DOE Research and Development Portfolio

Energy Resources

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DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

Department of Energy

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Energy is the vital force powering business, manufacturing and movement of goods and services throughout the country. The energy-related challenges facing our Nation in the next century are significant. Our economic well-being depends on reliable, affordable supplies of clean energy. Our environment requires a mix of energy sources that minimizes pollution and other undesired effects, even as our demands for energy services expand. Our national security requires secure supplies of oil and safe and affordable alternatives. Restructuring of the electricity sector may demand new end-use and grid technologies. For these reasons, as well as our country's stature in the global community of nations, we must maintain a strong leadership position in energy supply and end-use technology and in the related and supporting sciences.

The Department of Energy (DOE) has undertaken a major effort to ensure that our research and development (R&D) programs and Federal R&D investments are balanced, focused on mission, and appropriately coordinated with the needs of our clients, the public and the marketplace. To do this, we are instituting a new portfolio approach to managing our R&D activities. This entails building a comprehensive document that provides in one place, a clear description of our entire $7 billion research portfolio. This volume describes DOE's *Energy Resources R&D Portfolio*. It is Volume I of DOE's four-volume R&D Portfolio. The full set in the series includes one R&D portfolio volume for each of DOE's four major business lines, plus an Overview.

The *Energy Resources R&D Portfolio* focuses on the FY 1999-2001 timeframe. Its purpose is to help (1) describe our current R&D activities and showcase recent accomplishments; (2) evaluate whether our portfolio is appropriately balanced to meet our long term strategic mission goals; (3) align our technology investments with broader national policy goals; and (4) plan for future investments through technology roadmapping.

The investments presented in the *Energy Resources R&D Portfolio* are important and creative steps toward bringing forth the knowledge, innovation, technologies, and partnerships required to meet the challenges of the next century. It is our hope that this document will provide the means for illuminating our proposed investments for Fiscal Year 2001 and beyond, as a unified portfolio, and serve as a useful framework and resource for further analysis and dialogue among all interested parties.

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Foreword

The United States spends over one-half trillion dollars annually for energy, which is also the largest contributor to environmental impacts and waste production. While more efficient use of energy has occurred over the last few decades, total domestic energy produced and consumed continues to grow due to population and economic growth. Our nation's ability to continue to achieve its energy goals will depend on a balanced research portfolio, complemented by an appropriate public policy and regulatory regime.

The Department of Energy (DOE) is the lead Federal agency working to assure clean, affordable, and dependable supplies of energy for our nation. In carrying out this mission, DOE has developed an *Energy Resources R&D Portfolio* that has made significant contributions to the United States in helping to achieve the nation's energy goals. This portfolio was developed as a first step to help ensure that the Department maintains a balanced portfolio of R&D investments to meet our nation's challenges in environmental quality, economic prosperity, and energy security. The portfolio for fiscal years 1998-2000 is available on the internet at www.osti.gov/portfolio. In this current document the narrative and funding have been updated to reflect fiscal years 1999-2001.

Chapter 1 of the *Energy Resources R&D Portfolio* provides introductory remarks, including background for the goals of the *Energy Resources R&D Portfolio*. **Chapter 2** summarizes and describes the portfolio's characteristics from a number of viewpoints. Chapters 3 through 9 delve into the details of the Energy Portfolio's major technology areas and address various aspects of the research including: national drivers, uncertainties and technology challenges motivating the DOE-supported R&D, specific R&D activities, and past accomplishments. These seven chapters are organized into three broad energy areas:

- **Chapters 3 and 4** focus on activities supporting a ***Reliable and Diverse Energy Supply*** to address the Nation's need for stable, secure and clean sources of domestic energy. R&D is directed toward: domestic gas and oil supply; ultra-clean transportation and other fuels from petroleum, coal, natural gas and biomass; and hydrogen fuels.

- **Chapter 5 and 6** deal with ***Clean and Affordable Power*** activities, the largest portfolio area. Technology options include the use of fossil fuels, renewable energy resources, and nuclear power, in both large, high efficiency energy systems and in distributed and hybrid energy systems. Also included are systems that will help ensure the availability of a robust, reliable electricity and natural gas infrastructure required to serve emerging, competitive regional and interregional markets, and approaches for dealing with physical and cyber threats to this infrastructure.

- **Chapters 7, 8, and 9** describe ***Efficient and Productive Energy Use*** R&D, which seeks to reduce the growth of energy use in buildings and the industrial sector, and to dramatically improve the efficiency of passenger vehicles and light and heavy trucks, while increasing long-term economic benefits.

The applied research and development activities in the *Energy Resources R&D Portfolio* are supported by a strong portfolio of basic research activities, which are summarized in **Chapter 10**.

The organization of this report is similar to the FY 1998-2000 report, except for some changes in the box diagram of the energy R&D portfolio. In particular, Chapter 6 has been renamed *Enhancing Energy Systems Reliability* (formerly *Enhancing Utility Infrastructure*), and expanded to include Gas Storage and Delivery Systems (formerly under *Enhancing Domestic Supply*) as well as new initiatives. Geothermal activities formerly under *Enhancing Domestic Supply* have been moved to *Advanced Power Systems*.

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Executive Summary

Introduction

Energy needs of the United States are diverse and extensive. Energy is the vital force powering business, households, manufacturing and movement of goods and services throughout the country. The processes that link U.S. energy supply, conversion, and transmission systems to end uses comprise a complex system of technologies and scientific disciplines. Energy research and development (R&D) provides a systematic path to attaining the advanced technologies that enable achievement of our energy, environmental, and economic goals. Our energy needs can be satisfied and the nation's continued leadership in science and technology assured when R&D and appropriate policies and market forces are used together.

The United States consumes over 94 quads[1] of energy annually, representing an annual expenditure of over one-half trillion dollars. Energy use is also the largest contributor to environmental impacts and waste production. While more effective use of energy has occurred over the last few decades, total domestic energy produced and consumed continues to grow due to population and economic growth.

Energy Supply

Current U.S. energy consumption is sustained by oil (39 percent), gas (23 percent), coal (23 percent), nuclear (8 percent), and renewable sources (7 percent). The Energy Information Administration's 2000 Annual Energy Outlook (AEO2000) projects energy supply and demand through 2020. These are "business-as-usual" projections that do not assume new policies (e.g., incentives to encourage greater energy efficiency) or regulations (e.g., greenhouse gas constraints).

AEO2000 projects that by 2015, U.S. consumption of oil will increase more then 25 percent to nearly 24 million barrels per day, of which 63 percent will be imported; a higher ratio than at the time of the oil shocks of the 1970s. Demand for petroleum in non-industrialized countries is projected to increase about 70 percent by 2015, with the Middle East controlling over 60 percent of the world petroleum export market. Increasing U.S. import dependence is related not only to increasing demand, but also decreasing domestic production. Advanced technology can contribute to U.S. production by making it economical to recover some of the two-thirds of original oil-in-place that is typically not recovered.

Domestic natural gas consumption is projected by AEO2000 to increase about 40 percent by 2015 to over 30 trillion cubic feet (Tcf) per year, with a significant share of this increase for electricity production. While the domestic natural gas resource is large, sustained consumption

[1] One quad equals a quadrillion Btus, and is approximately equal to a trillion cubic feet of natural gas, 0.5 million barrels of oil per day, or 48 million tons of coal.

at these levels will require significant production from more geologically complex, harder-to-produce formations, and better technology to ensure reasonable gas prices.

U.S. recoverable reserves of coal are greater than in any other nation, and more than twice those of China, the world's leading coal producer. Every year the United States produces more than one billion tons of coal and exports nearly one-tenth of this production to a variety of markets. It uses 88 percent of the remainder to generate electricity. While coal is abundant and relatively inexpensive to produce, large-scale use presents a number of environmental control technology challenges due to emissions of carbon dioxide (the most pervasive greenhouse gas), very small particulates, and potentially hazardous air pollutants.

Nuclear energy is the second largest source of U.S. electricity, after coal, producing about 19 percent of our electricity. There are sufficient known domestic inventories of uranium to support the existing fleet of nuclear power plants throughout expected operating lifetimes. While there are advanced nuclear fuel cycles capable of generating their own fuel from non-fissile isotopes that are the subject of academic interest around the world, today's economics favor the simple uranium fuel cycle. Continued operation of existing nuclear plants is a growing concern as licenses, which must be renewed, expire in large numbers beginning around 2010.

Renewable energy includes hydropower, biomass (primarily agricultural residues, forest residues, tree crops and crops), geothermal, wind and solar resources. Although more than half of U.S. renewable energy produced is used to generate electricity, it is also used for transportation fuels (e.g., ethanol), and for heating industrial processes, buildings, and water. While renewable sources are currently dominated by hydropower, which provides about 10 percent of total U.S. electricity generation, other renewables are beginning to enter the market in specialized situations.

Energy Demand

Energy demand in the United States is dominated by four key areas: electric power generation; transportation; industry; and heating, cooling, and lighting of residential and commercial buildings. The U.S. consumes some $200 billion of electricity, which is more electricity than Europe and Japan combined. AEO2000 projects that approximately 250,000 megawatts of new power generation additions will by required by 2015 (current capability is about 750,000 megawatts). Electricity generation accounts for 38 percent of U.S. primary energy consumption and a similar share of U.S. greenhouse gas emissions, and in some areas adversely impacts local and regional air quality.

The electric power industry is in the midst of restructuring. Many in Congress and State legislatures and many Federal and State regulators have acknowledged that competition in electric supply is both possible and desirable. However, a new competitive electric marketplace will require the Nation's utility infrastructure to operate in ways for which it was not originally designed, and may not include sufficient incentives for developing and deploying more advanced technology. New technologies will be required to ensure that adequate, reliable, reasonably-priced, and environmentally sensitive electricity supplies are available during and after the restructuring process.

Transportation is 97 percent dependent on petroleum-derived fuels and uses 73 percent more petroleum than the United States produces. While there have been many improvements in vehicle/engine fuel efficiency, transportation fuel consumption continues to increase due to the growing economy and numbers of drivers and miles traveled, as well as in the demand for larger vehicles and lower fuel-economy vans, pickup trucks, and sport utility vehicles. Unless new technologies significantly increase vehicle efficiency, these trends are likely to continue and exacerbate our petroleum import concerns, including the impact on the U.S. balance of trade.

Homes and commercial buildings consume 34 quads annually, which is 36 percent of the Nation’s energy, as well as two-thirds of all electricity generated. Again, the growth in the economy and of the Nation’s population is leading to more, larger, and better equipped homes, resulting in increasing energy consumption in this sector. Introduction of new technology to increase energy efficiency can have significant economic and environmental benefits. The production of energy, primarily electricity, that is consumed in buildings represents a major source of acid rain, smog, and greenhouse gas emissions, and includes 47 percent of U.S. sulfur dioxide emissions, 22 percent of nitrogen oxide emissions, and 35 percent of carbon dioxide emissions.

The U.S. industrial sector accounts for well over one-third of the Nation’s energy consumption and relies on a mix of fuels. In particular, industry is the major consumer of natural gas. This energy use is concentrated in a relatively small number of industries, in particular the major materials processing and extraction industries. Nine of these industries alone account for about two-thirds of industrial energy consumption, and for them, energy use and waste disposal represent important fractions of operating costs and the cost of the end product. The industrial sector spent about $110 billion for energy in 1997. Industry also generated 14 billion tons of waste, including 200 million tons of hazardous and toxic waste (in 1994) to manufacture the goods we all consume. These wastes often impose expensive clean up and disposal costs. However, advanced technologies offer the potential to recover the “embedded” energy and materials value from this waste.

Manufacturing employs about 19 million people and these industries face increasing global competition. A thriving and growing economy will require more reasonable-cost energy and energy efficiency to remain competitive. There is also a rapidly growing world market for energy efficient technologies and more advanced energy supply products, particularly in developing countries.

Future environmental concerns and regulations could affect energy demand, and the development and adoption of advanced technologies, by changing relative compliance costs. Future air emissions standards, concern over climate change, and electric utility restructuring, for example, could have a significant affect on the attractiveness of different fuels and technologies.

The Energy Resources R&D Portfolio

The Department of Energy, in seeking to characterize and integrate the many programs which make up its energy resources R&D, developed an Energy Resources R&D Portfolio. The PCAST panel succinctly captured DOE's Energy Portfolio challenge when it stated:

> *"Developing the appropriate degree of diversity and balance in the Department's overall energy R&D portfolio is difficult. Technologies have many different attributes—cost… performance, risk, return, potential contributions over time to energy and environmental goals, and others. How can one fairly evaluate the many R&D alternatives and select an R&D portfolio that best meets our Nation's goals and needs? No single quantitative measure can encompass the range of relevant attributes."* [2]

DOE assembled its energy resources R&D portfolio recognizing the nature of this challenge, and the continuity implicit in DOE's current research activities, which in part reflect past Congressional guidance and intent. The Department also acknowledged that the complexity and inter-relatedness of the energy system means research in most any scientific or technological area may have direct as well as indirect effects on achieving the common sense goals of the Comprehensive National Energy Strategy. The R&D goals and objectives of the Energy Resources R&D portfolio are shown below. These can be related to the box diagram at the front of the Chapter that illustrates their relationship to the energy R&D programs.

R&D Goals	R&D Objectives
Reliable and Diverse Energy Supply	▪ Enhancing Domestic Supplies ▪ Producing Clean Fuels
Clean and Affordable Power	▪ Advanced Power Systems ▪ Enhancing Utility Infrastructure
Efficient and Productive Energy Use	▪ Clean and Efficient Vehicles ▪ Efficient and Affordable Buildings ▪ Clean and Productive Industries

Introduction to the R&D Goals of the Energy Resources R&D Portfolio

To understand the Energy Resources R&D Portfolio, we need to examine each of the energy R&D goals used to best represent how the CNES common sense goals are supported. This sets the stage for the chapters on each of the seven R&D objectives.

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[2] Federal Energy Research and Development for Challenges of the Twenty-First Century, Report of the Energy Research and Development Panel, The President's Committee of Advisors on Science and Technology; November 1997, p. ES-25.

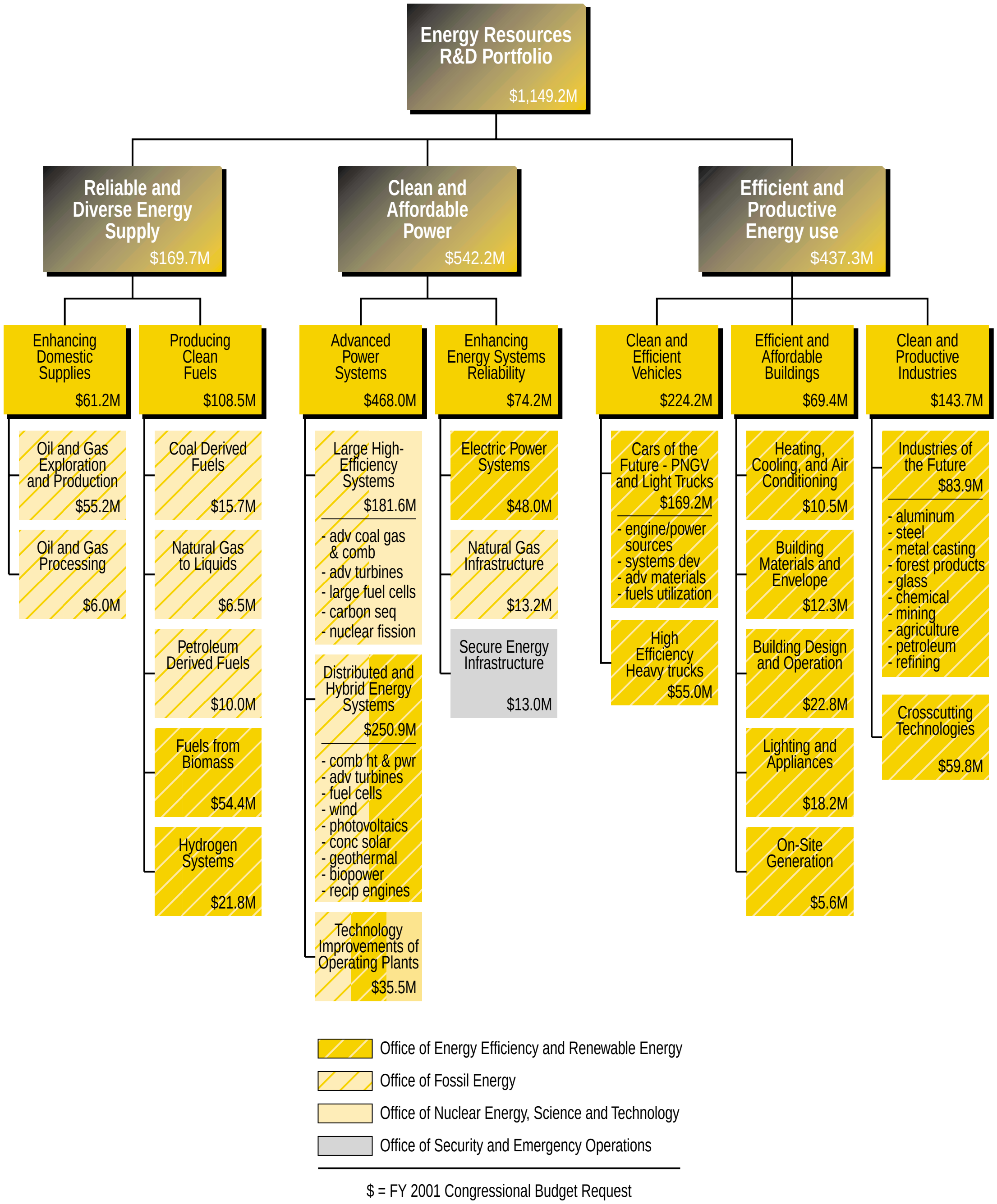


Figure ES-2

in Figure ES-2 (color-keyed to the managing DOE organizations), and discussed in Chapters 3 through 9 of this report. While the blocks under the objectives show applicable R&D areas, there is a large variation in the scope/funding and potential impact of activities in the different blocks.

The reasons why industry does not adequately invest in R&D important to meeting U.S. environmental, energy security, and economic goals vary by market. Figure ES-3 provides examples of why and where the private sector has underinvested in strategically important energy R&D.

Reasons for Industry Underinvestment in Energy R&D	Examples of Areas Affected by Underinvestment in Energy R&D
Industry too fragmented and/or members too small to fund significant R&D	Buildings and some industrial technologies; marginal oil/gas properties operated by small independent producers
Deployment time frame so long that increased uncertainty makes business risk unacceptable	Advanced coal, nuclear and renewable power technologies; hydrogen and biomass fuels
Investment so large that risk is unacceptable	Higher efficiency vehicles; central power systems
Low consumer demand for better technology due to high initial price and/or long payback	Higher efficiency vehicles; buildings-related technologies
Electric utility restructuring focuses utility discretionary funding away from mid- and longer-term R&D to near-term, competitiveness issues	New power and utility infrastructure technology
Expertise not readily available in private sector	Fundamental research in areas such as materials science
Extended periods of low world oil prices and resulting industry focus on low-cost, non-U.S. oil prospects	Oil exploration/production technology focused on domestic prospects; clean fuels from natural gas, biomass, and hydrogen

Figure ES-3

Portfolio Summary, Trends, and Accomplishments

Funding and Characteristics

Funding shares for DOE's FY 2001 Energy Resources R&D portfolio of applied research and development activities are shown in Figure ES-4 for 2 levels of detail. Shares of the overall FY 2001 budget request of $1.15 billion are 15 percent for energy supply, 46 percent for power, and 39 percent for energy end-use efficiency.

Energy R&D is conducted by leading private sector companies and organizations, DOE laboratories, that are world-class research facilities, and preeminent universities. Within the DOE program, industry R&D consistently accounts for 40-50 percent of the work in each area, and R&D with Federal Funded Research Centers (primarily National Laboratories) typically ranges from 30-40 percent. Work with universities and non-profits is more variable, ranging from 5-20 percent, and R&D supported in other Federal agencies is typically only a few percent.

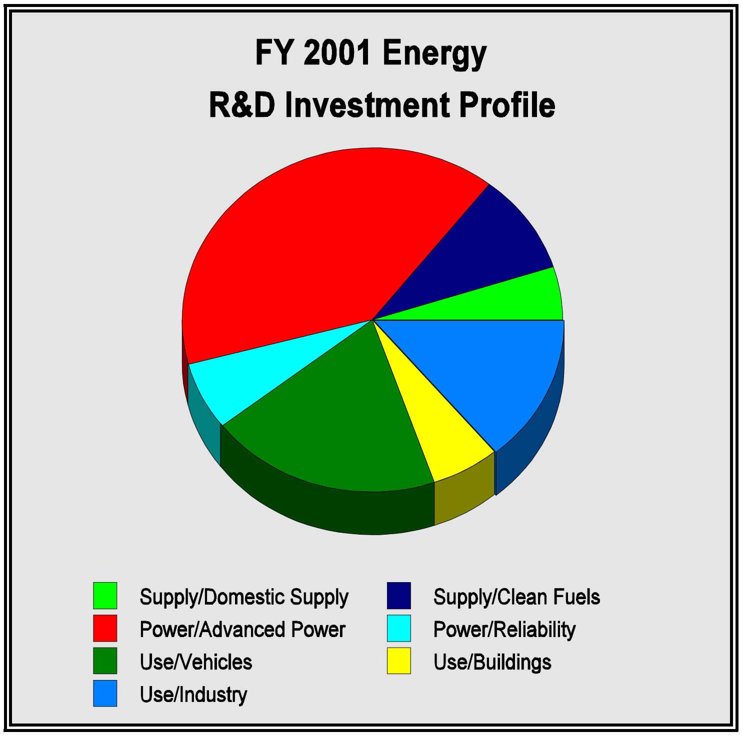


Figure ES-4

The mix of R&D performers is closely related to the mix of projects in different parts of the R&D cycle. Because industry must ultimately commercialize new technology, it is important to have industry's perspective in planning R&D and their direct involvement in the latter part of the R&D cycle, the "development" phase. This is also the phase where significant DOE-industry cost-sharing occurs. Most work performed by National Laboratories and universities is in the earlier R&D phases, that include basic and applied research. The vast majority of basic research related to energy is carried out by DOE's Office of Science. The Office of Science energy portfolio is discussed in Chapter 10, and treated in more detail in a separate Science Portfolio volume.

Federally-sponsored energy R&D should also be considered in the context of R&D support by the private sector. Private sector energy R&D investment, which is down about 30 percent from 1980s levels, is estimated to be about twice Federal R&D funding. Such estimates are subject to considerable uncertainty, however, due to industry activities that are proprietary and not reported. The major energy producers (i.e., electric power generators, integrated oil and gas producers, refiners, and transporters) account for the majority of industry expenditures, although much of this is for near-term operational issues, which is not the primary focus of DOE activities. Funding for the electricity industry has also declined in recent years, due in part to uncertainties associated with restructuring. Therefore, DOE energy R&D funding is a substantial part of the Nation's overall energy R&D expenditures, and is far more heavily focused on earlier R&D stages than that carried out by the private sector.

Portfolio Trends and Accomplishments

New Initiatives.

Several new initiatives significantly impact the FY 2001 portfolio. These are discussed below, as well as the major components of the energy R&D portfolio shown in Figure ES-2, and selected accomplishments that reflect progress toward goals.

Ultra-Clean Transportation Fuels Initiative

The Ultra-Clean Transportation Fuels Initiative (UCTFI) promotes, in partnership with the refining and transportation industries, the development and deployment of technologies that will produce ultra-clean, high performance transportation fuels for the 21st century from both petroleum and non-petroleum sources. These will enable the introduction of advanced, highly efficient fuel/engine combinations being developed by the Department, which offer the promise of lower regional emissions and greater than double the miles per gallon of fuel. 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, coal and other carbonaceous feedstocks 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. Activities related to UCTFI can be found in Chapter 4, *Producing Clean Fuels (*Coal-Derived Fuels, Gas-to-Liquids, and Petroleum-Derived Fuels), and in Chapter 7, *Clean and Efficient Vehicles*.

Energy Grid Reliability Initiative

The Grid Reliability Initiative includes three broad areas. Electric Power Systems Reliability focuses on systems that will help ensure the availability of a robust, reliable electricity infrastructure required to serve emerging, competitive regional and interregional markets. Activities relate to transmission reliability, distributed generation and energy storage. The Natural Gas Infrastructure program is a FY 2001 initiative that seeks to enhance gas pipeline system reliability and increase deliverability and operational flexibility of gas storage facilities The Secure Energy Infrastructure program was initiated in FY 2000 and is primarily a FY 2001 initiative and is focusing efforts on protecting critical energy system infrastructures from physical and cyber threats. These three efforts are described in Chapter 6, *Enhancing Energy Systems Reliability*.

Biobased Products and Bioenergy Initiative

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. Activities under this initiative can be found in Chapter 4, *Producing Clean Fuels* (Fuels from Biomass), Chapter 5, *Advanced Power Systems* (Biopower), and Chapter 9, *Clean and Productive Industries* (Forest Products, Agriculture, and Crosscutting Technologies)

International Clean Energy Initiative
The June 1999 report by President's Committee of Advisors on Science and Technology (PCAST) titled "Powerful Partnership – The Federal Role in International Cooperation on Energy Innovation," addresses ways to improve the U.S. program of international cooperation on Energy R&D to best support U.S. priorities and address the key global energy environmental challenges of the next century. The report includes funding recommendations for a variety of initiatives that include approaches such as tax credits, regulatory assistance, training and Federally-supported R&D. In response, the Department is proposing a variety of international activities in FY 2001 that total $46 million, span most of the seven objectives in Figure 1, and include R&D and other forms of international collaboration.

Reliable and Diverse Energy Supply. These activities address the Nation's need for stable, secure, and clean sources of domestic energy, and include R&D related to: domestic gas and oil supply; clean liquid fuels from petroleum, coal, natural gas and biomass; and hydrogen fuels.

The R&D emphasis for oil and gas is on exploration and production, and work in areas such as diagnostics, imaging and reservoir life extension. Much of the U.S. resource is in mature producing areas, and remaining new sources are frequently difficult to find and produce. An increasingly important thrust is providing fuels that can solve environmental problems. The Ultra-Clean Transportation Fuels Initiative is pursuing such fuels that can be derived from petroleum and other hydrocarbon feedstocks such as natural gas and coal. Biofuels R&D is stressing ethanol production as a gasoline additive and replacement fuel. Hydrogen fuels R&D, in addition to finding ways to economically produce hydrogen, is addressing the lack of a utilization infrastructure through development of gaseous hydrogen storage and distribution technologies.

Considerable progress has been made through DOE support toward achieving energy supply goals:

- A successful demonstration of a unique oil field waterflooding approach could, when replicated by the private sector in other parts of the region, double or triple reserves and increase Federal tax and royalty revenues by $500 million.

- Two technologies, 3-D seismic and vertical seismic profiling, were first used in the Texas Gulf Coast and Fort Worth Basins, and resulted in a substantial increase in reserve growth (estimated at 60 Tcf) from established gas fields which were previously thought to be depleted.

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

- Recent breakthroughs in air separation via ceramic membranes 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. Technologies capable of producing high purity gas streams, at such cost-savings, should have a positive impact on other energy intensive industries.

- Over the last two decades, the predicted cost of biomass-derived ethanol was reduced by at least 50 percent, and commercial production of biomass ethanol from low-cost cellulosic feedstocks, particularly agricultural and forest wastes, is expected by 2002.

- 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.

Clean and Affordable Power. The Department's power R&D portfolio includes a broad range of generation technology options that utilize fossil fuels, renewable energy resources, and nuclear power, in both large, high efficiency energy systems and in distributed and hybrid energy systems to deliver affordable, reliable, and clean electric power. Also included are systems that will help ensure the availability of a robust, reliable electricity and natural gas infrastructure required to serve emerging, competitive regional and interregional markets, and approaches for protecting the infrastructure from physical and cyber threats.

Advanced coal and natural gas-fueled power technologies are emphasizing high efficiency and low emissions, with eventual integration into "Vision 21" plants to achieve even higher efficiency, provide feedstock and product flexibility, reduced emissions, and lower cost. Carbon sequestration is seen as an increasingly important option for coping with greenhouse gas emissions. Efforts on nuclear fission are focusing on helping to ensure that nuclear plants can deliver affordable supplies beyond their initial 40 year license period, and developing new reactor designs that offer improved economics, reduced waste generation, increased safety, and proliferation resistance. Work related to distributed and hybrid systems, that includes renewable technologies and fuel cell technology, continues to expand in recognition of potential environmental benefits and advantages of increasing distributed generating capacity. In FY2001, particular emphasis has been placed on a group of technologies that can have a major, long-term impact on greenhouse gas reduction, as well as other benefits, in both domestic and international applications. These technologies include wind, photovoltaics, and biopower renewable systems (also part of Biobased Products and Bioenergy Initiative), carbon capture/sequestration and nuclear fission systems.

R&D for energy systems reliability is increasing emphasis on power systems and energy storage technologies, technologies to enhance the reliability and deliverability of the Nation's natural gas pipelines, research that can promote infrastructure integrity in key developing countries, and ways to protect energy systems from physical and cyber disruptions.

Considerable progress has been made through DOE support toward achieving advanced power systems goals:

- A new generation of coal gasification-based, higher-efficiency, cleaner, coal-fueled technologies is being demonstrated that will also be attractive in hybrid applications with advanced turbines and fuel cells.

- Successful demonstration of a variety of low-NO_x burners has led to installation of these low-polluting burners in about half of U.S. coal-fired capacity.

- Three advanced light water reactor designs, supported by DOE R&D, were certified by the Nuclear Regulatory Commission for construction in the United States. These plants, which are ready for export (with royalties accruing to DOE), are safer, more reliable, and more economic to construct and operate compared to existing technology.

- R&D has continued to reduce the cost of renewable systems suitable for distributed and base-load applications.

  – Biomass power is being demonstrated at scales from 10-75 MWE for dedicated feedstocks and for co-firing with coal.

  – Recent advancements in geothermal technology have reduced costs by increasing power plant efficiency 5-10 percent for certain key resources. Geothermal drilling-related advances led to a 30 to 50 percent reduction of geothermal exploration drilling costs.

  – The cost of producing photovoltaic modules has decreased 50 percent since 1991, making it cost-competitive in certain applications.

  – The cost of wind power has decreased by 85 percent since 1980, making it competitive in some areas that have good wind resources.

- Advanced fuel cells and turbines are being demonstrated and commercialized and are expected to achieve significant deployment in distributed and hybrid applications in the next decade.

- Fusion research has continued to raise the power achieved in test reactors (the Princeton Tokamak reached 10 MW in 1996) and is increasing the understanding of how to control plasma conditions and improve energy confinement.

- The satellite-synchronized (GPS) wide area measurement system (WAMS) developed by DOE and installed on the Western grid was used to diagnose the massive August 10, 1996 blackout in a matter of hours, rather than days that would have been required using conventional methods.

- Important advances have been made in superconductivity, including development of breakthrough methods for making superconducting wires with over 10 times the current-carrying capability of wires made with older methods, and development and successful testing of the world's largest superconducting motor (200 horsepower).

Efficient and Productive Energy Use. This part of the R&D portfolio seeks to reduce the growth of energy use by vehicles, in buildings, and in the industrial sector while increasing long-term economic benefits.

Clean and efficient vehicles R&D continues to stress advanced engines, batteries, and fuels cells to dramatically improve the efficiency of passenger vehicles and light and heavy trucks. Increased emphasis has been placed on achieving effective, affordable emissions control technologies for diesel engines. R&D for efficient and affordable buildings most heavily focuses on heating, cooling, air conditioning, building material and envelope, and building design and operations. Technology roadmapping is underway with industry that is likely to impact the thrust of the buildings R&D portfolio for FY 2001. Technology roadmapping carried out by industry continues to drive DOE's R&D agenda for clean and productive industries. Mining and agriculture have been added to the industries R&D portfolio, bringing the industries total to nine. Additional emphasis has been placed on the Agriculture and Forest Products programs in response to the Biobased Products and Bioenergy Initiative. Based on prior research results, two areas where major breakthroughs are possible have received increased priority: development of carbonless anodes and wettable cathodes that could lead to a totally new electrolytic smelting method for making aluminum, and an advanced black liquor gasification technology which could have significant environmental and economic benefits for pulp and paper manufacture. R&D emphasis has also been increased in areas such as advanced sensors and controls, advanced combustion technologies, and chemical catalysis.

Progress toward goals is illustrated by the following accomplishments from DOE-sponsored activities:

- The auto industry is moving toward adopting many of the technologies developed in the DOE program, as demonstrated by their use in industry concept cars at recent auto shows. DOE-supported technologies shown included advanced compression-ignition, direct-injection (CIDI) engines, parallel-hybrid vehicle configurations, a proton exchange membrane (PEM) fuel cell, a methanol reformer, and a nickel-metal hydride battery. In 1999, Ford delivered to DOE its P2000 LSR (Low Storage Requirement) hybrid vehicle, designed for a fuel economy of 60 mpg.

- Five Federal investments in building efficiency technology development made in the 1970s-80s have resulted in present value savings in the U.S. economy totaling nearly $33 billion through 1997, while simultaneously eliminating more than 60 million metric tons of cumulative carbon emissions. These 5 investments include building design software, electronic fluorescent lamp ballasts, low emissivity windows, advanced oil burners, and efficient refrigerator compressors.

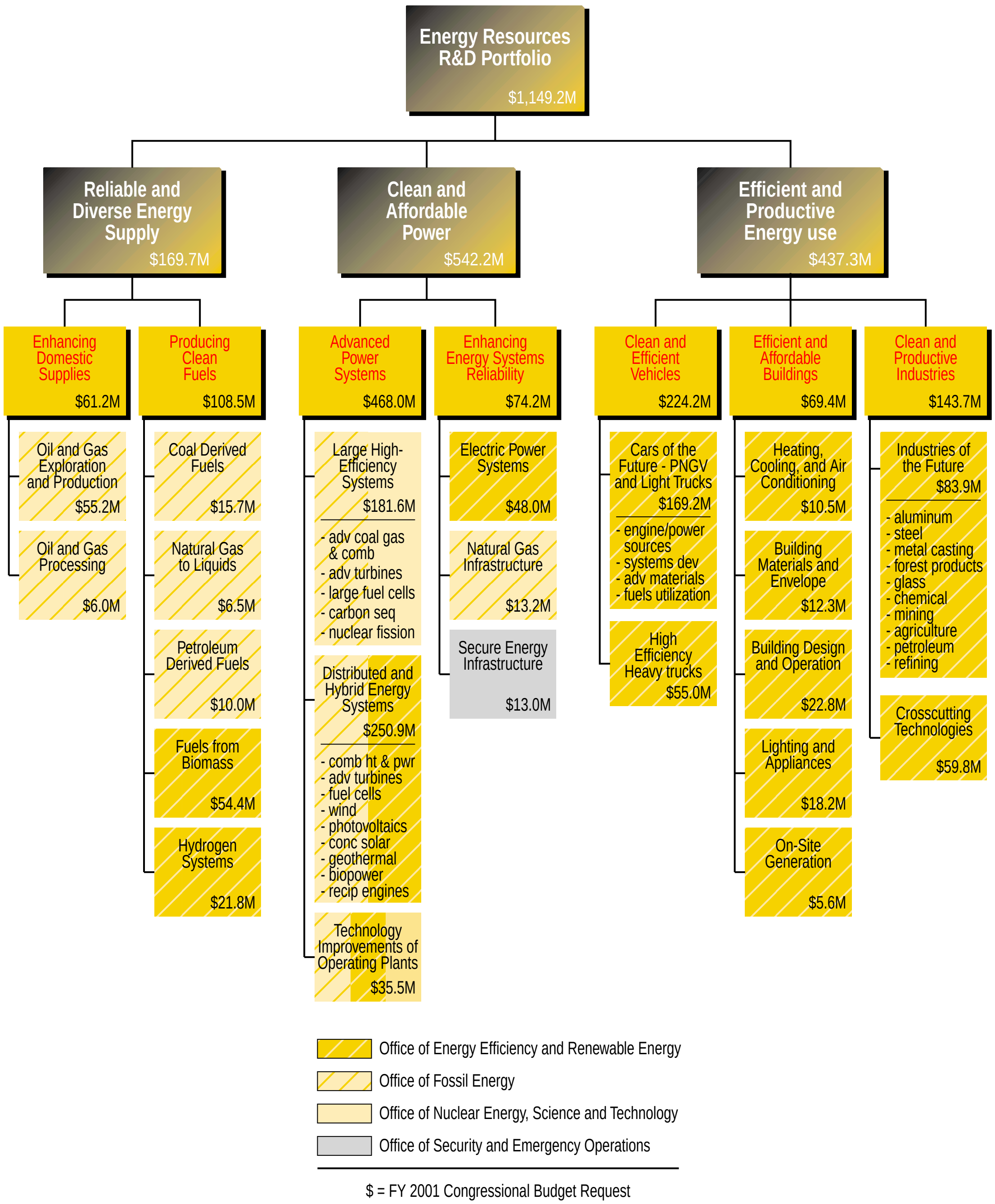
- A series of improvements to the lost foam casting process for steel and aluminum have resulted in reducing defects and producing higher quality, higher precision lost foam castings with less waste. By 2010 it is expected to save 4.6 trillion Btus/year of energy and prevent nearly a half-million tons of waste.

- New cleaning technology allowing the use of lower grades of recycled paper by papermakers will permit 50 percent recycling of all paper used, reducing energy used for recycling by 0.l quad/year and lowering CO_2 emissions by 0.6 million tons annually.

- Oxy-fuel firing for glass melting furnaces is in commercial use in 20 percent of glass furnaces, reducing a manufacturer’s fuel use by 48 percent, NO_x emissions by 70 percent, and particulates by 60 percent, and increasing productivity by 25 percent.

Development of the Energy Resources R&D portfolio has occurred over a long period of time with the cooperation of many experts and stakeholders, and guidance by Congress. This, however, is the first time that the portfolio has been articulated and presented for evaluation aligned with National and Departmental goals, rather than by organizational or budgetary structures. As a result, the Department, as well as its many stakeholders, will be in a better position to understand the existing and future contributions from the portfolio, its successes, limitations, balance, and potential effectiveness. The Department will continue to analyze its portfolio to improve its effectiveness, reduce possible duplication of effort, and better balance its priorities, if necessary.

Chapter 1
Introduction



Chapter 1

Introduction

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Background

"The United States faces major energy-related challenges as it enters the twenty-first century. Our economic well-being depends on reliable, affordable supplies of energy. Our environmental well-being—from improving urban air quality to abating the risk of global warming—requires a mix of energy sources that emits less carbon dioxide and other pollutants than today's mix does. Our national security requires secure supplies of oil or alternatives to it, as well as prevention of nuclear proliferation. And for reasons of economy, environment, security, and stature as a world power alike, the United States must maintain its leadership in the science and technology of energy supply and use."

Final report of the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST), November 1997

The energy-related challenges expressed in this quote from the PCAST report succinctly identify the major factors that make a reliable and diverse energy supply vital to the future security and prosperity of the United States. Affordable energy supply and efficient energy use are indispensable ingredients of the economic well-being of individuals and nations. In the United States and worldwide, energy accounts for 7 to 8 percent of gross domestic product and a similar share of international trade. Global investments in energy supply technology (energy supply and conversion to power) total hundreds of billions of dollars per year and annual global expenditures on items whose energy-using characteristics are potentially important to their marketability (vehicles, buildings, industrial machinery, etc.) run into the trillions. When and where energy becomes scarce or expensive, recession, inflation, unemployment, and the frustration of aspirations for economic betterment are the usual results.

