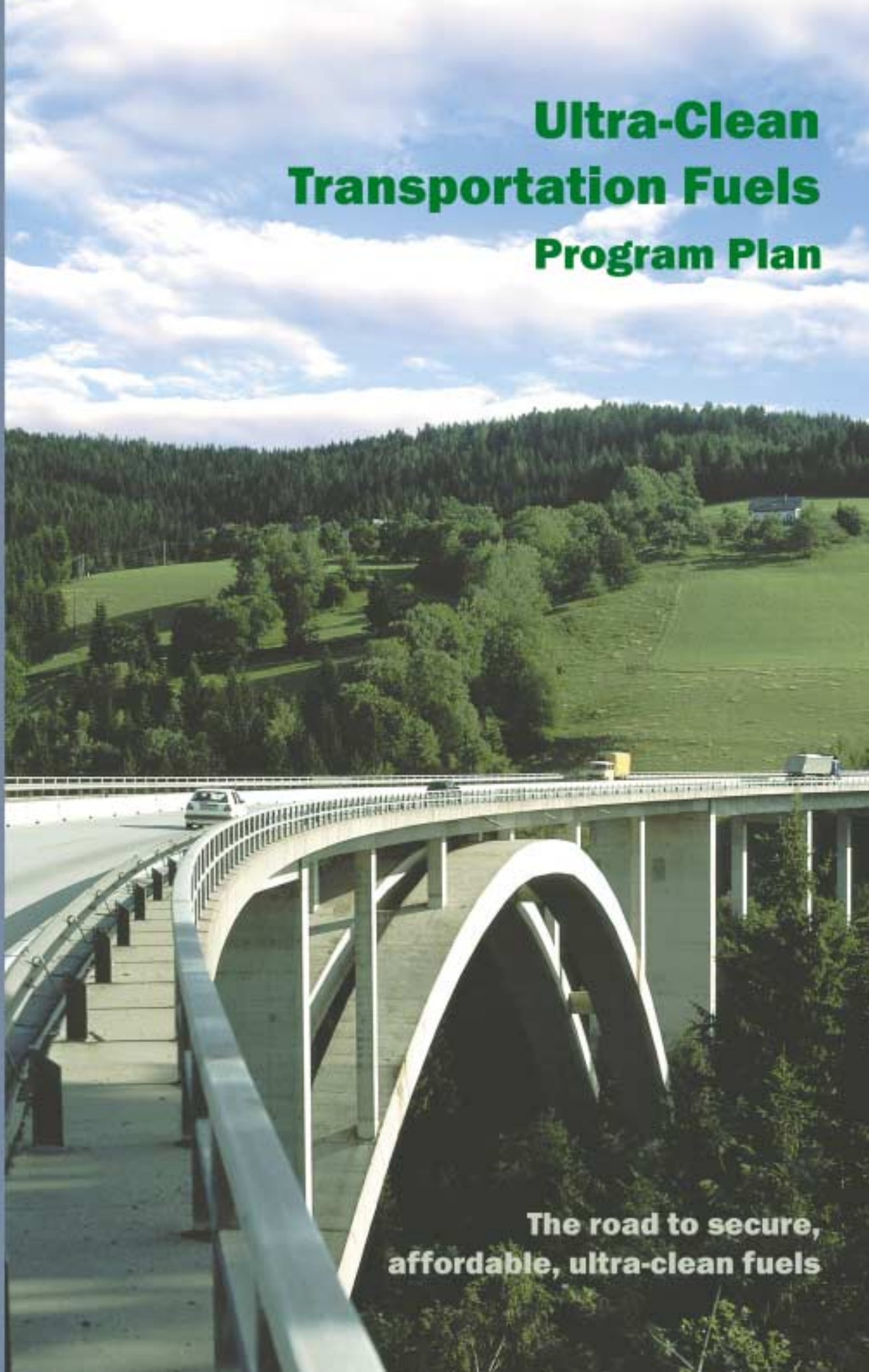
DOE/FE-0430

Ultra-Clean Transportation Fuels

Program Plan



The road to secure, affordable, ultra-clean fuels

U.S. Department of Energy

Mission

The mission of the Ultra-Clean Transportation Fuels (UCTF) Program, in association with industry as a partner, is to develop, demonstrate, and deploy technologies and systems that will ensure the Nation's future transportation fuels, utilized in advanced highway vehicles, which will result in dramatically improved energy security, environmental quality, and economic competitiveness.

Foreword

As we journey into the 21st century, the vehicles that populate our highway transportation system continue to provide our citizens with an unparalleled degree of personal mobility and our Nation with an essential lifeline for the transport of goods. In order to safeguard the personal mobility and maintain the economic vitality of this country, we must ensure that highway vehicles continue to retain the attributes necessary to support their intended transportation missions while simultaneously complying with evolving societal demands for energy security, improved air quality, and industrial competitiveness.

