15.74	10.36	0.75	5.72	2.52	1.25	0.75	0.21
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	1.33	1.13	1100.24	17.21	0.00	1201.12	63.12	0.82	2.77	18.34
Libraries, museums and the arts	0.00	0.00	74.09	10.96	0.00	176.12	30.36	12.70	17.21	34.47
Sport, gambling and recreational services	0.00	0.03	112.27	9.85	0.01	20.05	3.44	0.05	0.01	3.93
Personal services	0.68	0.58	54.93	4.40	0.00	21.05	0.66	1.29	0.00	0.00
Other services	0.00	0.00	21.74	5.28	0.00	6.74	18.56	0.82	0.00	0.00
Total intermediate usage including imports	**1697**	**6686**	**48333**	**9401**	**801**	**25751**	**22235**	**6070**	**2243**	**11196**
Wages and salaries	385	1445	28804	9540	1126	13483	11377	6018	461	4271
Gross surplus	264	396	18241	334	324	8547	8061	633	1177	894
Indirect taxes on production	77	360	3340	901	102	2747	2711	288	106	1573
Total gross output	**2423**	**8887**	**98718**	**20177**	**2354**	**50528**	**44384**	**13008**	**3987**	**17934**
Value added at factor cost to output ratio	0.30	0.25	0.51	0.53	0.66	0.49	0.50	0.53	0.44	0.38
Share of wages and mixed income in value added	0.60	0.75	0.68	1.05	0.85	0.62	0.72	0.88	0.29	0.66
Employment to gross output ratio	6.83	8.46	17.06	26.42	21.65	14.56	9.93	8.05	5.19	7.08
Foreign ownership ratio	0.15	0.20	0.10	0.04	0.04	0.09	0.20	0.02	0.40	0.38
Direct tax rate on surplus	0.25	0.25	0.13	0.36	0.01	0.04	0.04	0.10	0.04	0.39
Indirect tax rate on production	0.09	0.15	0.06	0.08	0.06	0.11	0.12	0.03	0.05	0.28
Foreign income payout ratio	0.05	0.04	0.03	0.00	0.01	0.03	0.05	0.00	0.26	0.06
Replacement depreciation to value added ratio	0.30	0.32	0.10	0.02	0.01	0.11	0.20	0.43	0.19	0.44
Net national product ratio	0.65	0.64	0.87	0.98	0.99	0.86	0.76	0.57	0.55	0.49
Domestic income distribution ratio	0.26	0.15	0.25	0.00	0.13	0.29	0.18	0.11	0.38	0.10

Table B.1(j) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Services to transport, storage	Commun-ication services	Finance	Ownership of dwellings	Other property services	Scientific research, technical and computer services	Legal, accounting, marketing and business management services	Other business services	Govern-ment admin-istration	Defence
Sheep	0.00	0.00	0.00	0.00	0.00	59.65	0.00	23.61	0.00	0.00
Grains	0.00	0.00	0.00	0.00	0.05	0.02	0.02	0.01	0.04	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poultry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other agriculture	41.78	0.83	4.47	0.00	86.43	44.41	68.76	7.67	68.08	4.92
Services to agriculture, hunting and trapping	0.00	0.00	0.00	0.00	0.00	91.51	0.00	7.89	53.64	16.02
Forestry and logging	1.57	6.24	0.00	0.00	0.00	1.41	0.58	0.64	0.00	0.00
Commercial fishing	0.00	0.00	2.27	0.00	0.00	5.57	0.09	2.60	0.00	0.00
Coal	5.92	4.03	2.26	0.01	26.00	0.95	1.42	2.73	13.81	15.06
Gas	30.22	152.28	7.56	3.62	65.42	30.98	40.38	23.63	62.70	63.74
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	1.71	1.72	0.95	0.00	10.45	0.39	0.60	1.16	1.50	1.11
Non-ferrous metal ores	8.00	4.93	2.66	0.01	40.41	1.23	1.71	3.33	48.55	54.88
Other mining	0.82	0.83	0.45	2.86	7.81	1.27	0.48	0.67	6.06	1.47
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat and meat products	3.61	20.06	9.22	1.24	18.22	41.00	34.20	18.85	3.00	10.77
Dairy products	10.03	73.75	10.59	0.38	20.61	108.77	22.56	47.58	3.26	4.28
Fruit and vegetable products	2.18	6.40	0.81	0.30	4.04	5.73	4.01	2.55	1.38	4.48
Oils and fats	1.36	5.27	0.31	0.13	2.46	7.52	4.33	2.08	1.21	1.42
Flour mill products and cereal foods	2.62	4.70	0.75	0.36	3.73	38.66	16.53	15.39	11.35	9.38
Bakery products	3.91	20.25	6.42	0.29	8.16	12.52	13.77	5.21	6.79	24.75
Confectionery	2.41	13.12	0.43	0.26	4.97	12.96	5.45	5.18	2.94	2.44
Other food products	12.08	24.25	6.05	23.29	17.05	57.84	26.92	22.19	25.12	27.46
Soft drinks, cordials and syrups	1.08	1.46	0.87	0.52	3.21	1.80	1.62	0.78	1.30	29.41
Beer and malt	3.44	2.34	3.74	0.62	3.54	3.16	1.96	1.40	5.46	3.25
Wine, spirits and tobacco products	11.14	11.12	32.94	0.80	9.49	5.58	4.03	2.70	84.13	4.39
Textile fibres, yarns and woven fabrics	2.07	12.87	0.69	1.75	4.43	4.17	1.91	1.80	4.73	5.55
Textile products	4.27	5.53	0.47	11.84	5.29	3.17	1.42	1.83	8.21	2.59
Knitting mill products	1.89	4.27	0.21	0.94	4.34	5.88	4.44	2.78	1.43	8.21

Table B.1(j) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Services to transport, storage	Commun-ication services	Finance	Ownership of dwellings	Other property services	Scientific research, technical and computer services	Legal, accounting, marketing and business management services	Other business services	Govern-ment admin-istration	Defence
Clothing	9.52	16.26	0.93	1.02	6.45	12.40	4.74	4.49	3.05	35.82
Footwear	1.51	2.64	0.19	0.30	1.64	1.37	0.87	0.66	0.63	1.94
Leather and leather products	2.03	3.48	0.46	0.57	1.35	1.85	1.90	1.50	1.03	6.63
Sawmill products	26.08	9.54	1.08	7.24	25.89	2.85	3.31	3.23	4.18	3.73
Other wood products	91.54	31.22	1.78	190.07	43.00	7.59	4.61	5.95	81.62	16.29
Pulp, paper and paperboard	3.39	93.68	26.39	1.08	9.07	13.84	37.76	8.81	122.58	4.90
Paper containers and products	7.36	33.88	3.19	0.27	9.45	16.69	10.71	5.55	57.23	6.15
Printing and services to printing	56.28	723.15	158.70	9.28	265.04	599.00	621.08	289.81	588.06	153.25
Publishing, recorded media, etc.	76.99	529.53	71.99	5.69	176.46	360.28	351.41	186.76	215.97	33.12
Petroleum and coal products	385.55	361.19	6.60	10.82	121.06	188.58	271.26	122.12	71.94	156.32
Basic chemicals	23.04	52.08	4.03	32.97	83.42	100.47	40.30	33.50	37.31	52.29
Paints	1.56	2.05	0.42	10.45	12.85	10.61	6.91	3.13	1.89	2.19
Medicinal and pharmaceutical products, pesticides	18.49	8.85	1.25	3.48	40.91	58.48	12.56	13.27	2.88	4.24
Soap and detergents	3.34	5.48	0.48	1.26	18.76	28.24	36.38	12.51	6.75	5.69
Cosmetics and toiletry preparations	0.41	0.61	0.05	0.45	1.60	0.68	0.61	0.35	0.43	0.79
Other chemical products	3.21	15.28	0.82	3.98	19.13	28.34	25.48	12.68	17.23	55.05
Rubber products	6.31	8.79	0.16	1.57	2.32	6.20	1.41	1.76	27.39	48.76
Plastic products	68.24	325.88	3.07	91.85	26.62	42.83	8.80	10.33	53.41	54.74
Glass and glass products	4.92	12.12	4.26	30.51	10.30	5.37	3.28	2.42	11.58	6.16
Ceramic products	1.49	29.17	0.24	3.14	2.52	1.66	0.76	0.82	1.18	0.78
Cement, lime and concrete slurry	2.03	9.98	1.01	56.51	8.93	12.82	2.26	6.57	4.71	3.18
Plaster and other concrete products	1.23	8.79	0.26	23.73	4.21	2.33	1.35	1.22	23.81	3.47
Other non-metallic mineral products	1.72	7.03	0.14	18.96	3.78	2.70	1.89	1.71	3.19	3.72
Iron and steel	7.91	62.75	1.73	163.75	17.20	19.18	5.76	4.50	15.89	31.22
Basic non-ferrous metal and products	20.96	80.45	7.13	141.40	62.12	24.68	20.03	15.81	41.61	41.90
Structural metal products	19.84	36.78	2.23	246.70	50.63	8.12	4.99	6.32	25.64	27.92
Sheet metal products	32.86	281.97	0.98	58.29	21.68	3.92	1.70	2.71	7.85	10.72
Fabricated metal products	19.21	86.39	5.54	67.09	56.49	56.78	17.43	15.96	50.95	117.27
Motor vehicles and parts, other transport equipment	110.92	187.51	7.04	3.82	97.83	46.03	22.23	19.25	21.43	94.20
Ships and boats	10.02	3.32	1.78	1.05	8.77	6.13	2.99	3.04	4.63	2066.14
Railway equipment	2.96	4.74	1.29	1.41	6.03	3.02	1.34	1.06	2.63	2.31
Aircraft	298.89	2.08	0.28	0.95	4.73	6.58	1.93	2.42	1.33	188.16

Table B.1(j) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Services to transport, storage	Commun-ication services	Finance	Ownership of dwellings	Other property services	Scientific research, technical and computer services	Legal, accounting, marketing and business management services	Other business services	Govern-ment admin-istration	Defence
Photographic and scientific equipment	39.36	94.93	3.29	4.12	30.34	60.23	15.50	12.36	18.83	63.41
Electronic equipment	163.18	270.11	5.80	13.46	37.22	84.53	41.60	20.35	15.25	21.59
Household appliances	17.97	20.07	1.76	33.06	19.03	10.29	5.84	4.61	3.65	20.10
Other electrical equipment	91.06	422.30	9.05	21.99	48.75	82.80	28.67	16.35	26.77	28.73
Agricultural, mining, etc. machinery	34.27	38.91	2.61	6.33	35.69	41.03	10.80	9.82	12.33	21.30
Other machinery and equipment	39.20	74.82	3.29	9.41	46.59	81.17	11.87	13.05	22.64	110.05
Prefabricated buildings	1.48	2.50	0.21	2.77	4.98	0.75	0.49	0.69	1.70	11.79
Furniture	10.25	26.68	6.43	30.05	52.66	13.63	14.06	22.13	68.50	40.41
Other manufacturing	24.93	76.65	4.11	13.35	47.34	34.47	20.52	16.07	18.07	32.94
Electricity supply	969.82	451.80	183.87	55.05	494.35	408.86	654.97	375.06	460.26	96.99
Gas supply	25.66	81.30	8.88	4.06	27.96	23.66	40.15	18.86	22.24	3.20
Water supply, sewerage and drainage services	307.59	289.88	89.89	5.36	841.35	667.32	631.30	414.66	283.62	140.94
Residential building	128.46	212.35	94.93	140.75	412.45	132.00	184.91	93.44	124.79	53.29
Other construction	269.60	293.34	127.52	261.56	606.92	181.06	271.50	127.48	273.64	185.80
Construction trade services	607.59	2469.77	68.67	1690.46	850.93	378.13	510.40	239.50	1487.62	1600.03
Wholesale trade	1057.69	2233.56	147.42	181.83	806.31	1215.16	723.43	400.91	571.25	676.30
Wholesale mechanical repairs	36.29	81.26	1.07	0.00	75.27	17.58	1.59	0.22	24.62	0.00
Other wholesale repairs	469.04	840.39	651.14	3.06	328.00	377.22	363.74	297.32	6.88	11.29
Retail trade	208.32	473.28	70.11	22.41	716.91	150.56	153.93	123.81	121.55	80.38
Retail mechanical repairs	712.44	874.32	107.38	0.00	438.44	172.40	288.21	260.05	165.44	68.79
Other retail repairs	23.48	17.85	47.78	1101.68	20.18	23.01	27.66	20.14	42.28	0.00
Accommodation, cafes and restaurants	257.45	415.68	336.40	0.00	20.04	395.60	1429.73	473.40	405.40	58.21
Road transport	467.62	543.43	98.73	53.05	164.38	250.92	294.53	100.70	389.88	144.04
Rail, pipeline and other transport	84.25	124.58	15.40	1.49	129.10	63.48	89.35	39.12	6.89	6.36
Water transport	3.64	102.98	0.15	0.16	31.88	70.46	31.49	32.87	71.57	10.57
Air and space transport	108.71	457.02	146.42	0.07	46.97	265.89	556.02	210.09	299.38	113.48
Services to transport, storage	4279.14	640.42	186.86	6.39	1440.85	546.41	1185.68	865.54	1120.62	481.32
Communication services	1584.87	1385.34	2238.48	16.59	1490.04	1651.04	2679.59	475.14	1822.75	99.93
Finance	971.83	1036.47	38388.03	6387.55	4822.26	889.67	2732.08	895.87	2538.96	287.73
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other property services	2848.14	3954.93	2035.85	2135.99	25342.34	333.86	4208.77	2557.51	557.73	106.63
Scientific research, technical and computer services	2460.93	691.59	1258.64	28.22	2552.66	7138.12	5398.46	1272.41	2383.55	60.81

Table B.1(j) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Services to transport, storage	Commun-ication services	Finance	Ownership of dwellings	Other property services	Scientific research, technical and computer services	Legal, accounting, marketing and business management services	Other business services	Govern-ment admin-istration	Defence
Legal, accounting, marketing and business management services	1576.41	670.55	3920.44	476.39	5066.07	4302.33	4389.78	1210.08	1815.81	289.37
Other business services	1801.82	585.32	1768.95	3.39	4121.64	2299.34	3114.86	1198.50	843.49	42.06
Government administration	455.92	306.06	82.43	5.28	99.97	425.71	471.22	105.03	1494.19	46.80
Defence	19.57	5.68	6.11	0.02	3.73	9.76	8.29	4.33	14.87	0.28
Education	214.53	48.87	584.44	0.01	209.72	457.66	547.59	295.57	195.85	42.01
Health services	85.43	78.21	20.12	0.01	10.95	13.46	11.36	10.09	43.24	58.02
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Motion picture, radio and television services	26.85	104.12	344.31	0.00	1294.89	1242.15	1737.30	565.23	113.23	85.69
Libraries, museums and the arts	25.28	43.17	136.21	0.00	119.85	161.10	353.28	88.32	45.67	12.54
Sport, gambling and recreational services	10.25	26.38	102.32	0.00	130.06	178.50	35.02	88.55	65.07	107.23
Personal services	1.05	29.19	3.16	0.06	34.73	53.01	77.10	28.21	2.96	43.93
Other services	30.81	19.58	9.14	0.00	71.63	46.61	58.14	31.34	35.04	26.62
Total intermediate usage including imports	**25567**	**27613**	**54460**	**14516**	**55612**	**31211**	**37774**	**15326**	**21317**	**11306**
Wages and salaries	9376	9636	44477	0	13749	25997	25657	23608	33990	4940
Gross surplus	15355	16546	37406	98384	27291	3241	7478	8761	1185	4547
Indirect taxes on production	1996	1466	4961	10668	2553	1410	3021	934	1170	726
Total gross output	**52294**	**55260**	**141304**	**123568**	**99205**	**61859**	**73930**	**48629**	**57663**	**21519**
Value added at factor cost to output ratio	0.51	0.50	0.61	0.88	0.44	0.50	0.49	0.68	0.63	0.47
Share of wages and mixed income in value added	0.37	0.41	0.55	0.00	0.38	1.01	0.90	0.86	0.95	0.49
Employment to gross output ratio	5.17	6.20	4.09	0.00	3.40	10.93	9.07	7.60	11.86	7.68
Foreign ownership ratio	0.10	0.10	0.20	0.00	0.10	0.15	0.05	0.15	0.00	0.00
Direct tax rate on surplus	0.02	0.12	0.39	0.00	0.09	0.22	0.23	0.09	0.00	0.00
Indirect tax rate on production	0.07	0.04	0.05	0.11	0.04	0.03	0.08	0.02	0.03	0.06
Foreign income payout ratio	0.06	0.04	0.06	0.00	0.05	0.00	0.00	0.02	0.00	0.00
Replacement depreciation to value added ratio	0.23	0.20	0.08	0.00	0.15	0.11	0.07	0.04	0.13	0.13
Net national product ratio	0.72	0.76	0.86	1.00	0.80	0.89	0.93	0.94	0.87	0.87
Domestic income distribution ratio	0.51	0.38	0.24	0.00	0.48	0.00	0.08	0.11	0.00	0.00

Table B.1(k) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Education	Health services	Community services	Motion picture, radio & television services	Libraries, museums & the arts	Sport, gambling & recreational services	Personal services	Other services	Households	Current government expenditure
Sheep	0.00	0.00	9.92	0.00	0.00	0.00	0.00	108.00	7.44	0.00
Grains	0.00	0.09	0.02	0.04	0.02	0.02	0.02	0.04	0.00	0.00
Beef cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.60	0.00
Dairy cattle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pigs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.44	0.00
Poultry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	424.46	0.00
Other agriculture	7.71	8.28	6.60	238.60	39.74	500.36	59.22	31.39	5505.94	0.00
Services to agriculture, hunting and trapping	0.00	0.00	5.14	3.01	0.75	2.79	3.37	25.29	45.25	192.25
Forestry and logging	0.00	0.00	0.00	0.63	0.17	0.60	0.10	2.38	27.07	227.93
Commercial fishing	0.00	0.04	0.47	4.39	1.92	5.21	0.06	8.24	1098.56	178.32
Coal	1.30	2.09	0.11	1.92	0.65	2.34	0.45	1.04	16.49	1.69
Gas	54.14	87.14	15.29	9.04	4.34	12.14	7.53	31.40	532.34	4.66
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron ores	0.18	0.45	0.04	0.54	0.19	0.73	0.19	0.41	0.88	0.03
Non-ferrous metal ores	0.72	1.94	0.17	1.53	0.55	2.04	0.53	1.52	2.20	0.10
Other mining	0.08	0.27	0.42	21.25	4.74	24.09	0.87	5.20	2.48	0.02
Services to mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	83.87
Meat and meat products	29.90	7.05	4.59	17.28	7.31	86.51	4.62	67.44	6065.47	3.11
Dairy products	116.71	17.76	17.49	6.16	3.89	26.68	2.50	156.79	5107.57	0.01
Fruit and vegetable products	7.80	7.42	1.40	2.05	2.10	5.14	1.04	5.60	2224.83	0.00
Oils and fats	6.96	5.32	1.03	1.97	1.38	4.79	4.42	2.81	719.19	11.60
Flour mill products and cereal foods	11.65	13.66	4.09	26.39	10.80	31.98	5.79	17.95	2013.20	0.01
Bakery products	56.26	20.88	12.34	4.69	2.80	8.82	0.53	8.44	2704.53	0.01
Confectionery	7.96	3.99	1.38	23.82	10.90	126.65	5.50	11.25	1949.20	0.01
Other food products	21.93	41.55	5.37	119.65	56.32	650.60	41.63	33.69	3459.07	29.57
Soft drinks, cordials and syrups	1.52	2.79	2.10	8.34	5.79	12.76	1.09	4.91	3166.43	0.01
Beer and malt	1.94	0.87	0.13	0.45	0.33	0.80	0.15	3.03	1589.55	0.01
Wine, spirits and tobacco products	13.01	1.93	0.16	1.25	0.63	1.04	0.96	5.14	2382.18	0.01
Textile fibres, yarns and woven fabrics	6.63	3.22	0.35	1.39	0.87	1.87	1.07	4.67	128.30	0.01
Textile products	10.70	11.37	0.79	1.95	0.56	7.62	1.99	7.37	741.08	0.00
Knitting mill products	3.00	110.23	5.01	2.46	0.79	2.61	0.40	4.33	445.83	0.01
Clothing	11.88	30.90	4.67	6.43	2.85	19.04	2.82	38.44	981.29	0.01

Table B.1(k) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Education	Health services	Community services	Motion picture, radio & television services	Libraries, museums & the arts	Sport, gambling & recreational services	Personal services	Other services	Households	Current government expenditure
Footwear	1.83	6.48	0.41	1.88	0.79	7.34	0.39	1.83	230.50	0.00
Leather and leather products	1.98	1.77	0.13	3.35	1.42	72.25	0.17	0.71	29.01	0.00
Sawmill products	6.71	3.44	0.24	2.45	1.67	2.67	0.62	1.44	24.72	0.06
Other wood products	162.31	9.69	1.36	48.65	27.34	18.57	3.35	7.65	156.49	0.07
Pulp, paper and paperboard	4.02	9.56	1.04	3.67	17.92	2.57	7.44	28.04	55.88	0.00
Paper containers and products	47.16	258.65	37.46	4.26	3.88	3.53	15.16	20.99	774.17	0.00
Printing and services to printing	507.29	108.59	19.69	145.34	141.13	175.77	132.09	215.34	971.34	3.63
Publishing, recorded media, etc.	1056.02	45.82	7.98	72.59	123.35	59.50	61.94	112.42	4678.66	0.08
Petroleum and coal products	7.94	169.09	11.46	23.17	9.48	39.56	26.97	179.19	6503.08	7.76
Basic chemicals	42.07	428.06	6.93	45.71	8.71	81.11	68.55	62.63	356.94	8.39
Paints	0.87	1.43	0.32	9.53	1.88	9.13	1.25	2.41	34.49	0.01
Medicinal and pharmaceutical products, pesticides	7.74	233.39	16.51	44.78	3.71	106.84	17.68	21.40	1209.88	936.84
Soap and detergents	5.67	16.71	2.20	1.76	1.10	2.01	13.90	14.63	848.87	1.66
Cosmetics and toiletry preparations	0.33	1.18	0.07	0.38	0.07	0.65	2.60	0.37	311.89	2.06
Other chemical products	4.84	8.50	2.16	3.94	1.28	4.94	5.91	27.00	231.08	2.33
Rubber products	2.63	5.27	0.40	1.27	0.36	1.93	1.48	4.65	270.56	0.45
Plastic products	40.92	64.36	3.99	13.83	8.16	14.20	32.09	37.93	785.63	0.37
Glass and glass products	14.80	24.80	1.44	5.14	3.38	5.56	1.83	8.01	386.06	0.01
Ceramic products	4.27	0.98	0.44	1.24	0.39	1.31	0.90	0.85	64.92	0.00
Cement, lime and concrete slurry	3.29	2.92	1.78	1.57	0.63	1.38	6.22	11.25	19.11	0.02
Plaster and other concrete products	6.25	2.39	0.40	2.55	1.16	1.64	3.60	6.61	12.73	0.01
Other non-metallic mineral products	2.41	2.38	0.77	1.78	0.62	1.12	10.99	7.32	17.71	0.00
Iron and steel	34.05	9.28	1.09	8.62	5.19	7.94	5.32	12.43	52.88	1.62
Basic non-ferrous metal and products	33.69	23.78	2.97	22.28	6.91	27.74	29.48	16.44	169.38	4.74
Structural metal products	172.82	6.94	0.65	26.97	24.42	25.70	4.24	6.82	71.77	0.11
Sheet metal products	17.94	20.81	1.08	5.53	2.43	6.22	2.71	3.14	95.25	0.05
Fabricated metal products	55.74	40.89	5.33	72.91	23.16	67.12	12.35	42.52	323.56	0.09
Motor vehicles and parts, other transport equipment	64.74	15.20	2.28	20.91	8.23	18.60	5.69	28.32	7152.68	1.60
Ships and boats	1.64	1.26	0.19	3.32	0.94	2.96	0.32	4.58	563.46	1.61
Railway equipment	0.95	1.67	0.08	0.48	0.21	0.67	0.18	0.63	7.63	2.54
Aircraft	2.58	0.60	0.49	6.81	0.71	4.98	0.09	8.53	25.43	1.01
Photographic and scientific equipment	134.70	639.53	1.78	7.50	2.78	18.16	3.30	24.90	1177.30	4.37
Electronic equipment	51.50	22.98	2.08	31.43	8.05	34.32	2.76	14.57	661.28	0.06

Table B.1(k) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Education	Health services	Community services	Motion picture, radio & television services	Libraries, museums & the arts	Sport, gambling & recreational services	Personal services	Other services	Households	Current government expenditure
Household appliances	9.11	23.71	2.98	31.27	10.20	45.54	1.64	6.54	2477.13	0.04
Other electrical equipment	34.40	24.94	2.69	53.58	15.84	54.09	4.51	27.46	414.90	0.09
Agricultural, mining, etc. machinery	20.20	12.43	1.58	8.41	2.80	9.27	1.72	16.01	250.42	0.07
Other machinery and equipment	33.45	27.54	2.30	15.89	5.82	21.57	6.39	31.96	303.22	0.09
Prefabricated buildings	4.34	0.85	0.07	0.71	0.76	0.78	0.27	0.95	10.27	0.01
Furniture	209.06	7.48	1.02	16.77	21.20	10.98	3.75	9.06	2358.71	0.08
Other manufacturing	75.74	50.92	5.79	37.10	14.08	31.68	10.09	36.58	820.05	0.07
Electricity supply	1299.86	389.10	62.00	181.78	57.23	216.41	104.90	281.62	10480.47	138.55
Gas supply	50.39	64.21	13.29	6.31	2.58	7.30	6.42	13.88	1180.41	38.18
Water supply, sewerage and drainage services	98.26	131.87	21.33	39.17	16.61	41.01	63.45	170.96	5128.88	1600.23
Residential building	12.41	45.81	3.93	27.59	10.09	31.52	16.18	35.71	118.03	15.17
Other construction	20.08	66.88	6.43	37.87	13.90	43.13	21.89	51.81	242.35	4735.46
Construction trade services	59.47	77.87	12.34	18.85	11.43	20.23	14.51	37.41	333.70	17.45
Wholesale trade	1196.80	1751.80	80.23	564.08	199.19	752.74	263.89	558.54	21074.07	285.60
Wholesale mechanical repairs	3.19	0.00	0.00	1.39	0.15	2.21	0.19	2.39	0.00	0.00
Other wholesale repairs	157.38	48.90	22.32	43.25	22.79	47.28	50.38	109.74	307.28	0.00
Retail trade	444.39	260.92	28.03	197.92	81.79	239.43	50.51	158.13	73095.76	3500.41
Retail mechanical repairs	60.68	243.63	14.20	90.81	42.36	147.86	25.82	137.28	6288.31	0.00
Other retail repairs	36.77	20.55	6.62	11.34	4.04	3.20	11.00	17.48	631.97	0.00
Accommodation, cafes and restaurants	173.11	18.00	19.00	171.36	58.26	172.01	45.03	125.15	36929.27	4.17
Road transport	321.95	462.56	18.62	177.54	61.09	428.09	87.28	149.39	9914.19	1350.71
Rail, pipeline and other transport	17.03	18.90	3.59	7.59	3.78	9.21	2.53	10.22	2955.80	7.74
Water transport	11.75	1.13	6.78	32.48	5.16	180.40	6.97	64.02	441.79	0.00
Air and space transport	145.94	49.68	6.33	84.65	27.62	114.93	23.64	47.94	8426.13	0.00
Services to transport, storage	259.32	180.97	12.54	100.92	42.55	111.51	16.38	97.86	1673.46	9283.50
Communication services	1219.91	1063.92	109.79	629.65	222.77	942.51	452.73	1054.68	15865.42	101.13
Finance	1061.16	1532.18	108.37	599.73	271.89	660.91	257.07	367.98	45326.34	9.78
Ownership of dwellings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	123166.19	-128.08
Other property services	318.30	485.89	51.82	919.47	346.22	1373.38	205.58	408.56	1258.70	71.81
Scientific research, technical and computer services	304.76	209.12	36.87	87.95	151.01	77.98	74.36	611.89	107.10	1763.98
Legal, accounting, marketing and business management services	605.67	1676.57	76.80	768.78	262.84	1049.42	436.74	508.53	3125.06	353.37
Other business services	489.54	1258.27	122.38	529.72	296.62	881.17	462.28	846.64	1286.38	4443.75

