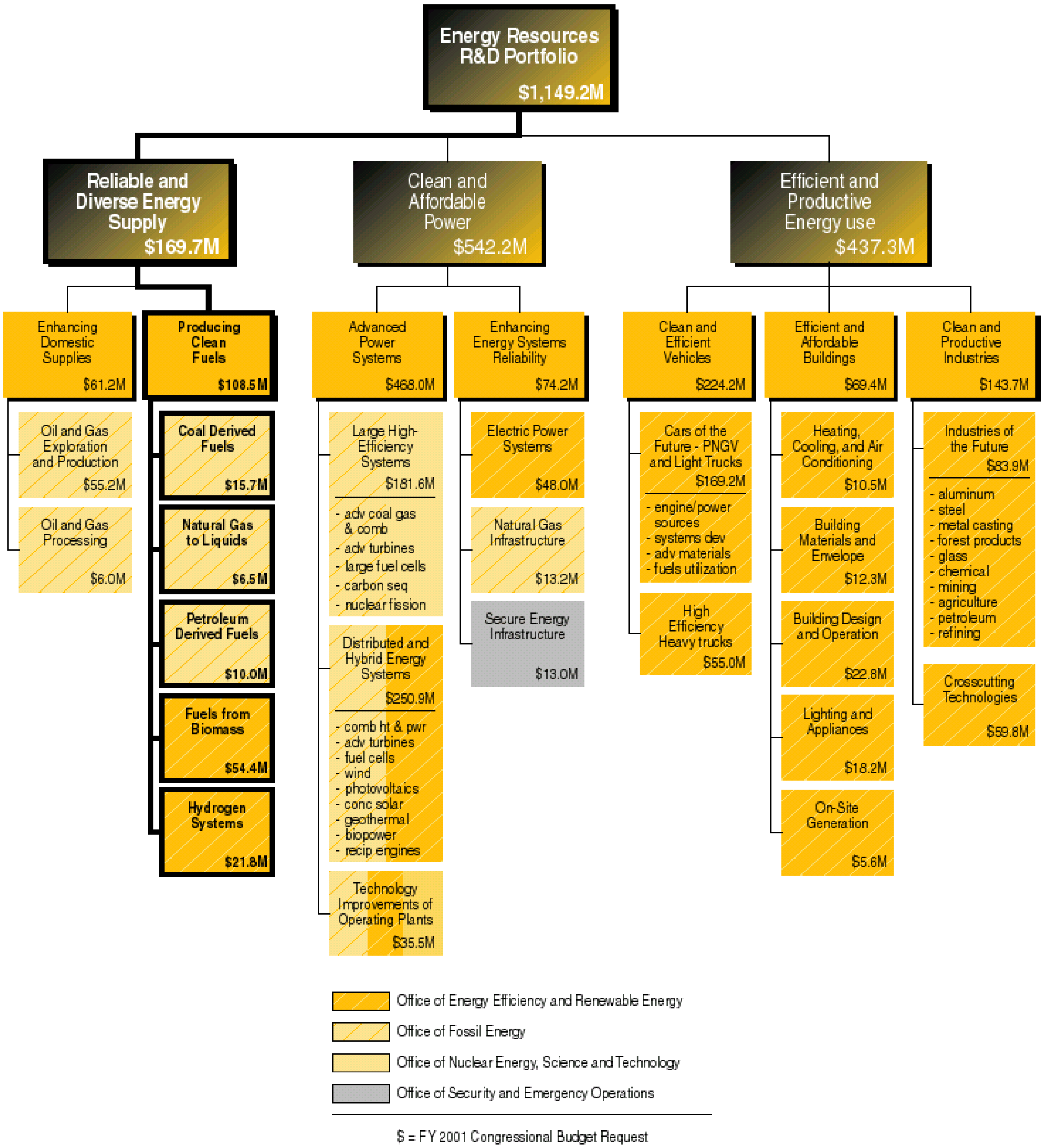
Chapter 4
Producing Clean Fuels



Chapter 4

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Overview

Definition of Focus Area

The Department's clean fuels R&D portfolio responds to important energy security and environmental challenges by providing the technical basis for a clean fuels industry capable of producing transportation fuels from domestic resources. These "clean fuels" produce very low emissions of regulated pollutants, and can be derived from carbon-based feedstocks such as petroleum, natural gas, coal, refinery byproducts, biomass, or any combination thereof. Use of biomass feedstocks to produce hydrogen and other fuels greatly reduces net emissions of carbon dioxide, the primary greenhouse gas associated with climate change. Further, there is the potential to eliminate carbon dioxide emissions through the use of hydrogen from non-biomass renewable sources, or by combining processes using carbon-based feedstocks with carbon sequestration.

National Context and Drivers

The U.S. transportation sector is 97 percent reliant on liquid fuels, and in spite of relatively low average oil prices in recent years and abundant world supply, past history suggests that there are credible scenarios where oil security is a concern. For example, the Energy Information Administration (EIA) Annual Energy Outlook 2000 and International Energy Outlook 1999 forecast that, by 2020:

- U.S. petroleum imports, already over 50 percent of the 19 million barrels per day consumed, will increase to 64 percent of the projected 25 million barrels per day consumed.

- Worldwide oil dependence will continue at nearly 40 percent of total energy consumed, and total petroleum imported by all countries will double.

- OPEC states, many in politically unstable regions, will be the source of the ever increasing amounts of oil imported by the United States and other countries.

There are also fuels-related environmental concerns. Vehicles currently account for a large portion of urban air pollution, including 77 percent of carbon monoxide, 49 percent of nitrogen oxides, and 37 percent of volatile organic compounds. The transportation sector also contributes over one-third of U.S. carbon dioxide greenhouse gas emissions which, absent new reduction initiatives, are projected to increase more than 35 percent by 2020. In coming decades, increasing public health and environmental concerns will likely lead to new environmental regulations that may be difficult or impossible to meet with current fuels.

The clean fuels that are the focus of this paper can be produced in abundance from indigenous resources, are environmentally superior, and are well-suited for advanced, clean, high efficiency engines. With essentially none of the impurities found in current fuels, they permit ready use of advanced emission control technologies in all types of vehicular engines. With these new fuels, even diesel engines are capable of meeting future US Environmental Protection Agency (EPA) and California Air Resources Board (CARB) standards for gasoline and diesel engines.

A clean fuels industry could take on different forms, including a series of plants that co-produce electric power, transportation fuels, and chemicals. These plants would operate in a deregulated gas and electric utility environment and their co-production capabilities and product flexibility would provide a robustness not available in single purpose plants. Co-production of high value products would act synergistically to reduce the costs of all energy products while further reducing the use of imported petroleum-based feedstocks.

Linkage to CNES Goals and Objectives

The primary outcome of clean fuels R&D is to make available, during the 2005-2020 period, a suite of competitive fuels that can be used in transportation and other applications to reduce conventional pollutants and greenhouse gases, and displace oil imports. These activities strongly support CNES goals and objectives dealing with energy/oil security and environmental protection. In particular:

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply. *(longer-term replacement of imported oil with clean fuels)*

- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner. *(all clean fuels offer environmental advantages)*

Uncertainties

Developmental clean fuels face uncertainties that will affect the timing and extent of market penetration. All must successfully meet R&D challenges (discussed later) in order to significantly reduce product costs below the current state-of-the-art. The marketplace may be reluctant to embrace these fuels if there is the perception that future oil prices could be low (e.g., under $20/barrel) for sustained periods. However, any future incentives to reduce greenhouse gas emissions would affect the relative attractiveness of these fuels. In addition:

- If greenhouse gas reduction is a priority, large-scale production of coal-derived liquid fuels would need to be combined with methods (some are currently under investigation) to significantly reduce carbon emissions during processing stages.

- The timing for domestic markets is uncertain for large volume production of natural gas-to-liquids. While it appears that new liquid sources could be needed in about a decade to maintain a viable Trans-Alaska Pipeline, new oil discoveries could delay the conversion of North Slope gas to fuel liquids.

- A key question for biofuels is regulatory and policy uncertainties for ethanol used as a transportation fuel. Several states have enacted legislation encouraging the use of ethanol, such as requiring ethanol to be used in state motor vehicle fleets and establishing minimum statewide oxygenate levels. Other states have passed laws or instituted legislation restricting the use of ethanol, such as limiting oxygenate levels or evaporative emissions limits. Although the tax incentive for ethanol was extended through 2007, some uncertainty remains with respect to the post-2007 period. It is likely that the incentive would be extended again, but the magnitude of the incentive is subject to changes.

- A significant hydrogen industry exists that produces hydrogen centrally in large plants and transports liquid hydrogen to the marketplace. The ultimate goal of achieving a distributed gaseous hydrogen storage and distribution system, however, is subject to a chicken-and-egg phenomenon. Hydrogen use will require establishment of a new fueling infrastructure with a set of codes and standards that are acceptable to the community. However, the development of such an infrastructure requires cost-competitive plants.

Investment Trends and Rationale

The clean fuels portfolio is designed to respond to both environmental and energy security drivers. Fuels derived from from coal, natural gas and petroleum could provide environmental benefits due to their suitability for use in advanced, high-efficiency vehicle engines.

Biofuels, and ultimately hydrogen fuels, provide renewable options with very low environmental impacts, although there will be infrastructure challenges. Several trends are evident in the portfolio:

- Petroleum will continue to be an important source of liquid fuels well into the next century. New processes will use more of the residuum, coke, and other low-value or waste products to increase yields of liquid fuels. This will have a combined effect of lowering energy use and decreasing imports. Increased effort is being devoted to making petroleum-derived fuels cleaner to meet anticipated stringent environmental regulation requiring new and improved technology

- For coal-derived fuels, there is increasing emphasis within current funding levels on reducing greenhouse gas emissions through strategies such as blending coal with biomass, and incorporating natural gas and waste products into the feed stream.