Over the next several years, this Nation will implement new, stricter Federal and state clean air requirements for highway vehicles; encounter more volatile global energy markets; face increased economic competition in the international market for clean highway vehicle and fuels production technologies; and confront the threat of global climate change. Given this emerging situation, it is clear that we must aggressively pursue the research and development (R&D) of advanced technologies for high-efficiency, low-emissions highway vehicles, as well as for the production of ultra-clean fuels required for their operation. Furthermore, it is imperative that we accelerate the transition toward the increased use of diversified domestic feedstocks, including those that are renewable, to ensure the sustainability of these ultra-clean transportation fuels.

At the U.S. Department of Energy (DOE), we are partnering with industry to identify, study, and develop advanced fuels for tomorrow's vehicles, and we are utilizing the unique scientific capabilities of our national laboratories. The DOE is providing the Federal government's largest technology R&D contribution to the government/industry Partnership for a New Generation of Vehicles and the 21st Century Truck Program. It also is collaborating with the heavy-vehicle industry to develop high-efficiency truck technologies. We have signed a compact with the petroleum industry to identify and pursue joint R&D efforts that satisfy our common goals. Also, within its integrated Petroleum-Based Fuels, Gas-to-Liquids, and Coal-Based Transportation Fuels Programs, DOE is developing technologies for the production of ultra-clean fuels from petroleum and other fossil energy feedstocks. Additionally, in support of the National Bioenergy Initiative, DOE is conducting a Biofuels Program to develop the technologies necessary for the production of ultra-clean transportation fuels from a broad array of biomass feedstocks.

It is essential that a systems approach be employed to concurrently develop technologies for fuels-sensitive elements of engines and emissions control systems, and for production of ultra-clean fuels. Furthermore, it is imperative that the appropriate elements of the associated R&D programs and activities be coordinated under an overarching collaborative program. DOE's Ultra-Clean Transportation Fuels (UCTF) Program has been conceived for these purposes. Central to the success of the UCTF Program is the implementation of the Program Plan described herein.

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Introduction

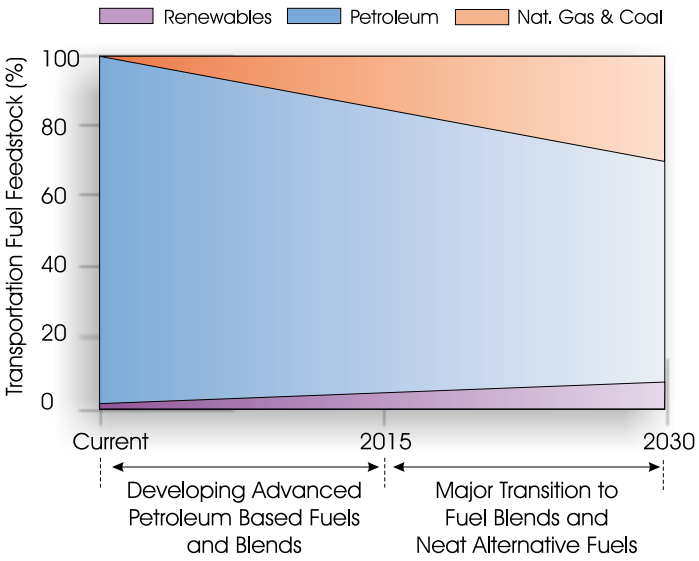
Providing our Nation with clean, plentiful transportation fuels for the 21st century presents enormous challenges. The availability of a clean and affordable energy supply for transportation is essential for sustaining economic growth, social stability, and public health. Major issues facing transportation include air pollution, emissions of greenhouse gases, and increasing reliance on imported oil. The DOE role is to promote the development of technologies that will provide our Nation with high-efficiency highway transportation power systems and a stable supply of clean and affordable transportation energy. As a vital element of its response to these challenges, DOE has initiated the comprehensive Ultra-Clean Transportation Fuels (UCTF) Program.

The UCTF Program encompasses research, development, and demonstration (RD&D) activities that will provide for near-term, mid-term, and longer-term results. In the near term, petroleum-based fuels will dominate the market; consequently, the Program will ensure that these fuels are compatible with emerging high-efficiency power system technologies under development in the Partnership for a New Generation of Vehicles (PNGV) and the 21st Century Truck initiatives. This will result in both dramatic decreases in emissions and significant increases in fuel economy. In the long term, other activities are included to facilitate a transition toward renewable and sustainable fuels.

The strategy of the UCTF Program is to make available a sustainable supply of ultra-clean transportation fuels consistent with projected changes in the characteristics of the Nation's fuel resources and to test, evaluate, and optimize advanced petroleum-based fuels in engines within the context of a systems approach (see Figure 1). The Program will develop advanced fuel production/

processing techniques that will enable advanced petroleum-based fuels to be producible and deliverable to the driving public in a cost-effective manner. In keeping with the mission of this Initiative, these fuels will be produced from a variety of domestic resources to include crude oil, refinery by-products, natural gas and coal, as well as renewable biomass. The utilization of these fuels will not require major changes to the Nation's existing liquid transportation fuels infrastructure. In this Program, natural gas is considered as a feedstock for the production of liquid transportation fuels. Plans for natural gas (i.e., pressurized gas) vehicles are not included.