Table B.1(k) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Education	Health services	Community services	Motion picture, radio & television services	Libraries, museums & the arts	Sport, gambling & recreational services	Personal services	Other services	Households	Current government expenditure
Government administration	284.70	114.37	13.89	18.88	20.03	16.52	65.08	17.71	1418.87	48922.65
Defence	1.90	0.51	0.20	0.54	0.97	0.49	0.64	4.94	0.00	21228.67
Education	756.21	76.87	15.69	34.67	94.49	21.92	49.31	282.61	20514.94	33273.19
Health services	49.77	480.58	4.55	25.36	2.13	39.81	3.50	34.02	23522.61	48432.90
Community services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3004.38	13455.31
Motion picture, radio and television services	11.51	14.04	9.46	2681.19	210.13	401.62	69.93	82.99	1907.64	1520.61
Libraries, museums and the arts	606.48	24.18	14.11	215.34	165.80	165.23	0.95	82.08	979.51	3513.40
Sport, gambling and recreational services	189.45	149.63	43.52	523.26	42.74	545.92	15.65	66.45	14871.53	2093.68
Personal services	51.89	559.33	2.41	39.79	6.22	12.62	14.40	9.34	9092.39	175.64
Other services	30.67	62.82	5.10	4.14	1.84	8.49	12.86	16.86	9898.33	14550.98
Total intermediate usage including imports	**15872**	**17842**	**1362**	**11299**	**4110**	**12951**	**4039**	**9231**		
Wages and salaries	43195	47633	11048	2589	2429	4977	4570	13807		
Gross surplus	3582	6524	3721	2428	949	2780	1755	2053		
Indirect taxes on production	1321	1862	333	482	163	567	267	808		
Total gross output	**63970**	**73862**	**16464**	**16798**	**7652**	**21275**	**10630**	**25899**	**590654**	**220243**
Value added at factor cost to output ratio	0.75	0.76	0.92	0.33	0.46	0.39	0.62	0.64		
Share of wages and mixed income in value added	0.94	0.92	0.80	0.54	1.10	0.73	1.23	0.85		
Employment to gross output ratio	12.97	12.19	14.95	7.72	21.08	14.42	25.65	11.97		
Foreign ownership ratio	0.01	0.02	0.01	0.08	0.01	0.05	0.00	0.03		
Direct tax rate on surplus	0.03	0.06	0.01	0.08	0.04	0.18	0.04	0.03		
Indirect tax rate on production	0.02	0.03	0.02	0.07	0.03	0.05	0.03	0.04		
Foreign income payout ratio	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00		
Replacement depreciation to value added ratio	0.09	0.06	0.06	0.37	0.06	0.22	0.12	0.08		
Net national product ratio	0.91	0.93	0.93	0.60	0.94	0.77	0.88	0.91		
Domestic income distribution ratio	0.06	0.07	0.19	0.37	0.00	0.22	0.00	0.13		

Table B.1(l) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Construction investment	Equipment investment	Inventories	Exports
Sheep	0.00	367.11	-8.63	1648
Grains	0.00	0.00	-64.03	5317
Beef cattle	0.00	2254.63	-37.56	490
Dairy cattle	0.00	459.16	0.55	52
Pigs	0.00	0.00	-14.40	0
Poultry	0.00	0.00	-19.61	8
Other agriculture	0.00	0.00	-25.27	1108
Services to agriculture, hunting and trapping	0.00	0.00	-48.42	415
Forestry and logging	0.00	0.00	-16.53	111
Commercial fishing	0.00	0.00	0.20	229
Coal	0.00	568.02	142.88	52158
Gas	0.00	3201.73	341.65	0
LNG	0.00	0.00	0.00	10086
Oil	0.00	0.00	0.00	8757
Iron ores	0.00	3.58	1.01	32652
Non-ferrous metal ores	0.00	131.56	-0.94	9501
Other mining	0.00	4.53	2.49	815
Services to mining	0.00	1354.05	0.00	6
Meat and meat products	0.00	46.94	58.23	5538
Dairy products	0.00	24.20	-5.49	2415
Fruit and vegetable products	0.00	37.87	28.69	995
Oils and fats	0.00	12.50	9.13	409
Flour mill products and cereal foods	0.00	42.06	5.52	1049
Bakery products	0.00	34.54	-2.99	383
Confectionery	0.00	29.83	16.29	555
Other food products	0.00	115.58	-18.45	3924
Soft drinks, cordials and syrups	0.00	9.59	-6.64	208
Beer and malt	0.00	10.96	-1.19	386
Wine, spirits and tobacco products	0.00	20.49	-0.94	2593
Textile fibres, yarns and woven fabrics	0.00	49.14	-5.38	342
Textile products	0.00	449.10	10.85	188
Knitting mill products	0.00	14.80	7.10	60
Clothing	0.00	87.42	-2.87	612
Footwear	0.00	18.90	-2.29	79
Leather and leather products	0.00	25.96	7.04	853

Table B.1(l) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Construction investment	Equipment investment	Inventories	Exports
Sawmill products	0.00	33.84	13.24	988
Other wood products	0.00	136.99	14.28	165
Pulp, paper and paperboard	0.00	10.03	23.00	575
Paper containers and products	0.00	18.60	1.81	317
Printing and services to printing	0.00	35.38	-7.12	195
Publishing, recorded media, etc.	0.00	664.14	19.64	337
Petroleum and coal products	0.00	4835.19	91.99	2642
Basic chemicals	0.00	171.26	16.52	2173
Paints	0.00	31.11	2.45	145
Medicinal and pharmaceutical products, pesticides	0.00	55.56	-1.65	2483
Soap and detergents	0.00	13.30	-0.16	264
Cosmetics and toiletry preparations	0.00	4.51	-0.27	277
Other chemical products	0.00	26.95	-4.89	477
Rubber products	0.00	44.93	1.00	256
Plastic products	0.00	495.63	2.16	716
Glass and glass products	0.00	25.24	4.32	285
Ceramic products	0.00	5.96	4.04	95
Cement, lime and concrete slurry	0.00	24.71	17.36	50
Plaster and other concrete products	0.00	31.73	45.95	59
Other non-metallic mineral products	0.00	8.86	16.48	118
Iron and steel	0.00	368.19	-26.72	4081
Basic non-ferrous metal and products	0.00	248.57	-90.04	34003
Structural metal products	0.00	323.32	60.62	278
Sheet metal products	0.00	966.17	11.80	235
Fabricated metal products	0.00	1213.54	14.21	816
Motor vehicles and parts, other transport equipment	0.00	4265.86	-18.35	3037
Ships and boats	0.00	675.16	-3.93	302
Railway equipment	0.00	431.41	-0.53	67
Aircraft	0.00	764.41	-4.96	529
Photographic and scientific equipment	0.00	775.40	1.48	1587
Electronic equipment	0.00	1053.21	-6.66	1075
Household appliances	0.00	776.38	29.04	260
Other electrical equipment	0.00	641.62	-16.43	777
Agricultural, mining, etc. machinery	0.00	3181.43	23.91	1013
Other machinery and equipment	0.00	2497.14	15.09	1612

Table B.1(l) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Construction investment	Equipment investment	Inventories	Exports
Prefabricated buildings	0.00	248.88	0.96	38
Furniture	0.00	1527.52	2.36	156
Other manufacturing	0.00	462.21	32.19	1137
Electricity supply	0.00	5618.74	3.14	65
Gas supply	0.00	872.11	176.07	2
Water supply, sewerage and drainage services	0.00	748.00	0.00	12
Residential building	51612.53	0.00	0.00	131
Other construction	99054.39	0.00	0.00	188
Construction trade services	25627.21	0.00	-0.69	398
Wholesale trade	0.00	20936.44	-31.07	14076
Wholesale mechanical repairs	0.00	0.00	0.00	0
Other wholesale repairs	0.00	0.00	0.00	1
Retail trade	0.00	2495.55	4.31	4076
Retail mechanical repairs	0.00	0.00	0.00	21
Other retail repairs	0.00	0.00	0.00	0
Accommodation, cafes and restaurants	0.00	1.36	0.00	5417
Road transport	0.00	2825.68	-17.96	7703
Rail, pipeline and other transport	0.00	109.78	-0.70	4429
Water transport	0.00	8.45	0.09	976
Air and space transport	0.00	58.65	0.00	4633
Services to transport, storage	0.00	85.99	-0.21	3365
Communication services	0.00	3980.24	0.00	816
Finance	0.00	142.67	0.00	1453
Ownership of dwellings	0.00	0.00	0.00	529
Other property services	0.00	8617.07	0.00	569
Scientific research, technical and computer services	0.00	12231.62	0.00	2652
Legal, accounting, marketing and business management services	0.00	955.75	0.00	2312
Other business services	0.00	0.00	0.00	970
Government administration	0.00	347.48	0.00	41
Defence	0.00	84.50	0.00	84
Education	0.00	64.59	0.00	4788
Health services	0.00	26.80	0.00	612
Community services	0.00	0.00	0.00	4
Motion picture, radio and television services	0.00	565.14	0.00	232

Table B.1(l) Australia input-output flow table with direct allocation of imports – $2009m (continued)

	Construction investment	Equipment investment	Inventories	Exports
Libraries, museums and the arts	0.00	85.63	0.00	162
Sport, gambling and recreational services	0.00	0.00	0.00	596
Personal services	0.00	0.00	0.00	163
Other services	0.00	0.00	0.00	48
Total intermediate usage including imports				
Wages and salaries				
Gross surplus				
Indirect taxes on production				
Total gross output	**176296**	**139197**	**587**	**269081**
Value added at factor cost to output ratio				
Share of wages and mixed income in value added				
Employment to gross output ratio				
Foreign ownership ratio				
Direct tax rate on surplus				
Indirect tax rate on production				
Foreign income payout ratio				
Replacement depreciation to value added ratio				
Net national product ratio				
Domestic income distribution ratio				

Large scale export of East Coast Australia natural gas: Unintended consequences

National Institute of Economic and Industry Research[1]

This note summarizes the major conclusions of the NIEIR study referenced here. Many major projects to export Liquefied Natural Gas from Eastern Australia have been approved and will start to operate over the next several years. This will significantly impact the domestic supply of natural gas. The National Institute of Economic and Industry Research (NIEIR) has done an assessment, reviewing the literature and conducting its own analysis of the sectoral and macroeconomic implications of these developments.

NIEIR has found that:

- If existing plans proceed, gas exports from eastern Australia will rise from 2 million tonnes (0.29 bcf/day) in 2015 to 20 million tonnes (2.9 bcf/day) in 2018, and possibly 24 million tonnes (3.44 bcf/day) in 2023;
- The current policy framework and market settings for the Australian gas industry favor export of LNG without a subsequent assurance of reliable, competitively priced supplies of gas for domestic industry. Such supplies have historically been a competitive advantage for Australian industry, and gas export revenue is insufficient to compensate Australia for the loss of this advantage;
- Natural gas is essential to a range of industries, particularly non-ferrous metals and basic chemicals, but also plastics, pharmaceuticals, paints and cosmetics. Secure local supply at competitive prices is a fundamental requirement for the continuation of a significant part of production and the development of new investment in these industries;
- Contracts for the long term supply of gas to domestic industry have 'evaporated' as a consequence of export commitments;
- Australia has only a few years before significant economic loss is likely to be felt from the failure to secure an affordable supply of natural gas to domestic users;
- Domestic gas users are increasingly being offered "surplus" gas volumes and prices that do not reflect domestic supply, demand or extraction costs, but are instead linked to East Asia's LNG market – the highest-priced gas in the world. This is a radical reshaping of the domestic gas market, constraining supply (in the near term at least) and driving prices to high (and for many industries uneconomic) levels;
- Current gas production and proven reserves will need to expand dramatically in order to support the LNG expansion without significant large scale suppression of gas use on the domestic economy. While the total gas resource is thought to be very large, proving up additional resources and developing them will take time and faces community opposition and other barriers. To ensure gas availability for domestic users, the management of reserves and their supply to market needs attention if domestic needs are not to be overlooked in the rush to export this valuable resource;
- There are important opportunities to expand use of gas in industrial production and electricity generation, but even so domestic consumers cannot make use of the whole gas resource. There are worthwhile benefits to pursue from exporting gas production beyond these needs. But each cubic foot of natural gas that is shifted away from industrial use towards export, whether because of tight supply or uneconomic pricing, means giving up $255 million in lost industrial output for a $12 million gain in export output. That is, for every dollar gained $21 is lost. This increases to $24 when economy-wide impacts are taken into account;
- The dramatic shift in the domestic gas market will have wider impacts well beyond the gas intensive industries:
    - Increased operating costs for gas-fired electricity generators due to high gas prices. Such generators would see cost increases three times greater than those currently resulting from the carbon tax. Wholesale electricity prices would thus rise, and the viability of new gas-fired generation would suffer. These plants already play an important role in the electricity market for both peak power and base load. That role is expected to grow to meet emissions reduction targets and provide backup for expanding renewable generation;

[1] http://www.nieir.com.au

    - Some substitution away from gas towards electricity by business and households, to reduce their exposure to rising gas prices. This would still leave their costs higher than at present, and would raise greenhouse emissions;
    - A slow-down of general economic activity resulting from impacts of the tighter gas supply and higher costs for gas and electricity;
- The expected economic response to the East Coast LNG expansion will involve a combination of the adjustments above. As a result, modeling indicates that, by 2040 the gross production benefit for East Coast LNG expansion will be $15 billion annually, in 2009 prices. However, taking into account the negative effects of adjustment on other sectors, annual GDP will be $22 billion lower than it would be with secure and affordable gas. An alternative 'benefit indicator' used for this study, which combines private consumption, tax receipts and net national product, will be reduced by $46 billion;
- Under current policy settings and market structures, the unwanted consequences of the significant boom in LNG exports will persist even if, as is likely, adequate natural gas reserves exist and are brought to market; and there are substantial further risks that would lead to even greater costs if realized. These risks include:
    - LNG prices may be lower than currently expected. While this would reduce the extent of domestic price rises, it would also reduce gross export benefits while leaving domestic supply constrained in the short-to-medium term by contracted export commitments; and
    - Industry will likely be unable to grow without secure affordable gas supplies, leading to additional damage.

The likely consequences of the current policy and industry settings on natural gas export are serious for both industry and households. LNG export is a positive for Australia as long as it proceeds without significant harm to the domestic sector and with confident assurance of domestic supply.

Reference

National Institute of Economic and Industry Research, "Large scale export of East Coast Australia natural gas: Unintended consequences." A report to the Australian Industry Group and the Plastics and Chemicals Industries Association, October 2012.

Quality of life

Canadian firm plans fracking campaign that could require 4 billion gallons of Michigan water

25 June 2013

by **Jeff Alexander**
Bridge Magazine contributor

KALKASKA — A Canadian firm has laid out plans to drill 500 new natural gas wells in Northern Michigan, using a technique that could consume more than 4 billion gallons of groundwater — or about as much water as Traverse City uses in two years.

THIRSTY WORK: The Encana Corp.'s Westerman well in Kalkaska County recently used 8.5 million gallons of water to complete a hydraulic fracturing process. (courtesy photo)

The firm, Encana Corp., will rely on hydraulic fracturing or "fracking," a technique cloaked in controversy that requires large amounts of water, mixed with chemicals and other elements, to break down rock formations and release natural gas. Encana, for example, used 8.5 million gallons of groundwater earlier this month to frack a single gas well, the Westerman in Kalkaska County, east of Traverse City.

Because most of the water used in fracking becomes contaminated and is left in geologic formations deep underground, a recent surge in drilling by Encana and other companies has raised concerns that fracking could drain water from some of the state's best rivers.

Encana recently drilled several new wells into the Collingwood shale formation, which lies about two miles underground. That's the first step in a plan to drill 500 more deep shale wells in the region using fracking, according to company records.

The company's plan to drill several new gas wells near Kalkaska will entail pumping about 300 million gallons of water out of the ground, injecting that water into several gas well bores and then leaving nearly all of the contaminated water in the ground when the fracking is completed, according to state records.

The result: A net loss of up to 300 million gallons of groundwater to the North Branch of the Manistee River, a blue-ribbon trout stream fed almost entirely by groundwater. One of Encana's drilling sites is a half-mile from the Manistee River's North Branch, according to company records.

"If the citizens of Michigan knew corporations were destroying hundreds of millions of gallons of Michigan water – water that is supposedly protected by government for use by all of us – they would be opposing this new kind of completion (fracking) technique," said Paul Brady, a fracking watchdog who lives near Kalkaska. "These deep shale, unconventional wells are using massive amounts of water without adequate testing and solid data on aquifer capacity."

Encana spokesman Doug Hock, however, is optimistic: "Can we access the (deep shale gas) and still protect the environment? Absolutely."

State's monitoring questioned, defended

Michigan's Water Withdrawal Assessment Tool, a computer-based program launched in 2006, was supposed to prevent water withdrawals that could harm streams and rivers. The tool is Michigan's first line of defense against excessive water withdrawals, but it was developed before drillers began using large quantities of water when fracking deep shale gas wells here.

Scientists, lawyers and Michigan courts have said the tool and other state estimates of stream flows are deeply flawed. If true, such a problem could result in the state inadvertently approving large water withdrawals that hurt rivers and streams.

Researchers at Michigan State University recently found several sites where the state's water tool over-estimated the volume of water in small headwater streams that feed the Manistee River.

"In some watersheds, we are seeing that the assumed flows (calculated by the state's water tool) are much higher than we measured. In one case the tool was off by a factor of three," said David Hyndman, a hydrogeologist, professor and chairman of MSU's Department of Geological Sciences.

Those findings were significant for three reasons, Hyndman said: Many of the Collingwood shale gas wells are being drilled in the ecologically fragile headwater areas of rivers; headwater streams are critically important to the health of entire river systems; and the state does little monitoring in headwater streams, where rivers originate.

Government and industry officials defended the state's water assessment tool.

State officials who developed the tool "did error analysis to make sure it was working and everywhere they tested, it worked," said Jill VanDyke, a senior geologist with the Michigan Department of Environmental Quality.

The Water Withdrawal Assessment Tool estimates flows in Michigan's 7,000 streams and river segments using data from river gauges and other information, including geology, soil characteristics, drainage area and precipitation. But only 2 percent of all river and stream segments in Michigan, 147 sites, have gauges that measure actual stream flows. That lack of in-stream data forced the DEQ to base much of the water assessment tool on general environmental conditions and mathematical models.

Dave Hamilton, a former DEQ official who helped develop the water assessment tool, said it takes a "very conservative" approach to ensure that large water withdrawals don't cause adverse impacts.

"Ninety percent of the time there is more water in a stream than what the tool is saying," said Hamilton, who is now a senior policy adviser for The Nature Conservancy's Michigan chapter.

Well uses 3 million gallons from village supplies

State law requires using the tool to screen water withdrawals that exceed 100,000 gallons daily. If the tool raises a red flag, state officials conduct a site visit. Those site visits usually lead to permit approvals, according to DEQ officials.

Since 2008, the DEQ has issued 52 permits for large, fracking-related water withdrawals. Another 17 permits are pending, according to state data.

Fracking critics said recent problems at the Westerman gas well in Kalkaska County — where water wells didn't produce as predicted and drillers had to truck in 3 million of gallons of water from Kalkaska and Mancelona to complete the fracking process — highlighted flaws in the water assessment tool.

Tanker trucks were used to ship millions of gallons of water from the nearby villages of Kalkaska and Mancelona to a gas and oil well. (courtesy photo)

Encana's Hock and DEQ officials blamed the problem on "geologic conditions" unrelated to the water assessment tool.

"Everyone wanted to jump to the conclusion that the (water assessment) tool didn't work and there wasn't adequate water," Hock said. "The tool worked well ... it was a matter of really tougher rock than we anticipated."

Industry watchdog Brady said the DEQ is trying to gloss over problems with the water assessment tool.

"Obviously the tool declared that the area had ample water and as we unfortunately found out the tool was inaccurate," said Brady, who has written extensively about fracking on the respectmyplanet.org website.

Concerns about Michigan's ability to accurately predict stream flows aren't new.

In 2005, the DEQ planned to issue a permit allowing an oil company to discharge 1.15 million gallons of slightly contaminated groundwater daily into Kolke Creek, the headwaters of the Au Sable River. The DEQ claimed that the index (or average) flow in Kolke Creek was about 6,000 gallons per minute, enough to dilute the oil company's contaminated water without harming the creek.

As part of a lawsuit challenging the DEQ permit, independent scientists proved that the state's estimate of Kolke Creek's index flow was up to 100 times greater than the actual flow.

A state circuit court concluded that the state's estimate of the flow in Kolke Creek was inaccurate and blocked the proposed discharge of polluted water into creek. The DEQ appealed but the state Court of Appeals upheld the lower court's ruling.

The prospects for natural gas drilling – and the subsequent need for water supplies for fracking – have waxed and waned in Michigan in recent years.

First came a boom of investment in drilling rights on state property as petroleum firms looked **to extend natural gas exploration from Pennsylvania and Ohio into Michigan**.

By late 2012, though, the pace of exploration in Michigan was still far below drilling rates seen in other Great Lakes states and low natural gas prices were seen **as a potential brake on activity**.

That may soon change.

Encana officials said the oil and gas industry wants to export natural gas extracted from shale formations in Michigan and other states to consumers in Asia. Demand for natural gas in China is strong and prices are double the cost of natural gas in the U.S., industry, watchdogs said.

China's government-controlled energy company, Sinopec, has already invested $2.5 billion in a joint venture with Oklahoma-based Devon Energy. Devon has permits to drill several Collingwood shale wells in Northern Michigan, according to state records.

And late last week, Michigan Congressman Fred Upton, R-St. Joseph and chairman of the House's energy panel, touted fracking as an aid in making the **U.S. "energy independent" in natural gas**:

"We're the largest natural gas producer in the world because of the advances that

"We're the largest natural gas producer now in the world because of the advances that we've done on hydraulic fracking. ... We are so rich in that resource."

Jeff Alexander is owner of J. Alexander Communications LLC and the author of "Pandora's Locks: The Opening of the Great Lakes – St. Lawrence Seaway." A former staff writer for the Muskegon Chronicle, Alexander writes **a blog on the Great Lakes**.

29 comments from Bridge readers.

Bruce McFee
June 25, 2013 at 9:37 am

4 billion gallons is equivalent to about 6 hours of water flowing over Niagara Falls.
While that might seem like a lot of water, it would probably occur over several years. It is not the same impact as in Los Angeles where they have diverted the entire Colorado River for their water use.
The dilemma in all this is that we could continue to import energy from countries that have much less interest in protecting the environment. But this means we need a strong military presence to keep that energy supply safe. Or we just bite the bullet and become energy independent.
One piece of good news is that a break through is right around the corner making desalination of sea water more practical.

Jim Olson
June 25, 2013 at 10:42 am

Ten million gallons over 21 days will most likely harm creeks and wetlands in headwaters areas of our lakes and streams or interfere with adjacent farmer who is irrigating crops or nearby landowners who rely on water wells. What the state and industry have to do is do what every other heavy water user does — conduct a pump yield test and monitor groundwater, wetlands, streams, creeks nearby during the test. Industry will know up front whether there is enough water and DEQ and DNR and citizens will know if there is enough water, that there will be no harm or interference.

Karen Dill-Wilson
June 25, 2013 at 12:53 pm

this example is ridiculous. fracking PERMANENTLY removes that water from the consumable water table and makes it toxic. in MI the flow back water that comes up must be disposed of in class II deep injection wells and the rest stays down hole. it's an industry spin tactic: they want to say they use less water than hydro-electric or agriculture but what they DON'T tell you is that it's PERMANENTLY lost and poisoned, unlike other uses. farmers out west are now competing with gas and oil for water usage...who would you rather have water? someone who grows your food or somebody that will poison your water and leave your well dry?

Russ Klettke
September 9, 2013 at 1:23 pm

Tell us about the desalinization. What is just around the corner and what will it cost — and be sure to include the costs of transport of ocean water to inland fracking wells.
Count me skeptical. Particularly when we already have alternative renewable sources of energy that are technologically developed and increasingly used. Given how solar was first used in the 1950s, we probably could have made use of that a long time ago — but the idea of self-generated energy on the rooftops of homes and businesses cede WAY too much control away from large fossil fuel companies.

Mark Knowles

June 25, 2013 at 9:57 am

June 25, 2013 at 9:57 am

Come on local…and state officials…protect the environment…Don't sell it some Oklahoma based.company and the Chinese. Stop selling your sole and protect your people…the streams and lakes of Michigan are far more important than selling natural gas.

Jim Olson
June 25, 2013 at 10:37 am

Jeff and Center for Michigan. Thanks for publishing and distributing this widely. Citizen organizations, and policy organizations like FLOW **http://www.flowforwater.org** have been calling on MDNR and Natural Resources Commission to investigate and require baseline estimates of water withdrawals, diversions, transfers, and losses from the water cycle for over a year. DNR rejected any talks when approached last year to reform its leasing procedures and lease so that right to use necessary water would not transfer until development plan is submitted to MDNR for approval for areas of the state and state land, with estimates and consideration of water loss and community, farmers, landowners, and environmental impacts. It is the only legal and sensible way to address this issue, and must be done immediately before it is too late. MDEQ must not issue permits until all of this has been done, and effects and alternatives fully considered. The state lands and waters under them and running through them, are held by Michigan through DEQ and DNR as trustees for benefit of citizens, not the oil and gas industry. If fracking is allowed at such a large scale, and the jury is still out on this, it should and can only be done after careful pump tests, hydrogeological monitoring of actual flows and levels of streams, wetlands, lakes, groundwater. There is no other way to know what will happen. And if it is not done, it is plainly reckless.

Caroline B Smith
June 25, 2013 at 12:17 pm

What's another 3 or 4 million gallons? Nestle's is also taking a LOT of ground water out of Michigan and selling it back to us from WalMart and many other outlets. Just remember, "THE ONE WITH THE MOST FRESH WATER WINS."

Jeff Alexander
June 25, 2013 at 2:59 pm

Here's a little perspective: According to state data, Nestle's Ice Mountain water bottling plant near Big Rapids pumped 226 million gallons of groundwater last year. At that rate, it would take Nestle roughly 17 years to withdraw the 4 billion gallons of groundwater that Encana Corp. could withdraw and use at 500 natural gas wells that are hydraulically fractured.
State officials also point out that agricultural operations in Berrien County withdraw 10 million gallons of groundwater daily (averaged over the course of a year). At that rate, all of those farms could pump that amount of water (350 million gallons annually) for 11 years before equaling the amount of groundwater that Encana may use at its hydraulically fractured natural gas wells.
There is one other important point to consider, regardless of whether you think the 4 billion gallons of water that Encana might use is a drop in the bucket or a small lake: The vast majority of water used in fracking is left underground or discarded in deep injection wells because it is contaminated with chemicals. So while Traverse City uses 4 billion gallons of water annually, most of that water remains in the water cycle. It goes back into the ground, surface waters or the air after people use it.
Unless recycled, the water that fracking operations pump out of the ground and use to fracture deep shale is taken out of the local, regional or global water cycle. it's gone forever. Just saying.

Tom Matych
June 30, 2013 at 6:03 am

Good job Jeff. The part where there's enough water in the creek to dilute. Isn't this the same reasoning they used way back when for dumping waste from factories in our lakes and rivers? I don't see anything good from

fracking. My well is 166 feet deep. I have good water, they want to drill around here. I refused to sign the

fracking. My well is 100 feet deep, I have good water, they want to drill around here, I refused to sign the contract, my neighbor did sign. I'm 2 miles from the Muskegon river.

LuAnne Kozma
June 25, 2013 at 12:39 pm

The Committee to Ban Fracking in Michigan is conducting a ballot initiative petition drive to ban horizontal hydraulic fracturing to end this practice in Michigan, and to prevent frack wastes from being dumped here. Donate to the campaign and volunteer to collect signatures at: **http://www.letsbanfracking.org**.
We must protect our state from this threat. The water used in fracking is transformed into industrial waste, which is then "disposed of" in injection wells–back into our ground and eventually contaminating our aquifers.
–LuAnne Kozma, campaign director, Committee to Ban Fracking in Michigan

Neil
June 25, 2013 at 1:02 pm

Is it conceivable and feasible to have a water purification plant to process fracking water back to potable drinking water?

Bill
June 25, 2013 at 1:18 pm

Yes. Frack water could be brought back to an acceptable quality but there must be a disposal method for remaining concentrated effluent. Although the fact does not serve naysayer's purposes, water is an almost endlessly renewable resource if we make reasonable efforts.

Jeff Alexander
June 25, 2013 at 3:02 pm

Not likely. However, the water could be recycled and re–used, thereby reducing use. Encana officials said that fracking operations in the water–starved west and southwest recycle the water used to fracture deep shale deposits.

spudnik
June 25, 2013 at 3:19 pm

No. The process is built around exploiting a ton of water and walking away. This water is nothing you'd want to drink after processing. And once these wells start leaking massive amounts of pollutants into our groundwater, guessing these corporations will go out of business. We as a culture will need to wake up before it's too late, but the greed seems to have the upper hand now.