Energy is no less crucial to the environmental dimensions of human well-being than to the economic ones. Energy supply, electricity production, and energy end-use have greater impacts on the environment than any other peaceful human activity. It accounts for a striking share of the most troublesome environmental problems at every geographic scale—from wood smoke in Third World village huts, to regional smog and acid precipitation, to the risk of widespread radioactive contamination from accidents at nuclear-energy facilities. The public places a high priority on having a clean environment.

If current energy supply and use patterns persist, the expected future growth will lead to increasing environmental emissions of global pollutants such as greenhouse gases, as well as regional and local pollutants. The importance of finding cost-effective means of reducing greenhouse gas emissions cannot be overemphasized. The Framework Convention on Climate Change (FCCC) and the Kyoto and Buenos Aires meetings (in December 1997 and November 1998, respectively) where most of the world's nations agreed to devise feasible, acceptable means for reducing greenhouse gas emissions, demonstrate the importance of climate change issues to the world community. Scientific and technical advances applicable to energy conversion and use, along with regulatory and other public policies compatible with a reduction in greenhouse gas emissions, will be essential towards meeting internationally agreed upon reduction goals. As the President's Committee of Advisors on Science and Technology stated in its November 1997 report:

> "*…there is a significant possibility that governments will decide, in light of the perceived risks of greenhouse-gas-induced climate change and the perceived benefits of a mixed prevention/adaptation strategy, that emissions of greenhouse gases from energy systems should be reduced substantially and soon…because of the large role of fossil fuel technologies in the current U.S. and world energy systems, the technical difficulty and cost of modifying these technologies to reduce their carbon dioxide emissions, their long turnover times, their economic attractiveness compared to most of the currently available alternatives, and the long times typically required to develop new alternatives to the point of commercialization, the possibility of a mandate to significantly constrain greenhouse-gas emissions is the most demanding of all the looming energy challenges…*" [1]

The importance of energy to national economies and the fact that more than a quarter of the total world energy supply (including more than half of the oil) is traded internationally, make energy a national security issue as well as an economic and environmental one. Gaining or protecting access to foreign energy resources has been a contributing motivation in a number of major conflicts during the twentieth century and could be again in the twenty-first. Another national security dimension of energy is the potential for large-scale failures of energy strategy with economic or environmental consequences serious enough to generate or aggravate social and political instability. This is a concern in both developing and industrialized countries.

It should be clear by now that living in a global economy as we and other nations do, means that one fundamental base of that economy, the energy system, is interconnected and interdependent between nations. All nations share common interests in economic, energy, and environmental security. Consequently, U.S. participation in international cooperative activities is essential to ensure its energy security, economic, and environmental interests are properly addressed as part of the global economic/energy equation.

Comprehensive National Energy Strategy

Improvements in energy technology and the widespread penetration of these improvements in the marketplace in the twenty-first century are necessary to enhance the positive connections between energy and economic well-being and to ameliorate the negative connections between energy and environment and between energy and international security. Thus, technological improvements can lead to lowering the monetary and environmental costs of supplying energy, reducing its effective costs by increasing the efficiency of its end uses, helping to minimize our dependence on oil imports, slowing the buildup of heat-trapping gases in the atmosphere, and

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[1] Federal Energy Research and Development for Challenges of the Twenty-First Century, Report of the Energy Research and Development Panel, The President's Committee of Advisors on Science and Technology; November 1997, pp. ES10 & ES11.

enhancing the prospects for environmentally sustainable and politically stabilizing economic development in many of the world's potential trouble spots.

To address these energy-related challenges, the Department of Energy engaged in an interactive strategic planning process, involving other agencies and energy stakeholders, that produced the Comprehensive National Energy Strategy (CNES) in April 1998. This strategy is based on five common-sense goals:

- Improve the efficiency of the energy system.
- Ensure against energy disruptions.
- Promote energy production and use in ways that respect health and environmental values.
- Expand future energy choices.
- Cooperate internationally on global issues.

A more complete description of the CNES strategic goals and objectives is shown on the following page.

From Strategic Planning to R&D for Required Technologies

Research and development is the only systematic means for creating the needed technical improvements and, therefore, is a necessary (although not always sufficient) condition for improving the energy systems that are actually deployed to meet strategic objectives. What is deployable today is the result of the energy R&D that was done in the past; what will be deployable in the future depends on the R&D that is being done now and will be done tomorrow. It is important to understand, moreover, that while some kinds of energy R&D can bring quite rapid returns (such as research on finding oil and gas or improving the efficiency of electric light bulbs or motors), the time scales on which most kinds of energy R&D exert a significant influence on deployed energy systems are longer. This relates not only to the time required to complete the R&D, but also to the long turnover times of most energy supply and energy end use equipment. On the supply side, for example, electric power plants and oil refineries have a useful life of 3 to 5 decades; on the end-use side, residential and commercial buildings last for 5 or more decades. Even the stock of automobiles and major household appliances takes 10 years or so to turnover.

The Comprehensive National Energy Strategy at a Glance

Goal I. Improve the efficiency of the energy system—making more productive use of energy resources to enhance overall economic performance while protecting the environment and advancing national security.

Objective 1. Support competitive and efficient electric systems.
Enact electric utility restructuring legislation, develop advanced coal/gas power plants, improve existing nuclear power plants

Objective 2. Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.
Develop more efficient transportation, industrial, and building technologies

Objective 3. Increase the efficiency of Federal energy use.
Adopt new/innovative energy-efficient and renewable technologies

Goal II. Ensure against energy disruptions—protecting our economy from external threat of interrupted supplies or infrastructure failure.

Objective 1. Reduce the vulnerability of the U.S. economy to disruptions in oil supply.
Stabilize domestic production, maintain readiness of Strategic Petroleum Reserve, diversify import sources, reduce consumption

Objective 2. Ensure energy system reliability, flexibility, and emergency response capability.
Ensure reliable electricity/gas supply, refining, and emergency response

Goal III. Promote energy production and use in ways that respect health and environmental values—improving our health and local, regional, and global environmental quality.

Objective 1. Increase domestic energy production in an environmentally responsible manner.
Increase domestic gas production, recover oil with less environmental impact, develop renewable technologies, maintain viable nuclear option

Objective 2. Accelerate the development and market adoption of environmentally friendly technologies.
Increase near-term deployment, expand voluntary efforts, design domestic greenhouse gas trading program, work with developing countries, design international trading/credit system

Goal IV. Expand future energy choices—pursuing continued progress in science and technology to provide future generations with a robust portfolio of clean and reasonably priced energy sources.

Objective 1. Maintain a strong national knowledge base as the foundation for informed energy decisions, new energy systems, and enabling technologies of the future.
Pursue basic research, including research on carbon/climate; support energy science infrastructure

Objective 2. Develop technologies that expand long-term energy options.
Develop long-term options, such as fusion, hydrogen-based systems, and methane hydrates, that can have major impacts

Goal V. Cooperate internationally on global issues—developing the means to address global economic, security, and environmental concerns.

Objective 1. Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.
Encourage adoption of favorable legal/policy framework in other countries, promote clean/efficient energy systems, and science/technology collaboration

Objective 2. Promote foreign regional stability by reducing energy-related environmental risks in areas of U.S. security interest.
Prioritize concerns and develop cost-effective solutions

The Energy Resources R&D Portfolio

The Department of Energy, in seeking to characterize and integrate the many programs which make up its energy resources R&D, developed an Energy Resources R&D Portfolio. The PCAST panel succinctly captured DOE's Energy Portfolio challenge when it stated:

> *"Developing the appropriate degree of diversity and balance in the Department's overall energy R&D portfolio is difficult. Technologies have many different attributes—cost… performance, risk, return, potential contributions over time to energy and environmental goals, and others. How can one fairly evaluate the many R&D alternatives and select an R&D portfolio that best meets our Nation's goals and needs? No single quantitative measure can encompass the range of relevant attributes."* [2]

DOE assembled its energy resources R&D portfolio recognizing the nature of this challenge, and the continuity implicit in DOE's current research activities, which in part reflect past Congressional guidance and intent. The Department also acknowledged that the complexity and inter-relatedness of the energy system means research in most any scientific or technological area may have direct as well as indirect effects on achieving the common sense goals of the Comprehensive National Energy Strategy. The R&D goals and objectives of the Energy Resources R&D portfolio are shown below. These can be related to the box diagram at the front of the Chapter that illustrates their relationship to the energy R&D programs.

R&D Goals	R&D Objectives
Reliable and Diverse Energy Supply	▪ Enhancing Domestic Supplies ▪ Producing Clean Fuels
Clean and Affordable Power	▪ Advanced Power Systems ▪ Enhancing Utility Infrastructure
Efficient and Productive Energy Use	▪ Clean and Efficient Vehicles ▪ Efficient and Affordable Buildings ▪ Clean and Productive Industries

Introduction to the R&D Goals of the Energy Resources R&D Portfolio

To understand the Energy Resources R&D Portfolio, we need to examine each of the energy R&D goals used to best represent how the CNES common sense goals are supported. This sets the stage for the chapters on each of the seven R&D objectives.

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[2] Federal Energy Research and Development for Challenges of the Twenty-First Century, Report of the Energy Research and Development Panel, The President's Committee of Advisors on Science and Technology; November 1997, p. ES-25.

Reliable and Diverse Energy Supply

Achieving a reliable and diverse energy supply includes activities involving the exploration, production, refining, storage, and transport of energy resources. These are addressed in the subsequent chapters on **Enhancing Domestic Supplies** and **Producing Clean Fuels**.

Oil and gas account for 62 percent of the total U.S. energy consumption, and 97 percent of transportation fuels. Consumption of oil and gas will continue to increase well into the next century (more than any other source of energy) despite energy efficiency improvements. Therefore, security of supply (primarily oil) remains a prominent issue despite the relative tranquility in the market in recent years. It is projected that by 2015:

- Demand for petroleum in non-industrialized countries will increase by about 70 percent..
- Domestic consumption of natural gas will increase about 40 percent to over 30 trillion cubic feet (tcf) per year, due mainly to its relative cleanliness and cost competitiveness with other fuels.
- U.S. petroleum consumption will increase by more than 25 percent to nearly 24 million barrels of oil per day, of which 63 percent will be imported.
- The Persian Gulf will control about half of the world petroleum export market compared to 45 percent today.

The effect of supply disruptions is two-fold. First, and most obvious, is the potentially serious impact on our economic well-being. The supply disruptions of the mid and late 1970s amply demonstrated the importance of adequate and reasonably priced energy to the domestic economy. Second, and nearly as significant, is the effect of supply disruptions on other nations and the consequent impact on the global economy, of which the United States is an integral part. Enhancing our domestic energy supplies through technological advances, and cooperating internationally to see such technologies are used elsewhere can protect us from the direct and indirect effects of global supply disruptions, while maintaining U.S. prominence as an innovator and leader in technology development and application.

The Department's approach to address the situation described above and meet U.S. needs to enhance its energy supply is two-pronged. First, it supports research activities designed to reduce the cost of finding new supplies of oil and gas, and to make recovery from existing oil and gas fields larger, more efficient and cost-effective. Many technology advances will also reduce the environmental impact of recovering oil and natural gas. Research in the gas area is particularly attractive because supplies of domestic natural gas appear abundant and gas can provide a low cost means to slow the rate of carbon dioxide emissions. Appropriate research to foster and nurture the application of new discovery and production technologies is thus an important component of the portfolio supporting the attainment of a reliable and diverse energy supply.

The second prong of the Department's research approach to the reliable and diverse energy supply issue is aimed at developing cost-effective and competitive clean fuels from indigenous sources. Clean fuels include liquid fuels from petroleum, coal, natural gas, and biomass, as well as hydrogen fuels. These fuels can be used in a manner that significantly reduces environmental impacts compared to conventional fuels. For example, liquid transportation fuels from coal, natural gas, and biomass, as well as petroleum-based fuels from advanced processing technology, are well-suited for advanced, clean, high efficiency engines. Some of these efforts are included in the Department's Ultra-Clean Transportation Fuels Initiative. This research is important because of the large contribution that vehicles make to urban and regional pollution. Fuels from biomass, and in the longer term, hydrogen from renewables, can help reduce greenhouse gas emissions. Carbon emissions, which account for over 80 percent of U.S. greenhouse gas emissions, are projected to increase 33 percent by 2020. Clean fuels can potentially be provided in significant quantities. Therefore, not only can they help decrease greenhouse gas emissions and other air pollutants; clean fuels also can offset oil imports, thus contributing to a reliable and diverse energy supply.

Clean and Affordable Power

Achieving clean and affordable power includes research focused on developing a better suite of electro-technologies. This involves electricity generation and energy transmission and distribution. These areas are addressed in the subsequent chapters on **Advanced Power Systems** and **Enhancing Energy Systems Reliability**.

Electricity generation represents the conversion of energy from a primary source (fossil fuel, uranium, or renewable forms) into a clean, easily transported, and flexible secondary energy source with innumerable uses. U.S. electricity generation has grown almost every year during the past four decades. The United States is the world's largest producer of electricity, generating more than all of Western Europe and Japan combined. More than half of all domestic electricity is generated by burning coal; about one-fifth is derived from nuclear power plants; renewable resources, primarily hydropower, provide about one-eighth; and the remainder is fueled by natural gas (about 9 percent) and oil (about 2 to 3 percent).

The electric power sector is the largest direct consumer of energy in the United States. It used 36 percent of all primary energy consumed in the country in 1996, while providing power worth approximately $200 billion annually to serve about 120 million U.S. residential, commercial, and industrial electricity customers. Most energy projections show the United States requiring an increase of 100,000 to 200,000 megawatts of power generation capacity by 2010. Electricity generation currently contributes 37 percent of the carbon emissions in the United States resulting from human activities. Adding more power without compromising the Nation's environmental standards is therefore essential to sustaining the Nation's economic growth, while at the same time protecting the health of our citizens and the environment.

The U.S. electric power industry is restructuring itself to become more competitive. The reasons why are many and varied, but the Congress, as well as State legislatures and Federal and State regulators have acknowledged that competition in electric supply is both possible and desirable.

They have thus taken steps to foster it. In response to increased competitive pressures, utilities and other companies that traditionally have invested significantly in power generation research have reduced or eliminated these investments. At the same time, many power generators, either in response to public pressure or State and Federal regulatory trends, are seeking to diversify their fuel choices and add renewable energy resources to their fuel mix.

To meet the needs and challenges of ensuring the country continues to have adequate, reliable, and environmentally sensitive electric power supplies in an evolving competitive market, the Department is pursuing research in advanced power systems; both large-scale high efficiency systems and smaller distributed power systems. Research to help make traditional large-scale power systems more efficient has been ongoing and will continue. This research includes advanced coal gasification and combustion systems, advanced gas turbines, large-scale fuel cell power systems, next-generation nuclear fission systems, and combined heat and power systems. Important research on carbon sequestration is also being supported. Smaller distributed power systems can enhance the efficiency of the transmission system and in some cases provide a lower cost alternative to new large-scale power systems. Expansion or strengthening of the existing transmission and/or distribution network by distributed power systems is a relatively new and very promising concept. Department supported research on distributed power systems includes distributed fuel cells, wind energy, photovoltaic systems, solar concentrators, and smaller, efficient reciprocating engines.

The United States is highly dependent on energy infrastructures, and the role of new technology for protecting and ensuring the reliability of this infrastructure is being increasingly recognized. Activities related to enhancing energy systems reliability, most of which are included in the Energy Grid Reliability Initiative, are in three broad areas: (1) systems to help ensure the availability of a robust, reliable electricity infrastructure to serve competitive markets that will require the Nation's utility infrastructure to operate in ways for which it was not designed; (2) technologies to enhance gas pipeline system reliability and increase deliverability and operational flexibility of gas storage facilities; and (3) approaches to protect critical energy system infrastructures from physical and cyber threats.

Efficient and Productive Energy Use

Attaining efficient and productive energy use involves research in both end-use and processing. These are addressed in the subsequent chapters on **Clean and Efficient Vehicles**, **Efficient and Affordable Buildings**, and **Clean and Productive Industries**.

Energy is consumed in the three basic demand sectors of our economy—transportation, industry, and residential and commercial buildings. Nearly all (97 percent) of transportation energy comes from petroleum, and transportation energy use accounts for about two-thirds of the petroleum consumed in the United States. The explosive popularity of low fuel-economy pickup trucks, vans, and sport utility vehicles used for personal transport, coupled with a growing economy, falling fuel prices, increasing numbers of drivers, and increasing miles traveled by each vehicle is pushing transportation fuel consumption higher. This situation will not change without a significant improvement in vehicle fuel efficiency. R&D must be undertaken to significantly reduce transportation's dependence on oil, to reduce vehicle emissions, thereby improving urban air quality, and to maintain the economic competitiveness of a major industrial sector of the economy. Specific DOE R&D activities in the transportation sector include fuel cell development, high power storage, power electronics, work on advanced materials, natural gas storage technologies, and high efficiency engines.

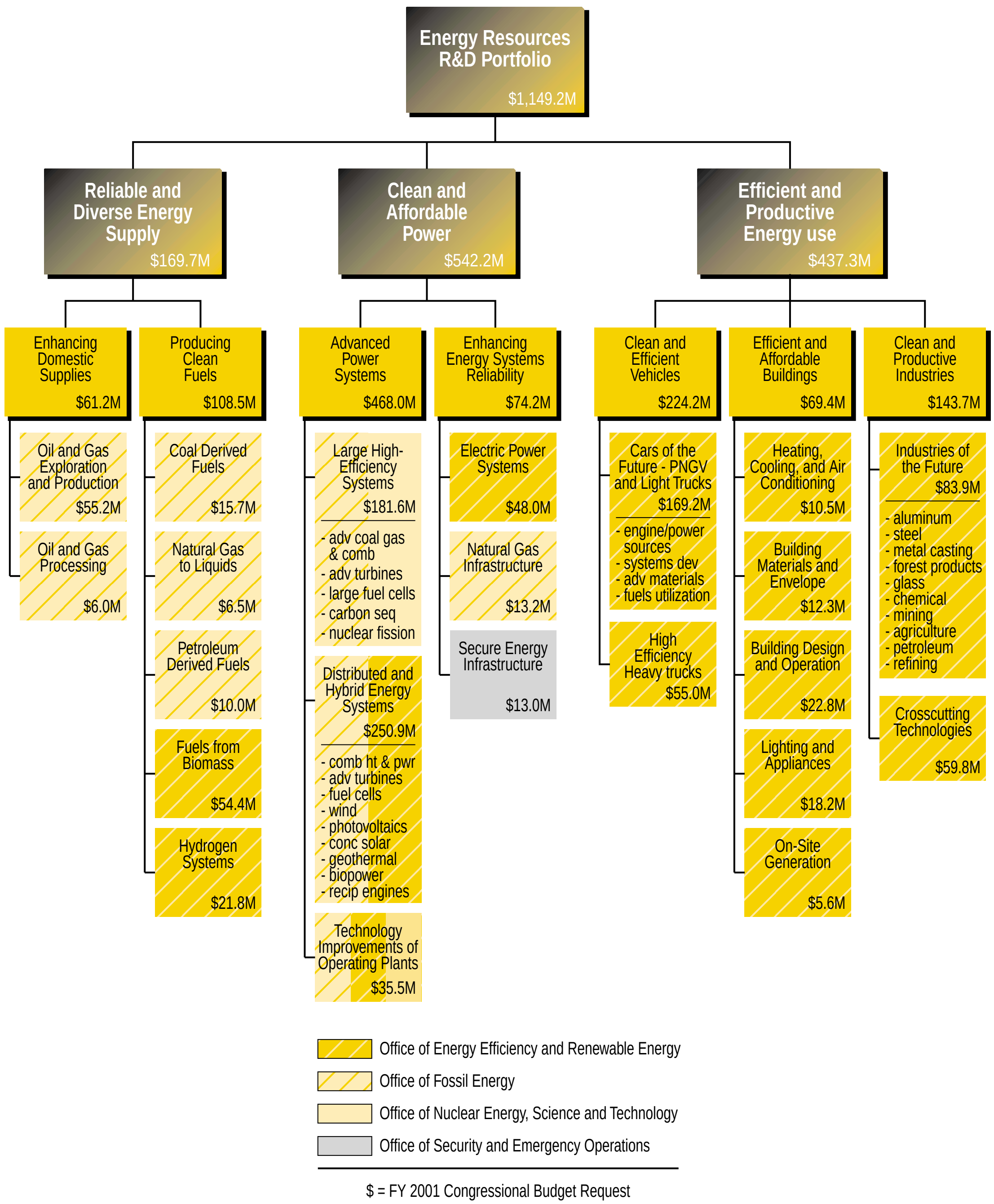
The United States consumes roughly 94 quadrillion Btu's (quads) of primary energy. The Nation's 80 million homes and commercial buildings consumed 36 percent or 34 quads of this total. Buildings also consume two-thirds of all electricity generated nationally. More than $230 billion is spent each year in the United States to provide heating, cooling, lighting, and related energy services for buildings. As more buildings are constructed, even with improvements in energy efficiency, energy consumption and associated economic and environmental costs will likely continue to rise. Energy consumption in buildings is a major cause of acid rain, smog, and greenhouse gas emissions in the United States, representing 35 percent of carbon dioxide emissions, 47 percent of sulfur dioxide emissions, and 22 percent of nitrogen oxide emissions. Given the large opportunity in the buildings sector for resource conservation and minimization of pollutant emissions, the Department has and continues to conduct important R&D related to buildings. This R&D includes high efficiency heating and cooling systems, building materials, building design and operation, advanced lighting systems, and appliances (e.g., refrigeration and water heaters, including solar hot water heaters).

Industry accounts for about 38 percent of U.S. energy consumption and relies on a mix of fuels to produce a myriad of products and services. The industrial sector contains extraction, material processing, and product manufacturing industries. By far, the bulk of energy consumption, emissions, and waste occurs in the processing industries, as well as in a few extraction industries. These process industries, such as steel, chemicals, aluminum, glass, forest products, and metal casting are highly capital intensive, have far larger energy and pollution abatement costs per unit sales, and typically invest far lower percentages of sales into research and development than the U.S. average. Two extraction industries, mining and agriculture, have somewhat similar characteristics. Reducing energy costs, waste, and environmental emissions are key to increased productivity, quality, profitability, and global competitiveness. The Department's R&D activities are grouped by industry, with crosscutting research in enabling technologies (e.g., ceramics, alloy/polymers, sensors and controls) supporting work in the nine industrial groups.

The Role of the Government in Energy-Related R&D

The long time scale required for energy R&D to exert significant influence on deployed energy systems is one reason that energy R&D is not and should not be left entirely to the private sector; even in a free enterprise based economic system such as that of the United States. It is in society's interest to pursue, as part of its strategy for preparing for an uncertain future, some potentially high payoff energy alternatives. The combination of long time horizons, uncertain economic returns, technological risk, and cost of research, development, and deployment makes investing in R&D unattractive to private firms. Another reason for a government role in R&D is that some of the most desirable improvements in energy technologies relate to "externalities" (such as environmental impacts) and to "the public good" (such as national security) that are not valued in the marketplace and hence do not generate the market signals to which firms respond. Still another reason is that the fruits of some kinds of R&D are difficult for any one firm or small group of firms to capture, even though these innovations may be highly beneficial to society as a whole. Finally, the structure of particular energy industries and markets may mask or dilute incentives for firms to conduct R&D from which they, their customers, and society as a whole would all greatly benefit. All of these reasons support publicly funded R&D as one means of insuring continued economic prosperity, environmental quality, and energy security.

Chapter 2
Portfolio Analysis



Chapter 2

Portfolio Analysis

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Overview

This chapter presents an overview of some of the key challenges and opportunities that the nation and the world face in the context of providing ample, economical and clean energy services for the continued economic development and quality of life for humankind in the decades to come. These challenges provide the strategic focus for DOE's Energy Resources R&D Portfolio. This chapter also characterizes the R&D Portfolio in a number of ways, including budget allocations, types of R&D activities, performers, and relationship with private sector activities. This chapter also describes a number of recent energy-related studies and reviews which have developed important conclusions and recommendations for the nations energy R&D programs. Finally, this chapter briefly outlines some of the portfolio changes and additions that DOE has made in response to the recommendations of those studies.

The Context for the Energy Resources R&D Portfolio

The availability of low-cost energy supplies and efficient energy services have been critical to the Nation's prosperity. Technological advances in both the supply and service areas, resulting from both Federal and private sector R&D investments, have reduced the cost of energy production and electricity, enhanced the ease and affordability of transportation, improved the comfort and utility of buildings, and supported a vibrant and competitive industry, while limiting environmental damage. For example, in the post-1970s era the rate of economic growth, as measured by the Gross Domestic Product (GDP), has outpaced the rate of primary energy consumption (see Figure 2-1). While both GDP and primary energy consumption have risen, and are projected to continue to do so, energy intensity – the ratio of energy consumption to GDP – is forecasted to continue to decrease, partly due to continued technological advances.

While energy use per GDP has been decreasing, energy use per capita has been increasing in the 1990s due to low energy prices and changing consumer habits and preferences (e.g., suburbanization and larger vehicles and buildings), as well as an increase in the use of electrical appliances in our homes and businesses (e.g., air conditioners, computers, motors, etc.). Assuming energy and electricity prices remain low into the twenty-first century, this trend is projected to continue, although at a modest rate due to the technological advances (see Figure 2-1). When coupled with an increasing population, the net effect is a projected increase in energy consumption. At the same time, the Energy Information Administration (EIA) is projecting a much smaller increase in domestic energy production. Thus we are facing a growing disparity between energy use and energy production in the years ahead (see Figure 2-1). If this situation occurs, America will be increasingly reliant upon energy imports, particularly oil imports and to a lesser extent gas and electricity imports, to meet energy needs in the twenty-first century.

America's expanding energy needs will present a number of challenges for the Nation in the coming years, a few of which are highlighted here. First, the Nation will face increasing energy demands in all three energy end-use sectors (see Figure 2-2):

- In buildings, to energize expanding building stocks for commercial and public services, and in the home, to provide comfort and entertainment of an increasing population.
- In industry, to power the industrial production for expanding GDP.
- In transportation, to meet the Nation's increasing transportation demands.

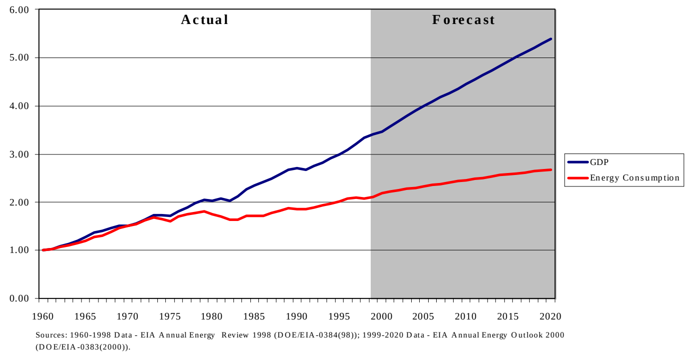
It is generally accepted that while shifts in the makeup of energy supplies and use patterns will occur, there are no "silver bullet" technologies to address the energy demands across the three sectors. Instead, the Nation will continue to require a broad portfolio of economically productive and reliable energy resource, production, conversion, delivery and storage, and end-use technologies to meet the growing energy needs of the buildings, industrial, and transportation end-use sectors.

A second energy challenge facing the Nation is the forecast growth in energy imports. Oil imports are expected to grow from about 50 percent of total use today to 65 percent in 2020 (see Figure 2-2). This has both economic and national security implications for the country. Economically, it represents a massive export of U.S. dollars and jobs to foreign countries. From a national security standpoint, it means that our country will become increasingly dependant upon foreign oil reserves in the twenty-first century, should recent trends continue. This challenge makes the Department's fossil fuel and alternative fuel R&D activities a prudent investment for the country's continued economic well-being and national security.

A third energy challenge facing the Nation is the recognition that energy resource production, conversion, delivery, storage and end-use technologies must be developed in ways that are environmentally responsible. This means pursuing environmentally friendly technologies. For example, energy production and use are the primary sources of the Nation's carbon emissions, accounting for 98 percent of total U.S. carbon emissions in 1997 (Source: EIA "Emissions of Greenhouse Gases in U.S. 1997). With increasing energy consumption, and absent any change in energy policies or regulations, carbon emissions are projected to increase about 33 percent over 1997 levels by 2020. The Department's Energy Resources R&D Portfolio is addressing the carbon emissions challenge by investing in a variety of clean fuel options, such as natural gas and renewable energy technologies, as well as energy efficiency technologies applicable to energy conversion (utilities) and the buildings, industry, and transportation end-use sectors.

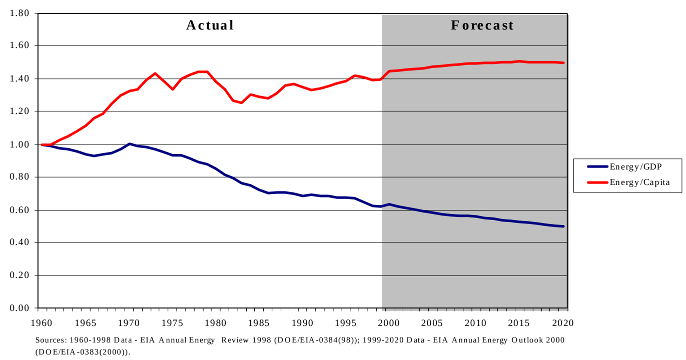
A fourth energy challenge facing the Nation is the electricity industry's transition from a regulated monopoly to a restructured electricity market. This transition poses new challenges to the continued reliable transmission and distribution (T&D) of electricity; the market penetration of advanced energy technologies that tend to be more costly than conventional options; and the universal access to electricity American's have come to expect in the latter part of the twentieth century. The Department's Energy Resources R&D Portfolio is addressing these challenges by

GDP and Energy Consumption
(Index 1960=1)



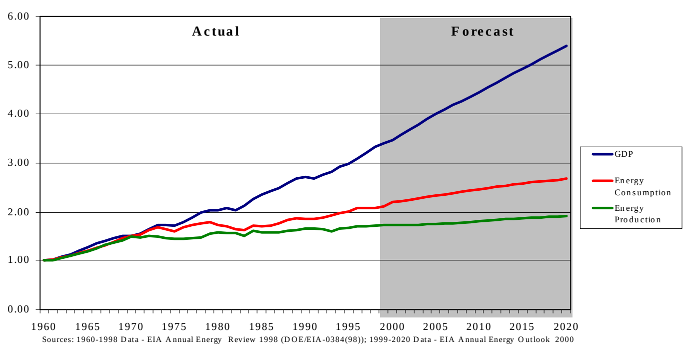
GDP growth is expected to continue at approximately the level of the past two decades. Energy use is also expected to increase, at a somewhat lower level, however, than the GDP.

Energy Use per Capita and per GDP
(Index 1960=1)



Energy use per unit of GDP is projected to continue to decrease. Advancing technology and shifts to less energy intensive industries are the primary contributors to that decrease. However, energy per capita is expected to continue to grow slowly.

GDP, Energy Consumption & Production
(Index 1960=1)

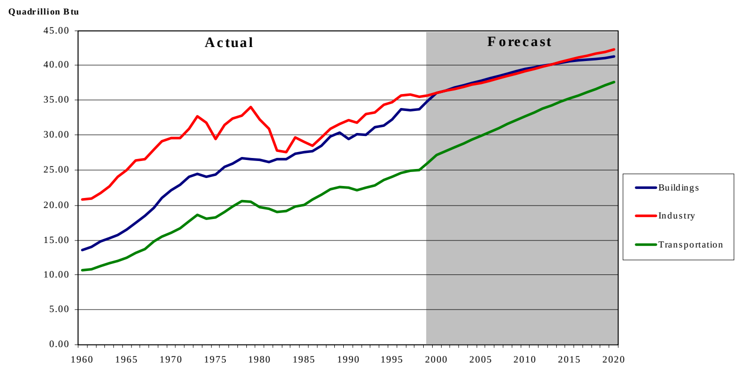


GDP Domestic energy production is projected to lag energy consumption, implying an increasing dependence on imports.

Energy Trends

Figure 2-1

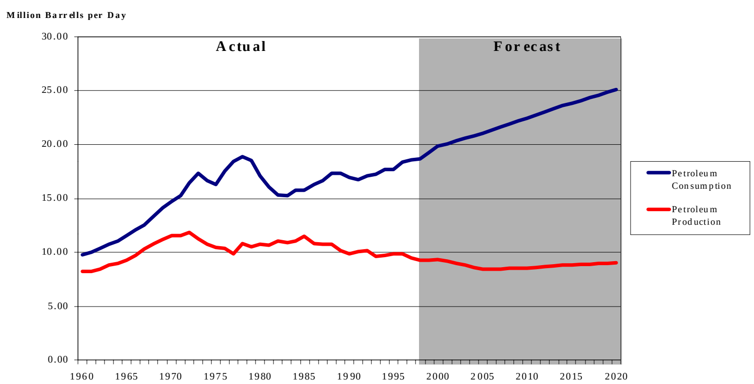
Energy Consumption by Sector



Sources: 1960-1998 Data - EIA Annual Energy Review 1998 (DOE/EIA-0384(98)); 1999-2020 Data - EIA Annual Energy Outlook 2000 (DOE/EIA-0383(2000)).

The growth in energy consumption is occurring across all three energy sectors.

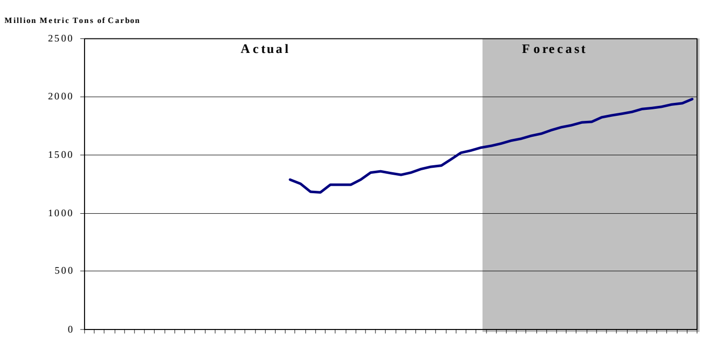
Petroleum Consumption and Domestic Production



Sources: 1960-1998 Data - EIA Annual Energy Review 1998 (DOE/EIA-0384(98)); 1999-2020 Data - EIA Annual Energy Outlook 2000 (DOE/EIA-0383(2000)).

Total petroleum consumption and petroleum imports are projected to continue to rise steadily, with imports representing 65% of total use by 2020.

Carbon Emissions



Sources: 1980-1997 Data - EIA Emissions of Greenhouse Gases in the United States 1997 (DOE/EIA-0573(97)); 1999-2020 Data - EIA Annual Energy Outlook 2000 (DOE/EIA-0383(2000))

Carbon emissions have risen steadily since 1990 and that trend is projected to continue under current laws and regulations.

Energy Consumption and Carbon Emissions Trends

Figure 2-2

investing in a Transmission Reliability program that is intended to ensure an efficient, reliable power system through development of advanced T&D technologies, as well as efforts to develop and promulgate a uniform, nondiscriminatory national interconnection standards to enable the integration of distributed power resources into the electricity infrastructure. The Department also participates in electricity policy formulation activities to help ensure fair consideration of energy efficiency and renewable energy resources, as well as access to affordable power for all citizens.

While the Nation faces these challenges, energy R&D must also consider the global environment. Human populations are more crowded, more consuming, more connected, and more diverse. By 2050 there will be nine billion people, by 2100 ten to eleven billion. The challenge is to translate global interests into energy supply and demand practices that also work locally and regionally; thereby providing reliable energy with less environmental damage. These global sustainability issues will present serious challenges for the long-term future.

In summary, the Nation is facing a range of serious challenges associated with our future energy economy. In addition the The Department's Energy Resources R&D Portfolio, which is described in detail in this document, is focused on addressing those challenges. The contents of this portfolio have been defined and are continually re- focused through an ongoing process of portfolio planning and analysis and technology roadmapping activities. The results of these processes are presented annually to the Nation in the Administration's budget request for this Energy Resources R&D Portfolio.

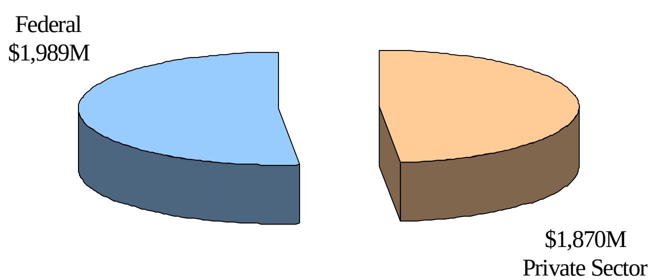
The Energy Resources R&D Portfolio in Brief

This section provides summary information on some of the key characteristics of the Energy Resources R&D Portfolio, including range and types of R&D activities, budgets, and R&D performers. Detailed information on the portfolio is presented in the following seven chapters. In addition, Chapter 10 discusses basic science programs that provide fundamental research support for the entire Energy Resource R&D Portfolio.

DOE and Private Sector R&D Funding

Research and development funded by DOE must be considered in context with that being funded by the private sector and others. Available data suggest that the Department's energy R&D investment is comparable to that of the private sector, although DOE's actual investment may be lower due to limitations in access to information on private sector R&D activities (see Figure 2-3). There are several considerations that are important for understanding the private sector and federal government motives for energy R&D. The private sector is very diverse, encompassing large companies, many of which are highly profitable, as well as areas containing mostly small start-up companies or not-yet profitable companies. Other factors include target market characteristics, the potential to affect national needs such as national security or environmental quality, the regulatory environment, and changes in R&D funding levels in recent

Private Sector and Federal Energy Resources R&D Funding - 1996 & FY2000 Respectively



Note: There is a difference in the years for private and Federal because 1996 is the latest year for which we have private sector data, and FY2000 is the earliest year for which actual DOE Energy Resources and Science R&D data are available.

Source: DOE Energy Resources and Science R&D programs, National Science Foundation, Electric Power Research Institute, and Gas Research Institute.

Figure 2-3

years—increasing in some industries and decreasing in many more. These all vary between industries and affect the prioritization and focus of DOE's R&D portfolio in each program area.

Typically, industry concentrates on near-term R&D and deployment of relatively mature technologies, while the DOE portfolio focuses more on mid-to long-term R&D—although there are exceptions in both cases. The ratio of Federal to private funding is much higher during the earlier and higher R&D risk stages and decreases during the innovation stages of product development and testing until, at the marketing and commercialization stages, it is essentially wholly a private sector undertaking. Another trend is the increasing collaboration and partnering between companies as well as between industries and DOE. The Department cost-shares with industry during the development stage.

The major energy producers (e.g., integrated oil and gas producers, refiners, and transporters) provide the largest portion of private sector energy R&D funding, representing $1.3 billion of the $1.9 billion private sector energy R&D total.[1] This is down from a peak of over $3 billion in 1991, and represents a considerable contraction of private sector funding for energy-related research, in part due to falling energy prices. Moreover, this R&D is aimed principally at improving the discovery, extraction, production, and refining of liquid, gaseous, and solid fossil fuels. Funding by the electricity industry has also declined significantly in recent years, in part due to uncertainties associated with restructuring of electricity markets.

