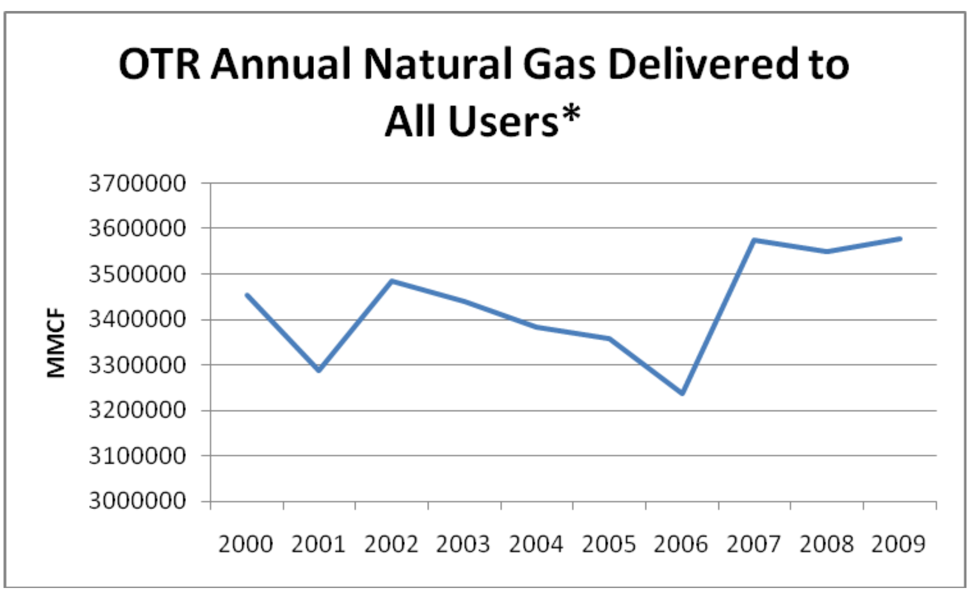
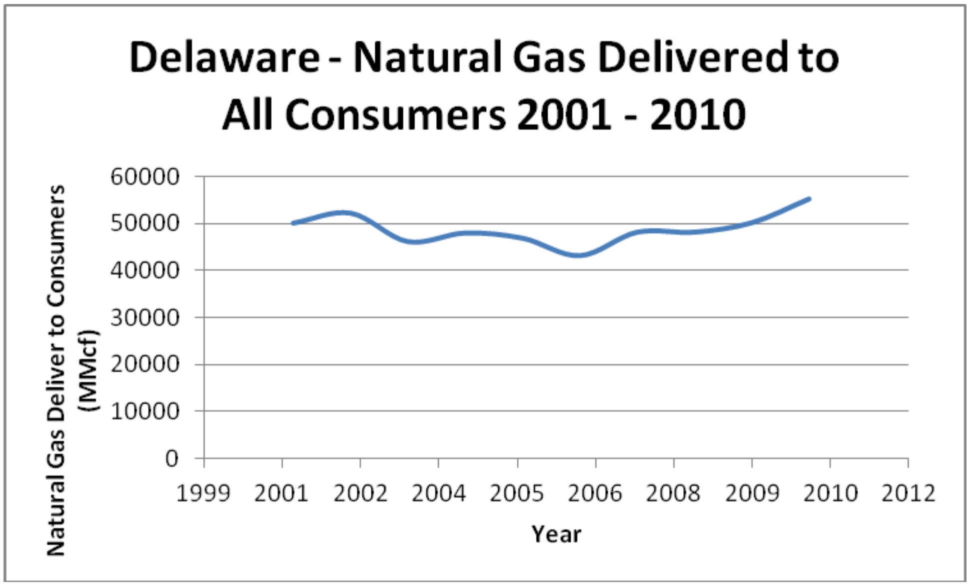
Background Information
Oil and Gas Sector
Significant Sources of NOx Emissions

Within the oil and gas sectors there are numerous significant sources of NOx emissions that contribute to air quality problems in downwind states. These sources operate in a wide variety of modes, with some only operating during initial phases of extracting the product from the ground, some operating almost continuously as long as the source well is productive, and some operating in a variable capacity to meet the demand for the product. While many of these sources, such as drilling rigs and well pumps and compressors, are concentrated in areas with abundant supplies of oil and/or natural gas, other sources such as fuel-fired gas compressors and oil pumps are located on pipelines throughout the country. The purpose of this review is to assemble relevant information and provide some background regarding the combustion devices utilized in the “upstream” and “mid-stream” gas and oil sector and investigate the possibility of achieving NOx reductions from these devices.

Please note that this document more heavily addresses the natural gas portion of the sector than the oil portion of the sector. There are several explanations for this “bias”. One reason is that within the neighboring states “upwind” from Delaware, the upstream natural gas sector is a much larger source of NOx emissions than the upstream portion of the oil sector. Additionally, the natural gas portion of the sector is rapidly expanding in the OTR and OTR-neighboring states relative to the oil sector, primarily due to the exploitation of shale gas in those states. There also appears to be a great deal of more precise, publicly available data and information related to the NOx emissions from sources in the natural gas sector than there is publicly available for the oil sector. And with the increased availability and relatively low cost of natural gas to the consumers, the consumption of natural gas in the OTR and Delaware has increased in recent years, even during the economic downturn. The increase in natural gas consumption results in increased operation of well head and field gathering compressors, storage compressors, and pipeline natural gas compressors. The increased operation of associated natural gas fuel fired prime movers to drive the compressors increases the total quantity of NOx emissions. The growth in natural gas consumption in the OTR and Delaware is shown in the following graphs:

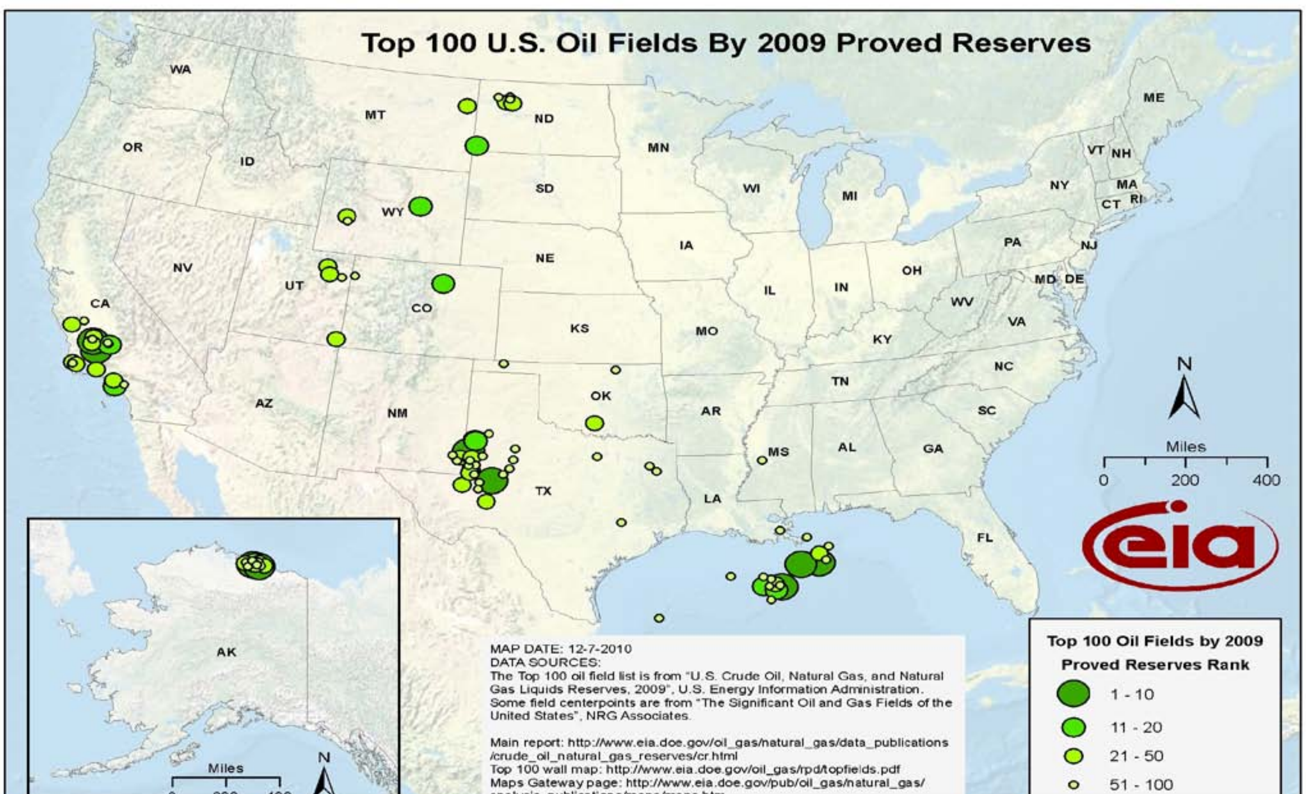


*Except VA

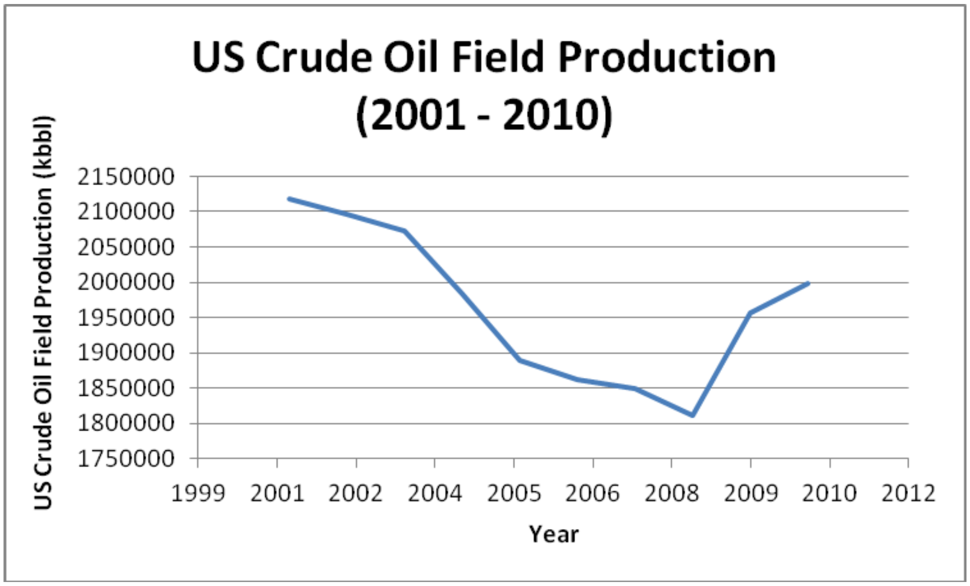


Crude Oil and Natural Gas Production

In 2010, 30 of the lower 48 states produced crude oil. Texas, California, and North Dakota were the largest crude oil producers in the lower 48 states. EIA data indicates that within the OTR, New York and Pennsylvania are producers of crude oil. Pennsylvania's crude oil production is far greater than that of New York, with Pennsylvania producing 3,539 thousand barrels in 2010 and New York producing 384 thousand barrels in 2010. Pennsylvania's 2010 crude oil production was approximately 0.3% of the lower 48 states total. It can be seen in the following map that none of the top 100 US oil fields are located in OTR states.



Crude oil production in the lower 48 states has been in a general decline for a long period of time, including a portion of the last decade. However, the crude oil production has demonstrated a slight increase in the last few years, as shown in the following graph:



As of the preparation of this document, the EIA website did not include 2010 state specific natural gas production figures; 2009 was the latest year that included state specific data. It can be seen in the 2009 EIA data that 32 of the lower 48 states produced natural gas in 2009. Texas, Wyoming and Oklahoma were the largest natural gas producing states in the lower 48 states. Within the OTR, Pennsylvania and New York were the largest gas producing states. Of all the natural gas producing states, Pennsylvania ranked as the 11th largest producer and New York ranked as the 22nd largest producer.

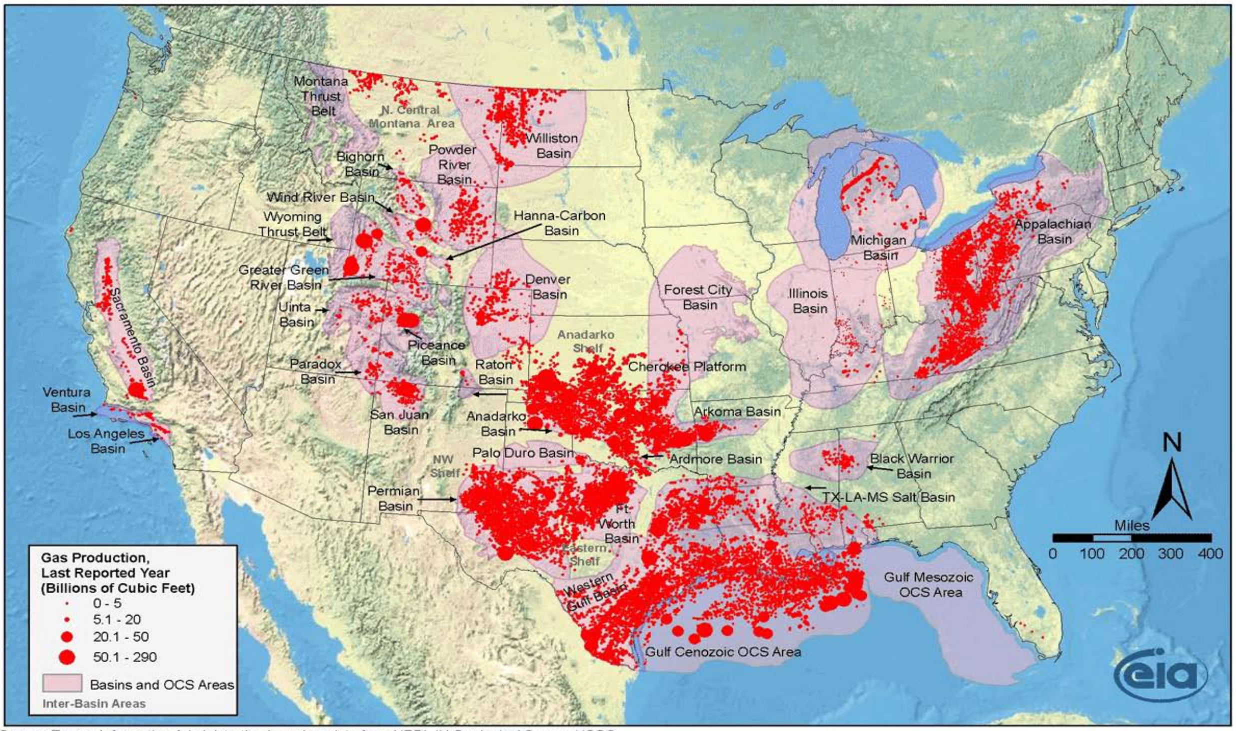
Natural gas production includes production from conventional wells, shale gas wells, a secondary product from oil wells, and coal bed methane wells. In 2009, approximately 57% of the total natural gas production was from conventional wells, approximately 22% of the total natural gas production was from oil wells, approximately 13% of the total natural gas production was from shale gas wells, and approximately 8% of the total natural gas production was from coal bed methane wells. It is interesting to note that the EIA data does not show any significant national annual natural gas production from coal bed methane wells until 2007, and also does not show any significant national annual natural gas production from shale gas wells until 2008.

Of the OTR natural gas producing states in 2009, Maryland's natural gas production was from conventional wells only, New York's natural gas production was from conventional wells and oil wells, and Pennsylvania's natural gas production was from conventional wells, shale gas wells, and coal bed methane wells.

"Upwind" OTR neighboring states that produce natural gas are Ohio (producing natural gas from conventional wells, oil wells and coal bed methane wells in 2009), Virginia (producing natural gas from conventional wells and coal bed methane wells in 2009), and West Virginia (producing natural gas from conventional wells, shall gas wells, and coal bed methane wells in 2009).

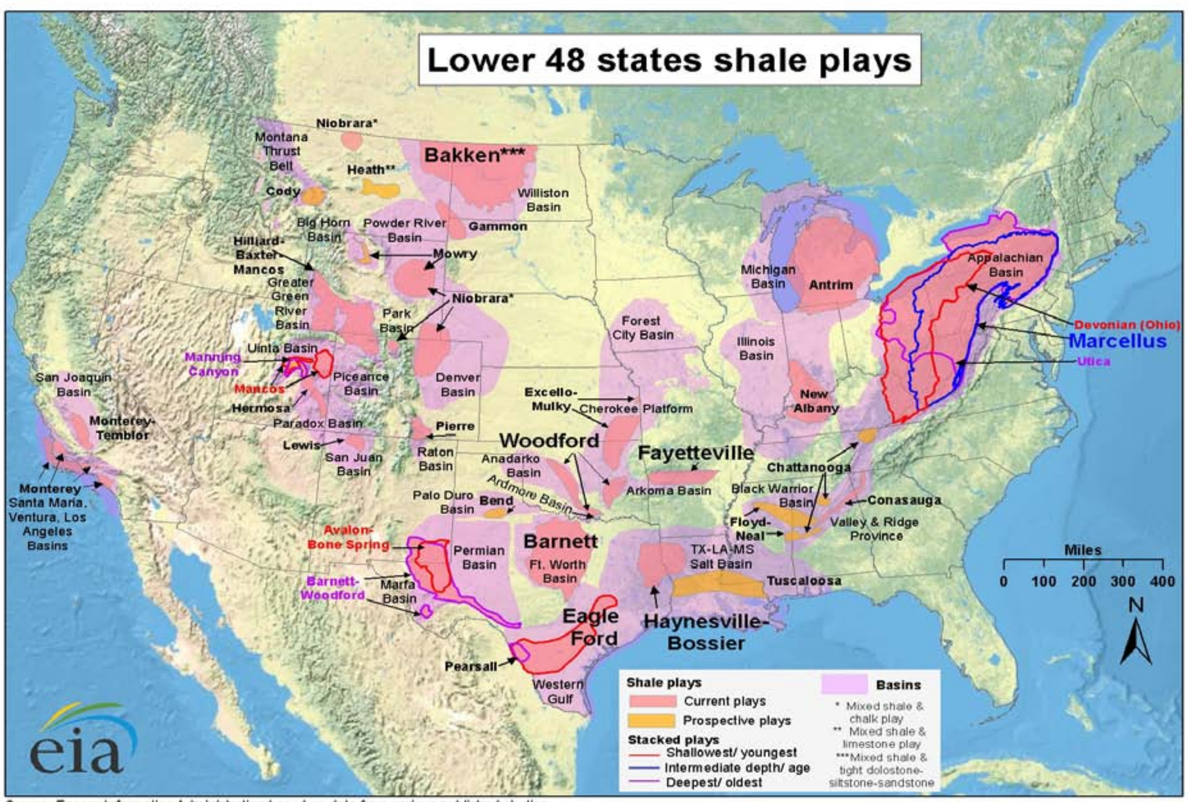
The following map shows the regions in the lower 48 states with natural gas production fields:

Gas Production in Conventional Fields, Lower 48 States



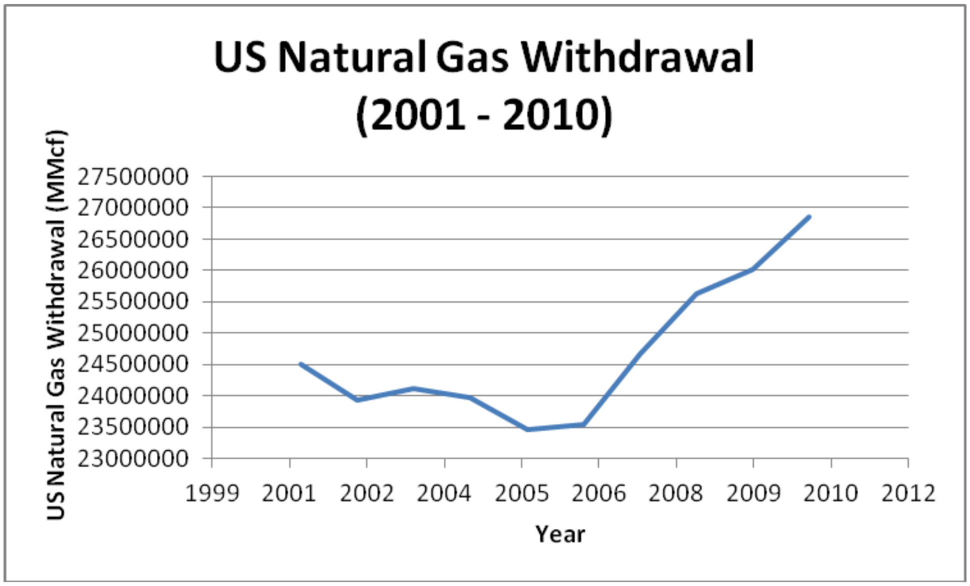
Source: Energy Information Administration based on data from HPDI, IN Geological Survey, USGS
Updated: April 8, 2009