Nancy Shiffler
June 25, 2013 at 3:21 pm

When you run into problems you didn't "anticipate," it's a pretty good sign that it's time to step back and take a longer, more careful look at what you are doing before you start issuing more permits and drilling more wells. The DEQ isn't doing it's job.

Charles Richards
June 25, 2013 at 3:27 pm

"Encana officials said the oil and gas industry wants to export natural gas extracted from shale formations in Michigan and other states to consumers in Asia. Demand for natural gas in China is strong and prices are double the cost of natural gas in the U.S., industry, watchdogs said" This smacks of autarky, a policy that has been proven throughout history to be inimical to human welfare. If the rest of the article is of similar quality, and I suspect it is, then I don't place much value

on it.

Mark L
June 25, 2013 at 5:56 pm

Interesting. A little geometry and one can visualize that the water it took to produce this well is about 1 acre (209 feet square) by 25 feet deep. At around 2.5 feet of precipitation per year in Michigan (NOAA), that would be the entire annual precipitation on 10 acres of land for a year to produce that well. 500 wells then would be 5000 acres or 7.8 square miles worth of annual precipitation out of a watershed to produce? It's not going to dry out the Great lakes, but its a lot of dirty water. The stuff is already toxic after well # 1, and the wells are usually clustered. Why can't it be filtered, reprocessed and re–used in the next hole? "because it's cheaper to inject it" doesn't seem like a very good answer…

Kerry Thompson
June 25, 2013 at 8:08 pm

For a publication that attempts to remain neutral you seem to be in "fear mongering overdrive". We are fracking in several places in Michigan without damage to the environment, We are helping the damaged economy and providing a product for a cost effective price. Benefactors are those land owners that receive dividends every month from the oil companies. Public agencies and charitable organizations are all receiving big dividends from fracking in Michigan. My good friend has a well drilled next to him and the horizontal fracking under him for over a year has not upset his ground water the level of his ponds his fish or his faucet (no gas fumes). The Boy Scout camp down the road has received more revenues from this well than from all of the donors public and private in the last two years combined.
Where are the articles that show the positive benefits of fracking in the state?

David Waymire
June 26, 2013 at 11:46 am

Kerry, the point here isn't that fracking is always bad…it's that it isn't always good, and can have major implications.That is indeed the very definition of neutral reporting, and is far, far from fear mongering.
The massive use of water detailed in this story is a huge change from the "old fracking" that used to consume maybe 100,000 gallons per well. Now we are talking hundreds of millions of gallons from one site, with potential implications for aquifers and small streams and rivers critical to the headwaters of our trout–friendly state. If that kind of withdrawal can be managed, that's one thing. If it is drying up wells, then it needs to be regulated much more strongly. And if it is affecting our blue ribbon trout streams, that needs to stop.

Jim Peters
June 26, 2013 at 2:44 pm

I think it is important to put a few things into perspective. First, it will take EnCana in my estimation 5 – 10 years or longer to drill the 500 wells and mcuh longer to get them completed and producing. More than likely a disposal well will be drilled on each pad or 1 disposal well located to handle several well pads and connected by pipelines eliminating the need to truck the water. Second, this moves EnCana from the explority phase into developement phase where economics of scale become very important. Third, these wells will likely be drilled over a fairly large geographical area (several different counties) on well pads that may contain 6 – 12 wells per pad. If water withdrawal becomes an issue then water recycling I'm sure will be used. EnCana is saying that they are seeing around 25% of the fracturing fluid returned to the surface so even if they recycle 100% of the returned fluid they will still need new water to continue. In Pennsylvania they are currently recycling 90% of the returned fluid. Pennsylvania has drilled now over 6,000 shale wells. Keep in mind that Pennsylvania has a very limited water supply and it's geology does not support deep disposal wells.

Jim Peters

June 26, 2013 at 3:40 pm

Nobody seems to want to discuss the economic impact of drilling 500 shale wells in the somewhat poor, rural areas of northern Michigan. Roughly, 500 wells at around $10 million per well works out to $5 billion dollars invested. Current unemployment rates in these counties range between 10 and 12%. Those rates would drop considerably not just for those counties but for all surrounding counties as well. It won't turn us into North Dakota where some McDonalds pay up to a $1,500.00 sign on bonus if you will stay for at least 2 weeks but the impact will be felt state wide. Local business will florish, families will move in including children for schools, local tax revenues will surge. The economic impact will last for at least a generation. But the water? We are blessed with a significant amount of fresh, clean water. More regulation needed? Possibly, but I believe it can be done in an environmentally safe matter as it is being done every day in Pennsylvania, North Dakota, Texas, Ohio, Colorado, Oklahoma, Arkansas, Louisiana, West Virginia and soon to be California and Illinois.

Brian W
June 30, 2013 at 11:21 pm

I agree with you Jim, There is a very negative spin here. None of the good that comes from this is being pointed out. I know I make a good living.... Most of the people working on these locations are local, EnCana is very conscious about the enviroment and the impact of its operations. Each person has "stop work authority" and are empowered to use it in the event of a safety or environmental concern. EnCana takes this VERY serious. There are wellbore integrity checks at regular intervals to ensure there will not be migration of fluids into the aquifer.
I also feel the protests are necessary... without them the industry would not be evolving to use safer fluids (Halliburton is a pioneer in fluids derived from the food industry). But big oil needs to know they are being watched.

Brian W
June 30, 2013 at 11:25 pm

This weekend was cherry festival too. I feel the tourism has a very profound effect on the environment. I know the garbage on 131 is up this weekend, is an airshow necessary or a waste of fuel? All the idiots on Torch lake, they dont care about the condition they leave the lakes in....

Tracy Davis
July 10, 2013 at 7:50 pm

Jim,
Nobody seems to want to discuss that while they think Fracking is such a horrible thing for our environment, they still keep driving their SUV's, ATV's, Snowmobiles, Boats etc.

acapoz
June 27, 2013 at 8:44 pm

once the drinking water is depleted, then what?
Fracking isn't about energy independence for Americans, its about profits for oil & gas. They will control the supply & demand to maximize profits. The cost Americans will have to pay in the end is the dependence on bottled water. Fracking will take the bottled water industry to the level of oil & gas profits. Once municipal water supply is depleted from fracking then Americans have no other source than bottled water. And you will pay more for water than for energy.

Kris Olsson
July 1, 2013 at 10:01 am

What is the timeline for a fracked well? Do they use the 8 million gallons or so all at once, or is it over the course of several fracking events? So, for a given well, over what period of time is the water consumed. Also, another question – in

the state online records for oil and gas, is there a way to distinguish the newer hydro fracking type of drilling from the "regular" oil and gas well permitting/plays?

trevor mcnamara
November 5, 2013 at 1:21 pm

frack fracking!

gary Markley
November 14, 2013 at 9:15 am

its a no-brainer. Stop all fracking in the state of Michigan-I can't understand how Michiugan lets money-seeking idiots get away with this. It needs to be illegal.

barbara
November 27, 2013 at 9:48 am

Hamilton Township in Clare Co. needs help. Besides being fracked recently, DCP Midstream wants to put a gas processing facility tucked right in among homes, farms, and a tourist area of lakes. Our township board says we will be sued if we try to stop this. How can you sue a whole community of people?!!! This facility would be the ruination of our area. Noise, increased traffic (trucks), odors, ground water contamination (everyone here is dependent on well water), an unsightly thing for a tourist area, nearby trout streams, etc. and , of course, air pollution are just a few of our concerns. If this facility has to be it should be away from families and farms. We invite anyone who has the time and the concern to write to our local newspapers. The Clare County Cleaver and The Clare Review accept editorials readily on line. We are a poor community and can not fight this alone. Thank you in advance and God bless.....

The White House

Office of the Press Secretary

For Immediate Release January 24, 2012

Remarks by the President in State of the Union Address

United States Capitol
Washington, D.C.

9:10 P.M. EST

THE PRESIDENT: Mr. Speaker, Mr. Vice President, members of Congress, distinguished guests, and fellow Americans:

Last month, I went to Andrews Air Force Base and welcomed home some of our last troops to serve in Iraq. Together, we offered a final, proud salute to the colors under which more than a million of our fellow citizens fought -- and several thousand gave their lives.

We gather tonight knowing that this generation of heroes has made the United States safer and more respected around the world. (Applause.) For the first time in nine years, there are no Americans fighting in Iraq. (Applause.) For the first time in two decades, Osama bin Laden is not a threat to this country. (Applause.) Most of al Qaeda's top lieutenants have been defeated. The Taliban's momentum has been broken, and some troops in Afghanistan have begun to come home.

These achievements are a testament to the courage, selflessness and teamwork of America's Armed Forces. At a time when too many of our institutions have let us down, they exceed all expectations. They're not consumed with personal ambition. They don't obsess over their differences. They focus on the mission at hand. They work together.

Imagine what we could accomplish if we followed their example. (Applause.) Think about the America within our reach: A country that leads the world in educating its people. An America that attracts a new generation of high-tech manufacturing and high-paying jobs. A future where we're in control of our own energy, and our security and prosperity aren't so tied to unstable parts of the world. An economy built to last, where hard work pays off, and responsibility is rewarded.

We can do this. I know we can, because we've done it before. At the end of World War II, when another generation of heroes returned home from combat, they built the strongest economy and middle class the world has ever known. (Applause.) My grandfather, a veteran of Patton's Army, got the chance to go to college on the GI Bill. My grandmother, who worked on a bomber assembly line, was part of a workforce that turned out the best products on Earth.

The two of them shared the optimism of a nation that had triumphed over a depression and fascism. They understood they were part of something larger; that they were contributing to a story of success that every American had a chance to share -- the basic American promise that if you worked hard, you could do well enough to raise a family, own a home, send your kids to college, and put a little away for retirement.

The defining issue of our time is how to keep that promise alive. No challenge is more urgent. No debate is more important. We can either settle for a country where a shrinking number of people do really well while a growing number of Americans barely get by, or we can restore an economy where everyone gets a fair shot, and everyone does their fair share, and everyone plays by the same set of rules. (Applause.) What's at stake aren't Democratic values or Republican values, but American values. And we have to reclaim them.

Let's remember how we got here. Long before the recession, jobs and manufacturing began leaving our shores. Technology made businesses more efficient, but also made some jobs obsolete. Folks at the top saw their incomes rise like never before, but most hardworking Americans struggled with costs that were growing, paychecks that weren't, and personal debt that kept piling up.

In 2008, the house of cards collapsed. We learned that mortgages had been sold to people who couldn't afford

or understand them. Banks had made huge bets and bonuses with other people's money. Regulators had looked the other way, or didn't have the authority to stop the bad behavior.

It was wrong. It was irresponsible. And it plunged our economy into a crisis that put millions out of work, saddled us with more debt, and left innocent, hardworking Americans holding the bag. In the six months before I took office, we lost nearly 4 million jobs. And we lost another 4 million before our policies were in full effect.

Those are the facts. But so are these: In the last 22 months, businesses have created more than 3 million jobs. (Applause.)

Last year, they created the most jobs since 2005. American manufacturers are hiring again, creating jobs for the first time since the late 1990s. Together, we've agreed to cut the deficit by more than $2 trillion. And we've put in place new rules to hold Wall Street accountable, so a crisis like this never happens again. (Applause.)

The state of our Union is getting stronger. And we've come too far to turn back now. As long as I'm President, I will work with anyone in this chamber to build on this momentum. But I intend to fight obstruction with action, and I will oppose any effort to return to the very same policies that brought on this economic crisis in the first place. (Applause.)

No, we will not go back to an economy weakened by outsourcing, bad debt, and phony financial profits. Tonight, I want to speak about how we move forward, and lay out a blueprint for an economy that's built to last -– an economy built on American manufacturing, American energy, skills for American workers, and a renewal of American values.

Now, this blueprint begins with American manufacturing.

On the day I took office, our auto industry was on the verge of collapse. Some even said we should let it die. With a million jobs at stake, I refused to let that happen. In exchange for help, we demanded responsibility. We got workers and automakers to settle their differences. We got the industry to retool and restructure. Today, General Motors is back on top as the world's number-one automaker. (Applause.) Chrysler has grown faster in the U.S. than any major car company. Ford is investing billions in U.S. plants and factories. And together, the entire industry added nearly 160,000 jobs.

We bet on American workers. We bet on American ingenuity. And tonight, the American auto industry is back. (Applause.)

What's happening in Detroit can happen in other industries. It can happen in Cleveland and Pittsburgh and Raleigh. We can't bring every job back that's left our shore. But right now, it's getting more expensive to do business in places like China. Meanwhile, America is more productive. A few weeks ago, the CEO of Master Lock told me that it now makes business sense for him to bring jobs back home. (Applause.) Today, for the first time in 15 years, Master Lock's unionized plant in Milwaukee is running at full capacity. (Applause.)

So we have a huge opportunity, at this moment, to bring manufacturing back. But we have to seize it. Tonight, my message to business leaders is simple: Ask yourselves what you can do to bring jobs back to your country, and your country will do everything we can to help you succeed. (Applause.)

We should start with our tax code. Right now, companies get tax breaks for moving jobs and profits overseas. Meanwhile, companies that choose to stay in America get hit with one of the highest tax rates in the world. It makes no sense, and everyone knows it. So let's change it.

First, if you're a business that wants to outsource jobs, you shouldn't get a tax deduction for doing it. (Applause.) That money should be used to cover moving expenses for companies like Master Lock that decide to bring jobs home. (Applause.)

Second, no American company should be able to avoid paying its fair share of taxes by moving jobs and profits overseas. (Applause.) From now on, every multinational company should have to pay a basic minimum tax. And every penny should go towards lowering taxes for companies that choose to stay here and hire here in America. (Applause.)

Third, if you're an American manufacturer, you should get a bigger tax cut. If you're a high-tech manufacturer, we should double the tax deduction you get for making your products here. And if you want to relocate in a community that was hit hard when a factory left town, you should get help financing a new plant, equipment, or training for new workers. (Applause.)

So my message is simple. It is time to stop rewarding businesses that ship jobs overseas, and start rewarding companies that create jobs right here in America. Send me these tax reforms, and I will sign them right away. (Applause.)

We're also making it easier for American businesses to sell products all over the world. Two years ago, I set a goal of doubling U.S. exports over five years. With the bipartisan trade agreements we signed into law, we're on

and continue to build on the progress we've made over the last four years, we need to invest in three areas: jobs, skills and opportunity.

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track to meet that goal ahead of schedule. (Applause.) And soon, there will be millions of new customers for American goods in Panama, Colombia, and South Korea. Soon, there will be new cars on the streets of Seoul imported from Detroit, and Toledo, and Chicago. (Applause.)

I will go anywhere in the world to open new markets for American products. And I will not stand by when our competitors don't play by the rules. We've brought trade cases against China at nearly twice the rate as the last administration –- and it's made a difference. (Applause.) Over a thousand Americans are working today because we stopped a surge in Chinese tires. But we need to do more. It's not right when another country lets our movies, music, and software be pirated. It's not fair when foreign manufacturers have a leg up on ours only because they're heavily subsidized.

Tonight, I'm announcing the creation of a Trade Enforcement Unit that will be charged with investigating unfair trading practices in countries like China. (Applause.) There will be more inspections to prevent counterfeit or unsafe goods from crossing our borders. And this Congress should make sure that no foreign company has an advantage over American manufacturing when it comes to accessing financing or new markets like Russia. Our workers are the most productive on Earth, and if the playing field is level, I promise you –- America will always win. (Applause.)

I also hear from many business leaders who want to hire in the United States but can't find workers with the right skills. Growing industries in science and technology have twice as many openings as we have workers who can do the job. Think about that –- openings at a time when millions of Americans are looking for work. It's inexcusable. And we know how to fix it.

Jackie Bray is a single mom from North Carolina who was laid off from her job as a mechanic. Then Siemens opened a gas turbine factory in Charlotte, and formed a partnership with Central Piedmont Community College. The company helped the college design courses in laser and robotics training. It paid Jackie's tuition, then hired her to help operate their plant.

I want every American looking for work to have the same opportunity as Jackie did. Join me in a national commitment to train 2 million Americans with skills that will lead directly to a job. (Applause.) My administration has already lined up more companies that want to help. Model partnerships between businesses like Siemens and community colleges in places like Charlotte, and Orlando, and Louisville are up and running. Now you need to give more community colleges the resources they need to become community career centers –- places that teach people skills that businesses are looking for right now, from data management to high-tech manufacturing.

And I want to cut through the maze of confusing training programs, so that from now on, people like Jackie have one program, one website, and one place to go for all the information and help that they need. It is time to turn our unemployment system into a reemployment system that puts people to work. (Applause.)

These reforms will help people get jobs that are open today. But to prepare for the jobs of tomorrow, our commitment to skills and education has to start earlier.

For less than 1 percent of what our nation spends on education each year, we've convinced nearly every state in the country to raise their standards for teaching and learning -- the first time that's happened in a generation.

But challenges remain. And we know how to solve them.

At a time when other countries are doubling down on education, tight budgets have forced states to lay off thousands of teachers. We know a good teacher can increase the lifetime income of a classroom by over $250,000. A great teacher can offer an escape from poverty to the child who dreams beyond his circumstance. Every person in this chamber can point to a teacher who changed the trajectory of their lives. Most teachers work tirelessly, with modest pay, sometimes digging into their own pocket for school supplies -- just to make a difference.

Teachers matter. So instead of bashing them, or defending the status quo, let's offer schools a deal. Give them the resources to keep good teachers on the job, and reward the best ones. (Applause.) And in return, grant schools flexibility: to teach with creativity and passion; to stop teaching to the test; and to replace teachers who just aren't helping kids learn. That's a bargain worth making. (Applause.)

We also know that when students don't walk away from their education, more of them walk the stage to get their diploma. When students are not allowed to drop out, they do better. So tonight, I am proposing that every state -- every state -- requires that all students stay in high school until they graduate or turn 18. (Applause.)

When kids do graduate, the most daunting challenge can be the cost of college. At a time when Americans owe more in tuition debt than credit card debt, this Congress needs to stop the interest rates on student loans from doubling in July. (Applause.)

Extend the tuition tax credit we started that saves millions of middle-class families thousands of dollars, and give more young people the chance to earn their way through college by doubling the number of work-study jobs in

the next five years. (Applause.)

Of course, it's not enough for us to increase student aid. We can't just keep subsidizing skyrocketing tuition; we'll run out of money. States also need to do their part, by making higher education a higher priority in their budgets. And colleges and universities have to do their part by working to keep costs down.

Recently, I spoke with a group of college presidents who've done just that. Some schools redesign courses to help students finish more quickly. Some use better technology. The point is, it's possible. So let me put colleges and universities on notice: If you can't stop tuition from going up, the funding you get from taxpayers will go down. (Applause.) Higher education can't be a luxury — it is an economic imperative that every family in America should be able to afford.

Let's also remember that hundreds of thousands of talented, hardworking students in this country face another challenge: the fact that they aren't yet American citizens. Many were brought here as small children, are American through and through, yet they live every day with the threat of deportation. Others came more recently, to study business and science and engineering, but as soon as they get their degree, we send them home to invent new products and create new jobs somewhere else.

That doesn't make sense.

I believe as strongly as ever that we should take on illegal immigration. That's why my administration has put more boots on the border than ever before. That's why there are fewer illegal crossings than when I took office. The opponents of action are out of excuses. We should be working on comprehensive immigration reform right now. (Applause.)

But if election-year politics keeps Congress from acting on a comprehensive plan, let's at least agree to stop expelling responsible young people who want to staff our labs, start new businesses, defend this country. Send me a law that gives them the chance to earn their citizenship. I will sign it right away. (Applause.)

You see, an economy built to last is one where we encourage the talent and ingenuity of every person in this country. That means women should earn equal pay for equal work. (Applause.) It means we should support everyone who's willing to work, and every risk-taker and entrepreneur who aspires to become the next Steve Jobs.

After all, innovation is what America has always been about. Most new jobs are created in start-ups and small businesses. So let's pass an agenda that helps them succeed. Tear down regulations that prevent aspiring entrepreneurs from getting the financing to grow. (Applause.) Expand tax relief to small businesses that are raising wages and creating good jobs. Both parties agree on these ideas. So put them in a bill, and get it on my desk this year. (Applause.)

Innovation also demands basic research. Today, the discoveries taking place in our federally financed labs and universities could lead to new treatments that kill cancer cells but leave healthy ones untouched. New lightweight vests for cops and soldiers that can stop any bullet. Don't gut these investments in our budget. Don't let other countries win the race for the future. Support the same kind of research and innovation that led to the computer chip and the Internet; to new American jobs and new American industries.

And nowhere is the promise of innovation greater than in American-made energy. Over the last three years, we've opened millions of new acres for oil and gas exploration, and tonight, I'm directing my administration to open more than 75 percent of our potential offshore oil and gas resources. (Applause.) Right now -- right now -- American oil production is the highest that it's been in eight years. That's right -- eight years. Not only that -- last year, we relied less on foreign oil than in any of the past 16 years. (Applause.)

But with only 2 percent of the world's oil reserves, oil isn't enough. This country needs an all-out, all-of-the-above strategy that develops every available source of American energy. (Applause.) A strategy that's cleaner, cheaper, and full of new jobs.

We have a supply of natural gas that can last America nearly 100 years. (Applause.) And my administration will take every possible action to safely develop this energy. Experts believe this will support more than 600,000 jobs by the end of the decade. And I'm requiring all companies that drill for gas on public lands to disclose the chemicals they use. (Applause.) Because America will develop this resource without putting the health and safety of our citizens at risk.

The development of natural gas will create jobs and power trucks and factories that are cleaner and cheaper, proving that we don't have to choose between our environment and our economy. (Applause.) And by the way, it was public research dollars, over the course of 30 years, that helped develop the technologies to extract all this natural gas out of shale rock –- reminding us that government support is critical in helping businesses get new energy ideas off the ground. (Applause.)

Now, what's true for natural gas is just as true for clean energy. In three years, our partnership with the private sector has already positioned America to be the world's leading manufacturer of high-tech batteries. Because of

federal investments, renewable energy use has nearly doubled, and thousands of Americans have jobs because of it.

When Bryan Ritterby was laid off from his job making furniture, he said he worried that at 55, no one would give him a second chance. But he found work at Energetx, a wind turbine manufacturer in Michigan. Before the recession, the factory only made luxury yachts. Today, it's hiring workers like Bryan, who said, "I'm proud to be working in the industry of the future."

Our experience with shale gas, our experience with natural gas, shows us that the payoffs on these public investments don't always come right away. Some technologies don't pan out; some companies fail. But I will not walk away from the promise of clean energy. I will not walk away from workers like Bryan. (Applause.) I will not cede the wind or solar or battery industry to China or Germany because we refuse to make the same commitment here.

We've subsidized oil companies for a century. That's long enough. (Applause.) It's time to end the taxpayer giveaways to an industry that rarely has been more profitable, and double-down on a clean energy industry that never has been more promising. Pass clean energy tax credits. Create these jobs. (Applause.)

We can also spur energy innovation with new incentives. The differences in this chamber may be too deep right now to pass a comprehensive plan to fight climate change. But there's no reason why Congress shouldn't at least set a clean energy standard that creates a market for innovation. So far, you haven't acted. Well, tonight, I will. I'm directing my administration to allow the development of clean energy on enough public land to power 3 million homes. And I'm proud to announce that the Department of Defense, working with us, the world's largest consumer of energy, will make one of the largest commitments to clean energy in history -- with the Navy purchasing enough capacity to power a quarter of a million homes a year. (Applause.)

Of course, the easiest way to save money is to waste less energy. So here's a proposal: Help manufacturers eliminate energy waste in their factories and give businesses incentives to upgrade their buildings. Their energy bills will be $100 billion lower over the next decade, and America will have less pollution, more manufacturing, more jobs for construction workers who need them. Send me a bill that creates these jobs. (Applause.)

Building this new energy future should be just one part of a broader agenda to repair America's infrastructure. So much of America needs to be rebuilt. We've got crumbling roads and bridges; a power grid that wastes too much energy; an incomplete high-speed broadband network that prevents a small business owner in rural America from selling her products all over the world.

During the Great Depression, America built the Hoover Dam and the Golden Gate Bridge. After World War II, we connected our states with a system of highways. Democratic and Republican administrations invested in great projects that benefited everybody, from the workers who built them to the businesses that still use them today.

In the next few weeks, I will sign an executive order clearing away the red tape that slows down too many construction projects. But you need to fund these projects. Take the money we're no longer spending at war, use half of it to pay down our debt, and use the rest to do some nation-building right here at home. (Applause.)

There's never been a better time to build, especially since the construction industry was one of the hardest hit when the housing bubble burst. Of course, construction workers weren't the only ones who were hurt. So were millions of innocent Americans who've seen their home values decline. And while government can't fix the problem on its own, responsible homeowners shouldn't have to sit and wait for the housing market to hit bottom to get some relief.

And that's why I'm sending this Congress a plan that gives every responsible homeowner the chance to save about $3,000 a year on their mortgage, by refinancing at historically low rates. (Applause.) No more red tape. No more runaround from the banks. A small fee on the largest financial institutions will ensure that it won't add to the deficit and will give those banks that were rescued by taxpayers a chance to repay a deficit of trust. (Applause.)

Let's never forget: Millions of Americans who work hard and play by the rules every day deserve a government and a financial system that do the same. It's time to apply the same rules from top to bottom. No bailouts, no handouts, and no copouts. An America built to last insists on responsibility from everybody.

We've all paid the price for lenders who sold mortgages to people who couldn't afford them, and buyers who knew they couldn't afford them. That's why we need smart regulations to prevent irresponsible behavior. (Applause.) Rules to prevent financial fraud or toxic dumping or faulty medical devices -- these don't destroy the free market. They make the free market work better.

There's no question that some regulations are outdated, unnecessary, or too costly. In fact, I've approved fewer regulations in the first three years of my presidency than my Republican predecessor did in his. (Applause.) I've ordered every federal agency to eliminate rules that don't make sense. We've already announced over 500 reforms, and just a fraction of them will save business and citizens more than $10 billion over the next five years. We got rid of one rule from 40 years ago that could have forced some dairy farmers to spend $10,000 a year

proving that they could contain a spill -- because milk was somehow classified as an oil. With a rule like that, I guess it was worth crying over spilled milk. (Laughter and applause.)

Now, I'm confident a farmer can contain a milk spill without a federal agency looking over his shoulder. (Applause.) Absolutely. But I will not back down from making sure an oil company can contain the kind of oil spill we saw in the Gulf two years ago. (Applause.) I will not back down from protecting our kids from mercury poisoning, or making sure that our food is safe and our water is clean. I will not go back to the days when health insurance companies had unchecked power to cancel your policy, deny your coverage, or charge women differently than men. (Applause.)

And I will not go back to the days when Wall Street was allowed to play by its own set of rules. The new rules we passed restore what should be any financial system's core purpose: Getting funding to entrepreneurs with the best ideas, and getting loans to responsible families who want to buy a home, or start a business, or send their kids to college.

So if you are a big bank or financial institution, you're no longer allowed to make risky bets with your customers' deposits. You're required to write out a "living will" that details exactly how you'll pay the bills if you fail –- because the rest of us are not bailing you out ever again. (Applause.) And if you're a mortgage lender or a payday lender or a credit card company, the days of signing people up for products they can't afford with confusing forms and deceptive practices -- those days are over. Today, American consumers finally have a watchdog in Richard Cordray with one job: To look out for them. (Applause.)

We'll also establish a Financial Crimes Unit of highly trained investigators to crack down on large-scale fraud and protect people's investments. Some financial firms violate major anti-fraud laws because there's no real penalty for being a repeat offender. That's bad for consumers, and it's bad for the vast majority of bankers and financial service professionals who do the right thing. So pass legislation that makes the penalties for fraud count.

And tonight, I'm asking my Attorney General to create a special unit of federal prosecutors and leading state attorney general to expand our investigations into the abusive lending and packaging of risky mortgages that led to the housing crisis. (Applause.) This new unit will hold accountable those who broke the law, speed assistance to homeowners, and help turn the page on an era of recklessness that hurt so many Americans.

Now, a return to the American values of fair play and shared responsibility will help protect our people and our economy. But it should also guide us as we look to pay down our debt and invest in our future.

Right now, our most immediate priority is stopping a tax hike on 160 million working Americans while the recovery is still fragile. (Applause.) People cannot afford losing $40 out of each paycheck this year. There are plenty of ways to get this done. So let's agree right here, right now: No side issues. No drama. Pass the payroll tax cut without delay. Let's get it done. (Applause.)