There are significant limitations in our knowledge of the total energy R&D expenditures by the private sector and others. Most significant is in the area of energy efficiency. Much of the data are proprietary and not reported. Even more significant is that much of the R&D in this area is multi-purpose and advances in energy efficiency might be a secondary motivation for the R&D investment. For example, technological advances may be undertaken to improve industrial

[1] This estimate is based on the $1.3 billion reported by the National Science Foundation's *Survey of Industrial Research and Development for 1996*, plus an estimated $560 million by the Electric Power Research Institute and Gas Research Institute. The U.S. Energy Information Administration's Financial Reporting System reported total R&D expenditures of $2.7 billion in 1996, of which $1.6 billion was for "nonenergy" R&D (primary chemicals and petrochemicals). Given the differences in the survey methodology, these data correspond closely to the National Science Foundation survey.

processes for better process quality control which at the same time increase energy efficiency. The development of new technology for a piece of equipment may be undertaken in such a way that the new product would have higher performance, more rapid throughput, and use less electricity at the same time. Hence, that portion of individual R&D activities associated with energy reduction cannot be isolated. The expenditures of this type are likely to be in the hundreds of millions of dollars, and if aircraft and military products were included, likely very much more.

For similar reasons, the R&D programs of non-DOE Federal agencies are not included in Figure 2-3. There also is energy research funding provided by some State governments and by the renewable energy industries that is not captured in the totals provided in Figure 2-3; however, the ratio of DOE to other funding sources would not be significantly affected by inclusion of these expenditures.

DOE Energy Resources R&D Portfolio Budgets

The Energy Resources R&D Portfolio is organized into three broad strategic areas.

- Reliable and Diverse Energy Supply
- Clean and Affordable Power
- Efficient and Productive Energy Use.

In addition, the energy-related research sponsored by the Office of Science provides the basic research underpinnings that support the full range of energy technology R&D efforts in these three areas. These areas are particularly well-suited for communicating DOE's R&D activities because they follow a supply/-conversion/end-use construct that is familiar to energy system stakeholders, and they create groupings where technology similarities are more easily identified. The budget allocation to these strategic areas is displayed in Figure 2-4.

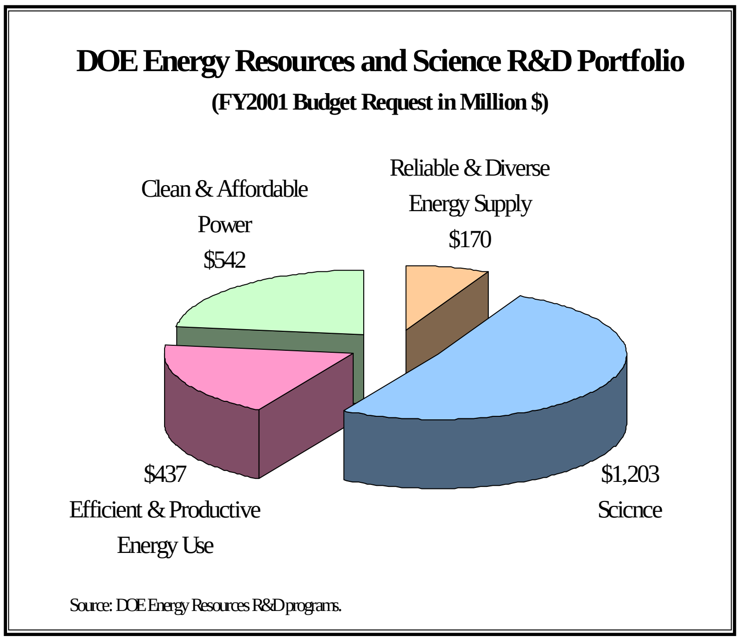


Figure 2-4

This resource allocation among the four strategic areas is reasonable when consideration is given to the characteristics of energy markets, the number of R&D opportunities, the associated R&D costs, and the appropriateness of a Federal role.

- Seven percent of the portfolio focuses on activities categorized as ***Reliable and Diverse Energy Supply***, that includes R&D to maintain and increase domestic production of oil, gas, and clean alternative fuels. Similar to many power technologies, technologies in this area are frequently characterized by large, complex systems. However, overall funding is lower because the timeframe associated with the development of hydrogen, liquid fuels from natural gas and coal, and some parts of the biofuels R&D portfolio are relatively longer-term. In addition, significant R&D is conducted by the private sector for oil and gas production, particularly activities directed toward near-term operational issues. This allows Federal efforts to focus on high benefit areas beyond industry's short-term focus.

- Funding for ***Clean and Affordable Power*** accounts for 23 percent of total portfolio expenditures. Faced with competitive pressures brought on by electric utility restructuring, industry-funded R&D has decreased from what were already relatively low levels, and are focused more on near-term operational issues. This adds even greater importance to the Federal R&D role, which has traditionally focused on longer-term power systems opportunities across a broad range of resource and conversion technologies, from coal and gas-fired power plants to nuclear and renewable power systems. There are attractive advanced technology options in all of these areas. This area is also important because power production, which accounts for 36 percent of domestic energy consumption, is one of the most significant contributors to air emissions, including greenhouse gases, and other local/regional pollutants.

- Funding for ***Efficient and Productive Energy Use*** is 19 percent of total portfolio expenditures. Industry R&D in this area, particularly for industrial and building-related efficiency, has historically been low due to the fragmented nature of the industry and the difficulty of any one company capturing sufficient benefits from the R&D. This area has a very high national priority because efficiency not only brings immediate economic benefits, but also offers a relatively quick path for achieving significant air emissions reductions. There are hundreds of technologies in the energy efficiency portfolio (compared to dozens in power generation), reflecting the myriad number of R&D opportunities available. These activities range in size from small scale (electronic controls) to broad complex programs such as the advanced, ultra-high mileage vehicle (PNGV) program.

- It should be noted that a nearly equivalent amount of ***Office of Science*** funds (51 percent) support energy-related basic research that provides the scientific underpinnings of the applied energy research and development programs, and which are described in Chapter 10 and the companion Science Portfolio.

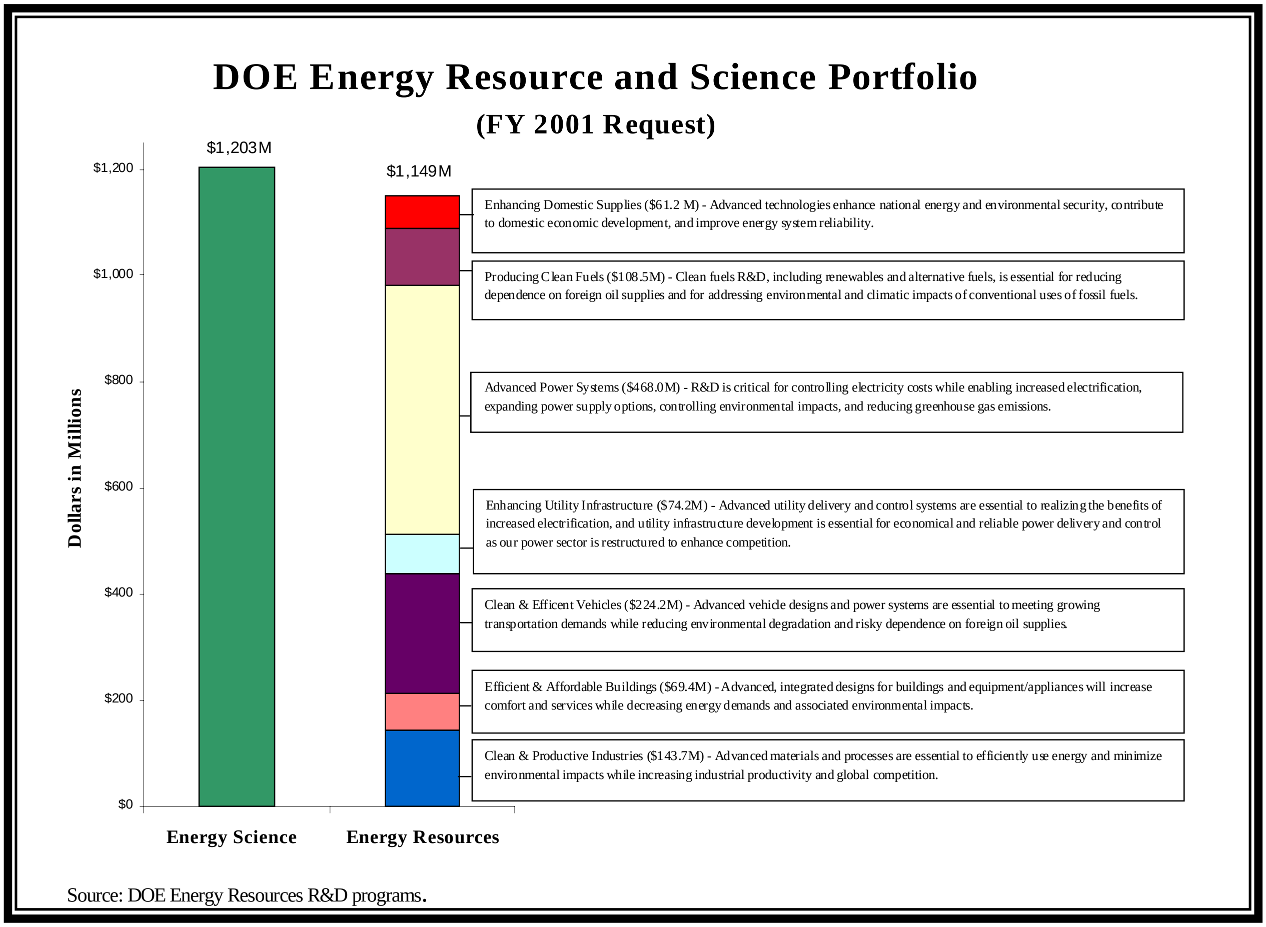
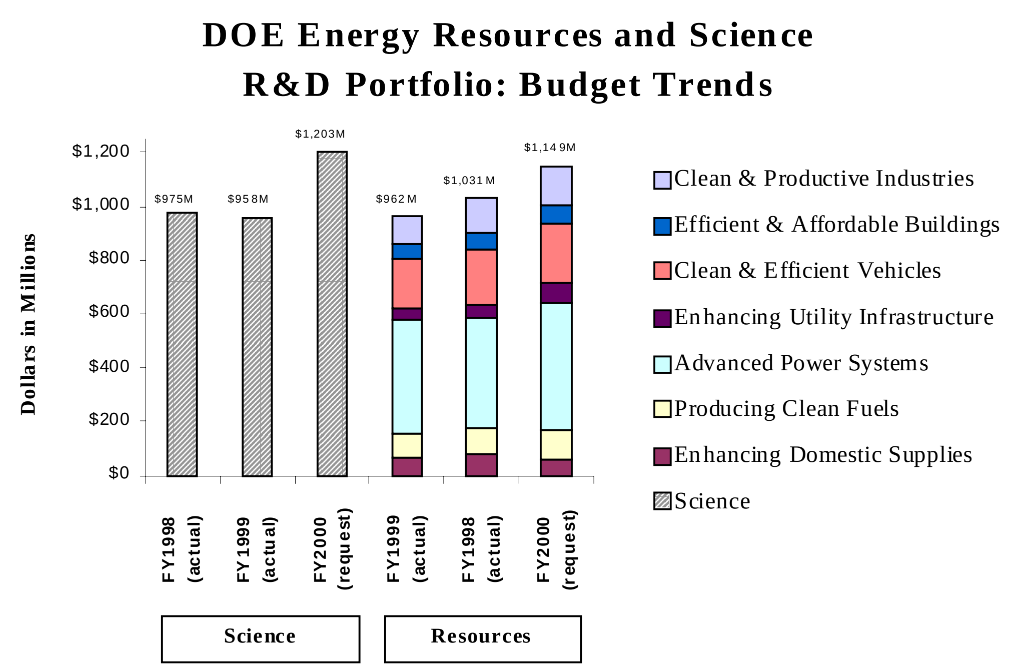


Figure 2-5

Figure 2-5 shows a breakout of the DOE budgets at the next level of detail for the seven portfolio areas shown as the second row of the Energy Resources R&D Portfolio diagram for the FY 2001 request. This figure also shows the more important roles of each of the portfolio areas.

Budgets for 3 years, FY 1999, FY 2000, and the President's request for FY 2001, are provided in Figure 2-6. This figure indicates that the budgets for science and the seven different areas are fairly stable over these 3 years. These budget levels reflect the evolution and balancing of R&D opportunities and priorities, as well as the need for Federal support, in these portfolio areas over many years. For example, R&D in ocean thermal energy conversion has been dropped, as we have learned that this technology offers only minimal potential for the United States because of resource and technology performance limitations. On the other hand, developments in biogenetics and in gasification technologies have led to an increased emphasis on R&D of bioenergy technologies. Similarly, the Department is recommending increased nuclear energy

R&D as a prudent action, in part, because of concerns over global warming. In addition, recent developments in the understanding of methane hydrates are leading to increased interest in the development of technologies for tapping those vast natural gas resources.



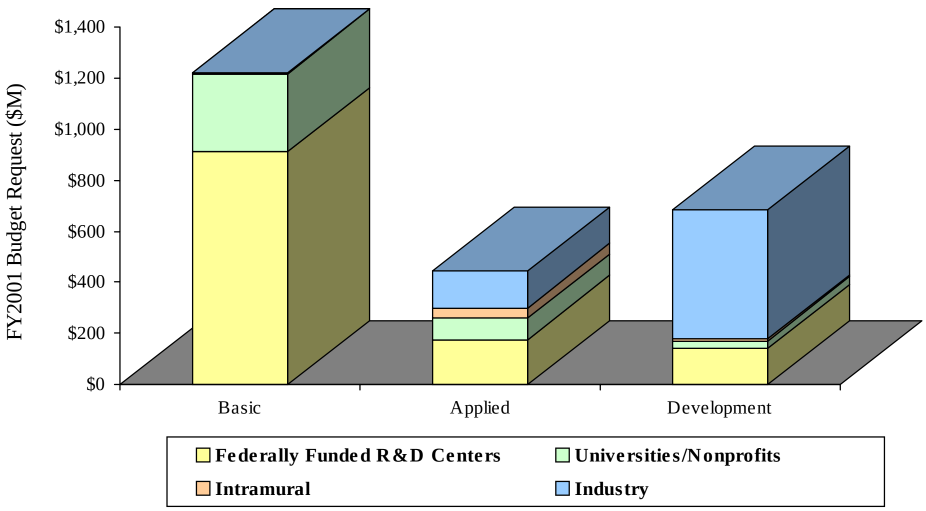
Source: DOE Energy Resources R&D programs.

Figure 2-6

Types of Energy R&D

The Department's R&D work in energy falls under three categories as defined by the Office of Management and Budget (OMB): basic research, applied research, and development. Basic research is defined as systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. Applied research is defined as systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met. Development is defined as systematic application of knowledge toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements. Figure 2-7 displays an estimate of the breakout of the FY2001 budget request by R&D type.

DOE Energy Resources and Science R&D Portfolio by Performer and Type of R&D



Note: Performer and Type FY2001 distributions are assumed to be similar to FY1998 distribution, which is the last year for which actual Performer and Type data are available.

Source: DOE Energy Resources and Science R&D programs.

Figure 2-7

Approximately 29 percent of the Energy Resources and Science R&D funding ($686 million) is devoted to technology specific developmental work. This R&D generally attempts to produce a technological prototype that is at sufficient scale to convince industry to move to the commercialization stage. This is generally the most expensive precommercialization step, and because profit potential is emerging at this point, the Department seeks the greatest amount of cost share in this stage. As an example, an Office of Fossil Energy-led team including industry, a National Laboratory, and several government organizations is developing alternative diesel fuel via the Fischer-Tropsch (F-T) indirect liquefaction process. The fuel has been shown in preliminary engine tests to produce much lower emissions than its petroleum-derived counterparts, which has generated strong interest among the diesel engine manufacturers.

Approximately 19 percent ($445 million) of energy R&D is applied research. The Department's energy resources R&D places significant emphasis on applied work which helps bridge the gap between fundamental science and marketable technologies. In this effort, we seek to apply the capabilities of the National Laboratories, universities, and industry to the resolution of specific technical barriers to the use of cleaner, more efficient energy processes (see Figure 2-7). For example, fuel cell research for transportation applications places particular emphasis on applied research of fuel cell materials and components to achieve high efficiency, long life, and low manufacturing costs. This work is directed at component development, subsystem development, and technology integration and validation for stacks, fuel processors, and hydrogen storage. Methanol, ethanol, natural gas, and gasoline are being evaluated as fuels for on-board reforming for fuel use. Industry teams led by Chrysler-Pentastar, Ford, and General Motors are completing development of 10-50 kW fuel cell systems under cost-shared contracts. These projects include both methanol-fueled and direct hydrogen systems.

About 52 percent ($1,221 million) of the Energy Resources and Science R&D Portfolio is categorized as basic. The applied energy technology programs (fossil, nuclear, efficiency, and renewables) spend a very small fraction on basic research while relying on the Office of Science to carry out the basic research that provides the foundation necessary to understand the fundamental principles and mechanisms that govern energy technologies. Much of this work is carried out in collaboration with programs in the Office of Science, and the bulk of the research is performed by National Laboratories and universities (see Figure 2-7). This basic research focuses on areas such as novel methods to produce hydrogen from renewable resources or to fabricate high value carbons, especially those useful for hydrogen storage, membranes and catalysts for fuels processing, and production of high value chemicals from coal.

DOE Energy R&D Performers

The Department of Energy uses a broad range of performers in carrying out the Energy Resources R&D Portfolio, including industry, universities, national laboratories, intramurals, and other governmental agencies.[2] Figure 2-7 also displays an estimate of the breakout of the FY2001 budget request by performer.

Industry plays an important role, especially in the development and applied research areas, reflecting the importance that the Department places on technology development in the private sector where these technologies must succeed, as well as a strong belief in the effectiveness of public-private research, development, and demonstration (RD&D) alliances which have also been recommended for energy R&D activities (see 11-Lab Report; PCAST; Yergin Report). Many of the R&D projects involving industry are cost-shared with industrial partners.

National laboratories, labeled as Federally Funded R&D Centers in Figure 2-7, are used in all areas because of their ability to conduct multidisciplinary research that is essential in the energy R&D area, and their extensive energy technology expertise, including world-class science and engineering staff who have conducted and managed R&D for more than 50 years. The National Laboratories have conducted much of the basic science research that provides the scientific underpinnings for many technology breakthroughs in energy and other areas. They also have a proven ability to successfully develop and evaluate advanced technologies, and they provide

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[2] Intramural refers to R&D performed by Federal employees at DOE or other Federal agencies.

unique facilities for use by researchers from industry and academia, as well as by their own researchers, for the development of energy-related technologies.

University researchers contribute both new concepts and in-depth, specialized capabilities. They provide a wealth of scientific and engineering talent to undertake the cutting-edge research required to address the energy-related challenges facing the country. In addition to providing scientific resources, universities are the training ground for the future scientists and engineers needed to sustain a national effort to meet the energy goals contained in the Comprehensive National Energy Strategy.

Analysis of the Portfolio

A number of studies have analyzed or reviewed all or parts of DOE's Energy Resources R&D Portfolio[1] over the past several years. This section reports on the most relevant of those studies, including their key conclusions and recommendations for the portfolio. Three of these studies, with very recent and specific relevance for the portfolio, are discussed in some detail. Several other studies are briefly outlined.

A necessary component of any such exercise is a set of strategic goals (or criteria) against which to carry out the analysis. The top-level goals of the Comprehensive National Energy Strategy (CNES) as listed in Chapter 1 are generally representative of the goals used in these various studies and reviews.. The goals address national needs in areas for which there is a government role: Economic productivity, Security, Environment, Future energy choices, and Global issues.

Federal Energy Research and Development for the Challenges of the Twenty-First Century (PCAST-Federal)[2]

This is the report issued by the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology (PCAST) in November of 1997. The report is referred to here as PCAST-Federal to distinguish it from the subsequent PCAST International study described below. The panel members were from universities, industry, and non-government organizations. The study was in response to President Clinton's request that PCAST undertake a review of the current national energy R&D portfolio.

The report addresses in some detail energy challenges and opportunities, the role of R&D, and the spectrum of energy technologies organized in five areas: energy efficiency, fossil energy, nuclear energy (fission and fusion), and renewable energy. The report concludes with crosscutting issues and synthesis. The report has many findings and recommendations. Included in the recommendations are the following that seem most relevant for present purposes:

- That the federal energy technology R&D portfolio be strengthened by increasing the funding for four of the major elements: energy efficiency, fission, renewables, and fusion.

- That the fossil energy element of the portfolio be strengthened by restructuring, including increasing the support for advanced coal-power programs, carbon capture and sequestration, fuels cells and other hydrogen technologies, and advanced oil and gas production and processing.

- That there should be a modest research initiative in the nuclear fission area to find out whether and how improved technology could alleviate concerns about this energy technology, given its ability to reduce carbon dioxide emissions.

- That there be better coordination between the fundamental research being carried out by Basic Energy Sciences and the applied energy technology programs.

- That DOE regularly and systematically conduct a portfolio analysis across the breadth of R&D options and to use this as an input to overall program planning.

- That the government [together with national labs, industry, and universities] should engage strongly in international energy technology R&D and, where appropriate, development and commercialization efforts to regain and/or maintain the scientific, technical, and market leadership of the U.S.

Energy Resources R&D Portfolio Analysis [The Portfolio Analysis Experiment][3]

In the Spring of 1999, the Undersecretary of Energy called up a group of Energy Program representatives to undertake an analysis of DOE's Energy Resources R&D Portfolio. The group selected the Vital Issues Process (VIP) developed by Sandia National Laboratories as the framework for the analysis. Because of time and other constraints, the process was not used to its fullest extent and did not involve the desirable participation of "stakeholders" from industry, academia, and non-government organizations (NGOs). For these reasons, the analysis has been considered an "experiment".

The portfolio of energy technologies to be analyzed was organized according to a "boxology" that was very similar to the one used this report. A set of strategic goals was "refined" from the CNES goals, taking into account the strategic criteria put forth by PCAST-Federal and certain conditions needed to conduct the analysis.

One important focus of the analysis was whether the portfolio adequately addresses each goal. The results are summarized as follows:

Goals adequately addressed, with some gaps	▪ Economic Productivity ▪ Oil Vulnerability ▪ Pollution
Goals inadequately addressed	▪ Energy System Reliability (electric and natural gas) ▪ Global Sustainability
Mixed Review	▪ Greenhouse Gases – near term adequate but long term inadequate

Another important outcome of the process was the identification of gaps in the portfolio and opportunities to strengthen the portfolio. The R&D areas so identified are summarized as follows:

- Electric infrastructure reliability, security, and integrity.
- Natural gas infrastructure reliability, security, and integrity.
- Maintaining a viable nuclear energy option.
- On-board hydrogen storage systems for vehicles.
- Advanced separations membranes.
- Carbon sequestration.
- Efficiency improvements in commercial buildings.
- Sensors and controls for a variety of applications.
- Methane hydrates.
- International collaborative R&D on advanced energy technologies, particularly for developing countries.

In addition, a number of opportunities were identified for cross-cutting portfolio planning. These are summarized as follows:

- Clean fuels: Coordination needed across various fuels R&D activities, and with various engines and fuel cell activities.
- Fuel cells: Integrated development of applications across a variety of end uses.
- Long-term greenhouse gas stabilization: Development of a comprehensive technology roadmap (with EPA, USDA, USAID, etc.).
- Biotechnology: Integration of the many aspects of biotechnology within the Department.
- Global sustainability: Development of a DOE vision and strategy for Multi-nation cooperation and collaboration.

Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation (PCAST - International)[4]

This report was issued by the PCAST Panel on International Cooperation in Energy Research, Development, Demonstration, and Deployment (ERD[3]) in June 1999. The Panel consisted of qualified individuals with diverse backgrounds and viewpoints, supported by a staff from various national councils, industry, and national laboratories. This report will be referred to here as PCAST-International to distinguish it from the PCAST-Federal described above.

The Panel reviewed the U.S. stake in international cooperation on energy innovation, the complementary roles of the public and private sectors in pursing such cooperation, and the existing array of related activities being carried out by the U.S. Federal government. Specific recommendations include:

- Stronger foundations for energy technology innovation and international cooperation related to it, including initiative clusters focused on capacity building, energy-sector reform, demonstration and cost-buy-down,[3] and financing.

- International cooperation for innovation on energy-end-use technologies, including initiative clusters focused on energy-efficient buildings, improved small vehicles and buses, factories of the 21st century, and cogeneration of heat and power.

- International cooperation for innovation on energy-supply technologies, including initiative clusters focused on widespread use of renewable energy technologies, fossil-fuel decarbonization and CO2 sequestration, and nuclear fission and fusion.

- Mechanisms and institutions through which the U.S. government, in cooperation with the private sector, can more effectively develop, manage, and coordinate a portfolio of governmental activities in support of international ERD[e] cooperation, including:
  - Establishing a new Interagency Working Group on Strategic Energy Cooperation to provide a strategic vision of and coordination for the government's efforts in international cooperation on energy-technology innovation, and
  - Providing – as the U.S. government's contribution – a new Strategic Energy Cooperation Fund (estimated by the PCAST Panel to be $250 million for FY2000, increasing to $500 million in FY2005) for the expansion of international energy cooperation activities.

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[*] Cost-buy-down is the process of subsidizing the difference in unit cost between an innovative energy technology and a conventional energy technology to increase sales volume, thus stimulating cost reductions through manufacturing scale-up and economics of learning throughout the production, distribution, deployment, use and maintenance cycle.

The bases for the PCAST Panel's proposed specific initiatives include a number of study findings and conclusions. A key conclusion is that world energy demand and use are tightly linked to the U.S. economic, environmental, and nation-security interests. These interests, therefore, can only be effectively addressed in a global context. The U.S. economic interests in energy-technology innovation, for example, include expanding the market share of U.S. companies in the multi-hundred-billion dollar per year global energy-technology market. Another example is the U.S. security interests in reducing the potential for conflicts over access to oil and gas resources thereby avoiding, for all countries, environmental or political consequences severe enough to aggravate or generate possibilities for armed conflict.

Other Reports Related to Portfolio Analysis

Energy R&D: Shaping our Nation's Future in a Competitive World (Yergin Report)[5] This is the report, dated June 1995, of the Task Force on Strategic Energy Research and Development - commonly know as the "Yergin" report after the chair of the Task Force, Daniel Yergin. The Task Force was commissioned by the Secretary of Energy and reported to the Secretary of Energy Advisory Board (SEAB). The members represented a broad cross-section of the energy community: universities, industry, non-government organizations, and state governments. The Task Force was asked by the Secretary "... to review the DOE strategic energy portfolio, from basic research through applied research and demonstration programs, ..."

The two most relevant recommendations of this report are:

1. That the Federal government continue to provide leadership, focus, and substantial financial support for energy R&D to ensure that the national goals of U.S. energy security, economic strength, environmental quality, and national leadership in science and technology are effectively achieved.

2. That DOE develop an integrated strategic plan and process for energy R&D, and use this process to determine funding priorities and manage a diverse energy R&D portfolio.

Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions ("11 Lab" Study)[6]
This study was stimulated by President Clinton's address before the UN on June 26, 1997:

> "The science is clear and compelling: we humans are changing the global climate... In order to reduce greenhouse gases and grow the economy, we must invest more in the technologies of the future. I am directing my Cabinet to work to develop them."

In response, Secretary of Energy Federico Peña called upon eleven DOE Laboratory Directors to provide him with a "climate change technology strategy". The report is commonly referred to as the "11 Lab" study. The study focused a single strategic goal: reducing greenhouse gas emissions.

The main body of the report makes the case that significant CO_2 emission reductions can be achieved through a combination of :

- Development and broader use of energy efficiency measures in the buildings, transportation, and industrial sectors, to reduce primary energy use.
- Development and broader use of "clean" energy supplies, including renewable, nuclear, advanced fossil supply technologies.
- Development and use of carbon sequestration technologies.

The report makes it clear that there are many R&D opportunities to develop technologies for reducing emissions, but does not present a "technology strategy" since such a strategy requires policies as well as R&D.

An appendix to the report describes some 47 Technology Pathways (e.g., Photovoltaics). The Pathways provide estimated carbon reductions, treat risk in a relatively systematic fashion, and outline the R&D and associated federal expenditures that would be needed to achieve the estimated carbon reductions. As such, the report provides a thorough description of a “portfolio of opportunities” for the nation to reduce greenhouse gas emissions.

Scenarios of U.S. Carbon Reductions - Potential Impacts of Energy Technologies by 2010 and Beyond (“5 lab” study)[7] This study was commissioned by the DOE Office of Energy Efficiency and Renewable Energy and carried out by the Interlaboratory Working Group on Energy-Efficiency and Low-Carbon Technologies. The Working Group had members from five labs - ANL, LBNL, NREL, ORNL, and PNNL - and the report is commonly referred to as the "5 Lab" study. The report focuses on energy efficiency in buildings, industry, transportation; renewable energy; and fuel switching in the utility sector from coal to natural gas. The emphasis is on the potential of existing technologies to reduce U.S. carbon emissions to 1990 level by 2010. While the report does address R&D which could lead to carbon reductions over the longer term, it is less comprehensive than the Yergin, PCAST, and 11 Lab studies and largely limited to analysis of the potential of energy efficiency and renewable energy technologies.

Electricity Technology Roadmap, 1999 Synthesis and Summary (EPRI Roadmap)[8] The Electric Power Research Institute issued this report in July 1999. It summarizes the results of a broad review of the appropriate role of electricity to meet global energy needs in the decades to come. Key conclusions relevant to this portfolio include:

- Targeting of a “2% solution” for global sustainability, which represents 2% per year global improvements in economic productivity, energy efficiency, emissions reductions, agricultural yields, and water consumption.
- A strategic science and technology initiative to address climate change concerns.
- An increase of nearly $5 billion per year in U.S. electricity technology related R&D.

Reliability: Energy Grid for the 21th Century (CERTS Paper)[9] This paper by the Consortium for Electric Reliability Technology Solutions (CERTS) provides a DOE-sponsored analysis of issues affecting short to long-term reliability and security of the electric utility infrastructure in a deregulated market. Under this emerging electricity market structure, ensuring reliable service will require new interface and control technologies and strategies to effectively integrate a wider variety of supply and delivery resources with load requirements that are also varying. The paper's key recommendation is that DOE initiate a new program in utility systems reliability

Review of the Research Program of the Partnership for a New Generation of Vehicles, Fifth Report (PNGV Peer Review)[10] The National Research Council (NRC) periodically reviews the Partnership for Next Generation Vehicles (PNGV), often referred to as the "Peer Review". In its 1999 report, the NRC committee concluded the PNGV technical efforts, for the most part, were properly directed.

The NRC committee noted that an integrating function to the portfolio is needed to prevent government agency support of specific regulatory objectives from adversely influencing advancement of promising technologies. For instance, the NRC committee advises that future emissions standards planning should be better integrated into the overall PNGV systems analysis.

Carbon Management: Assessment of Fundamental Research Needs[11] This study was commissioned by the Director of the Office of Energy Research (now Science) "to understand carbon management strategies in terms of the basic research needed to develop them – that is, research that might be supported by the Office of Energy Research, and to catalogue the areas in which further technological advances depend upon prompt improvements in the underlying science". The study was lead by four national labs, with participation of others.

The study addressed the research needs in five areas: (1) Decarbonization strategies, and carbon dioxide capture, transport, sequestration, and utilization, (2) Hydrogen development and fuel cells, (3) Enhancing the natural carbon cycle, (4) Biomass production and utilization, and (5) Improved efficiency of energy production, conversion, and utilization. The study provides a potpourri of fundamental research topics linked to these five areas.

Carbon Sequestration, State of the Science[12], and 1999 National Methane Hydrate Multi-Year R&D Program Plan[13] Research and development needs in specific areas of carbon management and future energy supply were examined in these reports. These complex areas present significant challenges that can only be addressed by a long-term national commitment. Within the specific areas addressed by these documents, there is good agreement between the needs identified and the Energy Portfolio.

Final Note

Common to all the reports and reviews is the need for coordination and integration of research and development activities. Whether at the sub-system component level as in PNGV or at the national and international level of anthropogenic carbon control, no single R&D activity can ultimately succeed as a standalone effort. Technical, regulatory and budgetary issues that crosscut the Energy Resources R&D Portfolio must be thoroughly identified and addressed to provide all levels of policy makers the information required to make correct decisions affecting energy issues for several decades.

R&D Portfolio Responses

The energy issues and program studies and reviews described above have led to a number of changes in DOE's Energy Resources R&D Portfolio. This section highlights some of the most important Portfolio additions and changes.

Nuclear Energy Research Initiative. In August 1997, the PCAST Federal study stated that "fission belongs in the R&D portfolio." In response to these and other recommendations from Congress, DOE initiated the Nuclear Energy Research Initiative in FY99, commissioned a Nuclear Energy Research Advisory Committee composed of "outside" experts, and chartered the development of a roadmap to chart a course for R&D over the next 30 years. Several promising and revolutionary projects were initiated in FY99 that could result in reduced capital costs for future nuclear plants, high efficiency energy conversion concepts, and advanced proliferation-resistant fuel cycle concepts that will also incorporate the rapid advances being made in information and sensor science and technology.

On May 7, 1999, DOE selected 45 science and technology research proposals for NERI awards from a total of 308 proposals submitted. These awards represent 46 separate organizations, including 21 universities, 8 national laboratories, 16 industrial organizations, and 1 Federal Government research organization. Many of these projects are collaborative research efforts among multiple organizations. The awards also involve substantial foreign collaboration with four universities and six industrial/R&D organizations including organizations in France, Japan, Italy, Great Britain, and Canada. A budget of $19 million was appropriated for the NERI Program in FY99.

Carbon Sequestration. Several of the studies described in the previous section call for R&D on carbon sequestration, including the PCAST Federal study, the Portfolio Analysis Experiment, the 11-lab Study, and the 2 studies focused on carbon management. In response to these recommendations, the Department has initiated a carbon sequestration R&D program to develop environmentally acceptable sequestration to reduce anthropogenic CO_2 emissions and/or atmospheric concentrations. The goal is to have the potential to sequester a significant fraction of 1 GtC/year in 2025 and 4 GtC/year in 2050.

Six promising R&D concepts were initiated in 1999 that could offer advanced, low-cost approaches for reducing the buildup of greenhouse gases in the world's atmosphere. These concepts have emerged from a year of exploratory studies and have been selected by the Department of Energy for further development. They explore different ways to capture or permanently dispose of greenhouse gases with concepts that range from advanced membranes that would extract carbon dioxide from hydrocarbon-fueled systems, to the disposal of carbon dioxide in the deep ocean or into underground saline formations, and to the capture of methane emissions from landfills. Two major multinational efforts aimed at testing the viability of sequestering carbon in oceans and unmineable coal seams were continued under the auspices of the International Energy Agency GHG Programme. The Department's National Laboratories are also contributing by developing advanced concepts for sequestering carbon.

Gas Hydrates. A number of recent studies have identified the remarkable potential of gas hydrates for extending the supply of natural gas for decades beyond conventional resources. This opportunity becomes increasingly important as the demand for natural gas is expected to grow by about 50% in the next 15 years, from about 22 Tcf today to over 30 Tcf by 2015. In recognition of this potential, both the PCAST Federal and the Portfolio Analysis Experiment recommended R&D on safe and economical production of methane hydrates. Congress has recently identified the Department as the coordinator for all governmental R&D associated with gas hydrates. The Department will work with the Department of Interior, Department of Defense, Department of Commerce, and the National Science Foundation to form a 5-member federal coordinating committee for gas hydrate R&D. In addition, an Advisory Panel of experts from industry, academia, and the federal government will be established to provide advice on applications of gas hydrates, set research priorities, and report to Congress.

Utility Systems Reliability. The vast, highly interconnected North American electric power system has operated reliably in the past. Now, however, profound changes are sweeping through the industry. The system is growing increasingly vulnerable to threats that include natural disasters, aging and degradation, and malevolent threats. Further, the system complexity is rapidly increasing as restructuring forces a transition from a regulated, rate-based, franchise mode of operation to a mode of competitive energy markets. Now, this complex grid is being required to work harder than ever before and perform in ways for which it was not originally designed. Under the pre-existing regulated utility structure, responsibility for ensuring the quality and reliability of electric service, as well as system security and system adequacy, was clearly in the hands of the utility company. However, in the emerging structure, responsibility for ensuring reliable service depends on a combination of competitive generation market forces, privately owned T&D infrastructure, Independent System Operator (ISO) control over dispatch, and the transformation of reliability management organizations from a voluntary to a mandatory structure. As a consequence, maintaining system reliability is a major challenge facing the nation.

In response to this challenge, and supported by the findings and recommendations of the Portfolio Analysis Experiment, the EPRI Roadmap, and the CERTS Paper, DOE has initiated a new program in utility systems reliability. The Department initiated this program in FY99 and plans to expand it in FY01. The program has seven major R&D areas:

- Regional Grid Control.
- High Capacity Transmission.
- Distributed Resources and Microgrids.
- Customer Demand and Reliability Management.
- Reliability and Markets.
- Information Systems Assurance.
- Convergence Analysis.

The work is being conducted by a consortium of national labs, universities, and private industry.

Biobased Products and Bioenergy Initiative. The Departments of Energy and Agriculture are leading this initiative which was established by Executive Order of the President in August 1999. This initiative results from an increasing recognition that biomass resources represent an important domestic source for fuels and power as well as raw materials and feedstocks for a broad range of chemicals and manufactured products. The recommendations of both the PCAST Federal study and the Portfolio Analysis Experiment also support this initiative. Development and increased use of bioenergy and biobased products offers expanded opportunities for U.S. farmers as well as the potential for expanded use of environmentally sustainable domestic resources for energy and manufacturing.

The Initiative has set a goal of a 3-fold increase in the use of bioenergy and biobased products by 2010 and a 10-fold increase by 2020. Planning and implementation of the Initiative will be done by a partnership of interested parties from industry, growers, academia, and government agencies and laboratories. The work has begun with development of a shared vision of the future among these players. Next steps will include development of a roadmap to guide R&D activities. The Initiative will support R&D across a broad spectrum of relevant research and technology areas, ranging from species development for specific uses, and economical and ecologically acceptable production of various types of biomass, to a wide range of conversion technologies to produce fuels, electricity, chemicals and a myriad of other bioproducts.

Because of the numerous and diverse set of players already involved in R&D related to bioenergy and bioproducts, plus the even broader set of players likely to benefit from this Initiative, an important emphasis is coordination and integration of planning and R&D programs, including formation of a federal Interagency Council with overall responsibility for strategic planning for the Initiative.

Clean Fuels. The availability of clean, affordable, and reliable fuels for transportation in the US is essential for sustaining economic growth, social stability, and public health. Demands on the quality of these fuels continues to grow because of concerns over regional and urban pollution.

In response, the Department established an Ultra-Clean Transportation Fuels program to develop and deploy technologies that will produce ultra-clean burning transportation fuels for the 21st century from both petroleum and non-petroleum resources. This five-year, two part initiative is being implemented in FY2000 and is directed at systems-oriented R&D projects that lead to the production of sufficient quantities of fuel to validate vehicle performance and emissions. A National Laboratory Partnership will focus on examining some of the key scientific issues (reaction chemistry, materials, etc.) associated with the conversion of natural gas, petroleum and coal to ultra-clean transportation fuels. This complements other components of the Department's activities that are focused on engine and emission control R&D and vehicle testing. Coordination of these activities with industry will ensure that the entire vehicle system is addressed and evaluated --- from fuel production to engine performance and tailpipe emissions.

Fuel Cells. Fuel cells have been identified as an important enabling and crosscutting technology for both civilian and military applications. The Department's goal is to bring the costs of a fuel cell stack (the central core of a fuel cell) down to $100 per kilowatt, and the entire fuel cell power plant down to a cost of approximately $400 per kilowatt.