The following map shows the regions in the lower 48 states with shale gas producing fields:



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Nationally, natural gas production has shown a moderate increase over the last decade. It is interesting to note that the gas production from conventional gas wells and oil wells has actually decreased over the same period of time. But that reduction in production from conventional gas wells and oil wells has been compensated for and surpassed by gas production from shale gas wells and coal bed methane wells. The natural gas production is shown in the following graph:



Within the oil and gas sector, there are many significant NOx emitting sources, including the following:

- Diesel and spark ignition reciprocating engines in drilling rig operations (gas and oil sectors).
- Diesel engines, spark ignition engines, and combustion turbines driving electric generators for power in remote locations and for supporting electric motor prime movers (gas and oil sectors).
- Diesel and spark ignition engines engine driving hydraulic fracturing pumps, recovery pumps, and water recirculating pumps (oil and gas sectors).
- Gas heating units in well field pipelines and processing facilities working with “wet” gas.
- Heating units and boilers supporting gas processing operations, such as for dehydration unit regeneration, etc., and oil processing operations such as water separation, etc.
- Refrigeration compressors supporting gas processing operations
- Prime movers for well field gas compressors, gas processing facility inlet and outlet gas compressors, and pipeline compressors
- Prime movers for wellhead oil pumps, field gather pumps, and transportation pipeline pumps
- Well flares (oil and gas sectors)(NOx emissions from this source category is specifically addressed in the current USEPA proposed rulemaking)

There is a great deal of publicly available information regarding the natural gas industry, including the prime movers utilized for natural gas compression services. Much of this information is at least generically applicable to the natural gas compressor prime movers. While this document does not pretend to represent all the information on the subject, many publicly available documents and websites were reviewed to obtain background and information for the preparation of this document. The “References and Additional Information” section of this paper lists those information sources reviewed. Additionally, several organizations were kind enough to provide presentations to the Ozone Transport Commission (OTC) Natural Gas Compressor Stations Workgroup that have proven beneficial in improving the understanding of natural gas compressor prime movers in the OTR. Those organizations include:

- Johnson Matthey Catalysts, coordinated by Wilson Chu, provided a presentation on the use of non-selective catalytic reduction (NSCR) and selective catalytic reduction (SCR) post-combustion NOx controls applicable to natural gas fueled gas compressor prime movers. Johnson Matthey also followed up their presentation with

information to address the questions that workgroup participants presented, including an installation list and documentation of the results of SCR testing on a 2-stroke test bed engine.
- The Interstate Natural Gas Association of America (INGAA) gave a presentation that provided a great deal of background information concerning the interstate transport of natural gas and the combustion prime movers utilized in instate gas transport compression services. INGAA also provided a discussion of technical aspects of the prime movers and past and current efforts regarding NOx reductions from those prime movers.
- The Gas Compressor Association's Environmental Committee gave a presentation that addressed natural gas compression, providing considerable insight into the compression that occurs related to well fields and gas preparation prior to injection into the main transmission line network. GCA also provided a discussion regarding the use of leased compressors for use at well fields, and also provided discussion of technical aspects of well field compressors in general (including NOx emissions from the compressor prime movers).
- Shell Oil provided a slide presentation regarding emissions related to natural gas production in Wyoming. In their presentation they noted a number of areas where significant NOx reductions have been achieved in those production operations, including the use of SCR for drill rig operations which Shell indicated achieved a 90% reduction in NOx emissions from those sources. Shell recommended consideration of similar activities in other locations, such as those currently being expanded for shale gas. Shell also indicated that they were moving some of their drill rig equipment from the western operations to support additional drilling in some of the eastern shale gas areas.

(It should also be noted that throughout the oil and gas sector, including the OTR, there are a number of existing gas compressors, and oil and water pumps that utilize electric motor prime movers powered from the electric grid. These units are not addressed in this discussion other than to acknowledge their existence and use. Additionally, replacement of existing fuel-fired movers with electric motor prime movers as a NOx reduction strategy is not addressed in this discussion except, again, to acknowledge the possibility.)

Well Drilling and Completion

A well is created by drilling a hole (diameter dependent upon product and expected flow rate) into the earth with a drilling rig that rotates a drill pipe with a drill bit attached. After the hole is drilled, sections of steel pipe, slightly smaller in diameter than the borehole, are placed in the hole. Cement may be placed between the outside of the casing pipe and the borehole. The casing provides structural integrity to the newly drilled wellbore, in addition to isolating potentially dangerous high pressure zones from each other and from the surface.

With these zones safely isolated and the formation protected by the casing, the well can be drilled deeper (into potentially more-unstable and violent formations) with a smaller bit, and also cased with a smaller size casing. Modern wells often have two to five sets of subsequently smaller hole sizes drilled inside one another, each cemented with casing.

Drilling the well may include the following steps:

- The drill bit, aided by the weight of thick walled pipes called "drill collars" above it, cuts into the rock. There are different types of drill bit; some cause the rock to disintegrate by compressive failure, while others shear slices off the rock as the bit turns.
- A drilling fluid is pumped down the inside of the drill pipe and exits at the drill bit. The drilling fluid is a complex mixture of fluids, solids and chemicals that must be carefully tailored to provide the correct physical and chemical characteristics required to safely drill the well. Particular functions of the drilling fluid include cooling the bit, lifting rock cuttings to the surface, preventing destabilization of the rock in the wellbore walls and overcoming the pressure of fluids inside the rock so that these fluids do not enter the wellbore.
- The generated rock cuttings are swept up by the drilling fluid as it circulates back to surface outside the drill pipe. The fluid then goes through shakers which strain the cuttings from the good fluid which is returned to a containment vessel or pit.

- The drill pipe to which the bit is attached is gradually lengthened as the well gets deeper by screwing in additional sections or "joints" of pipe under the drive mechanism at the surface.

This drilling process is facilitated by the use of a drill rig which contains all the necessary equipment to circulate the drilling fluid, hoist and turn the drill pipe, control down-hole movement, remove cuttings from the drilling fluid, and generate on-site power for these operations.

After drilling and casing the well, it must be 'completed'. Completion is the process in which the well is enabled to produce oil or gas. Often well completion is performed utilizing a specialized rig or platform, enabling the drilling rig to be moved to a new location to drill another well.

In a cased-hole completion, small holes called are made in the portion of the pipe casing which passed through the production zone, to provide a path for the oil or gas to flow from the surrounding rock into the production tubing. In open hole completion, often 'sand screens' or a 'gravel pack' is installed in the last drilled, uncased reservoir section. These maintain structural integrity of the wellbore in the absence of casing, while still allowing flow from the reservoir into the wellbore. Screens also control the migration of formation sands into production piping and surface equipment, which can cause washouts and other problems.

After a flow path is made, acids and fracturing fluids are pumped into the well to fracture, clean, or otherwise prepare and stimulate the reservoir rock to optimally produce hydrocarbons into the wellbore. Finally, the area above the reservoir section of the well is packed off inside the casing, and connected to the surface via a smaller diameter pipe called tubing. This arrangement provides a redundant barrier to leaks of hydrocarbons as well as allowing damaged sections to be replaced. Also, the smaller cross section of the piping produces reservoir fluids at an increased velocity in order to minimize liquid fallback that would create additional back pressure, and shields the casing from corrosive well fluids.

In some wells, the natural pressure of the subsurface reservoir is high enough for the oil or gas to flow to the surface. However, this is not always the case, especially in depleted fields where the pressures have been lowered by other producing wells, or in low permeability oil reservoirs. Installing smaller diameter tubing may be enough to help the production, but artificial lift methods, such as downhole pumps or surface pumps or compressors, may also be needed. Many new systems have been introduced for improving well completion in recent years that have cut completion costs and improved production, especially in the case of horizontal wells. Some of these well completion activities have also reduced the amount of gas that is flared by capturing the gas that might otherwise have been flared off and treating and utilizing it as a product.

Sources of NOx emissions from the drilling and completion processes include prime movers to power electric generators that provide electric power supporting the drilling process, sometimes prime movers for the drilling drive and related pumps and compressors, and sometimes flaring of relatively small amount of natural gas as part of completion. The majority of the fuel-fired prime movers in this service are diesel reciprocating engine prime movers.

In a presentation, Shell indicated that they have installed SCR on diesel engines that they utilize in drilling rig operations. They indicated that they had been able to achieve greater than 90% reduction in NOx emissions while encountering minimal operational issues.

EIA data indicates that in 2010 there were 1514 on-shore oil and gas drilling rigs in operation in the US, an increase of 468 drilling rigs being used for on-shore oil and gas drilling in 2009.

EIA data also indicates that in 2010 there were a combined total of 41,832 oil and gas exploratory and development wells drilled, an increase of 7,509 wells from those drilled in 2009. The data indicates that in 2010, a combined 305,988 thousand feet were drilled, compared to 228,872 thousand combined feet drilled in 2009.

Because of an overall lack of comprehensive emissions data for NOx sources in the oil and gas sector, and variability due to equipment and site specifics (material being drilled through, well depth, etc), it is difficult to estimate the magnitude of those NOx emissions from well drilling and well completion activities. Some related NOx emissions information was found in a report from the Western Region Air Partnership (WRAP), "An Emissions Inventory of Non-point Oil and Gas Emissions Sources in the Western Region". This report specifically addressed regional emissions from the gas industry, and investigated regional data to estimate NOx emissions factors primarily for natural gas industry operations, with some additional effort to assess oil and methane bed NOx emission factors. The regional data presented in the report indicated a relatively wide range in estimated emission factors, likely due to the site and equipment variability. While the NOx emissions factors presented in the report are based on region specific data, they appear to be realistic values that may be useful in estimating NOx emissions from similar equipment when site or region specific data is not available for other locations. The emissions factors presented in the WRAP report were as follows:

- Drilling: Range of 2.26 tons NOx/well to 9.78 tons NOx/well

- Well Completion: Range of 0.85 tons NOx/well to 1.5 tons NOx/well

Utilizing the above per well NOx emission rates, the additional of 41,832 oil and gas wells is estimated to have resulted in a range of 2010 NOx mass emissions of from 130,098 tons to 471,865 tons (drilling and completion related activities only). (To get some perspective on the magnitude of this value, the NOx emissions of upper end value of the range is larger than the combined 60 highest NOx mass emitting coal-fired electric generating units in the year 2010.)

A search of the EIA website did not identify any state-specific oil well counts, nor did it identify any state-specific gas well counts that included 2010. The only relevant state-specific data that could be located was gas producing well counts for the years 2008 and 2010, which allowed the determination of state-specific increase in gas producing wells between 2008 and 2009. The increase in gas producing wells was assumed to be the number of wells drilled in 2009. For states upwind of Delaware, the following table provides an estimate of the NOx emissions related for gas well producing activities:

State	New Gas Producing Wells in 2009	Estimated Range of NOx Emissions from Well Drilling/Completion (tons)
Ohio	547	1,701 - 6,170
Pennsylvania	1725	5,365 - 19,458
Virginia	877	2,727 - 9,893
West Virginia	1238	3,850 - 13,964

Oil Well Pumps

Pumps are often required to raise oil in an oil well from the oil's underground location to the surface. There are several types of pumping devices that are used to provide artificial lift in an oil field. These include: mechanical lift powered by a motor or engine on the surface; hydraulic lift, where oil or water is pumped down into the well to operate a hydraulic pump; electric submersible pump, where a electric motor driven pump at the bottom of the well is driven, is supplied electricity from the surface; and gas lift, where natural gas injected into the piping at intervals lightens the weight of the fluid, helping it rise to the surface. All four of these systems offer advantages and disadvantages for specific situations. Mechanical lift is one of the more commonly used oil well pumping devices.

When located near sources of grid supplied electric power, the above devices are generally powered by electric motors. In some more remote areas, those devices may still be powered by electric motors, but utilizing electricity generated locally using natural gas engine or diesel engine prime movers. In other instances, the devices may be driven directly by natural gas fueled engine or diesel engine prime movers. The required output rating of the prime movers would vary depending on the depth of the well, pumping capacity, etc. However, these prime movers tend to have a relatively small output rating, generally less than 200 hp.

Once the oil is extracted from the well, it is pumped to a storage tank(s) that may be common to multiple supply wells. The oil is then typically transported from the storage tank by truck or pumped out through a pipeline.

Little data was located that could be used to estimate the NOx emissions from oil well pumps. Documentation of previous estimation efforts were equally absent in the data searches. Variabilities such as well depth and type of prime mover make it very difficult to make any sort of reasonable estimate of the NOx emissions without some detailed inventory and operational information. Because of the lack of data and/or guidance information, no estimates were made of the potential NOx emissions from oil well pumping activities.

Oil Pipeline Pumps

Crude oil is often transported from field gathering locations to downstream locations through pipelines. Pumps are generally required to pump the oil through the pipelines, with pumps generally located at the originating field gathering location and at 20 to 100 mile intervals along the pipeline, depending upon pipeline design, pipeline path geography, and flow requirements. These oil pumps are often driven by electric motor prime movers, but some may utilize diesel engines, natural gas fueled reciprocating engines, or combustion turbines as prime movers when warranted. Little data could be found documenting the size and makeup of the population of oil pipeline pump prime movers on a national basis or within the Eastern half of the US.

Industry data indicated that in 2008, pipelines accounted for 71% of all petroleum transportation, up from 67% in 2007. The data indicates that it is estimated that in the US there is in excess of 55,000 miles of crude oil trunk lines connecting regional markets, and estimated that there is from 30,000 miles to 40,000 miles of small crude oil gathering pipelines. Pipelines are also utilized for transportation of refined petroleum products, and industry data estimates indicate that there are approximately 95,000 miles of refined products pipelines in the US.

Little data was located that could be used to estimate the NOx emissions from oil pipeline pumps. Documentation of previous estimation efforts were equally absent in the data searches. Because of the lack of data and/or guidance information, no estimates were made of the potential NOx emissions from oil well pumping activities.

Coal Bed Methane Pumps

In order to facilitate gas extraction from coal bed methane wells, it is often necessary to pump out large amounts of water to reduce the pressure in the coal bed and thereby facilitate methane desorption from the coal. Desorption from the coal allows the methane to be extracted and transported to gathering pipelines. Industry information indicates that the water pumping may occur throughout the useful life of the coal bed methane well, but will tend to experience a reduction with “age” of the well or well field.

Because of an overall lack of comprehensive emissions data for NOx sources in the oil and gas sector, and variability due to equipment and site specifics, it is difficult to estimate the magnitude of NOx emissions from coal bed methane pumping. Some related NOx emissions information was found in a report from the Western Region Air Partnership (WRAP), “An Emissions Inventory of Non-point Oil and Gas Emissions Sources in the Western Region”. This report specifically addressed regional emissions from the gas industry, and investigated regional data to estimate NOx emissions factors that included coal bed methane pumping NOx emission factors. The regional data presented in the report indicated a relatively wide range in estimated emission factors, likely due to the site and equipment variability. While the NOx emissions factors presented in the report are based on region specific data, they appear to be realistic values that may be useful in estimating NOx emissions from similar equipment when site or region specific data is not available for other locations. The emissions factors presented in the WRAP report for coal bed methane pumps ranged from 0.06 ton/year/well to 0.60 ton/year/well.

Oil Well Heaters

Some oil wells require heating of the crude oil, as the crude oil reaching the surface of a well may contain varying amounts of impurities. The well heaters are used to heat crude oil to separate water, solids such as paraffin, and natural gas from the crude oil. Heat from combustion in the heater's firebox heats the crude oil and helps water droplets and solids settle out and be drained out of the bottom of the heater. The heating of the crude oil also facilitates the separation of natural gas from the crude oil, allowing the gas to rise and be piped off from the top of the heater. The oil is then drawn off for pumping to a pipeline or storage tanks.

Because of an overall lack of comprehensive emissions data for NOx sources in the oil and gas sector, and variability due to equipment and site specifics, it is difficult to estimate the magnitude of NOx emissions from oil well heaters. Some related NOx emissions information was found in a report from the Western Region Air Partnership (WRAP), "An Emissions Inventory of Non-point Oil and Gas Emissions Sources in the Western Region" . This report specifically addressed regional emissions from the oil and gas industry, and investigated regional data to estimate NOx emissions factors that included oil well heater NOx emission factors. While the NOx emissions factors presented in the report are based on region specific data, they appear to be realistic values that may be useful in estimating NOx emissions from similar equipment when site or region specific data is not available for other locations. The average NOx emissions factor presented in the WRAP report for oil well heaters is 0.0005 lb NOx/barrel produced.

Gas Well Heaters

Due to varying amounts of condensates and moisture in the gas coming to the surface, some natural gas wells require treatment near the well head. Heating is often part of this "cleanup" process, generally utilizing natural gas fired heating units. The heating of the natural gas is sometimes required to ensure that the temperature of the natural gas does not drop too low where it could facilitate the formation of a hydrate with any water vapor in the gas stream. Natural gas hydrates are crystalline ice-like solids or semi-solids that can impede the passage of natural gas through valves and pipes.

Because of an overall lack of comprehensive emissions data for NOx sources in the oil and gas sector, and variability due to equipment and site specifics, it is difficult to estimate the magnitude of NOx emissions from gas well heaters. Some related NOx emissions information was found in a report from the Western Region Air Partnership (WRAP), "An Emissions Inventory of Non-point Oil and Gas Emissions Sources in the Western Region". This report specifically addressed regional emissions from the oil and gas industry, and investigated regional data to estimate NOx emissions factors that included gas well heater NOx emission factors. While the NOx emissions factors presented in the report are based on region specific data, they appear to be realistic values that may be useful in estimating NOx emissions from similar equipment when site or region specific data is not available for other locations. The average NOx emissions factor presented in the WRAP report for gas well heaters is 1,752 lb NOx/well/year.

Natural Gas Pipeline Compressors

The natural gas system in the continental United States is a complex network consisting of equipment and pipelines to gather natural gas from wellheads, transport the raw natural gas to processing facilities as required, transporting the natural gas from processing facilities across potentially large distances to storage facilities and distribution systems, and supplying natural gas to distribution systems that provide the natural gas to the end users (please see Attachment I for additional detail regarding the natural gas pipeline system in the Northeast) .

Compressors are utilized in natural gas fields to boost natural gas wellhead pressure so that the natural gas may be injected into the gathering pipelines to transport it to processing facilities and/or inject the natural gas into the transport pipelines. Compressors are utilized in the transportation network to keep the pipelines pressurized and achieve the desired flow of natural gas. Compressors are also utilized at storage facilities to inject the natural gas into storage and to extract the natural gas from storage and re-inject it back into the transportation or distribution pipelines. Compressors are also sometimes utilized in distribution systems to ensure adequate flow and pressure to the natural gas end users. Most natural gas compressor facilities are normally unmanned, and many are operated from remote facilities to start/stop/modulate output to meet the demands of the associated pipeline systems.

(Note: Much of the OTR mainline and underground storage natural gas compressor information in this document refers to data and information related to the 2007 OTR population of natural gas compressors. There are several reasons for this. One of the more important reasons is that the most complete data set of OTR natural gas compressor prime movers is for the year 2007. Another important reason is that this "historic" data is more representative of "existing" gas compressor prime movers, the population of OTR gas compressors more likely to achieve NOx reductions through the retrofit of NOx controls. It is assumed that more recent gas compressor prime movers were subject to NSPS and would be likely well controlled for NOx emissions purposes.)

Natural Gas Wellhead and Field Gathering Compressors

Many natural gas wells require the use of compressors to facilitate extracting the natural gas from the well, boosting the pressure for injecting the natural gas into the field gathering pipeline system, and transporting the natural gas to and from any required field processing facility. Typically, reciprocating engines fueled by raw natural gas are utilized in this service, but other prime movers such as natural gas fueled combustion turbines or electric motors may be utilized in some circumstances. Industry information indicates that compressors utilized in this service tend to run with a relatively constant capacity factor throughout any given calendar year.

Industry literature indicates that the number and size of the compressors utilized in wellhead/gathering systems varies greatly as a result of differences in needed flow capability and pressure boost requirements. The industry information indicates that utilized compressors can range from portable compressor units with 5 HP prime movers to units that have prime mover ratings in excess of 1500 HP. Natural gas fueled reciprocating engines and combustion turbines along with electric prime movers are commonly utilized in this service. Some locations may be remote relative to sources of off-site electric power, prohibiting the use of electric prime movers for gas compressors.