- Increasing funding for biofuels emphasizes lowering the cost of ethanol production technology through advances in pretreatment, cellulase enzymes, and fermentation. Increasing funding for hydrogen fuels emphasizes infrastructure-related activities such as development of molecular hydrogen storage and distribution technologies that will be demonstrated as hydrogen refueling stations for fleet vehicles and mass transit buses.

Ultra-Clean Transportation Fuels Initiative (UCTFI)

In the nearer term, ultra-clean transportation fuels can be produced from improved or new refinery upgrading technology. In the mid-to-longer term, ultra-clean transportation fuels from natural gas and coal would enjoy a high level of compatibility with the existing infrastructure, and could provide environmental benefits due to their suitability for use in advanced, high-efficiency vehicle engines. In order to fulfil this role in the most efficient and cost-effective manner, those fossil fuels-related activities that have clean fuels development as their goal have been integrated, along with new activities, into a comprehensive *Ultra-Clean Transportation Fuels Initiative (UCTFI)* for producing fuels for ultra-low emission vehicles. These activities reside in the Petroleum Program within the Office of Fossil Energy. It has near, mid and long-term goals and is supports by tenants of the *Petroleum Derived Fuels, Natural Gas-to-Liquids and Coal Transportation Fuels and Chemicals* efforts. The initiative seeks to mobilize industrial and National Laboratory capabilities in the development and demonstration of technology for making ultra clean, high performance motor fuels in large volumes from our diverse fossil energy resource base.

The initiative will have two components: the first component is a solicitation directed toward systems-oriented R&D projects that lead to the production of sufficient quantities of fuel to validate performance and emissions --- testing that will be done in collaboration with DOE's Office of Transportation Technologies. The second component is a supporting research program carried out by National Laboratories and co-sponsored with the fuel industry that is focused on the development of advanced fuel-making process components, materials, and chemistry needed for the manufacture of ultra-clean performing transportation fuels.

A competitive solicitation has been prepared for release to industry in December, 1999. It is anticipated that this solicitation will result in multiple cooperative agreement awards to industry teams comprised of fuel resource owners, technology developers and engine/vehicle manufacturers. The first awards are expected by early summer, 2000.

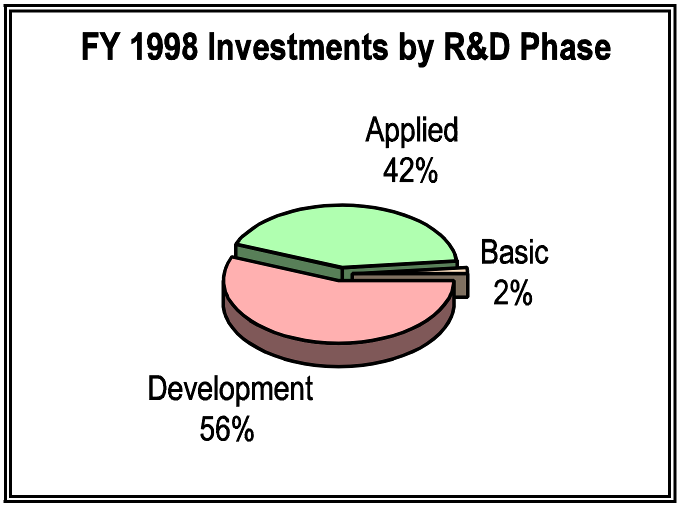
<u>Biobased Products and Bioenergy Initiative</u>

This is a government wide, integrated research, development and deployment effort in bio-based technologies that convert crops, trees, and other "biomass" into a vast array of fuels and products. Biobased industries use agricultural, forest, and aquatic resources to make commercial products including fuels, electricity, chemicals, adhesives, lubricants, and building materials. The initiative supports the President's August 1999 Executive Order 13134 and Memorandum on Promoting Biobased Products and Bioenergy, aimed at tripling the use of biobased products and bioenergy in the United States by 2010. The major goal of this initiative is to make biomass a viable competitor to fossil fuels as an energy source and chemical feedstock, while protecting the environment.

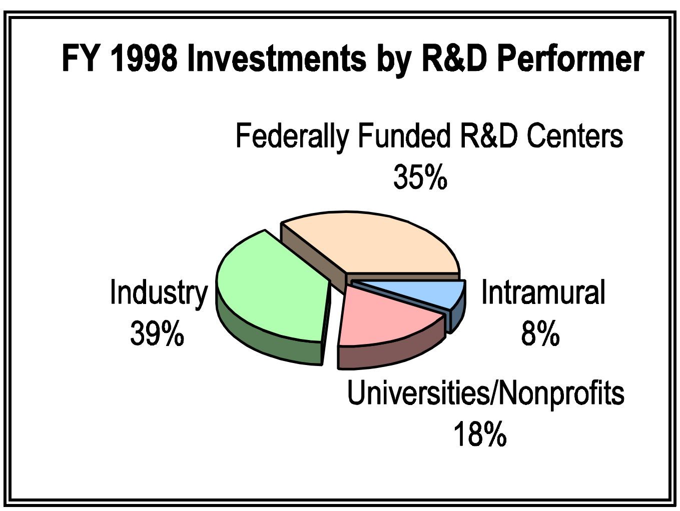
Clean Fuels funding for this initiative is under Fuels from Biomass, and focuses primarily on developing advanced technologies for more cost-effective biomass production and harvesting, and improved pretreatment and enzymes for hydrolyzing biomass to various sugars that can be converted to ethanol fuel and other high-value chemicals such as succinic acid, citric acid, adipic acid, and propylene glycol.

<u>Distribution of R&D by Performer and Phase</u>

The figures below show how funding for clean fuels programs are distributed by R&D performer and R&D phase. These distribution do not tend to change rapidly over time, and the FY 1998 results are expected to be valid for the FY1999-2001 period. Relatively little basic research is carried out within the clean fuels portfolio, although there is basic research carried out in crosscutting programs, e.g., materials programs in the Offices of Energy Efficiency and Renewable Energy (EE) and Fossil Energy (FE), and particularly in the Office of Science (SC), that could contribute to these programs.



R&D performers reflect the maturity and origins of the technologies. For example, technologies in the latter stage of the development, such as some of those in the coal fuels program, will normally have more industry participation. Other clean fuels areas that are less mature have greater university and National Laboratory participation. The significant "intramural" activity for natural gas and coal fuels reflects in-house R&D at the National Energy Technology Laboratory staffed by Federal employees.



Federal Role

Based on the environmental and security-related concerns associated with the current U.S. fuels mix, the Federal Government is investing in clean fuels technology development where the industry believes that the risk is too high to profitably recover the development costs of the long-term and/or high-cost R&D, or where the Government has unique R&D capabilities.

While global concern over the environmental impacts associated with transportation demands is growing, the relatively low price of conventional transportation fuels makes it difficult to change current fuel use patterns. There is little immediate market incentive for investment in cleaner fuels, especially for longer-term options. Accordingly, there is a significant gap between the level of advanced clean fuels R&D that the market will support and the level needed to address current and future concerns about availability and suitability of conventional fuels. The Department’s clean fuels research and development portfolio is designed to help bridge that gap.

Key Accomplishments

Clean Fuels R&D has resulted in significant progress in support of CNES goals and objectives. Broad accomplishments include:

- An initiative for ultra-clean transportation fuels has been prepared which includes near-term and mid-to-long term approaches for development of these ultra-clean fuels. The initiative builds on technology development carried out under Gas-to-Liquids, Transportation Fuels and Chemicals, and Petroleum-Derived Fuels.

- Recent developments in metals membranes for hydrogen separation and catalyst development for sulfur removal have created the potential for reducing costs of making cleaner fuels from petroleum.

- Recent breakthroughs in air separation via ceramic membranes have created the potential for reducing the cost of liquids from natural gas at least 25 percent below conventional technology and significantly reducing costs from coal-based synthesis gas.

- Validating that coal-derived transportation fuel for diesel applications can significantly reduce vehicle pollutant emissions.

- Coal liquids R&D has reduced the crude oil equivalent cost to approximately $30 per barrel, versus $60 per barrel in the late 1970‘s.

- Over the last 2 decades, the predicted cost of biomass-derived ethanol has been reduced by at least 50 percent, and commercial production of biomass ethanol from low cost feedstocks is expected to begin by 2002. Biodiesel is produced today from agricultural crops, such as rapeseed and soybeans, and from recycled restaurant grease.

- Experimental results achieved on a Sorbent Enhanced Reformer validate expectations for a system that will reduce the cost for the production of hydrogen by 25 percent from conventional steam reforming methods.

Coal-Derived Fuels

Budget: FY99-$16.7M, FY00-$13.6M, FY01-$15.7M

Background

The availability of a clean, affordable, and reliable energy supply for transportation and power generation in the United States is essential for sustaining our economic growth, social stability, and public health. However, there are several major concerns now facing the use of coal, which include regional and urban pollution and increasing emissions of greenhouse gases. The primary role for the Coal-Derived Fuels Program, as well as the other fuels programs, is to promote the development of technologies that will provide this nation with a stable supply of clean, affordable fuels in the 21st century.