Fuel cell research activities are currently spread throughout the Department. The Office of Fossil Energy has a focus on stationary fuel cell power plants using two major high temperature fuel cell technologies (solid oxide and molten carbonate).Within the Office of Transportation Technologies, the fuel cell program is working with the automotive industry to develop highly efficient, low- or zero-emission automotive fuel cell propulsion systems. The major focus is on pre-competitive R&D to improve the economics and performance of low temperature fuel cell technology (polymer electrolyte or PEM). The Hydrogen Program within the Office of Power Technologies has a recent focus on the development and demonstration of small (1-5 kW) PEM fuel cell systems for remote power applications. A major objective is to integrate the fuel cell power source with diesel fuel reformers as well as with renewable sources of hydrogen (e.g., wind, photovoltaics) and hydrogen storage technologies. Finally, the Office of Nuclear Non-Proliferation (NN) has a focus on attainment of non-proliferation goals and advancement of fuel cell technology through the Russian/American Fuel Cell Consortium (RAFCO). RAFCO seeks to improve the cost-effectiveness of fuel cell technologies through cooperative R&D between industry, national labs and universities in Russia and the US.

The Portfolio Analysis Experiment noted that there are significant opportunities for synergy among the various efforts. The review panel recommended that DOE consider consolidation of the various areas in such a way that fuel cells are viewed as a cross cutting technology that can serve many applications. DOE plans to increase its emphasis on the integration of the various R&D activities.

International Energy Innovation. In response to the 1999 PCAST International report on international energy cooperation, the Department is working with other key federal agencies to plan and implement a broad collaborative effort, referred to as the International Clean Energy

Initiative, to promote energy systems innovation around the world. The overall effort encompasses initiatives in 4 major areas:

1. Foundations of Energy Innovation – aimed at expanding international energy innovation-focused capabilities, energy sector reforms, demonstrations, and financial programs that support deployment of clean/efficient energy systems.
2. Energy Efficiency Research, Development, Demonstration, and Deployment (RD^3) – aimed at development of energy efficiency technologies for all energy end-use sectors and applications, as well as policies and collaborative programs to support their deployment
3. Energy Supply RD^3 – aimed at development of clean energy supply technologies, including renewables, clean fossil fuel technologies, and nuclear technologies, as well as policies and collaborative programs to support their deployment
4. Management – calls for an interagency Working Group on Strategic Energy Cooperation to provide strategic planning and to lead the development of mechanisms to efficiently and effectively implement the initiatives above

While this will be a collaborative effort that relies on contributions from many federal agencies, the Department will have the primary responsibility for energy technology R&D efforts as well as an important role in helping to develop and promote effective deployment mechanisms and programs. The Agency for International Development (USAID) will also have a major role in supporting the interactions necessary to establish successful international collaborations for energy innovation across the spectrum envisioned by the initiatives above.

Summary

This chapter has presented an overview of the challenges and opportunities that provide the strategic focus for DOE's Energy Resources R&D Portfolio. It has also characterized the R&D Portfolio in a number of ways, including budget allocations, types of R&D activities, performers, and relationship with private sector activities. Finally, this chapter has briefly described a number of energy-related studies and reviews, and has outlined a number of examples showing how the key conclusions of these studies have been used to identify portfolio changes or additions that are important for achieving national energy goals.

The principal conclusions of this chapter are as follows.

- Providing ample reliable and low-cost energy services without risking national security and degrading environmental quality represents major challenges – and opportunities – for decades to come.

- This energy portfolio responds to those challenges with broad-based energy programs addressing energy supplies, energy conversion and delivery, and energy end-uses, drawing upon the expertise of industry, universities, and national labs in collaborative efforts that span research, development, and field demonstration/evaluation activities.

- A number of reviews and studies have been conducted that provide valuable information on the adequacy and focus of this portfolio, including numerous studies sponsored or supported by DOE itself.

- Overall, these studies have confirmed that this energy portfolio is generally well focused on the nation's strategic energy goals.

- However, the studies also identified a number of deficiencies in how fully these goals are addressed by the portfolio, and made a number recommendations for important portfolio changes or additions, including:

  - Significantly enhanced energy R&D portfolio funding
  - Renewed emphasis on electric power systems reliability
  - A Nuclear Energy Research Initiative
  - Carbon management R&D activities
  - A Bioenergy Initiative
  - R&D on extraction of methane hydrates
  - R&D on hydrogen
  - Initiatives to develop clean fuels
  - Integration of fuel cell R&D efforts
  - An international energy RDD&D program

The Energy Resources R&D Portfolio described in this document already reflects changes that respond to most of these recommendations, and further responses are under consideration.

The Department will continue to review this energy F&D portfolio, including carrying out further structured portfolio analysis activities. These will guide the Department's portfolio planning and budget requests in the future.

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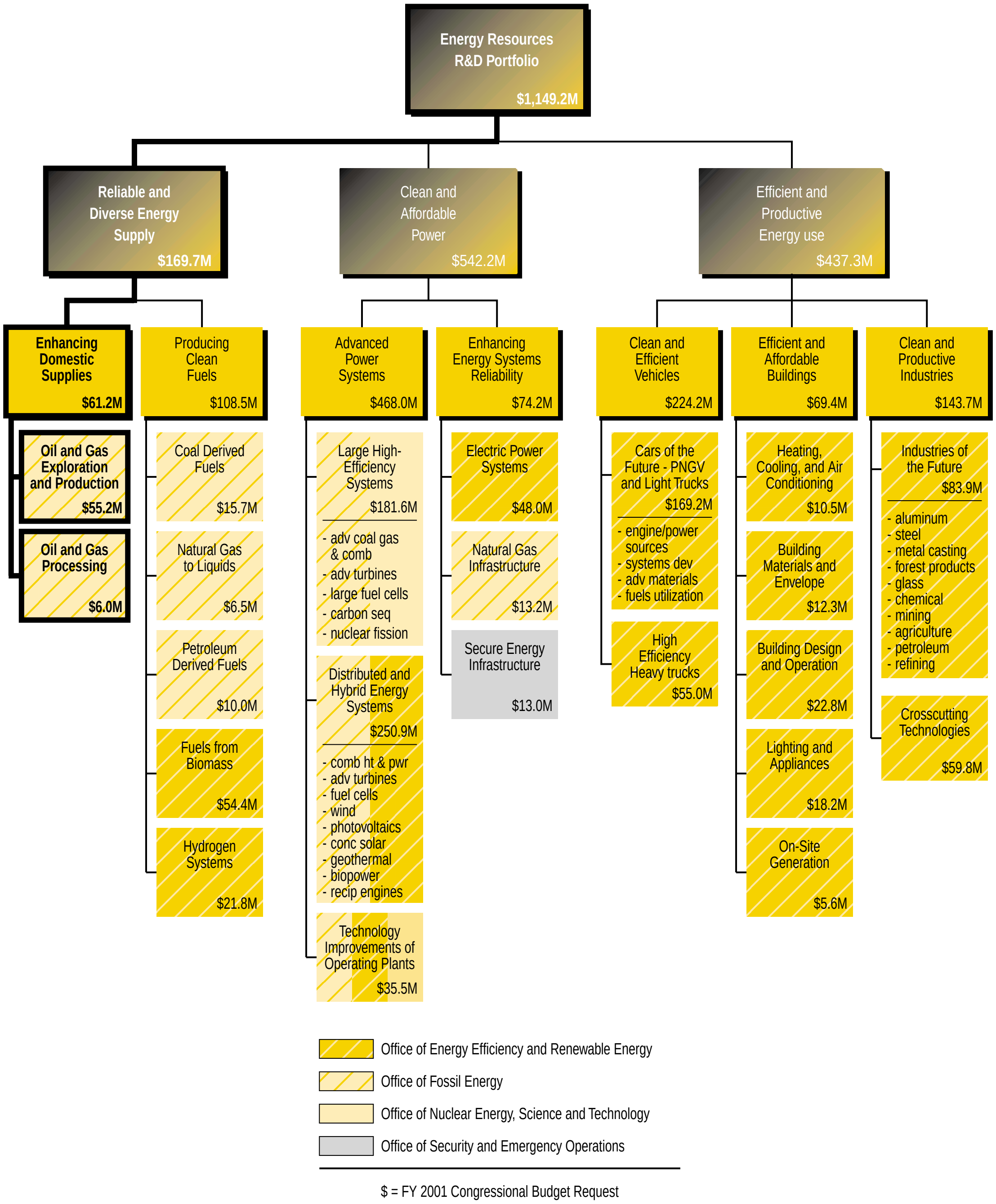
Chapter 3
Enhancing Domestic Supplies



Chapter 3
Enhancing Domestic Supplies

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Overview

Definition of Focus Area

The "enhancing domestic supplies R&D" portfolio address the Nation's need for stable and secure sources of domestic energy. Specifically, the R&D areas include oil and gas exploration and production (including environmental management), oil and gas processing, gas storage and delivery systems, geothermal energy, and preserving the Nation's critical energy infrastructure.

National Context and Drivers

A secure supply of reasonably priced energy is a prerequisite to U.S. strength in the global marketplace. Oil and gas account for two-thirds of the total U.S. energy consumption, and 97 percent of transportation fuels. Consumption of oil and gas will continue to increase (more than any other source of energy) despite energy efficiency improvements.

Oil security remains a prominent issue despite the relative tranquility in the market in recent years. Our economy is almost totally dependent on oil for its transportation needs. By 2015, it is projected that: (1) demand for petroleum in non-industrialized countries will nearly double; (2) the United States will consume more than 23 million barrels per day of oil and import more than 60 percent of it; and (3) the Middle East will control more than 62 percent of the world petroleum export market. This concentration of export market control will be greater than what existed in the 1970s and early 1980s when disruptions caused severe economic dislocations and fundamentally reordered U.S. and International Energy Agency (IEA) member nations' energy security program priorities.

Domestic natural gas consumption is expected to rise to more than 30 trillion cubic feet by 2015 (a one-third increase) because of its highly competitive cost and its cleanliness and efficiency. Gas can provide a low cost means to slow the growth rate of carbon dioxide emissions and be a bridge to a renewable energy future. Gas will be a significant energy source for moderating carbon emissions well into the middle of the next century. New resources of gas, such as methane hydrates, may prove to be a very large source of production worldwide.

Linkage to CNES Goals and Objectives

The enhancing domestic supplies R&D areas support the following CNES goals and objectives:

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply.
- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.

- CNES Goal IV, Objective 2 - Develop technologies that expand long term energy options.

Uncertainties

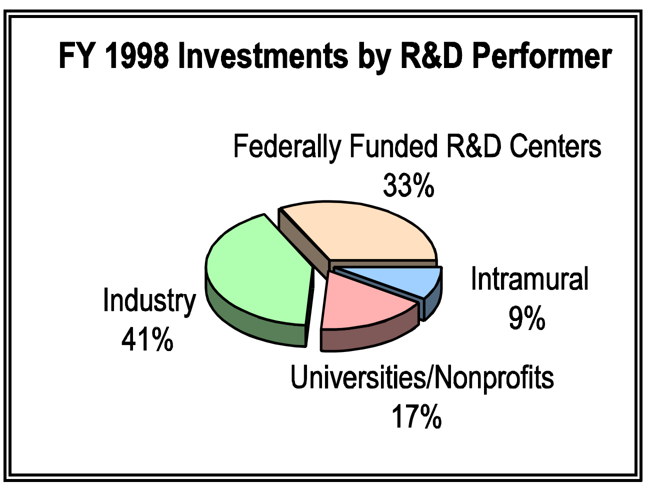
The United States is a mature oil-producing region, although domestic production is more difficult and more costly than overseas production. While an estimated two-thirds of all U.S. oil remains in the ground, much of it is located in deep, complex reservoirs or environmentally sensitive areas. High costs of operations and compliance with U.S. environmental regulations place U.S. producers at a competitive disadvantage with foreign producers.

Development of advanced oil and gas technologies is essential to efficiently maximize the production of domestic resources while preserving our environment. Advanced technologies are required to slow the decrease in domestic production of oil, to enable the processing and use of lower quality domestic crude, and to enhance the production and deliverability of natural gas.

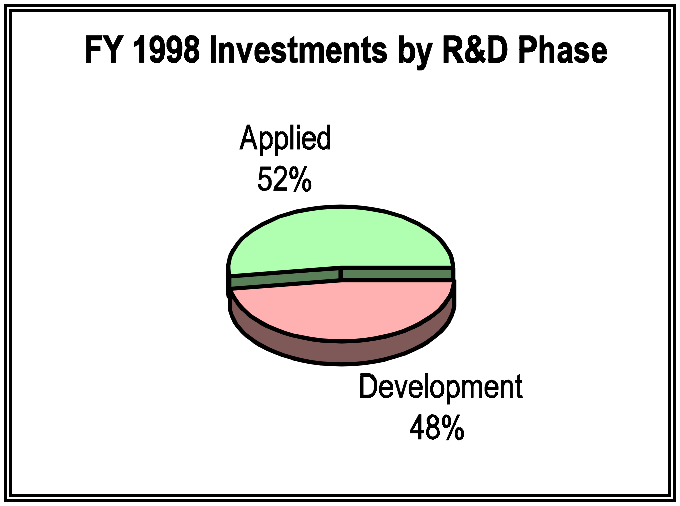
Declining R&D budgets, including the reduction in the Gas Research Institute's budget, have become a reality throughout the domestic energy industry. Electric utilities, in anticipation of increased competition, have already significantly reduced discretionary funding, including reductions of R&D by 30 percent in the past two years. The oil and gas industry has also reduced R&D applicable to domestic prospects by 29 percent, both in response to increased global competition and greater emphasis on overseas opportunities. Deficit-reduction has put increasing pressure on DOE-supported R&D, which has decreased in real terms by about one-third since 1990. Within these spending constraints, important decisions must be made on the priorities and emphasis in DOE's energy R&D programs.

Investment Trends and Rationale

As indicated in the figure below, over 40 percent of the research is performed by industry partners and over 30 percent is performed by the National Laboratories. However, a large



portion of this work is actually done by teams of researchers that frequently includes university participants. In addition, it is anticipated that the role of universities will increase in the future as a result of the closeout of the management and operating contract in the oil program. The type of research performed is evenly divided between applied and development. However, basic research that supports this technology portfolio is conducted in DOE's Office of Science.



Although the two figures above reflect FY 1998 data, the underlying funding trends are expected to be valid for the FY 1999-2001 period.

Issues that may impact the direction of future budgets include:

- The role of natural gas if greenhouse gas reduction becomes a higher National priority.
- The role of the United States in methane hydrate R&D to provide earlier answers on feasibility, production safety, and environmental impacts.
- The need for additional actions to slow or stop the decline in domestic oil production in light of frequent and recurring periods of low prices for oil.

Federal Role

The Federal government role includes:

- Maximize public benefit of oil and gas resources.
- Provide stewardship of Federal lands.
- Promote effective environmental protection.
- Ensure energy security.

- Foster strategic alliances.
- Enhance U.S. global competitiveness.

DOE's role in support of national goals includes efforts to:

- Enhance the efficiency and environmental quality of domestic oil and natural gas exploration, recovery, processing, transport, and storage operations.
- Focus on high risk technology that private companies alone won't undertake.
- Provide scientific and technological information and analysis to assist policymakers in their decision making.
- Contribute to science-based improvements in regulations to reduce uncertainties and costs while achieving optimal environmental protection.

Research needs are identified in combined workshops with Federal, industry, and research personnel. Competitive solicitations are used to identify qualified researchers. The applied research activities, supported by basic and enabling research, are managed by Federal personnel and performed by industry partners, National Laboratories, universities, and commercial research organizations. Centers of excellence and specialized expertise at National Laboratories support various elements of the program. In addition, cost-shared cooperative agreements and consortia are used as vehicles for joint funding of research with industry.

Key Accomplishments

Key accomplishments include:

The Oil Reservoir Class Program includes a total of 32 projects with a total DOE investment of $118 million and industry co-funding of $150 million (56 percent cost sharing). Successful demonstration of waterflooding in a high paraffin oil reservoir added 2.4 million barrels of oil to the region's reserves, resulting in over $12.7 million in taxes and royalties. Because of this demonstration, neighboring companies initiated 11 new waterfloods with more than 300 wells, which are expected to add 31 million barrels of oil and $160 million in Federal revenues. Because these 11 projects cover only 13 percent of the area, widespread application of waterfloods could double or triple the region's reserves and could increase Federal revenues to $500 million.

In the Natural Gas Program, new imaging technologies, including 3D seismic and vertical seismic profiling, were first utilized in the Texas Gulf Coast Basin and in the Fort Worth Basin. This work resulted in a substantial increase in reserve growth (estimated at 60 TCF) from established gas fields which were thought to be depleted.

A Risk Based Data Management System (RBDMS) originally developed for six States has proven so successful that 25 States have formed a users' group to help each other implement the system. The RBDMS is a PC based program that allows States to manage their underground injection data easily and use it to make risk based regulatory and operational decisions, such as where to assign inspectors for maximum effectiveness. The system enables States to generate reports quickly for the Environmental Protection Agency and the public.

The Department conducted initial design and testing of PDC drill bits now used in about 40 percent of drilling worldwide, an industry with annual sales in excess of $200 million. In addition, the program developed high-temperature drilling muds, high-temperature elastomers for downhole motors, advanced drilling fluid flow instrumentation, high-temperature memory logging tools; and fostered the use of slimhole drilling as an exploration tool for geothermal energy saving 30 to 50 percent of exploration drilling costs.

Industry and the Department of the Interior estimate that new discoveries in the Gulf of Mexico, an area with little exploration activity just a few years ago, may yield as much as 18 billion barrels of oil—more than Prudhoe Bay, Alaska. Technological innovations in subsalt imaging, reservoir characterization, and drilling technologies enhance the ability to discover such potential reserves.

Air motors based on DOE horizontal drilling technology are now being used for most new wells drilled in eastern gas formations. Horizontal drilling techniques, that use air in place of mud to drive and cool the downhole bit motor and remove drilling debris, have vastly improved the efficiency of drilling in Appalachian reservoirs, where mud use causes formation swelling and fracture blockage.

Production improvements at the earliest U.S. wells stimulated by CO_2/sand fracturing were so significant, that DOE received the 1994 Hart’s Oil and Gas World Award for introducing the “Best New Technology in the Northeast.”

Oil and Gas Exploration and Production

Budget: FY99-$60.8M, FY00-$70.0M, FY01-$55.2M

Background

Even though remaining U.S. oil and gas reserves are substantial, they are becoming more difficult and expensive to discover and produce. Past technology has recovered only an estimated one-third of the oil in place, leaving two-thirds of the U.S. oil resource base—about 350 billion barrels—still in the ground. Yet high operating costs are resulting in the abandonment of more than 16,000 U.S. oil wells each year. With the rising costs of environmental compliance, U.S. oil and gas producers and processors can face competitive disadvantages relative to operators in other areas of the world. These competitive disadvantages contribute to the fact that many major companies are concentrating their new exploration and production investments overseas.

Historical data demonstrate that technology advances are key to keeping energy prices low for consumers and to maintaining the profitability and long-term survival of the domestic industry. Since the 1980s, because of 3-D seismic, advanced drilling systems, and fracturing technologies, our Nation has seen a 14 percent increase in its gas production, despite a 50 percent decline in wellhead prices. Higher gas production in 1994 was achieved with fewer than 9,000 well completions, as compared to 14,250 completions in 1985. Further, success rates of exploratory wells have increased from 29 percent to 38 percent since the 1980s, while costs have substantially decreased. These technology advances, coupled with incentives such as deepwater royalty relief, have made the Gulf of Mexico one of the most active oil and gas exploration areas in the world.

Linkage to CNES Goals and Objectives

The oil and gas exploration and production R&D area supports the following CNES goals and objectives:

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply *(by stabilizing domestic production).*
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner *(by increasing domestic gas production and recovering oil with less environmental impact).*
- CNES Goal IV, Objective 2 - Develop technologies that expand long term energy options *(such as the production of gas from methane hydrates and deep gas formations).*

The program's efforts focus on enhancing the efficiency and environmental quality of domestic oil and natural gas exploration and production. Improved technology and information are required to boost production of natural gas, a clean and abundant domestic fossil fuel that is an increasingly important component of our Nation's energy portfolio, and to extend the life of domestic oil fields, many of which are marginally economic and operated by independent producers. Specific goals are to find and exploit new resources through resource- and reserve-base expansion, increase recovery through wellbore improvements, extend the life of domestic energy resources and reduce well abandonments, minimize any potential environmental damage from oil and gas operations, and improve understanding/industry cooperation in environmental compliance

Program Description

Technology advances can further the trend toward more cost-effective recovery of domestic oil and gas, particularly from geologically-complex deeper reservoirs. Such advances will enable domestic producers to continue exploring for and recovering oil and gas from reservoirs that would otherwise be economically unviable.

By reducing the costs of domestic oil and gas production, advanced technologies can help to maintain reliable domestic supplies of these vital fuels at competitive prices—a goal of strategic importance to our Nation.

Diagnostics and Imaging

Budget: FY99-$19.3M, FY00-$20.3M, FY01-$15.5M

Description, Objectives, and Performers. Advanced imaging is an increasingly powerful tool for discovery and insight in medicine, engineering, and many other fields. In the oil and gas industry, sophisticated diagnostics and imaging technologies can be used to cost effectively locate and produce domestic reserves. The program supports the development and use of advanced technologies for reservoir characterization and risk based decision making, preserves and provides access to subsurface data, and develops analytical tools to perform the analyses required for accurately quantifying oil and gas resources and reserves.

R&D Challenges. Although the Nation's largest, most easily identified reservoirs have been discovered, potentially substantial reserves still exist, both onshore and offshore, in geologically complex settings or in deeper and smaller compartmentalized reservoirs. The challenge is reducing the costs and risks of exploring for these reservoirs driven by the need to reduce risk and uncertainty in a low product price environment; the need for improved resolution to define smaller, more compartmentalized and deeper reservoirs; and the understanding that reservoir heterogeneity impacts all recovery processes

New imaging and modeling technologies can enable production from tight, inaccessible, and fractured reservoirs, that contain major portions of our Nation's future oil and gas resources. Such reservoirs include fractured shale, fractured tight gas reservoirs in the Rocky Mountain region, deeper parts of producing basins, and reservoirs in deep water or below salt in the Gulf of Mexico.

R&D Activities. Program activities include:

- Improve seismic and other geophysical acquisition, processing, and interpretation technologies to provide increased resolution and accuracy, with emphasis on single-well, crosswell, and novel surface methods.

- Increase the understanding and measurement of rock and fluid properties, rock-fluid interactions, and fluid flow, and develop techniques to monitor reservoir and production processes that are not currently measurable using, for example, multi-frequency crosshole electromagnetic technology or accelerometer based, multi-level receiver systems for seismic monitoring.

- Increase the accuracy and performance of geologic and reservoir modeling and simulation, especially fast, user friendly, PC-based techniques to mathematically simulate flows, predict the production from a reservoir, and assess the technical and economic viability of development.

- Develop and demonstrate techniques to predict, locate, and exploit reservoir fractures for improved production from low permeability reservoirs. These techniques may include high resolution aeromagnetic surveys to locate structural anomalies, integrated modeling methodology to identify targets, and direction drilling technology to optimize recovery.

- Improve industry knowledge of and access to reservoir characterization technologies.

  – Develop methodologies for the quantitative description and prediction of reservoir characteristics, including fractures and diagenesis, through laboratory analysis of the lithology, in-situ stress, and fracture conductivity.

  – Transfer reservoir characterization data, models, and tools to industry.

- Increase the accuracy of present and future oil and gas resources and reserves estimates, and industry access to them.

  – Work with industry and State and Federal agencies to preserve irreplaceable subsurface geologic data.

  – Provide industry, government, and academic customers with accurate, unbiased, and timely current and predicted future estimates of U.S. resources and reserves.

Accomplishments. The success of a U.S. Department of Energy-sponsored horizontal well drilled three miles deep into a dense sandstone formation in southwestern Wyoming has led to additional commercial drilling that could open up a potentially large new supply of "nonconventional" natural gas in the Rocky Mountain region.

In 1999, Union Pacific Resources Company (UPR) used fracture imaging and advanced drilling technologies developed by the Energy Department and the Gas Research Institute to drill a 17,000-foot deep well with a 1,700-foot horizontal section. Production exceeded expectations with more than 2.1 billion cubic feet of gas produced in the first six months. Now, based on the well's success, UPR is drilling two new horizontal wells into the same formation in the Greater Green River Basin. Additional wells are likely in 2000.

Prior to the Energy Department's Greater Green River Basin Production Improvement Project, which began in 1995, very little work had been done to define the geologic and production characteristics of the tight, fractured Frontier Formation in the Greater Green River Basin. The gas-bearing play covers 900 square miles and has potentially huge reserves. Knowledge from the Energy Department's project convinced Union Pacific Resources that this resource could be economically developed and led to the company's decision to expand its drilling program. The region is checkerboarded with Federal and State acreage. If UPR's current and planned wells achieve comparable production levels, they could generate almost $10 million in Federal and State royalties, almost double the Energy Department's investment.

Drilling Completion and Stimulation

Budget: FY99-$7.7M, FY00-$8.9M, FY01-$7.7M

Description, Objectives, and Performers. Of the entire exploration and production effort, drilling is the moment of truth for oil and gas producers. Drilling tests the validity of geological, geophysical, engineering, and mechanical theories on the existence of new oil and gas reservoirs, and demonstrates whether subsurface analyses have, in fact, succeeded in pinpointing productive pay zones. Sizable investments ride on the results.

DOE's Advanced Drilling, Completion and Stimulation Systems Program focuses on the development of sophisticated technologies and methodologies that can encourage investments in producing new oil and gas plays, and that can increase production from existing plays. Technology advances in this field have already succeeded in reducing costs per foot drilled in the United States by 8 percent over the last 10 years, and the potential for further improvements is significant. Future advances are most likely to result from addressing the full drilling system, not just individual components, with a focus on increasing the net present value of the entire investment. This program will by 2010 contribute the following economic and technological improvements:

- Reduced total drilling costs of 0.5 to 2.0 percent per year.
- Reduced development drilling costs of 10 to 20 percent.
- Reduced stimulation costs of 20 to 30 percent.
- Reduced operating costs of 1 percent per year.
- Reduced dry hole rates of 5 percent.
- Increased reserves per well of 5 to 10 percent.
- Reduced skin factor of 40 to 70 percent.

R&D Challenges. Risks have always been inherent in drilling for oil and gas. Today, the technology challenges are becoming even greater for producers in the United States because much of our remaining oil and gas is locked away in geologically complex formations that necessitate deeper drilling and penetration of harder rock, and the increasing application of such techniques as underbalanced directional drilling, slimhole drilling, and multilateral configurations to address specific geologic environments. Drilling challenges often make investment in domestic exploration and production less attractive than investment in overseas reservoirs often thought to be easier to produce. This uncertainty compounds the known technical risks with perceived to be greater economic risk.

R&D Activities. Technologies under development can increase the value of the exploration and production effort in several ways. First, by increasing the rate of penetration or by lengthening bit life, new methods can enable producers to drill faster, farther, and longer, resulting in reduced rig time. These technologies include the development of steerable air percussion drilling systems, advanced mud hammers, and high pressure downhole pumps for jet assisted drilling. Improved drilling and completion technologies also reduce formation damage, helping to maintain high well productivity. New stimulation technologies can be more effective than current methods in reviving well productivity after the well production rate declines to below economic levels. New methods also more effectively preserve the integrity of the wellbore over time, including the use of under balanced drilling fluids such as air, nitrogen, or foam. Finally, cost savings and increased environmental protection are also possible by reducing the volume of fluids needed in drilling and stimulation.

Carbon dioxide/sand fracturing technology was introduced into the United States by DOE for low permeability gas bearing formations. This non-damaging technology, which uses a sand-laden liquid CO_2 slurry to extend fractures, has the potential to significantly outperform traditional stimulation approaches. To encourage industry evaluation of the technology, DOE and its partner, Petroleum Consulting Services, have been working with industry to apply CO_2/sand fracturing, along with other stimulation methods, to newly-drilled wells of similar design and geological setting.

Accomplishments. In exploring for oil and gas in the 21st century, smaller may be better. Recent field experiments have enhanced prospects for "microdrilling" technology - a concept that could offer a revolutionary, lower cost approach to oil and gas exploration. This new technology currently allows for drilling holes up to 500 feet deep with all the equipment carried on a tandem-wheel trailer pulled by a standard pickup truck. When developed for deep drilling, the technology will replace traditional methods that use massive amounts of equipment, material and manpower, all of which are extremely expensive.

The concept could be a significant step toward futuristic "rig-less" drilling that could reduce the visual impact that has contributed to public objections to drilling in some areas.

In 1999, four microholes with diameters two to five times smaller than conventional holes were drilled to depths of 300 to 500 feet in alluvium and lake sediments. Microdrilling technology was highlighted as a likely "success story" emerging from the Energy Department's oil and natural gas research program.

Future microdrilling systems could occupy a space roughly 1/20th that of a typical rig and cost about 90 percent less. Companies using microdrilling would also realize additional savings because the technology could ultimately require only about a barrel of fluid per 1,000 feet of drilling to lubricate the bit and motor and remove dirt, whereas conventional drilling requires about 40 barrels of fluid per 1,000 feet. The microdrilling technology is based on the miniaturization of conventional coil tubing techniques that deploy a drill motor and bit on the end of tubing coiled around a spool. The recent test drilled 2 3/8-inch diameter microholes lined with 1 1/4-inch flush joint PVC tubing. Drilling fluids are run through the tubing to turn the motor and drill bit. In place of the usual large mud tanks needed to capture what's dug out of the ground, much smaller tanks suffice.

Reservoir Life Extension
(Includes PUMP – see next section)

Budget: FY99-$24.5M, FY00-$28.2M, FY01-$21.8M

Description, Objectives, and Performers. In partnership with the U.S. oil and gas industry, the Department supports the development of innovative and cost-effective technologies that can extend the productive life of domestic reservoirs. By encouraging advances in oil and gas recovery technologies and facilitating their transfer to producers, DOE can help slow the rate of premature abandonment of U.S. oil and gas wells and reduce our reliance on energy imports.

R&D Challenges. Production at most petroleum reservoirs includes three elements: primary, secondary, and tertiary recovery. Tertiary oil recovery is also known as improved oil recovery (IOR) or enhanced oil recovery (EOR). Primary recovery refers to production when energy stored in the reservoir is sufficient to drive the oil through reservoir rock into a wellbore. As reservoir pressure declines along with oil production rates, much additional oil can still be recovered using secondary recovery techniques. One such technology, waterflooding, displaces the oil and drives it to the wellbores of the producing wells.

Oil displacement in the reservoir is incomplete, however, even with secondary recovery processes. Tertiary oil recovery technologies such as thermal, gas-miscible, chemical, or microbial methods, can provide additional production. Such technologies could potentially recover about half of the 350 billion barrels of "discovered but unrecovered" oil in the United States. These technologies included polymer-augmented waterfloods and polymer-gel profile modification; continuous steam injection and in-situ combustion techniques; continuous gas injection, cyclic, and water-alternating-gas injection; and micellar surfactant and alkaline surfactant polymer flooding. Current U.S. oil production is 6.4 million barrels per day. Of this amount, 63 percent is produced by secondary and tertiary recovery.

In-situ combustion attempts to recover oil by heating it through the burning of a portion of in-place crude. Air or oxygen is injected to facilitate burning. The process is very complex, involving multi-phase flow of flue gases, volatile hydrocarbons, steam, hot water, and oil. Its performance in general has been insufficient to make it economically attractive to producers.

Polymer flooding involves injection into the reservoir of a small slug of surfactant solution, followed by polymer-thickened water, and then brine. Despite its very high displacement efficiency, micellar-polymer flooding is hampered by the high cost of chemicals and excessive chemical losses within the reservoir.

Even though improved oil recovery technologies have significant potential to extend reservoir life, and have been successfully demonstrated in the laboratory and in the field as early as the 1960s, their historically high cost has limited their widespread application. In the last decade, however, dramatic improvements in analytical and assessment tools including integrated reservoir description methods, have led to a greater understanding of the geology of reservoirs and the physical and chemical processes governing flows in porous media. This understanding has led to the development of new technologies that have potential for reservoir life extension.

The problems associated with more complete gas recovery are somewhat different. Research conducted by the Texas Bureau of Economic Geology, on behalf of the Gas Research Institute and DOE, has demonstrated that current production practices fail to recover a large portion of the gas in place. Even after 50 years of commercial production, substantial infield reserve growth exists in bypassed, incompletely drained, and untapped reservoir compartments, not to mention deeper pool potential in many fields.

R&D Activities. To demonstrate that today's reservoir life extension technologies are a highly cost effective alternative to abandonment in many real life situations, DOE launched the Reservoir Class Field Demonstration Program. This area represents the opportunity for in-the-field application of many improved and new reservoir life extension technologies.

The technological premise of the Reservoir Class Program is that reservoirs with a common geologic origin often have common producibility problems. These problems should respond similarly to reservoir life extension technologies. As new or advanced technologies are ready to be demonstrated in the field, a group of producing oil wells often spanning multiple States, are chosen as likely candidates for the demonstration. The wells are chosen because their reservoirs share similar geology, belonging to one of the three reservoir classes selected for demonstrations.

A commitment on the part of all program partners to technology transfer has been a critical factor in the program's success to date. Oil producers (including both small independent companies and major producers), universities, State agencies, service companies, and consultants, in partnership with DOE, team up for development, application, and transfer efforts. Project results are also being fed into a national petroleum technology transfer network. A revised strategy calls for revisiting the three classes and analysis of lessons learned.

In the Natural Gas Recovery Program, the focus is on a more complete characterization of complex heterogeneous reservoirs to afford a more precise placement of new wells and recompletions in existing wells.

Accomplishments. The Oil Reservoir Class Program includes a total of 32 projects with a total DOE investment of $118 million and industry co-funding of $150 million (56 percent cost sharing). Successful demonstration of waterflooding in a high paraffin oil reservoir added 2.4 million barrels of oil to the region's reserves, resulting in over $12.7 million in taxes and royalties. Because of this demonstration, neighboring companies initiated 11 new waterfloods with more than 300 wells, which are expected to add 31 million barrels of oil and $160 million in Federal revenues. Because these 11 projects cover only 13 percent of the area, widespread application of waterfloods could double or triple the region's reserves and could increase Federal revenues to $500 million.

In the Natural Gas Program, new imaging technologies, including 3D seismic and vertical seismic profiling, were first utilized in the Texas Gulf Coast Basin and in the Fort Worth Basin. This work resulted in a substantial increase in reserve growth (estimated at 60 TCF) from established gas fields which were thought to be depleted.

Reservoir Life Extension – Preferred Petroleum Upstream Management Practices (PUMP)*

Budget: FY99-$0.7M, FY00-$3.6M FY01-$2.0M

*PUMP described in detail here to highlight this initiative

Description, Objectives, and Performers. The PUMP program aims to stop the decline in domestic oil production by 2005, an objective of the Comprehensive National Energy Strategy (CNES), by encouraging implementation of the most promising and environmentally protective advanced technologies (Best Practices) for optimizing the recovery of the Nation's valuable oil resources. The program is expected to enable industry to increase domestic production by 200,000 barrels per day in five years.

The PUMP program will employ three strategies for a rapid impact on production:

1. Use known technology transfer mechanisms: DOE will work with States and organizations that are recognized by industry as expert technology providers, for example: The Petroleum Technology Transfer Council with its ten regional centers; State and Regional Industry Trade Associations; and State Geological Surveys.

2. Take a regional approach: The PUMP program will focus on geologic areas that present the highest potential for rapid increased oil production and those regions where the known oil resource is "underproduced." Preliminary analysis indicates that the Smackover Trend (AL, MS, LA, TX), the Delaware Basin (NM and TX), and the Mississippi Salt Basin (Offshore LA, State waters) are candidates for increased oil recovery from underutilized, advanced oil recovery technologies.

3. Support integrated solutions to technology, regulatory and data constraints: The implementation of advanced oil recovery technologies can face multiple hurdles, including incomplete data on geology, reservoir performance and environmental impacts, and outdated or overly burdensome regulations.

R&D Challenges Oil technology program research, by its nature, usually takes more than five years to show significant results in terms of production. Smaller independents do not rapidly implement new technology. In order to meet the five-year goal of the CNES, the PUMP program requires a targeted, aggressive, regional technology transfer program. It will take advantage of current technology transfer efforts and networks, to make direct contact with as many producers as possible, providing them with the most innovative technology, in ways they can most easily use.

In effect, PUMP accelerates the application of technology that could be expected to be implemented by industry over a much longer period of time. However, there is not only a quicker increase in production, but a larger total amount of U.S. oil ultimately recovered due to reductions in operating costs and reduced well abandonments.

R&D Activities. The program will conduct the following activities, in partnership with States, industry, tribes, and academia:

- Increase access to geologic, engineering, production, and environmental technology and information needed by oil producers to make wise investment decisions and improve the efficiency of their oil operations. This effort -- aimed at increasing the availability of data to oil producers in a user-friendly form -- has three components: 1) A best practices program and data base; 2) improved basin-scale analysis and other data management tools; and, 3) enhanced technology transfer, including demonstrations of best practices where needed.

- Environmental problem solving and regulatory streamlining targeted at addressing key regional constraints to the use of PUMP advanced oil recovery technology and avoiding unnecessary increases in compliance costs. The program also includes development of user-friendly, standardized data systems (Risk-Based Data Management System) to improve assessment of environmental risks in oil and gas exploration activities.

Accomplishments: Texas Electronic Compliance and Approval Process Pilot Project, a cooperative effort by the Texas Railroad Commission and the DOE that started August 1999, is streamlining the permit application process and improving access to regulatory data. Electronic drilling permit application will be implemented in 2000.

The Risk-based Data Management project with the Ground Water Protection Council implemented three new features in FY1999: 1) a generic version of the Risk-Based Data Management Systems, which can be inexpensively adapted for use in any State, reducing implementation costs from about $500K to $20K per State, 2) a Geographic Information System (GIS) utility that allows users to view environmental data spatially, and 3) an Internet reporting module for easy development of custom reports.

A competitive solicitation for other elements of the program is expected to be released in early 2000.

Drilling and Production Environmental Management

Budget: FY99-$8.7M, FY00-$9.6M, FY01-$8.9M

Description, Objectives, and Performers. The Department of Energy is working closely with industry to stem the rising costs of environmental protection, and to enable the domestic oil and gas producers to operate more efficiently, contributing fuels, jobs, and economic value to the Nation. DOE and industry are using the best information and science available to find new ways to address our Nation's environmental concerns, and to demonstrate that the needs of a strong economy and a healthy environment can be fully compatible.

Working with industry, DOE's Office of Fossil Energy is helping to ensure that environmental protection approaches make technical, environmental, and economic sense. DOE is well positioned between industry and regulators to champion balanced cost-effective approaches to environmental protection. DOE's environmental program pursues improvements to the regulatory process, supports development of new technologies, and exercises key responsibilities for energy policies that encourage efficient recovery and ensure adequate secure energy supplies.

R&D Challenges. The rising environmental compliance costs challenge the domestic oil and gas industry to continue its vital contributions to the economy. Compliance with increasing environmental regulation has become costly and increasingly complex. The challenge facing the Nation is to implement environmental and other regulations with greater flexibility and efficiency, while achieving optimal levels of environmental protection at the lowest possible cost.