Some natural gas gathering systems include a processing facility, which performs such functions as removing impurities like water, carbon dioxide or sulfur that might corrode a pipeline, or inert gases, such as helium, that would reduce the energy value of the gas. Processing plants also can remove small quantities of propane and butane. These gases may be used for chemical feedstocks and other applications. Compressors in this service may be utilized to transport natural gas from the wellheads to the processing facility, and then from the processing facility to the main pipeline network.

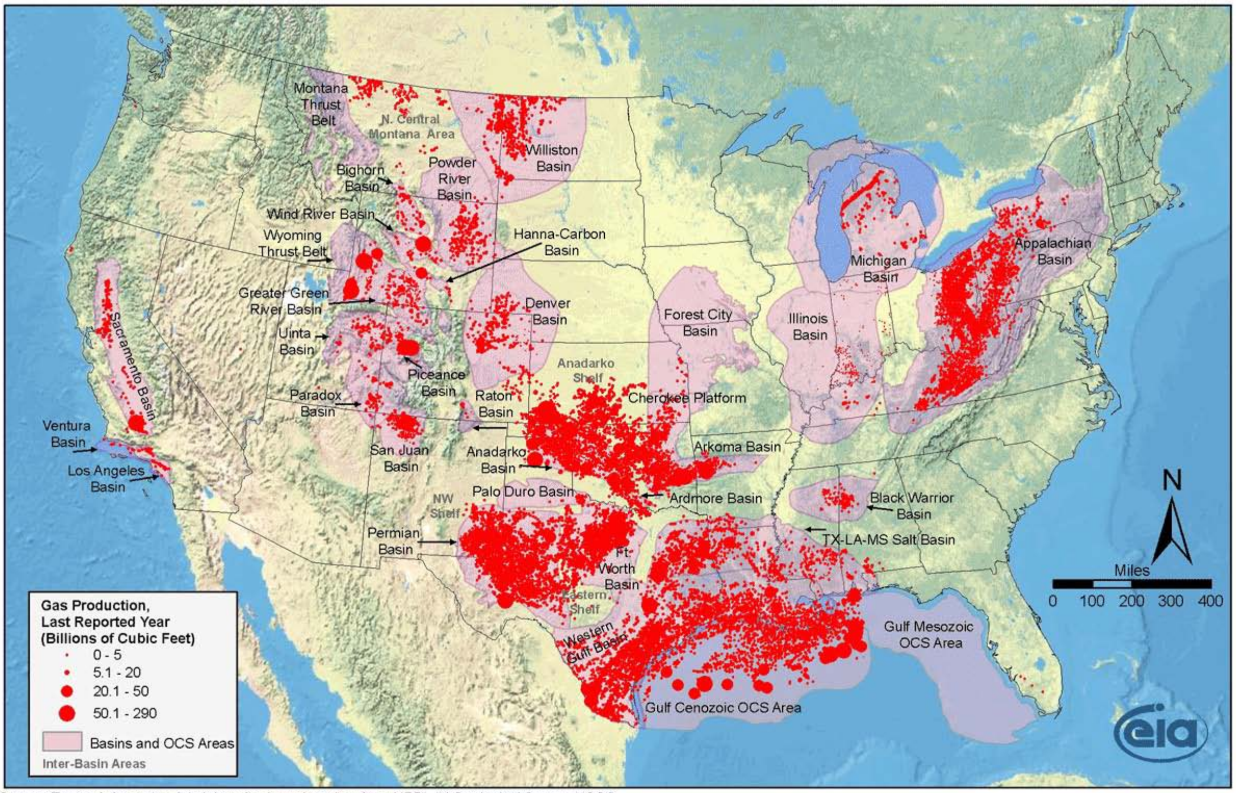
Because of the relatively small size of some (but certainly not all)of the combustion prime movers utilized in natural gas field gathering applications, the available data concerning these units is more limited than that available for the generally higher output mainline prime movers. Industry information indicates that some gas compressor prime movers used in this service are skid mounted, allowing the compressor to be moved with relative ease and thereby providing additional flexibility in meeting the changing demand associated with removing natural gas from any given well or well field. Industry information also indicates that many of the natural gas compressor prime movers used in this service are leased units.

Very little data was found regarding the number, output, operation, etc of natural gas field gathering compressors in the OTR. Of the few field gathering compressor installations that could be identified in the 2007 FERC data for the OTR, the range of horsepower ratings for the prime movers appeared to be from approximately 40 HP to 1800 HP. This is consistent with the limited data that could be located for this general application in the US.

While perhaps not directly relatable to the population of gas compressor prime movers in the US, there was a study performed in 2005 to support an investigation of natural gas field gathering engines in Eastern Texas that might provide some more insight into the potential diversity of engines utilized in the natural gas field gathering service. One of the goals of the Texas study was to get a more firm estimate of the inventory of compressors in use in the area in question. That study indicated that there were a number of engine manufacturers represented in the investigation area, along with a significant number of different engine models among the manufactures. The study was able to determine the age for only a very small portion of the engines in the study, but for that group the engine age ranged from 2 years to 25 years old. The output ratings of the engines in the study ranged from 26 HP to 1478 HP, with the majority rated between 50 HP and 200 HP. Some engines were owned by the gas/collection company, but the majority of the engines were leased units. The Texas report indicates that for this particular group of engines, there was little “seasonality” to their operating schedule, but that they seldom ran at full load (generally between 10% and 70% capacity). In the portion of the region covered in the Texas study that were non-attainment areas, the majority of the engines were found to be rich burn engines, with most required to have NSCR NOx emissions controls installed.   The report indicates that the engines in the non-attainment areas not requiring NOx emissions controls were 2-stroke engines, engines under 50 HP, and 4-stroke lean burn engines.

The EIA map below shows the areas of natural gas production in the lower 48 states. It can be assumed that the areas of gas production are also representative of the locations of the producing wells and the related well head and field gathering natural gas compressors. Within the OTR, New York and Pennsylvania are the primary producers of natural gas, as indicated in the Energy Information Administration (EIA) map below. Maryland also has a small number of producing natural gas wells. The OTR neighboring states Ohio, Virginia, and West Virginia are also indicated as significant producers of natural gas in the EIA map.

Gas Production in Conventional Fields, Lower 48 States



Source: Energy Information Administration based on data from HPDI, IN Geological Survey, USGS
Updated: April 8, 2009

As indicated above, New York and Pennsylvania are the largest natural gas producing states in the OTR. The following table is from EIA data, and provides counts for the number of natural gas producing wells in OTR states. It can be seen that there has been a large increase in the number of natural gas producing wells in New York and Pennsylvania in recent years, with New York indicating a net increase of 853 wells and Pennsylvania indicating a net increase of 21,356 wells.

Number of Producing Gas Wells in the OTR

Year	Maryland Natural Gas Number of Gas and Gas Condensate Wells (Count)	New York Natural Gas Number of Gas and Gas Condensate Wells (Count)	Pennsylvania Natural Gas Number of Gas and Gas Condensate Wells (Count)
2000	7	5775	36000
2001	7	5913	40100
2002	5	6496	40830
2003	7	5878	42437
2004	7	5781	44227
2005	7	5449	46654
2006	7	5985	49750
2007	7	6680	52700
2008	7	6675	55631
2009	7	6628	57356

The following table also represents EIA data, and indicates the annual natural gas production from gas wells in the OTR states.

Annual OTR States Natural Gas Production from Gas Wells

Year	Maryland Natural Gas Withdrawals from Gas Wells (MMcf)	New York Natural Gas Withdrawals from Gas Wells (MMcf)	Pennsylvania Natural Gas Withdrawals from Gas Wells (MMcf)
2000	34	17741	150000
2001	32	27632	130853
2002	22	36637	157800
2003	48	35943	159827
2004	34	45963	197217
2005	46	54851	168501
2006	48	55339	175950
2007	35	54232	182277
2008	28	49607	187295
2009	43	44273	178869

Because of an overall lack of comprehensive emissions data for NOx sources in the oil and gas sector, and variability due to equipment and site specifics, it is difficult to estimate the magnitude of NOx emissions from well head and field gathering natural gas fueled compressor prime movers. Some related NOx emissions information was found in a report from the Western Region Air Partnership (WRAP), "An Emissions Inventory of Non-point Oil and Gas Emissions Sources in the Western Region". This report specifically addressed regional emissions from the oil and gas industry, and investigated regional data to estimate NOx emissions factors that included natural gas fueled wellhead compressor prime movers. While the NOx emissions factors presented in the report are based on region specific data, they appear to be realistic values that may be useful in estimating NOx emissions from similar equipment when site or region specific data is not available for other locations. The NOx emissions factor presented in the WRAP report for gas well heaters is 2.34x10(-2) tons NOx/MMcf.

Utilizing the 2.34x10(-2) tons NOx/MMcf emissions factor, the NOx emissions from the use of wellhead and field gathering natural gas compressors in the OTR gas producing states of Maryland, New York, and Pennsylvania for calendar year 2009 is estimated to be approximately 5,223 tons.

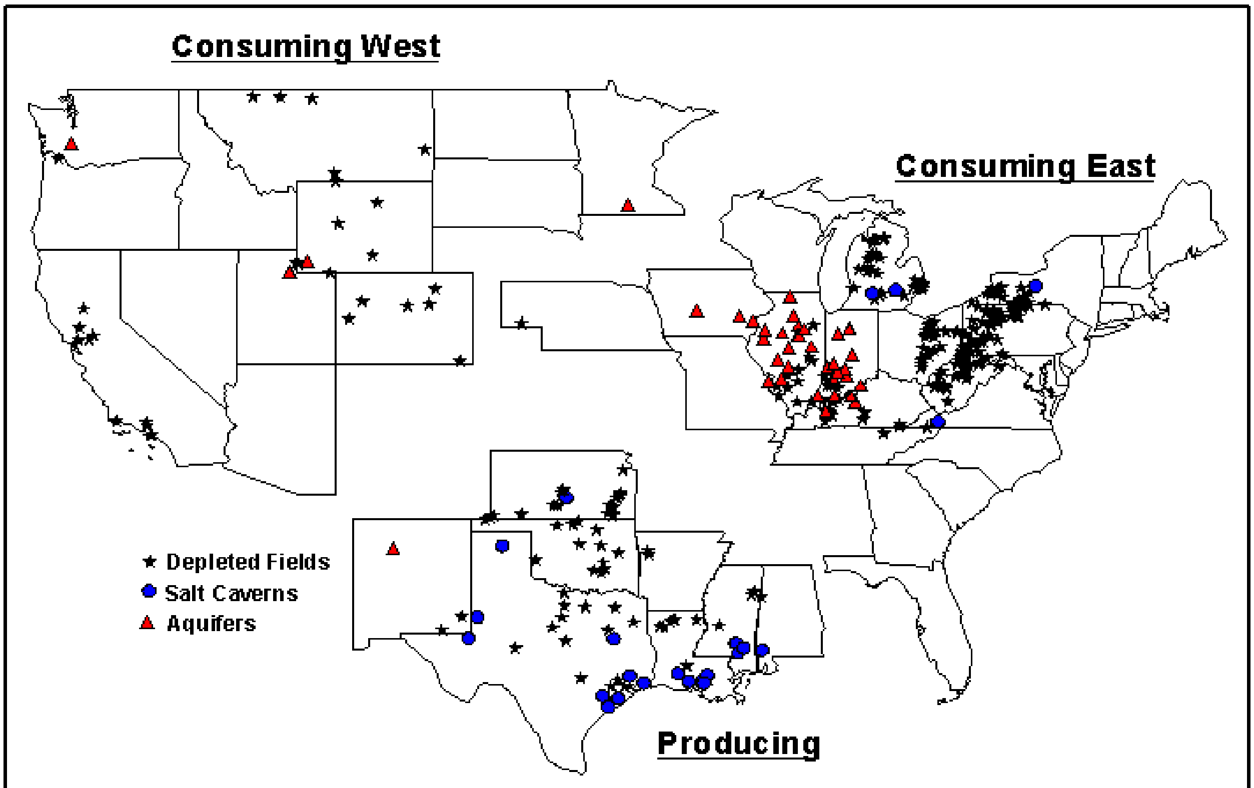
Natural Gas Underground Storage Facilities

In the Northeast, New York and Pennsylvania are the primary locations of underground natural gas storage facilities, as indicated on the following EIA map. The map also indicated that Ohio and West Virginia have significant gas storage facilities. The gas storage facilities in the Northeast are important for balancing natural gas demand with supplies during peak demand periods. Most of the existing underground storage facilities in the US are depleted natural gas or oil fields and salt caverns. In New York and Pennsylvania, the majority of the underground storage is depleted natural gas production fields. New York also has a salt cavern natural gas storage facility. Pennsylvania has more underground natural gas storage facilities than any other state. Depleted natural gas and oil fields may be able to take advantage of existing wells, gathering systems (sometimes including compressors), and pipeline connections. (Please see Attachment II for additional discussion of underground natural gas storage in the Northeast.)

The compressors at underground storage facilities may be used to inject pipeline natural gas into storage and then re-inject the natural gas back into the pipelines for transportation to the users. The characteristics of these compressors are typically similar to those of the gathering system mentioned above. EIA data from 2006 indicated that Pennsylvania and New York ranked 5th and 8th highest among states with the largest increase in natural gas underground storage deliverability for the period of 1998 through 2005. (Pennsylvania exhibited a 13% increase (969 MMcuft/day added) and New York exhibited a 44% increase (510 MMcuft/day added)).

From a review of 2010 Form 2 and Form 2A FERC data, there were 44 natural gas underground storage compression facilities in the Northeast region in 2010. The FERC data indicated that there were a total of 190 natural gas compressors in those facilities. The installed horsepower ratings for those facilities totaled 380,410 hp (an unknown portion is likely to be driven by electric motor prime movers), with a range in total horsepower for those facilities being from 75 hp to 43,800 hp per facility. The FERC data indicated that in 2010 these facilities collectively combusted 7,449,759 dth (approximately 7,449,759,000 cf) of natural gas for compression services.

Figure 2. Underground Natural Gas Storage Facilities in the Lower 48 States



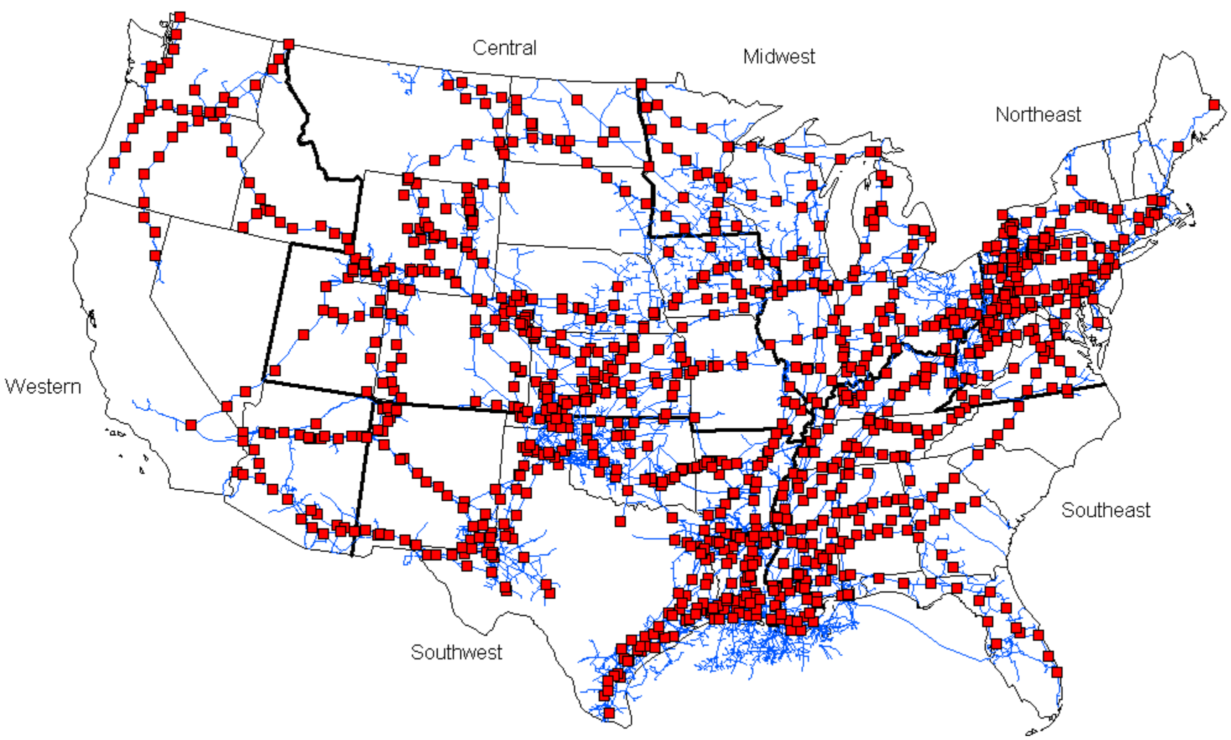
Source: Energy Information Administration (EIA), EIA GasTran Geographic Information System Underground Storage Data Base.

Mainline Natural Gas Pipeline Compressor Facilities

Mainline natural gas transmissions pipeline systems utilize compressors at gas compressor stations to maintain system flow and overcome pressure losses due to the movement of the natural gas through the natural gas pipeline system.

These compressor stations are typically located at 40 mile to 100 mile intervals along the transmission pipeline, as required by the particular pipeline section duty, to maintain the required flow and pressure. These mainline natural gas compressor facilities will often include multiple gas compressors to add flexibility and reliability in meeting the variable natural gas flow demand. Below is a map of the US interstate mainline gas system noting the location of the mainline compressor stations. This map is from 2006 EIA data, and is the latest map that could be located that shows the mainline compressor stations. The map shows that there are many mainline compressor stations in the Eastern US, with a relatively high concentration in New York and Pennsylvania. There have been a number of compressors stations (and compression additions to existing compressor stations) that have been put in service subsequent to 2006 to help meet the growing demand for natural gas as a fuel. EIA and Federal Energy Regulatory Commission (FERC) data indicates that additional compressor stations, and compressors at existing facilities, have also been added in the Northeast during the same time period. Prime movers for these mainline compressors are typically natural gas fired reciprocating engines and combustion turbines, although there are also a number of electric motor gas compressor prime movers in the system. In some instances, combustion compressor prime movers and electric motor compressor prime movers are located in the same compressor facilities. The horsepower ratings of the individual combustion compressor prime movers range from less than 300 hp to 15,000 hp and more.

Map of Interstate Natural Gas System Mainline Compressor Stations, 2006



The EIA data associated with the above map indicates that in 2006 there were 1201 natural gas mainline compressor stations in the US, with a combined installed horsepower combined rating in excess of 16.8 million horsepower. FERC, the approval authority for interstate pipelines projects (including compressor facilities), has records that show that between 2007 through 2010, FERC had approved new compressor facilities or upgrades to compressor facilities of approximately 2.6 million additional horsepower. Approximately 12% of that FERC approved compression horsepower increase was for compressor stations in OTR states.

Interstate Natural Gas Mainline Compressor Stations (US)

Number Stations		Total Installed H.P.		FERC Approved New H.P.
1996	2006	1996	2006	2007 - 2010
1047	1201	13,350,861	16,880,345	2,564,085

According to EIA information, the growth in natural gas compression capacity was not driven solely by an increase in overall natural gas production and consumption during the period. In fact, compared with 1996 levels, both natural gas production and consumption in the United States in 2006 were slightly lower than in 1996. The EIA information indicates that the expansion in natural gas compression capability was influenced by the following factors

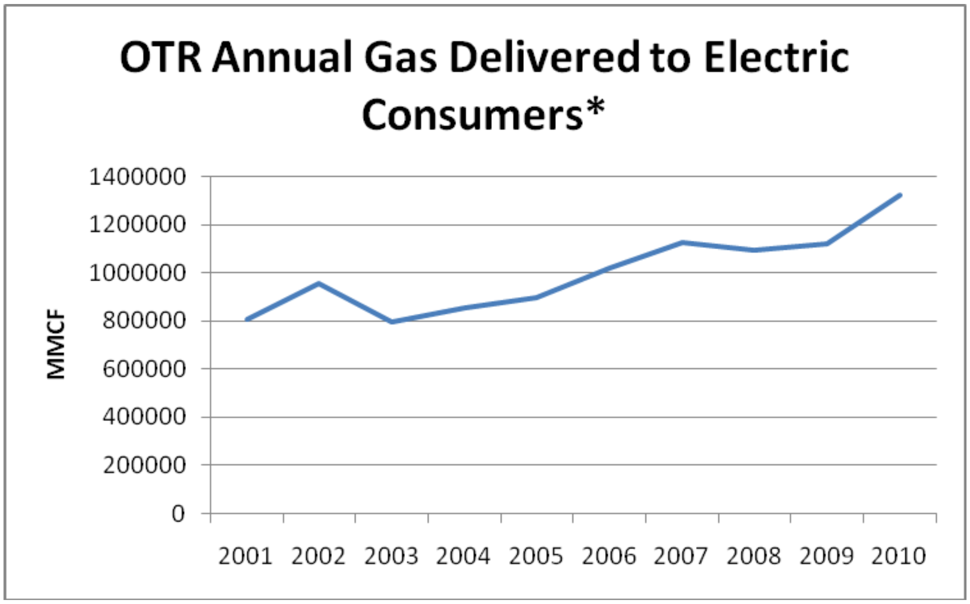
- New domestic production sources were developed in areas that required installation of new natural gas pipeline systems or expansion of existing ones.