Over the last several years, the Coal-Derived Fuels Program has been significantly re-engineered. Today's program emphasizes the development of ultra-clean transportation fuels and carbon-based chemicals that could enable vehicles to meet new, stringent regional and urban environmental emission regulations that are expected to be promulgated within the first decade of the 21^{st} century. These fuels will also be used in more efficient vehicles that are expected to double the miles per gallon of today's vehicles and, therefore, reduce greenhouse gas emissions. Further, the abundance of U. S. coal and its historically stable price provides an economic opportunity to produce clean transportation fuels while simultaneously lessening U.S. dependence on petroleum imports.

Much progress has been made in improving the efficiency of coal conversion processing technologies and concurrently, producing a better product at lower cost. For example, diesel fuel, prepared via coal gasification and clean up and conversion of the resulting carbon monoxide/hydrogen synthesis gas mixture, enables the emission controls on diesel engines to achieve 60 percent reductions in unburned hydrocarbons, 40 percent lower carbon monoxide and nitrogen oxides and 20 percent fewer particulates. This is achievable because the fuel is completely free of sulfur, which poisons the catalysts used in emission control devices. Similarly, many years of R&D on this process and others has brought about dramatic drops in the cost of substitute liquid fuels. Where in the late 1970's, for example, the projected cost of coal liquids approached $60 per barrel, today's technology has reduced the cost to about $30 per barrel. Moreover, the prospects of additional process breakthroughs has created the potential to lower costs to the low $20's per barrel by 2015.

Another significant environmental and economic benefit being achieved through the coal-derived fuels program is associated with the utilization of coal fines. An estimated 2 to 3 billion tons of these coal "fines"—microscopic coal particles—lie in waste impoundments at coal mines and washing plants around the country. This discarded "waste" contains the energy equivalent of 8 to 12 billion barrels of oil, as much as a massive oil field. Moreover, each year, mining operations dispose of as much as 30 million tons of coal as waste, and utilities discard millions of tons of unburned carbon along with fly ash in power plant landfills. Technologies are being developed to utilize these carbon resources, including co-firing applications with a diverse group of energy sources ranging from wood, agribusiness wastes, and landfill materials (municipal and animal waste, plastics, rubber, etc.) that are discarded in the United States, as well as fast-growing "energy crops."

While over half of U.S. power currently comes from coal, environmental concerns (e.g., emissions of hazardous air pollutants and greenhouse gases) could affect future use of the Nation's most abundant fossil fuel resource. Development of pre-combustion technology can address these issues.

Linkage to CNES Goals and Objectives

There are two main goals for Coal-Derived Fuels:

- By 2010, develop technology to permit continued use of our abundant coal resources in a cost-effective, environmentally-benign manner, including:
  - An alternative source of coal-derived liquid transportation fuels that is cost-competitive with equivalent petroleum products.
  - Technologies that utilize low-cost waste coal resources while significantly lowering power plant emissions, including carbon dioxide, by reducing pollutant-forming species in all coal resources and preparing suitable blends of coal with biomass/wastes.
- By 2015, develop technologies for the cost effective production of premium carbon products and feedstocks from coal.

These program goals support multiple CNES goals and objectives:

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply. *(coal-derived liquids represent a potentially large supply of domestic transportation fuels)*
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner. *(production of these fuels in combination with carbon management would be ideal for advanced, high-mileage, low emission vehicle engines)*
- CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(coal's main domestic use is for power production, and efforts to recover waste coal, reduce emissions, and produce high-value carbon-related products would enhance the overall economics of coal power)*

Program Description

Coal, our country's most abundant fossil resource, possesses much more potential utility than just raw fuel to be burned. The carbon and hydrogen in coal are a rich source of molecular "building blocks" that can form a diversity of liquid fuels and valuable commercial chemicals as historically exemplified by the coke and tar products industry. A key program thrust is the Early Entry Coproduction Plan to coproduce some combination of power, fuels, and chemicals with high efficiency and reduced capital cost. Another major thrust is a partnership among the Offices of Coal and Power Systems (FE), Natural Gas and Petroleum Technology (FE), and Transportation Technologies (EE) to support an Ultra-Clean Transportation Fuels Initiative. In addition to premium liquid fuels activities, the Coal-Derived Fuels Program is carrying out R&D on solid fuels and feedstocks. These activities are aimed at enhancing the value of coal through coal processing to reduce environmental emissions and waste coal, and production of premium carbon products.

Transportation Fuels and Chemicals – Base Program

Budget: FY99-$10.0M, FY00-$7.1M, FY01-$9.0M

Description, Objectives, and Performers. Transportation Fuels and Chemicals is a market-driven, product-oriented program. The goal of the program is, by 2015, to deploy commercial technologies that convert coal, alone or in combination with biomass, wastes and other carbon-based materials, to valuable transportation fuels and chemicals. R&D focuses on: a) making transportation fuels that will provide the transportation sector with major environmental benefits, and b) making chemicals with improved process efficiency and lower capital costs. The route or process used to make the products will be dictated by industry, who is signaling that the most likely near- to mid- term commercialization strategy will rely upon gasification-based systems that convert synthesis gas (carbon monoxide and hydrogen) to premium, zero-sulfur refinery feedstocks or chemicals. The mechanism by which the R&D is accomplished is through government-industry cost-shared partnerships. The R&D is being performed by 13 organizations, including 7 industrial companies that comprise about one-half the program funding, 2 universities, 2 National Laboratories and 1 Fossil Energy field laboratory.

R&D Challenges. The primary challenge is to simultaneously drive down costs and reduce environmental emissions. Improved techniques for synthesis gas and hydrogen production , hydrogen separation and purification, achieving greater reactor throughput, and the creation of higher value products can all lead to better marketability through lower product cost and environmental performance that leads to the DOE goal of near "zero-emissions" (which could require capture and sequestration of carbon if greenhouse gas emissions are included).

R&D Activities. The main focus is on developing specific high-value products, including diesel, gasoline and jet fuels and a range of premium chemicals. This market emphasis presents very clear economic and environmental targets that in turn drive the research activities. As an example, an FE-led team that includes industry, a National Laboratory and several government organizations is developing alternative diesel fuel via the advanced Fischer-Tropsch (F-T) process. The fuel has been shown in preliminary engine tests to produce much lower emissions than its current petroleum-derived counterparts. This result has generated strong interest among the diesel engine manufacturers.

The base research program addresses key technical issues associated with making premium fuels and chemicals and provides the foundation upon which to pursue initiatives such as coproduction and ultra-clean transportation fuels. Projects are currently emphasizing: a) continued improvements in the three-phase slurry reactor technology where technology advances have shown the productivity, i.e, product per unit volume of reactor, is moving far beyond what was anticipated, b) development of low cost iron-based catalysts for the slurry reactor, especially for their application and suitability to feedstocks that are low in hydrogen content such as coal, wastes and petroleum coke, c) separation techniques for both gaseous and liquid products to remove contaminants and d) extensive life cycle analyses to identify those areas of fuel conversion processing that offer the best opportunities for CO_2 mitigation. Concurrently, novel R&D is underway to include methods to reduce production of greenhouse gases through process improvements and utilization of multiple feeds such as waste material or biomass. Each of these projects is examining process details but within the context of a system that is intended to make a specific product.

Another major initiative is the the Early Entrance Coproduction Plant. Analyses indicates that coproduction of some combination of electricity, heat, fuels and chemicals using synthesis gas can facilitate commercial deployment of integrated gasification combined cycle (IGCC) plants through improved economics, as compared to a plant that produces only power. The conversion of a portion of the synthesis gas to liquids using the Fischer-Tropsch (F-T) process results in an extremely valuable refinery feedstock for producing high performance transportation fuels that lead to significantly lower vehicle emissions. Based on this, and feedback from industrial stakeholder, three projects are being pursued for coproduction systems.

Accomplishments. For the Early Entrance Coproduction Plant, Texaco and Waste Management Processors, Incorporated have been chosen to develop systems to coproduce F-T diesel fuel and electricity, and Dynegy will focus on producing electricity and methanol, which can be used as a chemical feedstock or fuel.

As the research progresses in the base program from laboratory to bench scale experiments, the advances in specific areas of the fuel production system are incorporated into production of specific products at the LaPorte TX proof-of-concept unit. This approach has worked very successfully over the past fifteen years, as exemplified by the Liquid Phase Methanol Process, whereby technical viability was proven at LaPorte and is now being demonstrated at commercial scale by Eastman Chemicals. More recently, successful operations at LaPorte included production of Fischer-Tropsch liquids and dimethyl ether, both of which are of interest to industry for their potential use as premium fuels.

Solid Fuels and Feedstocks

Budget: FY99-$5.0M, FY00-$4.3M, FY01-$4.5M

Description, Objectives, and Performers. Research and development activities support the environmentally-responsible utilization of the vast U.S. coal resource as well as the increased utilization of non-fossil resources such as biomass and waste. The objective is to provide for the development and deployment of technologies to produce environmentally acceptable, efficient, and affordable carbon-based solid fuels and feedstocks that can compete with those from alternate energy sources, including oil. In addition to ensuring low-cost environmentally acceptable supply of solid fuels for energy production, the activities will ensure a supply of quality feedstocks for specialty applications. The program currently involves more than a dozen participants, including two private sector consortia. These encompass a broad range of organizations including coal producers and technology developers, electric utilities, State and Federal agencies and universities.