R&D Activities. To support more informed regulatory decision making, DOE facilitates dialogue among Federal officials, State regulators, industry personnel, and other stakeholders. Through its program activities, DOE can provide assessments of costs or risks, lending an independent voice to the debate. DOE also characterizes problems and possible alternative solutions, catalyzing and contributing to the process of achieving common sense approaches.

Many times, more cost effective environmental approaches hinge on the development of new technologies. DOE supports such development, focusing on beneficial technology investments that could not be justified by a single company or small group of companies. Some of these technologies have longer term payoffs or high risks; others may have widely diffused benefits that a single company could not capture, but that will accrue to the Nation.

DOE brings unique capabilities to its role, including the scientific capabilities of its National Laboratories, and modeling/analysis tools developed specifically to address energy policy questions. A fundamental commitment to outreach and technology transfer—putting information and new techniques into the hands of those who can use them—enables DOE's efforts to generate maximum benefits for the Nation.

DOE is currently conducting over 60 environmental research and analysis projects. Some projects are national in scope and others are regional in nature, addressing specific technology needs or environmental constraints. Whether a project is initiated at a single site or in a handful of States, technology transfer is an integral part of the program approach. Once a project proves successful, the program focuses on transferring the results nationwide.

Accomplishments. A Risk Based Data Management System (RBDMS) originally developed for six States has proven so successful that 25 States have formed a users' group to help each other implement the system.

The RBDMS is a PC based program that allows States to manage their underground injection data easily and use it to make risk based regulatory and operational decisions, such as where to assign inspectors for maximum effectiveness. The system enables States to generate reports quickly for the Environmental Protection Agency and the public.

Gas Hydrates

Budget: FY99-$0.5M, FY00-$3.0M, FY01-$2.0M

Description, Objectives, and Performers. Methane production from hydrates could contribute low cost natural gas to satisfy domestic demand. As much as 200,000 trillion cubic feet (TCF) of methane may exist in hydrate systems in the U.S. permafrost regions and surrounding waters, which is hundreds of times greater than the estimated conventional U.S. gas resource base of 1,400 TCF. Even if actual reserves prove to be only a small fraction of these estimates, methane hydrate production could alter U.S. and world patterns of energy supply and consumption. Gas production from hydrates will also contribute to energy security and Federal revenues from royalties and lease rentals in the Outer Continental Shelf.

Methane hydrate is a methane bearing, ice-like material that occurs in abundance in marine and arctic sediments and stores immense amounts of methane. A cage of water ice molecules surrounds the gas molecule allowing high methane concentrations–one unit volume of methane hydrate can contain over 160 volumes of gas and less than one unit of water at surface pressures and temperatures. Methane hydrates are found on land in permafrost regions (Alaska) and within ocean floor sediments around the United States.

In the past year, a renewed interest in methane hydrates has been driven by:

- Growing recognition of the need for increased supplies of cleaner domestic fuels in the middle 21st century.
- Expanded industry activities in the Arctic and deep offshore that have increased awareness and interest in hydrate formation, occurrence, and stability.
- Concern about global climate change has emphasized the need to understand the role of hydrates in global carbon cycles.
- Technological progress over the past few years indicates that research will proceed more rapidly than previously expected and with increased expectations of commercial production.
- Increased international activity and significant spending in Japan and India points out the expectation of commercial production in the not-too-distant future.

This program can produce the knowledge and technology necessary for commercial production of methane from hydrates by 2015 and address associated environmental and safety issues.

R&D Challenges. The challenges to turning the potential hydrate resource into gas reserves while developing technologies to assure safe petroleum operations in hydrate areas, and defining the role of methane hydrates in global climate, involve the following:

- Determine the location, sedimentary relationships, and physical characteristics of methane hydrate resources to assess their potential as a domestic and global fuel resource (Resource Characterization).

- Develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems by 2015 (Production).

- Develop an understanding of the dynamics and distribution of oceanic and permafrost methane hydrate systems sufficient to quantify their role in the global carbon cycle and climate change (Global Carbon Cycle).

- Develop an understanding of the hydrates system in near-seafloor sediments and sedimentary processes, including sediment mass movement and methane release so that safe, standardized procedures for hydrocarbon production and ocean engineering can be assured (Safety and Seafloor Stability).

R&D Activities. Activities include the preparation of a strategy for methane hydrate R&D and an implementation plan.

Accomplishments. A ten-year program, starting in 1982, at the Department of Energy (DOE) Morgantown Energy Technology Center (now the National Energy Technology Laboratory, NETL) supported methane hydrate studies that: established the existence of hydrates in Kuparuk Field, Alaska; completed studies of 15 offshore hydrate basins; developed production models for depressurization and thermal production of gas from hydrates; and built the Gas Hydrate and Sediment Test Lab Instrument. The program was canceled as government policy shifted from long-term, high risk R&D to near-term exploration and production R&D. Although DOE funding stopped, work has continued at the United States Geological Survey (USGS), universities, other laboratories, and overseas.

Oil and Gas Processing

Budget: FY99-$6.3M, FY00-$8.0M, FY01-$6.0M

Background

Throughout many of our western States, there are gas reserves containing high levels of contaminants, which render these reserves economically unmarketable in most instances. Finding ways to utilize such unmarketable gas resources has become essential to sustaining a reliable domestic supply of gas and liquid fuels as our Nation’s most accessible and economical supplies are depleted.

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 products, such as gasoline, diesel fuel, jet fuel, and petrochemical feedstocks, 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. This 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 alone, 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 capital expenditures.

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 domestic gas production, recovering oil with less environmental impact, and developing cost-effective renewable technologies)*

Program Description

New processing technologies can equip the oil and gas industry to prevent pollution and protect the environment more efficiently than is possible with today's costly retrofit approaches, to handle the challenges posed by lower quality domestic feedstocks, and to produce the more complex, purer, high value product slates that the market now requires. By gathering the scientific information that is essential for sound regulatory decision making as well as developing processing technologies that increase efficiency, decrease costs, and enhance environmental performance, the industry may continue to be profitable in a highly global market place.

Low Quality Gas Upgrading

Budget: FY99-$1.9M, FY00-$1.6M, FY01-$1.6M

Description, Objectives, and Performers. In partnership with the U.S. oil and gas industry, the Department of Energy seeks to advance technologies and processes that will enable gas reserves with high contaminant levels to be upgraded to market specifications using gas purification technologies. Pursuing advanced processes to collect and utilize the methane released during underground coal mining would harness this greenhouse gas and prevent it from being vented into the atmosphere.

R&D Challenges. The Nation's natural gas resource base is vast, however, the primary challenge is to remove the high volumes of naturally occurring contaminants that are produced with the methane. Approximately one-third of our Nation's natural gas resource is low quality gas that does not meet market specifications for pipeline shipment. Typical specifications call for gas with no more than:2 percent carbon dioxide; 4 percent total carbon dioxide, nitrogen, and other inert gases; and 4 parts per million of hydrogen sulfide gas.

Some low quality gas can be blended with higher quality gas to meet market requirements. But much of our low quality gas must be upgraded through gas purification technologies that eliminate or substantially reduce inert and hazardous contaminants. Current technologies can be costly and, in some cases, cost prohibitive. In situations where the cost of upgrading would make producing the gas uneconomical, the gas is simply shut in. Advanced upgrading technologies under development will improve purification techniques while significantly lowering costs.

Another challenge is to capture the methane that is released naturally from coal and surrounding strata in the course of underground coal mining. Most of this methane is currently exhausted to the atmosphere through the mine's ventilation system.

R&D Activities. Low quality gas upgrading program efforts target two technology areas. The first is the development of organic and inorganic membranes that screen and separate gas components. Membranes offer high component selectivity and overall gas throughput. The second area of technology development is gas-contaminant absorption and adsorption systems that have rapid regeneration capability. Both areas of technology development have the potential to significantly reduce gas upgrading costs compared to current technologies.

Coal mine methane R&D efforts focus on the demonstration of available methods to economically collect and utilize this methane for pipeline sales, small-scale electric power generation, and other uses. The goal is to expand the number of mines that utilize emitted gas instead of passing it into the atmosphere.

Accomplishments. A DOE-sponsored project is focused on the development of more efficient and compact physical solvent systems for the upgrading of natural gas with high carbon dioxide and/or hydrogen sulfide content. Researchers at the Institute of Gas Technology are working with representatives from the Gas Research Institute, Shell Oil Company, Michigan Consolidated Gas Company, and others to develop the advanced system designs required to enable the separation processes to proceed using structured packing and/or rotating solvent-gas contactors in place of traditional large absorber towers with many sets of contactor trays. The new designs would allow a five-fold or greater reduction in the size of gas upgrading plants. Such size reduction is particularly valuable for platform-scale upgrading in the Gulf of Mexico.

Oil Processing and Environmental Protection

Budget: FY99-$4.3M, FY00-$4.4M, FY01-$4.4M

Description, Objectives, and Performers. Environmental regulations have resulted in the closing of a number of smaller, less efficient U.S. refineries that have been unable to afford the required capital expenditures. These regulations make the construction of new refineries in the United States unlikely. While larger refining operations are expected to remain viable, recent studies suggest that another 10 percent of U.S. refineries may close. With U.S. refineries already operating at near maximum utilization rates, such a loss in capacity exposes U.S. consumers to gasoline price spikes caused by interruption of operations at any one refinery.

R&D Challenges. Crude oil supplied to refineries is becoming heavier with more sulfur, nitrogen, and heavy metals, while the market requires a product slate that is lighter, with less sulfur and nitrogen, and more oxygenates. Current technology cannot address this. Using present technology, the processing of heavy crude yields unacceptably high levels of low value residual oils, coke by-products, and wastes.

Another challenge is that environmental regulations, particularly the Clean Air Act Amendments of 1990, are forcing refineries to devote substantially more of their budgets to environmental compliance at the expense of their technology development efforts. The impending fine particulate ($PM_{2.5}$) regulations have caused concern within the industry because of the lack of data about origin and formation of this fine particulate matter. Data must be produced that will allow science-based implementation of this proposed regulation.

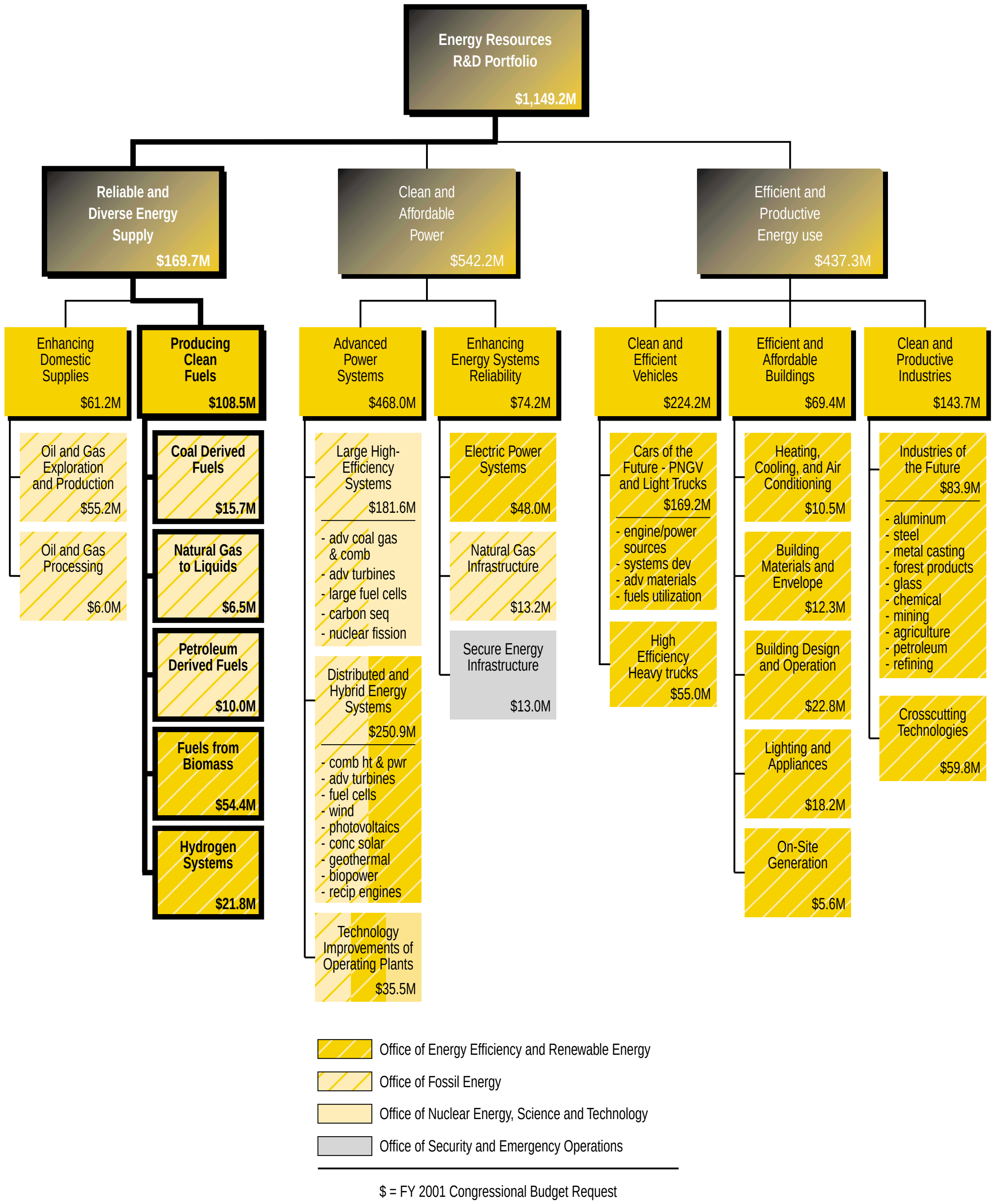
R&D Activities. This program serves the Nation's environmental objectives by providing sound science for improved regulation and develops fundamental scientific data to facilitate the development of effective refining technologies to prevent pollution formation.

Accomplishments. A recent success story concerns the measurement of emissions from heavy oil storage tanks. In complying with the Clean Air Act Amendments of 1990, which regulate emissions from heavy oil storage tanks, the California Air Resources Board had planned to use existing data on emissions from light oil storage tanks. But these data would probably over-estimate actual emissions by a significant degree because heavy oil has less volatile components than light oil. The project data will enable the State to issue regulations that are based on the more specific and appropriate risks of vapor from heavy oil.

Summary Budget Table (000$)

Enhancing Domestic Supplies Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Oil and Gas Exploration and Production	**60,757**	**69,967**	**55,219**
Diagnostics and Imaging	19,294	20,269	15,456
Drilling, Completion, and Stimulation	7,720	8,916	7,700
Reservoir Life Extension	24,514	28,164	21,840
Drilling and Production Env. Management	8,737	9,624	8,923
Gas Hydrates	492	2,960	2,000
Oil and Gas Processing	**6,225**	**6,015**	**6,015**
Low Quality Gas Upgrading	1,925	1,615	1,615
Oil Processing and Environmental Protection	4,300	4,400	4,400
Total	**66,982**	**77,948**	**61,234**

Chapter 4
Producing Clean Fuels



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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.

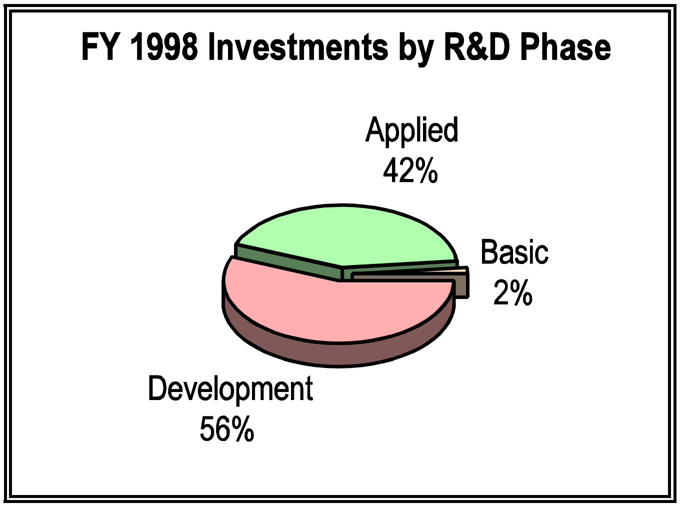
<u>Biobased Products and Bioenergy Initiative</u>

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.

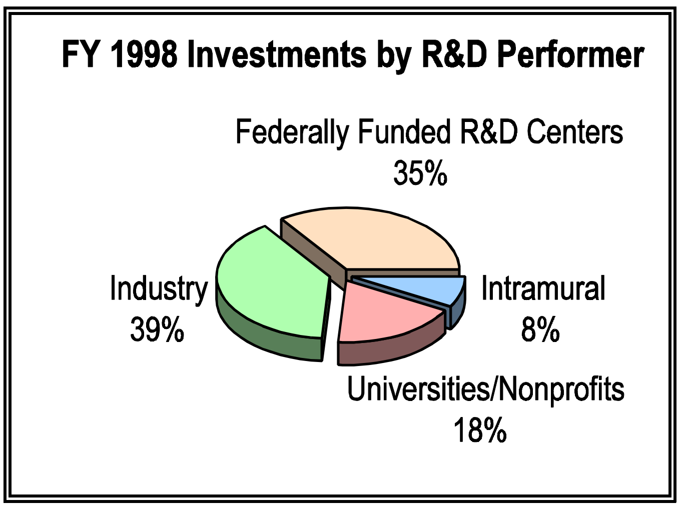
Clean Fuels funding for this initiative is under Fuels from Biomass, and focuses primarily on developing advanced technologies for more cost-effective biomass production and harvesting, and improved pretreatment and enzymes for hydrolyzing biomass to various sugars that can be converted to ethanol fuel 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 21st 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 21^{st} 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.

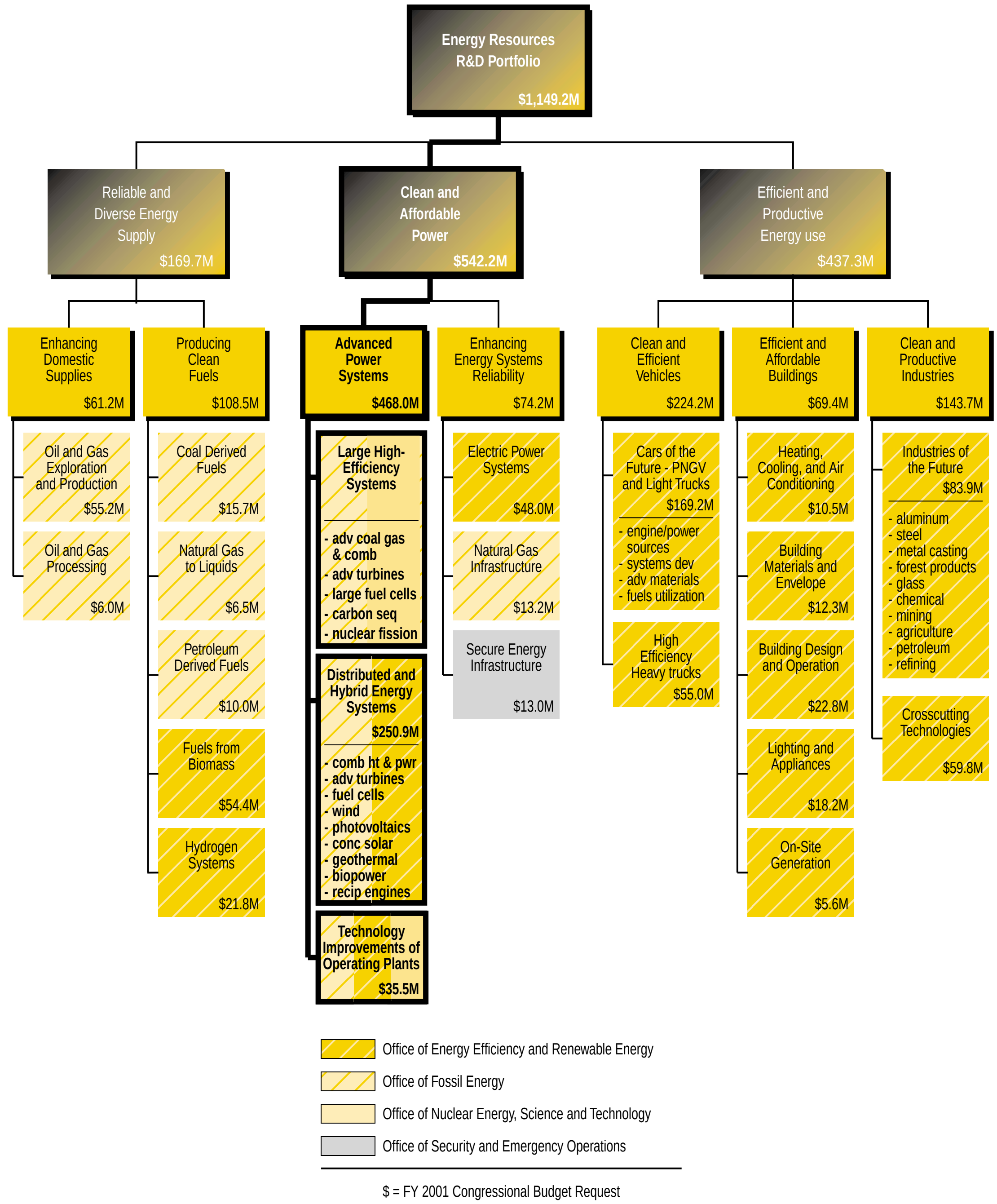
- Compared four coal to hydrogen options and identified an option that included carbon sequestration as being able to meet hydrogen production program goals.

- 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**

Chapter 5
Advanced Power Systems



Chapter 5

Advanced Power Systems

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Overview

Definition of Focus Area

The Department's advanced power systems research and development portfolio is comprised of a broad range of power generation technology options that utilize fossil fuels, renewable energy resources, and nuclear power in both large, high efficiency energy systems and in distributed and hybrid energy systems to deliver affordable, reliable, and clean electric power. The work is principally applied R&D which is cost-shared with industry, supported by basic and enabling research activities, managed by Federal personnel, and performed primarily by industry, National Laboratories, and universities. Longer-term R&D includes a modest investment in carbon sequestration and a more significant investment in the Science and Technology program in nuclear fusion.

National Context and Drivers

The electric power sector is the largest direct consumer of energy in the United States. It used 37 percent of all primary energy consumed in the country in 1998, while providing power worth approximately $200 billion annually to fuel myriad essential functions in our homes, businesses, and industries. Most energy projections show the United States requiring an increase of 100,000 to 200,000 megawatts of additional power generation capacity between now and the year 2010.

About 70 percent of the electrical power generated in the United States is fueled by coal, natural gas, and oil; the balance is provided by nuclear (19 percent), hydroelectric, and renewable technologies. Due to the reliance on fossil fuels, power generation currently contributes substantially to the pollutants and greenhouse gas emissions in the United States, at a time when world concern continues to grow regarding global climate change. Meeting the projected significant increase in demand for electric power without compromising the Nation's environmental standards is therefore essential to sustaining the Nation's economic growth while at the same time protecting human health and the environment.

Nearly 95 percent of the electricity consumed annually in the United States is generated by large (greater than 30 megawatt) power plants. Because of the significant capital investment in large plants, the existing residential, commercial, and industrial infrastructure connected to the plants, and the Nation's dependence on the large amounts of electricity they produce, large plants will continue to produce the majority of the Nation's electric power for the foreseeable future.

Under current market and regulatory trends, coal and, increasingly, natural gas, will continue to be the primary fuels for large systems, well into the 21st century. No significant new additions of nuclear, hydroelectric, or oil capacity are expected, and existing nuclear plants in the United States are expected to be retired over the next 50 years.

However, many power generators, either in response to public pressure or State and Federal regulatory trends, are seeking to diversify their fuel choices and add renewable energy resources to their fuel mix. Environmental concerns, ample supplies of cheap natural gas (the cleanest fossil fuel), current and potential constraints of large system power transmission and distribution, and technological advances are causing distributed and hybrid systems and technologies such as combined heat and power systems, gas turbines, photovoltaics, wind turbines, and solar, geothermal, and biomass systems gradually to augment and sometimes to replace conventional, generating technologies.

Linkage to CNES Goals and Objectives

There are three strategic ends for advanced power R&D:

1 Ensure the availability of large-scale, advanced technologies to: (1) reduce both fuel use and the volume of pollutants and greenhouse gases emitted per unit of useful electric power produced; and (2) maintain an adequate, reliable and affordable supply. This end supports:

   - CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(improve the efficiency of the energy system)*
   - CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.
   - CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.
   - CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.

2. Ensure the availability of a portfolio of advanced power technologies utilizing renewable and hybrid energy systems that will increase the flexibility, capacity and reliability of the U.S. power system. This end supports :

   - CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
   - CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.
   - CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.
   - CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.
   - CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe , and efficient energy systems.

3. Protect the Nation's investment in existing baseload power plants through the development of improved information management systems, sensors and controls, aging management, and regulatory compliance programs. This end supports:

   - CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(improve the efficiency of the energy system)*

   - CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe , and efficient energy systems.

Uncertainties

Renewable energy sources, nuclear power, and fossil fuel with sequestration (direct or indirect) are insurance against the possible occurrence of climate change. Government investment at this time is prudent as the country and the world face major environmental and energy security challenges and domestically the electrical power sector is dealing with the issues of restructuring.

The following major planning assumptions are implicit in the attainment of our strategic goals.

- *Robust U.S. Economy Depends on Low Cost Energy*.
  The continued strength of the U.S. economy depends on the availability of low-cost energy. It is virtually assured that there will be continued growth in demand for electricity and transportation fuels. Fossil fuels will meet much of the demand.

  Changes in electricity prices have significant effects on the economy. For example, an increase in the cost of electricity of 4 to 5 cents per kilowatt-hour (more than a 50 percent increase in the national average delivered price) leads to the same inflationary impacts as a 30-cent-per-gallon rise in gasoline price (about a 25 percent increase in delivered price.) Therefore, low cost electricity is essential to economic growth.

- *Electric Utility Restructuring Leads to Competition*
  Restructuring of the electric power industry and the movement towards competition will lead to lower electric bills for all consumers. This is evidenced by the Comprehensive Electricity Competition Plan (CECP), a proposal published by the Administration that is expected to result in lowered prices for electricity and a cleaner environment. Cost savings of $20 billion per year and greenhouse gas emissions reductions of 40 to 60 million metric tons are anticipated from implementation of the proposal. .

  These lower costs could increase demand. In the near term, most new capacity will be characterized by the lower-capital-cost technologies that use natural gas. In the longer term, this demand will be satisfied by using clean and efficient technologies being developed by the Department and others.

- *Public Wants Environmental Issues Addressed.*
  Significant environmental issues have been, are being, and will be addressed. Sulfur dioxide (SO_2) emissions have been capped. It is expected that permissible nitrogen oxide (NO_x) emissions will be lowered. Allowable levels of particulate and hazardous air pollutants (HAPs) emissions will be further reduced because of health considerations. Limitations on land use will increase pressure to reduce the quantity of waste generated.

- *International Community Urges the United States to Reduce Greenhouse Gas Emissions.*
  The effort to reduce greenhouse gas emissions, principally carbon dioxide (CO_2), will continue to increase. A major driver for the Department's fossil energy research program is a reduction of CO_2 emissions, with the vision of ultimately achieving near-zero emissions so that fossil fuels can be used in a greenhouse gas constrained economy. Nuclear power can provide electrical power on a large scale without harmful air pollutants. The Office of Nuclear Energy, Science and Technology is charged with maintaining the viability of this important technology.

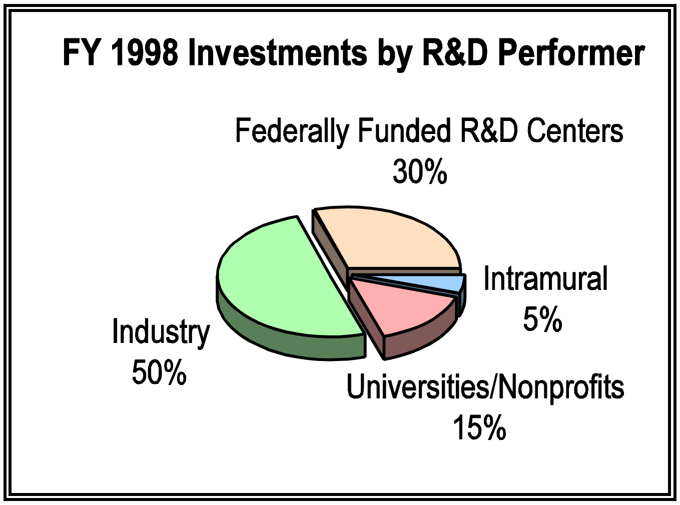
Investment Trends and Rationale

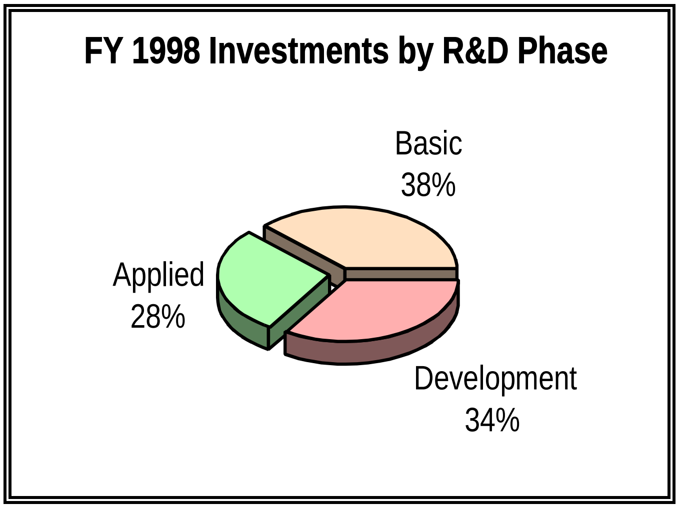
Domestic utilities are perceived to be in a "wait-and-see" mode, given the uncertainties associated with the restructuring of the power generation industry, uncertainties about recovery of new expenditures during the transition to retail deregulation, and competition from other entities such as independent power producers (IPPs) and energy service companies. It is expected that reserve margins will shrink before new facilities will be built. Utilities are currently pursuing life extension and asset management to optimize utilization of existing capacity, thereby delaying the need for new generating capacity. Under current conditions, these utilities foresee an extended period of operation for older units over the next two decades.

Utilities are concerned about proposed, tougher environmental regulations for NO_x, SO_2, particulates, and HAPs. They also are concerned about the treatment of assets in which they invested as a "regulated" industry. The trend in the industry is to focus on the "market clearing price" rather than the "obligation to serve." In the preparation for competition, some are planning to provide other energy services, shed assets, or enter into joint ventures. These competitive pressures and uncertainties, as well as the lack of demand for additional baseload capacity, limit U.S. private-sector R&D investment in advanced power systems.

As a response to the above, the Department is proposing to spend $451 million on advanced power systems in FY 2001. Advanced power R&D is performed cooperatively with industry, National Laboratories, universities, and State/local governments. The FY 1998 percentage split among these organizations, which not expected to change significantly in the FY 1999-2001 period, is shown below.

Also shown below is a chart showing the investment by R&D phases, that is, the type of R&D. The chart includes fusion from Science and Technology. Fundamentally, fusion accounts for the basic research performed in advanced power systems.





There are no foreseen factors that would alter substantially the current mix of R&D performers and types of R&D in the near term, so the FY 1998 breakdown is expected to be valid for the FY1999-20001 period.

Two significant trends are evident in advanced power area. The first is the move toward enhancing economics and environmental performance through the development of multi-product systems. For example, the gas and coal technologies in the large high efficiency systems can potentially be integrated into energy complexes consistent with the *Vision 21* concept, where the products could include power, clean fuels and chemicals. Such complexes could take advantage of opportunity fuels (e.g. agricultural wastes) and employ carbon capture and sequestration to minimize greenhouse gas emissions.

A second trend is the increased emphasis on environmental technologies with major application in domestic and international markets. These include wind, photovoltaic and biopower renewable energy systems, and carbon sequestration. The FY2001 request for these areas is $201 million, versus a FY 2000 appropriation of $139 million.

The following two FY2001 initiatives are also relevant to the Advanced Power portfolio:

<u>Biobased Products and Bioenergy Initiative</u>
Funding associated with biopower are included in 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.

<u>International Clean Energy Intiative</u>
The June 1999 report by President's Committee of Advisors on Science and Technology (PCAST) titled "Powerful Partnership – The Federal Role in International Cooperation on Energy Innovation," addresses ways to improve the U.S. program of international cooperation on Energy R&D to best support U.S. priorities and address the key global energy environmental challenges of the next century. The report includes funding recommendations for a variety of initiatives that include approaches such as tax credits, regulatory assistance, training and Federally-supported R&D. In response, the Department is proposing a variety of international activities in FY 2001 that total $46 million, span most of the seven Energy Resources objectives, and include R&D and other forms of international collaboration. Potential R&D areas relevant to Advanced Power include solar/renewable technologies, hydrogen production via gasification and advanced separation, improved efficiency of operating fossil plants, and nuclear fission.

Federal Role

Regulated utilities have traditionally invested significantly in power generation R&D, either individually or through industry R&D organizations like the Electric Power Research Institute. However, the U.S. electric power industry is restructuring in response to changes in State and Federal regulations requiring increased competition in the industry. In response to increased competitive pressures, utilities and other companies that traditionally have invested in research have reduced or eliminated their R&D budgets.

Moreover, while global concern over the environmental impact of power generation is growing, most U.S. power generation facilities are in compliance with existing environmental regulatory requirements. At the same time, the prices of fossil fuels, particularly oil and natural gas, are relatively low by historic standards. There is little immediate market incentive for investment in cleaner power generation technologies. To the contrary, an increasingly competitive market in power generation could well accelerate the decline in private sector investment in power generation R&D in the United States.

Concern for the environment and electric industry restructuring create a significant public interest challenge: how can the Nation mitigate and possibly eliminate the adverse environmental impact of power generation while ensuring the availability of affordable electricity to continue to grow our economy? An appropriate Federal role in addressing this challenge is to invest in advanced power generation technologies where the market will not support industry's incurrence of all of the costs of the long-term, high-risk, and/or high-cost R&D required to develop those technologies, or when the Government has unique R&D capabilities.

Accordingly, there is a significant gap between the level of advanced power generation R&D that the market will support and the level needed to address current and future concerns about the steady increase in the demand for electricity worldwide and the resulting impact of power generation on human health and the environment. The Department's advanced power systems research and development portfolio is designed to help bridge that gap.

Key Accomplishments

Considerable progress has been made through DOE support toward achieving the advanced power systems goals:

- A new generation of higher-efficiency, cleaner, coal-fueled technologies is currently being demonstrated (e.g., integrated gasification combined cycle) that will also be attractive in hybrid applications when combined with ongoing advances in coal power R&D, turbines, and fuel cells.

- R&D has continued to reduce the cost of renewable systems suitable for distributed applications:

  – Biomass power is being demonstrated at scales from 10-75 MWE for dedicated feedstocks and for co-firing with coal.

  – Recent advancements in geothermal technology have reduced costs by increasing power plant efficiency 5-10 percent for certain key resources.

  – Concentrating solar power has been combined with thermal storage to produce more competitive levels of cost.

  – The cost of producing photovoltaic modules has decreased 50 percent since 1991, making it cost-competitive in certain applications.

  – The cost of wind power has decreased by 85 percent since 1980, making it competitive in some areas that have good wind resources.

- Fuel cells and turbines have reached the stage where they are expected to achieve significant deployment in distributed and hybrid applications in the next decade:

  - Phosphoric acid fuel cells are commercially available, and molten carbonate fuel cells are being successfully tested at full scale.

  - An advanced, cleaner, higher-efficiency industrial turbine is nearing commercial readiness, including a 1999 demonstration.

- Numerous technologies have been deployed/demonstrated and actions taken to help protect the Nation's investment in existing power plants:

  - Test data has been used to help shape environmental regulation.

  - Reductions have been achieved in sulfur dioxide, nitric oxides, fine particulates and associated trace toxic substances.

  - New alloys and ceramics have increased equipment life.

  - Research on hydropower turbines is improving the understanding of advances needed to incorporate "fish-friendly" features.

- Fusion research has continued to raise the power achieved in test reactors (the Princeton Tokamak reached 10 MW in 1996) and increased the understanding of how to control plasma conditions and improve energy confinement.

Large High Efficiency Systems

Budget: FY99-$176.3M, FY00-$190.2M, FY01-$181.6M

Background

Of the 770 gigawatts of generating capability in the United States shown below for 1998, most are associated with larger, central station facilities. Actual generation (kilowatt hours) in 1998 breaks out differently since some plants are used more than others, and includes coal (52%), nuclear (19%), natural gas (14%), hyrdo/renewable (11%) and petroleum (3%).

Electricity Generating Capacity in 1998		
Primary Energy Source	**Capacity (Gigawatts)**	**Percent of Total Capacity**
Coal	305	40
Oil/Gas Steam	138	18
Gas Combined Cycle	20	3
Combustion Turbine/Diesel	73	9
Nuclear Power	97	13
Conventional Hydroelectric	77	10
Other Renewable	10	1
Cogenerators (60% gas)	50	6
Total Capacity	770	100

Large systems will continue to be needed to satisfy the majority of the Nation's increasing demand for electricity, and fossil energy-based systems are expected to continue to predominate the market. Conventional fossil plants, however, are extremely fuel inefficient, wasting as much as 70 percent of the energy that is used in the generation process. Moreover, these systems create the vast majority of the environmental impacts resulting from power generation in the United States.

Nuclear power plants do not emit air pollutants or greenhouse gases such as carbon dioxide, and are the largest non-emitting electricity supply technology used in the United States. These plants currently produce about one-fifth of the Nation's electricity. The country, however, is at a critical juncture with regard to the continued operation of its nuclear power plants. While many of the 105 existing nuclear power plants will continue to produce electricity well into the next century, licenses for existing U.S. nuclear power plants will begin to expire in large numbers in 2010. However, nuclear plants can be re-licensed for an additional 20 years under current regulations. Two plants have already applied for an extended license and expect approval from the Nuclear Regulatory Commission within the next 2 years. Also, competitive pressures resulting from electricity deregulation could result in the premature closure of some nuclear power plants with relatively high production costs. There have been no new orders for nuclear power plants in the United States since the 1970s, and this is likely to remain the case unless issues of plant economics, spent fuel disposal, and safety and proliferation are successfully addressed. As a result, nuclear units are projected to provide one-tenth of total electricity generation in 2015.

Linkage to CNES Goals and Objectives

The Department invests in large, high efficiency systems to ensure the availability of large-scale, advanced technologies to (1) reduce both fuel use and the volume of pollutants and greenhouse gases emitted per unit of useful electric power produced, and (2) maintain an adequate, reliable and affordable supply. These ends support:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.
- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.

Program Description

The Department invests in the development of a number of large, high-efficiency systems including coal and natural gas power generation technologies and systems, as well as nuclear fission and fusion systems. Nuclear energy's continued role in electricity production provides for our economic and energy security, and is a critical element of our Nation's global climate change responsibilities. Nuclear power plants currently produce about 20 percent of all U.S. utility-generated electricity without emitting carbon dioxide, a greenhouse gas, and sulfur and nitrogen oxide pollutants associated with the combustion of fossil fuels.

For coal and natural gas systems, a program called "Vision 21" aims for the upper end of performance efficiencies, 60 percent to over 70 percent, at near zero emissions. It features the capability of power generation systems to have fuel flexibility while generating a variety of energy products along with low-cost electricity. Due to the inherent fuel flexibility of gasification and coal-based combustion systems, they may be synergistically integrated into industrial processes (e.g., refineries, paper mills, food processing plants), delivering even greater economic and environmental benefit by converting process waste to electricity, steam, and chemical products as needed. The resulting fleet of large, high-efficiency power systems included in Vision 21 would have emissions well below the New Source Performance Standards (NSPS) for SO_2, NO_x, and particulates, with the most advanced systems achieving near zero emissions of regulated pollutants.