Figure 1: Ultra-Clean Transportation Fuels Program Strategy



Issues

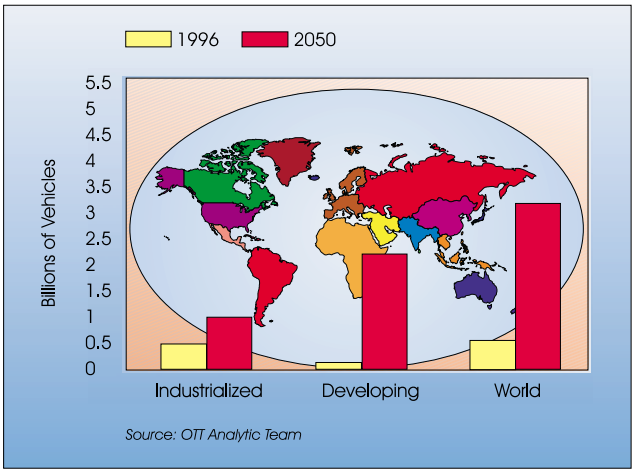
There are increasing national and global concerns regarding the energy demands and environmental impacts of highway transportation vehicles. The energy demand concerns, which pertain to both the magnitude of transportation energy required and dependence on foreign sources for transportation fuels or fuel feedstocks, have a major bearing on a nation's ***energy security***. The ***environmental concerns*** involve highway vehicle emissions that: (1) directly threaten the health of individuals that reside within a given metropolitan area or region of the country; and/or (2) induce atmospheric conditions which, in turn, produce climate changes that are potentially deleterious to the health of the overall populations and economies of the world.

Energy Security

The world's driving population, the vehicle population, and the vehicle-miles-traveled (VMT) per vehicle are rapidly expanding. In fact, world vehicle use is anticipated to quadruple in the next 50 years (see Figure 2). Given the fact that the global highway transportation fleet is almost totally dependent on petroleum-based fuels, the escalating demand being placed on the world's finite supply of petroleum is creating unprecedented levels of volatility in the availability and market value of transportation fuels. This volatility is a clear and present threat to the security of the United States because it jeopardizes this country's ability to transport the goods required to sustain its economic growth and preserve the degree of personal mobility essential to its citizens.

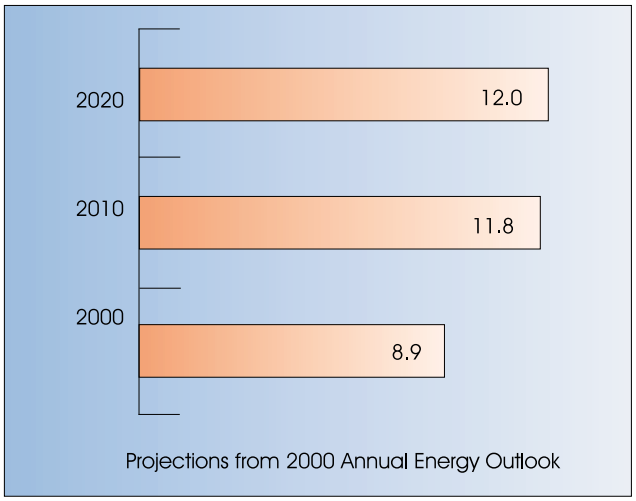
Furthermore, the threat represented by this market volatility is exacerbated by the fact that the quality of conventional crude oil, with respect to sulfur content, also is expected to deteriorate in the future; this decline in quality will occur at the same time that the quality requirements for refined transportation fuels are becoming more stringent. Given current petroleum refining technologies, this quality gap between available feedstock and required product will compound the shortfall and market volatility of petroleum-based highway transportation fuels. It is urgent that advanced, cost-competitive petroleum refining technologies be developed to enable the production of higher quality fuels from lower quality petroleum crude.

Figure 2: Worldwide Vehicle Registrations



Ultimately, a nation's energy security is proportional to its ability to produce the energy it requires from domestic feedstocks. In the case of its transportation sector, the United States is essentially dependent on petroleum and uses substantially more oil than is produced domestically. Furthermore, imports are projected to significantly increase in the future (see Figure 3). Highway transportation accounts for approximately 75 percent of all petroleum used in U.S. transportation, which is half of all the U.S. petroleum consumed on an annual basis. To enhance its energy security, the U.S. must establish a definitive process by which it can transition away from foreign petroleum and toward the primary use of domestic feedstocks for the production of its highway transportation fuels. A national priority must be placed on the R&D of advanced technologies and processes that will enable this country to utilize domestic heavy crude and alternate feedstocks, especially those fossil and biomass feedstocks that are abundantly available in the United States. Given the research nature of such an endeavor and the probable long lead time required to achieve success, this research must be conducted on an aggressive schedule.