When it comes to the deficit, we've already agreed to more than $2 trillion in cuts and savings. But we need to do more, and that means making choices. Right now, we're poised to spend nearly $1 trillion more on what was supposed to be a temporary tax break for the wealthiest 2 percent of Americans. Right now, because of loopholes and shelters in the tax code, a quarter of all millionaires pay lower tax rates than millions of middle-class households. Right now, Warren Buffett pays a lower tax rate than his secretary.

Do we want to keep these tax cuts for the wealthiest Americans? Or do we want to keep our investments in everything else –- like education and medical research; a strong military and care for our veterans? Because if we're serious about paying down our debt, we can't do both.

The American people know what the right choice is. So do I. As I told the Speaker this summer, I'm prepared to make more reforms that rein in the long-term costs of Medicare and Medicaid, and strengthen Social Security, so long as those programs remain a guarantee of security for seniors.

But in return, we need to change our tax code so that people like me, and an awful lot of members of Congress, pay our fair share of taxes. (Applause.)

Tax reform should follow the Buffett Rule. If you make more than $1 million a year, you should not pay less than 30 percent in taxes. And my Republican friend Tom Coburn is right: Washington should stop subsidizing millionaires. In fact, if you're earning a million dollars a year, you shouldn't get special tax subsidies or deductions. On the other hand, if you make under $250,000 a year, like 98 percent of American families, your taxes shouldn't go up. (Applause.) You're the ones struggling with rising costs and stagnant wages. You're the ones who need relief.

Now, you can call this class warfare all you want. But asking a billionaire to pay at least as much as his secretary in taxes? Most Americans would call that common sense.

We don't begrudge financial success in this country. We admire it. When Americans talk about folks like me paying my fair share of taxes, it's not because they envy the rich. It's because they understand that when I get a

tax break I don't need and the country can't afford, it either adds to the deficit, or somebody else has to make up the difference -- like a senior on a fixed income, or a student trying to get through school, or a family trying to make ends meet. That's not right. Americans know that's not right. They know that this generation's success is only possible because past generations felt a responsibility to each other, and to the future of their country, and they know our way of life will only endure if we feel that same sense of shared responsibility. That's how we'll reduce our deficit. That's an America built to last. (Applause.)

Now, I recognize that people watching tonight have differing views about taxes and debt, energy and health care. But no matter what party they belong to, I bet most Americans are thinking the same thing right about now: Nothing will get done in Washington this year, or next year, or maybe even the year after that, because Washington is broken.

Can you blame them for feeling a little cynical?

The greatest blow to our confidence in our economy last year didn't come from events beyond our control. It came from a debate in Washington over whether the United States would pay its bills or not. Who benefited from that fiasco?

I've talked tonight about the deficit of trust between Main Street and Wall Street. But the divide between this city and the rest of the country is at least as bad -- and it seems to get worse every year.

Some of this has to do with the corrosive influence of money in politics. So together, let's take some steps to fix that. Send me a bill that bans insider trading by members of Congress; I will sign it tomorrow. (Applause.) Let's limit any elected official from owning stocks in industries they impact. Let's make sure people who bundle campaign contributions for Congress can't lobby Congress, and vice versa -- an idea that has bipartisan support, at least outside of Washington.

Some of what's broken has to do with the way Congress does its business these days. A simple majority is no longer enough to get anything -- even routine business -- passed through the Senate. (Applause.) Neither party has been blameless in these tactics. Now both parties should put an end to it. (Applause.) For starters, I ask the Senate to pass a simple rule that all judicial and public service nominations receive a simple up or down vote within 90 days. (Applause.)

The executive branch also needs to change. Too often, it's inefficient, outdated and remote. (Applause.) That's why I've asked this Congress to grant me the authority to consolidate the federal bureaucracy, so that our government is leaner, quicker, and more responsive to the needs of the American people. (Applause.)

Finally, none of this can happen unless we also lower the temperature in this town. We need to end the notion that the two parties must be locked in a perpetual campaign of mutual destruction; that politics is about clinging to rigid ideologies instead of building consensus around common-sense ideas.

I'm a Democrat. But I believe what Republican Abraham Lincoln believed: That government should do for people only what they cannot do better by themselves, and no more. (Applause.) That's why my education reform offers more competition, and more control for schools and states. That's why we're getting rid of regulations that don't work. That's why our health care law relies on a reformed private market, not a government program.

On the other hand, even my Republican friends who complain the most about government spending have supported federally financed roads, and clean energy projects, and federal offices for the folks back home.

The point is, we should all want a smarter, more effective government. And while we may not be able to bridge our biggest philosophical differences this year, we can make real progress. With or without this Congress, I will keep taking actions that help the economy grow. But I can do a whole lot more with your help. Because when we act together, there's nothing the United States of America can't achieve. (Applause.) That's the lesson we've learned from our actions abroad over the last few years.

Ending the Iraq war has allowed us to strike decisive blows against our enemies. From Pakistan to Yemen, the al Qaeda operatives who remain are scrambling, knowing that they can't escape the reach of the United States of America. (Applause.)

From this position of strength, we've begun to wind down the war in Afghanistan. Ten thousand of our troops have come home. Twenty-three thousand more will leave by the end of this summer. This transition to Afghan lead will continue, and we will build an enduring partnership with Afghanistan, so that it is never again a source of attacks against America. (Applause.)

As the tide of war recedes, a wave of change has washed across the Middle East and North Africa, from Tunis to Cairo; from Sana'a to Tripoli. A year ago, Qaddafi was one of the world's longest-serving dictators -- a murderer with American blood on his hands. Today, he is gone. And in Syria, I have no doubt that the Assad regime will soon discover that the forces of change cannot be reversed, and that human dignity cannot be denied. (Applause.)

How this incredible transformation will end remains uncertain. But we have a huge stake in the outcome. And while it's ultimately up to the people of the region to decide their fate, we will advocate for those values that have served our own country so well. We will stand against violence and intimidation. We will stand for the rights and dignity of all human beings –- men and women; Christians, Muslims and Jews. We will support policies that lead to strong and stable democracies and open markets, because tyranny is no match for liberty.

And we will safeguard America's own security against those who threaten our citizens, our friends, and our interests. Look at Iran. Through the power of our diplomacy, a world that was once divided about how to deal with Iran's nuclear program now stands as one. The regime is more isolated than ever before; its leaders are faced with crippling sanctions, and as long as they shirk their responsibilities, this pressure will not relent.

Let there be no doubt: America is determined to prevent Iran from getting a nuclear weapon, and I will take no options off the table to achieve that goal. (Applause.)

But a peaceful resolution of this issue is still possible, and far better, and if Iran changes course and meets its obligations, it can rejoin the community of nations.

The renewal of American leadership can be felt across the globe. Our oldest alliances in Europe and Asia are stronger than ever. Our ties to the Americas are deeper. Our ironclad commitment -- and I mean ironclad -- to Israel's security has meant the closest military cooperation between our two countries in history. (Applause.)

We've made it clear that America is a Pacific power, and a new beginning in Burma has lit a new hope. From the coalitions we've built to secure nuclear materials, to the missions we've led against hunger and disease; from the blows we've dealt to our enemies, to the enduring power of our moral example, America is back.

Anyone who tells you otherwise, anyone who tells you that America is in decline or that our influence has waned, doesn't know what they're talking about. (Applause.)

That's not the message we get from leaders around the world who are eager to work with us. That's not how people feel from Tokyo to Berlin, from Cape Town to Rio, where opinions of America are higher than they've been in years. Yes, the world is changing. No, we can't control every event. But America remains the one indispensable nation in world affairs –- and as long as I'm President, I intend to keep it that way. (Applause.)

That's why, working with our military leaders, I've proposed a new defense strategy that ensures we maintain the finest military in the world, while saving nearly half a trillion dollars in our budget. To stay one step ahead of our adversaries, I've already sent this Congress legislation that will secure our country from the growing dangers of cyber-threats. (Applause.)

Above all, our freedom endures because of the men and women in uniform who defend it. (Applause.) As they come home, we must serve them as well as they've served us. That includes giving them the care and the benefits they have earned –- which is why we've increased annual VA spending every year I've been President. (Applause.) And it means enlisting our veterans in the work of rebuilding our nation.

With the bipartisan support of this Congress, we're providing new tax credits to companies that hire vets. Michelle and Jill Biden have worked with American businesses to secure a pledge of 135,000 jobs for veterans and their families. And tonight, I'm proposing a Veterans Jobs Corps that will help our communities hire veterans as cops and firefighters, so that America is as strong as those who defend her. (Applause.)

Which brings me back to where I began. Those of us who've been sent here to serve can learn a thing or two from the service of our troops. When you put on that uniform, it doesn't matter if you're black or white; Asian, Latino, Native American; conservative, liberal; rich, poor; gay, straight. When you're marching into battle, you look out for the person next to you, or the mission fails. When you're in the thick of the fight, you rise or fall as one unit, serving one nation, leaving no one behind.

One of my proudest possessions is the flag that the SEAL Team took with them on the mission to get bin Laden. On it are each of their names. Some may be Democrats. Some may be Republicans. But that doesn't matter. Just like it didn't matter that day in the Situation Room, when I sat next to Bob Gates -- a man who was George Bush's defense secretary -- and Hillary Clinton -- a woman who ran against me for president.

All that mattered that day was the mission. No one thought about politics. No one thought about themselves. One of the young men involved in the raid later told me that he didn't deserve credit for the mission. It only succeeded, he said, because every single member of that unit did their job -- the pilot who landed the helicopter that spun out of control; the translator who kept others from entering the compound; the troops who separated the women and children from the fight; the SEALs who charged up the stairs. More than that, the mission only succeeded because every member of that unit trusted each other -- because you can't charge up those stairs, into darkness and danger, unless you know that there's somebody behind you, watching your back.

So it is with America. Each time I look at that flag, I'm reminded that our destiny is stitched together like those 50 stars and those 13 stripes. No one built this country on their own. This nation is great because we built it together. This nation is great because we worked as a team. This nation is great because we get each other's

backs. And if we hold fast to that truth, in this moment of trial, there is no challenge too great; no mission too hard. As long as we are joined in common purpose, as long as we maintain our common resolve, our journey moves forward, and our future is hopeful, and the state of our Union will always be strong.

Thank you, God bless you, and God bless the United States of America. (Applause.)

END
10:16 P.M. EST

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Economic and Environmental Impacts of Increased US Exports of Natural Gas

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ABSTRACT

With the shale gas boom, the US is expected to have very large natural gas resources. In this respect, the key question is would it be better to rely completely on free market resource allocations which would lead to large exports of natural gas or to limit natural gas exports so that more could be used in the US. Even after accounting for the cost of liquefying the natural gas and shipping it to foreign markets, current price wedges leave room for considerable profit from exports. On the other side, there is potentially large domestic demand for natural gas in electricity generation, industrial applications, transportation, and for other uses. A hybrid modeling approach has been carried out using our version of the well-known MARKAL-Macro model to keep bottom-up model richness with macro effects to analyze these choices. The major conclusion of this research is that permitting natural gas exports causes a small reduction in GDP and also increases GHG emissions. We also evaluate the impacts of natural gas exports in the presence of a Clean Energy Standard for electricity. In this case, the GDP and sectoral impacts are similar, but the impacts on electricity and transport are substantially different.

1 Introduction

The main objective of this paper is to examine the likely economic and environmental impacts of increased US exports of natural gas. With the shale gas boom, the US is expected to have very large natural gas resources, so the key question is would it be better to rely completely on free market resource allocations which would lead to large exports of natural gas or to limit natural gas exports so that more could be used in the US. Exports would be economically attractive because there is a very large price gap at present between US natural gas price (around $3.50/MCF) and prices in foreign markets, which can range up to $15/MCF. Even after accounting for the cost of liquefying the natural gas and shipping it to foreign markets, current price wedges leave room for considerable profit from exports. On the other side, there is potentially large domestic demand for natural gas in electricity generation, industrial applications, the transportation sector, and for other uses. There is no doubt that exporting a large amount of natural gas would increase the domestic natural gas price for all these potential uses. Higher natural gas prices would, in turn, mean higher electricity prices in addition to higher energy costs for all other sectors that use natural gas. These higher energy costs would also lead to contraction in energy intensive sectors relative to the reference case with small natural gas exports. On a global scale, more natural gas exports would benefit foreign companies and hurt domestic energy intensive industries. Foreign consumers also would benefit through lower energy costs, and US consumers would be hurt.

Thus, the question is which pathway provides the best economic and environmental outcome for the US. This is a very important energy policy question and one difficult to answer because of all the complex economics linkages among different economic sectors and also

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among the primary energy supply sectors. Our approach is to use a well-established bottom-up energy model named MARKAL (MARKet ALlocation). Bottom-up means that the model is built upon thousands of current and future prospective energy technologies and resources. These energy resources supply projected energy service demands for the various sectors of the economy. In addition to the standard MARKAL model, we also have adapted a version of the MARKAL-Macro model which permits us to include feedbacks between energy prices and economic activity. Thus the GDP effects of alternative energy policies are captured as well as technology and supply impacts. For these reasons, MARKAL-Macro is an ideal tool for this kind of analysis.

Our focus in this paper is on the impacts of different levels of natural gas exports on the economy and environment. We include 2.7 BCF/day of natural gas exports in the reference case because that level is already permitted, and the other simulated cases are additions of 6, 12, and 18 BCF/day of natural gas exports. These levels were chosen based on the EIA simulated levels (Energy Information Administration, January 2012) and to provide a wide range of natural gas export levels to determine how sensitive the various metrics are to the level. The export levels are compared with a reference case. Since the Renewable Fuels Standard (RFS) for biofuels and the CAFE standard for automobile and light duty vehicle fuel economy are now established US policy, we have included those policies in the reference case. However, the reality is, for this particular question, the results would not be very different between a reference case with and one without these policies. Our interest is in the difference or delta caused by three levels of increased natural gas exports compared with the reference case.

We do also examine one additional policy called the Clean Energy Standard (CES). This is the CES proposed by President Obama in his first term. The CES calls for doubling the percentage of clean electricity from 40 to 80 percent by 2035. Clean electricity includes coal with carbon capture and sequestration, nuclear, solar, hydropower, biomass, and wind. Natural gas based electricity is considered 50% clean in the CES. We develop a reference with CES case and then compare that with the three levels of natural gas exports as well.

The remainder of this paper is divided into four sections. First we provide a short literature review. Then we provide a more complete description of the MARKAL-Macro model used for the analysis. Third we provide the main results of the analysis comparing the three levels of natural gas exports with the reference and reference plus CES cases. Finally, we provide the conclusions we glean from this analysis.

2 Relevant literature

While there are many papers in the literature that have used MARKAL and some that have used a version of MARKAL-Macro, we will not review that literature. Other papers we have done provide that literature review. Here, the only directly relevant study is the recently completed NERA Economic Consulting study done for the US Department of Energy (DOE) (NERA Economic Consulting, 2012). They used their own proprietary energy-economy model named NewERA for the analysis. Their results suggest that the US achieves economic gains from natural gas exports and that the gains increase as the level of natural gas exports grows. Their result is the classical economic result that free trade provides net gains to the economy under most conditions. While economic theory does not suggest that free trade always produces economic gains for all parties under all conditions, the general argument is that under a wide range of conditions, free trade does provide net benefits with some winners and some losers. The NERA results do show higher natural gas prices due to exports with the magnitude of the

increase depending on domestic and global supply and demand factors. The NERA study used input data and information from a companion study done by the Energy information Agency in DOE (Energy Information Administration, January 2012), which estimated the impacts of export levels on US natural gas prices.

The NERA analysis focused on export levels of 6 and 12 BCF per day, but there were many other scenarios and sensitivity analyses. In general, the welfare or net income increases estimated in the NERA scenarios were very small, generally ranging from 0.01 to 0.025 percent over the reference case. There were considerable losses in capital and wage income in sectors affected by the higher natural gas prices, and income gains to natural gas resource owners through export earnings and wealth transfers to resource owners. By 2030 the total net increase in GDP amounted to about $10 billion 2010$, which could be perceived as being quite small in a $15 trillion economy (Trading Economics, 2012). Wage income falls in agriculture, energy intensive sectors, and the electricity sector. The percentage declines in wages in these sectors were generally much greater than the percentage increases in net national income. Natural gas price increases did not exceed 20 percent in any of the simulations. The NewERA energy-economy model takes inputs from the EIA NEMS natural gas projections (Energy Information Administration, January 2012) and from a global natural gas model.

3 Modeling Methodology

3.1 US MARKAL – Macro model

MARket ALlocation (MARKAL) is a widely applied, dynamic, perfect-foresight, technology-rich linear programming, energy systems, optimization model. In its standard formulation, its objective function is the minimization of the discounted total system cost which is formed by summation of capital, fuel and operating costs for resource, process, infrastructure, conversion and end use technologies. The general framework enables the calibration of a model to local, national, regional or multiregional energy systems. Model applications include, but are not limited to, climate policy, impact assessment of new technologies, taxes, subsidies, and various regulations. Further details regarding the methodology can be found in Loulou et al. (2004).

The US EPA MARKAL is a standard MARKAL model where energy service demands are inelastic, exogenous, and model structure is linear. A database that represents a particular energy system must be developed to use with MARKAL. The U.S. EPA (2006) developed MARKAL databases that represent the US energy system at the national and regional levels. Both databases cover the period 2005 through 2055 in five-year increments and represent the sectors: resource supply, electricity production, residential, commercial, industrial and transportation sectors. The US EPA MARKAL model has been used for several national or international case studies (Hu and Hobbs, 2010; Sauthoff et al., 2010; Schafer and Jacoby, 2006). The original model has now been updated to 2010 data. In this study we use the national single region US EPA MARKAL model.

Characterizations of current and future energy demands, resource supplies, and technologies within the databases were developed primarily from the Energy Information Agency's 2010 Annual Energy Outlook report, extrapolated to 2055 using National Energy Modeling System (NEMS) outputs published by DOE (2010). Additional data sources include the AP-42 emission factors from US EPA (1995), and Argonne National Laboratory's Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) model

(Burnham et al., 2006). Further details regarding US EPA MARKAL can be found in Shay et. al. (2006).

3.2 Model Modifications

Significant data and model changes were introduced into MARKAL for this analysis. First, biomass supply was introduced using land rent outputs from the Global Trade Analysis Project (GTAP) model. Essentially, we captured the land rents as increasing amounts of biofuels were demanded in that model and used those for land supply curves for MARKAL. Second, the biochemical conversion technologies in MARKAL were updated to the latest and most reliable available. Third, biomass thermochemical conversion technologies were added to the model. All these changes are detailed in previous work (Sarica and Tyner, 2013). Fourth, new data on natural gas supply was introduced to reflect the increased supply of shale gas. Fifth, the transportation sector CNG use has been restructured. Each of these modifications is discussed in greater detail below.

The approach for the modeling of biomass production in the original US EPA MARKAL is similar to the approach used for modeling oil, natural gas, coal or hydraulic power production, where the production activity itself does not interfere with any other economic activity. No competition for another resource is present due to the production processes of coal, natural gas or uranium. You do not have to sacrifice production of oil to produce uranium or vice versa. In reality use of land for biomass production itself interferes with the ongoing biomass production for crops, vegetables or any other related economic activities. In that sense the current US EPA MARKAL model or any national or international MARKAL model does not reflect this reality.

The introduction of land to the supply chain of corn, corn stover, switchgrass and miscanthus required that a considerable amount of data be implemented in the MARKAL modeling framework. The land data came from the Global Trade Analysis Project (GTAP) database. The GTAP land data is stratified into agro-ecological zones (AEZ), so it permitted us to introduce the yield levels by region (Taheripour and Tyner, 2011; Tyner et al., 2011). Land data is incorporated as piecewise linear approximations to the GTAP output and more detail regarding this issue can be found in Sarica and Tyner (2013). With these changes we have depicted the total supply chain of the selected biomass products. Land rent is now a part of the cost of producing biomass. In addition, we have introduced the most up to date seeding, harvesting, transport and harvesting costs for the feedstocks mentioned earlier (Taheripour and Tyner, 2011).

Another set of changes is the update of natural gas resource supply curves in the US EPA MARKAL database based on the MIT Energy Initiative report (The MIT Energy Initiative, 2011).Natural gas is expected to be available at low cost for the US, due to shale gas and other technological improvements. Due to the expectation of improvements in gas extraction techniques, the high availability case is quite plausible as suggested by the MIT Energy Initiative Report (The MIT Energy Initiative, 2011). With this expectation we make the use of high availability case supply curve in the modified MARKAL database.

The last set of changes is the restructuring of the Compressed Natural Gas (CNG) use in the transportation sector. The distribution of CNG within the sector is restructured such that it can be tracked based on type of use such as Light Duty Vehicles (LDV), transit buses, school buses, garbage trucks and Heavy Duty Vehicles (HDV). And relevant policies can be modeled and adapted accordingly. Based on the fleet sizes and energy use distribution from Federal Transit Authority's National Transit Database (2010), Institute of Education Sciences' National Center for Education Statistics (2011), Waste and Recycling News magazine's 2010 Hauling and

Disposal Rankings (2011) and 2002 Economic Census - Vehicle Inventory and Use Survey (Department of Commerce, 2004), database has been updated to reflect the economies of scale in those subsectors. Besides the cost of CNG stations is based on the study carried by Caley Johnson (2010), VICE model which shows the economies of scale effect on CNG station design.

Our US MARKAL-Macro model is based on the national US EPA MARKAL model with the modifications described in this section and earlier references. In the first stage of the calibration process, the MARKAL model is calibrated to the base year, 2005, to match the model outputs to the electricity outputs, primary energy use, installed technology capacity and sectoral outputs. After the first phase, MARKAL and MACRO modules went through an iterative calibration process which is used to match the projected energy service demands and projected GDP growth rates. Annual Energy Outlook (Department Of Energy, 2010) is the principal data resource in all calibration processes.

3.3 Macro Linkage

In this paper, a neoclassical growth model has been integrated to the technology rich representation of the US energy system. Despite the simplicity, MARKAL-Macro is one of the very few hard-linked top-down bottom-up hybrid modeling approaches (Messner and Schrattenholzer, 2000). Figure 1 graphically summarizes the integration process.

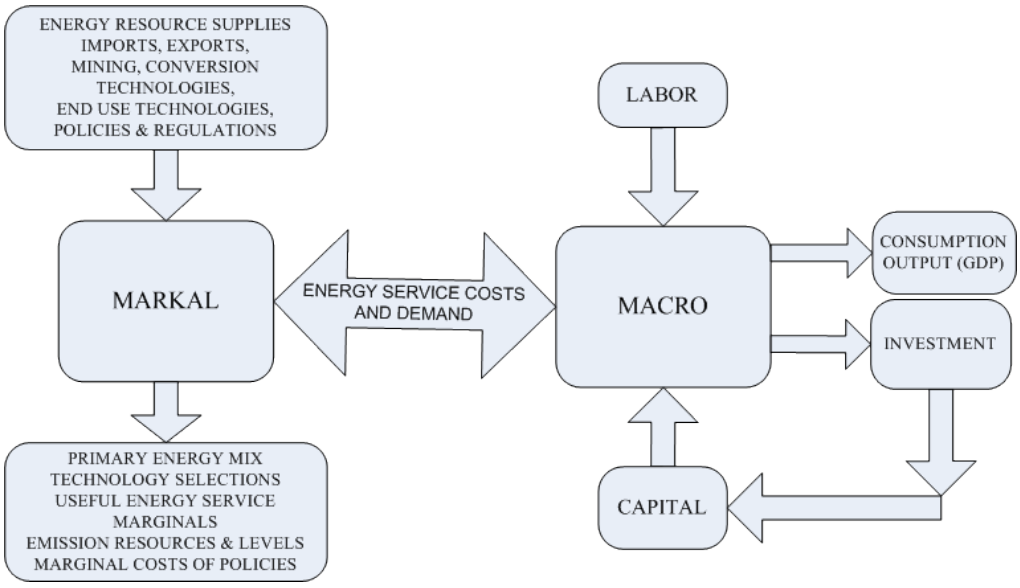

Figure 1 MARKAL-Macro Integration

The objective function of MARKAL-Macro, as can be seen in Equation 1, is the maximization of the discounted log of utility, which is basically derived as the log of consumption, accumulated over all modeling horizon periods (t), with an added terminal value. Where C_t is consumption; *kpvs* is the value share of capital in the labor–capital aggregate; *kgdp* is the initial capital-to-GDP ratio; *depr* is the annual depreciation of the capital stock; and *grow* is the expected growth rate of the economy. The discount factor udf_t is accumulated discount rate from year t to 0 and udr_t is the year t's annual discount rate. *ny* is the number of years per period.

$$
\begin{aligned}
Utility &= \sum_{t=1}^{T-1} (udf_t)(\log C_t) + \frac{(udf_T)(\log C_T)}{1-(1-udr_T)^{ny}} \\
udf_t &= \prod_{t=0}^{t-1} (1-udr_t)^{ny} \\
udr_t &= \frac{kpvs}{kgdp} - depr - grow
\end{aligned}
\tag{1}
$$

The output of the economy (Y_t) is composed of consumption, investment and energy costs, as shown in Equation 2, in a single economic sector with perfect foresight. The financial link between MARKAL and Macro module is represented by EC_t.

$$Y_t = C_t + I_t + EC_t \tag{2}$$

where I_t is investment; and EC_t is the total energy cost where a simplified breakdown is given in Equation 3. *k* stands for utilized technologies in this equation. The key point in Equation 3 is the revenue generated from export activities. Any export activity has a potential to reduce the energy system cost thus creating growth potential for other economic activities. Besides, for this to hold, the cost of extracting exported commodity and extra burden created by the disturbance in the energy system must be less than the revenue generated. A more detailed cost description can be found in Loulou *et al.* (2004).

$$
\begin{aligned}
EC_t = \sum_k \{ & Annualized\ Investment\ Costs(t,k) \\
& + Fixed\ Operating\ \&\ Maintaining\ Costs\ (t,k) \\
& + Variable\ Operating\ \&\ Maintaining\ Costs\ (t,k)\} \\
& + \ Mining\ Activity\ Costs(t) \\
& + Trade\ Related\ Costs(t) \\
& + Energy\ Import\ Costs(t) \\
& - Energy\ Export\ Costs(t) + Enviromental\ Tax\ (t)
\end{aligned}
\tag{3}
$$

Production roots from three substitutable inputs by a nested Constant Elasticity of Substitution (CES) function. As can be seen in Equation 4, under this formulation, capital and labor substitute directly for one another based on the value share of capital in the labor–capital aggregate (*kpvs*). Their aggregate is then substituted for a separable energy aggregate. Investment is used to build up the stock of (depreciating) capital, while labor is exogenous.

$$
\begin{aligned}
Y_t &= \left[akl\ (K_t)^{\rho\alpha}\ (L_t)^{\rho(1-\alpha)} + \sum_{dm} b_{dm}\ \left(D_{dm,t}\right)^{\rho} \right]^{1/\rho} \\
L_t &= (1+grow_{t-1})^{ny}\, L_{t-1}\,, where\ L_0 = 1 \\
\alpha &= kpvs, \rho = 1 - \frac{1}{ESUB}
\end{aligned}
\tag{4}
$$

where *akl* is the production function constant, b_{dm} are the coefficients on demands in the MACRO objective function; K_t is the capital stock; L_t is labor; $D_{dm,t}$ is the demand for energy services of type *dm* in period *t*; and *ESUB* is the elasticity of substitution between the energy and the capital–labor aggregate. Parameters *akl* and b_{dm} can be determined using base year statistics, via the following two-step procedure. First, the reference price of energy service *dm* ($price(ref)_{dm,t}$) is equated to the partial derivative of Y_t , as can be seen in Equation 4, with respect to D_{dm}, yielding:

$$\frac{\partial Y_t}{\partial D_{dm,t}} = \left(\frac{Y_t}{D_{dm,t}}\right)^{1-\rho} b_{dm} = price(ref)_{dm,t} \tag{5}$$

thus allowing the computation of b_{dm}, for all dm. Next, the expression of the production function (Y_t) in base year is used to directly compute *akl*.

Due to the first order optimality condition for the partial derivative of production with respect to demand, the marginal change in output is equal to the cost of changing that demand. In practice this has two main conclusions. First, different demands will be altered based on the cost of changing that demand. So if it is very expensive to reduce a particular demand, then this will be reduced relatively less. Secondly, great care is needed to have smooth (and certainly not zero) shadow prices which can occur due to over-constrained runs. This ensures that the marginal output (demand) responses are realistic.