DOE and its predecessor agencies played a significant role in development of nuclear fission power in the United States. The most recent example is the Advanced Light Water Reactor program that resulted in the design certification of new evolutionary and passive light water reactor technology. However, in light of the uncertainties facing nuclear power, the President's Committee of Advisors on Science and Technology (PCAST) and the Directors of seven

National Laboratories recommended that DOE reestablish a strong nuclear energy R&D portfolio. Although there were no nuclear fission programs in FY 1998, in FY 1999, Congress funded the Department's proposed Nuclear Energy Research Initiative (NERI). NERI sponsors innovative scientific research and technology development to address the longer-term issues facing the future use of nuclear energy, namely proliferation, waste, and economics.

The Department's nuclear fusion program is conducted by the Office of Science. The Fusion Energy Sciences program conducts basic research in plasma science and alternative confinement concepts to understand the physics of plasma (the fourth state of matter), identify and explore innovative and cost-effective development paths to fusion energy, and explore the science and technology of energy producing plasmas, the next frontier in fusion research.

Advanced Coal Gasification and Combustion Systems

Budget: FY99-$65.5M, FY00-$69.9M, FY01-$58.9M

The coal gasification and combustion program is part of the Vision 21 program plan described above. Its overall goal is to make available, by 2010, coal-fueled power technology: (1) with a net electricity system efficiency of at least 60 percent (new plants are currently about 35 percent); (2) that reduces emissions to less than 1/10 of New Source Performance Standards and CO_2 emissions 45 percent below conventional plants; and (3) achieves a cost of electricity below that of conventional new pulverized coal power plants. There are 3 technologies addressing this area.

Advanced Coal Combustion - LEBS/HIPPS

Budget: FY99-$21.0M, FY00-$9.0M, FY01-$2.0M

Description, Objectives, and Performers. This program is re-engineering today's pulverized coal boiler to incorporate advanced combustion and innovative flue gas cleaning into the original design, rather than adding them after the plant is built. The low emissions boiler system (LEBS) has been underway since 1992 and builds on earlier research in the areas of emission control, materials, and combustion. The program will be completed in FY 2001 with operation of a small proof-of-concept plant. The program objective is, by the year 2001, to make available technology: (1) with a net plant system efficiency of at least 42 percent; (2) that reduces emissions to 1/6 of the Clean Air Act's New Source Performance Standards (NSPS) for SO_2 and NO_x and 1/3 the NSPS for particulates; and (3) that achieves a capital cost of less than $1,000 per kilowatt and a cost of electricity 10 percent lower than a conventional pulverized coal power plant. The program is a cost-shared partnership with industry, supported by university and National Laboratory research.

Also as part of advanced pulverized coal combustion, a program to develop an indirect fired cycle having (1) a net plant system efficiency of at least 47 percent; (2) emissions 1/10 of the Clean Air Act's NSPS for SO_2, NO_x, and particulates; and (3) a capital cost 20 percent lower than that of a conventional pulverized coal power plant. In addition to inherently high system efficiency, indirectly fired cycles have other advantages that include no requirements for an oxygen plant or hot gas cleanup, and fuel flexibility, since the products of coal combustion do not contact the gas turbine. This high performance power system (HIPPS) program is also a cost-shared partnership with industry supported by university and National Laboratory research. The engineering development and testing associated with this program ends in 2001, with designs for large commercial plants, prototype plants, and repowering for existing coal-fired plants. The next phase, if undertaken, would be the operation of a prototype HIPPS by 2006.

R&D Challenges. To achieve the more aggressive performance levels, there must be advances in the areas of combustion, heat transfer, and materials. These advances are needed in order to develop the high temperature air furnace, the coal pyrolyzer, and the char burner required in the indirect fired cycle.

R&D Activities. Two different concepts for an indirectly fired cycle are being pursued, but both require R&D necessary for technology and systems development to support the design and operation of the major subsystems, particularly, a high temperature air furnace. Designs for these subsystems will be verified in test facilities. Equipment to be developed includes radiant and convective air heaters, coal burners, integrated slag removal and slag handling components, and char combustors. Research in high-temperature ash deposition, materials, and CO_2/O_2 recycle combustion is required in order for this effort to meet its objectives.

Accomplishments. Successes include the development of new combustion technology (so-called U-fired combustors) capable of reducing NO_x emissions below 0.2 lbs per million Btu at very low cost. NO_x levels approaching natural gas firing are achieved with the addition of a copper oxide cleanup unit. The U-fired combustors produce a granular slag by-product that is preferable to flyash. A HIPPS 2000°F radiant air heater has been tested successfully.

Pressurized Fluidized Bed (PFB) Combustion

Budget: FY99-$14.4M, FY00-$12.2M, FY01-$11.2M

Description, Objectives, and Performers. The PFB program is developing an advanced combustion system capable of utilizing a wide variety of coals (including very low quality coals) to generate electricity cleanly and efficiently. The highly effective mixing of coal particles in the boiler allows combustion temperatures to be kept below the point where most nitrogen pollutants form. Elevated pressures and temperatures produce a high-pressure gas stream that can drive a gas turbine, and steam generated by the combined cycle system powers a steam turbine. The program has progressed from its basic research or idea stage to the commercial demonstration stage today. A large commercial scale PFB plant is now being designed under the Clean Coal Technology Demonstration Program. This first generation plant will have efficiencies in the 40 percent range and will lay the engineering foundation upon which further technology advances now in the R&D pipeline will be made to achieve the program's 2010 goals. The Advanced Circulating Pressurized Fluidized Bed Combustion (APFBC) combined cycle power system is capable of achieving efficiencies of 46% or higher and is highly suited for repowering as well as greenfield site applications. The program objective is, by the year 2010, to make available technology: (1) with a net electricity system efficiency of at least 50 percent; (2) that reduces emissions to 1/10 of the New Source Performance Standards for SO_2, NO_x, and particulates; and

(3) that achieves a capital cost of less than $1000 per kilowatt and a busbar cost of electricity that is 10-20 percent below that produced by a new conventional pulverized coal power plant.

The PFB program is a 20-60 percent cost shared partnership with industry, supported by university and National Laboratory research.

R&D Challenges. The key R&D challenge for PFBC is a reliable, available, maintainable, and affordable hot gas cleanup system. Hot gas cleanup systems for advanced high efficiency PFBC power systems remove virtually all particulate matter that would otherwise enter the gas turbine. These filter systems operate under high temperature conditions (e.g., 1400^{o}F to 1700^{o}F). Advanced high efficiency PFBC power systems of the future will include supercritical power conversion systems (PCS) steam conditions, fuel cells, and higher temperature gas turbines. These PFBC systems will necessitate that gas streams be free from impurities (e.g., sulfur, alkalies, and particulates) in order to provide for long term, reliable, trouble free operation.

R&D Activities. The thrust of the research is in hot gas particulate filtration, critical to advanced PFB systems, and improvements in subsystems and their interfaces to enhance system efficiency and reduce cost and pollutant emissions necessary for market entry.

Accomplishments. The program has already succeeded in completing a first generation 80 MW_e 40% efficient pressurized fluidized bed demonstration project in Brillant, Ohio (TIDD Plant) . The program also succeeded in developing and commercially deploying very clean, atmospheric fluidized bed systems globally—over $8 billion in sales have been reported.

Gasification Technologies

Budget: FY99-$30.2M, FY00-$48.7M*, FY01-$45.7M*

*Includes $13.5M in FY00 and $13.7M in FY01 for gasification related to pulp/paper

Description, Objectives, and Performers. In the IGCC program, a coal gasifier (which generates a synthetic gas by means of “partial combustion” of coal) is used instead of a traditional combustor and is coupled with an advanced gas turbine. This combination of technologies gives the advantage of adding steam power generation to gas power generation along with new coal gasification processes and breakthrough gas cleanup technologies. IGCC is unique in that it is highly flexible for all coals, liquids, and waste or other opportunity fuels; it can produce high value co-products; and its electricity is predominantly extracted from the more efficient gas turbine portion of the combined cycle. IGCC is the most efficient and cleanest of the available technologies for coal-based power generation. The objective of the program is, by the year 2010, to make available technology: (1) with a net electricity system efficiency up to 55 percent; (2) that reduces emissions to less than 1/10 of the NSPS for SO_2, NO_x, and particulates; and that (3) achieves a capital cost of less than $1,000 per kilowatt with a cost of electricity 80-90 percent of that produced by a new conventional pulverized coal power plant.

The DOE IGCC program is a 20-60 percent cost-shared partnership with industry, supported by university and National Laboratory research.

In FY 2000, a major new initiative focusing on the application of gasification to the pulp and paper industry is being implemented. The objective is to develop safer, less expensive, and environmentally friendly alternatives to conventional pulping liquor processing and wood residual combustion. Gasification has the potential for achieving higher thermal efficiency, exceeding known and anticipated emissions standards for SO_2 and NO_x, enhanced separation and regeneration of pulping chemicals, higher electric power generation, and improved safety.

R&D Challenges. The key R&D challenge for IGCC is to reduce capital and operating costs while simultaneously improving both the reliability and overall system availability, increasing plant efficiency, and further reducing emissions. To accomplish these goals, the IGCC program has diversified its activities to include a range of technology options to meet existing and future market requirements for electricity and other high-value products. These activities are also consistent with the goals and objectives of Vision 21.

DOE is investing in the development of novel air separation technologies that have potential for significantly reducing capital cost while simultaneously improving efficiency when integrated in IGCC systems.

To employ advanced technologies such as fuel cells, to convert synthesis gas to other products (i.e., chemicals and fuels) and to meet the environmental goals of Vision 21, the gas exiting the gasifier must be cleaned of all impurities such as sulfur, mineral matter, and other toxic materials. The development of reliable, affordable, and high efficiency gas cleanup technologies is, therefore, another major technical challenge for IGCC. First-generation hot gas cleanup technologies have been developed and are being demonstrated under the Clean Coal Technology Demonstration Program. Although suitable for power generation, these technologies must be extended to meet the stringent gas quality requirements for fuel cell and co-production applications. Novel approaches for achieving this, while simultaneously reducing cost and improving efficiency, are also being explored.

To meet the goals of Vision 21 for high efficiency and reduced emissions of greenhouse gases, cost-competitive technologies for hydrogen and CO_2 separation from the synthesis gas stream are required. Advanced technologies using membranes are being investigated to accomplish the desired separation, as well as novel chemical approaches to separating CO_2 from the gas.

R&D Activities. Currently, the focus of the program is centered around four primary activities: (1) Advanced Gasification, that includes accelerating development of the transport-bed gasifier and associated control devices, investigating cofiring of coal with other low-cost feedstocks, improvements in refractory design, and high temperature instrumentation; (2) Gas Cleaning and Conditioning that enables the production of ultra-clean syngas for fuel cell and co-production applications, novel gas clean-up technologies that minimize consumables and waste streams, and more sorbent development work to meet the need of more stringent applications; (3) Gas Separations that are aimed at enabling the development of new air separation technologies for producing low cost oxygen and enriched air, novel hydrogen separation technologies capable of operating at high temperatures and pressures in the presence of chemicals and particulate contaminants, and technologies for mitigating, separating and utilizing CO_2 emissions; and (4)

Products/By-Products Utilization that is looking into aspects of improving slag/ash quality to promote utilization and direct sulfur recovery processes.

This new government/private sector pulp and paper initiative is focusing on the commercial demonstration of gasification-based technologies at existing U.S. mills. Successful demonstration of these technologies will provide the industry with the information needed to make informed capital budgeting decisions regarding the replacement of existing technologies with technologies that are far superior in complying with emissions regulations.

Accomplishments. The program has progressed from the basic research or idea stage over 20 years ago through large-scale demonstration to the early stages of commercial operations. Three first-generation (42 percent efficient) commercial demonstration plants are now operating under the DOE's Clean Coal Technology Demonstration Program and one which is in the design/engineering phase is estimated to commence operation in 2002. During this time period, which is atypical for developing new power systems, the program has been highly successful in developing the critical system components (e.g., gasifiers, gas stream clean-up subsystems, coal-fuel compatible turbines, and others), some of which have already been commercialized (e.g., the Texaco gasifier).

Advanced Gas Turbine Systems

Budget: FY99-$43.4M, FY00-$44.2M, FY01-$26.0M

Description, Objectives, and Performers. A gas turbine is a major component used in the generation of electricity. Advanced turbines are initially being developed using natural gas as the fuel, but will later be designed for use with other fuels derived from coal, biomass, etc. In the turbine, the high-temperature, high-pressure gases rushing out of the combustor push against the turbine blades, causing them to rotate. The turbine is connected by a shaft to a generator that turns to produce electricity. Much of the remaining heat supplied by the gas can be converted to useful energy in a steam bottoming cycle (i.e., a second lower temperature power generator).

The Department's Advanced Turbine Systems (ATS) program is developing ultra-high efficiency gas turbines for utilities, independent power producers, and industrial markets. The objective is to break the 60 percent barrier in net thermal efficiency for gas turbine systems and reduce SO_x emissions to zero and NO_x emissions to 9 parts per million or less, while achieving operating costs 10-20 percent lower than conventional power systems. The potential domestic and global markets for advanced turbines are large. At least half of all new power generating capacity to be added between now and 2010 is likely to use gas turbines. EIA forecasts over 200 gigawatts of new gas capacity additions in the United States between now and 2015. If ATS were to capture half of this market, it would result in 0.43 quads less fuel use and 94,000 tons less NO_x in 2015 compared to using current systems that operate at an electric efficiency of 50 percent and generate about 10 to 24 parts-per-million of NO_x (without external controls). Because of their high efficiency, advanced turbines will emit less CO_2.

This program is an innovative partnership between DOE, State governments, gas turbine manufacturers, universities, natural gas companies, National Laboratories, and electric power producers for developing lower cost, higher efficiency gas turbines that have better environmental performance than existing machines, to meet current and projected power generation needs. A university consortia works directly with industry to resolve key technical problems encountered in the program. Current industry cost sharing is up to 70 percent.

Supporting research and development is performed as part of the ATS Program. This technology base effort includes the Advanced Gas Turbine Systems Research (AGTSR) managed by the South Carolina Energy Research and Development Center (SCERDC), Federal Energy Technology Center (FETC) research, Department of Energy Combustion Systems Cooperative Research and Development Agreements, research on advanced alloys, thermal barrier coatings, and catalytic combustion, and small business and innovative research.

The AGTSR, a national industry-university R&D consortium, is currently in its sixth year of operation. AGTSR is dedicated to supporting the advancement of land-based gas turbines for future power generation systems which include both the ATS and post-ATS technology programs. The major goals of AGTSR are to promote multi-disciplinary engineering education to realize gas turbine challenges for the 21st century and industry-oriented collaborative R&D with U.S. universities. There are 95 universities which qualify to participate in the consortium and 9 industrial review board members. Over the past 5 years, AGTSR has supported 51 research subcontracts at performing member universities. Ten new projects were selected in 1997. These selections include 3 projects in combustion, 4 in aerodynamics and heat transfer, and 3 in materials.

In advanced materials development, research to develop advanced alloys for ATS hot gas path components has continued. Advanced single crystal alloy developments are enabling the scale up of technologies used to produce high-temperature blades and vanes for the aircraft engines. Recent accomplishments have reduced levels of sulfur and defects in large production castings of these components. Future emphasis is being placed on the cost-effective manufacturing of these components. Projects have recently been initiated to develop advanced casting and fabrication methods to increase the yield rates to reduce the production costs of these components. Successful commercialization of these new processes is critical to achieving the cost of electricity goals of the ATS Program. Currently, the teams of Howmet Corporation-General Electric Company-Solar Turbines Incorporated and General Electric Company-PCC Airfoils Inc. are participating in the new casting projects under the advanced alloys program.

R&D Challenges. Technological advances in the turbine components and systems, such as cooling system design, materials development, and thermal barrier coatings, will permit higher gas turbine combustor firing temperatures that are necessary to reach program efficiency goals. Other design advances are needed to reach NO_x emissions goals and carbon monoxide and unburned hydrocarbon emissions of less than 20 parts-per-million without post-combustion cleanup.

R&D Activities. R&D activities focus on materials science advances, integral thermodynamic changes, base technology research, systems design, development, and integration. Solicitation and awards were made for “Advanced Turbine Airfoil Manufacturing Technology” to develop advanced manufacturing methods in order to increase the yields of turbine blades from low sulfur content, single crystal materials.

Accomplishments. Many technological advances have been achieved since 1992, when the ATS program was initiated. Howmet Corporation developed a single crystal material with a sulfur content significantly below 1 ppm in a non-production size heat and in production size heats (5,000 pounds) with a sulfur content around 0.5 ppm. They were able to produce utility size blades with acceptable grain defects. PCC has produced products with the grain defects contained only in the tips and platforms, has identified and partially eliminated core break locations, and has produced a single crystal of material with a sulfur content of 0.3 ppm using a melt desulfurization process. As a result, U.S. turbine manufacturers will be ready to supply the first ATS machines early in the next century (with expected further improvements afterwards including the incorporation of aeroderivative designs).

Under the industry-university consortium, significant accomplishments were made in the areas of heat transfer, combustion, materials and aerodynamics, providing many design methods, models, and concepts for the gas turbine industry. Faculty principal investigators completed sabbaticals at gas turbine manufacturers and successful workshops were conducted in areas of specific need or emphasis. Numerical models were developed for lean premixed combustion, simplified chemistry, unsteady aerodynamics, and heat transfer for designing advanced gas turbines. Novel probes and control strategies were developed for improving lean premix combustion processes, and advanced coating and materials development processes were produced.

DOE's National Energy Technology Laboratory completed tests on new combustor lean pre-mix configurations using liquid fuels, tests of a novel low-NO_x burner developed by Alzeta Corporation that showed very low emissions performance, and a series of tests for humid air turbine configurations. The humid air turbine tests verified that very low NO_x and CO emissions can be achieved with high steam loadings in the combustor.Under the Small Business and Innovative Research Program, Precision Combustion Incorporated of New Haven CT was awarded the Tibbetts Award in recognition of their unique contributions as an "SBIR Model of Excellence" in developing and commercializing important environmental technologies.

Advanced Large-Scale Fuel Cell Power Systems

Budget: FY99-$43.1M, FY00-$44.5M, FY00-$42.2M

Description, Objectives, and Performers. Over the longer-term, quiet, virtually non-polluting fuel cells could become a new option for electric utilities. Unlike conventional power generation technologies, fuel cells work without combustion and the associated environmental side effects—atmospheric emissions of sulfur and nitrogen compounds. Instead, fuel cells act like continuously fueled batteries, to produce electricity using an electrochemical process. In a fuel cell power plant, natural gas or coal gas is first cleaned, then converted to a hydrogen-rich gas by a fuel processor or by an internal catalyst. This fuel is then fed along with air to a fuel cell power section to generate high quality electricity. Fuel cell power plants can be built by combining cells into stacks to obtain the needed voltage and power output in a wide range of sizes—from

200 kilowatt units suitable for powering commercial buildings, to 100 megawatt plants that can add baseload capacity to utility power plants.

The program objective is to make available, by 2003, natural gas fuel cells for electricity production with up to 60 percent efficiency and negligible emissions of regulated pollutants. This performance, coupled with the quietness, small size and modularity of the technology, make fuels cells an attractive option for meeting fast-growing demand in global markets.

R&D Challenges. The challenges for advanced, large-scale fuel cells are, in the near-term, reducing costs and extending cell life and reliability. Longer-term challenges are the solution of integration issues related to combining fuel cells with turbines and gasifiers for hybrid fuel cell/turbine systems and for Vision 21 applications.

R&D Activities. DOE is continuing its industry cost-sharing partnerships to develop advanced, next generation fuel cells, with support from the National Laboratories. Molten carbonate and solid oxide fuel cell technology is being tested at full-scale. Supporting research is focused on improved electrodes, electrolytes, interconnects, materials and seal, and thin film advanced cell processing techniques.

Studies are being conducted on various fuel cell/turbine combined cycle configurations, and investigations will focus on pressurization, the design of fuel cell gas passages to allow integration with turbines, high temperature seals, reliability, fuel gas cleanup, improved thermal cyclability, and high temperature material issues. Hybrid system studies will investigate system reliability and operability, control, dynamic response, matching of gas flow rates, system optimization, mode of operation, and cost and ease of installation.

Accomplishments. The DOE, in partnership with industry, has cost-shared (30-50 percent industry contribution) the development of fuel cells since the mid-1970s. The first generation fuel cell products, phosphoric acid fuel cells (PAFC), entered the commercial market in 1992. More than 160 PAFC power plants have been delivered to sites in the United States, Europe, and Asia. The current fleet has an impressive availability above 95 percent, and demonstrates reliable, safe operation in a variety of climates, applications, and service scenarios. The electric efficiency of these natural gas fired plants is in the 40-45 percent range. Early versions of molten carbonate systems have been tested at the 250 kilowatt and at the megawatt size, while solid oxide fuel cells are being tested at the full-size 100 kilowatt unit module.

Carbon Sequestration

Budget: FY99-$5.8M, FY00-$9.2M, FY01-$19.5M

Description, Objectives, and Performers. Fossil fuel-fired power plants emit about one-third of the Nation’s CO_2 emissions. Moreover, these plants account for 70 percent of U.S. electricity generation, and are projected to dominate generation for the foreseeable future. Increased concentrations of CO_2 due to carbon emissions are expected unless energy systems reduce the carbon load to the atmosphere. Accordingly, carbon sequestration–carbon capture, separation, and storage or reuse–must play a major role if we are to continue to enjoy the economic and energy security benefits which fossil fuels bring to the nation’s energy mix. Sequestration has the potential to offset a large portion of the 1.6 billion tons per year of U.S. carbon emissions attributable to human activities.

The program vision is to possess the scientific understanding of carbon sequestration and develop to the point of deployment those portfolio options that ensure environmentally acceptable sequestration. The long-term program cost goal is to reduce the net cost of sequestration to $10 per ton or lower by 2015.

Compared to most research in the Department, the sequestration research portfolio is a relative newcomer. In the near- and mid-term, the program will examine science-based sequestration approaches that have the greatest potential to yield cost effective technologies. This includes “value-added” approaches with multiple benefits, such as in promoting enhanced oil recovery while sequestering CO_2, sequestering CO_2 associated with natural gas production, and enhancing recovery of coal bed methane. Longer-term, the technology products will be more revolutionary, relying less on site-specific or application-specific factors to ensure economic viability. The program’s research portfolio is closed linked to the Vision 21 program. For example, many of the advanced energy technologies being developed as part of the Vision 21 Program produce a relatively new stream of CO_2 that is amenable to capture and storage.

The program selects research topics and projects through competitive solicitations involving industry, universities, and national laboratories. International collaboration is extensive, and includes work with the International Energy Agency (IEA) Greenhouse Gas R&D Programme and the Climate Technology Initiative of the Framework Convention on Climate Change.

R&D Challenges. The challenge is to develop technologies and practices to sequester carbon that (1) are effective and cost-competitive, (2) provide stable, long-term storage, and (3) are environmentally benign.

R&D Activities. The program is examining approaches which separate, capture, and store (in geologic formations, the oceans, and vegetation and soils in terrestrial ecosystems) emissions from advanced power cycles, including technologies which enhance natural processes for removing CO_2 from the atmosphere and novel concepts which transform CO_2 to a valuable resource or a benign material.

Accomplishments. Since the initiation of the program in 1998, extensive stakeholder outreach and planning exercises have been conducted to help determine the appropriate R&D focus and direction. In particular, in collaboration with the DOE Office of Science, the report *Carbon Sequestration: State of the Science* was developed. It identifies the five major areas of needed R&D that are the basis of the program. Subsequently, focused workshops are being held on specific technical topics. For example, a September 1999 workshop in CO_2 Capture and Geologic Sequestration was cosponsored by DOE, the IEA, and BP/Amoco, an industry leader in reducing CO_2 emissions. In late 1999 the Office of Fossil Energy issued two related solicitations: One limited to National laboratory proposers and another aimed at academia and industry. Both solicitations are broad-based, covering the five program areas of interest: capture and separation, ocean sequestration, geologic sequestration, terrestrial sequestration, and advanced chemical, biological, and other concepts. Selections under the two solicitations will be made in early 2000. In addition, 6 of the 12 projects which were funded under the Novel Concepts procurement in 1999, were chosen for continued research under a down-selection procedure in late 1999.

Nuclear Fission Systems

Budget: FY99-$18.5M, FY00-$22.4M, FY01-$35.0M

Description, Objectives, and Performers. The Nuclear Energy Research Initiative (NERI) complements Nuclear Energy Plant Optimization by addressing our Nation's nuclear energy future. Despite nuclear energy's advantages, unless issues such as plant costs and spent fuel disposal are successfully addressed, the United States is unlikely to see new orders for nuclear power plants. NERI, started in FY 1999, funds investigator-initiated research and development at universities, National Laboratories, and industry to advance nuclear power technology, paving the way for expanded use of nuclear energy in the future.

The International Nuclear Energy Research Initiative (I-NERI) provides for world-wide R&D of new technologies to address the key issues affecting the future of nuclear energy, in particular, the economics of nuclear plants, safety, proliferation, and waste management issues. I-NERI will give the U.S. a key "seat at the table" at on-going international discussions regarding the future implementation of nuclear technologies and those areas that are important to U.S. policy objectives.

Science and engineering research is needed to develop new, innovative, and advanced reactor designs in three distinct areas: proliferation resistant reactor technology, high efficiency reactor concepts, and low output reactor applications. The overall objective is to develop new reactor designs that offer improved economics, reduced waste generation, increased safety, and proliferation resistance. Research proposals are solicited from a broad range of researchers, including universities, National Laboratories, and industry. International collaboration will be encouraged in order to leverage Federal research funds, although no Federal funds will be used to directly support research outside of the United States.

R&D Challenges. The new reactor design challenge is to bring the capital cost of nuclear power in line with other electricity supply options while also reducing the amount of spent nuclear fuel produced per kilowatt-hour of electricity generation. Internationally, several developing countries expect to see rapidly growing electricity demand over the next few decades and are looking to nuclear power as an option for meeting those needs. In those markets, issues of plant safety and proliferation risk are also of concern. The challenge in those areas will be to develop reactor designs that require a minimum of maintenance, operator action, and refueling during the lifetime of the reactor.

R&D Activities. Activities planned under NERI would focus on scientific and/or engineering research to further reduce the potential for proliferation of nuclear fuel materials and increase the efficiency of nuclear energy systems. Research into new fuel types and fuel cycles that reduce plutonium buildup, produce less waste, and improve efficiency will be studied.

Innovative research could be conducted on reactor designs offering improved thermal-to-electric efficiencies or specialized, new applications such as cogeneration process heat/electricity systems to compete in the global market. Research would include technologies, design concepts, and approaches that incorporate construction and operations simplicity and cost reduction features.

I-NERI will include foreign collaborative research focused on advanced technologies for improving the cost, safety, waste management, and proliferation resistance of advanced nuclear energy systems through specific cost-sharing arrangements with each participating country. Long-term nuclear technology research will be in the areas of new and innovative reactor designs, proliferation-resistant fuel cycles, nuclear science and engineering with particular countries under bilateral agreements.

Finally, research and development of innovative, low power reactor designs employing passive safety systems, and long life cores for electricity generation or process heat use in developing countries could be conducted. The ultimate objective is to develop small reactor systems, primarily for export, that need no on-site refueling for the life of the reactor, employ high safety margins, automated operation, minimized waste production, and cost effectiveness.

Accomplishments. In FY 1999 initial R&D procurement was completed by soliciting research proposals, conducting proposal peer-review and awarding the first research grant and contracts in May 1999. NERI initiated innovative scientific and engineering research and development projects at universities, national laboratories, and industrial organizations that will enhance the performance, efficiency, reliability, proliferation resistance, and economics of nuclear power. A total of 46 proposals were selected for award.

Nuclear Fusion Systems

Budget: FY99-$216.1M, FY00-$237.7M, FY01-$240.1
(These funds are part of the Science Portfolio and are repeated here for information purposes only)

Description, Objectives, and Performers. The process of nuclear fusion - evident in stars, including the sun - releases enormous amounts of energy. The three goals of the program are to advance plasma science, identify and explore innovative and cost-effective development paths to fusion energy, and explore the science and technology of energy producing plasmas as a partner in an international effort. The mission is to advance the knowledge base needed to make fusion an economically and environmentally attractive power source for the future. This research is conducted at national laboratories, universities, and industrial firms.

Research Challenges. There are two promising approaches to achieving fusion energy: magnetic and inertial confinement. Theory and simulation of plasma behavior in both magnetic and inertial fusion is complex because of the many orders of magnitude in spatial and temporal scales involved. It is further complicated by the need to understand electromagnetic wave/plasma interactions and plasma material interactions. Magnetic confinement experiments require innovative configurations of magnetic field lines to contain the hot fusion plasmas. Inertial fusion experiments require simultaneous illumination of the full surface of fusion fuel pellets by high-energy beams to create the needed inertial confinement.

The long-term potential for successful commercialization of fusion energy could radically change the overall pattern of electricity generation. Because fusion power plants would not produce air pollutants that contribute to acid rain and that may contribute to global climate change, they could minimize the environmental risks associated with the burning of fossil fuels. Further, because fusion power plants would contain only small quantities of fuel at any time, they could eliminate the potential for runaway reactions that might lead to accidents. The development of low-activation materials or advanced fuel cycles for fusion reactors could make the amounts of high-level radioactive waste that result from fusion-produced energy far smaller than those produced by fission reactors-thus simplifying waste disposal problems.

Although the burning of fusion fuels (deuterium and tritium) does not produce radioactivity, the tritium itself is radioactive, and the neutrons produced by fusion will induce radioactivity in surrounding materials.

Although fusion has great potential as a safe and environmentally benign source of energy, there are safety and environmental issues associated with radioactive materials in future fusion devices; these issues will need to be addressed Developing an attractive fusion energy source requires major advances in technologies for plasma and neutron-interactive fusion power core components and in neutron-interactive structural materials with the potential for superior performance in fusion energy systems. The hostile neutron irradiation environment of future fusion power cores will place unprecedented demands on structural materials.

Research Activities. Theoretical and computational research in plasma science provides the predictive capability needed to make progress in plasma and fusion science. Current research areas include plasma turbulence and its effect on the transport of particles and energy in plasmas, macroscopic equilibrium and stability of confined plasmas, edge plasma physics and plasma material interactions, plasma heating and current drive with radio-frequency waves, and understanding the characteristics of innovative confinement configurations. Plasma theory and simulation are also key to understanding other scientific phenomena, such as magnetic reconnection in solar and magnetospheric plasmas or turbulence, chaos, and self-organized behavior in complex systems. Finally, simulation in plasma physics is similar to and promotes progress in fields such as computational fluid dynamics and climate modeling.

The plasma technologies program provides the technology tools needed to create, control, and understand the high-temperature plasma state in fusion experiments. Collaborative experiments with our major international partners are under way in magnetic fusion research. The experimental program with heavy ion drivers for inertial fusion energy shows promise for significantly advancing inertial fusion science.

Accomplishments. Substantial technical progress has been made in domestic and worldwide fusion programs. In 1996, the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory, became the first fusion device in the world to produce 10 megawatts of fusion power. This power was produced in a plasma with a deuterium-tritium fuel mix that is expected to be used in fusion energy sources. More recently, the Joint European Torus in England has produced even greater levels of fusion power than the 10 megawatts produced in TFTR. Substantial progress also has been made in the last 3 years in understanding and controlling plasma conditions to improve the energy confinement capability of Tokamaks. By selectively heating the plasma and shaping the current, the thermal energy of the plasma is better contained which would lead to a smaller and more efficient advanced Tokamak power plant.

Distributed and Hybrid Energy Systems

Budget: FY99-$224.1M, FY00-$201.8M, FY01-$250.9M

Background

The U.S. electric industry and natural gas industry are undergoing fundamental change due to restructuring and the addition of new electric generation power suppliers and products and gas transmission, as well as the changing nature of decision making. Grid-sited, large central power plants have long dominated electric utility technology decisions and today these plants remain the backbone of the power system. However, market factors—including ample supplies of low-cost natural gas, constraints at the transmission and distribution level, environmental considerations, and technological advances—are causing alternative, modular technologies such as fuel cells, gas turbines, photovoltaics, wind turbines, solar, geothermal, and biomass systems gradually to augment and sometimes to replace conventional, large-scale generating technologies. In particular, gas turbine and I.C. engine technologies have a dominant role in both distributed energy and hybrid systems.

Renewable resources, such as hydroelectric, wind, solar, photovoltaics, geothermal, and biomass, are abundant. Hydropower provided about 10 percent of the electricity consumed in the United States in 1998, while the remaining renewable resources supplied is nearly 2 percent. The primary advantage of these renewable resources in power generation is they produce virtually no harmful emissions or solid wastes. Their primary disadvantages are the cost of producing power (with the exception of hydropower) compared to coal and natural gas, and the need to create the infrastructure required to deliver electricity to the market. Because hydropower already has a well developed market and infrastructure, the Department currently does not invest significantly in hydropower technologies. The Department focuses instead on improving the performance and lowering the costs of the technologies using other renewable resources.

Where these technologies are available locally, the cost of infrastructure development on the transmission and distribution system is reduced, and a reliable power supply system is made available at critical times in those locations. In a recent study, the Electric Power Research Institute indicated that these small modular units, located primarily on the distribution system, would capture at least half of all new U.S. electric capacity needs between now and 2020. These distributed and hybrid power systems using renewable and fossil energy sources have many benefits such as improving environmental quality, short construction lead time, modular installation, and low capital expense, which all contribute to their growing popularity.

The portfolio of technologies represented by distributed and hybrid systems have numerous applications, for example, at customer sites, to provide heat, power, and cooling and improved indoor air quality in buildings; on the distribution system, to provide high value electricity and deferral of costly power line upgrades and replacement; off-grid in stand alone power applications; and for electricity supply to the bulk power market.

Diesel electric generators currently provide electrical power in remote villages. These generators are reliable if properly maintained, and the low cost of oil make them relatively economical. In their most efficient use, the waste heat is recovered and used for space heating (usually for a large building, such as a school) with total system efficiencies of about 60%. The cost of producing electricity is high in the villages for several reasons. Transporting diesel fuel to the village is the most obvious cost. Since there are no roads, fuel must be barged or flown into the village. Building and operating an electrical utility also requires skilled labor, both for linemen to string wires between houses, and also for mechanics to maintain the diesel engines. As the villages grow smaller, it becomes less and less likely that a person with these skills will be found in the village, so technicians must be brought in from outside, at considerable expense. Since each village is isolated and not connected to a grid, backup power must be provided within the village, by redundancy in the diesel generators, resulting in high capital costs. And furthermore, as the villages become smaller, the per residence cost rises simply due to the reverse of the economies of scale: fixed costs are distributed over fewer users. In addition, because the generators need to be sized for peak demand the generators are most frequently operated significantly below the optimal efficiency

The hydrogen program promotes the development of distributed electric power systems using hydrogen-powered fuel cells. These systems are expected to have many long-term benefits: increased energy efficiency through cogeneration; reduced pollution through the use of hydrogen-powered fuel cells; and increased energy independence by enabling renewable energy sources that produce hydrogen as an energy carrier. The near-term goal of this program is the advancement of this technology by proving that current technologies can be used for distributed, proton exchange membrane fuel cell (PEMFC) energy generation in remote locations. Of specific interest here is the development of systems several kilowatts in size, optimized for and located in individual homes that are not connected to an external electric grid. The power systems under development are comprised of a fuel reformer for conversion kerosene or diesel into hydrogen for use in a fuel cell, a PEMFC, and utilization of waste heat from the PEMFC for residential space and water heating.

Linkage to CNES Goals and Objectives

The Department invests in distributed and hybrid energy systems to ensure the availability of a portfolio of advanced power technologies utilizing renewable and hybrid energy systems that will increase the flexibility, capacity and reliability of the U.S. power system. This end supports:

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.

- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe , and efficient energy systems.

Program Description

The Department is developing a suite of distributed and hybrid power systems to significantly contribute toward the goal of providing reliable and affordable power generated in an environmentally benign manner. Technologies being developed include renewable energy (wind, photovoltaic, concentrating solar power, geothermal, and biomass), and in the area of co-generation, both Industrial Combined Heat and Power (ICHP) and Buildings Cooling Heating and Power (BCHP), with smaller fuel cells (25-50kW), and small gas turbines and reciprocating engines. Emerging technologies in the BCHP programs will significantly contribute to electric peak shaving during the cooling season, when cooling energy is dominant, in buildings comfort conditioning using desiccant systems, and gas heat pumps and chillers.

Industrial Combined Heat and Power Systems

Budget: FY99-$0.2M, FY00-$3.0M, FY01-$1.0M

Description, Objectives, and Performers. Industrial Combined Heat and Power (ICHP) is not a new technology, especially for large industrial applications. With the passage of the Public Utilities Regulatory Act of 1978 (PURPA), new rules were put into effect designed to increase the efficiency of fuel use by removing regulatory and institutional barriers to the development of CHP. PURPA required utilities to interconnect with qualified CHP facilities, provide back up power at reasonable rates, and purchase any excess electricity at the same rate the utilities would have had to pay to generate it themselves. Additionally, on average, two-thirds of the fuel used to make electricity in the U.S. is wasted. Combined heat and power, or cogeneration, involves capturing the waste heat and putting it to some useful purpose at the customer site. The development of combined heat and power systems for generation systems has the potential for over 85 percent fuel utilization efficiency in industrial, commercial, and residential applications.

Since the oil price shocks of the 1970s there have been impressive energy efficiency gains in many sectors of the economy , but the introduction of state-of-the-art (more efficient) fossil fuel power plants has been slow. The result is that the average plant efficiency of power generation in the U.S. has increased very little. However, there has been a dramatic increase in the use of combined heat and power systems at large industrial plants. The program objective is to eliminate the barriers of combined heat and power technologies to increase the overall power industry efficiency and reduce atmospheric emissions, as well as field-test innovative CHP systems.

With utility restructuring and competition in the power generation market and new environmental regulations on the horizon, the market landscape for energy production and use is likely to change even more. Government and industry, in partnership, have the opportunity to address the technology challenges associated with optimizing heating, cooling, and power systems for on-site distributed use for both industrial and buildings applications. These new government-industry partnerships should be in addition to those that are already addressing the technical issues associated with infrastructure development for energy transport and storage.

A related new initiative is the Combined Heat and Power Challenge (CHP) that addresses major existing barriers to the implementation of combined heat and power systems, to achieve a goal of doubling the amount of CHP in the United States (46 GW) by 2010. Some of the barriers addressed follow:

- Environmental permitting that is complex, costly, time consuming and uncertain.
- Environmental regulations that do not recognize the overall energy efficiency of CHP or credit emissions avoided from displaced electricity generation.
- Utilities that charge (or threaten to charge) prohibitive exit and/or stranded asset fees for customers wanting to build CHP facilities, or charge unreasonable rates for use of the distribution grid, and/or prevent the use of alternative backup and supplemental power suppliers.
- Long and varied Federal tax depreciation schedules for CHP investments that differ depending on system ownership.