R&D Challenges. R&D is needed to: (1) reduce the environmental impacts associated with the generation of hazardous air pollutants from the utilization of coal, particularly the pre-combustion removal of mercury; (2) reduce the generation of greenhouse gases (i.e., CO_2) associated with the utilization of coal; (3) enable and encourage the recovery of previously lost carbon raw materials from waste (culm piles/ponds); (4) permit greater recovery of the useful energy of mined coal; (5) decrease the reliance of the carbon products industry on increasingly dirty (higher sulfur and metals content) imported petroleum; (6) support the development of technology for the production of new premium carbon and industrial products for U. S. Strategic industries necessary for national security and growth of the economy; (7) enable the co-utilization, with coal, of historically discarded biomass and waste materials, therefore better utilizing domestic energy resources

R&D Activities. R&D specifically focuses on the development of advanced technologies for the recovery and dewatering of fine coal now lost as waste or already disposed of in waste ponds and discard coal piles/culms; the processing of coal, biomass, and/or waste materials to produce new solid fuels for the generation of power and heat and to mitigate emissions of CO_2 and other greenhouse gases; the pre-combustion removal of trace elements for the reduction of hazardous air pollutants (HAPs) from coal-fired power plants; the production of value-added, premium-quality carbon products (such as light-weight, high-strength carbon fibers, and composites and electrodes) from anthracite, bituminous, and subbituminous coals; the production of solid feedstocks from coal, biomass, and/or waste for producing premium transportation fuels, low-smoke fuels, electricity, and chemicals; and improvement in the handleability and transportability of various solid fuels.

Accomplishments. This activity has enjoyed notable successes. For example, the Microcel flotation column coal cleaning technology, developed by Virginia Polytechnic Institute with DOE support, has had significant commercial success in coal and minerals applications worldwide. The ENCOAL and Rosebud projects have successfully demonstrated technologies for converting low quality coals to cleaner, higher-value solid and liquid fuels.

Steelmaking Feedstock Program. This Congressionally mandated activity co-funds with industry a commercial-scale demonstration of an innovative coal coking process in a continuous flow reactor. The high quality coke produced can be used directly in the steelmaking process. The process to be demonstrated promises economic advantages over conventional coke making processes by reducing operating and feedstock costs, and has minimal environmental impact. The unique process is capable of easily meeting environmental restrictions faced by the coking industry because it takes place in a completely closed system that prevents emissions. The demonstration site will be at an existing steel plant in Cleveland, Ohio, and will include a crucial long term crucial test of the product coke in a full scale commercial blast furnace. The demonstration is critical to providing a final technical and economic assessment of the process, which has already been successfully tested in a process development unit, for commercial development.

Advanced Research

Budget: FY99-$1.8M, FY00-$2.2M, FY01-$2.2M

Description, Objectives, and Performers. Advanced Research (AR) explores new concepts and ideas that lead to the development of technologies that significantly enhance the economics and reduce the environmental consequences of coal conversion and utilization. Surveying and evaluating new ideas allows AR to bridge the gap between basic research and line programs and provides the technical foundations which serve as the basis for advanced process development. AR is carried out by Federal laboratories, academia, National Laboratories, and industry through various mechanisms and financial support vehicles.

R&D Challenges. Key to the concept of the "hydrogen economy" is the low cost production of high purity hydrogen, preferably without the emission of carbon dioxide. Regardless of the source of the hydrogen (e.g., fossil, biomass, photoelectric, photochemical, etc.), storage, in a fashion that would provide a high enough energy density for it to be used as a vehicular fuel, is problematical and rife with concerns of safety and infrastructure compatibility. This area presents the current and most difficult R&D challenge. A lesser, but still important technical challenge, is the development of advanced computer modeling techniques that will permit prediction of ultra-clean diesel fuel characteristics from the hydrocracking of Fischer Tropsch wax.

R&D Activities. R&D focuses on areas such as novel methods to co-produce hydrogen and high value carbons, especially those useful for hydrogen storage; coprocessing of coal and biomass; advanced, clean burning diesel fuels; production of high value chemicals and non-traditional carbon products from coal; the chemistry of single carbon compounds and derivatives; and new applications of combinatorial chemistry and advanced computer modeling directed toward fuels production.

Accomplishments. Many of the coal conversion technologies now in use were developed through the AR program. These include low-cost, high-efficiency catalysts for coal conversion processes, advanced synthesis gas technologies which will produce fuels in future Vision 21 co-production facilities, coal-waste co-processing technologies, and development of unique analytical methods and protocols suitable for characterization of coal-derived products. More recently, the stability of proposed oxygenated additives in diesel fuel was determined, which will allow determination of the feasibility of using such environmentally enhancing additives within the existing fuels infrastructure.

Natural Gas-to Liquids

Budget: FY99-$6.7M, FY00-$6.3M, FY01-$6.5M

Background

Despite being discovered 30 years ago, the vast natural gas reserves in Alaska's North Slope remain largely unproduced, without access to urban markets. Pipeline construction to an ice-free port, enabling physical conversion and tanker export of the gas as LNG to Asian markets, has long been seen a possibility. However, this option has been stymied by less costly foreign competition. An alternative production and marketing route for the gas would be for it to be chemically converted into a liquid that is more easily transported via an existing oil pipeline and tankers to market. Similar gas-to-liquids (GTL) conversion processing could be used on offshore platforms or barges in the Gulf of Mexico and in many remote locations worldwide to facilitate oil and gas production from wells that do not have pipeline access. Chemical conversion of a syngas produced from natural gas using the Fischer-Tropsch process yields zero-sulfur, zero aromatic paraffinic liquids that with minimal treatment make a superb, ultra clean diesel fuel.

Converted gas from Alaska's North Slope could be transported through the underutilized Trans-Alaska Pipeline System, which carries crude oil from the Prudhoe Bay field on the North Slope to Valdez for tanker shipment to markets. Production from that field is declining at a rate of about 10 percent per year. Even with additional production from newer, more marginal fields, pipeline flow will eventually fall below the minimum volume needed for viable pipeline operation, cutting short final North Slope oil recovery. The useful life of this pipeline could be extended by using it to transport liquid fuels produced from natural gas conversion.

The investment hurdles of present natural GTL technology are significant, and the gas conversion industry in the United States is in its infancy. Recent breakthroughs in ceramic air separation, however, have created the potential for meeting conversion technology cost goals.

Linkage to CNES Goals and Objectives

The main goal of the gas-to-liquids program is to develop, for deployment by 2008, breakthrough technology to convert unmarketable Alaskan and other remote natural gas to high quality, cleaner transportation fuels and premium chemicals at costs 25 to 35 percent below current technology. As a potentially large source of fuels suitable for advanced, high-mileage, low emissions vehicle engines, liquids derived from natural gas could:

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply.

- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner. *(transportation applications)*

Program Description

GTL R&D is focusing on several key technical areas, the most prominent being advanced Fischer-Tropsch (F-T) conversion technology. F-T usually involves two major processing steps: generation of an intermediate process gas ("syngas") composed of hydrogen and carbon monoxide, and synthesis of the intermediate gas with a special catalyst to a hydrocarbon liquid, which also can be followed by separate steps of catalyst/liquid separation and liquid finishing to exact product specification. The major capital plant investment required is for the first step of syngas generation, and this is where DOE's research emphasis is currently placed. At the same time, technology advances are being sought for the second step conversion of the syngas to paraffin hydrocarbon liquids, chiefly in the diesel fuel range. Other DOE work addresses the problem of unmarketable natural gas through development of physical liquefaction technology that is economic at smaller-scale than typical giant LNG trains of today, handling upwards of 500 mmcfd of natural gas.

By furthering the advancement and validation of economical GTL conversion processes, the Federal program can serve not only as a technical facilitator for the public-private Alaskan decision making needed to utilize our large Alaskan gas resources, but one exceedingly helpful in opening up a significant supply of highly desirable, clean-burning liquid transportation fuels. The three areas of GTL research are as follows:

Ceramic Membrane Reactor Systems for the Conversion of Natural Gas to Syngas

Budget: FY99-$5.4M, FY00-$5.0M, FY00-$5.2M

Description, Objectives, and Performers. This research seeks major cost reductions by using a novel ceramic membrane capable of integrating oxygen separation from air, and methane partial oxidation in a single step. This process would eliminate the need for expensive oxygen produced by cryogenic means to make the intermediate syngas product of carbon monoxide and hydrogen, which then can be readily converted to the desired hydrocarbons. Other cost reductions in F-T processing are being investigated in cooperation with the Coal-Derived Fuels Program through development of high-volume slurry reactors and delineation of characteristics of productive catalysts for syngas conversion to liquids. Liquid product optimization for Alaska pipeline transport is also a subject of GTL. The overriding objective of all of these F-T efforts is to develop, advance and identify optimum gas conversion technology to enable timely and economic conversion of presently unmarketable Alaska North Slope natural gas to quality liquid motor fuel stock.

The major work element of GTL ceramic membrane reactor system development is being conducted on a significant cost-shared basis by a competitively selected, industrial research consortium headed by Air Products and Chemicals, Inc., with team partners including DOE

National Laboratories, major gas holding oil companies, ceramic producers, and others. Federal funding is provided by FE's GTL program (75 percent) and EE's hydrogen program (25 percent). Other ceramic membrane work is being conducted by a university consortium with guidance from BP-Amoco.

R&D Challenges. Critical to the success of the novel membrane system will be the ability of the ceramic to allow oxygen ion and reverse electron flow at steady rates (flux) while maintaining strength, durability and chemical stability, all in the face of significant pressure and temperature differentials. Metal-ceramic seals likewise will be a challenge, particularly as the process moves from laboratory confirmation scale to extended, high volume commercial module scale, able to weather normal operating interruptions and accompanying temperature swings of several hundred degrees Centigrade.