- As domestic natural gas production reached a plateau during the 1990s, demand increased for Canadian natural gas supplies and new pipelines to transport them were created.

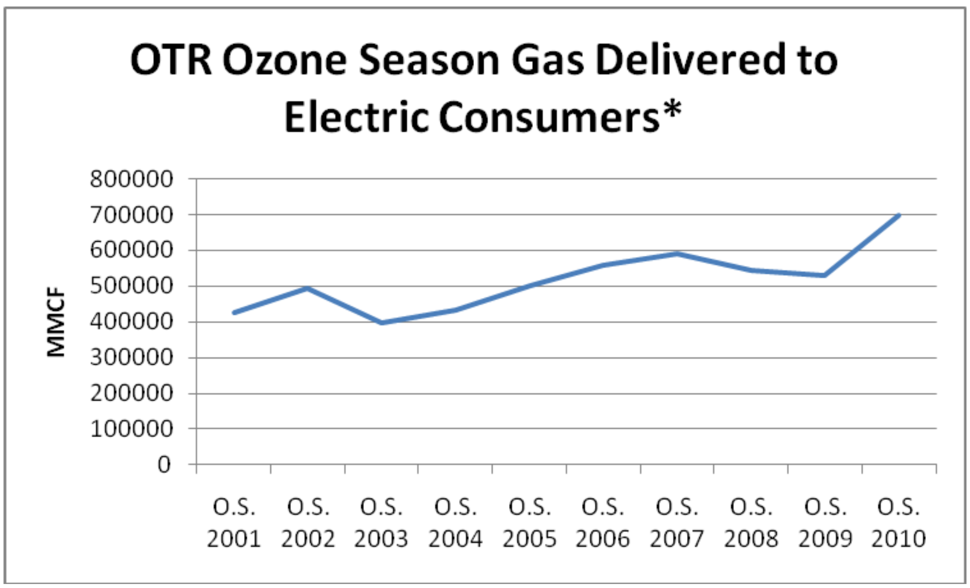
- Major growth in the number of large-volume natural-gas-fired electric power generating plants required additional capacity in specific markets.

- Regulatory demands to reduce the environmental footprint of compressor stations increased the scale of station revitalization and retrofits with improved technology.

The following two charts were prepared using EIA data, and indicate that over the last ten years there has been a large increase in natural gas delivered to electric generating consumers in the OTR. The increase in natural gas delivered to electric consumers in the OTR is due to increased electric generation using natural gas. This is a largely a result of the operation of new combined cycle units and the conversion of other electric generating units to being primarily gas-fried units. The increase in natural gas consumption can be seen for both the annual values and ozone season values. This data helps explain the need for increased gas compression capacity in the OTR.



*Excluding VA



*Excluding VA

Natural gas fueled reciprocating engines and combustion turbines are the most common prime movers for mainline natural gas compressors, with some facilities utilizing electric motor prime movers. The natural gas used to fuel the fuel-combusting prime movers is typically taken from the natural gas pipeline that the devices serve.

Many mainline natural gas compressor stations have multiple compressors operating in parallel to help meet large variations in the natural gas flow, and may also have some redundancy to minimize the impact of maintenance or problems with any given compressor unit. Industry data indicated that many of the mainline natural gas compressor stations have compressors in operation 24 hrs/day and 365 days/year, although not all compressors may be operating or may not be operating at high capacity. The industry data indicates that on average a compressor unit will tend to experience an annual average capacity factor of approximately 40%. [Within the OTR, FERC compressor facility specific (not unit specific) data indicated that for 2007 the range of facility operating capacity (in terms of compressor operating hours) ranged from 0% to approximately 95%, with an average of approximately 35%] For many mainline natural gas compressor facilities, reciprocating engine prime movers are preferred for their ability to adjust their output to meet the pipeline demand. Compressor loading will tend to increase during periods of high natural gas demand, such as cold periods with high heating fuel demand or high electric demand days in the northeast when natural gas fired electric generation is a significant consumer of natural gas. [Within the OTR, FERC compressor facility specific data for 2007 indicated that 24 of 141 compressor facilities saw their peak 2007 day during the ozone season.]

Many of the installed mainline natural gas compressor prime movers are of the age to have pre-dated modern OEM installed NOx emissions controls and any otherwise applicable NSPS. The following data was taken from a 2003 Pipeline Research Council International (PRCI) document. It can be seen that many of the prime movers are in excess of 40 years old. Little information was readily identifiable regarding the number of these units that may have undergone any NOx emissions reduction modifications as a result of federal or state NOx reduction rules and regulations subsequent to the initial installation.

2003 Pipeline Research Council International Data

US Natural Gas Pipeline Compressor Station Combustion Drives

Combustion Unit Type	US Total Units	Avg. Age (2003)	Avg. H.P.
2-stroke Leanburn Recip	2955	42	2113
4-stroke Leanburn Recip	1059	33	1844
Rich Burn Recip	1672	32	589
Combustion Turbine	1016	24	6121

A review of 2010 FERC Form 2 and Form 2A data indicated that in 2010 there were 149 compressor stations in the OTR used for natural gas transmission service. The FERC data indicated that these compressor stations collectively had 518 natural gas compressors with a collective total horsepower rating of 2,053,510 hp (an unknown portion of which s likely powered by electric motor prime movers). The FERC data indicates that in 2010 these facilities collectively combusted 47,426,022 dth (approximately 47,426,022,000 cf) of natural gas for compression services.

Reciprocating Engine Prime Movers

In a reciprocating engine, combustion of a compressed fuel-air mixture is used to drive pistons in one or more cylinders, with the linear piston motion converted to rotary motion with a crankshaft. The rotary motion developed by the reciprocating engine may then be utilized to drive natural gas compressors, pumps, mechanical drives, or other rotary loads.

Spark ignition engines use a spark (across a spark plug) to ignite the compressed fuel-air mixture to create the motive force. There are three main types of gas-fired, spark ignition engines used as prime movers for natural gas compressors; two stroke lean-burn engines (2SLB), four-stroke lean burn engines (4SLB), and four-stroke rich-burn engines (4SRB). Within these categories, there are various engine manufactures and some of the manufacturers have multiple engine sizes (outputs) and models.

Another type of reciprocating engine is the diesel or compression ignition engine. Compression ignition engines utilize the heat generated during relatively high levels of compression of the combustion air in the combustion chamber to cause ignition of the fuel air mixture when the fuel is introduced into the combustion chamber. Diesel engines may be either two-stroke or four-stroke. There are various diesel engine manufacturers, with most manufacturing multiple models with a range of rated outputs.

Two Stroke Spark Ignition Engines

Two-stroke engines complete the power cycle in a single engine revolution compared to 2 revolutions for 4-stroke engines. With the 2-stroke engine, the air/fuel charge is injected with the piston near the bottom of the power stroke. The ports or valves are all covered or closed, and the piston moves to the top of the cylinder compressing the charge. Following ignition and combustion, the power stroke starts with the downward movement of the piston. Exhaust ports or valves are then uncovered to remove the combustion products, and a new air/fuel charge is ingested. Two-stroke engines may be turbocharged using an exhaust-powered turbine to pressurize the charge for injection into the cylinder. Non-turbocharged engines may be either blower scavenged or piston scavenged to improve removal of combustion products. The air and fuel are mixed inside the power cylinder and fired by either a spark plug or pre-combustion chamber. Two stroke engines generally are set to operate with a lean mixture to minimize combustion temperatures, and the fuel lean combustion mixtures tend to produce lower combustion temperatures and therefore lower NOx emissions. Some lean burn engines can be modified to operate with very fuel lean mixtures, further reducing NOx emissions, up to the point where engine miss-fire becomes a problem. Some of the combustion improvements discussed below (high energy ignition, pre-chamber combustion, improved fuel mixing) facilitate the use of very fuel lean mixtures before engine miss-fires are encountered.

There are many 2-stroke spark ignition prime movers in natural gas compression service in the OTR, representing a number of different manufacturers and model numbers.

There are a number of methodologies commercially available to help control NOx emissions from two-stroke lean burn spark ignition engines, most of which are related to efforts to acceptably operate with very lean air/fuel mixtures. While most of the technologies are generically applicable to most of the existing two-stroke lean burn engines, application on any specific make/model of engine may present unique circumstances that may affect the effectiveness of the control and the cost of installation on that particular project.

When an engine's air/fuel mixture is lean to achieve NOx emissions reductions, the amount of spark required from the ignition system to start combustion is increased. High energy ignition systems are applicable to most lean burn engines that are not already equipped with such a system. The high energy ignition system is generally a conventional open-chamber system with the spark plug (or plugs) generally located with the spark plug protruding from the bottom of the combustion cylinder head into the combustion chamber. High energy ignition systems allow more energy to be delivered to the spark plug(s) with a larger gap, thereby increasing the spark energy delivered to the air/fuel mixture and ensuring proper ignition. High energy ignition systems may be digitally controlled systems that use crankshaft referenced angle encoders to deliver precise, high energy ignition sparks. These high energy ignition systems may have the capability to generate multiple, successive sparks during combustion to ensure proper air/fuel light- off. Modern high energy ignition systems tend to reduce miss-fires and engine detonation, and provide a more stable combustion over an engine's entire operating range. Industry information indicates that a slight NOx emissions reduction, approximately 10%, can be achieved through application of a high energy ignition system on an engine that does not have an existing high energy ignition system.

Another methodology for controlling NOx emissions is by improving the combustion airflow characteristics of the engine. Increasing the airflow tends to produce a leaner air/fuel mixture, reducing the peak combustion temperature which tends to reduce NOx emissions. For some engine designs, this may be accomplished by varying the engine load or increasing the engine speed (if within the manufacturer's limits). The airflow of many engines can be increased by converting non-turbocharged engines to incorporate a turbocharger system, modifying or upgrading existing turbocharger systems on engines already incorporating turbochargers, or other unit-specific means to supply combustion air or scavenge the cylinder of combustion products. Turbocharger additions or upgrades often also require upgrades to the rest of the air intake and exhaust systems to accommodate and optimize the new or upgraded turbochargers. Additionally, a turbocharger installation or upgrade may be optimized through the use of intake/combustion air cooling systems. Industry information indicates that, depending upon the degree of upgrade, NOx emissions reductions of up to 75% may be expected for the addition of properly engineered turbocharger systems with intake /combustion air cooling.

Enhanced air fuel mixing technologies are another method of achieving NOx emissions reductions. The design of some two-stroke engines exhibit problems with the ability to thoroughly mix combustion air and fuel. For these engines, the combustion air and fuel may not be introduced for mixing until each has entered the combustion cylinder. The combustion air and fuel mix as the fuel is "sprayed" into the combustion air already in the cylinder. For some engine designs, the air and fuel mixing results in a non-homogeneous mixture that can cause a sporadic and unstable burning process as the flame burns through the cylinder filled with different regions of differing air/fuel mixtures. To improve the mixing process, the fuel supply system and components can be converted to utilize higher fuel injection pressures that force a more rapid and turbulent interaction between the combustion air and fuel and result in a more homogeneous mixture. Industry information indicates that increasing the pressure at which the fuel is injected, and directing the dispersion of the fuel during injection, can significantly reduce emissions and fuel consumption. Industry information indicates that relative to an older low pressure fuel injection system, a well engineered high pressure fuel injection system may be able to facilitate NOx emissions reductions of up to 90% in some engines.

As mentioned above, leaner air/fuel ratios have a tendency to help reduce NOx emissions. However, as the air/fuel ratio is further leaned to attain lower NOx emission rates, the extremely lean air/fuel mixtures become more difficult, if not impossible, to ignite using a standard open-chamber spark plug ignition system. In these cases, a combustion pre-chamber (typically less than 10 percent of the volume of the main chamber) may be installed in the power cylinder head and fitted with a conventional spark plug in the pre-chamber. The fuel supply system is modified to inject fuel into the pre-chamber as well as the main power chamber. During the intake process, the pre-chamber is charged with a richer air/fuel mixture than the main chamber. This richer pre-chamber combustion mixture is easily ignited by the sparkplug. As the pre-chamber combustion ignition burns, the pressure of the combustion pushes the burning mixture into the main power chamber, igniting the main power chamber's lean air/fuel mixture. Industry information indicates that the use of ignition pre-chambers may facilitate NOx reductions capabilities of up to 90% in some engines.

Modern electronic engine controls also may be utilized to facilitate the NOx reduction benefits of the above modifications. This is especially true for varying engine load or speed conditions, varying ambient conditions, or startup/shutdown conditions. Some of these devices are air/fuel ratio controllers. Some of these air/fuel ratio controllers utilize mathematical models to monitor certain engine parameters and atmospheric conditions to determine the correct air/fuel mixture for the operating conditions. By tracking and maintaining the "correct" air/fuel mixture, the engine runs clean and more efficiently. In this way, the engine is more capable of maintaining NOx emissions compliance even with changing operating conditions and ambient condition changes.

Selective catalytic reduction (SCR) is a post-combustion NOx control that utilizes a catalyst and a reducing agent to reduce the concentration of NOx in the exiting combustion gasses. The reagent, typically ammonia or urea, is injected into the exhaust stream of the engine. Once in the exhaust, the ammonia (or urea that decomposes to produce ammonia in the exhaust stream) that passes over a catalyst to turn NOx into water, nitrogen and CO2. Catalyst selection is somewhat based on the expected temperature range of the engine exhaust, and is sized to achieve the desired amount of NOx reduction. The reagent injection system is comprised of a storage tank, reagent injector(s), reagent pump, pressure regulator and electronic controls to accurately meter the quantity of reagent injected as a function of engine load, speed, temperature and NOx emissions. Industry information indicates that the use of SCR for NOx control may facilitate NOx reductions of up to 95%.

Four Stroke Spark Ignition Engines

Four-stroke engines use a separate engine revolution for the intake/compression stroke and the power/exhaust stroke. Four-stroke engines complete the combustion cycle in two revolutions of the crankshaft. Each of the piston's four strokes has an important function in the engine cycle (intake, compression, power and exhaust). These engines have intake and exhaust valves to introduce combustion air into the cylinder and exhaust combustion gases from the cylinder. Most four-stroke spark ignition engines use open-chamber spark plugs to ignite the air/fuel mixture, and can be configured as rich- or lean burn, depending on the air/fuel mixture. These engines may be either naturally aspirated, using the suction from the piston to entrain the air charge, or utilize a supercharger or turbocharger to pressurize the inlet air/fuel charge.

Lean-burn four-stroke spark ignition engines usually have a fuel injection system that injects the fuel near the intake valves or in the power head. They use either open-chambered or pre-combustion chamber ignition systems to assure ignition of the lean mixture. Engines generally are fitted with a mechanically driven blower or turbocharger to supply the required combustion air. Lean burn engines have higher oxygen levels in the combustion chamber (and exhaust), which decreases the combustion temperature thereby reducing how much NOx is formed. Because the air-to-fuel ratio is lean with fuel, less fuel is used, which results in decreased combustion temperatures, decreased engine power, and increased engine efficiency relative to a rich burn engine. As discussed for two-stroke engines, some lean burn four-stroke engines can be modified to operate with very fuel lean mixtures, further reducing NOx emissions, up to the point where engine miss-fire becomes a problem. The same combustion improvements discussed for two-stroke engines (high energy ignition, pre-chamber combustion, improved fuel mixing) may be used on four-stroke engines to facilitate the use of very fuel lean mixtures before engine miss-fires are encountered.

There are many 4-stroke lean burn spark ignition engines in natural gas compressor prime mover service in the OTR, representing a number of different manufacturer's and model numbers.

NOx emission controls for four-stroke lean burn spark ignition engines are conceptually similar to those described above for two-stroke lean burn engines. This includes high energy ignition systems, improved air fuel mixing (higher pressure fuel injection), combustion pre-chamber installation, improved control systems, and the use of SCR. While the control system specifics may differ to accommodate the difference in engine configurations, industry literature indicates that the NOx reduction capabilities of the NOx control technologies are similar between the two-stroke lean burn engines and four-stroke lean burn engines.

Another potential NOx reduction technology for four-stroke lean burn engines is the use of exhaust gas recirculation (EGR). EGR systems utilize hardware changes to recirculate engine exhaust gases into the combustion chamber of the engine as an inert substitute for the excess air normally supplied in lean burn engine operation. EGR allows the combustion chamber to operate as if it were a rich burn engine and, since no excess oxygen is present in the exhaust, a much less expensive nonselective reduction catalyst (NSCR) can be used when post-combustion NOx controls are needed to meet NOx emissions standards. NOx emissions rates from an EGR and nonselective catalyst equipped engine can be as low as, or lower than, a lean burn engine equipped with a selective catalytic reduction (SCR) system. Several independent companies have installed retrofit systems on existing natural gas engines and have reported some success in meeting very low emissions requirements during initial and limited field testing. Engine performance and fuel efficiency are reported to be the equivalent of standard lean burn engines yet are still able to utilize NSCR for meeting stringent NOx emissions limitations.

Rich-burn four-stroke engines are configured to operate at or near a stoichiometric air/fuel ratio with little or no excess air. The engines can be carbureted or fuel injected, and they use the intake stroke of the piston to draw air into the cylinder (naturally aspirated). Manufacturers have added superchargers and turbochargers to increase the delivery of combustion air, which increases horsepower output capability. Because the air-to-fuel ratio is rich with fuel, more fuel is used, which results in increased combustion temperatures, increased engine power, and decreased engine efficiency relative to a lean burn engine.

There are a number of 4-stroke rich burn spark ignition prime movers in natural gas compression service in the OTR, representing several manufacturers and model numbers.

Similar to the lean burn engines, application of high energy ignition systems on rich burn engines has the potential of resulting in NOx reductions. These modern high energy ignition systems tend to reduce miss-fires and engine detonation, and provide a more stable combustion over an engine's entire operating range. Industry information indicates that a slight NOx emissions reduction, approximately 10%, can be achieved through application of a high energy ignition system on a rich burn engine that does not have an existing high energy ignition system.

Non Selective Catalytic Reduction (NSCR) is an effective NOx reduction technology for rich burn engines that exhibit low levels of excess oxygen in the exhaust. A NSCR, or three way catalyst, is similar to the catalyst controls installed on most modern automobiles. Exhaust from the engine is passed through a metallic or ceramic honeycomb covered with a platinum group metal catalyst. The catalyst promotes the low temperature (approximately 850 degF) reduction of NOx into N2, the oxidation of CO into CO2, and the oxidation of VOCs into H2O and CO2. NSCR catalyst efficiency is directly related to the air /fuel mixture and temperature of the exhaust. Efficient operation of the catalyst requires the engine exhaust gasses contain no more than 0.5% O2. In order to obtain the proper exhaust gas O2 across the operating range, an air/fuel ratio controller is installed that measures the oxygen concentration in the exhaust and adjusts the inlet air fuel ratio to meet the proper 0.5% O2 exhaust requirement for varying engine load and engine speed conditions and varying ambient conditions. Industry literature indicates that the proper use of NSCR on four-stroke rich burn engines has NOx reduction capabilities of up to 99%, with NOx emission rates well below 1 g/bhp-hr. Industry information indicates that, across the US, there are thousands of NSCR installations. [Retrofit installation of NSCR on 5 Caterpillar rich burn engines in Texas achieved a NOx reduction of 96% or greater on all of the engines. On two of those engines, testing conducted after more than 4000 hours of operation with the NSCR indicated the NSCR controls were still achieving 95% NOx reduction.]

Some industry literature suggests that some particular 4-stroke rich burn engines can be converted to lean burn configurations with the accompanying lean burn engine NOx reduction capabilities. One vendor indicates that conversion to a lean burn configuration and the use of exhaust gas recirculation delivers the advantages of a lean burn engine's efficiency and the rich burn engine's capability of utilizing NSCR for NOx control.