Capital stock (K_t) formation is endogenous and has its own dynamics as expressed in Equation 6. An additional equation ensures new capital is provided through investment, accounting for depreciated capital.

$$\begin{aligned} K_{t+1} &= (1 - depr)^{ny} K_t + (ny/2)\,[(1 - depr)^{ny} I_t + I_{t+1}] \\ I_0 &= (grow_0 - depr)\, K_0 \end{aligned} \tag{6}$$

Terminal condition, Equation 7, ensures sufficient investment for replacement and constant growth of capital at all-time intervals.

$$K_t(grow_t + depr) \leq I_t \tag{7}$$

Finally MARKAL supply activities are linked to Macro demand variables through two equations. The demand levels ($D_{dm,t}$) and cost of energy (EC_t) are the links between MARKAL and the Macro module.

Let $X_{j,t}$ be an activity *j* of MARKAL supplying energy service demand (*dm*) proportional to $supply_{j,dm,t}$ in time *t*. With the 'autonomous energy efficiency improvements factor (efficiency of converting physical energy to energy services) $aeeifac_{dm,t}$ MARKAL supply activities are linked to Macro demand variables. This process is also termed demand decoupling since it permits the model to decouple demands from the linear relationship with GDP e.g. primary metals industry is projected to squeeze down, while high duty vehicle energy service demand is projected to grow very close to GDP growth rates.

$$\sum_j supply_{j,dm,t}\, X_{j,t} = aeeifac_{dm,t}\, D_{dm,t} \tag{8}$$

To transfer the costs from MARKAL to Macro, the link in Equation 9 computes for each activity *j* and period *t* the cost, $cost_{j,t}$,per unit of activity $X_{j,t}$ (which is equivalent to Equation 3)

and quadratic penalty terms are introduced to smooth the rate of market penetration of new technologies:

$$\sum_{j} cost_{j,t}\, X_{j,t} + c \sum_{tch} c_{tch}\, XCAP_{tch,t}^{2} = EC_t$$
$$CAP_{tch,t+1} = expf\ CAP_{tch,t} + XCAP_{tch,t+1} \quad (9)$$

Where $CAP_{tch,t}$ is the capacity of technology *tch* during period *t*, and $XCAP_{tch,t}$ is the capacity installed beyond the capacity expansion factor *expf* that limits the projected capacity of technology *tch* in period *t* due to technological, economical and/or environmental factors.

Useful energy services from MARKAL are aggregated to form the energy input in the output (production) function of the Macro module. In the Macro module, there exists a competition between investment in energy and investment in the rest of the economy. Economic output is shaped based on this competition and this information is passed back to MARKAL. With this connection between MARKAL and Macro, MARKAL–Macro determines a baseline and resultant dynamic changes for energy services demand, carbon emissions, technology choices, and GDP. Even though aggregated energy demand responds to single price elasticity (*ESUB*), sub-sectoral energy service demands will react decoupled from aggregated energy demand dependent on the economic impacts of their reductions, in which demand marginals express the magnitude of those impacts.

In summary, MARKAL-Macro, with its described structure, is able to incorporate aggregated energy service demand feedback due to price changes in energy. Since the demand changes are autonomous, some energy service demands may be decoupled from economic growth. By integration of Macro portion; calculation of GDP, consumption and investment in an explicit manner is possible. Overall, detailed energy systems analysis is maintained, without loss compared to MARKAL.

3.4 Model Key Parameters

US MARKAL-Macro model uses 2000 real U.S. dollars as the financial metric throughout the modeling horizon. GDP growth estimates are 3%, 2.5% and 2.4% for 2010 – 2020, 2020-2030, 2030-2045 periods respectively in line with AEO 2010. Energy service demand changes through the modeling horizon are displayed in Table 1. Annual growth rate estimate for the period 2030-2045 is set to be long term historical average growth rate for the US.

Parameters regarding the Macro portion of the US MARKAL-Macro model are chosen to best represent the US economy. The aggregated elasticity of substitution between the energy aggregate and labor-capital aggregate (*ESUB*) is assumed to be 0.4, in line with the ETSAP estimate range, 0.2-0.5 (Loulou et al., 2004). The initial capital to GDP ratio, *kgdp, is* 2.4, and the optimal value share of capital in the value added nest, *kpvs,* is 24% are based on historical economic data for the US. Model wide discount rate of 5% real is used for all non-demand related sectors. For end use related technologies, hurdle rates (technology specific discount rates) are applied differentially to simulate the consumer's reluctance to purchase newer technologies.

Table 1 Annual growth rates of demand (%)(Source AEO (2010)).

Energy service demands	Average Growth		
	2010 - 2020	2020-2030	2030-2045
Commercial			
Cooking	1.16%	1.30%	1.23%
Lighting	1.36%	1.27%	1.24%
Misc - DSL	-0.66%	-0.20%	-0.98%
Misc - ELC	2.46%	2.22%	2.28%
Misc - LPG	0.34%	0.40%	0.54%
Misc - NG	0.53%	1.42%	0.98%
Misc - RFL	-0.58%	0.13%	0.74%
Office Equipment	1.80%	1.34%	1.80%
Refrigeration	1.36%	1.27%	1.24%
Cooling	2.11%	1.74%	1.48%
Heating	1.06%	1.01%	1.03%
Ventilation	1.36%	1.27%	1.24%
Water Heating	1.36%	1.27%	1.24%
Industry			
Chemical	0.26%	-0.97%	-0.38%
Food	1.92%	1.61%	1.67%
Primary Metals	2.80%	-1.90%	-0.61%
Non-metallic	2.19%	0.49%	0.59%
Paper	1.33%	0.48%	0.61%
Transport Vehicles	0.28%	2.82%	1.93%
Aggregate Non-Manufacturing	-0.09%	-0.51%	-0.22%
Other Sector	2.99%	1.31%	1.65%
Residential			
Freezing	1.40%	0.99%	1.14%
Lighting	1.93%	1.42%	1.03%
Refrigeration	1.29%	1.61%	1.30%
Cooling	1.70%	0.58%	0.50%
Heating	1.04%	1.00%	0.80%
Water Heating	0.83%	1.14%	0.74%
Other Appliances - Electricity	1.62%	0.27%	-0.10%
Other Appliances - Natural Gas	0.47%	-0.19%	-0.56%
Transportation			
Air	1.61%	0.98%	1.35%
Bus	1.16%	1.09%	1.12%
Truck	1.93%	1.42%	1.34%
High Duty Vehicle	2.33%	1.82%	1.75%
Light Duty Vehicle	1.83%	1.83%	0.69%
Offroad Diesel	0.16%	0.16%	0.16%
Offroad Gasoline	0.18%	0.18%	0.18%
Rail - Freight	1.34%	0.74%	0.63%
Rail Passenger	1.52%	1.15%	1.24%
Shipping	1.00%	0.75%	0.67%

4 Results

We will report results on GDP, primary resource mix, electricity sector price and generation source changes, transport sector impacts, impacts on selected other sectors, and impacts on domestic GHG emissions. In each case, we will compare the reference case with the three levels of natural gas exports.

4.1 GDP impacts

Our analysis shows that increasing natural gas exports actually results in a slight decline in GDP. Essentially the gains from exports are less than the losses in electricity and energy intensive sectors in the economy. Figure 1 shows the changes in GDP over time. The GDP losses are around 0.04%, 0.11%, and 0.17% for the 6, 12, and 18 BCF/day cases respectively for the year 2035. We recognize that this result runs counter to the standard expectation that more open trade results in a net gain for society. However, modern trade theory has many instances of welfare losses to countries and regions from more open trade. Any combination of terms of trade or allocative effects can lead to reduced welfare from more open trade. In any event, the reduction in GDP is relatively small, but it is negative. When we examine the sectoral results below, the sources of the losses will become clearer.

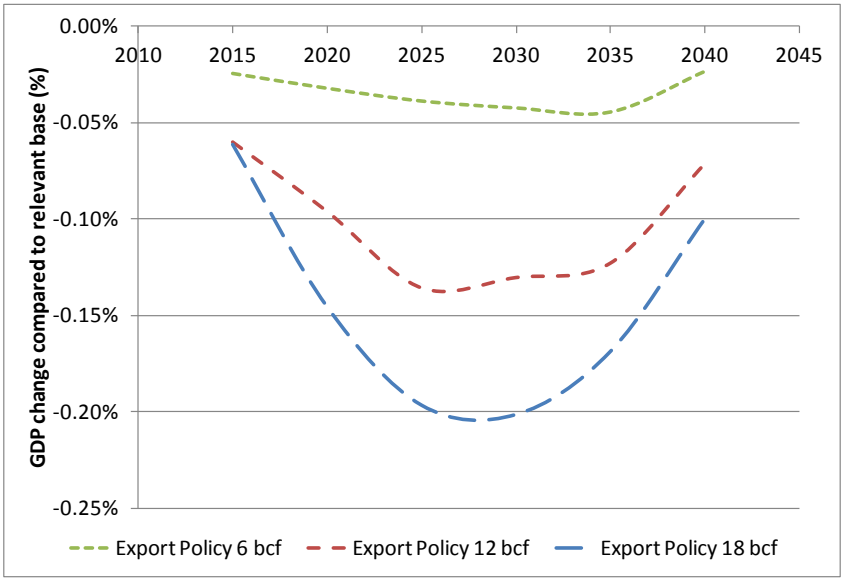

Figure 2 The changes in GDP over time in relevant scenarios compared to reference.

4.2 Energy resource mix

The change in energy resource mix with the different levels of natural gas exports for the year 2035 is shown in Table 2. The relative changes are similar for other years, so we pick 2035 to illustrate the differences among the export levels. The general trends are as follows: 1) the domestic energy share for natural gas falls from 25 to 22 percent) as exports of natural gas increase; 2) domestic use of coal increases from 21 to 23 percent as natural gas exports increase; 3) the fraction of oil in total consumption increases from 36 to 37 percent; 4) there are small increases in nuclear and renewables (hydro, solar, wind, and biomass). The directions of all these changes correspond to prior expectations.

Of course, the changes in primary energy mix are driven primarily by the changes in natural gas prices brought on by the increased demand for natural gas for export. Figure 3 shows the percentage changes in natural gas prices over time for the three export cases compared with the reference case. In 2035, natural gas price is 16%, 41%, and 47% higher for the 6 BCF, 12 TCF, and 18 BCF cases. These results are higher than the EIA and NERA analysis, and this difference likely is a major driver of the differences in results.

Table 2 Energy Resource Mix for 2035 for the Different Export Cases

Energy source	reference	6 BCF/day	12 BCF/day	18 BCF/day
Coal	20.7%	21.6%	22.3%	22.6%
Natural gas	25.2%	23.8%	22.5%	22.0%
Oil	36.1%	36.4%	36.8%	37.0%
Nuclear	8.3%	8.4%	8.5%	8.5%
Renewables	9.3%	9.4%	9.5%	9.6%
Elec. import	0.3%	0.3%	0.3%	0.3%

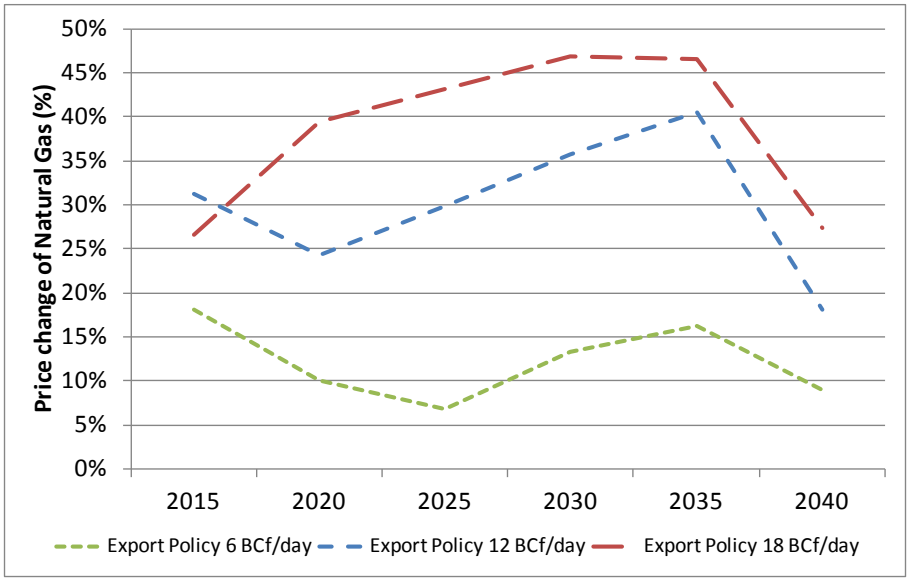

Figure 3 Price change wellhead Natural Gas price with respect to the reference as percentage.

The patterns of primary energy use over time are illustrated in Figure 4, which shows the time profile of primary energy use for the reference and 12 BCF/year cases. The patterns evident in Table 2 are clear in Figure 4, but also one can see that the total primary energy consumption is lower in the export case because of the negative impact on GDP.

4.3 Electricity sector impacts

The impacts on the electricity sector come in higher electricity prices and higher GHG emissions. In 2035, electricity price is up compared with the reference case by 1.1%, 4.3%, and 7.2% for the 6 BCF, 12 BCF, and 18 BCF cases respectively. Of course, these higher electricity prices are passed through the entire economy through industrial, commercial, and residential sectors.

Electricity GHG emissions in the early years of the simulation horizon are around 2% higher for the 6 BCF case, and 7-12% higher for the 12 and 18 BCF cases. However, by the end of the simulation period, the differences are all in the 1-4% range. This decline in emission difference is due to the emergence of less expensive renewable energy technology after 2020 and to some increase in nuclear. The increase in coal use shown in Table 2 exists, but the higher coal emissions relative to natural gas in later years are partially offset by lower emissions from nuclear and renewables. Coal use for electricity generation for the four cases is shown in Figure

5. In the early years, higher natural gas exports results in substantially higher coal use for electricity generation.

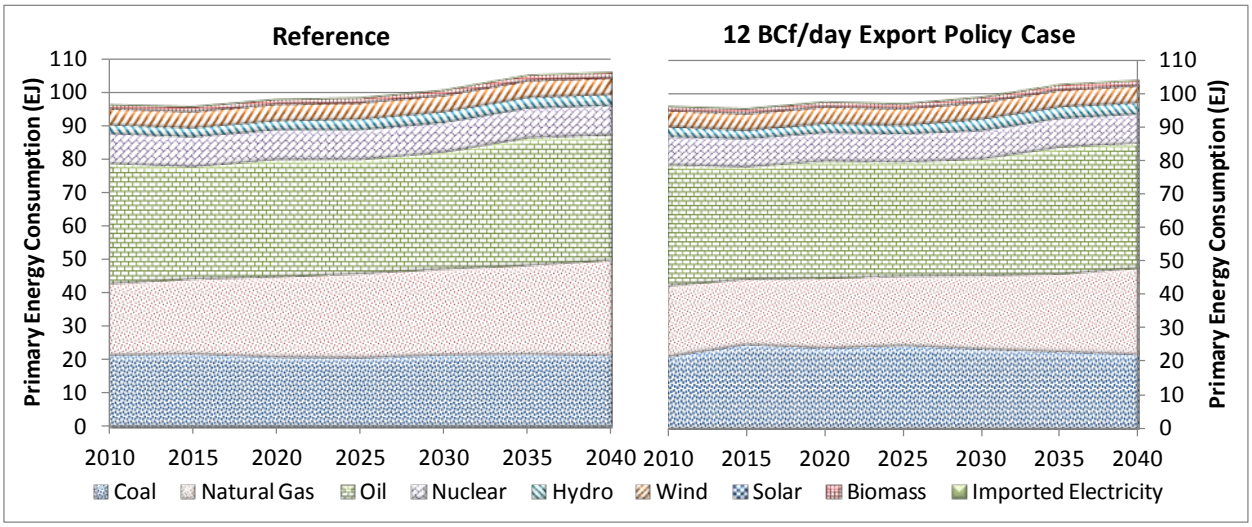

Figure 4 Primary energy mix for the 12 BCf/day export policy case and the reference scenario.

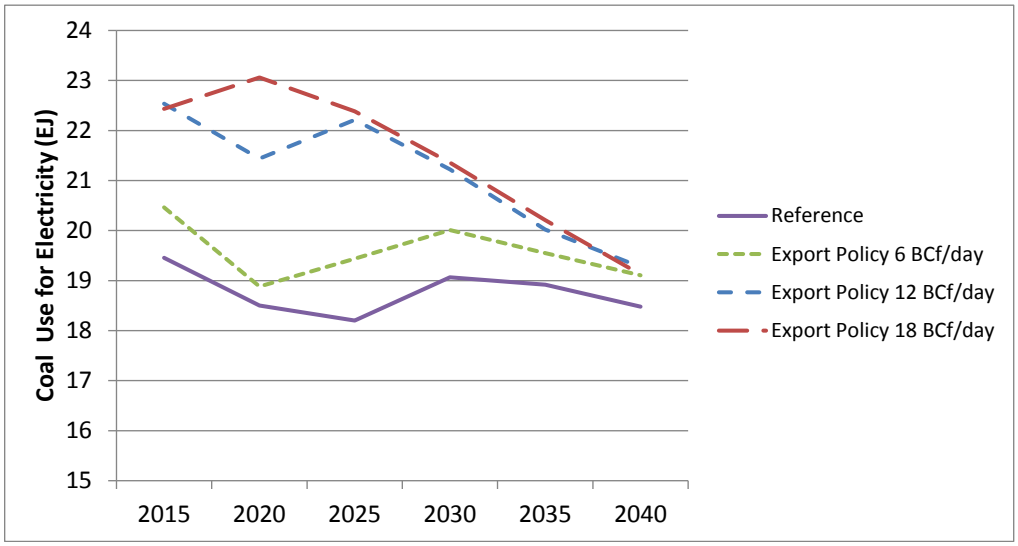

Figure 5 Coal use for electricity generation.

4.4 Transport sector

Figure 6 shows the CNG use in transportation over time for the reference and three export cases. In 2035, CNG use in transportation for the reference case is 1.3 bil. gal. gasoline equivalent, but it drops to 0.2-0.3 in the three export cases. Figure 7 shows what happens over time to fleet use of natural gas in the reference and 12 BCF cases. CNG use in heavy duty vehicles disappears in the 12 BCF case, and CNG use in most of the vehicle categories drops considerably. The bottom line is that while CNG use in transport is not large even in the reference case, it plummets in the export cases.

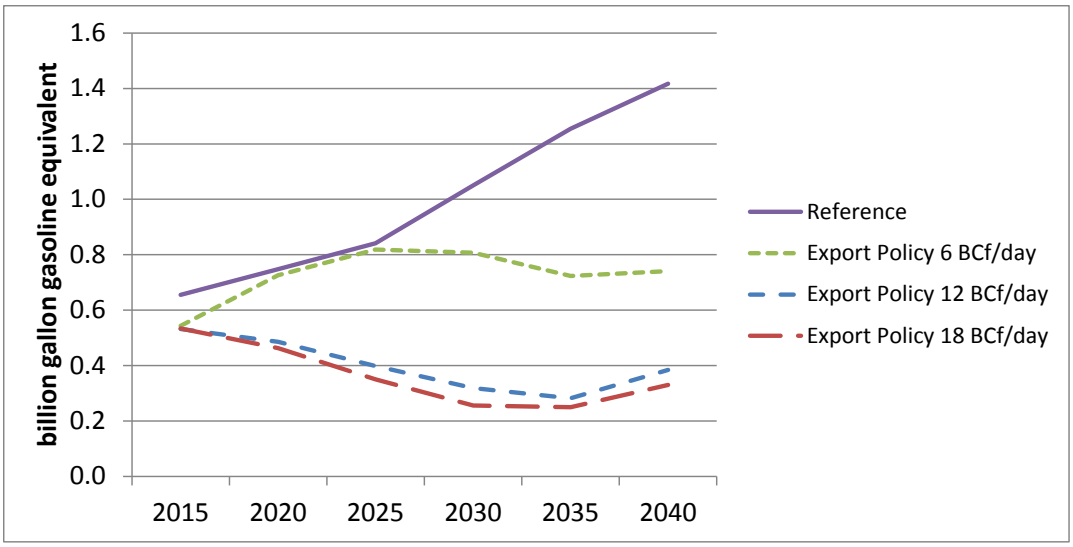

Figure 6 The CNG use in transportation over time for the reference and three export cases.

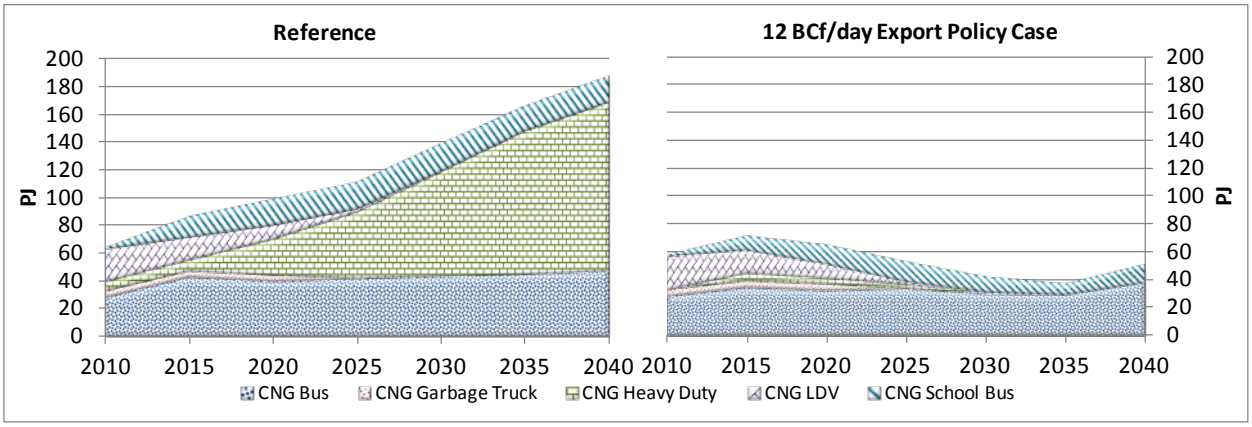

Figure 7 The CNG use breakdown in the Transportation Sector for the 12 BCf/day export policy case and the reference scenario.

4.5 Other sectors

Examination of impacts on certain sectors of the economy, particularly energy intensive sectors provides insight on why our analysis shows declines in GDP from the natural gas exports and associated higher natural gas prices. Table 3 provides the decline in total energy use in four important sectors of the economy for 2035. In every case, total energy use and therefore total sector output declines. The declines are less pronounced for the paper sector, which uses some renewable energy from wood.

4.6 Results with CES included in reference case

The Clean Energy Standard, as described above, substantially reduces GHG emissions in the electricity sector. Essentially, the sector goes from being 40% to becoming 80% clean by 2035. In all our results natural gas (considered 50% clean) plays a large role in meeting the CES. We do not know if the CES will be enacted or not, but increased attention on global warming

suggests it is a real possibility and something that must be considered in evaluating future energy policy options.

Table 3 Declines in Total Energy Use for Four Important Sectors

Sector	Percentage Energy Use Decline Relative to Reference Case in 2035
Primary metals	
6 BCF/day	-1.4
12 BCF/day	-3.0
18 BCF/day	-4.0
Non-metalic	
6 BCF/day	-2.2
12 BCF/day	-3.1
18 BCF/day	-3.5
Paper	
6 BCF/day	-0.8
12 BCF/day	-2.0
18 BCF/day	-2.8
Chemical	
6 BCF/day	-1.8
12 BCF/day	-2.4
18 BCF/day	-3.8

The biggest impact of the CES is substantially higher natural gas prices, as natural gas achieves significant penetration in the electric power sector. Thus, it is useful, first, to compare natural gas prices with and without the CES before moving to evaluating impacts of different levels of natural gas exports. Figure 8 shows the absolute price levels over time for the previous reference case and the reference with CES added. In every period, natural gas price is substantially higher under the CES than the standard reference. For example, in 2030, the reference price is $7.02, and the reference with CES is $10.60. Thus, the added demand for natural gas for electricity leads to much higher natural gas price even before considering exports.

Of course if we add exports, the price increases are even higher as illustrated in Figure 8, which shows the percentage increase in natural gas price with 12 BCF/day of exports for both the CES and standard reference cases, both compared with the standard reference. The bottom line is that the CES leads to relatively high natural gas price increases, which are accentuated by natural gas exports.

The GDP impacts of this policy case are pretty comparable with the cases described above. For example, the GDP reductions that were -0.10 to -0.15% for the standard reference are in the same range for the reference with CES. The sectoral impacts also were similar to the standard reference described above.

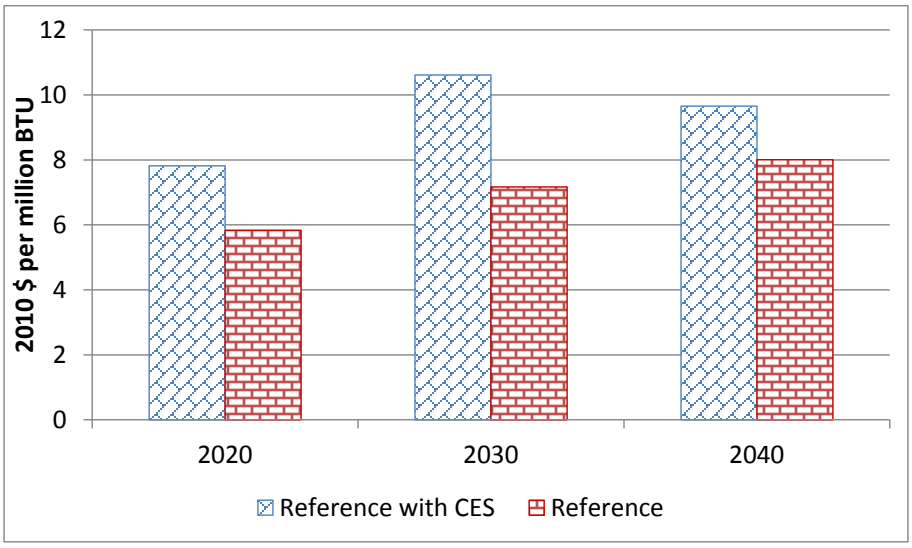

Figure 8 Wellhead Natural Gas prices

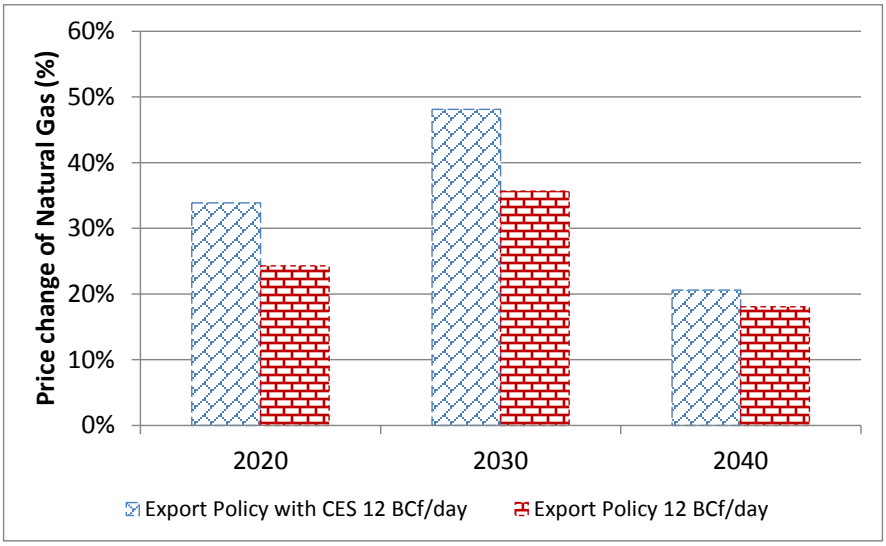

Figure 9 Natural Gas price change comparison for 12 BCf/day policy.

The primary energy source mix is quite different for the standard reference and reference with CES as would be expected. In the standard reference, coal use was relatively flat over the time horizon, and it increased with increasing natural gas exports. With the reference plus CES, coal use drops drastically (Figure 10) as would be expected since the CES cannot be met with so much coal power in the mix. Compare this primary resource mix with that shown in Figure 4 for the reference case.

Finally, we examine the impacts on the use of CNG in the transport sector. The CES virtually eliminates the use of CNG or LNG in the heavy duty truck sub-sector as shown in Figure 11. Compare this fleet mix (left panel of Figure 11 with the left panel of Figure 7. The right panel of Figure 11 shows the transportation fleets using CNG for the 12 BCF/day export level. It is clear that the combination of CES plus exports causes a huge reduction in CNG use in transportation in the US.