R&D Activities. Early ceramic membrane system research has been focused on ceramic and metal-seal development and testing, leading to fabrication plans for bench and pilot process operations. Numerous reactor design options were evaluated, and will be followed by careful trial and scaleup of the preferred design under a full range of anticipated GTL operating conditions. The final scaleups of the membrane reactor will be linked with comparably scaled, continuous operating liquid conversion units to make target, ultra clean-burning motor fuels and feedstock.

Accomplishments. Preliminary design evaluations for the Air Products ceramic membrane reactor, and low and high pressure tests of critical metal/ceramic seals at high temperature were completed in FY 1999. Two ceramic membrane compositions remain under consideration. Recommendations for Phase II laboratory and engineering scaleup reactors are expected in mid-winter 2000 with continuous operating laboratory trials slated for fall, 2000.

Thermoacoustic Natural Gas Liquefaction

Budget: FY99-$0.6M, FY00-$0.6M, FY01-$0.6M

Description, Objectives, and Performers. This process, designed for small-scale liquefied natural gas (LNG) manufacture at remote offshore and onshore locations, uses direct gas burning to generate sound waves to drive an orifice pulse tube refrigerator. The liquefier has no moving parts and requires no electric power. The objective is to develop a process for small-scale liquefaction of natural gas that achieves one-half the cost of traditional small-scale refrigeration at a scale of 10,000 gallons per day (gpd), or about 1 million cfd. Conceived by researchers at the Los Alamos National Laboratory, and also the National Institute of Standards and Technology, the *"Thermoacoustic Sterling Hybrid Engine Refrigerator"* (TASHER) is now entering the cost-shared prototype development phase led by Cryenco, a division of Chart Industries Inc. and a leading equipment maker for the cryogenics industry.

R&D Challenges. Economic viability of the TASHER concept for LNG manufacture will require liquefaction efficiency in the 80 percent range. This compares with large scale unit efficiency of 90 percent and experimental TASHER results of 60 percent to-date.

R&D Activities. Near-term plans call for a pre-commercial scaleup to 500 gpd, gas well-site liquefaction testing, and trial use for LNG-servicing of small LNG-powered truck fleets (funded by EE's Transportation Technology Program). Subsequent scaleup and demonstration with participating industry users is planned at the 10,000 gpd scale or higher.

Accomplishments. Small-scale production at a rate of 100 gallons/day of LNG has been achieved for several hours duration in an experimental unit. Efficiency of 60 percent was 30 times the original laboratory runs.

Novel Conversion and Syngas Processes

Budget: FY99-$0.7M, FY00-$0.7M, FY01-$0.7M

Description, Objectives, and Performers.
Novel exploratory routes are being pursued to convert natural gas to other intermediate products such as ethane, ethylene, and oxygenates for direct use or subsequent conversion to valuable liquid products, and to generate syngas from natural gas and carbon dioxide using electric power and other heat injection. The conversion objective is to develop catalytic and non-catalytic alternative approaches to gas conversion that are more direct than the multi-step syngas route. Exploratory conversion work is currently underway at Lawrence Berkeley National Laboratory, Oklahoma University, a Canadian government laboratory, and at Fossil Energy's Federal Energy Technology Center. Exploratory syngas work is underway at Thermal Conversion Corp. with Rentech Co. support and at the National Energy Technology Laboratory (dry reforming).

R&D Challenges. Methane is an extremely stable molecule, and breaking it down to separate hydrogen and carbon components without full oxidation is extremely difficult. Reaction thermodynamics must be tightly controlled for success in any 'reconstitution' process.

R&D Activities. Research areas currently under investigation include electrochemical conversion, plasma conversion, novel hydrogen separation reactor technology, and photochemical conversion.

Accomplishments. While selected novel conversion reactions and products have been achieved, sustainable processes remain elusive. Explorations continue, however, at a measured pace.

Petroleum-Derived Fuels

Budget: FY99-$0, FY00-$3.3M, FY01-$10.0M

Background

In the last decade, environmental regulations have had a far-reaching impact on both the processes and products of the U.S. refining industry. Refineries must comply with increasingly stringent emissions and discharge limits on their processes. At the same time, they must meet demands for lighter, high-value finished fuel products, such as gasoline and diesel fuel, whose composition and quality have changed markedly to meet environmental standards. The Clean Air Act Amendments of 1990 have required the production and use of reformulated gasoline, for example, and new EPA Tier 2 guidelines call for gasoline sulfur concentrations lower than what was thought practical a few years ago. There is little or no commercial experience with the prospective implementing technology for this low-sulfur gasoline. These and other projected changes in the product slate will result in higher storage and transportation costs, added capital expenditures, and product exchange complications.

According to a recent study by the National Petroleum Council, between 1991 and 2010 environmental compliance costs are projected to exceed $150 billion, including $36 billion for capital equipment. Since 1994, the refining industry has committed over $20 billion to capital equipment for improving environmental performance. Such equipment has absorbed between 75 and 90 percent of total refinery capital expenditures in the last five years. These expenditures do not, as yet, address the low-sulfur gasoline and diesel fuels required by Tier 2 regulations.

The declining quality of crude oil feedstocks compounds the challenges facing U.S. refineries. Crude oil feedstocks, particularly those domestic and Western Hemisphere oils, are becoming heavier, with rising levels of sulfur, nitrogen, and heavy metals. Current processing technology for these heavy crudes yields unacceptably high levels of low-value residual oils, coke, by-products, and wastes while requiring more processing energy than lighter domestic or foreign crudes.

New technologies or processes must be developed to utilize these materials if petroleum derived fuels are to be produced at costs acceptable to the marketplace.

Linkage to CNES Goals and Objectives

The program supports the following CNES goal and objective:

- CNES Goal III, Objective 1 -- Increase domestic energy production in an environmentally responsible manner. (*by increasing yield of valuable products from low-value Western hemisphere crudes decreases imports and increases value or production of these heavy crude feedstocks)*

Program Description

New refinery technologies can equip the industry to prevent pollution and protect the environment more effectively than is possible with today’s costly retrofit approaches. New technologies can handle the challenges posed by lower quality domestic and Western hemisphere feedstocks, and produce the more complex, high-value product slates that the market requires now and enable production of these fuels to meet anticipated future fuel requirements. These process technologies allow increased efficiencies, decreased costs and enhanced environmental performance to enable the industry to continue to be world leaders in refining technology while remaining profitable and helping a heavy oil production industry to market heavy crudes more on a par with lighter, sweeter crudes.

Biodesulfurization of Diesel Fuel

Budget: FY99-$0, FY00-$3.3M, FY01-$0

Description, Objectives, and Performers. This Congressionally mandated program is evaluating the potential for using bioprocessing to remove sulfur from diesel fuel at a small refinery in Alaska. This advanced process has the potential for assisting small refiners in meeting EPA proposed Tier 2 fuel-sulfur specifications.

R&D Challenges. Many smaller refineries do not have the hydroprocessing capability for removing sulfur from products. Some of these small refineries are in isolated locations and the fuels made by them serve local markets where pipelines are not available and transportation of fuels from remote refiners represents significant financial hardship. Laboratory tests indicate that this process can remove the sulfur. However, pilot-scale verification studies are necessary to ascertain the applicability of the process, to provide data needed for designing full-scale facilities, and to determine if full-scale operation is both technically and economically feasible.

R&D Activities. The R&D activity involves building and operating a pilot-scale facility at a small refinery in Alaska to verify the viability and operability of the process at larger scale and to provide data for full-scale engineering design and economic analysis.

Accomplishments. Proposals will be solicited from small refiners in Alaska to build and evaluate the bioprocessing unit for sulfur removal from diesel fuel. Research is expected to begin in the spring of FY2000.

Ultra-Clean Transportation Fuels Initiative (UCTFI)

Budget: FY99-$0M, FY00-$0M, FY01-$10.0M

Description, Objectives, and Performers. The Petroleum-Derived Fuels Program as one of three integrated fuels efforts integral to the UCTFI being carried out by the Office of Fossil Energy to promote the development of technologies that will provide this Nation with a stable supply of affordable transportation fuels that are responsive to 21st century environmental challenges. This initiative is described in the Chapter Overview.

R&D Challenges. While small amounts of ultra clean fuels can be made through high-grading of low impurity feedstock, meeting the demands of 12-15 million bpd of ultra clean vehicle fuels seen needed in the decades ahead will require near-complete sulfur and other impurity removal at minimum cost from a full suite of fossil feedstocks----high sulfur crude as well a low sulfur, sweet crude; refinery bottoms, natural gas, and coal. New processes must be verified as well as invented and demonstrated, and the quality of the product fuel confirmed.

R&D Activities. Manufacturing costs, impurity removal limitations, molecular chemistry, conversion catalysts, feedstock variables in impurity content, and vehicle engine performance are just six of many of the factors that must be addressed in the making of fuels far cleaner in performance that present-day gasoline and diesel fuels. In the near-term, industry-government projects will demonstrate advanced petroleum-based fuel-making processes at pre-commercial scale, generating sufficient advanced fuel to enable engine/fuel verification testing. The mid-to-longer term activities of the UCTFI will be concerned with the economic utilization of feedstocks such as petroleum coke and heavy hydrocarbon bottoms, and coal. The initiative will build on the catalyst and reactor development being conducted in the base program activities under Transportation Fuels and Chemicals and Gas-to-Liquids. The focus will be on catalyst and reactor development, and larger scale system activities for producing economic, ultra clean transportation fuels, in sufficient quantities, which will meet more stringent environmental standards in advanced vehicles required in the early decades of the next century. Life cycle performance of the fuel production and utilization will be critical. The particular fuels to be developed will be identified by private sector teams which include technology developers, resource holders and engine manufactures selected through competitive procurement. Process and other improvement research may precede demonstrations of advanced fuel-making. Supporting research by National Laboratories is expected to be principally laboratory scale in nature.