	Potential NOx Reduction		
Spark Ignition Engine NOx Control Retrofit	**2 Stroke Lean Burn**	**4 Stroke Lean Burn**	**4 Stroke Rich Burn**
High Energy Ignition System	10%	10%	10%
Intake Air Upgrade (turbocharger, etc)	75%	60% - 70%	N/A
Improved Mixing (high pressure fuel injection)	90%	90%	N/A
Pre-Combustion Chamber Ignition System	90%	90%	N/A
NSCR Catalyst (with air/fuel ratio controller)	N/A	N/A	90% - 99%
SCR Catalyst	50% - 95%	50% - 95%	N/A

Diesel Engines

In a diesel engine, combustion air is drawn into the cylinder and compressed in the combustion chamber with a relatively high compression ratio compared to most spark ignition engines. As a result of the compression, the combustion air temperature is raised to a high level, often 1300 degF to 1650 degF. With the piston at or near the top of the compression stroke, diesel fuel is injected into the combustion chamber through an atomizing fuel nozzle, mixing the fuel with the hot combustion air. The fuel air mixture ignites as a result of the high temperature in the combustion chamber. The expanding combustion products push down on the piston and connecting rod, which transfers this motion to the crankshaft, resulting in rotary motion and engine output power. The inlet of combustion air and exhaust of spent combustion products occurs through ports or valves in the cylinder heads. To further improve the output and efficiency of a diesel engine, turbochargers are often utilized to compress the combustion air prior to entry into the cylinder and attaining a high level of cylinder filling and pressure. The use of air coolers between the air outlet of the turbocharger and the cylinder inlet cools the combustion air and helps further improve the engine efficiency.

Diesel engines may be either 2 stroke or 4 stroke configurations, with the majority being 4 stroke and some large units being 2 stroke. Diesel engines are lean burn engines.

Control of the start of fuel injection timing, relative to the crankshaft angle of top-dead-center for the specific cylinder, can affect the diesel engine's efficiency and NOx emissions, depending upon engine design and load. Advancing the fuel injection timing, relative to the cylinder's compression top dead center, will tend to improve the engines efficiency and result in higher NOx emissions. Retarding the injection timing, relative to the cylinder's compression top dead center, will tend to reduce NOx emissions but also reduce the engine's efficiency, possibly increasing the engine's particulate emissions. The amount of effective control is highly dependent upon the engine design and operating characteristics. While this NOx reduction technology is applicable to nearly any diesel engine, its effectiveness is likely greatest on older, otherwise uncontrolled, diesel engines. Industry literature suggests that NOx reductions of up to 20% to 25% may be possible utilizing diesel injection timing retard.

The use of emulsified fuels has been demonstrated to achieve reductions in diesel engine NOx emissions. Emulsified diesel fuel is a blended mixture of diesel fuel, water and other additives. The water is suspended in droplets within the fuel, creating a cooling effect in the combustion chamber that decreases NOx emissions. A fuel-water emulsion creates a leaner fuel environment in the engine, lowering PM emissions. Emulsified diesel can be used in any diesel engine, but there is a decrease in power and fuel economy due to the fact that the addition of water reduces fuel energy content. Emulsified fuel can achieve emission reduction of NOx by about 10 to 20 percent and PM by about 50 to 60 percent.

Exhaust gas recirculation (EGR) is an effective NOx control for diesel engines in new and retrofit applications. Both low-pressure and high-pressure EGR systems exist but low-pressure EGR is used for retrofit applications because it does not require engine modifications. EGR involves recirculating a portion of the engine's exhaust gas back to the turbocharger inlet or intake manifold, in the case of a naturally aspirated engines. In most systems, an intercooler lowers the temperature of the recirculated exhaust gas. The cooled recirculated exhaust gas mixed in with the combustion air tends to result in an overall lower combustion temperature in the engine, thus inhibiting NOx formation. Diesel particulate filters are always used with a low-pressure EGR system to ensure that large amounts of particulate matter are not recirculated to the engine. EGR systems are capable of achieving NOx reductions of more than 40 percent in both new and retrofit applications.

Selective catalytic reduction (SCR) is a post-combustion NOx control applicable to diesel engines that utilizes a catalyst and a reducing agent to reduce the concentration of NOx in the exiting combustion gasses. The reagent, typically ammonia or urea, is injected into the exhaust stream of the engine. Once in the exhaust, the ammonia (or urea that decomposes to produce ammonia in the exhaust stream) that passes over a catalyst to turn NOx into water, nitrogen and CO2. Catalyst selection is somewhat based on the expected temperature range of the engine exhaust, and is sized to achieve the desired amount of NOx reduction. The reagent injection system is comprised of a storage tank, reagent injector(s), reagent pump, pressure regulator and electronic controls to accurately meter the quantity of reagent injected as a function of engine load, speed, temperature and NOx emissions. Industry information indicates that the use of SCR for NOx control may facilitate NOx reductions of up to 95%, although 75% to 90% reduction is more typical. Industry information indicates that there are a number of suppliers of SCR systems for diesel engines, and many systems have been installed and are successfully in commercial operation. SCR may be utilized in either a new or retrofit application.

A presentation by Shell indicated that Shell has been installing SCR NOx reduction systems on diesel engines used to support drilling rig operations. Shell's information indicated that Shell has observed NOx reductions of greater than 90% in this application with minimal impact on operations.

Industry information indicates that there are additional NOx reduction technologies applicable to diesel engines. One, lean NOx catalyst systems, utilize injection of a small amount of fuel into the exhaust to act as a reductant in conjunction with a zeolite catalyst to attain NOx reductions of 10% to 30%. Another, lean NOx traps, traps NOx in a barium hydroxide or barium carbonate material during normal engine lean operation, and engine controls periodically cause the engine to operate fuel rich mode to regenerate the trap material and release the NOx as N2 or NH3. No information was found regarding commercial operation of these technologies in the field.

Combustion Turbine Prime Movers

Combustion turbines have three main sections; the compressor, the combustor, and the power turbine. The compressor draws in and pressurizes ambient air. In the combustor, fuel is mixed and combusted with a portion of the compressed air. The resulting combustion gases are diluted with the remainder of the air from the compressor to create a large volume of a hot, compressed combustion gas mixture. The hot, compressed gases then expand in the turbine section, driving the power turbine and creating the turbine's output rotary motion. The rotating turbine shaft is connected to the compressor load, sometimes through a gear box.

There are several different manufacturer's of combustion turbine prime movers (and multiple prime mover models) represented in the OTR in natural gas compressor prime mover service. There are a number of commercially available NOx reduction technologies for combustion turbines, but not all may be applicable/available for any given make/model of combustion turbine.

Water injection is a NOx reduction technology applicable to most combustion turbines. Injecting water into the combustion zone tends to lower peak flame temperatures, thereby lowering the amount of thermal NOx formation during combustion. Water may be injected directly into the turbine combustor, or may be converted to steam using turbine exhaust waste heat (with an HRSG), and then injected into the combustor as steam. More steam than water must be used to achieve a comparable NOx reduction, but the use of steam may result in a lower energy penalty than use of water if the turbine's waste heat would not otherwise be recovered and used. Depending upon the make/model of the applicable combustion turbine, turbine modifications may be as simple as replacement of fuel nozzles with nozzles capable of supplying fuel and water/steam (and associated plumbing), or may be as complex as requiring replacement of the combustors designed to operate with water/steam injection (and associated plumbing). Other required equipment would include appropriate combustion turbine control systems, source of demineralized water (onsite water plant with storage, or storage tank for demineralized water prepared offsite), and water injection pump and flow metering station. Industry literature indicates that water/steam injection can result in combustion turbine NOx emissions reductions of 40% or more.

The use of dry low NOx burners (DLNB) is a NOx emissions reduction technology available for many makes and models of combustion turbines. DLNB technology utilizes a lean, premixed flame in the combustor as opposed to a turbulent diffusion flame. In a lean, premixed combustor, the fuel and air are premixed prior to entering the combustion zone. With a lean, premixed flame, the contribution of prompt and thermal NOx can be much lower than for a turbulent diffusion flame that is typical for non-DLNB combustion turbine combustors. Many DLNB combustors are capable of achieving NOx emissions reductions across the full load range, but some require more sophistication to allow variable operating modes in order to maintain flame stability across the full load range. Not all turbine designs can accommodate a DLNB, and DNLB combustors may not be available for all makes and models of combustion turbines. In addition to the replacement of the turbine's combustors, installation of DLNB technology would include associated piping changes and turbine combustion control modification or replacement. Industry literature indicates that the utilization of DLNB technology can achieve NOx reductions of 60% or more for those units where the technology is available.

Selective catalytic reduction (SCR) is a NOx reduction technology applicable to combustion turbines. SCR is a post-combustion NOx control that utilizes a catalyst and a reducing agent to reduce the concentration of NOx in the exiting combustion gasses. The reagent, typically ammonia or urea, is injected into the exhaust stream of the combustion turbine. Once in the exhaust, the ammonia (or urea that decomposes to produce ammonia in the exhaust stream) that passes over a catalyst to turn NOx into water, nitrogen and CO2. Catalyst selection is somewhat based on the expected temperature range of the combustion turbine exhaust, and is sized to achieve the desired amount of NOx reduction. The reagent injection system is comprised of a storage tank, reagent injector(s), a reagent pump, pressure regulator and electronic controls to accurately meter the quantity of reagent injected as a function of combustion turbine load, temperature and NOx emissions. Industry information indicates that the use of SCR for NOx control on combustion turbines may facilitate NOx reductions of 95% or more.

Natural Gas Compressor Combustion Prime Mover Data Sources

To date, no comprehensive database of natural gas compressor combustion prime movers and their NOx emissions has been located. Several sources of data have been located that provide partial information regarding the OTR natural gas compression facilities, the types of prime movers in those facilities, and the NOx emissions from the prime movers. For example, data from the 2007 MARAMA Point Source Inventory provided a listing of reported unit-level 2007 annual estimate data (ton/yr), but did not provide sufficient information to estimate unit NOx emission rates (g/HP-hr, ppm, etc). The 2007 MARAMA inventory also provided some limited technical information regarding the a portion of the prime movers, such as make, model, rating of the prime movers.

Another source of data that provides some information regarding pipeline compressor facilities is FERC's database of the required FERC Form 2 and Form 2A submittals. FERC Form 2 is a required financial and operational information report for major interstate natural gas pipelines subject to the jurisdiction of the FERC. Form No. 2-A is an abbreviated Form No. 2 filed by non-major (having total gas sales or volume transactions exceeding 200,000 dekatherms) interstate natural gas pipelines subject to the jurisdiction of the FERC. While providing compressor facility operating information, this database has limitations such as it does not provide unit-level information, does not provide emissions information, and does not include compressor facilities from relatively small capacity pipelines. For the compressor facilities subject to this FERC reporting requirement, the database includes the total installed compressor horsepower capability, number of installed compressors, total hours of compressor operation (for annual or quarterly), total fuel consumption (for annual or quarterly), and the number of compressors operating during peak periods. The data also indicates whether the individual compressor station's primary purpose is field gathering, underground injection, or pipeline transportation. While this FERC information does not provide unit-specific emissions information, it does provide some insight into the service loading of the individual compressor stations and that station's fuel consumption. In order to get a more direct comparison with the 2007 MARAMA data, 2007 annual FERC data was also collected and reviewed.

Finally, some data regarding individual prime mover technical information and permitted NOx emission rates for those prime movers was located through internet searches of operating permits for the associated compressor stations. However, not all of the applicable permits were located through the internet searches, and not all of the permits located provided the desired level of technical or emission data.

Collectively, the above data sources still did not provide the amount or quality of the desired data to fully understand the OTR population of natural gas compressor prime movers or their NOx emissions. For example, the data extracted from the 2007 MARAMA Point Source Inventory regarding OTR natural gas compressor combustion prime movers (and their identified facilities) did not match the OTR natural gas compressor facility inventory identified in the FERC data. In the 2007 MARAMA data, 107 individual OTR gas compressor facilities were identified. In the 2007 FERC data, 150 natural gas compressor facilities were identified as having combusted natural gas for compression service in 2007. It is uncertain why there is such a large discrepancy. It is possible that additional compressors are in the 2007 MARAMA data, but could not be clearly identified as natural gas compressor prime movers from their database descriptions. It also appears likely that some of the compressor prime movers are identified as area sources and therefore did not show up in the point source inventory. There are likely other explanations. Regardless, it is clear that the data extracted from the 2007 MARAMA Point Source Inventory is incomplete regarding the population of the OTR compressor prime movers and the associated annual NOx emissions.

Population of Compressor Prime Movers

Regardless of the assumed data limitations, data from MARAMA's 2007 Point Source Inventory was reviewed to obtain an understanding of the makeup of the OTR's population of fuel-combustion natural gas compressor prime movers. The review of the data indicated that a number of the units in the database did not give sufficient information to categorize each unit, sometimes not identifying the prime mover configuration (engine, turbine, 2SLB, etc), manufacturer, model number, output capacity, etc. It was possible to supplement some of the MARAMA data with information obtained from internet searches of compressor station operating permits, but there remains a significant number of units in the database with only partial information.

From the available information, it can be seen that the population of OTR natural gas compressor prime movers is diverse with regards to make, model, and capacity. For the reciprocating engine prime movers (2SLB, 4SLB, and 4SRB), the available data indicates that there are at least 60 different engine models spread among 13 different manufacturers. For the turbine prime movers, the available data indicates that there are at least 20 different models spread among 6 different manufacturers. [It should be noted that the number of manufacturers represented in the data are sometimes the result of mergers and buyouts. For example, the reciprocating engine manufacturer Superior (existing since the early 1900's) became White-Superior in the mid-1960s, then became Cooper-Superior in the early 1970s, and became Superior (within Cameron) in the mid-1970s. In fact, Cameron is also the current OEM for the Cooper-Bessemer line of engines.]

Within the available OTR compressor inventory data for reciprocating engines, the range of output for 2SLB prime movers is approximately 400 HP to 5500 HP, the range of output rating for 4SLB prime movers is approximately 650 HP to 4,300 HP, and the range of output rating for 4SRB prime movers is approximately 200 HP to approximately 1,300 HP. Also within the available OTR compressor inventory data for turbine prime movers, the range of output is approximately 1,000 HP to approximately 20,000 HP.

The data inventory also does not provide an indication of the vintage or age of the prime movers. Of most concern is the vintage of the reciprocating engines, as they have been available as compressor prime movers longer than combustion turbines and have been shown to have long service life. Industry information indicates that nationally there are many natural gas compression reciprocating engines that are in excess of 40 years old. While the data available at this time for the OTR natural gas pipeline compression reciprocating engines does not include an indication of the age of these engines, some inference can be made that many "vintage" reciprocating engine compressor prime movers continue in operation in the OTR by reviewing the manufacturer and model number of the subject engines. For example, industry information indicates that the Cooper-Bessemer family of GMW 2-stroke integral engines was manufactured between 1946 and 1965. The 2007 MARAMA database indicates that there are a number of such engines in the OTR that were still operating in 2007. The database does not contain sufficiently detailed information to determine if any of these vintage engines have undergone NOx RACT or been subject to any other NOx reduction activities.

The 2007 MARAMA point source data collected for this review indicted that, collectively, the compressor prime movers in the OTR compressor facilities emitted approximately 11,000 tons of NOx in 2007, with the average facility emitting approximately 112 tons of NOx in 2007. The highest NOx emitting facility emitted in excess of 1100 tons of NOx in 2007, those emissions collectively from 12 reciprocating engines. Because portions of the 2007 MARAMA point source data is presented as "per facility" rather than all on a "per unit" basis, it is difficult to get a thorough understanding of the unit-by-unit annual NOx emissions of the OTR gas compressor prime movers. It appears that the range of unit specific 2007 annual NOx emissions ranged from approximately 177 tons of NOx to less than 0.1 ton of NOx. The gas compressor prime movers at the upper end of the range appear to be predominately gas turbines and 2-stroke lean burn reciprocating engines.

The reviewed databases did not provide any information regarding NOx emission rates (g/bhp-hr, ppmvd, etc) from the subject gas compressor prime movers. As an alternate, where they could be located through internet searches, operating permits were reviewed to determine any NOx emission limits rate limits for the subject prime movers. Numerical NOx emission rate limits values were obtained for only a small portion of the prime movers in the 2007 MARAMA database. For the 2SLB engines in that small population of prime movers, the permit NOx rate limits ranged from 1.0 g/bhp-hr to 13.3 g/bhp-hr. For the 4SLB engines in that small population of prime movers, the permit NOx rate limits ranged from 0.5 g/bhp-hr to 6.0 g/bhp-hr. Permit NOx rate limit data for 4SRB prime movers was limited to 3 engines at a single facility, and each had a permit NOx emission rate limit of 1.5 g/bhp-hr. For combustion turbine prime movers, the permitted NOx emission rates ranged from 25 ppmvd to 160 ppmvd.

Because of the limited amount of data that was found, it can not be assumed that the ranges of the identified NOx emission rates discussed above are representative of the entire OTR population of compressor prime movers. For example, little technical data was located regarding natural gas compressor prime movers located in Pennsylvania, yet Pennsylvania accounts for approximately 58% of the number of natural gas compressor combustion prime movers identified in the 2007 MARAMA point source data. This makes it difficult to make any assumptions or conclusions from the existing data with a high degree of certainty.

For comparison purposes, the NOx emissions requirements of 40 CFR Part 60, Subpart JJJJ (NSPS) (1/18/08 73 FR 3567) applicable to natural gas-fueled, spark ignition engines are summarized in the following table:

Engine Type	**Output Rating**	**Manufacture Date**	**NOx Emissions Limit**
SI Nat. Gas	100≤HP<500	mfg after 7/1/2008	2.0 g/HP-hr
SI Nat. Gas	100≤HP<500	mfg after 1/1/2011	1.0 g/HP-hr
SI Nat. Gas	HP≥500	mfg after 7/1/2007	2.0 g/HP-hr
SI Nat. Gas	HP>500	mfg after 7/1/2010	1.0 g/HP-hr
SI Nat. Gas Lean Burn	500≥HP<1350	mfg after 7/1/2008	2.0 g/HP-hr
SI Nat. Gas Lean Burn	500≥HP<1350	mfg after 7/1/2010	1.0 g/HP-hr

Also for comparison purposes, the NOx emissions requirements of 40 CFR Part 60, Subpart KKKK (NSPS) (7/6/06 71 FR 38482) applicable to natural gas-fueled combustion turbines are summarized in the following table:

Turbine	**Heat Input Rating**	**NOx Emissions Limit**
New Nat. Gas Fired	≤ 50MMBTU/hr	100 ppm @ 15% O2
New Nat. Gas Fired	50<MMBTU/hr≤850	25 ppm @ 15% O2
New, Modified, or Reconstructed Nat. Gas Fired	>850MMBTU/hr	15 ppm @15% O2
Modified or Reconstructed Nat. Gas Fired	≤50MMBTU/hr	150 ppm @15% O2

Modified or Reconstructed Nat. Gas Fired	50<MMBTU/hr≤850	96 ppm @15% O2

The following table lists a few state's rules regarding NOx emissions limitations from stationary internal combustion engines and combustion turbines:

State	Rule	NOx Rate Limits	Comment
Texas	Chapter 117 - Control of Air Pollution from Nitrogen Compounds, SUBCHAPTER D: COMBUSTION CONTROL AT MINOR SOURCES IN OZONE NONATTAINMENT AREAS, DIVISION 1: HOUSTON-GALVESTON-BRAZORIA OZONE NONATTAINMENT AREA MINOR SOURCES	Stationary Gas-Fired RICE > 50 HP: 0.5 g/bhp-hr Stationary Combustion Turbine > 10 MMBTU/hr: 0.15 lb/MMBTU	Rule contains relief for units with average annual capacity factors of 3.83% or less (0.60 lb/MMBTU NOx limit), and provides for alternate RACT
Texas	Chapter 117 - Control of Air Pollution from Nitrogen Compounds, SUBCHAPTER B: COMBUSTION CONTROL AT MAJOR INDUSTRIAL, COMMERCIAL, AND INSTITUTIONAL SOURCES IN OZONE NONATTAINMENT AREAS	Stationary Gas Fired Rich Burn RICE ≥ 300 HP: 2.0 g/bhp-hr Stationary Gas Fired Lean Burn RICE ≥ 300 HP: 3.0 g/bhp-hr Stationary Combustion Turbine ≥ 10.0 MW: 42 ppm @ 15% O2	Rule contains exemption for units operating less than 850 hrs per year, and provides for alternate RACT
New York	New York State Department of Environmental Conservation, Subpart 227-2, Reasonably Available Control Technology (RACT) For Major Facilities of Oxides Of Nitrogen (NOx)	Stationary Gas Fired RICE ≥ 200 HP in severe ozone non-attainment, ≥ 400 HP outside severe ozone non-attainment: 1.5 g/bhp-hr Stationary Gas Fired Combustion Turbine ≥ 10 MMBTU/hr: 50 ppm @ 15% O2	Rule provides for alternate RACT
Pennsylvania	CHAPTER 145. INTERSTATE POLLUTIONTRANSPORT REDUCTION, Subchapter B. EMISSIONS OF NOx FROM STATIONARY INTERNAL COMBUSTION ENGINES	Stationary Rich Burn RICE > 2400 HP: 1.5 g/bhp-hr Stationary Lean Burn > 2400 HP: 3.0 g/bhp-hr	Rule part of allowance trading program

Industry Available Retrofit NOx Controls

For a large part of the population of engines and turbines in OTR gas compressor prime mover service, there are commercially available NOx controls. In some instances there is more than one level of retrofit NOx reduction technology available. Application of the retrofit controls to any specific engine model is likely dependent upon many factors, and a thorough review is necessary to evaluate any given potential application. The following is a list of some of the retrofit controls found through an internet search.