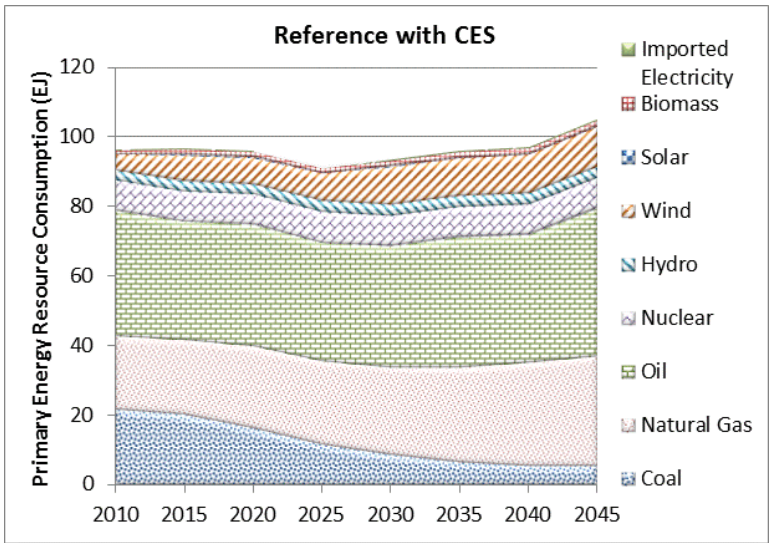

Figure 10 Primary energy mix for the Reference with CES policy.

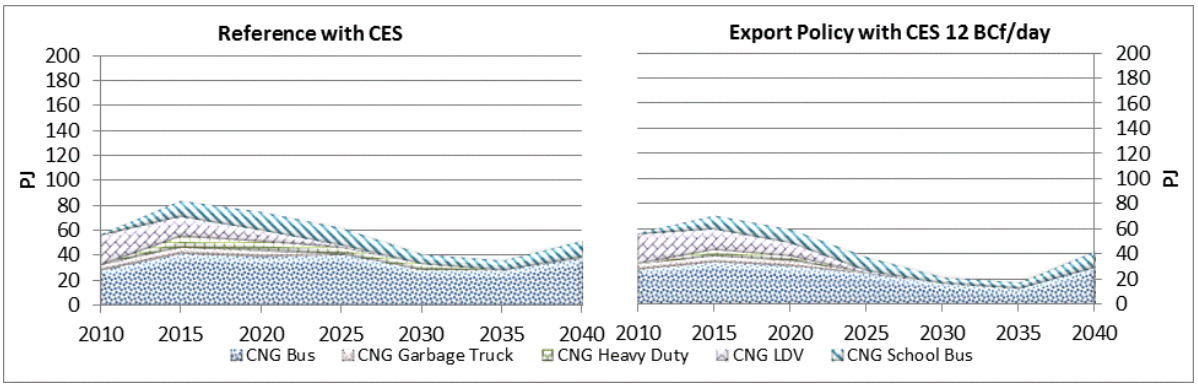

Figure 11 CNG use breakdown under selected policies.

5 Conclusions

The major conclusion of this research is that permitting natural gas exports causes a small reduction in US GDP and also increases GHG emissions and other environmental emissions such as particulates. There is loss of labor and capital income in all energy intensive sectors, and electricity prices increase. The major difference between our results and the other major study (NERA) are that we get considerably higher natural gas price impacts, and we do not get export revenue as large. The higher natural gas prices cause pervasive losses throughout the commercial, industrial, and residential sectors.

We also evaluate the impacts of natural gas exports in the presence of a Clean Energy Standard for electricity. In this case, the GDP and sectoral impacts are similar, but the impacts on electricity and transport are substantially different. The CES induces considerably higher natural gas prices because of the added demand for natural gas for power generation. Natural gas exports on top of CES cause prices to go even higher. In transport, the CES eliminates use of CNG or LNG for heavy duty trucks, and natural gas exports reduce CNG fleets substantially more in addition.

Beyond the analysis conducted here, it is important to note that neither the model used in this analysis nor the NERA model are global in scope. Thus, neither includes the trade impacts of US natural gas exports. However, we can describe those impacts qualitatively. Increased US natural gas exports will reduce energy costs for industry and consumers in foreign countries and increase those costs for the US. Thus, US industry will be rendered less competitive compared with foreign industry. This loss of export revenue would be in addition to the GDP loss estimated in this analysis. Moreover, US consumers lose due to higher energy prices, and foreign consumers gain.

Given all the results of this analysis, it is clear that policy makers need to be very careful in approving US natural gas exports. While we are normally disciples of the free trade orthodoxy, one must examine the evidence in each case. We have done that, and the analysis shows that this case is different. Using the natural gas in the US is more advantageous than exports, both economically and environmentally.

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UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY

IN THE MATTER OF	**)**	
	)	
WALLER LNG, LLC	**)**	**FE DOCKET NO. 13-153-LNG**

SIERRA CLUB'S MOTION TO INTERVENE, PROTEST, AND COMMENTS

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UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY

IN THE MATTER OF	**)**	
	)	
WALLER LNG Services, LLC	**)**	**FE DOCKET NO. 13-153-LNG**

SIERRA CLUB'S MOTION TO INTERVENE, PROTEST, AND COMMENTS

In the above-captioned docket, Waller LNG Services,LLC (Waller) requests authorization to export approximately 1.5 tons per annum (mtpa), or approximately 0.19 billion cubic feet per day (bcf/d), of natural gas as liquefied natural gas (LNG) from a natural gas liquefaction and LNG export terminal located along the Calcasieu Ship Channel in Cameron Parish, Louisiana. Sierra Club hereby moves to intervene in this docket, protests this proposal, and offers related comments.

Waller fails to acknowledge many of the project's harmful effects while failing to support Waller's assertions of purported benefit. The proposed export project will cause extensive environmental harm, impacting the environment around the export site, inducing harmful natural gas production, and likely increasing global greenhouse gas emissions. DOE/FE cannot authorize exports without fairly weighing significant environmental and economic impacts of this production. *See NAACP v. Federal Power Comm'n*, 425 U.S. 662, 670 n.4 (1976). Exports will also harm the public interest by increasing domestic gas prices and causing related economic damage.

Because Sierra Club's members have a direct interest in avoiding the environmental harms Waller's proposal will cause and in ensuring that any exports do not adversely affect domestic consumers, Sierra Club moves to intervene in FE Docket No. 13-153-LNG and protests Waller's application.

I. Sierra Club Should be Granted Intervention

Sierra Club members live and work throughout the area that will be affected by Waller's export proposal, including in the regions of Louisiana that will be affected by supporting infrastructure. Sierra Club members also live in the domestic gas fields that will likely see increased production as a result of the proposed exports. Sierra Club members everywhere will also be affected by the increased gas prices that would result from

completion of proposed LNG export facilities like the Waller project. As of April 2014, Sierra Club had 2,954 members in Louisiana and 632,604 members overall.[1]

To protect our members' interests, Sierra Club moves to intervene in FE Docket No. 13-153-LNG, pursuant to 10 C.F.R. § 590.303. Consistent with that rule, Sierra Club states that its rights and interests in these matters include, but are not limited to, the following:

- The environmental consequences of any gas exports from the Waller project, including emissions and other pollution associated with the liquefaction process, environmental damage associated with construction and operation of the facility and associated infrastructure, environmental impacts caused by shipping traffic, and the emissions associated with all phases of the process from production to combustion.
- The environmental and economic consequences of any expansion or change in natural gas production, especially in shale gas plays, as a result of increased gas exports. Members living in these regions will be affected by the damage to air, land, and water resources caused by the increasing development of these plays, and the public health risks caused by these harms.
- The economic impacts of any gas exports from the Waller project, whether individually or in concert with exports from other such facilities, including the consequences of price changes upon members' finances, consumer behavior generally, and industrial and electrical generating facilities whose fuel choices may be affected by price changes. Sierra Club, in particular, works to reduce U.S. and global dependence on fossil fuels, including coal, gas, and oil, and to promote clean energy and efficiency in order to protect public health and the environment. To the extent changes in gas prices increase the use and production of coal and oil, Sierra Club's interests in this proceeding are directly implicated.
- The public disclosure, in National Environmental Protection Act and other documents, of all environmental, cultural, social, and economic consequences of Waller's proposal, and of all alternatives to that proposal.

In short, Sierra Club's members have vital economic, aesthetic, spiritual, personal, and professional interests in the expansion project.

The Club has demonstrated the vitality of these interests in many ways. Sierra Club runs national advocacy and organizing campaigns dedicated to reducing American dependence on fossil fuels, including natural gas, and to protecting public health. These campaigns, including its Beyond Coal campaign and its Beyond Natural Gas campaign,

[1] Attached Declaration of Yolanda Andersen at ¶ 7, attached as Exhibit 1.

are dedicated towards promoting a swift transition away from fossil fuels and to reducing the impacts of any remaining natural gas extraction.

Thus, although 10 C.F.R. § 590.303 states no particular standard for intervention, Sierra Club has interests in these proceedings that would be sufficient to support intervention on any standard. DOE has consistently found that these interests are sufficient to warrant intervention in other LNG export proceedings. Accordingly, this motion to intervene must be granted.[2]

II. Service

Pursuant to 10 C.F.R. § 590.303, Sierra Club identifies the following persons for service of correspondence and communications regarding these applications.

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III. Sierra Club Protests this Application Because It Is Not In the Public Interest and Is Not Supported by Adequate Environmental and Economic Analysis

Section 3 of the Natural Gas Act provides that DOE/FE cannot authorize exports unless it finds the exports to be in the public interest. 15 U.S.C. § 717b. DOE/FE must consider environmental factors in the course of this public interest analysis. *NAACP*, 425 U.S. at 670 n.4; *Jordan Cove, L.P.*, DOE/FE Order 3413, 6, 7 (March 24, 2014). Accordingly, DOE/FE cannot proceed with Waller's application without fully evaluating the environmental impacts of Waller's proposal.

Waller's application is silent as to important environmental impacts of the proposal. As we explain below, the proposal will cause many types of significant environmental harm, and these harms must be considered as part of DOE/FE's public interest analysis. First, the construction and operation of the liquefaction facilities, export terminal, and related pipelines will directly impact local water quality, habitats, and air quality. Second, the project will induce additional natural gas production in the United States,

[2] If any other party opposes this motion, we respectfully request leave to reply. *Cf.* 10 C.F.R. §§ 590.302, 590.310 (allowing for procedural motions and briefing in these cases).

primarily hydraulic fracturing (fracking) of unconventional gas sources, thus causing the myriad environmental harms associated with such production. Third, the project will increase domestic gas prices, likely causing an increase in coal-fired electricity generation and thus increasing emissions of greenhouse gases, conventional, and toxic air pollutants. Fourth, notwithstanding Waller's assertion that LNG exports will displace use of heavy fuel oil and other fossil fuels, it is likely that LNG exports will also compete against wind, solar, and other clean renewable energy sources that would have lower environmental impacts.

Moreover, DOE/FE must reject Waller's threadbare economic arguments in support of its proposal. Domestically, exports will have adverse economic impacts as a result of increasing gas prices, lost jobs, and increased coal-fired electricity generation. Communities where increased gas production occurs will likely suffer from the "resource curse" and end up worse off than they would have been otherwise. LNG exports will result in net domestic job losses and economic harm to most Americans, overwhelming the purported economic benefits Waller asserts. Internationally, DOE/FE must disregard Waller's outsize rhetoric regarding Haiti entirely unless Waller provides an enforceable commitment—or at least a clear and convincing indication—that Haiti will actually receive a meaningful share of Waller's output.

For these reasons, and the reasons set forth below and in the comments incorporated herein by reference, Sierra Club files this protest, pursuant to 10 C.F.R. § 590.304.

A. Legal Standards

DOE/FE has significant substantive and procedural obligations to fulfill before it can authorize Waller's export application. Here, we discuss some of these obligations created by the Natural Gas Act, National Environmental Policy Act, and the Endangered Species Act, before explaining why these obligations preclude Waller's request for authorization.

1. Natural Gas Act

Pursuant to the Natural Gas Act and subsequent delegation orders, DOE/FE must determine whether Waller's proposal to export LNG to nations which have not signed a free trade agreement (FTA) with the United States is in the public interest.[3] While Waller contends that the sole determinant of this inquiry is whether "an export will not jeopardize supply to domestic needs during the term of the export" App. at 13, Courts, DOE/FE, and the Federal Energy Regulatory Commission (FERC) all agree that the "public

[3] The Natural Gas Act separately provides that DOE/FE must approve exports to nations that have signed a free trade agreement requiring national treatment for trade in natural gas "without modification or delay." 15 U.S.C. § 717b(c).

interest" at issue in this provision is wide ranging, including environmental impacts as well as economic impacts.

Section 3 of the Act provides:

> [N]o person shall export any natural gas from the United States to a foreign country or import any natural gas from a foreign country without first having secured an order of [DOE/FE] authorizing it do so. [DOE/FE] shall issue such order upon application unless, after opportunity for hearing, it finds that the proposed exportation or importation will not be consistent with the public interest.

15 U.S.C. § 717b(a).[4]

Courts interpreting this provision have long held that the "public interest" encompasses the environment. Although the public interest inquiry is rooted in the Natural Gas Act's "fundamental purpose [of] assur[ing] the public a reliable supply of gas at reasonable prices," *United Gas Pipe Line Co v. McCombs*, 442 U.S. 529 (1979), the Natural Gas Act also grants DOE/FE "authority to consider conservation, environmental, and antitrust questions." *NAACP v. Federal Power Comm'n*, 425 U.S. 662, 670 n.4 (1976) (citing 15 U.S.C. § 717b as an example of a public interest provision); *see also id.* at 670 n.6 (explaining that the public interest includes environmental considerations). Subsequent cases have confirmed *NAACP*'s holding that the purposes of the Natural Gas Act include environmental issues. *Pub. Utilities Comm'n of State of Cal. v. F.E.R.C.*, 900 F.2d 269, 281 (D.C. Cir. 1990). In interpreting an analogous public interest provision applicable to hydroelectric power and dams, the Supreme Court has explained that the public interest determination "can be made only after an exploration of all issues relevant to the 'public interest,' including future power demand and supply, alternate sources of power, the public interest in preserving reaches of wild rivers and wilderness areas, the preservation of anadromous fish for commercial and recreational purposes, and the protection of wildlife." *Udall v. Fed. Power Comm'n*, 387 U.S. 428, 450 (1967) (interpreting § 7(b) of the Federal Water Power Act of 1920, as amended by the Federal Power Act, 49 Stat. 842, 16 U.S.C. § 800(b)). Other courts have applied *Udall*'s holding to

[4] The statute vests authority in the "Federal Power Commission," which has been dissolved. DOE/FE has been delegated the former Federal Power Commission's authority to authorize natural gas exports. Department of Energy Redelegation Order No. 00-002.04E (Apr. 29, 2011). *See also* Executive Orders 12038 & 10485 (vesting any executive authority to allow construction of export facility in the Federal Power Commission and its successors).

the Natural Gas Act. *See, e.g.*, *N. Natural Gas Co. v. Fed. Power Comm'n*, 399 F.2d 953, 973 (D.C. Cir. 1968) (interpreting section 7 of the Natural Gas Act).[5]

DOE/FE and FERC have also acknowledged the breadth of the public interest inquiry and recognized that it encompasses environmental concerns. Most recently, DOE/FE explained that factors weighing on the public interest "include economic impacts, international impacts, security of natural gas supply, and environmental impacts, among others."[6] DOE rules require export applicants to provide information documenting "[t]he potential environmental impact of the project." 10 C.F.R. § 590.202(b)(7). DOE Delegation Order No. 0204-111 interpreted the NGA's public interest standard to require consideration of matters beyond the mere "domestic need for the gas to be exported."[7] Similarly, in FERC's recent order approving siting, construction, and operation of LNG export facilities in Sabine Pass, Louisiana, FERC considered potential environmental impacts of the terminal as part of its public interest assessment, which is analogous to DOE/FE's.[8]

In the face of this extensive authority indicating that the public interest inquiry requires consideration of environmental impacts, Waller's argument that the public interest turns solely on the adequacy of gas supply rests only on citation to DOE/FE's outdated import guidance. App. at 13. Waller argues that, because this guidance favors competitive markets for gas, impacts on domestic gas prices should be beyond the scope of DOE/FE's analysis. *Id.* Even if the guidance's determination not to directly prices of imported gas broadly implied that price impacts are outside the scope of analysis, this in no way implies that environmental impacts can or should similarly be excluded. More generally, however, the import guidance is itself outdated, and DOE/FE should reject Waller's argument that this import applies to exports. App. at 8-9. This thirty year old guidance does not reflect current understanding of the environmental impacts of gas production and consumption, nor does its reasoning apply to exports. In 1984, DOE published *Policy Guidelines and Delegation Orders Relating to the Regulation of Imported Natural Gas*, 49 Fed. Reg. 6,684 (Feb. 22, 1984). The primary issue confronted by these guidelines was whether to directly regulate prices at which gas

[5] Further support for the inclusion of environmental factors in the public interest analysis is provided by NEPA, which declares that all federal agencies must seek to protect the environment and avoid "undesirable and unintended consequences." 42 U.S.C. § 4331(b)(3).

[6] Jordan Cove, DOE/FE Order No. 3413, 6-7 (March 24, 2014); accord *Phillips Alaska Natural Gas Corporation and Marathon Oil Company*, 2 FE ¶ 70,317, DOE FE Order No. 1473, 1999 WL 33714706, *22 (April 2, 1999) (specifically enumerating environmental concerns as a factor in the public interest analysis).

[7] DOE Delegation Order No. 0204-111, at 1, 49 Fed. Reg. 6686, 6690 (Feb. 22, 1984). This order has been rescinded, but DOE/FE continues to cite it in discussing export applications. *See, e.g.,* Freeport Conditional Authorization, DOE/FE Order 3282, at 7.

[8] 139 FERC ¶ 61,039, PP 29-30 (Apr. 14, 2012). Sierra Club contends that other aspects of this order were wrongly decided, as was FERC's subsequent denial of Sierra Club's petition for rehearing, as we explain below.

could be imported from Canada.[9] DOE/FE determined that, if U.S. buyers were willing to pay market rates for imported gas, this would generally demonstrate a need for that gas.[10] This reasoning underlying this guidance does not apply to exports. First, the question before DOE/FE here is not to regulate the prices at which gas can be exported, but rather, whether to allow exports at all. A foreign purchaser's willingness to outbid domestic purchasers does not demonstrate that the US does not "need" that gas. Similarly, international gas markets and a foreign purchaser's willingness to pay for U.S. exports do not account for the environmental impacts of those exports. As we explain below, LNG exports have extensive environmental impacts, all of which have severe costs, but these costs are externalized by existing markets. Moreover, these costs are generally borne by the US public, whereas the benefits accrue to a small subset of US citizens and to the foreign purchasers of LNG. Accordingly, international gas markets are a wildly inappropriate indicator of the impacts of exports on the public interest.

Sierra Club recognizes that DOE/FE has referred to this guidance in prior export proceedings,[11] but in those proceedings, DOE/FE neither acknowledged nor discussed these differences between imports and exports. In this regard, the import guidance is akin to DOE/FE's outdated practice of conditionally authorizing export applications. Although DOE/FE conditionally authorized several export applications, DOE/FE has recently recognized that the purported policy justification for conditional authorizations does not apply to the export context, and DOE/FE has proposed to abandon this practice. Similarly, although DOE/FE's recent conditional export authorizations have relied on DOE/FE's import guidance, DOE/FE must acknowledge that the reasoning underlying this guidance has no application to the export context.

Finally, although DOE/FE has adopted a presumption that LNG export applications are consistent with the public interest, this presumption is rebuttable and not determinative. The D.C. Circuit has explained to DOE/FE that this presumption is "highly flexible, creating *only* rebuttable presumptions and leaving parties free to assert other factors." *Panhandle Producers & Royalty Owners Ass'n v. Economic Regulatory Admin.*, 822 F.2d 1105, 1110-11, 1113 (D.C. Cir. 1987) (emphasis added) (internal quotation marks omitted). Put differently, although DOE/FE may "presume" that an application should be granted, this presumption is not determinative, and DOE/FE retains an independent duty to determine whether an application is, in fact, in the public interest. *See* 10 C.F.R. § 590.404.

[9] 49 Fed. Reg. at 6,684-85.
[10] *Id.*
[11] *See, e.g.,* Jordan Cove, DOE Order 3413, at 7-8.

2. National Environmental Policy Act

NEPA requires federal agencies to consider and disclose the "environmental impacts" of proposed agency actions. 42 U.S.C. § 4332(C)(i). Agencies must "carefully consider [ ] detailed information concerning significant environmental impacts" and NEPA "guarantees that the relevant information will be made available" to the public. *Dep't of Transp. v. Public Citizen*, 541 U.S. 752, 768 (2004) (quoting *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 349 (1989)). DOE/FE's NEPA obligations are informed by general regulations promulgated by the Council on Environmental Quality and by additional agency-specific regulations promulgated by DOE. *See* 10 C.F.R. § 1021.103 (DOE regulation adopting CEQ NEPA regulations in full). These regulations implement NEPA via procedures that "insure that environmental information is available to public officials and citizens *before* decisions are made and *before* actions are taken." 40 C.F.R. § 1500.1(b) (emphases added). Agencies must "integrate the NEPA process with other planning at the earliest possible time to insure that planning and decisions reflect environmental values." 40 C.F.R. § 1501.2. "It is DOE's policy to follow the letter and spirit of NEPA; comply fully with the [CEQ] Regulations and apply the NEPA review process early in the planning stages for DOE proposals." 10 C.F.R. § 1021.100. In particular, while an EIS is being prepared "DOE *shall take no action* concerning the proposal that is the subject of the EIS" until the EIS is complete and a formal Record of Decision has been issued. 10 C.F.R. § 1021.211 (emphasis added). More generally, prior to completion of NEPA review, CEQ directs agencies to avoid actions that would tend to "limit the choice of reasonable alternatives," or "tend[] to determine subsequent development." 40 C.F.R. § 1506.1.

For purposes of the intersection of NEPA and the NGA, the NGA designated the former Federal Power Commission as the "lead agency" for NEPA purposes. 15 U.S.C. § 717n. The lead agency prepares NEPA documents for an action that falls within the jurisdiction of multiple federal agencies. FERC has since generally filled that role, preparing the NEPA documents for LNG export and import decisions, as it did in *Sabine Pass*. *See* 10 C.F.R. § 1021.342 (providing for interagency cooperation). Whichever agency plays the lead NEPA role, however, DOE's ultimate NEPA obligations are the same: DOE may not move forward until the full scope of the action *it* is considering – here, the approval of LNG export – has been properly considered. Thus, if the NEPA analysis that another agency prepares is inadequate to fully inform DOE/FE's decision or discharge DOE/FE's NEPA obligations, DOE/FE must prepare a separate EIS.[12]

[12] *See Sabine Pass LNG*, FERC Dkt. CP11-72-001, 140 FERC ¶ 61,076 P 32 (July 26, 2012) ("DOE has separate statutory responsibilities with respect to authorizing the export of LNG from Sabine Pass; thus it has an independent legal obligation to comply with NEPA."), DOE/FE Dkt. 10-111-LNG, Order 2961-A, 27 (Aug. 7, 2012) (DOE/FE recognizes that it is "responsible for conducting an independent review" of FERC's analysis and determining whether "the record needs to be supplemented in order for DOE/FE to meets its statutory responsibilities under section 3 of the NGA and under NEPA.").

NEPA requires preparation of an "environmental impact statement" (EIS) where, as here, the proposed major federal action would "significantly affect[] the quality of the human environment." 42 U.S.C. § 4332(C). An EIS must describe:

> i. the environmental impact of the proposed action,
>
> ii. any adverse environmental effects which cannot be avoided should the proposal be implemented,
>
> iii. alternatives to the proposed action,
>
> iv. the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
>
> v. any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

42 U.S.C. § 4332(C). The alternatives analysis "is the heart of the environmental impact statement." 40 C.F.R. § 1502.14. Here, the proposed action is to export LNG from a to be constructed facility; DOE/FE must consider alternatives to this action. DOE/FE must take care not to define the project purpose so narrowly as to prevent the consideration of a reasonable range of alternatives. *See, e.g.*, *Simmons v. U.S. Army Corps of Eng'rs*, 120 F.3d 664, 666 (7th Cir. 1997). If it did otherwise, it would lack "a clear basis for choice among options by the decisionmaker and the public." *See* 40 C.F.R. § 1502.14.

An EIS must also describe the direct and indirect effects and the cumulative impacts of a proposed action. 40 C.F.R §§ 1502.16, 1508.7, 1508.8; *N. Plains Resource Council v. Surface Transp. Bd.*, 668 F.3d 1067, 1072-73 (9th Cir. 2011). These terms are distinct from one another: Direct effects are "caused by the action and occur at the same time and place." 40 C.F.R. § 1508.8(a). Indirect effects are also "caused by the action" but:

> are later in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effect on air and water and other natural systems, including ecosystems.

40 C.F.R. § 1508.8(b). Cumulative impacts, finally, are not causally related to the action. Instead, they are:

> the impact on the environment which results from the incremental impact of the action when added to other

> past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

40 C.F.R. § 1508.7. The EIS must give each of these categories of effect fair emphasis.

Agencies may also prepare "programmatic" EISs, which address "a group of concerted actions to implement a specific policy or plan; [or] systematic and connected agency decisions allocating agency resources to implement a specific statutory program or executive directive." 40 C.F.R. § 1508.17(b)(3); *see also* 10 C.F.R. § 1021.330 (DOE regulations discussing programmatic EISs). As we discuss below, such an EIS is appropriate here.

3. Endangered Species Act

The Endangered Species Act (ESA) directs that all agencies "shall seek to conserve endangered species." 16 U.S.C. § 1531(c)(1). Consistent with this mandate, DOE/FE must ensure that its approval of Waller's proposal "is not likely to jeopardize the continued existence of any endangered species . . . or result in the destruction or adverse modification of [critical] habitat of such species." 16 U.S.C. § 1536(a)(2). "Each Federal agency shall review its actions at the earliest possible time to determine whether any action may affect listed species or critical habitat." 50 C.F.R. § 402.14(a); *see also* 16 U.S.C. § 1536(a)(2).

Here, DOE/FE's section 1536 inquiry must be wide-ranging, because Waller's export proposal will increase gas production across the Gulf region, if not nationwide. Thus, DOE/FE must consider not just species impacts at the proposed project site (although it must at least do that), but the effects of increased gas production across the full region the terminal affects.

To make this determination, DOE/FE should, first, conduct a biological assessment, including the "results of an on-site inspection of the area affected," "[t]he views of recognized experts on the species at issue," a review of relevant literature, "[a]n analysis of the effects of the action on the species and habitat, including consideration of cumulative effects, and the results of any related studies," and "[a]n analysis of alternate actions considered by the Federal agency for the proposed action." *See* 50 C.F.R. § 402.12(f). If that assessment determines that impacts are possible, DOE/FE must enter into formal consultation with the Fish and Wildlife Service and the National Marine Fisheries Service, as appropriate, to avoid jeopardy to endangered species or adverse modification of critical habitat as a result of its approval of Waller's proposal. 16 U.S.C. § 1536(a), (b).

B. Relationship Between DOE/FE's Other LNG Export Analyses and DOE/FE's NEPA, NGA, and ESA Obligations Here

LNG exports have the potential to significantly alter the American energy landscape, and represent a significant policy shift. As Sierra Club has repeatedly argued, DOE's existing guidance and practice are ill-suited to meeting DOE's statutory obligation of determining whether LNG exports are consistent with the public interest, and the appropriate course of action would be DOE to promulgate new regulations or guidance defining the process by which DOE will consider applications to export LNG.[13] This revision to DOE policy should be accompanied by a programmatic EIS evaluating the environmental impacts of LNG exports. Such a programmatic EIS would allow DOE/FE and the public to understand these proposals' relationship and their cumulative environmental and economic impacts, thus improving DOE/FE's ability to make informed decisions on export terminal applications and allowing DOE/FE, the public, and industry to identify prudent alternatives to serve the public interest and minimize environmental impacts.

To date, DOE has not responded to Sierra Club's petition for rulemaking or NEPA review regarding LNG exports. DOE has, however, commissioned two groups of studies regarding the general effects of LNG exports. In 2012 DOE released the two part "LNG Export Study," which consisting of the Energy Information Administration ("EIA") report titled "Effect of Increased Natural Gas Exports on Domestic Energy Markets," ("EIA Export Study")[14] and the NERA Economic Consulting report titled "Macroeconomic Impacts of LNG Exports from the United States" ("NERA Study"). In 2014, DOE released an "Addendum to Environmental Review Documents Concerning Exports of Natural Gas from the United States,"[15] together with three supporting reports from the National Energy Technology Laboratory. DOE accepted public comments on the NERA report and the 2014 documents. While these studies provide important information, there are not a substitute for formal rulemaking or programmatic NEPA review. Notably, DOE did not open new dockets for these proceedings. Accordingly, these studies do not have bind DOE's review of export applications or have any precedential effect.