Accomplishments. The UCTFI is a new program initiative and significant accomplishments are not anticipated before FY2001. The award schedule is summarized in the Chapter Overview.

Fuels From Biomass

Budget: FY99-$41.2M, FY00-$38.8M, FY01-$54.4M

Background

The existing ethanol production capacity is approximately 1.7 billion gallons per year from corn kernels and the average production cost is nearly $1.10 per gallon. Approximately 30 million gallons of biodiesel capacity is available in the United States today, with production costs ranging from $1.60/gal to $2.30/gal. However, market price is substantially higher because of volume related marketing and distribution costs. Beginning in the 2001-2004 period, ethanol plants using cellulosic biomass that are currently under construction or being designed, will start up and will be competitive with those using corn. This market value allows investors to obtain the high rates of return needed for initial production facilities. Cellulosic ethanol costs are expected to decrease by over 40 percent over the next 12 years thanks to ongoing research and development funded by the private sector, DOE and the United States Department of Agriculture (USDA). With California and possibly other States contemplating the phasing out of MTBE as an oxygenate, the demand for ethanol as a replacement is expected to grow sharply. Several companies are aggressively engaged in commercial development of biomass ethanol utilizing niche feedstocks, including municipal solid wastes, bagasse, and rice straw.

There are three Midwest biodiesel producers using soy oil (one of which is combining soy oil with recycled grease); two firms producing biodiesel from recycled grease in the eastern United States, and at least one firm producing biodiesel from tallow and other low cost feedstocks in

South Carolina. Several producers are working with urban planners to build new facilities, primarily recycled grease biodiesel plants. By focusing on new nonedible, nonindustrial oil seeds, future biodiesel costs could be reduced to about $1.00/gal by 2010.

Linkage to CNES Goals and Objectives

The goal of biomass fuels activities is to reduce transportation petroleum use and carbon emissions by using renewable resources such as agricultural and forest residues beginning in 2001, higher value agricultural residues beginning in about 2005, and finally, crops grown specifically for use as energy feedstocks beginning in 2010. As a potentially large-volume, renewable source of transportation fuels, biomass fuels could:

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply.

- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner. *(transportation applications)*

Program Description

DOE conducts research on a variety of feedstocks and conversion processes to produce a wide menu of biofuels for the future. The near-term focus is on biofuels that can be deployed in niche markets for solving environmental problems associated with large quantities of waste material, such as ethanol from rice straw, forest residues, municipal solid wastes, and other low value biomass. Two companies, in partnership with DOE, are exploiting the use of "concentrated acid hydrolysis" processes that can handle a broad range of waste materials. A third industry partner is focusing on the use of dilute acid processes to produce ethanol from sugarcane bagasse. Several companies are commercializing biodiesel technology that will be able to utilize waste oils and greases from restaurants and other commercial operations.

DOE laboratories and university partners will continue to improve the cost effectiveness of ethanol production. This research has two major emphases: the development of enzymes capable of efficient release of sugars from biomass, and the development of microorganisms capable of high yield conversion of all available sugars in biomass.

At the same time, DOE is supporting research on biomass feedstocks. Farmers are already sitting on a huge potential resource for ethanol—agricultural residues. Corn farmers leave tons of residue on the field after the harvest. Understanding how much of this residue can be safely and cost effectively removed offers a way to create a new co-product for the farmer. Using these residues will give farmers new sources of income, while allowing the ethanol industry to expand without competing for new farm acreage. "Waste" biomass has its limits. Therefore, it is important to expand the resource base for ethanol production. Ultimately, dedicated energy crops will provide another source of biomass, and DOE is supporting the development of trees and grasses with characteristics that will ensure their successful deployment as energy crops.

DOE analysis shows that standard vehicles using blends of 10 percent ethanol in gasoline could require several billion gallons per year before 2015. In addition, hundreds of thousands of flexible fuel vehicles are already available today. These can handle blends of up to 85 percent ethanol in gasoline.

Both biomass ethanol and biodiesel reduce greenhouse gases (80 percent for ethanol and 78 percent for biodiesel), on a total fuel cycle basis. When used as a low blend, both fuels are readily blended with petroleum fuels used in conventional vehicles, and require minimal changes to the existing fuel distribution infrastructure. Collaboration with USDA and their research units at land-grant universities allows us to tap into a unique combination of Federal and academic expertise in biomass R&D. Partnerships with industry help transfer Federally funded technologies from the Government research organizations to the private sector, thereby reducing the biofuels production costs and accelerating their market entry.

Feedstock Production

Budget: FY99-$2.8M, FY00-$3.0M, FY01-$4.5M

Description, Objectives, and Performers. Studies are carried out in the areas of wood energy species, herbaceous energy species, environmental research, systems integration and analysis, and market development factors. The current DOE program focus is on switchgrass, hybrid poplars, and willows. Switchgrass will be among the first of the dedicated energy crops to made available. Bioethanol producers using waste feedstocks should begin to supplement their resource base with switchgrass by around 2005 based on availability near conversion facilities. The objective is to develop and demonstrate environmentally acceptable crops and cropping systems for producing large quantities of low-cost, high-quality biomass feedstocks to support future large-scale deployment of lignocellulosic-based ethanol in many parts of the country. Sixty percent of the funding is for R&D work being performed by universities, USDA research organizations, private research companies, and forest products companies. The Oak Ridge National Laboratory conducts some R&D in-house, and also coordinates the work done at the institutions cited above.

R&D Challenges. While past R&D has enabled biomass yield per acre to increase significantly, additional yield improvements will directly benefit the economics of biomass production. The variety of soils and climates dictates the need for additional varieties of switchgrass and woody crops, and for numerous test sites throughout the country in order to maximize the likelihood of cost-effective deployment on a large scale. Biomass harvesting technologies need to be refined and demonstrated in partnership with industry. Three basic areas for information are being collected to better define research needs. Water quality, regulated by the Environmental Protection Agency, including non-point source pollution from agricultural practices, is becoming of increasing concern to both regulators and the public. Soil sustainability is of major concern to producers and users of energy crops as well as to environmental groups that take a national view of environmental issues. Biodiversity, particularly wildlife diversity, is a top priority environmental issue because of the continued loss of habitat both nationally and internationally.

R&D Activities. Biofuels feedstock development activities focus on planting genetically transformed poplars in commercial fields, expanding switchgrass breeding and testing in the North Central region, and identifying locations for potential low-cost perennial crop establishments. Poplar R&D involves an integrated portfolio of R&D in genetics, breeding, physiology, and/or biotechnology to allow for continued progress towards the development of a single model wood energy crop. The switchgrass research plan for 1998 and beyond focuses on promoting advanced breeding, facilitating scale-up and commercial utilization, obtaining long-term yield data, and understanding the microbial ecology affecting longer term carbon and nitrogen cycles which sustain switchgrass production.

Accomplishments. More than 125 tree and nonwoody species have been screened and a limited number of model species for development as energy crops have been selected. The pulp and paper industry deployed over 70,000 acres of hybrid poplars in the Northwest based in part on DOE's development of new faster-growing clones. A number of new switchgrass varieties have been tested successfully at several university and USDA test sites.

Ethanol Production

Budget: FY99-$35.4M, FY00-$30.1M, FY01-$36.9M

Description, Objectives, and Performers. The major research effort in biofuels production is the development of technologies for producing ethanol. Continued improvements will make biochemical conversion of biomass to ethanol a more efficient and economical route to renewable fuels production. By 2004, two ethanol plants will be in operation, using biomass wastes, and a partnership with the corn ethanol industry will have completed at least 50 percent of pilot scale work on ethanol production from corn stover. The ultimate objective is to reduce the cost of producing ethanol from biomass residues and dedicated crops and trees that will allow the displacement of nearly 5 percent of projected gasoline use by 2020 with 10 billion gallons of ethanol.

The National Renewable Energy Laboratory (NREL), leads the development of improved technology in collaboration with industry and selected universities. Specific targets for technology improvement have been established. The improvements targeted lean heavily on biotechnology tools such as metabolic engineering and gene shuffling. NREL conducts R&D in-house, but subcontracts out a large chunk of its budget in order to utilize unique expertise in academia and industry. Some industry pioneers are in various stages of partnership formation and financing in terms of building the first generation of biomass ethanol production plants. There is currently considerable interest in the western States whose forests have too much residue which could lead to devastating fires. Several communities, environmental groups, and local government organizations are assessing the feasibility of using the excess residues as feedstocks for producing ethanol fuels on a commercial scale.

R&D Challenges. Specific improvement targets have been identified to reduce the cost of ethanol from biomass by over 40 percent over the next 12 years. This will be accomplished by the development of improved enzymes, fermentation microorganisms, and pretreatment processes through collaboration with industry and academia in partnerships that are driven by industry's needs.

R&D Activities. In order to expand the available resource base, the program focuses on non-starch, non-food-related biomass such as trees, grasses, and waste materials. The three largest components of biomass are cellulose, hemicellulose and lignin. Cellulose and hemicellulose contain sugars that can be converted to ethanol. Lignin is a biopolymer rich in phenolic components, which provides structural integrity to plants.