The ICHP Challenge will assist plants that experience the above problems when implementing CHP systems through assessments of future combined heat and power facilities, State outreach, modeling, and technology verification. The program will field-test innovative CHP technology solutions for the industrial, residential, and commercial systems. The program has provided several grants to California, Vermont, Indiana, and Washington to initiate case studies to implement advanced combined heat and power technologies. The program is also investigating the use of biomass and black liquor (produced in the paper-making process) for large-scale combined heat and power systems that are synergistic with industrial processes and district heating/cooling needs.

R&D Challenges. R&D challenges include prime mover (fuel cell, turbines, etc.) technology development, related low emissions, cost effective technology development, and technology development and technology integration into the end-use sector.

R&D Activities. Some of the power generation technologies being developed by DOE and industry such as microturbines, reciprocating engines, and fuel cells are aimed at fuel flexibility and other modifications to accommodate a variety of energy needs. CHP is an energy efficiency strategy that includes the Offices of Building Technologies (and??), Power Technologies, and Industrial Technologies.

Accomplishments. In December 1998, the program held a national workshop. In August 1999, the program initiated a technology demonstration of a ceramic combustor liner CHP system in the industrial sector; and facilitated industry in developing a vision for advanced power generation systems. In addition, three regional workshops were held. In February 2000, an international workshop will be held to address the issues of reducing global emissions and increasing efficiency in developing countries (in support of PCAST).

Buildings Cooling Heating and Power (BCHP) Systems

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

Description, Objectives, and Performers. The Department of Energy has embarked on significant partnerships with industry with the intent of creating meaningful research, development and commercialization program plans. Reviewing progress among these important efforts, the natural gas industry together with manufacturing trade allies in the onsite power generation and thermally activated HVAC industry concluded that a significant technology synergism opportunity exists. To address this opportunity, the DOE with industry has created the BCHP Initiative and is proposing BCHP 2020 Vision in support of the Department's ICHP program in the Buildings Sector.

New and emerging BCHP system choices include a spectrum of technologies, such as fuel cells, micro turbines and the about-to-be commercialized industrial advanced turbine system (ATS), which are more economically attractive, reliable, and versatile and should open new markets for both BCHP and ICHP. New thermally driven cooling and humidity control technologies are likewise being developed and demonstrated which can potentially utilize the heat output very effectively.

BCHP along with ICHP offers great potential for the environment. A September 1997 study in which five DOE laboratories examined more than 200 technologies, entitled *Scenarios of U.S. Carbon Reductions*, found that just three BCHP and ICHP type applications –advanced turbines, fuel cells, and integrated combined cycle technologies – accounted for nearly 10 % of the projected carbon savings. The next generation of turbines, fuel cells, and reciprocating engines offer efficiency at reduced size, versatility in the ratio of electric or mechanical energy to thermal energy, and can be combined with advanced heat recovery-driven cycles for the highest possible overall source energy efficiency and lowest carbon emissions.

Energy is used to provide a wide variety of services in buildings including occupant comfort (temperature and humidity control), desiccants, lighting, water heating, and power to drive appliances and other miscellaneous electrical devices. The US consumed almost 93 quadrillion

BTUs (Quads) of energy in 1996. Of this total, commercial buildings accounted for over 15 Quads. This is equivalent to the amount of gasoline consumed in a year.

There is a distinct opportunity to significantly conserve resources and reduce climate change gas emissions by accelerating the use of Building Cooling, Heating and Power systems in commercial buildings. Good planning and development in the area of building envelopes and windows will yield a 15% benefit. Historically research, development and commercialization efforts have been focused on individual equipment (e.g. cooling, thermal storage, ventilation air systems, power generation and cooling). BCHP now focuses on building power and HVAC system optimization and integration using efficient equipment. This yields remarkable building level energy efficiency gains and emission reduction achievements

Today, electric power industry restructuring, coupled with the unbundling of various components of electric service, is ushering a new era in which customers will have greater opportunities to optimize their energy services than ever before.

Many of the same barriers that confront the implementation of ICHP confront the implementation of the BCHP.

- Environmental permitting, codes and standards, regulations.
- Energy incentives, tax credits
- Cost of fuel
- Cost of new and emerging technologies

BCHP has the potential to reduce carbon and air pollutant emissions and increase source energy efficiency dramatically. BCHP produces both electricity and useable thermal energy onsite for input to thermally activated heat pumps, chillers or desiccant regeneration, converting as much as 90% of the fuel into useable end use energy. This is compared to conventional central station power plants, which convert only about a third of the fuel's available energy into useable electric power energy. New and emerging BCHP system choices include a spectrum of technologies, such as fuel cells, micro turbines and the about-to-be commercialized industrial advanced turbine system (ATS), large commercial chillers, residential heat pumps which are more economically attractive, reliable, and versatile and should open new markets for BCHP. New thermally driven cooling and humidity control technologies are likewise being developed and demonstrated which can potentially utilize the BCHP heat output very effectively.

R&D Challenges. R&D challenges include cost effective, advanced absorption commercial chillers, higher temperature PEM fuel cells, residential chillers/heat pumps, advanced desiccant materials and systems.

R&D Activities: R&D in small-scale (25 – 50 kW) PEM fuel cells for buildings, large commercial building LiBr/H20 chiller, residential NH3/H2O absorption heat pumps, liquid and solid advanced desiccant systems.

R&D Accomplishments. In FY1999, the program held three workshops for BCHP, fabricated two gas fired Ammonia/Water prototype absorption heat pumps for residential application. Tested several desiccant systems in high occupancy buildings.

Advanced Industrial Turbine Systems

Budget: FY99-$49.4M, FY00-$22.3M, FY01-$13.3M

Description, Objectives, and Performers. Advanced turbine systems, with their wide range of potential sizes, are particularly attractive for distributed generation applications. Competition and emerging technologies are causing the power generation industry to abandon its larger-is-more-efficient philosophy for a customer-based, tailored energy mindset. In the competitive environment, electric power suppliers will need to pay more attention to customers needs in order to retain them. The result will be a growing demand for custom power plants designed to most efficiently meet the end-use residential/commercial/industrial customer's specific needs. DOE's Advanced Turbine Systems (ATS) Program is focusing on this market through it objective to make available turbine systems for distributed applications, including: (1) industrial gas turbines that are 40 percent efficient with single digit emissions and provide a 10 percent reduction in the cost of electricity while maintaining the reliability, durability and availability of today's industrial turbines, and (2) advanced microturbines with 40 percent efficiency and emissions of less than 9 parts per million NO_x and CO_2 at an equivalent reliability and reduced cost compared to today's technology.

There are over 150 partners in the Advanced Turbine Systems program that represent suppliers, universities, and national laboratories. The program is a joint effort between the Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy.

R&D Challenges. Meeting the goals for advanced industrial turbines will require advancements in engine and component design, including innovations in cooling, heat recovery, combustion, materials, and coatings. For advanced turbines improved and new ceramics and coatings will enable turbines to have higher efficiency, lower emissions, longer life, and to be fuel flexible.

R&D Activities. The Advanced Turbine program is developing industrial gas turbines and microturbines to meet goals previously mentioned. Additional work supports major component development in the combustor and power turbine. These elements include low-emissions technology development and advanced materials (e.g., ceramics, advanced coatings). Engine development and testing continues to improve gas turbine efficiency, environmental performance, and long-term durability.

In the microturbine area, the program is working with the Electric Power Research Institute (EPRI), the California Energy Commission (CEC), and Southern California Edison to test the performance characteristics of commercially available microturbines to establish a technology baseline. Additional information will be gained from a joint field test program with EPRI and the National Rural Electric Cooperative Association (NRECA) to site nine microturbines at cooperative locations across the United States. The development of ceramics and new corrosion-resistant metals for recuperators will continue, focusing on improving durability of the materials in microturbine engine environments. A competitive solicitation will be released in FY 2000 for advanced microturbine projects including concept design, component and sub-component development, and testing.

Accomplishments. An early success of the program will be the demonstration of the "Mercury 50" advanced turbine by Solar Turbines, Inc., in early 2000. A second success is, with DOE support, Solar Turbine's ceramic development effort to replace cooled metallic hot section parts (combustor liner, vanes, and nozzles) with uncooled ceramic parts. To date, ceramic composite combustor liners have been run for approximately 2000 cumulative hours in an industrial gas turbine at Texaco in Bakersfield, California. The goal of the effort is to run several ceramic components (blades, vanes, and nozzles) for 4000 hours.

Data reports on microturbine performance and operating and maintenance logs are being generated for the various microturbines tested under the Southern California Edison project. Work continues to develop a performance-based design database for silicon nitride ceramics and improve the durability in high-temperature water vapor environments. Advanced manufacturing, including automation, are being applied to the production of silicon nitride small turbine parts.

Hydrogen Fuel Cell Systems

Budget: FY99-$0.0M, FY00-$5.5 M, FY01-$8.8M

Description, Objectives and Performers. This is a three-year effort to develop distributed PEMFC technology and demonstrate its use in remote settings, specifically in Alaskan villages. This is being accomplished by fostering ongoing commercial activity in the areas of importance for this activity, including the development of diesel and kerosene reformers capable of producing useful hydrogen streams, efficient fuel cell systems in the several kilowatt range, and encouraging systems integration to achieve high overall system efficiencies through cogeneration.

The near-term objective of this program, which is being accomplished through a solicitation process, is to assemble teams of industrial partners that can supply field distributed, hydrocarbon fed, and fuel cell power systems. As many of the necessary components are in the development stage, the near-term goals are set to ensure that components with the necessary long-term specifications are being developed now, leaving system integration and fielding for later in the program.

This program is being executed in three phases. During the first phase, three PEMFC stacks and two reformers were delivered for evaluation. The second phase will focus on systems integration, with the components being integrated into hydrocarbon-fed, fuel cell powered, energy systems. The third phase will consist of field testing the completed distributed energy systems in a remote setting

The principle customer for this program is the residents of Alaskan Villages. The University of Alaska at Fairbanks (UAF) is a partner in this program and provides arctic engineering expertise.

The UAF will actually qualify these technologies for use in the remote village environment. Hence, UAF is the most immediate customer for this program.

The performers are Teledyne Brown Engineering, Schatz Energy Research Center, Schatz Energy Research Center and another team to be awarded in January, 2000.

R&D Challenges: A significant technical barrier is the development of a reformation technology that can suitably reform diesel and/or kerosene for use in PEMFC's and do so with a reasonable time between failure. In addition, the systems are being designed to be fully automated in the field.

R&D Activities: Steam reforming and auto-thermal reformers are being developed for this system that include the development of advanced catalysts that are resistant to sulfur and soot formation. Small-scale hydrogen fuel cells are being developed to operate off the gases produced by these reformers.

Accomplishments: A diesel reformer was operated in July 1999. A three to five kilowatt PEMFC using hydrogen reformed from diesel fuel operated in September 1999.

Wind Energy Systems

Budget: FY99-$34.1M, FY00-$32.5M, FY01-$50.5M

Description, Objectives, and Performers. Wind turbines convert the kinetic energy in the wind into electrical energy. Most turbines today employ two or three propeller-like blades mounted on a rotor connecting to an electric generator that typically is 500-1000 kilowatts in output. Larger sizes that have been tested are just now entering the commercial marketplace. Because they are modular, wind turbines can be sited either individually, grouped in small clusters, or in larger windfarms totaling 10 to 50 megawatts or larger. In 1997, 3.2 billion kilowatt-hours of electricity were produced by 16,000 wind turbines in the United States.

The program's near-term objective is to develop advanced wind turbine technologies capable of bringing the costs down to $0.025/per kilowatt-hour by 2002 compared to today's cost of $0.04-0.05 per kilowatt-hour. In the longer term, R&D will focus on turbine systems, component materials, electronic controls, and wind forecasting combined with hybrid systems to expand wind energy applications. The target is 10,000 MW of wind energy installed in the United States by 2010, by combining a vigorous technology development effort with activities to reduce barriers and to promote supportive energy policies.

The program conducts R&D with significant cost-sharing through industry partnerships and collaboratives. Partners working collaboratively with DOE include the wind and electric utility industries, National Laboratories (National Renewable Energy Laboratory [NREL], Sandia National Laboratory [Sandia]), and universities.

R&D Challenges. Wind has proven to be an extraordinarily complex energy resource. To be cost-effective, a wind turbine must have high aerodynamic efficiency and must be durable and reliable, while also having minimal weight and complexity. The challenge for the wind program, therefore, is to assist industry in bringing the cost of wind technology to a level where it can compete with traditional energy sources.

R&D Activities. The wind program has three R&D thrusts. The first, the Applied Research program, focuses on basic issues of wind characterization, aerodynamics, structural dynamics and fatigue, hybrid systems, and advanced components and controls. The second, Turbine Research, includes five distinct efforts to develop advanced deployable technology. These efforts include next generation technology development for both utility-scale and small systems and field verification tests at actual operating locations. The third thrust encompasses a number of activities that support the development of certification and standards, technical assistance for industry's international programs, and operation of the National Wind Technology Center at Rocky Flats, CO.

Accomplishments. The DOE wind program has been increasingly successful in improving the performance and decreasing the cost of wind systems and subsequently enhancing its commercial prospects. Today, in areas with ideal wind resources, electricity can be produced for less than $0.05 per kilowatt-hour compared to wind energy in 1980 at $0.35 per kilowatt-hour—a decrease of 85 percent in just 15 years. Recent partnerships with DOE have produced 3 commercially-offered wind turbines, with another 8 now under development.

Photovoltaic Systems

Budget: FY99-$70.6M, FY00-$65.9M, FY01-$82.0M

Description, Objectives, and Performers. Photovoltaic (PV) solar technology uses semiconductor-based cells to directly convert sunlight to electricity. The greater the intensity of the light, the more power that is generated. PV can be used to produce electricity on almost any scale, depending only on how many PV modules are connected together. The worldwide market for PV is growing rapidly, with the United States retaining the largest market share in 1997.

The objectives of the PV program are: (1) by 2000, reduce the direct manufacturing cost of commercial modules by 15 percent from current average costs of about $4.25 per watt and increase annual U.S. sales of commercial modules from 40 megawatts in 1996 to 70 megawatts; and (2) by 2004, increase the efficiency of both thin film and crystalline silicon PV cells, reduce the retail sales price of commercial modules by 40 percent, increase lifetimes to greater than 25 years, and increase annual U.S. industry sales to 180 megawatts.

Partners working collaboratively with DOE include the PV and electric utility industries, National Laboratories (NREL, Sandia), and universities. Almost all work with industry is heavily cost-shared.

R&D Challenges. Even though the cost of PV is rapidly decreasing, it is currently too high for the bulk power market. R&D challenges to reduce costs include improving the fundamental understanding of materials and processes to provide a technology base for advanced PV options, optimizing cell and module materials and design, scaling up cells to product size, validating performance in outdoor and accelerated conditions, and improving manufacturing processes.

R&D Activities. The Photovoltaic R&D program is divided into three areas. The first, Fundamental Research, includes the measurement and characterization of cell materials and devices. Work is also performed to improve cell structure and materials processing for thin film technologies. As part of the second area, Advanced Materials and Devices, the Thin Film Partnership Program is a government/industry/university partnership to accelerate development of cost-effective thin-film technologies. The program also operates a core research effort in high efficiency III-V gallium arsenide (GaAs) materials and devices for concentrator and flat plate applications. Finally, under the third area, Collector Research and Systems Development, the Photovoltaic Manufacturing Technology Project (PVMaT) is improving manufacturing processes for thin-film technologies and assisting industry in the development of advanced techniques for producing higher performance and lower cost commercial products. The program is continuing R&D on advanced PV Building products, concepts, tools, and modeling procedures in support of industry efforts for technology development/deployment. The Million Solar Roofs Initiative will increase outreach activities to establish partnerships with communities, cities, builders, Federal and State agencies, corporations, and financial institutions across the Nation.

Accomplishments. The program has contributed to a 50 percent reduction in the cost of producing PV modules since 1991, resulting in the technology being used in grid-connected, distributed power, and off-grid, remote electric power. A recent success is the development, in partnership with industry, of a Photovoltaic roofing shingle that is now on the market and can replace conventional roofing shingles to generate clean electricity.

Concentrating Solar Power Technology

Budget: FY99-$16.8M, FY00-$15.2M, FY01-$15.0M

Description, Objectives, and Performers. Concentrating solar power (CSP) systems use sun-tracking mirrors to reflect and concentrate sunlight onto a receiver where it is converted to high-temperature thermal energy. The high-temperature heat is then used to drive a heat engine and electric generator.

The CSP program has recently reviewed its objectives to ensure that the program is focused on the needs of the evolving utility marketplace. By 2004, the program will, in collaboration with industry, help develop a reliable (4000 hours mean time between failures) distributed power system and a competitively priced dispatchable power system. that will enable full participation by CSP systems in domestic generation markets, prompted by the restructuring activities in various States.

The Program has cost sharing with industry of roughly 50 percent. R&D partners working collaboratively with DOE include the solar thermal and electric utility industries, National Laboratories (NREL, Sandia), and universities.

R&D Challenges. The program is addressing the challenges of harnessing an intermittent resource, i.e., sunlight, and cost-effectively converting that resource into electricity that has high value to the utility supply system. One approach is to store thermal energy for later conversion into electricity as utility system demand dictates. A second approach is to produce electricity whenever sunlight is available, and to supply that electricity to the grid either in high-value peak periods or in applications where the price of alternative power supplies is high. Because thermal conversion efficiencies are greatest at higher temperatures, the program is seeking advanced materials and heat receivers that operate at higher temperatures.

R&D Activities. The CSP R&D program activities are categorized into four paths. The first path, Develop and Demonstrate High-Reliability Distributed Power Systems, focuses on reliability of dish/engine systems for emerging markets for distributed energy sources. The second path, Reduce Costs of Dispatchable Solar Power, is currently focused in two areas: advanced trough component R&D and the development of high-temperature CSP systems. Penetration of broad domestic and international markets will, however, require further significant technology advances addressed in path 3, Develop Advanced Components and Systems. A fourth path, Expand Strategic Alliances and Market Awareness, will keep technology efforts focused on the most critical needs of industry, ensure a technology capable of meeting market needs, and support domestic and international information flow and policy decisions favorable to renewable energy.

Accomplishments. The CSP program is concluding a decade-long program to develop a utility-scale dispatchable solar electricity system. The 10-MW Solar Two power tower concept, being demonstrated in Southern California, incorporates molten salt thermal storage to extend its operation into early evening hours at a more competitive level of cost.

Geothermal Energy

Budget: FY99-$21.7M, FY00-$23.6M, FY01-$27.0M

The accessible geothermal resource is the thermal energy contained in the rocks within the top three miles of the Earth’s crust. This heat energy is carried by naturally occurring hot water or steam brought to the surface through deep wells, and the fluid is used to drive turbine-generator systems to produce electricity or heat is used directly for industrial, agricultural, or domestic purposes. The Department is working with industry to solve the major R&D challenges in the exploration, drilling, and reservoir management of geothermal resources. The goals are to reliably detect producing fractures in hydrothermal systems; to efficiently drill and complete wells under conditions of high temperature, hard rock, and corrosive fluids; and to economically operate production and injection wells for the maximum energy yield as a sustainable resource.

Geothermal Exploration

Budget: FY99-$5.4M, FY00-$6.0M, FY01-$6.0M

Description, Objectives, and Performers. To improve the detection of producing zones in geothermal reservoirs, the Department in partnership with the geothermal industry is augmenting the technology for 3-D seismic surveys and electromagnetic logging.

R&D Challenges. The major challenge in exploration for geothermal resources is the detection of producing zones deep in the subsurface so that drill holes can be directed from the surface to intersect them. Lower well costs would result in expanded use of geothermal power by making this environmentally-preferred alternative more economical.

Present exploration techniques are not specific enough to identify producing zones, and their application results in too many dry wells, driving up development costs. The industry needs better geological, geochemical, and geophysical techniques to identify and characterize the geothermal reservoirs. Technology improvements are needed to reduce the cost of drilling into hard rock at high temperatures which contain corrosive formation fluids, and cements must be developed to maintain well integrity in acidic conditions and high temperature.

R&D Activities. The geothermal reservoir contains steeply dipping faults and fracture zones which provide the high permeability pathways for geothermal fluid production, and the opposing rocks may have only a slight contrast in seismic velocity. Shear-wave generators are being tested to determine the best technique to provide the seismic energy needed for characterization of the geothermal production zones. Geophone array configurations will be tested in mathematical models to determine the optimal design for increased accuracy of location and decreased biasing of the data.

To increase the success of exploration wells intersecting productive fractures, joint Department-industry research is developing a deep-penetration electromagnetic logging tool. The initial activity will be development of the theoretical basis for the electrical response and the mathematical procedures for interpretation of the measurements. The major challenge will be the construction of a tool that will have sufficient signal strength and receiver separation distance to allow the imaging of potential producing fractures within a radius of 100 feet from the exploration well.

Accomplishments. Development of better interpretation methods for imaging logs have revealed the evolution of faults and fractures in relation to regional stresses in the Earth, and this has led to knowledge of the local control of fracture permeability in the geothermal reservoir. Research on surface electromagnetic survey methods has resulted in improved geothermal field definition with greater instrument reliability and more credible interpretation mathematics. Fluid inclusion studies of secondary alteration minerals from geothermal systems allow developers to determine the changes in salinity and temperature of geothermal fluids with time.

Geothermal Drilling and Completion

Budget: FY99-$4.9M, FY00-$5.5M, FY01-$5.5M

Description, Objectives, and Performers. Geothermal drilling R&D consists of two key components over the next 5-years: incremental improvements for geothermal drilling technology and a high-speed diagnostics-while-drilling (DWD) system.

R&D Challenges. Geothermal wells cost 35-50 percent of the costs of a typical geothermal electric power project. Geothermal well costs can be significantly reduced by improving the technology used in geothermal drilling. Reduced drilling costs is the key to the expansion of geothermal power from traditional hydrothermal resources to hot dry rock, the next generation of geothermal power.

R&D Activities. Activities include the application of advanced techniques, materials and equipment including: a core-tube data logger to collect downhole data while drilling; advanced hard rock polycrystalline diamond compact (PDC) drill bits to drill harder rock; a dewared pressure/temperature/spinner logging tool to provide data in high-temperature wells; and development of slimhole drilling to reduce exploration costs by about 50 percent. The second involves the conceptual work, technology development, field testing necessary, and possible commercialization for the use of a high-speed DWD system. Real-time drilling and logging data, analyzed and used in real-time to control the drilling process, will result in dramatic improvements in drilling performance and reductions in well costs.

Accomplishments. Conducted initial design and testing of PDC drill bits now used in about 40 percent of drilling worldwide, an industry with annual sales in excess of $200 million. In addition, the program developed high-temperature drilling muds, high-temperature elastomers for downhole motors, advanced drilling fluid flow instrumentation, high-temperature memory logging tools; and fostered the use of slimhole drilling as an exploration tool for geothermal energy saving 30 to 50 percent of exploration drilling costs.

Geothermal Reservoir Technology

Budget: FY99-$5.4M, FY00-$6.0M, FY01-$5.5M

Description, Objectives, and Performers. The strong collaboration between the Department and industry in the areas of reservoir modeling, tracer technology, and the study of water absorption is the major focus of geothermal reservoir production.

R&D Challenges. The development of geothermal energy systems requires improved computer methods for modeling heat-extraction and water injection strategies from geothermal reservoirs. An entire suite of chemical tracers are needed to track the migration of injected water through the geothermal reservoir to the production zone to avoid premature breakthrough of cooled production fluid. It is necessary to quantify the relative permeabilities of water and steam in the geothermal reservoir to develop the best strategy for injection of cold water to avoid reservoir pressure loss. A knowledge of adsorption of water on mineral surfaces is important in low-pressure geothermal reservoirs to determine the amount of fluid reserves available for production.

R&D Activities. The possibility of water adsorption on mineral surfaces as a significant source of fluid in low-pressure geothermal reservoirs is being investigated by collaboration between Lawrence Berkeley National Laboratory and Stanford University through measurements of mass change in rocks as a function of water saturation in steam. This research will have important ramifications for the operating pressure of a geothermal reservoir and for the optimum conditions during water injection.

Collaboration between the Department and industry is enabling the development of chemical tracers that are compatible with the environment, do not react with the reservoir rocks, are thermally stable at reservoir temperatures, and can be detected in minute quantities. These tracers show the path of injection water through the reservoir, and they provide a measurement of transit time for a chemical front between injection and production wells. Operators can avoid the temperature drop that would result from rapid breakthrough of cold injection water into the production zone of the reservoir. When cold injection water is used properly to maintain reservoir pressure, geothermal energy is sustainable over long periods of time.

Basic experimental laboratory studies are being conducted to determine the relative permeabilities of reservoir rock to steam and hot water. Empirical evidence has shown that the different phases travel through the reservoir at different rates, and this fundamental property is required for accurate reservoir modeling. Testing of potential tracers is continuing because different tracers are needed to identify the water from each injection well in an operating geothermal field with a large number of production and injection wells.

Accomplishments. Program accomplishments include:

- Demonstrated the application of reservoir modeling to geothermal systems to predict longevity and total energy recovery. Model improvements are underway to incorporate mineral precipitation in the prediction of reservoir permeability.
- Identified and tested chemical tracers for monitoring flow of injected water through geothermal reservoirs.
- Analyzed causes of reservoir pressure decline at the Geysers Geothermal Field and developed effective injection strategies to sustain reservoir productivity.

Geothermal Systems

Budget: FY99-$6.0M, FY00-$6.1M, FY01-$10.0M

Description, Objectives, and Performers. Geothermal power plants use the natural heat in the earth's interior to drive a turbine generator and produce electricity. Currently, the installed commercial geothermal electric capacity in the United States exceeds 2,800 megawatts. Today, electricity is produced domestically only from hydrothermal resources (reservoirs of steam or hot water) in the western United States. In the future, hot dry rock resources, which are far more abundant, could contribute to clean power production.

The program objectives are: (1) by 2005, lower the cost of geothermal energy production to $0.035 per kilowatt-hour from typical geothermal resources, compared to current costs ranging between $0.05 and $0.08 per kilowatt-hour; and (2) by 2010, provide technology to facilitate increased geothermal power that will supply electric power to 7 million U.S. homes, and meet the needs of people in developing countries.

The DOE Geothermal Electric R&D program is implemented through a combination of contract research at National Laboratories (principally Idaho National Engineering and Environmental Laboratory, Sandia National Laboratory, and National Renewable Energy Laboratory) and financial assistance to private companies whose proposals are selected by a competitive process of objective merit review.

R&D Challenges. Longer-term (beyond 2005) geothermal R&D challenges include improved methods for predicting reservoir performance and lifetime, innovative low-cost drilling technologies, improved conversion of energy from hot dry rock, and lowering equipment costs through materials science and process chemistry.

R&D Activities. The Geothermal Electric R&D Program focuses its efforts in three areas. Exploration and production technology work seeks new, more cost-effective ways to identify and exploit geothermal reservoirs. Support for drilling technology development includes drill bit development and advanced computerized well logging tools. Energy conversion technology focuses on advanced systems for controlling non-condensible fluids in geothermal fluids, and development of a small-scale demonstration plant at a remote location.

Accomplishments. The DOE Geothermal Electric R&D Program improved the flashed-steam cycle during the 1970s and 1980s by developing technology for managing solids, making possible exploitation of over 200 megawatts of the geothermal resources near the Salton Sea in California. More recently, it has developed technologies that have achieved 5 to 10 percent efficiency improvements of power plants operating with high non-condensible gas loading (at The Geysers, CA) and with reduced brine temperatures (at Mommoth, CA). The program was a key participant in the development of the polycrystalline diamond drill bits now used in about 40 percent of oil and gas drilling worldwide, and since then has demonstrated the use of slimhole drilling for geothermal exploration, reducing drilling exploration costs by 30 to 50 percent.

Biopower Energy Systems

Budget: FY99-$30.8M, FY00-$31.8M, FY01-$48.0M

Description, Objectives, and Performers. Biopower systems generate electric power from resources such as energy crops, agricultural residues, wood, and wood residues. These can be co-fired with coal, burned directly as a single fuel in new power plants, or converted through a gasification process to a high energy gas stream to be burned in an advanced, high efficiency gas turbine to produce electricity. Biopower systems can also be integrated in industrial processes such as paper and allied products.

Objectives of the program include: (1) develop advanced biomass conversion technology that, when combined with dedicated crop and tree feedstocks, will reduce the cost of electricity production by nearly 50 percent compared to current costs of $0.07-0.09 per kilowatt-hour for direct biomass-fired power plants now in the marketplace, (2) increase the viability of clean, efficient, biopower technologies for a variety of markets to achieve an additional 3,000 MW of new biomass power in the United States by 2004, and (3) develop integrated biomass/black liquor process streams for the manufacturing sector.

Biomass power research performers include industry partnerships and consortia, the National Laboratories (NREL, Oak Ridge National Laboratory [ORNL], Sandia), and other Federal agencies such as USDA. The program has significant cost-sharing with industry.

R&D Challenges. Short-term R&D challenges include finding ways to improve fuel feed systems, combustion characteristics, gas cleanup, effects on materials and component life and heat transfer performance, discharge handling, NO_x reduction potential, and ash chemistry. Regarding advanced gasification, near-term objectives focus on demonstrating the feasibility of various conversion technologies. Research challenges include demonstrating long-term operation of gas turbines on biogas, improving materials, developing sufficient energy crops for feedstocks, demonstrating advanced technologies, and integration into the forest products sector.

R&D Activities. The Biopower Program is pursuing the development and use of "dedicated" crops and trees which would be regrown to recapture the carbon dioxide emitted when the biomass is burned as a fuel in power plants, creating an energy cycle in which there is no net greenhouse gas emissions. Biomass gasification technologies are being developed through a program that examines advanced techniques for thermochemical conversion of biomass feedstocks and that demonstrate the use of gasifier technology in utility and industrial manufacturing settings. The development of biomass co-firing in existing coal power plants is being pursued in partnership with the utility industry.

Accomplishments. Program successes include the demonstration of the gasification process at the Vermont Biomass Indirect Gasification Project (8-12 megawatts). Three projects competitively awarded in 1996 to industry consortiums will validate integration of dedicated feedstocks with existing or new power plants. These are Niagara Mohawk/Salix Consortium Willow Cofiring Project—47-megawatts of biomass power in an existing coal plant, the Minnesota Valley Alfalfa Producers Gasification Project (MnVAP)—a new 75-megawatt alfalfa biomass-based power plant, and the Chariton Valley RC&D (Iowa) Switchgrass Cofiring Project—35-megawatts of biomass power cofired in an existing coal plant.

Reciprocating Engines

Budget: FY99-$0.5M, FY00-$2.0M, FY01-$2.3M

Description, Objectives, and Performers. Reciprocating engines are piston internal combustion engines (typically less than 20 megawatts) that are well known for their use in combined heat and power applications and back-up power generation. Advantages of reciprocating engines are low capital cost, fuel flexibility, and easy maintenance and operation. These advantages will continue to make reciprocating engines the option of choice for onsite power production for the foreseeable future while more advanced technologies such as microturbines or fuel cells are under development. Primary markets include the transportation, residential, commercial, and industrial (chemicals, petroleum, natural gas, agriculture, metal refining and casting) sectors. Another application is gas compression. Reciprocating engines use a variety of fuel sources, including natural gas, diesel, waste fuels, and low-Btu fuels. The objective of this activity is to develop a 50 percent efficient natural gas fired reciprocating engine with emissions less than 9 parts per million of NO_x.

R&D Challenges. Challenges include developing low-emission technology solutions, obtaining efficiencies greater than 40 percent, fuel-flexible ignition systems, maintenance and operation, and the heavy use of lubricating oils.

R&D Activities. Elements of this program are leveraging efforts performed in the Office of Transportation Programs, Diesel Engine program. A Stationary Engine program will be initiated in FY 2000 to develop an advanced reciprocating engine system as a key component to enhancing industrial power generation/cogeneration technologies. A research consortium is performing work on pre-competitive issues such as advanced materials, advanced ignition systems, combustion development, sensors and controls, catalyst development, and oil reduction. Partners in this gas engine consortium include the Federal Energy Technology Center, Gas Research Institute, and Southwest Research Institute.

Accomplishments. In December1998, a workshop was held to identify research needs and opportunities to meet stated goals. A program plan will be developed in FY 2000.

Technology Improvement of Operating Plants

Budget: FY99-$22.2M, FY00-$31.5M, FY01-$35.6M

Background

The existing fleet of operating plants include fossil, nuclear, and hydroelectric units, which make up over 98 percent of the power generated in the United States. The existing fossil fleet is aging, while the licenses for the fleet of operating nuclear plants will begin to expire in large numbers beginning in 2010. Environmental concerns created by hydroelectric plants, particularly with their impact on fish life, are increasing.

Despite expected energy efficiency measures, the projected growth in electricity demand coupled with expected plant retirements would require 363,000 megawatts of new power capacity by 2020. It is critical, therefore, that the contribution of current fossil, nuclear, and hydroelectric powered plants be optimized. In order to do so, improved technology must be deployed in current power plants and a large percentage of existing nuclear power plants must achieve license renewal.

Linkage to CNES Goals and Objectives

The Department protects the Nation’s investment in existing baseload power plants through the development of improved information management systems, sensors and controls, aging management, and regulatory compliance programs. This end supports:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.
- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.

Program Description

DOE and industry are partners in the development of technologies to improve the operations of fossil energy plants, to provide for cost-effective compliance to new environmental regulations, to ensure acceptable levels of safety and reliability as these plants begin to age, and to improve efficiencies for their remaining life.

With respect to nuclear plants, the Department conducted no R&D in FY 1998 or FY 1999, but is starting a new R&D initiative in FY 2000, the Nuclear Energy Plant Optimization (NEPO) program. The NEPO program is a 50-50 cost-shared with industry with a goal of ensuring that current nuclear plants can continue to deliver adequate and affordable energy supplies up to and beyond their initial 40-year license period. Technology improvements for both fossil and nuclear plants are targeted primarily in three areas: information management systems, aging effects in key components, and sensors and controls.

Regarding hydropower plants, the Department's work is focused on the development of improved hydropower turbines.

The continued operation of existing U.S. nuclear power plants avoids emission of over 150 million metric tones of carbon annually. Nuclear energy's continued role in electricity production is necessary so that our Nation can meet its global climate change commitment. These plants are also critical to helping utilities meet state implementation plans and EPA requirements for Clean Air Act compliance. In addition, the loss of nuclear power plants would not only have negative environmental impacts, but also threaten the reliability of the electric generation systems in several States.

Aging Effects in Key Components

Budget: FY99-$6.1M, FY00-$7.0M, FY01-$7.4M

Description, Objectives, and Performers. In coal-fired plants, technical issues related to plant aging include fouling, corrosion/erosion, fatigue, and creep life of components. The DOE and industry, with support from the National Laboratories and universities, are developing improved materials, developing fabrication techniques, and conducting research to gain a better understanding of the combustion science, corrosion, and transport mechanisms that impact the life of components. Although the research and development are aimed primarily at advanced coal power systems, these improvements would be applicable to components in existing plants and could be deployed at the time of scheduled maintenance and change out.

Degradation of materials in nuclear reactor plant structures and components caused by radiation, high temperatures, high pressure cyclic stresses, and a relatively corrosive environment costs utilities that operate light water reactors (LWRs) hundreds of millions of dollars each year. Not only does this degradation increase current operating costs significantly, but, if continued, material degradation could force the premature shutdown of some plants before the end of their initial 40-year license term. Even for plants that can operate until the end of their current license period, material degradation issues will strongly affect license renewal decisions. Work in this area under the NEPO program will be conducted by a combination of universities, National Laboratories, and industry.

R&D Challenges. The challenges are to develop improved materials and detection devices to reduce costs associated with component aging in coal and nuclear power plants.

R&D Activities. Advanced austenitic alloys will be developed to address the issue of stable alloys in super heaters and reheaters of advanced coal combustion plants with 1300 ^{o}F and 5000 psi steam conditions. Creep strengthening of promising alloys such as iron aluminites will be accomplished through oxide dispersion strengthening. A New generation of corrosion resistant high temperature alloys will be developed as hot components in advanced fossil energy combustion and conversions systems.

Research is planned in the NEPO program to understand, characterize, and manage service-induced degradation of steam generation tubes, reactor internals, primary system piping, electric cables, and safety-related structures. Technology development will be focused on timely detection, mitigation, and prevention of significant long-term effects of aging such as stress corrosion cracking, irradiation assisted stress corrosion cracking, reduction in fracture toughness due to neutron irradiation, thermal embrittlement of cast austenitic stainless steels, piping fatigue, and structure degradation. Research will involve laboratory tests, component inspections, and technology demonstrations.

Accomplishments. The development of the modified-9Chrome-molybdenum steel alloy by DOE and Oak Ridge National Laboratory over the last 20 years has been a resounding success for boiler tube applications in coal-fired power plants. The application of new alloys and ceramics or refractory materials can improve plant life and reduce the frequency of scheduled maintenance.

The NEPO program will be a new start in FY 2000, so the program has no accomplishments to date.

Nuclear Power Plants

Budget: FY99-$0.0M, FY00-$5.0M, FY01-$5.0M

Description, Objectives, and Performers. Over the last couple of years, there have been significant changes in the strategic landscape -- a growing recognition of the importance that our existing nuclear power plants play in meeting the needs of the nation for electricity during the first half of the next century and their importance in complying with our environmental laws and meeting international commitments on climate change. Two years ago, with electricity restructuring looming and concerns over regulatory uncertainty, the prediction was that the existing nuclear plants were doomed -- that fewer plants would seek license extensions and that many would shut down prematurely. Today, with consolidations in ownership occurring and several plants announcing their intention to seek license extensions, it is clear that there is a future for many of the U.S. nuclear power plants. However, for these plants to remain viable beyond 2020, both government and industry must take action – government reducing regulatory and other barriers to operation and industry, investing capital in the upgrading their facilities for the future and investing in short-term R&D. Also, together, government and industry should explore intermediate-term evolutionary technologies to sustain these plants. For these reasons, the Department is initiating the Nuclear Energy Plant Optimization (NEPO) program, a new program in fiscal year 2000.

The goal of NEPO is to cooperate with industry to develop advanced technologies that can help ensure that existing U.S. nuclear power plants continue to safely generate reliable and affordable electricity up to and beyond their initial 40-year license periods. Overall, NEPO aims to help increase the average capacity factor of existing nuclear power plants from 71 percent in 1997 to 85 percent by 2010.

R&D Challenges. NEPO will work with industry to develop and apply new technologies to improve plant economics, reliability, and availability. The program will work to resolve issues related to plant aging while maintaining a high level of safety.

The Department is well prepared to take on this challenge:

- NEPO will be guided by a chartered subcommittee of the Nuclear Energy Research Advisory Committee.

- The Department and the electric utility industry's Electric Power Research Institute have developed a Joint Strategic Research and Development Plan to prioritize and coordinate research and development needed over the next 7 to 10 years to sustain the operation of commercial nuclear power plants.

- The Department will continue to coordinate its program planning activities with the Nuclear Regulatory Commission to ensure that agency activities are not duplicated, but are complementary and performed in a cost-effective manner.

R&D Activities. Funds provided by the Department will be matched by industry in conducting peer-reviewed research and development to include:

- *Managing the long-term effects of nuclear plant aging.* R&D conducted under NEPO would provide a better understanding of material degradation mechanisms and how they occur, enabling development of cost-effective aging management strategies which will provide capabilities to easily prevent, detect, or repair the degradation.