Instead of proceeding with programmatic treatment of these issues, DOE has determined to adjudicate each export application individually. Yet even if DOE reviews Waller's application in an individual docket, this does not change the scope of the required analysis or of the materials DOE must review. Accordingly, DOE's review must incorporate the following.

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[13] *See* Sierra Club *et al.*, Petition for Rulemaking Regarding Natural Gas Export Policy (Apr. 8, 2013), attached as Exhibit 2.

[14] *See* http://energy.gov/fe/services/natural-gas-regulation/lng-export-study.

[15] *See* http://energy.gov/fe/draft-addendum-environmental-review-documents-concerning-exports-natural-gas-united-states.

First, DOE must include in this docket the general reports on LNG exports discussed above. These reports, and the comments thereon, should more generally be included in the dockets for all future LNG export applications. We raise this issue because, in soliciting comments on the NERA study and 2014 environmental reports, DOE strangely stated that the reports and comments thereon would "be included in the dockets of"[16] various subsets of the pending export applications: 15, 25, and 13 enumerated dockets for the NERA study, greenhouse gas lifecycle analysis, and general environmental addendum, respectively. Although more than 18 months have passed since NERA report was released, DOE has not revisited its list of 15 dockets or included the NERA materials in any subsequently opened dockets. Nor has DOE explained the consequences of this omission: for example, it is unclear whether DOE's decision to file these materials in earlier dockets, but not later ones, indicates that DOE somehow contends that the NERA materials are not pertinent to the later applications. DOE should resolve this unnecessary confusion. Absent such clarification from DOE and in an abundance of caution, in a separate filing in this docket, Sierra Club submits these reports, Sierra Club's comments thereon, and the exhibits thereto. We incorporate our comments on the NERA study and 2014 materials into this protest by reference.

Second, DOE cannot approve Waller's application without a full EIS. NEPA requires an EIS where a proposed major federal action would "significantly affect[] the quality of the human environment." 42 U.S.C. § 4332(C). If there is even a "substantial question" as to the severity of impacts, an EIS must be prepared. *See Klamath Siskiyou Wildlands Ctr. v. Boody*, 468 F.3d 549, 561-62 (9th Cir. 2006) (holding that the "substantial question" test sets a "low standard" for plaintiffs to meet). DOE/FE has categorically determined, by regulation, that "[a]pprovals or disapprovals of authorizations to import or export natural gas . . . involving major operational changes (such as a major increase in the quantity of liquefied natural gas imported or exported)" will "normally require [an] EIS." 10 C.F.R. Part 1021, Appendix D, D9. Thus, a full EIS, rather than an abbreviated Environmental Assessment, is required here.

Third, the EIS and Natural Gas Act analysis must consider upstream impacts, including induced gas production and changes to U.S. energy markets. DOE's environmental addendum wrongly concluded that NEPA did not require consideration of exports' effects on induced production. Sierra Club explained the errors in this conclusion in our comment on the environmental addendum, and as with all our arguments contained in those comments, we incorporate that argument here by reference. In addition, below, we provide further discussion regarding the ability to foresee impacts of induced gas production.

[16] *See* http://www.energy.gov/fe/life-cycle-greenhouse-gas-perspective-exporting-liquefied-natural-gas-united-states.

Because the environmental impacts of induced gas production, and similar indirect effects, must be included in the NEPA and Natural Gas Act analyses, DOE must consider alternatives that would lessen these impacts. The NGA public interest analysis requires an "exploration of all issues relevant to the 'public interest'," an inquiry which the Supreme Court held in *Udall* must be wide-ranging. In that case, which concerned hydropower, the regulatory agency was required to consider, for instance, "alternate sources of power," the state of the power market generally, and options to mitigate impacts on wildlife. 387 U.S. at 450. Under NEPA, the alternatives analysis is "the heart of the environmental impact statement," designed to offer "clear basis for choice among options by the decisionmaker and the public." 40 C.F.R. § 1502.14. Crucially, the alternatives must include "reasonable alternatives not within the jurisdiction of the lead agency," and must include "appropriate mitigation measures not already included in the proposed action or alternatives." *Id.* Here, alternatives that could lessen the indirect environmental effects include:

1. Whether export from other locations would better serve the public interest by mitigating or better distributing economic or environmental impacts;

2. Whether limitations on the sources of exported gas – e.g., limiting export from particular plays, formations, or regions – would help to mitigate environmental and economic impacts;

3. Whether conditioning export on the presence of an adequate regulatory framework, including the fulfillment of the recommendations for safe production made by the DOE's Shale Gas Subcommittee, would better serve the public interest by ensuring that the production increases associated with export will not increase poorly regulated unconventional gas production;

4. Whether to delay, deny, or condition exports based upon their effect on the U.S. utility market (including changes in air pollution emissions associated with the impacts of increased export demand on fuel choice);

5. Whether to require exporters to certify that any unconventional gas produced as a result of their proposal (or shipped through their facilities) has been produced in accordance with all relevant environmental laws and according to a set of best production practices (such as that discussed by the DOE's Shale Gas Subcommittee);

6. Whether to permit exports only if the export facilities are designed and operated so as to minimize their environmental impacts;

Fourth, DOE must consider the cumulative impact of all pending and completed export applications. The public, after all, will not experience each proposed terminal as an

individual project: It will experience them cumulatively, through the gas and electricity prices that they will raise and the environmental damage that they will cause. All analysts and observers have agreed, for example, that higher volumes of exports will cause greater gas price increases. Indeed, several models indicate that prices increase non-linearly with export volumes. That is, going from 4 to 6 bcf/d in exports, for example, may impact domestic prices more than going from 0 to 2 bcf/d.[17]

DOE cannot perform necessary cumulative impact assessment until, at a minimum, EIA completes the requested update of to its January 2012 export study.[18] This update is necessary because DOE has already granted final or conditional authorization to projects that meet the upper limit of export demand considered in the 2012 study (10.9 bcf/d of exports, which will require additional gas to drive liquefaction equipment).[19] Even this update may fall short of addressing the potential cumulative impacts, because the highest volume of demand DOE requests consideration of, 20 bcf/d, remains much less than the volume of exports DOE is likely to have considered before reviewing Waller's application.

DOE/FE cannot shirk the obligation to consider the full volume of proposed exports by asserting that is uncertain whether these exports will occur. Under NEPA, an agency may only exclude analysis of an event and its consequences when the event "is so 'remote and speculative' as to reduce the effective probability of its occurrence to zero." *See New York v. NRC*, 681 F.3d 471, 482 (D.C. Cir. 2012); *see also San Luis Obispo Mothers for Peace v. Nuclear Regulatory Comm'n*, 449 F.3d 1016, 1031 (9th Cir. 2006)

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[17] Robert Brooks, *Using GPCM to Model LNG Exports from the US Gulf Coast* 5 (2012), available at http://www.rbac.com/press/LNG%20Exports%20from%20the%20US.pdf, attached as Exhibit 3. One reason prices may increase this way is that domestic gas consumers differ in their ability to reduce gas consumption. *Id.* at 7. As export volumes increase, increasing numbers of inflexible domestic consumers are forced to compete with exports, further driving up prices. When export volumes are lower, by contrast, price-sensitive domestic consumers can respond to price increases by reducing their consumption, freeing gas supplies for exports and limiting price impacts. The Brooks study, which estimates low price-sensitivity, predicts significantly higher price increases than the EIA Export study. *Id.* at 5, 7. Similarly, while the Deloitte "Made in America" report cited by Waller only considers a single, 6 bcf/d export scenario, in another report Deloitte considered multiple export volumes, and Deloitte predicted that doubling exports will more than double price impacts thereof. Deloitte MarketPoint, *Analysis of Economic Impact of LNG Exports from the United States*, at 3, 24, attached as Exhibit 4 (originally filed as Appendix F to Excelerate Liquefaction Solutions I, LLC, *Application for Long-Term, Multi-Contract Authorization to Export Liquefied Natural Gas to Non-Free Trade Agreement Countries*, DOE/FE Dkt. 12-146-LNG (Oct. 5, 2012)).

[18] Department of Energy, *Request for an Update of EIA's January 2012 Study of Liquefied Natural Gas Export Scenarios* (May 29, 2014), available at http://energy.gov/sites/prod/files/2014/05/f16/Request%20for%20Updated%20EIA%20Study.pdf, attached as Exhibit 5.

[19] Applications Received by DOE/FE to Export Domestically Produced LNG from the Lower-48 States (as of August 28, 2014), available at http://energy.gov/sites/prod/files/2014/09/f18/Long%20Term%20LNG%20Export%20Concise%20Summary%20Table%209_4_14%20%282%29.pdf, attached as Exhibit 6.

(same). Here, DOE/FE cannot rule out as speculative the possibility of all proposed exports occurring. We note that EPA has repeatedly and explicitly argued that NEPA review of proposed export projects include "the context of the larger energy market, including existing export capacity *and export capacity under application to the Department of Energy*."[20]

If DOE/FE looks—wrongly—only at the range of exports it deems likely to occur, DOE/FE must not underestimate this likelihood. In particular, although Sierra Club has repetedly explained that the NERA study underestimates the likely market for U.S. LNG exports, DOE/FE's recent conditional authorizations have not addressed many of Sierra Club's arguments.[21] NERA concluded that exports would only occur when the spread between US gas prices and prices in potential foreign markets exceeded the cost of liquefying, transporting, and regassifying US produced gas. But NERA overstates these transaction costs and ignores the ways in which "take-or-pay" contracts distort this market.

As to transaction costs, proposed West Coast terminals will have significantly lower costs for export to Asia than will the Gulf Coast facilities NERA considered. The proponents of the proposed Jordan Cove Energy Project explained that its transportation costs to Japan were significantly lower than those assumed by the NERA Study. Although Jordan Cove Energy Project would face higher facility construction and thus liquefaction costs than Gulf Coast facilities, Jordan Cove asserts that, in aggregate, its total processing and transportation costs will be $0.44/MMBtu lower than the estimates used by NERA.[22] Accordingly, insofar as the cost of processing and transporting LNG sets the ceiling on price increases resulting from exports, that ceiling could be $0.44/MMBtu higher than the NERA Study estimates. $0.44/MMBtu represents roughly 5 to 10% of NERA's predicted 2035 wellhead gas prices, meaning NERA may have significantly underestimated the price range within which exports will occur.[23] Although Sierra Club raised this argument in its initial and reply comments on the NERA study,[24] DOE/FE has not addressed it in its export conditional authorizations.[25]

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[20] *See, e.g.,* EPA, Scoping Comments – The Jordan Cove Energy Project LP, FERC Dkts. PF12-7 and PF12-17, at 3 (Oct. 29, 2012) (emphasis added), attached as Exhibit 7. *See also* EPA, Scoping Comments – Cove Point Liquefaction Project, FERC Dkt. PF12-16-000, at 2 (Nov. 15, 2012), attached as Exhibit 8; EPA, Scoping Comments – The Oregon LNG Export Project and Washington Expansion Project, FERC Dkts. PF12-18 and PF12-20, at 3 (Dec. 26, 2012), attached as Exhibit 9.

[21] *See, e.g.*, Jordan Cove, DOE Order 3413.

[22] Comment of Jordan Cove Energy Project on NERA study, at 2 (Jan. 24, 2013), available at http://www.fossil.energy.gov/programs/gasregulation/authorizations/export_study/Joan_Darby01_24_13.pdf, attached as Exhibit 10.

[23] Macroeconomic Impacts of LNG Exports from the United States ("NERA Study"), at 50.

[24] Sierra Club Initial comments on NERA Economic Consulting's study ("Initial NERA Comment"), at 12-13, Sierra Club Reply comments on the NERA Economic Consulting's study, ("Reply NERA Comment") at 11-12; *see also* Jordan Cove, DOE/FE Order 3413, at 116 (summarizing this argument).

[25] *See, e.g.,* Jordan Cove, DOE/FE Order 3413, at 116, 122-123.

As to contract structure, previous export applicants have adopted "take or pay" liquefaction services arrangements, wherein would-be importers will be required to pay a fee to reserve terminal capacity, regardless of whether that capacity is actually used to liquefy and export gas.[26] The "pay" provision constitutes a sunk cost that will effectively raise the price ceiling under which exports will occur. For example, if the cost to liquefy, transport, and regassify gas is $4/MMBtu, but an importer has entered a "take or pay" contract reserving terminal capacity but requiring payment of $1.50/MMBtu[27] for unused capacity, the importer will have an incentive to import gas so long as the spread between US and foreign prices exceeds $2.50/MMBtu, whereas NERA predicts that no exports will occur once the price spread falls below $4/MMBtu. Exports may continue to occur – and domestic prices may therefore continue to rise – even where NERA predicts that exports will cease.[28] Again, in its recent conditional authorizations, DOE/FE has ignored this aspect of Sierra Club's argument. Sierra Club does not contend that contracts will "lock up natural gas for export" such that exports will occur regardless of market conditions in the US or abroad.[29] Instead, Sierra Club has shown that market forces and the industry structure will likely cause exports to occur in certain conditions where NERA concluded that exports would not, such that the overall volume of exports is likely to be higher than NERA forecasts. Thus, DOE/FE's cumulative impact analysis must not be limited to the volumes of exports the NERA study predicts, both because DOE/FE's statutory obligations prevent DOE/FE from excluding proposed projects from the cumulative effects analysis on the assumption that those projects are economically unlikely to occur, and because NERA understates the range of projects that are likely to occur. We further note that EIA's most recent Annual Energy Outlook forecasts 9.6 bcf/d of US LNG exports by 2029.[30]

Finally, consistent with the policy finalized on August 15, 2014, DOE must reject Waller's request for a conditional authorization prior to completion of NEPA review.[31]

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[26] *See Sabine Pass* DOE Order No. 2961, at 4 (May 20, 2011); Cheniere Energy April 2011 Marketing Materials, *available at* http://tinyurl.com/cqpp2h8 (last visited Sept. 3, 2014) and attached as Exhibit 11, at 14.

[27] Within the $1.40 to $1.75/MMBtu range of "capacity fees" contemplated by Sabine Pass's parent company, Cheniere Energy April 2011 Marketing Materials at 14.

[28] *See* NERA Study, at 37-46.

[29] Jordan Cove, DOE Order 3413, at 118.

[30] *See, e.g.* EIA, 2014 Annual Energy Outlook, MT-22 (May 7, 2014) (predicting an increase of net exports of 3.5 trillion cubic feet per year, or 9.6 bcf/d, by 2029), available at http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

[31] Application at 20; 79 Fed. Reg. 48132 (Aug. 15, 2014).

C. Waller's Proposal Will Have Numerous Harmful Environmental and Other Effects and Is Contrary to The Public Interest

LNG exports will have wide ranging effects on the public and environment. Gas exported as LNG must come from somewhere. The only options are an increase in domestic supply to match this new demand or a decrease in other domestic consumption to free up gas that would otherwise be used elsewhere, both of which have significant environmental impacts. The US will likely see a combination of both, as explained in the EIA's LNG Export Study and numerous other analyses. These analyses uniformly agree that the predominant effect will be an increase in supply, provided by gas producers increasing their output in response to exports' demand. The extra demand created by exports will also cause increases in domestic gas prices, which will cause some domestic consumers to reduce their consumption.

Thus, the proposed project will impact the environment on many levels:

- At and near the terminal site, as a result of construction and operation of the liquefaction and export facilities.
- In the regions where gas production increases in response to exports.
- Nationwide, as higher gas prices increase utilization of other fuels.
- Globally, as greenhouse gas emissions increase as a result of increased gas production and combustion.

Each level of impacts carries environmental cost—which have significant economic impact—as well as more traditional economic impacts. For example, increases in domestic gas prices will limit real wage growth, eliminate jobs in manufacturing and other domestic industries, disrupt communities, and regressively transfer wealth from working class families to large corporations. Available evidence indicates that even when these environmental and intra-US distributional effects are ignored (although they must not be), LNG exports will likely have a negative impact on GDP and other measures of aggregate welfare.[32] Each of these adverse impacts requires additional consideration in the NEPA process and in DOE/FE's ongoing review of the economic impacts of gas exports. Even the evidence of adverse impacts available now, however, greatly overwhelms Waller's assertion that its proposal will provide public benefits.

DOE/FE cannot rely on its prior authorization of exports from other terminals to demonstrate that the current application is in the public interest. Prior decisions by DOE/FE are not binding and the agency retains an independent duty to determine whether an application is, in fact, in the public interest. *See* 10 C.F.R. § 590.404.

[32] *See* Kemal Sarica & Wallace E. Tyner, *Economic and Environmental Impacts of Increased US Exports of Natural Gas* (Purdue Univ., Working Paper, 2013) (available from the authors); *see also* Wallace Tyner, Initial Comment on NERA Study (Jan. 14, 2013) (summarizing the results of the above study), attached as Exhibit 12.

1. Local Environmental Impacts

Waller proposes to build a new LNG export terminal at a 180-acre site on the Calcasieu Ship Channel in Cameron Parish, Lousiana. Adverse environmental effects will include (but are not limited to) air pollution, disruption of aquatic habitat, increased noise and light pollution, and impacts on fish and wildlife related to the preceding impacts. These impacts must be considered in both the NEPA analysis and in DOE/FE's public interest determination.

Sierra Club cannot provide a thorough discussion of local impacts in this filing, because the precise nature and extent of these impacts will depend on the final site design and plan, which Waller has not yet provided. Therefore, Sierra Club must be permitted to supplement this protest once NEPA review is complete, to address the impact of environmental effects on the overall public interest analysis.

Even on the available record, however, it is clear that the project will have significant direct impacts. It is likely that the project will significantly affect wetlands: although the proposed export volumes are smaller than for some other projects, Waller indicates that it will use a project site larger than many other facilities, amounting to 180 acres. In this region, it is unlikely that a project of this size can be constructed without significantly impacting wetlands. Waller's application also indicates that the project will have significant air pollution impacts, including higher impacts per unit of output than many other proposed facilities. Waller apparently proposes a different technology, which may be less efficient than other designs. Air emissions from liquefaction facilities roughly correlate with fuel consumption.[33] EIA generally assumes that the liquefaction process requires fuel equivalent to 9-10% of the volume of gas liquefied. Here, however, Waller states that exporting 0.19 bcf/d will increase demand by 1.07 bcf per day. Application at 12. While this statement may be in error, it highlights the possibility that Waller's process, while producing lower volumes of LNG than projects DOE has considered to date, may have higher impacts per unit of LNG produced than larger and apparently more efficient facilities.

Ultimately, direct environmental impacts undoubtedly impact the public interest; DOE/FE must consider these impacts in its public interest analysis; and Sierra Club, together with the broader public, must be given an opportunity to comment on these issues once additional information is available.

[33] This correlation is stronger for GHGs, and somewhat less strong for other pollutants, which are more often subject to post-combustion pollution control equipment.

2. Induced Gas Production

Further, and likely greater, environmental impacts will result from increased gas production. Waller, the EIA, NERA, essentially every other LNG export applicant, and other informed commenters all agree that LNG exports will induce additional production in the United States. EIA, for example, anticipates that production will increase by roughly 63% of the amount of demand created by exports.[34] DOE has recognized the climate impacts of this additional production can be assessed without knowing where this production will occur. Even where DOE determines that analysis of environmental impacts requires predictions regarding the location of additional production, available tools allow DOE to predict where increased production will occur. NEPA and the NGA therefore require DOE/FE to consider the effects of this additional production.

a. Waller's Proposal Will Induce Additional U.S. Gas Production

Waller's application repeatedly argues that its proposed exports would lead to increased gas production. Waller asserts that its project "would allow otherwise un-utilized natural gas [to] be sold into the regional, if not global, LNG market, driving the development of new resources that might otherwise go untapped and not make their way to market." Application at 15. In discussing impacts of exports on prices, Waller repeatedly contends that price impacts will be minimal, because, *e.g.*, "Producers can develop more reserves in anticipation of demand growth, such as LNG exports." Application at 14.

LNG exports represent a new source of gas demand, composed of both the volume of gas exported as well as with the gas necessary for the operation of export facilities. As noted above, EIA's figures indicate that when demand from liquefaction equipment operation is considered, Waller's export of 0.19 bcf/d would be expected to create a total of 0.21 bcf/d, or 76 bcf/year, of new demand.

EIA and private modelers agree that US LNG exports will increase domestic production by at least 60 percent of the demand created by export projects. EIA provides the specific estimate for its reference cases at 63%.[35] The EIA further predicts that "about three quarters of this increased production [will come] from shale sources," with the remainder derived from other production types.[36] Thus, EIA indicates that Waller's proposed project would induce 48 bcf/year of new production.

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[34] EIA Export Study at 6, 10.

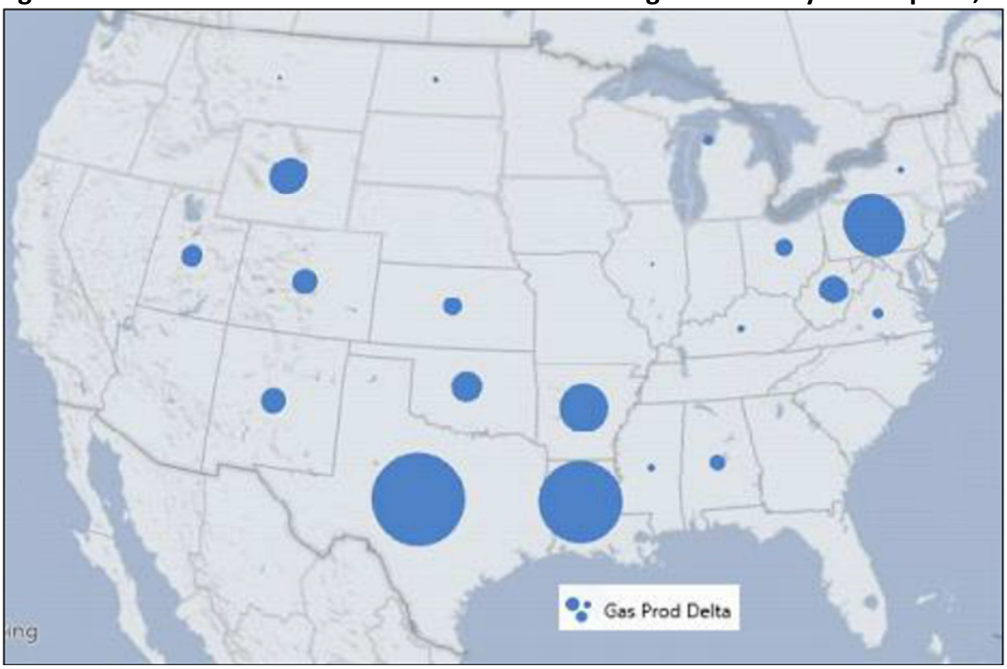
[35] From the EIA Export Study at 6, 10. *See also, e.g.*, Deloitte MarketPoint, Analysis of Economic Impact of LNG Exports from the United States, *supra* n.17, at 3, 24.

[36] EIA Export Study at 6. Specifically, EIA concluded that EIA has concluded that "[o]n average, across all cases and export scenarios, the shares of the increase in total domestic production coming from shale gas, tight gas, [and] coalbed sources are 72 percent, 13 percent, [and] 8 percent," respectively. *Id.* at 11.

While DOE has previously stated that it is uncertain where additional production induced by exports would occur, DOE has not acknowledged—much less discussed—the models that have been developed to provide precisely this kind of prediction. As Sierra Club explained in comments on the DOE Addendum and in our prior protest in this docket, EIA's National Energy Modeling System[37] and Deloitte Marketpoint's world gas model[38] are sophisticated tools that can predict where this additional production is most likely to occur.

Another report, by ICF, has already published forecasts of state-specific increases in gas production in response to exports.[39] The ICF State Level Impact study uses a detailed model of new production in response to exports. That report's map of predicted production increases in response to the particular LNG export scenario used by the authors is provided below.[40] This same tool could likely be used to predict where production would increase in response to Waller's particular project. Alternatively, the general export scenario already conducted by this study provides a basis for evaluating the cumulative impacts of proposed export projects.

Figure 1: ICF Forecast of Natural Gas Production Changes Caused by LNG Exports, 2025



Source: ICF GMM

Note: The map above shows the relative natural gas production changes in the ICF Base Case in 2025 (relative to the Zero LNG Exports Case).

[37] *See* Sierra Club, et al., Comments on DOE Environmental Addendum, page 6, and Exhibits 1 – 3 thereto.
[38] *Id.* at 7 and Exhibit 4 thereto.
[39] *See* U.S. LNG Exports: State-Level Impacts on Energy Markets and the Economy (November 13, 2013), available at http://www.api.org/~/media/Files/Policy/LNG-Exports/API-State-Level-LNG-Export-Report-by-ICF.pdf, and attached as Exhibit 13.
[40] *Id.* at 15.

We offer no opinion at this time about the strengths or weaknesses of these private models relative to EIA's. We simply note that multiple tools exist which allow predictions of how and where production will respond to exports.

b. Harms Caused by Induced Gas Production

This additional gas production would have significant environmental impacts. Natural gas production is a significant air pollution source, can disrupt ecosystems and watersheds, leads to industrialization of entire landscapes, and presents challenging waste disposal issues. As we have explained in our prior comments incorporated herein by reference, DOE must consider these harms as part of the NEPA and Natural Gas Act assessments.

DOE has understated the air pollution emissions caused by natural gas production. As we explained in our comments on the DOE environmental materials, while DOE estimates, on the basis of emission factors and component counts, that gas production has a methane leak rate of 1.3 to 1.4%, numerous peer reviewed studies that have measured methane in the atmosphere indicate that the actual leak rate is more likely to be 3%.[41] Since the DOE environmental materials were released, yet another peer reviewed paper has supported this estimate. This paper, by researchers at Carnegie Mellon and the National Ocean and Atmospheric Administration, concludes that the most likely methane leak rate is between 2 and 4 percent.[42] Emissions of methane are generally correlated with emissions of volatile organic chemicals (VOC) and other pollutants, as we explain below.

Of particular concern for the Waller project are ozone impacts of induced gas production, especially because the majority of production induced by the Waller project is likely to occur in nearby shale gas plays and exacerbate existing unhealthy ozone levels in the region. Oil and gas production is a significant source of VOC and nitrogen oxides (NO_x), which lead to ozone formation. Numerous areas of the country with heavy concentrations of drilling are now suffering from serious ozone problems[43]. For example, the Alamo Area Council of Governments recently concluded that increasing oil and gas production in the Eagle Ford shale would increase 8-hour ozone design values at regional air quality monitors by 0.5 to 0.7 parts per billion.[44] This explained that in light

[41] Sierra Club, et al., Comments on DOE Export Life Cycle Analysis, at 7.
[42] Stefan Scheietzke *et al*., "Natural gas fugitive emissions rates constrained by global atmospheric methane and ethane" *Environmental Science & Technology*, (June 19, 2014), DOI: 10.1021/es501204c, attached as Exhibit 14 (see pages 22 to 23 of "Just Accepted" manuscript)
[43] See Sierra Club Comment on Environmental Addendum, at 16 – 19.
[44] Alamo Area Council of Governments, *Development of the Extended June 2006 Photochemical Modeling Episode: Technical Report* (October 2013), available at https://www.aacog.com/DocumentCenter/View/19262 and attached as Exhibit 15.

of these increases, "If the EPA lowers the 8-hour ozone standard, it will be difficult for the San Antonio-New Braunfels MSA to meet that lower attainment threshold."[45] A decrease in the 8-hour ozone standard was recently recommended by EPA's "Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards,"[46] and is therefore increasingly likely.

As we have discussed above, Waller's proposal is likely to inducd 48 bcf/year of additional production. A significant fraction of the gas produced will leak during the gas lifecycle: we estimate emissions associated with production induced by Waller under multiple leak rates, including a 1% leak rate (which is included as a conservative case to reflect successful air pollution controls more extensive than those which EPA has promulgated), the 1.4% figure used in the NETL GHG lifecycle study, and the 3.0% leak rate provided by the Miller *et al.* PNAS study.[47] EPA conversion factors allow us to estimate the emissions of individual pollutants associated with this volume of production and each leak rate.[48] Here, we estimates for methane, VOC, and HAP.

Table 1: Emissions Associated with Production of 48 bcf/y of Natural Gas

Leak Rate	Methane (tons)	VOC (tons)	HAP (tons)
1%	9,984	1,457	106
1.40%	13,978	2,039	148
3.00%	29,952	4,370	317

Thus, Waller's proposal would be responsible for hundreds of thousands of tons of increased air pollution. For perspective, these emissions are far above the thresholds for "major" source permitting under the Clean Air Act, which are generally just tens of

[45] *Id*. at v. *See also* Ahmadi, Mahdi and Kuruvilla John, *An evaluation of the spatio-temporal characteristics of meteorologically-adjusted ozone trends in North Texas*, Air Quality Technical Meeting NCTCOG: Arlington, TX (Apr. 17, 2014) (modeling recent history Barnett Shale gas well contribution to ozone levels in the Dallas/Fort Worth area), *available at* http://www.nctcog.org/trans/committees/aqtc/041714/Item.4.pdf and attached as Exhibit 16**.**

[46] U.S. EPA, *Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards*, available at http://www.epa.gov/ttn/naaqs/standards/ozone/data/20140829pa.pdf and attached as Exhibit 17.