Figure 3: Oil Imports



Environmental Concerns

In addition to the energy security threat inherent in continued dependence on petroleum as the dominant feedstock for transportation fuels, there are imminent national and global environmental consequences of major magnitude. At the national level, criteria pollutants play a major role in affecting ground level air quality. For example, of the total manmade air emissions in the U.S., highway transportation is responsible for 57 percent of the carbon monoxide (CO), 30 percent of the nitrogen oxides (NO_x), and 27 percent of the volatile organic compounds (VOC) (see Figure 4).

In response to this, the U.S. Environmental Protection Agency (EPA) Tier 2 emissions regulations for light-duty vehicles impose stricter limits on tailpipe emissions. Additionally, to meet the durability requirement imposed on emission control devices, the regulations will require significantly lower levels of sulfur content in fuels. The EPA has proposed regulations for heavy-duty engine emissions and diesel fuel quality that would be much stricter than current regulations.

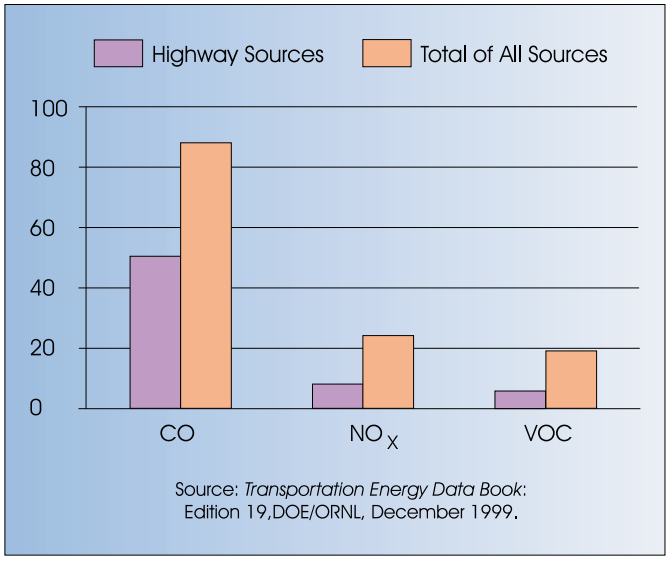
These stricter-than-anticipated emission control regulations, along with their timing, significantly increase the challenge and sense of urgency facing major government/industry initiatives aimed at developing high-efficiency highway vehicle technologies (e.g., PNGV, and 21st Century Truck Program). The timely success of these initiatives is critically dependent on the development of advanced, ultra-clean fuels that will enable the resulting technologies to achieve their dramatically improved levels of fuel economy while complying with current and anticipated environmental regulations and policies.

Globally, due to rapidly expanding petroleum-based transportation energy use, emissions of greenhouse gases (e.g., carbon dioxide) that contribute to climate perturbations are increasing. Highway transportation accounts for approximately 80 percent of total transportation emissions of carbon. The DOE Energy Information Agency projects that by 2020, total carbon emissions in the United States will increase to 1,975 million metric tons (MMT) under business-as-usual assumptions, with transportation petroleum combustion accounting for 665 MMT, or 34 percent of total U.S. carbon emissions. It is urgent that broad-based research be applied to the development of advanced fuels that will enable a reversal in the increasing rate of greenhouse gas production by highway transportation vehicles.

National Urgency

Collectively, the national security and environmental implications of the trends described above present a compelling case for establishing a robust, aggressive, technically-driven, collaborative government/industry program to develop: (1) a portfolio of ultra-clean highway transportation fuels that can be derived from domestic feedstocks, and (2) advanced technologies that will enable their commercial production and nationwide distribution.

Figure 4: Highway Emissions



Source: *Transportation Energy Data Book*: Edition 19,DOE/ORNL, December 1999.

Critical Needs

The critical need to reduce highway transportation-related air pollution, increase energy security, and minimize greenhouse gas emissions dictates that the UCTF Program undertake the following actions:

- Develop an integrated "systems approach" methodology to determine and predict the effects of interactions among the fuels-sensitive elements of engines and emissions control systems, and fuels on the performance of power systems.
- Reduce tailpipe emissions responsible for regional and urban air pollution to ultra-low levels by providing fuels having the characteristics, including low sulfur content, that provide for optimum engine performance and allow emissions control systems to perform effectively in advanced technology vehicles.
- Work with the petroleum industry to improve energy and process efficiency associated with the production of fuels. The result will be a highly efficient, flexible refinery that can produce a wider range of products from crudes of variable quality, as well as non-conventional feedstocks.
- Develop the technology base necessary to successfully upgrade poor feedstocks such as petroleum residuals and crude oil of inferior quality to meet stringent fuel specifications.
- Develop the technology base necessary to produce ultra-clean fuels from natural gas, coal, and carbonaceous wastes using processes that are compatible with carbon reduction and sequestration.
- Accelerate the development and deployment of cost-competitive biofuels for transportation via improved feedstock pretreatment, harvesting, fermentation, and enzyme system development.
- Develop databases and predictive models for performance of advanced, new, or reformulated fuels in advanced, high-efficiency vehicles.