- Dresser-Rand, engine OEM, offers a retrofit NOx emission technology system. While somewhat dependent upon the specific model, the retrofit NOx emission reduction system may include a screw-in combustion pre-chamber high energy ignition system, earlier fuel injection timing and directional fuel injection for improved air/fuel mixing, improved controls for more precise fuel injection and engine timing, and improved air flow to further lean the mixture when applicable. Dresser-Rand also offers more extensive (and expensive) NOx reduction systems for retrofit, which depending upon engine model may include new cylinder heads with pre-combustion chambers, new main fuel gas injection valves, high efficiency turbochargers, larger turbocharger combustion air intercooler with plenums, new fuel management system, air/fuel ratio controller, new spark controller, new cams and/or camshaft on four-stroke engines, and a high-energy ignition system. Industry literature indicates that Dresser-Rand offers related retrofit NOx reduction controls for TVC, TCVA, TCVD, TLA, TLAD, LA, HLA, HLA/T, BA, HBA, HBA/T, RA, HRA, and HRA/T two stroke engines (Clark, Dresser-Clark). Industry literature also indicates that Dresser-Rand offers related NOx controls for KVS, KVSR, KVR, KVT, SVS, TVS, and TVR four stroke engines (Dresser-Rand, Ingersoll-Rand). The literature also indicates that NOx emission guarantees of between 2.5 g/bhp-hr and 3.0 g/bhp-hr have been provided with these NOx reduction technologies, and that those guarantees have been consistently met or improved upon. Dresser-Rand information indicated that Dresser-Rand was in the process of developing a low-NOx emission technology system for Worthington engines, but further internet information searches did not reveal any documentation of the results of the effort.

- Dresser-Rand also markets a retrofit NSCR NOx reduction system for rich burn engines.

- CleanAir Systems offers a NSCR NOx reduction catalyst for rich burn engines and a SCR system that they advertise as being applicable to lean burn natural gas fired engines, including those utilized for gas compression. CleanAir indicates that their SCR catalyst allows NOx reduction operation in a wide range of temperatures, from approximately 300 degF to approximately 1000 degF. CleanAir Systems was acquired by Caterpillar in 2010, and is now called CleanAir Systems, A Caterpillar Company. Their lean burn engine SCR product is now being referred to as ENSURE SCR. CleanAir Systems' NSCR is now referred to as ASURE TWC (three way converter). The use of an air fuel ratio controller is also recommended in these applications, and they are also offered by CleanAir Systems. CleanAir indicates that their lean burn engine capable SCR achieves up to 95% reduction in NOx emissions across a wide range of exhaust temperatures. CleanAir indicates that their ASSURE TWC NSCR can achieve NOx emission reductions up to 99%.

- CleanAir Systems also offers a SCR system for combustion turbines, similar to that described for lean burn engines described above, which they refer to as ENDURE SCR.

- Clean Air Power offers a NSCR NOx reduction catalyst for rich burn natural gas engines and a SCR NOx reduction system for lean burn natural gas engines. They indicated that they provide NSCR systems for engines with ratings from 100 HP to 2500 HP, with NOx reduction capabilities of up to 99%. They also indicated that they supply SCR systems for engines with ratings from400 HP to 5400 HP, with NOx reduction capabilities of up to 98%.

- Johnson Matthey offers a NSCR catalyst system for NOx reduction from rich burn engines and a SCR based NOx reduction system that is advertised to be applicable to lean burn engines used in natural gas compression applications. Johnson Matthey offers both as turnkey NOx reduction systems, and includes PC based control systems that offer several NOx control options. Johnson Matthey literature indicates that their SCR catalyst can be formulated for operation at a wide range of temperatures, permitting NOx control over a wide range of engine operation.

- Johnson Matthey also offers SCR systems for combustion turbine applications. The Johnson Matthey literature indicates that their SCR catalyst can operate over a wide temperature range offering flexible operation. Johnson Matthey indicates that their SCR systems are designed to startup quickly and bring the gas turbine into emission compliance within minutes. Johnson Matthey indicates that their designs allow reagent availability as soon as the catalyst reaches its minimum operating temperature, which allows NOx reduction to begin minutes sooner than with other SCR systems. Johnson Matthey literature indicates they have designed SCR systems for combustion turbines as small as 3 MW.

- Miratech Corporation offers a NSCR catalyst system for NOx reduction from rich burn engines and a SCR based NOx reduction system that is advertised to be applicable to lean burn engines used in natural gas compression applications.

- Cameron (engine OEM) has introduced an exhaust expansion chamber for the AJAX engine to improve the engine exhaust scavenging process. The exhaust expansion chamber was developed to speed up the process of removing the residual gases from the cylinder and to avoid the loss of fresh air into the exhaust after the residual gases are scavenged. The result is a large increase in the mass of air trapped in the power cylinder, which results in improved performance and cooler combustion, which reduce the NOx levels. This process is accomplished strictly by the shapes and lengths of the various sections of the exhaust system. Cameron literature indicates that NOx emissions rate levels of 0.5 g/bhp-hr to 0.8 g/bhp-hr have been achieved.

- Attainment Technologies company markets gas recirculation systems for NOx control for both lean burn and rich burn engines. Gas recirculation as a NOx control for these engines is also being offered by some OEMs. Attainment Technologies' literature indicates that retrofitted lean burn and rich burn prime movers have achieved NOx emission rates of 0.1 g/bhp-hr in testing using the Attainment Technologies NOx reduction systems.

- Caterpillar literature indicates that they offer emissions upgrade groups for retrofit for certain of its engine models, including many 3306 and 3406 models. These emissions upgrade groups may include an upgraded turbocharger, fuel pump/governor, nozzles, cylinder pack, after-coolers (if applicable), and installation parts. Caterpillar literature also indicates that they offer NSCR three way catalysts for retrofit NOx reduction application for gas fired rich burn engines, and SCR retrofit for natural gas lean burn engine NOx reduction applications, with NOx reduction capabilities of 95% or greater.

- GE offers retrofit dry low NOx emissions systems for many of their combustion turbines. For certain models, GE offers dry low NOx emissions systems along with water injection for further NOx emissions reductions.

- Solar Turbines information indicates that Solar offers an extensive line of standard NOx reduction retrofit kits for the entire Solar gas turbine product line, including their low-NOx SoLoNOx gas fuel system upgrade.

- Cameron offers retrofit NOx reduction systems for many Cooper Bessemer gas compression prime movers. Depending upon the model, the retrofits may include electronic fuel injection, pre-chambers with electronic check valves, and improved intake and exhaust systems. For certain models Cameron may also redesign the cylinder head to allow for leaner combustion and improving combustion stability.

- Nationwide Environmental Solutions offers their CataStak SCR NOx reduction systems for combustion turbines, delivering reliable NOx emissions as low as 2.5 ppm @ 15% O2. Nationwide Environmental's literature indicates that they offer SCR systems for combustion turbines sized down to an output rating of 0.5 MW, and with a combustion gas exhaust temperature of up to 1000 degF. The Nationwide information also indicates that their design includes simple controls, requires minimal operator intervention (Auto Start/Stop) and is easy to retrofit on existing equipment (vertical or horizontal arrangements).

- EF&EE (Engines, Fuel & Emissions Engineering Incorporated) announced on November 10, 2010, that it had received an order from Clean Air Power, Inc. for six SCR reductant metering and control systems. These systems were due to be delivered by the end of 2010, to be installed on large, lean-burn natural gas compressor engines at gas storage sites in Texas and Mississippi.

- EF&EE, on November 22, 2010, also announced Compact SCR(tm) system that enables conventional lean-burn natural gas and biogas engines to meet the California ARB Distributed Generation standard of 0.07 pounds of NOx per megawatt-hour.

- Clean Air Power has a case study, dated 3/4/2009, indicating that they had supplied four SCR units (in 2006, with an additional 2 ordered for 2009 delivery) for emissions control of natural gas fueled reciprocating engines at the Pine Prairie Energy Center, a salt cavern natural gas storage facility in Louisiana. FERC information indicates that the Pine Prairie Energy Center was incorporating six Caterpillar G16CM34 reciprocating engines, each rated 8,100 HP.

- Clean Air Power has a case study, dated 3/4/2009, indicating that they had supplied an SCR unit for a Caterpillar G3616 natural gas engine located at the salt cavern natural gas storage/hub services facility EXTERRAN / TRES PALACIOS in Texas.

- Clean Air Power has a case study, dated 3/4/2009, indicating that they were involved in a project that would include supplying four SCR units for natural gas fueled Caterpillar G3616 engines at the EXTERRAN / LEAF RIVER facility in Mississippi. This facility is a salt cavern natural gas storage and delivery site.

- Windrock offers an autobalance system that automatically balances the cylinder-to-cylinder combustion in multi-cylinder slow speed integral engines such as Cooper-Bessemer, Clark/Dresser, Ingersoll-Rand, Worthington, and other two- or four-stroke engines with individual cylinder fuel adjustment valves. The system constantly adjusts fuel flow to each power cylinder in order to maintain peak firing pressures to ± 5% of engine average during differing ambient conditions, varying speeds and changing loads. Eliminating unbalanced operation across all operating conditions enables the engine to run with the minimum possible NOx and facilitates the positive results of other NOx reduction modifications.

In its *Response to Comments, Phase II NOx SIP Call Rulemaking*, April 1, 2004, EPA indicated that they believed that virtually all reciprocating engines utilized as gas compressor prime movers could be retrofit with low emissions combustion (LEC) technology. EPA noted that:

- As previously noted, INGAA supplied information on the engine models used by the natural gas pipeline industry in the SIP Call area. The EPA also obtained information from various IC engine manufacturers. Various references were obtained on the availability of LEC to be retrofitted on existing engines.

- For Cooper-Bessemer engines, all 2 and 4 cycle Cooper engines (Cooper-Bessemer, Enterprise, Superior, Ajax) can be retrofitted with LEC; either Clean Burn or EcoJet. Also the EcoJet can be adapted to any IC engine model including Worthingtons and Clarks. The Clean Burn system can only be installed on a Cooper engine (Cooper, Enterprise, Ajax, Superior).

- For Clark, Ingersoll-Rand engines several sources of information were obtained. Low cost PCC retrofits are available for engines that are Clark TLA, TLAB-D; TCV, TCVA-D; HLA, BA, HBA models.

- According to Dresser-Rand personnel, the screw-in pre-chamber (SIP) has been installed on 79 engines at 7 different owner/operators in 5 different states. The SIP can be installed on any Dresser-Rand, Ingersoll-Rand, Clark or Worthington engine. Screw-in pre-chambers are available for TCV, TCVA, TVAD, TLA, TLAD, TCVC,LA, HLA, BA, HBA, RA, HRA, KVS, KVSR, KVR, and KVT.

- LEC using lean-burn operation, pre-combustion chambers, and enhanced in-cylinder mixing of fuel and air can be applied to Ingersoll-Rand KVS, KVSR, KVT, TVS, TVR, and SVS models regardless of the number of cylinders.

- Information obtained by EPA from the various IC engine manufacturers indicates that LEC technology is often guaranteed by the manufacturers to achieve at most 3.0 g/hp-hr.

- From Copper-Bessemer, a reasonable level of performance expected to be achieved by LEC retrofits is 3 g/hp-hr.

- According to another major vendor (Dresser- Rand/Clark), LEC has no problem meeting the 3.0 g/hp-hr level even for Worthington engines.

- Information at www.enginuityinc.com, indicates that addition of a PCC system to Duke Energy; Vidor, Texas met a 2.0 g/bhp-hr guarantee.

Gas Compressor Prime Movers in 2007 MARAMA OTR Data		
Drive	**Manufacturer**	**Model(s) in 2007 MARAMA OTR Database**
Recip Engine	Ajax	?
Recip Engine	Caterpillar	3306, 3612, D333, G3406TA, G3516, G3508, G3612, G3616LE, G399NA
Recip Engine	Clark	HBA-5, HBA-8T, HRA-6, TCV-12, TLA-10, TLA-6, TLA-8
Recip Engine	Cooper	8Q1551, GMV-10TF, GMV-10C2, GMVC-6, GMVH-10, GMVH-6, GMVH-6C, GMVH-8, GMVR-6
Recip Engine	Cooper-Bessemer	10V-250, 10W-330C2, 16V-250, 80155HC2, 8V-250, 8W-330, GMV-10, GMV-4, GMV-6, GMVA-10, GMVH-10C, GMVH-6C2, GMWC-10
Recip Engine	Cooper-Superior	8GTLB
Recip Engine	DeLaval	HV8
Recip Engine	Dresser-Clark	TLA-6, TLAD-6
Recip Engine	Dresser-Rand	412-KVSE, KVG-104, TLAD-8
Recip Engine	Ingersoll-Rand	12-SVS, 412-KVS, 8-SVS, KVG-103, KVG-48, KVG-62, 36-KVS, 412-KVSDT, 412-KVSE, 4XVG, 512-KVS, 512-KVSR, 6JVG, 412-KVG
Recip Engine	Waukesha	7042G, L5790GV
Recip Engine	White-Superior	2416
Recip Engine	Worthington	ML-12, UTL-16ST
Turbine	Allison	501K13
Turbine	Clark	DC-990
Turbine	Dresser-Clark	DC-990
Turbine	GE	?
Turbine	Solar	Centaur 40-4700, Centaur 60-78250, Centaur H, Centaur T-4500, Cntaur T-4700, Mars 100-15000LS, Mars 90-12000, Saturn T-1000, Saturn T-1001, Saturn T-1200, Saturn T-1300, T-7000, T-7000S, Taurus 60, Taurus 10-10300, Taurus 60-7800, Taurus 70, Taurus 70-1030S
Turbine	Westinghouse	?

For comparison purposes, it should be pointed out that some OEM engine manufacturers are offering new natural gas fueled engines with very low NOx emission ratings. Some examples are listed below:

- Dresser Waukesha has introduced 12 and 16 cylinder lean burn engines, with horsepower ratings up to approximately 4800 HP, that are capable of achieving NOx emissions limits of 0.5 g/bhp-hr without post-combustion NOx emissions controls.

- Caterpillar offers a range of sizes of lean burn engines, with ratings up to approximately 5000 HP, that Caterpillar advertises are capable of achieving NOx emissions limits of 0.5 g/bhp-hr without post-combustion NOx emission controls.

- General Electric information indicates that they market a number of combustion turbines models for use in the gas compression role with dry low NOx combustors with a range of NOx emissions of 15 ppmvd to 25 ppmvd @ 15% O2.

Discussion Items Related to OTR Natural Gas Pipeline Compressor Prime Movers

As discussed earlier, the data that was located regarding OTR-specific natural gas compressor prime movers is insufficient to accurately identify the population of those units, quantify their actual NOx emissions, and quantify their potential for NOx emissions reduction. OTR specific natural gas compressor data sources accessed were the 2007 MARAMA point source inventory, the 2007 and 2010 FERC Form 2 and 2A databases, and certain gas compressor facility operating permits. (Also note that the FERC Form 2 and Form 2A databases primarily address only the corporate entities that represent the larger gas processing/transmitting entities. Smaller companies utilizing compression, including distribution companies, many not be required to report data for inclusion on the FERC Form 2 or Form 2A.) The MARAMA data was the primary source of unit-specific information, including annual emissions. The FERC database provided some technical and operating information on a facility-wide basis. For those natural gas compressor facility permits that could be located, those specific facility operating permits provided some technical information and any NOx emissions limitations. Specific data related limitations/issues associated with these data sources include the following:

- The population of natural gas compressor stations represented in the data extracted from the MARAMA database was smaller than the population of natural gas compressor facilities identified in the FERC databases. This may be due to some facilities/units being addressed as area sources and not point sources for MARAMA purposes, inadequate documentation in the MARAMA database to facilitate the unit to be identified as a natural gas compressor, or other reason.

- The technical data for a large number of gas compressor prime movers is incomplete in that data to identify the OEM manufacturer, model number, capacity, etc. is not in the database. This makes it difficult to access the availability and applicability of NOx reduction technologies for those engines.

- The technical data does not include information such as the vintage of the gas compressor prime movers (to help estimate any NOx controls that may have been included in their installation) or if the prime movers have undergone any previous NOx emission control upgrades/retrofits.

- The data is not sufficient to estimate the actual gas compressor prime mover specific NOx emissions rates for the OTR gas compressor prime movers. This makes it difficult to estimate the potential for NOx reductions from any given gas compressor prime mover or gas compressor facility.

- Operating permits for many of the natural gas compressor stations identified in the MARAMA point source inventory could not be located through internet searches, eliminating those potential sources of technical and NOx emissions data.

While the OTR specific data appears to be insufficient to fully analyze the NOx emissions and NOx emissions potential of the OTR gas compressor combustion prime movers, the information available in the many references provides a great deal on insight into potential NOx reduction controls for the generic types of gas compressor prime movers (2SLB, 4SLB, 4SRB, combustion turbine) in the OTR. From a technically feasible standpoint, the following generic NOx control strategies offer the potential for significant NOx reductions from otherwise uncontrolled gas compressor combustion prime movers:

- 2SLB Retrofit Combustion Modifications: The literature suggests that there are often significant differences in design characteristics between 2SLB engine manufacturers' designs such that applicability and effectiveness of generic NOx combustion controls is highly variable. Variability also potentially exists from installation to installation due to equipment clearances, etc. The information suggests that most 2SLB prime movers would be responsive to combustion and airflow modifications (potentially including installation/upgrade of turbochargers and inter-cooling, pre-chamber ignition or high energy ignition, improved fuel injection control, air/fuel ratio control, etc). These (or some of these) modifications/upgrades may comprise a generic NOx reduction strategy with the potential of reducing NOx emission rates by up to 90% from uncontrolled by facilitating operation with very lean fuel air mixtures. All of the mentioned retrofit NOx controls may not be commercially available for all manufacturers and models of gas compressor prime mover 2SLBs. The actual achievable NOx emission rate, in terms of g/bhp-hr, would tend to be engine design specific. These modifications/upgrades also offer the possibility of improving the 2SLB prime mover's efficiency.

- 2SLB Retrofit SCR: The literature suggests that SCR is technically feasible to achieve significant NOx emission rate reductions from 2SLB engines, but that there are problems that make SCR installation questionable. The first issue is that the 2SLB engine operation is very sensitive to changes in exhaust pressure, which could be problematic with the retrofit of SCR on existing engines. The next issue is that many compressor facilities are unmanned and that SCR installations have not been demonstrated in un-manned facilities. While it may be true that are few SCRs in un-manned facilities, with modern software based controls and SCADA type communication technologies there does not appear to be any technical barrier to operating the SCR related controls and auxiliaries successfully from a remote location. Another stated issue is that SCRs have not been demonstrated on combustion devices with variable loads, citing the use of SCR on EGUs and referring to the EGUs as steady state operating units. SCRs have been installed on EGUs that start and stop on a daily basis, and change loads across a wide range while on line to balance electric generation to electric demand. Manufactures of SCRs offer catalysts that are effective over wide temperature ranges characteristic of a range in engine operating load. Modern controls also have the ability to closely regulate fuel and air flows to ensure combustion gas oxygen and temperature levels at expected levels and to regulate reagent flow, all serving to ensure proper SCR function over a broad range. The use of SCR for NOx control does not appear to be technically infeasible generically, but individual prime mover characteristics and installations may be greatly problematic or not cost effective.

- 4SLB Retrofit Combustion Modifications: Similar to that for the 2SLB prime movers, the literature suggests that there are often significant differences in design characteristics between 4SLB engine manufacturers' designs such that applicability and effectiveness of generic NOx combustion controls is highly variable. Variability also potentially exists from installation to installation due to equipment clearances, etc. The information suggests that most 4SLB prime movers would be responsive to combustion and airflow modifications (potentially including installation/upgrade of turbochargers and inter-cooling, pre-chamber ignition or high energy ignition, improved fuel injection control, air/fuel ratio control, etc). These (or some of these) modifications/upgrades may comprise a generic NOx reduction strategy with the potential of reducing NOx emission rates by up to 90% from uncontrolled by facilitating operation with very lean fuel air mixtures. All of the mentioned retrofit NOx controls may not be commercially available for all manufacturers and models of gas compressor prime mover 4SLBs. The actual achievable NOx emission rate, in terms of g/bhp-hr, would tend to be prime mover design specific. These modifications/upgrades also offer the possibility of improving the 4SLB prime mover's efficiency.