Key R&D areas include pretreatment of feedstocks, fermentation micro-organisms, cellulase enzymes and lignin utilization. A pretreatment process is used to reduce the feedstock size, break down the hemicellulose to sugars, and open up the structure of the cellulose component. New pretreatment processes under development at universities and national laboratories will make the biomass more amenable to subsequent bio-processing. The greatest promise for improvement lies in biotechnology. By combining computer technology, robotics and genetic engineering, researchers can generate mutant strains that can be rapidly screened and selected for improved enzyme performance. As with enzymes, fermentation organisms can be improved through a variety of genetic engineering tools.

Accomplishments. Over the last 2 decades, the predicted cost of biomass-derived ethanol was reduced by at least 50 percent. Technology developers are partnering with DOE to commercialize bioethanol technology. Using the technology as it exists today, these entrepreneurial partners are exploiting niche markets and unique investment opportunities. While the list of improvements developed in biomass technology is extensive, one of the most important advances has been in the development of new fermentation organisms that are now available. Today these patented organisms are at the heart of the first commercial plants that are scheduled to start up in the early 2000s.

Renewable Diesel Alternatives

Budget: FY99-$0.8M, FY00-$0.8M, FY01-$1.0M

Description, Objectives, and Performers. Biodiesel can be used as a blend in any proportion with diesel fuel, or used as a pure fuel without major vehicle modifications, with excellent efficiency and performance characteristics. The use of biodiesel reduces hydrocarbons, particulates, carbon monoxide, and carbon dioxide emissions. Production costs for biodiesel from recycled grease are approximately $1.60/gal, but further cost reductions are desirable. Nonfeedstock operating and capital costs represent a very small portion of biodiesel production costs. Reducing feedstock cost is the key to reducing biodiesel costs.

Some micro algae species produce oils which can be used to make biodiesel. R&D investments will be required to reduce algae oil costs for commercialization purposes. Other research programs focus on edible/industrial oil seeds. The high value which markets placed on edible and industrial oils makes these oils too expensive for biodiesel production. The current focus is on identifying and optimizing an oil seed that has an inedible, nonindustrial, low-value oil

(<$0.10/lb) suitable for high quality biodiesel, and a meal (or residue) that has a high value (>$0.20/lb) industrial use.

The biodiesel industry is likely to expand from 30 million gallons to 75 million gallons per year by 2004, with the majority of the new capacity using recycled greases. By 2005, new oil seeds should be ready for commercial demonstration by the seed processing and chemical industries. The objective is to reduce the production cost to $1 per gallon by 2010, and provide new crops for rotation in the Great Plains and other agricultural regions.

Most of the DOE/NREL biodiesel research will be conducted through subcontracts and partnerships with industry. Partnerships with other Federal agencies, universities, biotechnology firms, chemical industries, and agricultural companies will provide unique expertise and resources that will be crucial for near-term success.

R&D Challenges. Recycled grease and some animal fats (tallow and lard) are available, but in limited quantities, and are price sensitive to increased demands. Large supplies of trap and sewage grease are available in urban areas but these free feedstocks require production technology improvements with respect to eliminating contaminants and improving yields and quality control.

R&D Activities. Research projects in fuel quality include consumer education on fuel quality parameters and emissions, support of research needed to establish fuel standards, and research to identify fuel-specific characteristics that may explain high NO_x emissions from biodiesel. NREL is also supporting industry-led research to determine if biodiesel emissions are significantly less toxic and harmful than diesel emissions. Other activities have included a life cycle study of biodiesel and diesel, and a publication of a report summarizing the last five years of biodiesel research in the United States. Development of new oil seeds that produce inedible, non-industrial oil, and industrial chemicals will require R&D on a few species with a high probability of near-term success. Production R&D will focus on integrated technologies that crush oil seeds and co-produce biodiesel and other high value co-products.

Accomplishments. The U.S. Department of Agriculture and DOE have jointly completed a life cycle inventory of petroleum diesel and biodiesel that provides information on all of the energy and environmental flows associated with raw materials extracted from the environment, energy resources consumed, and air, water, and solid waste emissions. Several manufacturers of biodiesel are using waste greases as their feedstocks. A draft waste grease assessment is now available for review. A draft report on oxidative stability test methods is also available and will be used in developing a fuel standard for biodiesel.

Regional Biomass Energy Program

Budget: FY99-$2.3M, FY00-$2.0M, FY01-$3.5M

Description, Objectives, and Performers. The Regional Biomass Energy Program (RBEP) seeks to increase the use of biomass energy resources through activities related to technology transfer, industry support, and matching local resources to conversion technologies. Its major focus is to transfer current, reliable information to potential biomass users, with emphasis on technologies best suited to near-term use. The program provides a strong complement to the other biomass activities by bringing in 5 regional offices and a network of 49 State biofuels and biomass contacts. Partners include universities, industry, local and State governments, and other stakeholders.

R&D Challenges. The program's challenges are partly technical, and are also associated with ensuring cost-effective and timely technology transfer in view of the diverse portfolio of the RBEP bioenergy applications and the unique needs and opportunities of each region.

R&D Activities. The program is funding the pilot-testing of a continuous stirred reactor/separator system for ethanol production, and demonstration of biodiesel use in heavy trucks. Active industry partners are working with RBEP on a 200,000 mile demonstration of a long haul diesel truck which includes performance and emissions testing. Several other efforts focus on cost-shared field demonstrations of a spectrum of biofuels technologies and on overcoming market barriers.

Accomplishments. Numerous successes have allowed the leveraging of almost twice the programs's resources through contributions from private industry and States, and enabling bioenergy technologies to be used in solving environmental and other problems.

Integrated Bioenergy Technology R&D

Budget: FY99-$0.0M, FY00-$3.0M, FY01-$8.5M

Description, Objectives, and Performers. This activity supports the Biobased Products and Bioeneregy Initiative discussed in the Chapter Overview. Coordination and integration of biomass related activities are critical to the future economic viability of biomass-based products such as fuels, chemicals, and electricity. Increased collaboration among industry partners, stakeholders, DOE programs (e.g., biomass fuels, biomass power, etc.), and DOE laboratories will result in a convergence toward an industry R&D agenda, will lay the foundation for accelerating the development and use of diverse biomass feedstocks, and enhance the Nation's capability for turning out a variety of products in response to market demands.

R&D Challenges. The integration of diverse biomass activities on a national scale in order to achieve synergy is a challenging task and will require close coordination among DOE, industry, and various stakeholders.

R&D Activities. A total systems analysis will be conducted, with industry participation, to support the goal of optimizing the integration of bioenergy feedstocks, equipment, and end products for biomass energy systems. High priority technologies and processes will be identified and a roadmap will be developed for R&D needs. Existing and planned technology projects will be re-evaluated and enhanced to allow for integrated processing of diverse feedstocks and options for a variety of products.

Accomplishments. Executives and senior representatives from industry and other stakeholder groups participated in a recent meeting with DOE management to initiate discussions of this integration process.

Hydrogen Systems

Budget: FY99-$22.0M, FY00-$22.2M, FY01-$21.8M

Background

Hydrogen is a carbon-free energy carrier that has the potential to replace fossil fuels in every sector of the economy. For near-term transportation applications, hydrogen may be produced in a central facility and then stored on-board, resulting in a zero-emission vehicle. In the mid-term, hydrogen can be produced off-board the vehicle at distributed refueling stations and high-pressure hydrogen stored on the vehicle. The changing electricity supply industry presents an opportunity for fuel cells for distributed electric generation, cogeneration, and the production of hydrogen for vehicles. Hydrogen feedstock for the fuel cell can be produced from either natural gas or coal, with the option of carbon sequestration, or directly from renewable resources to eliminate greenhouse gas emissions. At the same time, the use of hydrogen permits increasing use of domestic resources for transportation fuels.

The Proton Exchange Membrane (PEM) fuel cell is becoming a reality. The automobile industry is expected to be producing commercial buses by 2002 and tens of thousands of cars annually by 2004 that employ the PEM fuel cell. The electric generation industry has also recognized the potential for PEM fuel cells to deliver clean, quiet, and cost-effective premium electricity. GPU International has formed a joint venture with Ballard Power Generation to produce 250 kW PEM fuel cells by 2002. Several industry consortia plan to commercialize 5 kW residential PEM fuel cells in the same time frame.

Moreover, there are a number of very aggressive companies pursuing the PEM fuel-cell market. These companies include Teledyne Brown Engineering, Energy Partners, H-Power, Detroit Edison, Idaho Power, General Electric, Schatz Energy Research Center, Northwest Power, Plug Power, and International Fuel Cells, to name a few.

Linkage to CNES Goals and Objectives

The goal of the Hydrogen Program is to conduct research and development for the purpose of making hydrogen systems cost-effective for use with fuel cells for the production of electricity for deployment beginning around 2004, and for transportation applications for deployment beginning around 2008. As a potentially large-volume, renewable source of fuels for transportation and other applications, hydrogen use could:

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply.
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.

Program Description

The Hydrogen Program has four strategies: (1) expand the use of hydrogen in the near-term by working with industry, including hydrogen producers, to improve the efficiency, lower the emissions, and lower the cost of technologies that produce hydrogen from hydrocarbons and to introduce renewable-based production options; (2) work with fuel cell manufacturers to develop hydrogen-based electricity storage and generation systems that will enhance the introduction and penetration of distributed, renewable-based utility systems; (3) coordinate with the Department of Defense and the DOE's Office of Transportation Technologies to demonstrate safe and cost-effective fueling systems for hydrogen vehicles in urban non-attainment areas and to provide onboard hydrogen storage systems; and (4) work with the National Laboratories to lower the cost of technologies that produce hydrogen directly from sunlight and water. Concerning transportation applications, the Federal role concentrates on the hydrogen refueling infrastructure, onboard vehicle storage of hydrogen, and the cost effectiveness of the hydrogen fuel. On the utility side, a key program need is the demonstration of integrated renewable and hydrogen systems to provide increased operational and peaking generation flexibility.