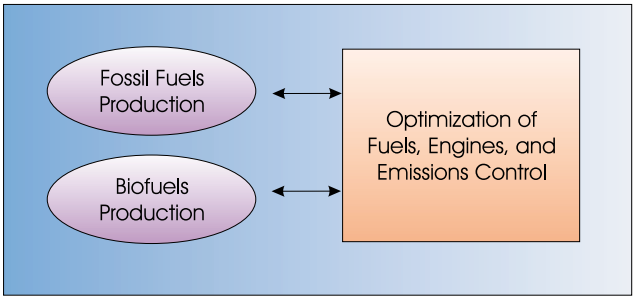
Program Structure

The Ultra Clean Transportation Fuels Program is structured to capitalize on DOE's strengths in resolving the issues of the highway transportation sector, to result in increasing energy security (e.g., increasing domestic production and resource diversification), thereby reducing emissions and minimizing greenhouse gases.

The Program features near-term options that are inclusive of petroleum, and consider alternative fuels (derived from natural gas, coal, and renewable feedstocks), as candidate blending stocks for petroleum-based fuels. Longer-term options include alternative neat fuels derived from non-petroleum, fossil, and biomass feedstocks.

The Program includes three major functions: fossil fuels production, biofuels production, and optimization of fuels, engines, and emissions control (see Figure 5). The goals of the functions are to:

Figure 5: Three Major Functions of the UCTF Program



- Produce petroleum-based ultra-clean fuels.
- Produce ultra-clean, non-petroleum, fossil-based fuels for use as blending stocks in the near term to mid term and potentially as neat fuels in the long term.
- Develop advanced refinery processes and innovative fuel-making components, materials, and technologies.
- Produce ultra-clean biofuels for use as a blending stock for petroleum-based fuels in the near term and as a neat fuel in the long term.
- Optimize fuels-sensitive engine and emissions control components through iterative testing and refinement.
- Component optimization will be coordinated with existing emissions control R&D programs.
- The Program recognizes that events, domestic and international, require that its schedule for technology development be shortened and its objectives achieved at an accelerated rate. The Program Plan integrates the associated supporting activities ongoing in the Office of Fossil Energy and Office of Energy Efficiency and Renewable Energy.
- Each of the three major program functions is described in the following pages.

Program Elements

Fossil Fuels Production

Goal

The goal of this program function is to promote the development of technologies that will ensure the availability of the Nation's fossil fuel resources for production of a stable supply of clean and affordable transportation fuels. These fuels will be cost-competitive while addressing global and domestic challenges. Public/private partnerships will be achieved with the refining and transportation industries to promote the development and deployment of technologies to produce ultra-clean, high-performance transportation fuels from all fossil energy resources. These fuels will enable the introduction of advanced, high-efficiency fuel/engine/emissions control combinations. Resource diversity will be promoted that will result in fossil feedstocks other than petroleum being used to produce ultra-clean fuels, thereby reducing our dependence on imported petroleum. These ultra-clean liquid fuels will use the Nation's existing fuel transportation infrastructure.

R&D Challenges

Meeting the demand of 12–15 million barrels per day of ultra-clean vehicle fuels will require technologies that can achieve near-complete removal of emission precursors at reasonable cost from a full suite of fossil feedstocks. These fossil feedstocks include high-sulfur crude, refinery bottoms, natural gas and coal, as well as high-value, low-sulfur, sweet crude resources that are being rapidly depleted. Improved techniques for synthesis gas and hydrogen production, and synthesis gas conversion to premium products are needed. New processes must be invented, verified, demonstrated, and deployed, and the quality of the product confirmed.

R&D Initiative

These new fossil fuels production activities will build on the fundamental research (particularly the catalyst and reactor development effort) being conducted in the Petroleum Processing, Gas-to-Liquids, and Coal-based Transportation Fuels Programs that have clean fuels development as their primary goal. These programs will be coordinated and integrated to implement the UCTF Program in the most efficient and cost-effective manner.

The activities in this function will concentrate on developing options for the near, mid, and long range. In the near term, industry/government projects will demonstrate advanced petroleum-based fuel-making processes at pre-commercial scale, generating sufficient advanced fuels to enable fuel/engine/emissions control verification testing. The mid-to-longer term activities will be concerned with the economic production and utilization of feedstocks such as natural gas, petroleum coke, heavy hydrocarbon bottoms, and coal.

Biofuels Production

Goal

The goal of this program function is to foster the development of a domestic biofuels industry through RD&D activities in partnership with industry, universities, other Federal agencies, and state/local governments.

R&D Challenges

The cellulose in wood, agricultural residues, and other biomass can be hydrolyzed into sugars for subsequent fermentation into ethanol fuel. This hydrolysis process must be made less costly through innovative biomass pretreatment techniques and efficient enzymes. Next generation fermenting micro-organisms need to be more robust and versatile to achieve low-cost fermentation of multiple sugars into ethanol. While agriculture residues are an important source of feedstock for the near term and mid term, energy crops (specialized, fast growing grasses and trees) will ensure an abundant feedstock supply in the long term when biofuels would be widely used. The yields per acre and resistance to diseases and drought for such crops need to be improved to support a major biofuels industry. Harvesting, handling, and storage of biomass need additional development and demonstration to reduce time and manpower requirements.