[47] Sierra Club, et al., Comments on DOE Export Life Cycle Analysis, at 9.

[48] EPA, Oil and Natural Gas Sector: Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution, Background Technical Support Document for the Proposed Rules, at 2-4 (July 2011) ("2011 TSD"), at Table 4.2. EPA calculated average composition factors for gas from well completions. EPA's conversions are: 0.0208 tons of methane per mcf of gas; 0.1459 lb VOC per lb methane; and 0.0106 lb HAP per lb methane. These estimates, which are based on a range of national data, provide a beginning point for quantitative work, although greater precision could be provided using forecasts of the distribution of production likely to be induced by the Waller project and emission rates particular to those plays.

tons of pollution; for greenhouse gases, the threshold is generally 75,000 tons of carbon dioxide equivalent. Waller would thus greatly increase air pollution in the regions from which it draws its gas, imperiling public health and the global climate.

3. Environmental Impacts of Increased Domestic Gas Prices

Just as all observers agree that exports will increase gas production, all observers agree that exports will increase domestic gas prices. Waller agrees with this consensus, as it must, disputing only the magnitude of the increase. App. at 14-15. As we explain elsewhere, the EIA and NERA studies, and materials submitted in connection with this application, all understate the likely price increase that would result from proposed LNG exports.

These price increases will, in turn, likely increase greenhouse gas emissions from the U.S. electricity sector, as some U.S. generators shift from natural gas to coal. We discussed this effect in our comment on DOE's materials regarding the environmental effects of LNG exports.[49]

4. Environmental Impacts of End User Consumption of LNG

DOE/FE must reject Waller's argument that "Because natural gas is a cleaner burning fuel than other fossil fuels traditionally used in commerce, increases in LNG exports can significantly benefit environmental." [sic]. Application at 18. Waller discusses solely combustion emissions, but as we have explained above, LNG exports have many other environmental impacts. Moreover, whereas Waller seeks to contrast LNG with other fossil fuels, countries importing LNG will likely use imported gas, at least in part, in place of renewable sources of energy or conservation. There is no evidence indicating that the primary (much less sole) effect of LNG exports will be substitution other fossil fuel consumption. We discuss these issues in greater detail in our incorporated comment regarding DOE's environmental addendum and life cycle analysis. For the reasons given there, DOE must reject Waller's assertion of potential environmental benefit.

5. Economic Impacts

As we have shown, LNG exports will have significant adverse environmental impacts, which must be weighed against any potential economic benfits in DOE's Natural Gas Act public interest analysis. The potential economic benefits, however, are overstated. Indeed, available evidence indicates that even from a purely economic perspective (ignoring, inappropriately, economic impact of environmental harm), the project is contrary to the public interest. Based on a sober assessment of likely economic impacts, rather than balancing environmental harm against economic benefit, DOE will find both

[49] Sierra Club, et al., Comments on DOE Export Life Cycle Analysis at 4-5.

environmental and economic factors indicating that the application is contrary to the public interest and must be denied.

a. Price and Supply Impacts

LNG exports will increase domestic gas prices, as Waller concedes. Application. at 14-15. Price increases are contrary to the public interest. Price increase will harm the majority of the American public by decreasing real wages and reducing employment in energy-intensive industries. In addition, as explained above, price increases in domestic coal consumption in the electricity sector. Because both of these harms are correlated with the magnitude of price increases, informed forecasts of prices are important.

Price impacts are closely related to available supplies, and DOE must reject Waller's Pollyannaish statements regarding gas supply. Waller contends that studies have revealed "a consistent trend of upward re-adjustment of US recoverable natural reserves." Application at 11. Even looking solely at the EIA forecasts cited by Waller reveals this not to be the case: EIA's 2011 estimates were revised downward in 2013. *Id.*[50]

When discussing price directly, Waller relies on estimates from Deloitte, but provides no basis for using these estimates over EIA's. Even the EIA estimates, which are higher than Deloitte's, do not reflect the range of potential price increases, because export proponents plan to bring exports online faster than EIA's "rapid" scenarios, and because proposed exports exceed the volumes of proposed exports. Finally, to the extent that NERA indicated that price increases would be self-limiting, NERA understates the likely market for exports. We explain each of these issues below.

EIA's 2012 LNG export study provides the foundation model for how domestic gas prices will increase in response to exports. EIA modeled prices and production over a 20 year period for a range of export scenarios, including scenarios involving 6 and 12 bcf/d of demand from exports.[51] In EIA's "reference" case for gas production recoveries, EIA predicts 10 to 13% increases in the 20-year average of Henry Hub prices for scenarios with 6 bcf/d of demand from exports. [52] For the 12 bcf/d scenarios, EIA's reference case predicts 14 to 26% increases in Henry Hub prices.[53] In dollar amounts, these range from

[50] Waller further mischaracterizes the EIA Annual Energy Outlooks by contending that they do not include projections for LNG exports. Waller's application, filed in November of 2013, strangely cites the 2012, rather than the 2013, Annual Energy Outlook. Application at 12 n.28 (apparently citing AEO 2012 at table A13 (mistakenly cited as table 13)). The cited estimates *do* include exports, and forecasts net LNG export of 0.62 to 0.66 tcf/year from 2020 to 2035. http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf *See also supra* n.30 (discussing forecasts of LNG exports in EIA's 2014 AEO).

[51] As noted above, these scenarios assumed that the liquefaction process would consume gas as well, so the actual volume of exports would be closer to 5.5 or 10.9 bcf/d.

[52] EIA Export Study at table B1.

[53] *Id.*

$0.55 to $1.22 per MMBtu price increases. The Deloitte report Waller cites, in contrast, estimates that 6 bcf/d of exports would produce only a $0.22 increase in Henry Hub prices.[54] Absent a strong showing that Deloitte's estimates are superior to those prepared by EIA (a showing that Waller has not even attempted), it would be arbitrary and capricious for DOE/FE to use industry estimates instead of the estimates produced by the impartial federal agency DOE/FE specifically tasked with examining this particular issue. 5 U.S.C. § 706, *Motor Vehicle Mfrs. Ass'n of the United States v. State Farm Mut. Auto. Ins. Co.*, 463 U.S. 29, 43 (1983).

Even EIA's 2012 estimates are too low, because EIA considered far lower volumes of exports than are currently proposed,[55] and EIA did not consider the possibility of exports coming online as quickly as project applicants propose. The EIA's "rapid" scenario considered an increase in export demand of 3 bcf/d per year (i.e., 2.7 bcf/d of actual LNG exports). A review of easily-attainable information of projected facility start-up times indicates that export proponents claim that facilities will come on line more rapidly than this. A non-exhaustive search provided anticipated start-up times for 12 of the 32 proposed export projects. Waller anticipates a start date of 2017. Application at 12. Several export applicants have estimated three year phase-in periods for bringing their facilities fully online.[56] Assuming that other facilities will also follow this three-year on-ramp period, we see the following:

[54] Deloitte, Made in America.
[55] *Supra* Part III.B.
[56] Japan's Kansai to buy U.S. Cameron LNG from Mitsui, Thompson Reuters (March 31, 2014), available at http://in.reuters.com/article/2014/04/01/lng-kansai-elec-p-idINL4N0MT0D020140401 and attached as Exhibit 18, Sabine Pass Monthly Progress Report February 2014, attached as Exhibit 19.

Table 2: Anticipated Commencment Dates for Proposed Exports

	New LNG Export Capacity Brought Online, in bcf/d			
	2016	2017	2018	2019
Sabine Pass[57]	1.38	1.38	1.38	
Cameron		0.57	0.57	0.57
Cove Point[58]		0.26	0.26	0.26
Oregon LNG[59]		0.42	0.42	0.42
Excelerate[60]		0.46	0.46	0.46
Delfin[61]		0.35	0.35	0.55
Waller		0.06	0.06	0.06
Magnolia LNG[62]			0.81	0.27
Cheniere/Corpus Christi[63]			0.7	0.7
CE FLNG[64]			0.36	0.36
Jordan Cove[65]				0.27
Lake Charles[66]				0.67
Totals:	1.38	3.5	5.37	4.59

The figures represent LNG export volumes, not new demand volumes. Using EIA's assumption that additional gas equal to 10% of the processed volume is generally used to drive liquefaction equipment, the facilities on this chart represent new demand of 3.58, 5.907, and 5.049 bcf/d in the years 2017, 2018, and 2019, significantly more than

[57] *Id.*

[58] DOE approves Dominion Cove Point LNG exports to non-FTA countries, Oil & Gas Journal (September 11, 2013), available at http://www.ogj.com/articles/2013/09/doe-approves-dominion-cove-point-lng-exports-to-non-fta-countries.html and attached as Exhibit 20.

[59] FACTBOX – North America natural gas export plans, Thompson Reuters (March 14, 2014), available at http://uk.reuters.com/article/2014/03/07/lng-export-north-america-idUKL1N0M418820140307 and attached as Exhibit 21.

[60] *Id.*

[61] *See,* Delfin LNG LLC, *Application for Long-term Authorization to Export Liquefied Natural Gas to Non-Free Trade Agreement Countries*, at 7. Available at http://www.fossil.energy.gov/programs/gasregulation/authorizations/2013_applications/13_129_lng_Application.pdf and attached as Exhibit 22.

[62] Magnolia LNG fact sheet, available at http://www.magnolialng.com/IRM/Company/ShowPage.aspx?CategoryId=190&CPID=1980&EID=50440019 and attached as Exhibit 23.

[63] LNG World News, Endesa Buys More LNG from Cheniere (April 8, 2014), available at http://www.lngworldnews.com/endesa-buys-more-lng-from-cheniere/ and attached as Exhibit 24.

[64] FACTBOX, *supra* n.59.

[65] U.S. approves Veresen's LNG project in Oregon, The Globe and Mail (March 24, 2014), available at http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/us-approves-veresens-oregon-lng-project/article17652931/ and attached as Exhibit 25.

[66] Lake Charles LNG export project partners file FERC application, Oil & Gas Journal (March 26, 2014), available at http://www.ogj.com/articles/2014/03/lake-charles-lng-export-project-partners-file-ferc-application.html and attached as Exhibit 26.

the 3 bcf/d in EIA's "high" scenarios. And these 12 facilities are only a fraction of the 34 different terminals (some with multiple applications) with applications before DOE.[67]

Furthermore, as explained in our discussion of cumulative impacts above, [68] the NERA study overstates the extent to which price increases from exports will be self limiting. about self-limiting nature of price increases is wrong for reasons stated above (transaction costs and take-or-pay contracts). In particular, NERA fails to account for the role of sunk costs in export agreements and by overstates the costs of some LNG transport.

b. Waller's Project Will Harm U.S. Workers and the U.S. Economy

To determine consistency with the public interest, DOE cannot look at price impacts in isolation: DOE must look at the effect given price increases will have on the public (together with the other aspects of the public interest inquiry). Available evidence, including the NERA study DOE commissioned, indicates that the exports Waller proposes will decrease wages and make most US families worse off. Waller's pending application provides minimal discussion of these issues. As we have explained in comments on the NERA study, the project will likely cause net economic harm even if environmental impacts are excluded from consideration. When environmental impacts (and their economic effects) are considered in addition to these purely economic harms, as they must be, it is clear that the project is contrary to the public interest.

Waller does not acknowledge, much less discuss, the economic harms exports will cause. Domestic gas price increases that will result from exports will have far-reaching effects on the U.S. economy. Consumers will face higher total gas bills despite reducing their consumption of gas. Employment and wages in energy-intensive industries such as manufacturing will decline because of reduced gas prices. Even in regions where export spurs additional gas production, temporary growth in jobs will likely lead to long-term economic decline, as these regions suffer from the "resource curse" and boom-bust cycle that plagues extractive economies. The result will be decreases in real wage growth for the overwhelming majority of Americans who do not own (directly or indirectly) stock in gas producing companies, as well as decreases in nationwide employment.[69] As with environmental effects, DOE/FE cannot approve the pending application without thoroughly considering these impacts. If DOE/FE were to make a decision on the available evidence, DOE/FE would have to conclude that these impacts render exports contrary to the public interest.

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[67] Applications Received by DOE/FE to Export Domestically Produced LNG from the Lower-48 States (as of August 28, 2014), *supra* n.19.
[68] *Supra* Part III.B
[69] EIA Export Study, at 6, 14; NERA Study, at 8-9.

Perhaps the most immediate and dramatic economic effect of exports will be job losses in energy intensive industries, such as manufacturing. Research on the effects of LNG export in Australia, which has already accumulated experience with gas exports, demonstrates the adverse effects exports can have on domestic industry.[70] The NERA study indicates that similar adverse effects are likely to occur in the U.S., despite the fact that the NERA study was not designed to capture these effects. Specifically, NERA predicts declines in wage income for each of its export scenarios, and changes in wage growth can be translated into losses of job equivalents (as NERA has done using the same model elsewhere). According to NERA, exports will cause these industries to suffer job losses in the tens to hundreds of thousands.[71]

Even gas producing regions will likely be worse off in the long term, despite short-term job growth as a result of increases in gas production. "Resource curse" effects are well documented in the economic literature. One of the most comprehensive surveys, by Professors Freudenburg and Wilson, of economic studies of "mining" communities (including oil and gas communities) concludes that the long-term economic outcomes are "consistently and significantly negative."[72] Headwaters Economics performed a similar study in 2009, documenting this trend in western U.S counties which focused on resource extraction rather than more durable economic growth strategies. The Headwaters study looked at the performance of "energy-focusing" regions compared to comparable counties over the decades since 1970.[73] It concludes that "counties that have focused on energy development are underperforming economically compared to peer counties that have little or no energy development."[74] A third study, by Amanda Weinstein and Professor Mark Partridge of Ohio State University, found this general trend to apply specifically to communities where shale gas extraction is occurring.[75] Using Bureau of Economics Analysis statistics, the Ohio study directly compared employment and income in counties in Pennsylvania with significant Marcellus drilling and without significant drilling, and before after the boom started.

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[70] National Institute of Economic and Industry Research, "Large scale export of East Coast Australia natural gas: Unintended consequences." A report to the Australian Industry Group and the Plastics and Chemicals Industries Association, October 2012, attached as Exhibit 27 (full document), Exhibit 28 (summary).

[71] Sierra Club Initial NERA Comments, at 8, Ex. 5 thereto (Synapse Report) at 5.

[72] W.R. Freudenburg & L.J. Wilson, *Mining the Data: Analyzing the Economic Implications of Mining for Nonmetropolitan Regions*, 72 Sociological Inquiry 549 (2002) at 549, attached to Initial Sierra Club NERA comments as Exhibit 13.

[73] Headwaters Economics, *Fossil Fuel Extraction as a County Economic Development Strategy: Are Energy-Focusing Counties Benefiting?* (revised July 2009), attached to Initial Sierra Club NERA comments as Exhibit 14.

[74] *Id.* at 2.

[75] Amanda Weinstein and Mark D. Partridge, *The Economic Value of Shale Natural Gas in Ohio*, OHIO STATE UNIVERSITY, Swank Program in Rural-Urban Policy Summary and Report (December 2010) ("Ohio Study"), attached as to Initial Sierra Club NERA comments as Exhibit 16.

Communities where resource extraction occurs will suffer further harms not captured by these examinations of job statistics. Raw numbers of jobs or job-equivalents failure to capture the continuity or quality of jobs, but as we explain elsewhere, the gas production jobs that exports will create are typically short-term jobs, whereas the manufacturing and energy-intensive industry jobs it will eliminate are typically stable and long-term.[76]

While Waller extensively cites DOE/FE's conditional authorization of the Freeport LNG project, that conditional authorization gave short shrift to these concerns. Although DOE/FE acknowledged that regional impacts should be considered in DOE/FE's review of individual LNG export applications, Order 3282 at 77, DOE/FE dismissed the evidence of a resource curse that Sierra Club and other commenters had provided, including the three studies cited above, with the superficial statement that "DOE/FE . . . finds that authorizing the Liquefaction Project is likely to have positive local and regional impacts. As explained above, the comments submitted in response to the LNG Export Study do not support a different conclusion," *id.* at 78. Despite DOE/FE's use of "as explained above," DOE/FE provided no examination of this evidence or reason for disagreeing with it. Thus, DOE/FE's rejection of this argument there was arbitrary and capricious, as it would be for DOE/FE to similarly disregard the resource-curse effect here.

These adverse effects on rate payers, employees in energy intensive industries, and communities where production occurs mean that exports will have grave distributional effects, as they harm wage-earning households and reduce employment while providing benefit to the relatively few shareholders in gas industries.[77] The NERA study attempts to downplay this fact by arguing that benefits realized by gas production companies are realized by "consumers" generally, because "[c]onsumers own all production processes and industries by virtue of owning stock in them."[78] As Sierra Club explained, however, only about half of American families own any stock at all, and only a small subset of stock owners own stocks in the gas production companies that will benefit from exports.[79] Moreover, the NERA study wrongly assumes that gas production and liquefaction service companies are American owned, but as Sierra Club explained in its comments on the NERA study, this assumption is incorrect.[80] Thus, in describing who will economically benefit from exports, NERA overstates both the extent to which benefits will accrue to most Americans and the extent to which benefits will accrue to Americans at all. In the Freeport Conditional Authorization, DOE/FE refused to examine this issue, assuming that foreign investment in gas production would cause a dollar-for-dollar displacement of domestic investment in other industries. Order 3282 at 93.

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[76] Sierra Club Initial NERA Comment at 20-21.
[77] *See, e.g.,* Sierra Club Initial NERA Comments, at 10.
[78] NERA Study, at 55 n.22.
[79] Sierra Club Initial NERA Comment, Ex. 5, 9-10.
[80] Foreign investment in wells. http://bridgemi.com/2013/06/canadian-firm-plans-fracking-campaign-that-could-require-4-billion-gallons-of-michigan-water/, attached as Exhibit 29.

DOE/FE did not identify any evidence of this, nor any analysis of its implications. Of course, as the NERA study indicates, exports will have winners and losers. It may be that, because foreign investors already own shares of gas companies, this has freed up American investment money for other industries, but the NERA study provides no indication that those other industries will receive the same benefits the foreign owners of gas companies will receive as a result of exports. For all these reasons, most Americans will not share in the benefits of LNG exports.

Because LNG exports will cause all Americans to pay higher energy rates, they will cause many Americans to lose their jobs, and they will benefit only a few Americans, who are generally already wealthy, who own shares of companies in a few industries, it is clear that most Americans will be worse off with LNG exports than they would be without them. DOE/FE's Freeport Conditional Authorization refused to acknowledge this evidence, concluding that this evidence was not "sufficiently compelling" to demonstrate that the harmful distributional effects of exports outweigh the minimal GDP growth forecast by NERA. Order 3282 at 75. DOE/FE's only explanation as to the purported deficiency in this evidence was that "None of the commenters [making distributional arguments] has performed a quantitative analysis of the distributional consequences of authorizing LNG exports at the household level." *Id.* In light of the aggregate job data, ratepayer effects, and shareholder data provided by the Sierra Club, there is no apparent reason why a household-level study is necessary.

The Obama Administration has repeatedly emphasized the need to avoid regressive policies that transfer wealth from the middle classes to the wealthy.[81] The President recently explained that "Our economic success has never come from the top down; it comes from the middle out. It comes from the bottom up."[82] Similarly, the President has warned against short-sighted management of wealth. As he explained in the 2009 State of the Union address, the nation erred when "too often short-term gains were prized over long-term prosperity, where we failed to look beyond the next payment, the next quarter, or the next election."[83] DOE/FE must not allow a "surplus [to] bec[o]me an excuse to transfer wealth to the wealthy instead of an opportunity to invest in our future."[84] Thus, LNG exports are at odds with fundamental aspects of executive policy.

Before granting Waller's or any other would-be exporter's application, DOE/FE must analyze exports' implications for the economy not just on a macroeconomic scale, but also at local and regional levels; it must consider the effects of increasing U.S. dependence on resource exports on gasfield communities, domestic industry, and the

[81] *See, e.g.,* State of the Union Address (January 24, 2012), attached as Exhibit 30, available at http://www.whitehouse.gov/the-press-office/2012/01/24/remarks-president-state-union-address
[82] Remarks by the President at the Daimler Detroit Diesel Plant, Redford, MI (Dec. 10, 2012), attached to Initial Sierra Club NERA comments as Exhibit 8.
[83] State of the Union Address (Feb. 24, 2009), attached to Initial Sierra Club NERA comments as Exhibit 9.
[84] *Id.*

environment; and it must consider counterfactuals, allowing it to evaluate whether the national would be better off without LNG export, or with lower export volumes.[85]

In summary, the NGA's "public interest" test requires DOE/FE to determine whether the country would be better off with Waller's proposal than without it. Information in the record demonstrates that exports will transfer wealth from the many to the few.

c. GDP Impacts

The NERA Study's broad conclusion that the US would be better off with exports, or that the net effect of exports is positive, rests almost entirely on a forecast of net GDP growth as a result of exports. DOE/FE rested on this conclusion in refusing to consider distributional effects in the Freeport Conditional Authorization. Order 3282 at 75. Even on this narrow issue, however, the NERA Study's conclusion is contradicted by other available studies, such as the comprehensive model of LNG exports' impacts conducted recently by Purdue University economists Kemal Sarica and Wallace E. Tyner.[86] The Tyner study found that exports would cause a net reduction in GDP, and acknowledged that its methodology, like NERA's, excluded numerous other factors that would further drive down GDP.

Among these excluded factors are the environmental impacts of gas production, and of the failure to regulate it. These impacts must be factored into assessment of exports' net and distributional impacts. In terms of net impacts, the economic cost of environmental harm, such as the cost of increased air emissions, erodes (if not entirely erases) the net benefit NERA purports to find. Although DOE/FE cannot limit its consideration of environmental impacts to those that are easily monetizable, DOE/FE must, at a minimum, apply available tools to estimate the economic impacts of environmental harms.

Thus, even putting aside the serious distributional concerns identified in the previous section, and the the environmental and other effects that can be difficult to monetize, exports' costs are likely to outweigh their benefits. DOE/FE therefore cannot use the NERA Study's prediction of an increase in GDP as evidence that exports will in fact be consistent with the public interest.

D. DOE/FE Cannot Rationally Approve Waller's Export Plan On the Record Before It

The NGA, and subsequent DOE delegation orders and regulations, charge DOE/FE with determining whether or not a gas export application is in the public interest. *See, e.g.* 15 U.S.C. § 717b(a). DOE/FE must make this decision on the record before it. This

[85] *See* Sierra Club Initial NERA Comments; *see also* Sierra Club Reply NERA Comment.
[86] *See* Kemal Sarica & Wallace E. Tyner, *Economic and Environmental Impacts of Increased US Exports of Natural Gas* (Purdue Univ., Working Paper, 2013), attached as Exhibit 31.

means that, regardless of DOE/FE's decision to presume, initially, that an application should be granted, this presumption does not, and cannot, absolve DOE/FE of its duty to make its *own* determination. *Panhandle Producers and Royalty Owners Ass'n*, 822 F.2d at 1110-11. Simply put, "the *agency* must examine the relevant data and articulate a satisfactory explanation for its action including a rational connection between the facts found and the choice made." *Motor Vehicle Mfrs. Ass'n of the United States v. State Farm Mut. Auto. Ins. Co.*, 463 U.S. 29, 43 (1983) (emphasis supplied). DOE/FE cannot rationally find for Waller on the record in this case.

As we have demonstrated, record support for Waller's claimed benefits is extraordinarily thin. Waller has submitted no detailed studies or information demonstrating the specific benefits expected from its proposed LNG exports, instead relying on the EIA and Deloitte studies.

Sierra Club, on the other hand, has shown that the gas and electricity price increases associated with exports will add billions of dollars in costs to consumers. These costs will propagate through the economy, retarding growth. We have also shown that the economic benefits, if any, associated with gas production increases may actually do long-term damage to the U.S. economy by plunging large regions of the country into a boom-and-bust extractive cycle. Further, we have shown that gas extraction and export have major environmental (and, hence, additional economic) costs, which Waller has failed to even acknowledge.

On this record, DOE/FE cannot approve export. Were it do so, it would be violating basic norms of agency record rulemaking, as well as its own rules. *See, e.g.*, 5 U.S.C. § 706; 10 C.F.R. § 590.404 (requiring DOE/FE to base its final opinion "solely on the official record of the proceeding" and to impose terms "as may be required by the public interest" after record review).

E. If DOE/FE Does Move Forward, It Must Impose Rigorous Monitoring Conditions

If DOE/FE nonetheless approves Waller's application, it must recognize its continuing duty to protect the public interest, as it explained in its earlier *Sabine Pass* decision. This duty is of crucial importance in the context of LNG export, where circumstances are rapidly changing. DOE/FE therefore announced its intention to monitor environmental, economic, and other relevant considerations. *Sabine Pass* at 31-33. Such a monitoring provision must be imposed here, as well, but must be significantly expanded.

Specifically, although *Sabine Pass* announces an intention to monitor many different considerations, it most clearly states that the agency will act if there is a "reduction in the supply of natural gas needed to meet essential domestic needs." *Id.* at 32. This consideration is undoubtedly of great importance, but it is not the only way in which changing circumstances could imperil the public interest.

On the contrary, as we have demonstrated at length in these comments, there is strong evidence that the public interest will be impaired by gas exports. These impairments include (1) regional and national economic dislocations and disruptions caused by natural gas extraction, including by the industry's boom-and-bust cycle, (2) national increases in gas and electricity prices and resulting shifts to more polluting fuels, (3) and environmental impacts of many sorts. Any one of these categories of interests could be impaired by gas export. DOE/FE must therefore state that it will monitor each of these areas, providing specific monitoring terms and thresholds which will trigger agency actions of various types, ranging from further study through reductions in export volume or changes in timing to a revocation of DOE/FE's approval.[87]

If DOE/FE fails to include such provisions in any final approval, it will fail to fulfill its "continuing duty to protect the public interest," *id.* at 31, and so violate the Natural Gas Act. Because neither Waller nor DOE/FE have described or proposed such terms, Sierra Club protests this application to the extent that DOE/FE fails to develop adequate monitoring terms of the sort we have described.

IV. Conclusion

Sierra Club therefore moves to intervene, offers the above comments, and protests Waller's export proposal for the reasons described above. Waller's application is not consistent with the public interest and must be denied.

Respectfully submitted,

Nathan Matthews
Sierra Club Environmental Law Program
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San Francisco, CA 94105

[87] Providing a clear monitoring plan of this sort will also benefit Waller, which will be better able to determine when and how DOE/FE may act, improving the company's ability to plan its actions and investments.

UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY

IN THE MATTER OF	**)**	
	)	
WALLER LNG SERVICES, LLC	**)**	**FE DOCKET NO. 13-153-LNG**
	)	

CERTIFICATE OF SERVICE

I hereby certify that I caused the above documents to be served on the applicant and all others parties in this docket, in accordance with 10 C.F.R. § 590.017, on September 5, 2014.

Dated at San Francisco, CA, this 5th day of September, 2014.

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UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY

IN THE MATTER OF	)	
	)	
Waller LNG Services, LLC	)	**FE DOCKET NO. 13-153-LNG**
	)	

CERTIFIED STATEMENT OF AUTHORIZED REPRESENTATIVE

Pursuant to C.F.R. § 590.103(b), I, Nathan Matthews, hereby certify that I am a duly authorized representative of the Sierra Club, and that I am authorized to sign and file with the Department of Energy, Office of Fossil Energy, on behalf of the Sierra Club, the foregoing documents and in the above captioned proceeding.

Dated at San Francisco, CA, this 5th day of September, 2014.

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UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY

IN THE MATTER OF	)	
	)	
Waller LNG Services, LLC	)	**FE DOCKET NO. 13-153-LNG**
	)	

VERIFICATION

SAN FRANCISCO	§
	§
CALIFORNIA	§

Pursuant to C.F.R. §590.103(b), Nathan Matthews, being duly sworn, affirms that he is authorized to execute this verification, that he has read the foregoing document, and that facts stated herein are true and correct to the best of his knowledge, information, and belief.

Nathan Matthews
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Subscribed and sworn to before me this 5th day of September, 2014.

Notary Public

NICHOLAS JAMES LIFE
Commission # 1951418
Notary Public - California
San Francisco County
My Comm. Expires Sep 9, 2015

My commission expires: 09/09/2015