- 4SLB Retrofit SCR: Similar to that of the 2SLB, the literature suggests that SCR is technically feasible to achieve significant NOx emission rate reductions from 4SLB engines, but that there are problems that make SCR installation questionable. One issue is that many compressor facilities are unmanned and that SCR installations have not been demonstrated in un-manned facilities. While it may be true that are few SCRs in un-manned facilities, with modern software based controls and SCADA type communication technologies there does not appear to be any technical barrier to operating the SCR related controls and auxiliaries successfully from a remote location. Another stated issue is that SCRs have not been demonstrated on combustion devices with variable loads, citing the use of SCR on EGUs and referring to the EGUs as steady state operating units. SCRs have been installed on EGUs that start and stop on a daily basis, and change loads across a wide range while on line to balance electric generation to electric demand. Manufactures of SCRs offer catalysts that are effective over wide temperature ranges characteristic of a range in engine operating load. Modern controls also have the ability to closely regulate fuel and air flows to ensure combustion gas oxygen and temperature levels at expected levels and to regulate reagent flow, all serving to ensure proper SCR function over a broad range. The use of SCR for NOx control does not appear to be technically infeasible generically, but individual prime mover characteristics and installations may be greatly problematic or not cost effective.

- 4SRB Retrofit Combustion Controls: There are few highly effective combustion related NOx emission controls utilized for 4SRB prime movers, other than ignition related controls that would be expected to have only minor NOx reduction benefits. Industry literature suggests that some model 4SRB prime movers can be converted to a 4SLB configuration and thereby achieve NOx reductions similar to those of 2LLB prime movers. However, such conversion capabilities appear to be very limited and expensive.

- 4SRB Retrofit NSCR: Industry literature suggests that the use of retrofit non-selective catalytic reduction NOx controls, in conjunction with a modern air/fuel controller, on 4SRB prime movers is a highly effective NOx control for these prime movers and has been installed in relatively high numbers. NSCR controls are available from a number of suppliers including some engine OEMs. With proper air/fuel controllers, the NSCR is an effective NOx control over a broad range of engine operation. The data suggests that there are many prime mover NSCRs are in successful service. Industry literature suggests that NOx control in excess of 90% can be expected through utilization of NSCR on an otherwise uncontrolled 4SRB prime mover.

- Combustion Turbine Retrofit Combustion Controls: The literature suggests that water injection and dry low NOx burners (DLNB) are commercially available NOx reduction technologies for combustion turbines that are capable of achieving NOx reductions of 40% and 60%, or greater, respectively. Although there appears to be both OEM and aftermarket suppliers of these NOx reduction technologies for combustion turbines, the literature also indicates that these NOx reduction technologies may not be commercially available for all makes and models of combustion turbines.

- Combustion Turbine Retrofit SCR: SCR appears to be a technically feasible NOx reduction technology for many gas compressor prime movers, and systems appear to be commercially available for simple cycle combustion turbines. Similar to potential installation of 2SLB and 4SLB prime movers, several issues have been raised questioning the applicability of SCR to gas compressor prime mover application. The first issue is that many compressor facilities are unmanned and that SCR installations have not been demonstrated in un-manned facilities. While it may be true that are few SCRs in un-manned facilities, with modern software based controls and SCADA type communication technologies there does not appear to be any technical barrier to operating the SCR related controls and auxiliaries successfully from a remote location. Another stated issue is that SCRs have not been demonstrated on combustion devices with variable loads, citing the use of SCR on EGUs and referring to the EGUs as steady state operating units. SCRs have been installed on EGUs that start and stop on a daily basis, and change loads across a wide range while on line to balance electric generation to electric demand. Manufactures of SCRs offer catalysts that are effective over wide temperature ranges characteristic of a range in prime mover operating load. The use of SCR for NOx control does not appear to be technically infeasible generically for these combustion turbine prime movers, but individual prime mover characteristics and installations may be greatly problematic or not cost effective.

The determination of NOx emissions rate limits for the population natural gas compressor combustion prime movers located in the OTR is a complex issue due to the diversity of the population and the multitude of problems and variables associated with that population. In order to provide flexibility it may be desirable to establish a model rule that utilizes a RACT approach that considers the most up to date available retrofit control technologies and achievements. Some elements for consideration may include some the following:

- Applicable to gas compressor combustion prime movers with a rating of 50 HP [or other value], or greater.
- A 90% [or other value] reduction from uncontrolled NOx emission rate, prime mover specific.
- A NOx emission rate limit range of 2.0 g/bhp-hr to 1.0 g/bhp-hr for 4-stroke rich burn engines, varying with engine output rating.
- A NOx emission rate limit range of 2.0 g/bhp-hr to 1.5 g/bhp-hr for 4-stroke lean burn engines, varying with engine output rating.
- A NOx emission rate limit range of 3.0 g/bhp-hr to 1.5 g/bhp-hr for 2-stroke engines, varying with engine output rating.

- A NOx emissions rate limit range of 50 ppmvd to 25 ppmvd for combustion turbines, varying with combustion turbine output rating.
- An acceptable alternative RACT limit based on technological or economic criteria, including consideration of previously accomplished NOx reduction projects (if any).
- Consideration of averaging of prime mover NOx emission rates at a facility as an alternative RACT.
- Sufficient lead time to permit control installation without disrupting natural gas supplies.

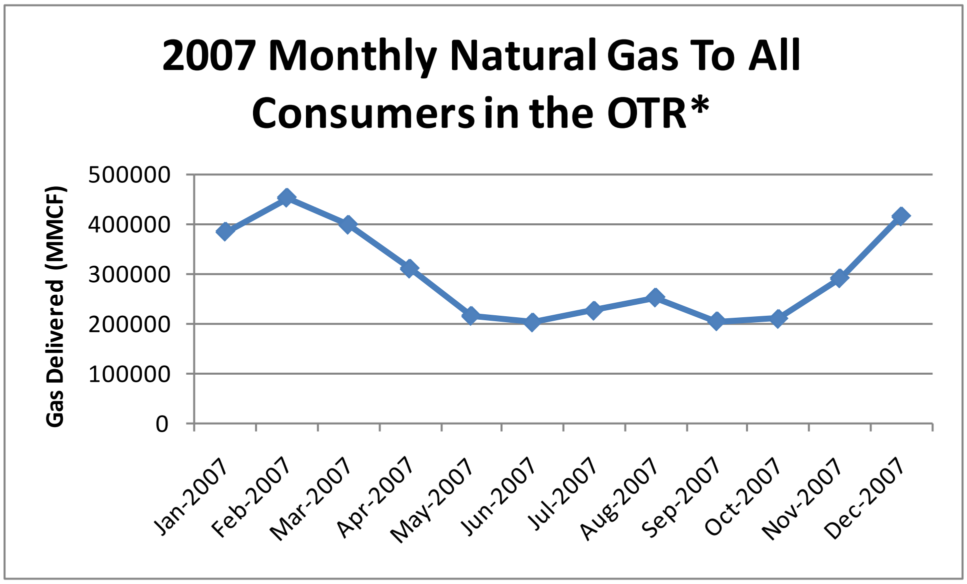
NOx Reduction Potential of Natural Gas Pipeline Compressor Prime Movers

As mentioned earlier, the data that was located for this review regarding natural gas compressor prime movers is insufficient to properly and fully define the population of subject prime movers, is insufficient to properly and fully document technical and operating characteristics of those prime movers, and is insufficient to properly and accurately assess the actual NOX emissions and emissions reduction potential of those prime movers. However, as a mathematical exercise, some broad assumptions and speculations were made to facilitate the creation of an estimation methodology. The following assumptions were utilized for this estimation:

- Base annual NOx emissions and unit population is that of the 2007 MARAMA point source inventory as assembled for this review.
- Individual prime mover base NOx emission rates were assumed to be the NOx emission rate limits taken from the respective permit limits (where available) as assembled for this review. For units with unknown pre-rule emissions, the pre-rule NOx emissions were assumed to be 50 ppmd for combustion turbines, 16.4 g/bhp-hr for 2-stroke reciprocating engines, and 18.9 g/bhp-hr for 4-stroke reciprocating engines.
- Compressor prime movers with an annual operating period of less than 438 hrs were not expected to make reductions. Compressor prime movers whose permitted NOx emissions rate was within 3 g/bhp-hr of the proposed rule limits would not be expected to make additional reductions. Compressors with output rating less than 200 hp would not be expected to make reductions.
- For 4-stroke rich burn engines, assumed rule NOx emissions limits would be 2.0 g/bhp-hr for units with an output rating of 200 hp to under 500 hp, 1.5 g/bhp-hr for units with an output rating of 500 hp to under 2000 hp, and 1.0 g/bhp-hr for units with an out rating of 2000 hp and greater.
- For 4-stroke lean burn engines, assumed rule NOx emissions limits would be 2.0 g/bhp-hr for units with an output rating of 200 hp to under 500 hp, 2.0 g/bhp-hr for units with an output rating of 500 hp to under 2000 hp, and 1.5 g/bhp-hr for units with an out rating of 2000 hp and greater.
- For 2-stroke lean burn engines, assumed rule NOx emissions limits would be 3.0 g/bhp-hr for units with an output rating of 200 hp to under 500 hp, 2.0 g/bhp-hr for units with an output rating of 500 hp to under 2000 hp, and 1.5 g/bhp-hr for units with an out rating of 2000 hp and greater.
- For combustion turbines, assumed rule NOx emissions limits would be 150 ppmvd@15%O2 for units with an output rating of less than 2000 hp, 50 ppmvd @15%O2 for units with an output rating of 2000 hp to less than 5000hp, and 25 ppmvd @15%O2 for units with an output rating of 5000 hp or greater.
- For units where the database did not provide a unit configuration, the unit was assumed to be a 2-stroke lean burn engine.
- For units where the database did not provide a unit rating, the unit was assumed to have a 1000 hp rating.
- The operating hours for a compressor prime mover estimated from the 2007 FERC Form 2 and Form 2 database, with individual compressor operating hours being the FERC facility operating hours equally divided among all compressors at the facility.

Based on the above assumptions and the assembled data, it is estimated that there is a potential for an approximate 50% reduction in annual NOx emissions from the OTR population of natural gas compressor combustion prime movers. This results in an estimated reduction in annual NOx emissions of approximately 4,221 tons. Again, this value is based on an uncertain population of combustion gas compressor prime movers due to data limitations of the existing data set.

On a strictly 365-day basis, the above estimate of annual NOx reduction potential would lead to an estimated average daily NOx emissions reduction of approximately 11.5 tons/day from the gas compressor prime movers. However, natural gas consumption in the OTR shows seasonal variation as indicated in the following chart of 2007 monthly OTR natural gas consumption:



*Excluding VA

In 2007, approximately 31% of the natural gas delivered to the OTR states (excluding VA) was delivered during the ozone season. If it assumed that the NOx emissions from the gas compressor prime movers is proportional to the gas consumption in the region, the estimated daily NOx emissions from the gas compressor prime movers during the ozone season is approximately 8.5 tons/day.

Estimated Cost of NOx Reduction Technologies for Gas Compressor Prime Movers

In order to get an estimate of the capital costs associated with the potential NOx controls for reciprocating engine prime movers, a number of publicly available documents were reviewed to obtain information concerning those costs. Very little recent NOx control retrofit cost data was located, so cost estimates had to be compiled using some older publicly available information. This then leaves these estimates to be subject to similar concerns expressed about previous retrofit cost estimates performed by the EPA and other state agencies using this same information; the values are not representative of all gas compressor prime movers, the values tend to underestimate the costs of the projects, and the emissions reduction achieved are overly optimistic. As with the variability of the effectiveness and availability of retrofit NOx controls for the variety of makes, models, installations, and ratings of the combustion prime movers utilized for gas compressors in the OTR, the costs and cost effectiveness of the NOx controls vary greatly and follow the same variability. The cost effectiveness is additionally greatly affected by the operating schedule and capacity factor of any given prime mover.

As an example, in its comments (dated September 14, 2009) concerning the USEPA's proposed rule, National Ambient Air Quality Standards for Nitrogen Dioxide, the INGAA stated that the EPA's estimation of cost impact to the gas pipeline sector was grossly underestimated. INGAA cited a NOx control installation project at a compressor facility where low emissions combustion (LEC) NOx control was installed on three reciprocating engine prime movers with ratings of 3,400 hp each. INGAA indicated the capital costs for the project were over $3.4 million, or approximately $340 per hp. INGAA cited a second NOx control project at another facility, where LEC controls were installed on 11 reciprocating engine prime movers, each engine rated at 911 hp. INGAA indicated that the capital cost for this project was approximately $8.8 million, or approximately $880 per hp, with an annualized cost of $2.5 million or $228,000 for each engine. INGAA indicated that the higher relative cost for control of smaller engines has also been documented by other INGAA members because more significant upgrades are often required for the smaller reciprocating engine prime movers used in gas transmission.

For the table below addressing reciprocating engine prime movers, the basis for the cost estimates is the information provided in California Environmental Protection Agency Air Resources Board document" DETERMINATION OF REASONABLY AVAILABLE CONTROL TECHNOLOGY AND BEST AVAILABLE RETROFIT CONTROL TECHNOLOGY FOR STATIONARY SPARK-IGNITED INTERNAL COMBUSTION ENGINES", dated November 2001. Where necessary, costs were estimated using best-fit curves from the existing data. The capital and O&M costs were also inflated from 2001 using the CPI index. O&M costs were also revised to reflect an average annual capacity factor of 35%. The values given below should be considered order of magnitude values only.

Estimated Cost Of NOx Controls for Reciprocating Engine Prime Movers

Range of Horsepower	LEC Estimated Capital Cost ($)	Rich Burn NSCR Estimated Capital Cost ($)	Rich Burn NSCR Estimated Annual O&M Cost ($)	Lean Burn SCR Estimated Capital Cost ($)	Lean Burn SCR Estimated Annual O&M Cost ($)
50 - 150	17665	22334	11622	56781	38740
151 - 300	30283	29653	12978	56781	50362
301 - 500	52996	32176	14915	75709	67795
501 - 1000	79494	45173	19757	188010	151085
1001 - 1500	79500 - 323,000	49810	23438	233435	226628
1501 - 2000	79500 - 323,000	54447	27118	280563	260498
2001 - 3000	79500 - 323,000	63721	34478	339581	318052

The cost effectiveness of NOx controls for the reciprocating engine prime movers was estimated from the above data and assuming a 10-year life expectancy of the controls, 10% interest rate, base NOx emissions rate of 11 g/bhp-hr, controlled NOx rate of 2 g/bhp-hr, and an annual capacity factor of 35%. The values given below should be considered order of magnitude values only.

Estimated Cost Effectiveness of NOx Controls for Reciprocating Engine Prime Movers

HP Range	Range of LEC Cost Effectiveness ($/ton)	Range of Rich Burn NSCR Cost Effectiveness ($/ton)	Range of Lean Burn SCR Cost Effectiveness ($/ton)
50 - 150	11640 - 3880	10052 - 3351	31613 - 10538
151 - 300	6607 - 3326	3884 - 1955	13004 - 6545
301 - 500	5800 - 3491	2205 - 1328	8769 - 5279
501 - 1000	5227 - 2619	1783 - 893	11947 - 5985
1001 - 1500	7094 - 2616	1038 - 693	8709 - 5812
1501 - 2000	5321 - 1745	790 - 593	6720 - 5043
2001 - 3000	3547 - 1309	738 - 492	6146 - 4100

A number of documents were also reviewed in order to get an estimate of the capital costs associated with combustion turbine prime movers. Less cost information was located concerning retrofit of NOx controls on small combustion turbines prime movers than was located for the reciprocating engine prime movers. For the table below, the basis for the cost estimates is the information provided the document "Cost Analysis of NOx Control Alternatives for Stationary Gas Turbines" dated November 5, 1999. Costs were estimated where necessary using a best-fit curve of the given data, and were inflated from the 1999 values using the CPI index. O&M costs were estimated to reflect an average annual capacity factor of 35%. The values given below should be considered order of magnitude values only.

Estimated Cost of NOx Controls for Combustion Turbine Prime Movers

Heat Input Capacity	DLNB Capital Cost ($)	Annual DLNB O&M Cost ($)	SCR Capital Cost ($)	Annual SCR O&M Cost ($)
10 MMBTU/hr	257500	20300	469500	19900
100 MMBTU/hr	2414400	26400	2280300	79200

The cost effectiveness of NOx controls for the combustion turbine prime movers was estimated from the above data and assuming a 10-year life expectancy of the controls, 10% interest rate, base NOx emissions rate of 110 ppmvd, controlled NOx rate of 25 ppmvd, and an annual capacity factor of 35%. The values given below should be considered order of magnitude values only.

Estimated Cost Effectiveness of NOx Controls for Combustion Turbine Prime Movers

Range of Heat Input (MMBTU/hr)	Range of Cost Effectivenss for DLNB ($/ton)	Range of Cost Effectivenss for SCR ($/ton)
10 - 100	10366 - 6987	16047 - 7503

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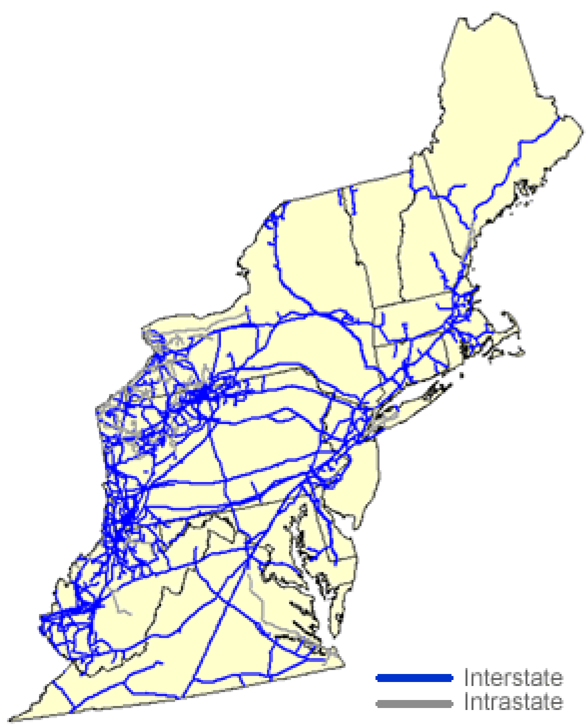
Attachment I
Natural Gas Pipelines in the Northeast Region

Overview

Twenty interstate natural gas pipeline systems operate within the Northeast Region (Connecticut, Delaware, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Virginia, and West Virginia). These interstate pipelines deliver natural gas to several intrastate natural gas pipelines and at least 50 local distribution companies in the region. In addition, they also serve large industrial concerns and, increasingly, natural gas fired electric power generation facilities.

The natural gas pipeline and local distribution companies serving the Northeast have access to supplies from several major domestic natural gas producing areas and from Canada. Domestic natural gas flows into the region from the Southeast into Virginia and West Virginia, and from the Midwest into West Virginia and Pennsylvania. Canadian imports come into the region principally through New York, Maine, and New Hampshire.

Liquefied natural gas (LNG) supplies also enter the region through import terminals located in Massachusetts, Maryland, and New Brunswick, Canada.



Transportation of Domestic Natural Gas Supplies

Almost all of the interstate natural gas pipelines entering or operating within the Northeast Region terminate there as well, including several very large long-distance natural gas pipeline systems that deliver supplies to the region from natural gas producing areas in the U.S. Southwest. The largest of these natural gas pipelines is the Transcontinental Gas Pipeline Company system (8.5 billion cubic feet (Bcf) per day systemwide), which extends from South Texas to the New York City area.

The Tennessee Gas Pipeline Company (6.7 Bcf per day) and Texas Eastern Transmission Company (7.3 Bcf per day) natural gas pipeline systems bring supplies to the Northeast from Texas, Louisiana, and the Gulf of Mexico. The Tennessee Gas Pipeline Company system, unlike the Transcontinental Gas Pipeline Company and Texas Eastern Transmission Company systems, extends its service northward as far as New Hampshire and is a major transporter of natural gas to Connecticut, Massachusetts, and Rhode Island.