R&D Initiative

DOE, industry, and leading universities are collaborating on R&D focusing on enzymes, biomass pretreatment, and fermenting micro-organisms, including genetically engineered yeasts and bacteria. Feedstock R&D involves close collaboration with the U.S. Department of Agriculture (USDA), the forestry industry, farmer organizations, and universities. Industry/Federal agencies/state and/or local government partnerships will demonstrate ethanol production technologies at commercial scale. The Bioenergy Initiative embodies increased coordination with industry, agricultural interests, other DOE programs, USDA, and various public sector organizations. The Biofuels Production Program function is developing a variety of biomass ethanol production technologies for use at: (1) at corn ethanol plants for converting their abundant corn harvesting residues into ethanol; (2) municipal solid waste facilities for converting the organic components of their waste into ethanol; (3) biomass power plants for producing electricity and ethanol using forest residues; and (4) future integrated biomass processing plants for producing a variety of products including ethanol, electricity, and industrial chemicals. DOE and its partners also will develop improved, high yielding energy crops and demonstrate their deployment in a manner consistent with environmental sustainability principles.

Optimization of Fuels, Engines, and Emissions Control

Goal

The goal of this program function is to optimize the combined performance of fuels, advanced high-efficiency engines, and emissions control systems to meet Federal light-duty and projected heavy-duty emissions standards.

R&D Challenges

Diesel powered light- and heavy-duty vehicles face major challenges in meeting Federal nitrogen oxide and particulate matter emissions standards. The technology development pathway involves determining the changes necessary in fuels and lubricants to enable advanced, high-efficiency engine and emissions control systems to reduce emissions dramatically over the useful life of vehicles. Optimization of a complete system also involves changes to engine and emissions control devices in order to maximize system performance.

The fuels-related fuel cell challenges are to obtain high efficiency, quick start-up, and required catalyst durability utilizing advanced ultra-clean fuels that can be made by U.S. refineries and can use the existing highway transportation fuel infrastructure with minimal impact.

R&D Initiative

DOE will partner with the fuels industry, and automotive, engine, and emissions control manufacturers to evaluate and optimize systems to meet the vehicle emission standards and fuel economy goals. Ultimately, the integrated fuels, engine, and emissions control system will be validated by vehicle testing.

Diesel fuel sulfur effects on nitrogen oxide catalysts and particulate traps will be determined. The appropriate sulfur level must be compatible with required conversion efficiency and durability targets. In addition, fuel sensitive engine and emissions control components, such as specialized fuel injectors, will be developed and tested. Also, improved fuel additives (e.g., oxygenates) and lubricant formulations will be identified to minimize particulate emissions.

DOE will partner with the fuels industry, automotive manufacturers, and fuel cell developers to evaluate and identify optimal ultra-clean fuels for on-board vehicle fuel processors. On-board methods, to remove sulfur and define the tolerance of both fuel processors and fuel cells to fuel sulfur content, will be explored. Effects of various impurities and gasoline constituents (e.g., detergents, antioxidants, etc.) on fuel processor performance and durability will be investigated. In addition, the effects of fuel components (e.g., isooctane, toluene, etc.) on fuel processor efficiency and on catalyst activity and durability will be determined.

Safety, environmental, and cost analyses will be conducted to determine the feasibility of integrating ultra-clean fuels with advanced vehicle technologies in order to achieve the desired results.

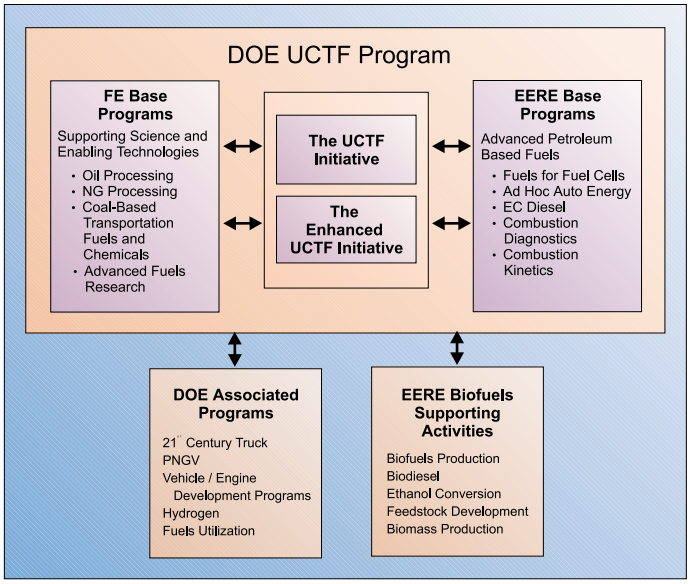
Program Integration

The UCTF Program brings together fossil fuel and biofuels production research as well as research on advanced engines and their emission control systems. The coordination of these activities will generate a synergistic effort that can advance the utilization of fuels from both fossil and renewable resources, and enable the use of very efficient and low-emission engine and emission control systems being developed in the PNGV and the 21st Century Truck Program. The result will be vehicle systems that are highly efficient and characterized by ultra-low emissions.