Hydrogen Production

Budget: FY99-$6.3M, FY00-$8.5M, FY01-$7.9M

Description, Objectives, and Performers. Current hydrogen production processes are based on the thermal conversion of fossil and biomass fuels, or the electrolysis of water. Thermal processes use heat and steam to convert carbonaceous feeds such as natural gas, coal, biomass, and municipal solid waste into hydrogen and carbon dioxide. Several advanced processes that improve the efficiency and lower the temperature of the reaction are being investigated to reduce the cost of production of hydrogen by 25 to 30 percent. The objective is to reduce the production costs of thermal processes from fossil and biomass resources to $6 to 8/million BTU and the cost from electrolytic and biological processes to $10 to 15/million BTU.

Industry support is provided by traditional hydrogen producers in the research and development of low temperature thermoconversion processes for distributed applications. Universities are contributing to research in this area. The National Renewable Energy Laboratory, with university support, is leading the activities associated with biomass to hydrogen conversion systems, and the photoelectric and photobiological production of hydrogen.

R&D Challenges. Key challenges include the development of low-cost processes using thermoconversion to enhance the separation of carbon and hydrogen streams; and producing hydrogen directly from water.

R&D Activities. R&D of thermoconversion systems for natural gas, coal and biomass feedstocks are being pursued. R&D for advanced electrolysis systems is being addressed for utilization in solar/electrolysis and wind/electrolysis systems. Hydrogen produced directly from sunlight and water by biological organisms and by using semiconductor-based systems similar to photovoltaic is also receiving attention.

Accomplishments. Program accomplishments include:

- In the Sorption Enhanced Reformer process at Air Products and Chemical, Inc., a two-bed PDU reactor demonstrated over 85 percent conversion of natural gas to produce a product stream with 98 percent purity prior to conventional cleanup via pressure swing absorption.
- In the Plasma Reformer process, a hydrogen production system demonstrated power densities of 10kW(H_2 HHV)/liter of reactor with low CO content (3 to 5 percent).
- In the Biomass to Hydrogen via Fast Pyrolysis process, hydrogen yields of 80-90 percent of stoichiometric amount in a fluid bed experiment were achieved.
- In the Photoelectrochemical (PEC)-based Direct Conversion Systems project, a PEC water splitting system was operated with a world-record solar-to-hydrogen efficiency of 14.5 percent.

Hydrogen Storage and Use

Budget: FY99-$2.7M, FY00-$4.8M, FY01-$5.1M

Description, Objectives, and Performers. The storage, transport and delivery of hydrogen are important elements in a hydrogen energy system. With intensive interest in mobile applications, and as the amount of intermittent renewable electricity increases, hydrogen storage becomes an essential element of these systems. The objective of this activity is to develop hydrogen storage options that will cost less than 50 percent of production costs and be more than 5 percent weight hydrogen systems.

With the advent of the Proton Exchange Membrane fuel cell, hydrogen utilization should increase significantly in electric generation and transportation applications. The objective is to develop low-cost manufacturing approaches for fuel cell and reversible fuel technologies, and enable the development of more reliable, less expensive hydrogen sensors.

Hydrogen storage and use activities are carried out primarily by three industrial partners (Thiokol, Thermo Power Systems, Energy Conversion Devices) four National Laboratories

(Sandia National Laboratories, Oak Ridge National Laboratory, National Renewable Energy Laboratory, and Lawrence Livermore National Laboratory), and the University of Hawaii.

R&D Challenges. Key challenges are to facilitate the use of hydrogen as a vehicular fuel, develop lower cost storage technologies and demonstrate their competitiveness in integrated renewable energy systems, and develop a low-cost fuel cell and reversible fuel cell.

R&D Activities. High pressure, liquid, hydride, and carbonaceous storage systems are being investigated to achieve technical and cost goals that include measures for volumetric and gravimetric density. Hydrogen use activities include fuel cell research focused on the development of inexpensive, easy-to-manufacture membrane electrode assemblies, and the development of reversible fuel cells for stationary applications

Accomplishments. Program accomplishment include:

- Designed and fabricated lightweight pressure vessels that represent >7 wt percent tanks.
- Measured dehydrogenation rates at temperatures as low as 100°C and rehydrogenation to >5 wt percent at 170°C for a metal hydride.
- Successfully tested lithium hydride and calcium hydride for potential use in hydride slurries.
- Began testing a short stack of a low-cost fuel cell with significantly less than 10 percent parasitic power loss.

Technology Validation

Budget: FY99-$10.9M, FY00-$6.4M, FY01-$6.3M

Description, Objectives, and Performers. This activity supports industry in the development and demonstration of hydrogen systems in the utility and the transportation sectors. Concerning transportation applications, the barriers to the introduction of the hydrogen option include the lack of a hydrogen refueling structure, onboard vehicle storage, and affordability. On the utility side, a key program need is the demonstration of integrated renewable and hydrogen systems to provide increased operational and peaking generation flexibility. In addition there is support (outside of the Hydrogen Program) of projects for small fuel cells for remote and village power systems. Some of the industry that is participating in the 50/50 cost-share efforts on the renewable hydrogen systems are Proton Energy, Energy Partners, Inc., and Energy Conversion Devices. Other industry include Teledyne Brown, Stuart Energy, NRG and other companies to be selected for the hydrogen infrastructure program. Teledyne Brown, Hydrogen Burner Technologies, Schatz Energy Research Center, Energy Partners, Plug Power and Northwest Power are all involved in the remote power element. Sandia National Laboratory contributes technically and programmatically to this program area.

R&D Challenges. Challenges include demonstrating: (1) renewable hydrogen systems for niche markets; (2) cost-effective hydrogen refueling and generation systems; (3) >5 wt percent and cost-effective onboard storage of hydrogen on vehicle systems; and (4) fuel cells for remote applications.

R&D Activities. Activities include Concentrating Solar, Wind, and Photovoltaic/Hydrogen systems for islands and remote areas, and reversible fuel cells with a wind system. Several refueling station concepts will be demonstrated. They will include an electrolysis system, co-production of hydrogen and electricity from a PEM fuel cell, advanced thermoconversion systems, and a renewable system. In addition, vehicles that use natural gas/hydrogen mixtures and extended range electric vehicles will be demonstrated at the refueling sites.

Accomplishments. Program accomplishments include:

- Successfully demonstrated a Crown Victoria vehicle with a natural gas/hydrogen mixture.
- Successfully demonstrated 47 percent indicated thermal efficiency in an optimized Internal Combustion Engine, with near zero NO_x levels.
- Demonstrated the conversion of diesel fuel to hydrogen (99.8%) and the operation of a 3 kWe fuel cell with that product hydrogen..

Analysis and Outreach

Budget: FY99-$2.2M, FY00-$2.5M, FY01-$2.5M

Description, Objectives, and Performers. Analyses will be performed to ensure that Federal R&D investments in hydrogen production, storage, distribution, and end-use technologies will provide maximum value. Distributed Utility Associates, Directed Technologies, and Energetics support the program with analyses. Also, the National Renewable Energy Laboratory and Princeton University perform key evaluations.

R&D Challenges. Challenges include identifying and evaluating key market segments and market entry conditions for hydrogen utilization, and developing and applying metrics to measure the program's contribution to attaining national strategic energy goals and market share in key market segments.

R&D Activities. The focus is on analyses that support the program in making informed decisions in research and development and demonstration activities, including portfolio analysis, market segment and market entry analyses for technology validation projects, and techno-economic analyses of hydrogen research and development projects to define key goals.

Accomplishments. Program accomplishments include:

- Analyzed the cost advantages of the co-production of electricity and hydrogen at a refueling station.

- Compared four coal to hydrogen options and identified an option that included carbon sequestration as being able to meet hydrogen production program goals.

- Completed an analysis of village remote power systems for electricity generation and cogeneration of heat.

Summary Budget Table (000$)

Producing Clean Fuels Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Coal-Derived Fuels	**16,710**	**13,575**	**15,700**
Transportation Fuels and Chemicals	9,955	7,075	9,000
Solid Fuels and Feedstocks	5,006	4,300	4,500
Advanced Research	1,749	2,200	2,200
Natural Gas-to-Liquids	**6,650**	**6,300**	**6,500**
Ceramic Membrane Reactor Systems	5,350	5,000	5,200
Thermoacoustic Natural Gas Liquefaction	600	600	600
Novel Conversion and Syngas Processes	700	700	700
Petroleum-Derived Fuels	**0**	**3,300**	**10,000**
Biodesulfurization of Diesel Fuel	0	3,300	0
Ultra-Clean Transportation Fuels Initiative	0	0	10,000
Fuels from Biomass	**41,236**	**38,800**	**54,441**
Feedstock Production	2,800	3,000	4,500
Ethanol Production	35,436	30,050	36,941
Renewable Diesel Alternatives	750	750	1,000
Regional Biomass Energy Program	2,250	2,000	3,500
Integrated Bioenergy Technology R&D	0	3,000	8,500
Hydrogen Systems	**21,976**	**22,198**	**21,830**
Hydrogen Production	6,259	8,510	7,910
Hydrogen Storage and Use	2,692	4,843	5,110
Technology Validation	10,856	6,365	6,330
Analysis and Outreach	2,169	2,480	2,480
Total	**86,572**	**84,173**	**108,471**