The Tennessee Gas Pipeline Company system is also a significant source of supply for the regional Algonquin Gas Transmission Company system, which is the principal interstate natural gas pipeline serving the Boston, Massachusetts area. The Texas Eastern Transmission Company, an affiliate of the Algonquin Gas Transmission Company, is the primary source of supply for that pipeline, delivering approximately 65 percent of Algonquin's requirements at interconnections in New Jersey. The Algonquin Gas Transmission Company system (1,100 miles) has the capability to move 1.5 Bcf per day of its 3.3 Bcf per day system capacity from New Jersey into the New York metropolitan area.

The Algonquin Gas Transmission Company is also the recipient of 0.8 Bcf per day of natural gas processed at the Northeast Gateway liquefied natural gas (LNG) import terminal (installed in late 2008) located 10 miles offshore of Massachusetts. The Northeast Gateway port's infrastructure features two submerged turret loading buoys for off loading. The operation is linked to the Algonquin Gas Transmission Company system by a 16-mile submerged pipeline. It is the first new LNG terminal built on the East Coast in 30 years.

The largest interstate natural gas pipeline system operating in the region is Columbia Gas Transmission Company (9.4 Bcf per day capacity). Columbia has an extensive network of natural gas pipelines that provide service in the region to the States of Maryland, New Jersey, New York, Pennsylvania, Virginia, and West Virginia, but also extends into Ohio in the Midwest and Kentucky and North Carolina in the Southeast Region. Columbia receives Gulf-of-Mexico natural gas at the Kentucky border from its major trunkline transporter, Columbia Gulf Transmission Company, but it also transports Appalachian (regional) production as well.

In late 2008, the long-delayed 0.5 Bcf per day Millennium Pipeline was finally completed. This 182-mile natural gas pipeline system begins at an interconnection with the Empire Pipeline system in southwest central New York State and terminates in the New York City metropolitan area. It is part of an overall regional effort involving expansion of the existing Empire, Algonquin and Iroquois Pipelines, which will be among its major supply sources.

The Dominion Transmission Company system, although not as extensive as the Columbia Gas Transmission Company system, serves the same States, except for New Jersey. Neither interstate pipeline, however, extends service to the New England States. Both companies are also the major suppliers of some of the largest LDCs in the region, some of which are affiliates.

In addition to the interstate natural gas pipeline companies that bring natural gas into the region, several smaller interstate natural gas pipeline companies operate totally within the region. Among these are systems such as Equitrans Inc. (0.1 Bcf per day), serving West Virginia and western Pennsylvania, that were developed to move local production to regional markets. West Virginia, western Pennsylvania, and southwestern New York were once the region's and the Nation's largest natural gas producing areas and, consequently, have many local gathering, distribution, and storage interconnections. These local facilities also have many interconnections with natural gas pipeline operations in Ohio, which is the reason for the 2.1 Bcf per day of capacity exiting the region to the Midwest.

Some of these smaller interstate and intrastate natural gas pipelines serve niche areas within the region. For instance, Eastern Shore Natural Gas Company (0.1 Bcf per day) is the only natural gas pipeline serving southern Delaware and the lower Delmarva Peninsula. It receives its supplies from Transcontinental Gas Pipeline Company and Columbia Gas Transmission Company at points in southeastern Pennsylvania, with a route that takes it southward through Delaware to Maryland's eastern shore.

Further to the north, Granite State Transmission Company (0.1 Bcf per day) receives natural gas from the Tennessee Gas Pipeline Company and/or the PNGTS/Maritimes and Northeast Pipeline system at the southern New Hampshire/Massachusetts border. From there it transports to customers in New Hampshire and to the Northern Utilities Company system -- which has been the historical source of natural gas for the southern portion of the State of Maine. While the KeySpan Energy Delivery Company is the principal provider of natural gas service to New York City and Long Island, New York, its intrastate operations now also include service in Massachusetts and New Hampshire as well.

Importance of Canadian Imports to the Region

During the past 17 years (1990-2005), several new natural gas pipelines were built that substantially increased regional access to Canadian natural gas supplies.

The Iroquois Gas Transmission Company system, completed in 1991, draws just over one Bcf per day off the TransCanada Pipeline Ltd system in Ontario, Canada, a large portion of which is delivered to the New York City metropolitan area. The Empire Pipeline Company system (0.7 Bcf per day), built in 1994, and an intrastate affiliate of National Fuel Gas Supply Corporation, brings in Canadian natural gas at Grand Island, New York (near Niagara Falls) to north central New York State with interconnections to the Dominion Transmission Company and National Fuel Gas Supply Corporation systems. These latter two companies also access Canadian supplies via Tennessee Gas Pipeline, which maintains a 0.9 Bcf per day import point at Niagara Falls, New York.

Moreover, in 2000, the Portland Natural Gas Transmission System (PNGTS), which begins at the northern neck of New Hampshire and extends to the coast of Maine, was completed. PNGTS merges with the Maritimes and Northwest Pipeline system at Wells, Maine, where they form a joint 100-mile, 0.6 Bcf per day, natural gas pipeline that extends south through southern New Hampshire and terminates in northern Massachusetts (with an interconnection to the Tennessee Gas Pipeline Company system).

In 2003, PNGTS, originally designed only to import natural gas (into New Hampshire), was reconfigured to provide bidirectional service to its customers. The objective of the reconfiguration was to provide shippers of Canadian Sable Island natural gas, which use the Maritimes & Northeast Pipeline Company system, with an opportunity to redirect some of their natural gas to markets located in Quebec (which previously had access only to western Canadian natural gas supplies).

The U.S. portion of the Maritimes and Northeast Pipeline Company (0.8 Bcf per day) system begins at Calais, Maine, at the Canadian border and extends to Wells, Maine. The full 730-mile Maritimes and Northeast Pipeline system (343 miles of which are in the U.S.) was built to access natural gas production off the eastern coast of Canada (Sable Island) and to transport it to New England. In late 2003, the Maritimes and Northeast Pipeline Company system was extended from Dracut to Boston, Massachusetts, providing an additional 0.2 Bcf per day of service to that metropolitan area. In 2008, its system was also expanded to transport an additional 0.4 Bcf per day of natural gas, processed at the new Canaport liquefied natural gas (LNG) import terminal located in New Brunswick, Canada, to New England markets.

Several smaller regional natural gas importing pipelines, such as North County Pipeline Company (0.6 Bcf per day) and the St. Lawrence Gas Company (0.1 Bcf per day), both located in upper New York State, and the Vermont Gas Systems Company (0.05 Bcf per day), the only natural gas pipeline in the State of Vermont, depend upon Canadian natural gas imports completely for their natural gas supplies since they do not interconnect with any other U.S. natural gas pipeline.

Attachment II
Underground Natural Gas Storage

Underground natural gas storage provides pipelines, local distribution companies, producers, and pipeline shippers with an inventory management tool, seasonal supply backup, and access to natural gas needed to avoid imbalances between receipts and deliveries on a pipeline network.

There are three principal types of underground storage sites used in the United States today. They are:

- depleted natural gas or oil fields (326),
- aquifers (43), or
- salt caverns (31).

Most underground storage facilities, 82 percent at the beginning of 2008, were created from reservoirs located in depleted natural gas production fields that were relatively easy to convert to storage service, and that were often close to consumption centers and existing natural gas pipeline systems.

Since the 1980s, the number of salt cavern storage sites developed in the United States has grown steadily, principally because of its unique capabilities and high cycling rate (inventory turnover). The large majority of salt cavern storage facilities have been developed in salt dome formations located in the Gulf Coast States. Salt caverns leached from bedded salt formations in Northeastern, Midwestern, and Western States have also been developed but the number has been limited due to a lack of suitable geology. Cavern construction is more costly than depleted field conversion when measured on the basis of dollars per thousand cubic feet of working gas capacity, but the ability to perform several withdrawal and injection cycles each year reduces the per-unit cost of each thousand cubic feet of gas injected and withdrawn.

The States of Pennsylvania and New York are the key transit areas for gas deliveries within the region and include the major service territories of Dominion Transmission Company and Columbia Gas Transmission Company systems. These States, along with West Virginia, also have the largest underground storage capacity in the region. Storage is essential as a supply backup and for balancing gas supplies on the pipelines operating in the region. More pipeline capacity exits these States than enters, reflecting their storage capability as a seasonal supply source for the States to the north and east.

The largest storage operators in the Northeast are also three of the largest pipeline companies in the region. Columbia Gas Transmission Company operates 22 storage facilities (out of 110 within the region), with a working gas storage capacity of 138 Bcf (out of a total 796 Bcf). Although Dominion Transmission Company operates only 15, its facilities have the largest amount of working gas capacity in the region, 413Bcf. National Fuel Gas Supply Company operates the largest number of storage facilities in the region, 31, but its storage fields are only capable of storing up to 106 Bcf of working gas.

(Note: The peak-day deliverability from LNG in the region, 5.1 Bcf per day, is 33 percent as large as the total daily deliverability from underground storage facilities. This backup capability is incorporated into the operations of the regional network and is used to meet the rapid increases in demand that can occur because of sudden temperature changes in the region. Three of the eight currently active LNG importing facilities in the U.S. are located in the Northeast Region, the Cove Point LNG Company facility, located on the eastern shore of Maryland, the Northeast Gateway LNG Terminal located 16 miles offshore of Massachusetts, and the DistriGas Company’s Everett LNG facility located outside of Boston, Massachusetts.)

Attachment III
2007 OTR Compressor Stations
FERC Form 2 and 2A

State	Name Location	Service	No. Compr.	Total HP	2007 Total Compressor Operating Hours
CT	Chaplin Compressor Station, Chaplin, CT	Transmission	2	13900	2747
CT	Cromwell Compressor Station, Cromwell, CT	Transmission	8	21400	29577
MA	#261 - Agawam, MA Electric/Gas	Transmission	5	17110	10704
MA	#264 - Charlton City, MA	Transmission	2	12552	4726
MA	#266A - Mendon, MA	Transmission	3	8150	8360
MA	#267 - Hopkinton, MA	Transmission	5	5000	3491
MD	Rutledge, MD	Transmission	3	12000	9089
MD	Accident, MD	Undrgrd Strg	2	11000	7580
MD	No. 190 Ellicott City, Maryland	Transmission	12	29250	85828
ME	Baileyville Compressor Station,ME	Transmission	2	16622	7170
ME	Richmond Compressor Station, ME	Transmission	2	16622	3965
NJ	Hanover Compressor Station, Hanover, NJ	Transmission	2	14300	4810
NJ	#325 - Sussex, NJ	Transmission	2	9360	5149
NJ	Franklin (Freehold), NJ	Transmission	1	5000	14
NJ	Hanover, NJ	Transmission	3	9200	4
NJ	Lambertville, NJ	Transmission	7	24600	13026
NJ	Linden, NJ	Transmission	3	6150	12799
NJ	No. 240 Hackensack Meadows, New Jersey		5	4320	10097
NJ	No. 205 Lawrenceville, New Jersey	Transmission	3	30200	613
NJ	No. 505 Centerville, New Jersey	Transmission	8	16000	7450
NJ	No: 207 Sayreville, New Jersey	Transmission	2	10000	411
NY	Southeast Compr Station, Southeast, NY	Transmission	3	22000	6899
NY	Stony Point Compr Station, Stony Point, NY	Transmission	7	32350	9446
NY	Corning, NY	Transmission	1	1240	1997
NY	Dundee, NY	Undrgrd Strg	3	2280	1484
NY	North Greenwood, NY	Undrgrd Strg	1	1240	846
NY	Borger, NY		3	17400	4491
NY	Brookmans Corner, NY		1	7300	446
NY	Lockport, NY		0	0	0
NY	Underground StoragWoodhull, NY	Undrgrd Strg	6	11100	12217
NY	Quinlan, NY	Undrgrd Strg	2	4740	4167
NY	Utica, NY		6	7250	4544
NY	Athens Compressor Station, Athens, NY		1	10028	7916
NY	Boonville Compressor Station, Boonville, NY		1	18371	6209
NY	Croghan Compressor Station, Croghan, NY		2	17180	11368
NY	Dover Compressor Station, Dover, NY		1	18371	6271
NY	Wright Compressor Station, Wright, NY		2	14302	16172
NY	Concord		5	11250	23897
NY	Lockport		4	18000	0
NY	Underground Storage Compressor Sta NY	Undrgrd Strg	26	20785	45866
NY	#224 - Clymer, NY	Transmission	4	8000	759
NY	#229 - Hamburg, NY	Transmission	6	8400	15809
NY	#230C - Lockport, NY	Transmission	4	18000	16073
NY	#233 - Geneseo, NY	Transmission	2	7000	9722
NY	#237 - Clifton Springs, NY	Transmission	3	8000	16239
NY	#241 - Lafayette, NY	Transmission	5	18400	9182
NY	#245 - West Winfield, NY	Transmission	9	19700	21317
NY	#249 - Carlisle, NY	Transmission	4	16200	9833

NY	#254 - Nassau, NY	Transmission	7	12900	14849
NY	#405A - CONNEXION NEW ENGLAND	Transmission	1	7700	151
PA	Artemas #2, PA	Transmission	3	3670	1283
PA	Delmont, PA	Transmission	2	1904	2844
PA	Downingtown, PA	Transmission	2	12000	1249
PA	Eagle, PA	Transmission	4	7900	19047
PA	Easton, PA	Transmission	3	2810	804
PA	Ellwood City, PA	Transmission	2	1000	1462
PA	Emporium, PA	Transmission	4	900	0
PA	Gettysburg, PA	Transmission	4	7500	6486
PA	Greencastle, PA	Transmission	4	7070	6580
PA	Hellertown, PA	Transmission	2	2200	1629
PA	Marietta, PA	Transmission	3	4050	3819
PA	McClellandtown, PA	Transmission	1	225	0
PA	Milford, PA	Transmission	2	680	6
PA	Renovo, PA	Transmission	5	3310	10931
PA	Rimersburg, PA	Transmission	1	350	8108
PA	Salisbury, PA	Transmission	5	5480	24970
PA	Waynesburg, PA	Transmission	5	5400	30215
PA	Artemas #1, PA	Undrgrd Strg	2	4800	6030
PA	Donegal, PA	Undrgrd Strg	2	2000	7440
PA	Holbrook, PA	Undrgrd Strg	1	130	0
PA	Harrison, PA	Undrgrd Strg	6	11100	16447
PA	Ardell 2, PA		2	3550	8505
PA	Ardell, PA		1	15000	1182
PA	Beaver, PA		4	12800	18574
PA	Bedford-TE, PA		0	0	0
PA	Big Run, PA		1	1775	8306
PA	Chambersburg, PA		4	24800	3406
PA	Chambersburg, PA		0	0	0
PA	Chambersburg, TE, PA		0	0	0
PA	Chambersburg-TE, PA		0	0	0
PA	Cherry Tree, PA		2	1520	15820
PA	Connellsville-TE, PA		0	0	0
PA	Crayne, PA		2	15600	5508
PA	Extraction Hutchinson, PA		2	300	806
PA	Finnefrock, PA		6	17500	27131
PA	Helvetia, PA		1	330	7982
PA	J.B. Tonkin, PA		1	6000	7698
PA	Little Greenlick, PA		3	11135	6472
PA	Luthersburg, PA		2	880	8417
PA	NFG-Ellisburg, PA		0	0	0
PA	Punxsutawney, PA		3	13132	5586
PA	Rochester Mills, PA		3	1320	22566
PA	South Bend, PA		6	12000	10637
PA	Stoney Run, PA		3	1152	16953
PA	Uniontown-TE, PA		0	0	0
PA	Boom, PA	Undrgrd Strg	2	5200	23
PA	Ellisburg, PA	Undrgrd Strg	8	18400	32709
PA	Greenlick, PA	Undrgrd Strg	4	13600	12474
PA	Leidy, PA	Undrgrd Strg	13	25800	45951
PA	Lincoln Heights, PA	Undrgrd Strg	2	500	16024
PA	North Oakford, PA	Undrgrd Strg	0	0	0
PA	North Summit. PA	Undrgrd Strg	2	6400	3963
PA	Oakford, PA	Undrgrd Strg	15	43800	45080
PA	Sabinsville, PA	Undrgrd Strg	7	10500	14110

PA	South Oakford, PA	Undrgrd Strg	4	24200	21076
PA	South Oakford, PA	Undrgrd Strg	0	0	0
PA	tate Line, PA	Undrgrd Strg	4	4650	18555
PA	Tioga, PA	Undrgrd Strg	2	8400	3273
PA	Mt. Morris-Greene County, PA	Field Comp	2	220	8312
PA	Ryerson-Greene County, PA	Field Comp	1	41	351
PA	Waynesburg-Greene County, PA	Field Comp	2	3600	14651
PA	Pennview-Beaver County, PA	Transmission	2	2400	0
PA	Pratt-Greene County, PA	Transmission	5	4400	12048
PA	Rogersville-Greene County, PA	Transmission	3	3600	0
PA	Sleepy Hollow-Allegheny County, PA	Transmission	1	1200	0
PA	Hartson-Washington County, PA	Undrgrd Strg	3	3300	2687
PA	Boone Mountain		1	280	7040
PA	Costello		2	1440	11546
PA	East Fork		5	3060	25316
PA	Eldred		2	300	5746
PA	Ellisburg		5	11450	18686
PA	Field Compressor St - Appalachian Field	Field Comp	0	0	0
PA	Heath		1	1160	7790
PA	Island Run		4	615	11199
PA	Kaylor		1	150	7325
PA	Knox		4	1920	20394
PA	Lamont		9	1640	35940
PA	Roystone		12	5500	67628
PA	Sackett		4	675	28551
PA	Underground Storage Compressor Sta PA	Undrgrd Strg	17	14690	50725
PA	Van		1	296	7418
PA	#219 - Mercer, PA	Transmission	14	21550	39222
PA	#307 - Pigeon, PA (Kane)	Transmission	6	15500	38484
PA	#313A Elllisburg, PA	Transmission	2	4730	8512
PA	#315 - Wellsboro, PA	Transmission	1	9300	1678
PA	#317 - Troy, PA	Transmission	3	19330	6232
PA	#319 - Wyalusing, PA	Transmission	2	9000	6778
PA	#321 - West Clifford, PA	Transmission	3	9999	6329
PA	#323A - Hawley, PA (Stagecoach) El/Gas	Transmission	1	13400	1983
PA	#313 - Coudersport, PA	Undrgrd Strg	14	24120	82339
PA	Armagh, PA		1	22000	343
PA	Bechtelsville, PA		4	33500	12246
PA	Bedford, PA		11	33880	22147
PA	Bernville, PA		2	41800	4291
PA	Chambersburg, PA		4	18500	1229
PA	Delmont, PA		12	46430	52025
PA	Entriken, PA		1	22000	672
PA	Grantville, PA		4	33500	14590
PA	Heidlersburg, PA		1	16000	0
PA	Holbrook, PA		18	38450	63021
PA	Leidy, PA		4	8085	10331
PA	Lilly, PA		4	34800	14019
PA	Marietta, PA		7	23960	14214
PA	Perulack, PA		4	34800	24150
PA	Phoenixville,PA/Eagle, Pa		1	6000	314
PA	Shermans Dale, PA		2	41800	3975
PA	Uniontown, PA/Connelsville		7	38250	1640
PA	Leidy, PA	Undrgrd Strg	13	25800	45951
PA	Oakford, PA (Lincoln Heights)	Undrgrd Strg	2	500	16024
PA	Oakford, PA (Oakford)	Undrgrd Strg	15	43800	45080

PA	Oakford, PA (South Oakford)	Undrgrd Strg	4	24200	21076
PA	Waynesburg, PA		1	5000	323
PA	Wind Ridge, PA		0	0	0
PA	No. 195 Delta, Pennsylvania	Transmission	5	19460	22777
PA	No. 200 Malvern, Pennsylvania	Transmission	13	30860	86467
PA	No. 515 Bear Creek, Pennsylvania	Transmission	6	32000	7926
PA	No. 517 Benton, Pennsylvania	Transmission	4	38500	2746
PA	No. 520 Salladasburg, Pennsylvania	Transmission	7	35200	9736
PA	No. 530 Leidy-Tamarack Stroage Field, PA	Undrgrd Strg	0	0	0
PA	No. 535 Wharton Storage Field, PA	Undrgrd Strg	5	8500	11997
RI	Burrillville Compressor Station, Burriville, RI		5	22000	10563
RI	#265E - Burrillville, RI (Rise)	Transmission	1	7170	7182
VA	Loudoun, VA		3	11840	2544
VA	Leesburg, VA		3	14200	5798
VA	No. 185 Manassas, Virginia	Transmission	10	20000	31045

2007 OTR Natural Gas Compressors
FERC Form 2 and Form 2A Data

State	No. Compressors	Total Rated HP
CT	10	35300
MA	15	25702
MD	17	52250
ME	4	33244
NJ	36	129130
NY	120	359487
PA	467	1331164
RI	6	29170
VA*	22	49390

*OTR Area Only