As previously stated, the Program will enable the development and deployment of PNGV and 21st Century Truck fuel-engine emissions control systems, and ensure that multiple feedstock options are available and producing next generation ultra-clean fuels. The Program will develop and deploy fuel production options for both petroleum- and non-petroleum-based fuels. Candidate fuels are to be provided in sufficient quantities to support larger scale engine and vehicle testing for a number of ultra-clean transportation fuel options. A technical verification effort also will be implemented to identify refinery modifications that can utilize existing resources to produce ultra-clean fuels for distribution through the existing fuel supply infrastructure. The activity also will identify and develop alternative transportation fuels for powering advanced engines (e.g., fuel cells, and the Homogeneous Charge Compression Ignition (HCCI) engine).

Integrating this effort of the UCTF Program with numerous supporting activities ongoing as part of the base R&D programs of the Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy is expected to be a significant factor in accomplishing the objectives of the Program. The relationship among these activities is presented in Figure 6.

Figure 6: DOE Clean Fuels Program



Program Management/Coordination

UCTF Program Management

The UCTF Program is jointly directed by the DOE Office of Energy Efficiency and Renewable Energy and the Office of Fossil Energy. This combined management provides the essential complementary strengths, expertise, and resources to make the Program successful. The Office of Fossil Energy contributes fossil fuel development and production technology needed to deliver a stable, clean, and affordable energy supply for transportation. The Office of Energy Efficiency and Renewable Energy delivers advanced technologies for clean and efficient vehicles, biofuels from domestic renewable feedstocks, and petroleum-based fuels testing. From these coordinated efforts will emerge the best "resource-to-road" system.

Co-management of the Program provides an integration and coordination of Office missions and resources to achieve the overall Program goals. Key industry and government organizations will collaborate to set priorities, guide the R&D tasks, and evaluate progress.

External Interfaces and Coordination

The UCTF Program is proactive in its efforts to coordinate with industry. Additionally, the Program coordinates with state agencies and other Federal organizations that can make important contributions to this Program.

Key trade groups in the energy industry include the American Petroleum Institute and the National Petrochemical and Refiners Association, which signed a compact with DOE for collaborative R&D. The natural gas industry is represented by such groups as the American Gas Association and the Gas Technology Institute. Key groups from the automotive/heavy-vehicle industry include the U.S. Council for Automotive Research, the Engine Manufacturers Association, and the Manufacturers of Emission Controls Association. Key agricultural groups include the National Corngrowers Association, the Corn Refiners Association, the Renewable Fuels Association, and the American Coalition for Ethanol.

Program Roadmap

The key milestones that mark the progress of the UCTF Program correspond directly with the objectives of the Program and the supporting activities. The UCTF Program will effectively utilize the associated R&D efforts of the Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy in a coordinated fashion to ensure that the data and/or technology needed for a fully integrated system (i.e., fuels, emissions controls, engine) are available. Milestones also have been established to ensure efficient resource utilization by the government and industry participants over the duration of the Program.

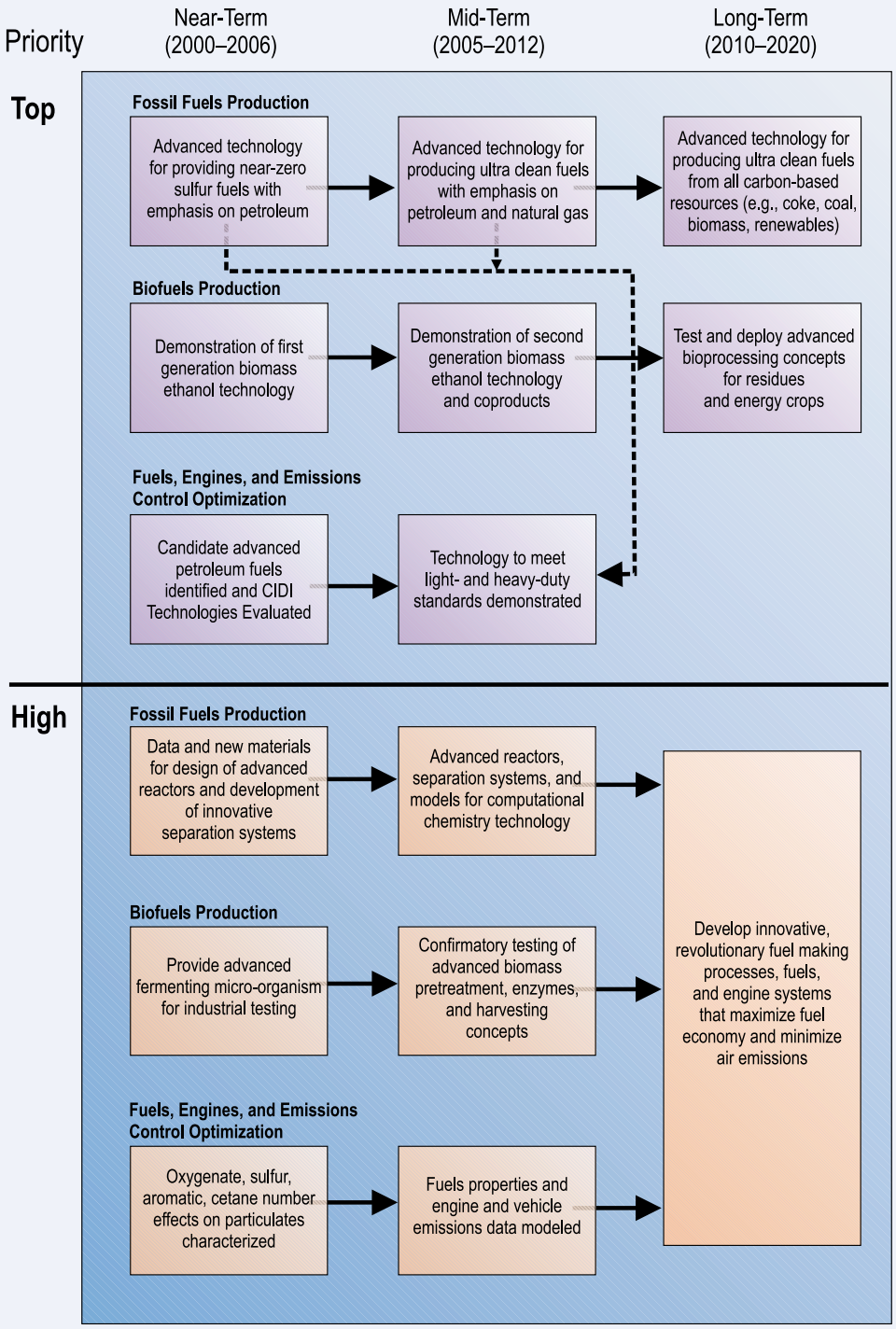
The overarching milestones established for the UCTF Program are provided in Figure 7. The key outcomes include:

- Develop and demonstrate several technologies to produce ultra-clean transportation fuels from oil, natural gas, coal, and petcoke/petroleum bottoms.
- Produce substantial quantities of ultra-clean gasoline and diesel fuel for testing purposes.
- Demonstrate the potential to incorporate fuels derived from renewable resources into refinery processes which make ultra-clean transportation fuels.
- Test several representative light-duty vehicles and heavy-duty engines optimized for each ultra-clean transportation fuel.
- Identify a new generation of ultra-clean fuels for fuel cell vehicles and engines, and for use with advanced combustion systems such as Homogeneous Charge Compression Ignition.
- Augment the database of fuel properties and engine and vehicle emissions with information to identify engine and emission control systems that will have significantly reduced emissions of toxic materials and ultra-fine particles.

Achievement of the milestones will provide, in the long term, the technology and database for production and utilization of ultra-clean fuels in extremely efficient transportation systems capable of operating with very low emissions. These technologies will be able to fully utilize a wide range of feedstocks of varying qualities as raw material to produce the fuels demanded by the marketplace.

It also will make these technologies and the database available to the EPA, industry, and the public within the time frame currently identified for the phasein of these new fuels.

Figure 7. UCTF Program Milestones



Budget

The UCTF Program was planned and implemented subsequent to conduct of the DOE R&D portfolio analysis. The significance of the UCTF Program Plan and the need for its implementation were confirmed through subsequent interactions with the EPA, the energy industry, and transportation vehicle manufacturers. These discussions emphasized the importance of the milestones established for the Program and the need to proceed at an accelerated rate and at an expanded level of Program activity. The level of activity is based on more stringent requirements for sulfur content in fuels, as well as an acceleration of schedules for fuel production.

It is anticipated that the resource requirements of the Ultra-Clean Transportation Fuels Initiative, the first activity in the Program, will require an average of $50 million per year. An additional average yearly requirement of $45 million per year is needed to meet the objectives of the full Program. These funding levels recognize that the UCTF Program is being supported by associated R&D activities in the Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy.

Full implementation of this UCTF Program Plan is required to help the U.S. energy industry mitigate the technical, financial, and environmental risks of producing ultra-clean fuels. These fuels will improve vehicle fuel economy, while satisfying EPA's Tier 2 light-duty vehicle emission and gasoline quality standards, as well as currently proposed diesel fuel quality and diesel engine emission standards. Full Program funding at these levels will also provide, in the long term, the technologies required to achieve further fuel efficiency improvements while meeting more restrictive emissions standards anticipated for the time period of 2010 and beyond.

It is anticipated that these funds will constitute the Government's participation in a Government/industry cost-shared R&D program. Industry will contribute between 35–50 percent of a project's total cost, depending on the estimated risk associated with the project jointly being performed.

For more information, contact:

Stephen Goguen, EE-33
Team Leader, Fuels and Lubricants Program
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585-0121

C. Lowell Miller, FE-24
Director, Coal Fuels and Industrial Systems
U.S. Department of Energy
19901 Germantown Road
Germantown, MD 20874-1290

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