- *Optimizing power generation through efficiency and productivity improvements.* Current nuclear plants were designed and are operating with technology developed over 25 years ago. As plants age, components and parts degrade or become obsolete, introducing inefficiencies, added costs, and unreliability. There have been significant technology advancements over the last 25 years that are applicable to power generation, particularly in computers, communications, materials, sensors and digital electronics, and artificial intelligence that provide more accurate, reliable and cost-effective technologies; however, most of these technologies are not qualified to meet Nuclear Regulatory Commission requirements. Further R&D developments will produce new technology applications that meet regulatory requirements and that will improve plant operation and maintenance, increasing overall plant output. This initiative is focused on demonstrations of technologies necessary to achieve regulatory acceptance of the new technologies.

Accomplishments. The NEPO program will be a new start in FY 2000, so the program has no accomplishments to date.

Regulatory Compliance

Budget: FY99-$12.9M, FY00-$14.6M, FY01-$18.2M

Description, Objectives, and Performers. Existing coal-fired power plants must comply with a number of existing EPA regulatory requirements. Additional requirements are being considered by the EPA, or have been proposed, but not promulgated. DOE research provides three types of inputs into this process. First, DOE contributes to the science base of regulations by collecting data on emissions and environmental quality near power plants, and by drawing on its knowledge base of mitigation technologies to identify the likely cost and performance of pollution control technology. Second, DOE develops emission control technology for major categories of pollution, such as sulfur dioxide, nitrogen oxides, particulate matter, and toxic air pollutants. Finally, DOE evaluates pending regulations which can significantly impact the electric power sector, and offers recommendations to EPA during the OMB-refereed interagency review process. Current goals for continued research in this area include the development of sound scientific data on which environmental regulations can be based, and the development of lower cost emission control technology to address current and future regulatory mandates.

The Nation's nuclear power plants are aging and approaching the end of their licensed period of operation. Extension of these licenses is critical if this carbon-free source of electric power is to continue beyond 2020. In order to continue to realize the benefits from operation of the current fleet of nuclear power plants, a viable, demonstrated process for license renewal is required within the next few years. Unnecessary costs and uncertainties associated with license renewal need to be eliminated, and practical, economic solutions to generic technical issues have to be developed today and confirmed through longer term R&D activities. The Department, working with the National Laboratories, universities, the Electric Power Research Institute, participating utilities, and other industry organizations, will help resolve the generic issues associated with license renewal and demonstrate a viable license renewal process.

R&D Challenges. During the 2003-2010 period, make technologies available for existing coal power plants that will significantly lower the cost of meeting more stringent environmental regulations.

R&D Activities. DOE is continuing development of technologies to reduce NO_x emissions from fossil-fueled power plants, primarily to reduce the cost of known technologies. In addition, DOE is pursuing several technologies to reduce mercury emissions from power plants, and technologies which simultaneously reduce multiple pollutants including particulates ($PM_{2.5}$), mercury, and SO_2.

DOE, under the International Clean Energy Initiative, will also seek opportunities to for international collaboration to optimize the performance of coal-fired plants in key developing countries. This will reduce greenhouse gases as well as other emissions.

Research under the NEPO program will address the three primary needs that nuclear utilities have with respect to license renewal: (1) generic license renewal technical issues need to be satisfactorily resolved now so that the costs of license renewal will be known with more certainty; (2) the entire license renewal process has to be successfully demonstrated, removing the economic uncertainties associated with preparation, approval and operation under a renewed license for plant designs that are representative of current operating plants; and (3) the utilities need a license renewal process that is efficient and relies largely on existing programs so that the cost of a renewed license does not make license renewal uneconomic for smaller, single unit nuclear power plants.

Accomplishments. This effort has met with major successes. For example, due to DOE-sponsored stack testing of power plants, it was no longer necessary to use inaccurate estimates of emissions of toxic air pollutants. The better quality data resulted in decisions that further pollution controls for most of these pollutants would not be productive or necessary, saving perhaps billions of dollars per year. Technologies for conventional air pollutants emitted from power plants, developed over the past 25 years through collaboration between DOE, EPA, industry, and academia, are in use both in the United States and internationally. Currently, about one-fourth of all U.S. coal-fired power plants have been equipped with control hardware for sulfur dioxide; nearly all units will have nitrogen oxide controls by December 1999. Research by DOE and the private sector has roughly halved the cost of meeting related environmental regulations. Continued research in this area is projected to have an additional payoff of about $7 billion per year, in reduced compliance costs, by 2010.

The NEPO program will be a new start in FY 2000, so the program has no accomplishments to date.

Hydropower Turbines

Budget: FY99-$3.2M, FY00-$5.0M, FY01-$5.0M

Description, Objectives, and Performers. Hydropower currently contributes a carbon-free 10 percent of the Nation's electricity. However, existing generation is declining, due to a combination of real and perceived environmental problems, regulatory complexity and pressures at the Federal and State level, and changes in economics as a result. Potential hydropower resources are often not being developed for similar reasons.

Current hydropower technology, while emission-free, can have undesirable environmental effects such as fish injury and mortality from passage through turbines, as well as detrimental changes in the quality and quantity of downstream water. The Department's hydropower R&D program is therefore focused on developing advanced hydropower turbine technology which will allow the Nation to maximize the use of its hydropower resources, while minimizing adverse environmental effects.

Program activity is principally applied R&D, managed by Federal personnel and performed by industry partners and National Laboratories. Biological testing and analysis activities are performed entirely by National Laboratories, while the proof-of-concept testing initiated in 1999 is being conducted with an industry partner, and testing activities in the out-years will be conducted with competitively-selected industry and university partners. The program will continue to be supported with environmental and engineering research and analysis by National Laboratories.

R&D Challenges. The challenges are to demonstrate turbine technology capable of maintaining a dissolved oxygen level of 6 mg/liter by 2005 (ensuring compliance with Federal and State water quality standards), and technology capable of reducing turbine-induced fish mortality to 2 percent or less by 2006, compared to current levels of 30 percent or greater.

R&D Activities. Experiments are currently under way to assess the effects of shear, turbulence, and pressure on juvenile fish, with emphasis on juvenile salmonids and American shad. The fish will be exposed to levels of stress that they might encounter during passage through a turbine and draft tube, and the biological effects will be quantified. The resulting data will be used to develop biological performance criteria for advanced hydropower turbine design.

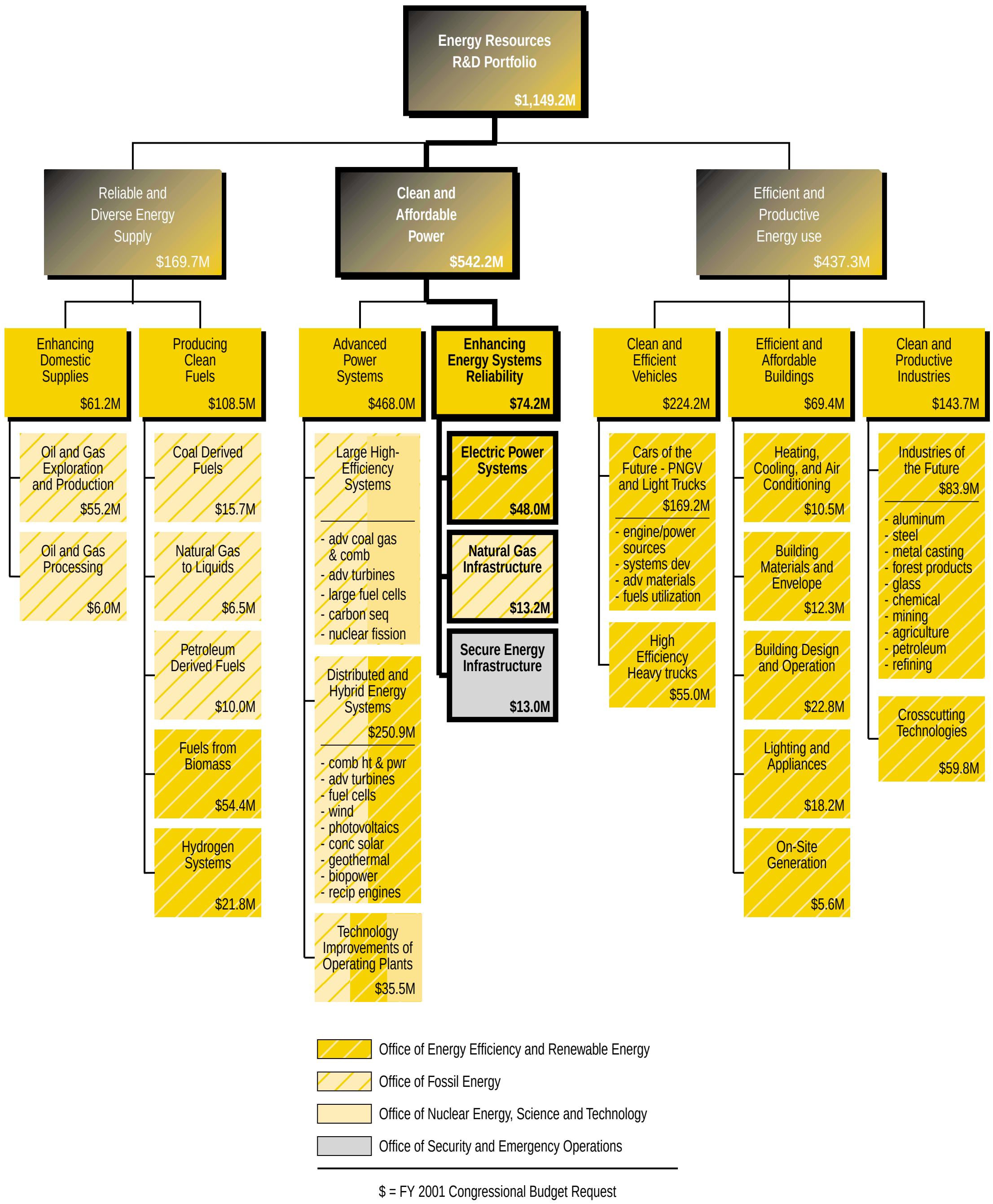
Proof-of-concept testing of a conceptual design completed in 1997 was initiated in 1999 in order to verify predicted biological performance. Environmental testing of competitively-selected low head/low power turbines will be initiated in FY 2001.

Accomplishments. In 1995, the Department, in collaboration with industry and other Federal agencies, initiated research and development to provide a biological and engineering basis for advanced hydropower turbines. Conceptual designs completed in 1997 incorporate “fish-friendly” features which (among others) minimize the number of blade leading edges, minimize the gap between the blade and blade housing, and maximize the size of flow passages, with minimal penalty on turbine efficiency. The conceptual design phase also revealed gaps in the knowledge of fish response to physical stresses experienced in the turbine environment. Research is now underway to understand these stresses and effects and provide biological performance criteria for advanced turbine detailed design.

Summary Budget Table (in $1,000)

Advanced Power Systems Research Areas	**FY 1999 Appropriated**	**FY 2000 Appropriated**	**FY 2001 Request**
Large High Efficiency Systems	**176,279**	**190,219**	**181,590**
Advanced Coal Gasification & Combustion Systems	65,491	69,923	58,890
- *Advanced Coal Combustion*	*20,967*	*9,010*	*2,000*
- *Pressurized Fluidized Bed Combustion*	*14,356*	*12,202*	*11,185*
- *Gasification Technologies*	*30,168*	*48,711*	*45,705*
Advanced Gas Turbine Systems	43,398	44,188	26,000
Advanced Large-Scale Fuel Cell Power Systems	43,069	44,499	42,200
Carbon Sequestration	5,825	9,217	19,500
Nuclear Fission Systems	18,496	22,392	35,000
Distributed and Hybrid Systems	**224,081**	**201,826**	**250,890**
Industrial Combined Heat and Power Systems	200	3,000	1,000
Buildings Cooling Heating and Power Systems	0	0	3,000
Advanced Industrial Turbine Systems	49,403	22,300	13,300
Hydrogen Fuel Cell Systems	0	5,530	8,770
Wind Energy Systems	34,076	32,481	50,500
Photovoltaic Systems	70,561	65,912	82,000
Concentrating Solar Power Technology	16,791	15,168	15,000
Geothermal Energy	21,734	23,600	27,000
-*Geothermal Exploration*	*5,400*	*6,000*	*6,000*
-*Geothermal Drilling and Completion*	*4,934*	*5,500*	*5,500*
-*Geothermal Reservoir Technology*	*5,400*	*6,000*	*5,500*
-*Geothermal Energy Conversion Systems*	*6,000*	*6,100*	*10,000*
Biopower Energy Systems	30,816	31,835	48,000
Reciprocating Engines	500	2,000	2,320
Technology Improvement of Operating Plants	**22,199**	**31,543**	**35,550**
Aging Effects in Key Components	6,066	7,000	7,350
Nuclear Power Plants (NEPO)	0	4,976	5,000
Regulatory Compliance	12,923	14,646	18,200
Hydropower Turbines	3,210	4,921	5,000
Total [Advanced Power Systems]	**422,559**	**423,588**	**468,030**

Chapter 6
Enhancing Energy System Reliability



Chapter 6

Enhancing Energy System Reliability

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Overview

Definition of Focus Area

The security, economic prosperity, and social well being of the United States relies on a complex system of interdependent infrastructures. Energy infrastructures are the foundation of American life, upon which the United States is highly dependent. Enhancing energy system reliability encompasses programs to enhance the reliability and security of the Nation's electricity and natural gas infrastructures. The electricity and natural gas infrastructures annually deliver energy services worth over $200 billion and $90 billion, respectively, to U.S. customers.

Electricity also powers other critical national service infrastructures such as telecommunications, oil and gas pipeline systems and water supply systems that are basic to the functioning of U.S. society. The electricity infrastructure consists principally of the transmission and distribution system, but also extends beyond the utility meter on the customer side, and into the power plant on the production side. Customer equipment such as large motors, power quality management, and load control technologies are included, as well as efficient mechanical equipment for generating electricity. As electric industry restructuring revolutionizes the way electric power is produced and consumed, the continued successful development of regional and interregional competitive markets depends upon the availability of a robust, efficient, reliable electricity infrastructure.

Natural gas is delivered to about 175 million U.S. customers through an integrated network of pipelines. From field production to burner-tip, natural gas moves through a complex infrastructure of producing wells, gas gathering systems, natural gas processing centers, natural gas storage facilities, intrastate and interstate pipeline transmission systems, to the city gate delivery points, and finally through the local distribution lines to the customer. A 1.26 million mile network of underground pipe consisting principally of the natural gas gathering lines (50,000 miles), natural gas transmission pipelines (265,000 miles), distribution pipelines (955,000 miles) is owned by the gas utility industry. The natural gas industry is in the midst of unprecedented change. Traditionally regulated energy markets are being transformed into competitive ones, facilitated by changing regulations and new technology.

While the electricity system powers other infrastructures, it will also be increasingly dependent itself on the natural gas system as a fuel source for both central station, and small, distributed generation. The Annual Energy Outlook, 1999 projects that the annual growth for the use of natural gas for electricity generation will be 6.8% from 1996 through 2020. In addition, these energy delivery system are becoming increasingly reliant on telecommunication and computing systems for fast, efficient operation. This reliance increases their vulnerability to deliberate physical and cyber intrusion, and calls for focused measures to counter this threat. Although these two energy systems are interdependent and have reliability issues in common, their operating characteristics are quite different, and the technologies being developed to maintain their reliability under their respective restructuring scenarios are also unique to each system.. Where relevant, some of these differences are noted in the Overview, and expanded upon in the Program sections.

The Enhancing Energy System Reliability sector presents the research and development programs that provide an integrated approach to insuring reliable system operation and efficient markets for the Nations's electric and natural gas infrastructures while assuring their viability under the threat of deliberate disruption. Taken together, these programs comprise the Secretary's Initiative on Energy Grid Reliability.

National Context and Drivers

The Nation's electricity and natural gas systems are being asked to operate in ways for which they were not designed at the same time that new demands for improved performance are being made on them. Restructuring and competition in the electric power and natural gas industry are creating new offerings for energy services, and creating new patterns of demand on energy delivery infrastructures.

- Restructuring within the electric power and the natural gas industries presents the opportunity for companies to develop new businesses and markets. However, uncertainty in receiving a reasonable rate of return, caused by the lack of defined market structures, is preventing industry competitors from investing in R&D that would ensure energy system reliability, flexibility, and infrastructure security.

- Competitive electric markets are operating across far larger geographic areas than the traditional utility service territory. Regional or even national purchase contracts are possible. Wide area competitive electric markets require reliable transmission with capacity for large scale transfers across long distances.

- The integrity of the North American natural gas delivery and storage infrastructure will be critically important in meeting future U.S. energy demands. An average of approximately 2,000 to 2,100 miles of new gas transmission pipeline will be needed each year to achieve a 30 Tcf natural gas marketplace by 2010.

- Future energy delivery systems are likely to use high speed telecommunications and computing in advanced control systems to operate them closer to their limits. These operating conditions, and reliance on electronic controls increases the vulnerability of energy delivery systems to deliberate attack, requiring examination of tools and technologies to determine and mitigate this risk.

- Presidential Decision Directive 63 designates DOE as the lead federal agency for the energy infrastructure to assure the continuity and viability of the nation's critical energy infrastructures, and the elimination of any significant vulnerability of that sector to physical and cyber disruptions.

- The North American Electric Reliability Council (NERC) in its Reliability Assessment (1998-2007) states: "Transmission systems are increasingly challenged to accommodate demands of evolving competitive electricity markets. Market driven changes in usage patterns, the number and complexity of transactions, and the need to deliver replacement power to capacity-deficient areas are causing new transmission limitations to appear in different and unexpected locations."

- Large power outages are more likely today as power systems operate closer to their limits, and in ways for which they were not planned or designed. The Western outage on August 10, 1996 was such an outage, and its cost in California alone was estimated to be over $1 billion. As a result of the 1996 Western outages, the Secretary of Energy Advisory Board convened a Task Force that recommended that DOE participate in technical studies related to transmission reliability.

- In July 1999, the Secretary of Energy announced a six-point plan to assist utilities with heat-related power outages. Under this plan, DOE expert teams investigated Summer 1999 outages in four areas in the Eastern United States, and will issue a report to the Secretary this Spring that recommends actions the Secretary can take to prevent recurrences. This report will consider the impact of restructuring.

- The required new gas pipeline and storage infrastructure will have to be constructed on existing and new rights of way and facility sites. It is important that the environmental permitting process balance the need for energy and enhanced energy system reliability in a growing economy, against other public interests.

Linkage to CNES Goals and Objectives

Enhancing Energy System Reliability directly supports the five CNES Goals:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(by reducing network and end use losses with superconducting power equipment technologies, and investigating real time control of power systems)*

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability. (by developing active system controls, storage technologies, and advanced superconducting applications such as the superconducting fault current limiter, and developing advanced technology for natural gas and oil transportation and storage)

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(by developing control and storage technology that could help enable the integration of distributed and renewable resources)*

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options. *(by increasing system capacity, removing bottlenecks, and enabling distributed resource options)*

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems. (*by working with other countries through the International Energy Agency to promote* *communications and collaborations on an integrated North American natural gas pipeline delivery system that can ensure energy system reliability*)

Enhancing Energy System Reliability has four objectives that support the CNES goals that will be achieved through partnerships with industry: (1) provide technical and policy options to enable the operation of large scale, interregional, real time, competitive electricity markets while maintaining system reliability and security; (2) by 2020, develop technologies that could reduce by one-third the approximately 9 percent of electricity lost to network inefficiency and the associated greenhouse gases produced; (3) provide network technology options that would allow the electric and natural gas systems to incorporate market-driven penetration of distributed resources, including renewable generation technologies, of up to 20 percent of new capacity by 2010; and (4) provide technology development for advanced control and monitoring of pipeline and storage facilities to assure the reliability, integrity, and security of the Nation's natural gas delivery systems.

Uncertainties

Technical, regulatory, environmental, and political uncertainties could affect the success of the Enhancing Energy System Reliability programs. Technical challenges (possible barriers to achieving either performance or cost goals) are described in the program planning documents and are summarized in the subsequent R&D challenges sections. Non-technical issues include uncertainty over the nature of incentives for construction of transmission facilities in a competitive marketplace. Without assurance of investment recovery in the regulated natural gas or electric transmission systems, providers may limit involvement in new technologies.

Competition has led many utilities to eliminate or significantly reduce funding for reliability R&D even though R&D needs have increased. Research that enhances reliability through improved market structures or technologies will improve reliability for all. However, due to competition and uncertainty regarding how and when an individual investor will realize a return on his investment in the new restructured industry, no single market participant or entity is generally willing to invest in this research when the benefits will flow equally to all market participants.

An aging U.S. energy infrastructure raises concerns over environmental issues. As local natural gas distribution systems continue to age, the potential for methane leaks and the negative impact of this potent greenhouse gas increases. Uncertainty under restructuring is stifling private sector funding for R&D, including reduction the Gas Research Institute budget, to develop advanced mitigating technologies for this effect, and for capital improvement funds for upgrade of facilities in the natural gas infrastructure.

Investment Trends and Rationale

The FY 1999 DOE investment in the energy system reliability program was $41.7 million, an amount that increases to $43.9 million in FY 2000 and rises to $74.2 million in FY 2001. The FY2001 increase reflects the addition of natural gas and energy security infrastructure programs to the Secretary's Energy Grid Reliability Initiative, which places unified emphasis on maintaining and enhancing the reliability and energy security of the Nation's electric and natural gas infrastructures.

The Energy Storage Systems program develops storage technologies that enhance power system capacity, power quality, and reliability. Funding for this effort decreased $4.5 to $3.5 million in FY 2000, and is projected to increase to $5.0 million in FY 2001 to increase focus on the contribution of advanced storage technologies such as flywheels and superconducting magnetic energy storage (SMES), and their integration into the electric power system to support the Reliability Initiative.

The Superconductivity in Power Systems program was charged in 1989 with fostering cooperative research and development with U.S. industry to capture the benefits of high-temperature superconductors for power applications. Six new cost-shared, multi-year partnerships designed to produce operating, pre-commercial power equipment using the best available long-length HTS wires will be underway in FY 1999. In addition, to help accelerate the development of wires based on 1996 National Laboratory discoveries, new cooperative research projects will also be initiated with industry. For these partnerships, funding increased in FY 1999 to the $ 32.5 million level, and funding will remain at a relatively constant level in FY 2000 and FY 2001 to enable continued progress at the laboratories and within the industry teams.

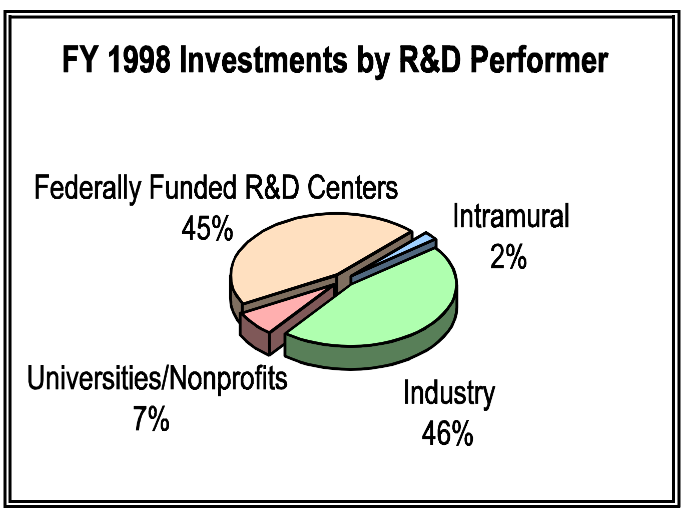
Recognizing the need for a program element focused on the development of system technologies to enable competitive markets and maintain reliability in a restructured electricity industry, a new initiative, the Transmission Reliability program was funded in FY 1999 at $2.5 million. This initiative is projected to increase from $2.5 million in FY 2000 to $8.0 million in FY 2001, and, under the Energy Grid Reliability Initiative, focus on development of technologies and policy options to enhance the reliability of the Nation's electric delivery system during the transition to competitive power markets.

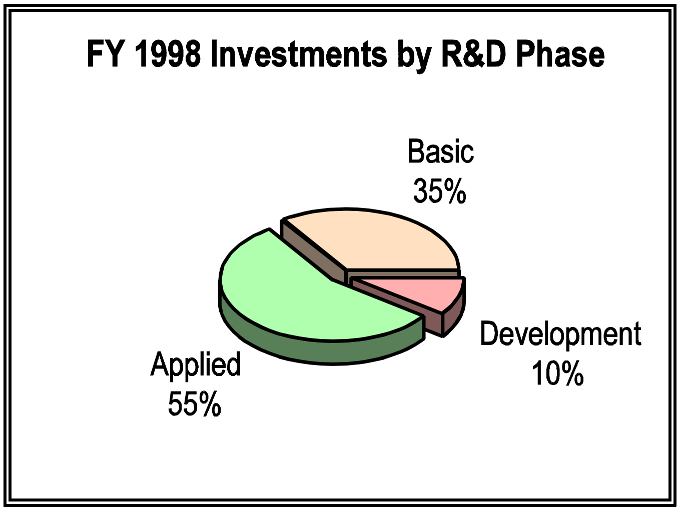
The Distributed Power program conducts R&D to address the technical, institutional, regulatory, and financial issues that are critical to realizing the full potential of distributed generation, energy storage, and demand-side management on the power distribution system. This work was also initiated in FY 1999 at $1,232 million, and is projected to decrease from $3.5 million in FY 2000 to $3.0 million in FY 2001, and focus on completing the utility interconnection standard for distributed generation and storage, and follow-on work to a broad solicitation issued in FY 1999.

The Natural Gas Infrastructure program is a new initiative in FY 2001 that will enhance reliability and deliverability of the Nation's natural gas pipelines and gas storage facilities. It builds on the gas storage technology program which was funded at $1.0 million in FY 2000. Funding for the new program will increase to $14.0 million in FY 2001 and focus on gas storage technology, pipeline reliability technology research, and international infrastructure integrity research. Research and development activities will concentrate on advanced materials and enabling technology for longer life, high-strength, non-corrosive pipeline; an obstacle detection systems for horizontal boring applications in distribution pipe; a pipeline leak and intrusion detection system using optical methods; pipeline inspection sensors with an internal leak sealing capabilities; and a portable methane leak detection systems for real-time visualization of gas pipeline systems.

The Secure Energy Infrastructure Program focuses on assuring the continuity and viability of the nation's critical energy infrastructures and the elimination of any significant vulnerability of that sector to physical and cyber disruptions. This is a new program. Funding for FY2000 was only $2.1M, but is projected to increase to $13M for FY2001. Research and Development activities will be concentrated in two areas--analysis and risk management, and protection and mitigation technologies.

The figure below indicates the division of FY 1998 funding between the principle performers of research tasks, and is representative of the current distribution. Industrial firms account for 46 percent of the program's Federal funding, in line with the applied focus of the program and the desire to use partnerships with industry to hasten the development of necessary private manufacturing infrastructure for eventual commercialization. Pre-commercial pilot projects are selected by a competitive process which solicits cost-shared proposals from integrated teams including users, suppliers of materials and/or components, and systems integrators. This process minimizes public funding requirements, and determines the commitment of the marketplace to the technology. Such projects are cost shared with private sector funding at a level at least equivalent to the Federal share. After industry, the most significant performer is the complex of DOE National Laboratories, representing 45 percent of the Federal funding. The emphasis on National Laboratories reflects the need for sophisticated equipment, extensive facilities, concentrated expertise, and the sustained effort required. Though not counted as research performers, industry experts sitting on steering and oversight committees in all program areas provide important reality checks on the progress and future value of research activities.





The figure above shows the division of effort between basic, applied and development activities. In FY 1998, approximately 90 percent of research funding was devoted to basic or applied activities, reflecting the focus of major parts of the program on the long term development of technologies that enable fundamental shifts in concept for electric power equipment design. The relatively low level of development activities reflect the fact that the majority of the technologies under development have commercial horizons of 5 years or more. Development activities are also heavily cost shared with the level of Federal funding rarely exceeding 30 percent of total project cost.

Federal Role

As described under the Uncertainties section above, in the transition to competitive energy markets, the Federal government and State organizations are picking up the critical role of performing energy system reliability technology R&D until market structures and economic incentives are in place for the energy providers to assume this work. In particular, R&D in energy delivery systems and storage systems for electricity and natural gas, and R&D on the integration of distributed energy generation at the customer level are critical activity areas that require long-term Federal involvement. In addition, at the same time these energy delivery systems are converging, their control centers are using advanced communications and computing systems that increase the need for the Federal R&D in infrastructure surety from deliberate physical or cyber attack.

For the electricity infrastructure, maintaining reliable electric service under competitive electricity markets, requires R&D to match generation to load in real time in the most efficient manner. In the near-term, an adequate power delivery system combined with the application of energy storage is essential. In this time frame, the very existence of viable, large-scale markets for electricity depends on the ability to move power over long distances reliably with a minimum of restrictions. In the mid-term, the Distributed Power program will enable energy service choices at the individual customer level through R&D that allows the integration of distributed generation, storage and demand-side management technologies into the distribution system. As penetration of natural gas-fired distributed generation increases, the interdependencies and synergies of these two energy delivery systems increase dramatically, requiring close coordination through the Energy Grid Reliability Initiative. New technologies that increase the capability of existing systems while maintaining reliability, and that improve the public acceptability of new facilities are needed to maintain progress toward competitive markets in the electric and natural gas industries.

At the same time that the need for new technology increases, incentives for privately funded power and natural gas delivery systems research in the restructured industry are being reduced. While profit opportunities in the competitive marketplace will likely spur generation innovation, the Secretary of Energy Advisory Board (SEAB) Task Force on Electric System Reliability notes that it is " concerned that reliability related R&D with long term focus may be underfunded by market forces." For instance:

- Independent System Operators (ISOs) have been established to take over from utilities the responsibility for reliable operation and planning of the transmission grid while providing equal access to all market players. ISOs have made great strides toward establishing operating arrangements that support competitive markets, but as a result of the transfer of responsibilities, reliability research efforts funded directly by utilities have largely been terminated and not been replaced.

- Historically, the bulk of public interest R&D on system reliability was carried out by research providers like the Electric Power Research Institute (now EPRI), and the Gas Research Institute, research associations funded by the Nation's electric and natural gas utilities. As a result of changes in the business climate of its members, these research associations have seen precipitous declines in their systems research funding. More importantly, these organizations are now more likely to focus their effort on near term, proprietary, commercially viable technology. Projects in longer term strategic research make up decreasing amounts of the total budget, and their public interest value is limited by the proprietary nature of the work.

- State agencies, such as the California Energy Commission (CEC) and the New York State Energy Research and Development Administration (NYSERDA), have funded electric delivery system research and may continue to do so. CEC, with the guidance of the California ISO, funds electric power system reliability research on topics of importance to California consumers. California supports State public benefit research funding through transition charges on electric power sales. However, transition funding usually has a limited duration, focuses on immediate benefits as opposed to strategic research, and may not be available to ISO's that cover multiple States.

- Federal support of electric power and natural gas delivery research is becoming an increasingly important factor. DOE funding of electric and natural gas infrastructure research is necessary to maintain support for activities that are in the national interest, and to sustain adequate levels of long term development necessary to provide the basis for future industry innovations until new market and/or regulatory structures are developed that provide the incentives for the private sector to assume this work. The realities of energy industry restructuring call for an increased DOE role in energy delivery research with both near term goals to assure reliable systems during the transition to competitive markets, and long range goals to develop advanced, enabling technologies. DOE also has a Federal role in supporting the system integration of the diverse array of DOE-developed distributed technologies, and in providing technically-based policy options, and "third-party" technical expertise to support Federal decision-makers.

- Presidential Decision Directives PDD-62 and PDD-63 define the inherently Federal role of assuring the security of the Nation's energy infrastructures from deliberate attack.

The timeframes used to describe work in this sector are as follows:

- Near Term(< 3 yrs.)
  Execution of the recommendations of the SEAB Task Force for evaluation of risk based analytical tools for reliability assessment, examination of alternatives to central station reactive power supply, and monitoring of private research on reliability technologies to assure that gaps do not develop.

- Mid-Term (3-7 yrs.)
  Development of system control technologies that enhance system stability and market performance, distributed resource integration strategies that enhance the flexibility of energy delivery, and transmission technologies for low cost mitigation of bottlenecks.

- Long Term (7-15 yrs.)
  Development of fundamental and enabling technologies for high capacity transmission.

Key Accomplishments

DOE began investigating synchronized measurements of power system quantities in 1991 through National Laboratory and university research performers. In 1995, the DOE co-sponsored Wide Area Measurement System (WAMS), an advanced satellite-synchronized monitoring system, entered field trials on the western U.S. power grid. During the western system outages of July and August, 1996, this prototype synchronized measurement system proved its worth by dramatically reducing the time needed to understand the causes and progression of the outages.

In recent years, a number of integrated, multi-benefit energy storage systems have been field tested in collaboration with private partners. For instance, a newly-developed R&D 100 Award winning mobile storage system, operating at a Georgia lithography plant, successfully corrected over 90 percent of the plant's power quality events in its first 6 months of operation. A 3.5 MW storage facility at a heavy metals recycling plant in California carries critical emission control loads in the event of a power outage to eliminate environmental noncompliance. A 1.4 MWh storage system recently installed in Alaska improves power quality in an isolated power system on an Indian reservation. The success of these state-of-the-art systems is helping to address power quality and reliability problems, enable increased use of renewable power generation, and increase the productivity and competitiveness of U.S. industry.

Superconductivity Partnership Initiative (SPI) partners hold world records for high temperature superconducting (HTS) equipment of all types, including fault current limiters, motors, transmission cables, and power transformers. Current-carrying capability of HTS wires has increased 10-fold since 1990, and wire-making costs have decreased substantially as companies gear up for larger orders. A record 6 license agreements have been signed over the last 24 months for industrial use of the innovative second-generation wire technology developed with DOE support. In addition, 4 R&D 100 Awards have been received for Department-sponsored HTS technology.

Transmission Reliability

Budget: FY99-$3.0M, FY00-$2.5M, FY01-$8.0M

Background

The existing electric power grid links nearly 3,500 U.S. utilities operating under the supervision of 150 control areas and 22 security coordinators in 3 functionally and physically independent regional interconnections. It has been characterized as an energy superhighway, though it actually bears more resemblance to the network of two-lane roads that existed before the interstate highway system was built. That system allowed travelers to go from town to town, but those who attempted long distance travel risked delays due to bottlenecks created by local traffic congestion and fragmented, piecemeal routing. Similarly, the electric network has bottlenecks that can become congested and restrict power transfers, while routing for long distance power sales is often fragmented by multiple jurisdictions.

The revolution in system operations resulting from competition has increased pressure to cut costs and to drive the power grids harder, to squeeze as much economic value out of them as possible. Some catastrophic outages in the western system during the summer of 1996 pointed out the fragility of the network in the face of high levels of interregional power transfers. At the same time, the presence of system bottlenecks and the fragmented, independent control structure has made it more difficult for competitive, reliable regional electricity markets and institutions to thrive, and has frustrated attempts to create a national commodity market in electricity.

A major new DOE/industry/university initiative, Transmission Reliability, was funded in FY 1999 to addresses near- and mid-term objectives of the Enhancing Energy System Reliability sector. It supports a National Laboratory/electric industry/universities partnership to conduct electric system reliability research in the context of competitive markets. Technologies that can automatically control networks over large areas at high speed, and that coordinate operation of distributed resources, offer the potential for creating reliable, interregional markets. Incentives that allow markets to provide system upgrades and reliability services, and efficient use of distributed resources can eliminate system bottlenecks at minimum cost. This projected five-year program will be reassessed each year to determine the need for Federal involvement depending on the nature and implementation needs of new regulations, and the impact of market forces. The Transmission Reliability Program builds on accomplishments from the DOE's earlier program in electric reliability research which was last funded in FY 1995.

Linkage to CNES Goals and Objectives

The research and development program in Transmission Reliability contributes to the following CNES goals and objectives:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.
- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

In addition, the Transmission Reliability program supports the Secretary's Initiative on Energy Grid Reliability, and the Secretary's Power Outage Study Team (POST). The Secretary formed POST to investigate major electric power outages, and recommend actions the Department can take to avoid reoccurrences.

Program Description

The Transmission Reliability program collaborates with electric industry stakeholders on a research agenda to develop technologies that promote competitive markets, ensure system reliability (adequacy and security), increase network capacity for large scale, long distance power transfers, and integrate distributed resources, including distributed generation and storage, and demand management, into the electric power grid. The program performs analyses and develops technologies in three program areas: Real Time System Control, Distributed Resource Integration, and Reliability and Markets.

Real Time System Control

Budget: FY99-$1.2M, FY00-$0.9M, FY01-$3.0M

Description, Objectives and Performers. Conventional power system control uses off-line models, planned generation dispatch, and anticipated load patterns to identify secure system configurations. With relatively few configurations to monitor, manual control suffices to maintain the system in the secure state. In a competitive marketplace, with a multiplicity of possible generation and load patterns in a constant state of flux, the number of possible system configurations and potential modeling scenarios could become unmanageably large. Agile competitive markets that permit large numbers of long distance power transactions suggest a transition from manual control and off-line modeling to automated, on-line strategies that manage the system in real time. The objective of the Real Time System Control program is to develop technologies leading to automated security assessment and control based upon real time system measurements. High speed communications and distributed intelligent controllers would adjust power electronic network management devices and actively suppress disturbances with only limited human supervision. Real time system measurements will also provide information to enable efficient operation of competitive electricity markets.

Since this program element seeks to introduce a completely new paradigm in system control, initial efforts are expected to rely heavily on university and National laboratory performers. Work on wide area synchronized measurements, which can be used in existing systems to more accurately investigate disturbances, would be done in cost shared partnerships with electric industry operations partners.

R&D Challenges. Technical developments that are necessary for successful real time control include:

- Measurement systems that extract information that allow calculation of system states in real time.
- Cost effective communications that securely coordinate high speed data exchange under dynamic circumstances.
- Security assessment models that operate in a distributed environment at high speed using measured system data.
- Autonomous reasoning agents that can carry out secure distributed decision making and issue appropriate control commands.

R&D Activities. Real Time System Control research addresses near- and mid-term research goals of the Enhancing Energy System Reliability sector. Near-term activities include those identified by the Secretary of Energy Advisory Board (SEAB) Task Force on Electric System Reliability, (report published September 29, 1998) while the development of measurement-based, automated system controls supports mid-term objectives. The following R&D activity elements describe tools to meet the challenges.

Wide area synchronized measurements: This program element extends work on system measurements that proved extremely useful in the summer of 1996. The existing network of satellite-synchronized transient data recorders can provide measurements to be analyzed using advanced transient analysis methods, such as wavelet decomposition, and correlated with models of known events. This will both improve the value of existing models, and identify signatures of disturbances that can be used to guide control actions.

On-line measurement-based security assessment models: This element examines modeling algorithms that operate in a distributed environment to both validate measurements and rapidly screen the hundreds of contingencies represented by the expanded geographic extent of interregional competitive markets.

Adaptive automated control: The advent of power electronics devices capable of actively managing system power flows at high speed creates the need for an automated control capable of coordinating the response of widely dispersed groups of such devices. This research examines development of autonomous reasoning agents that can monitor the state of the system in real time and issue control commands to suppress developing disturbances.

Development of risk assessment planning models for transmission networks: This program element seeks to carry out the SEAB Task Force near-term recommendation by pursuing development of transmission planning models that incorporate real-time control systems and power electronics, as well as extend the accuracy of modeling to larger portions of the grid. Because, in very large systems, conventional deterministic contingency analysis becomes inadequate, the mathematical basis for assessment of transmission capacity through systematic statistical evaluation of a large number of individually unlikely risks will be developed. In order to better define the behavior of very large systems nearing collapse, non-linear modeling methods might also be devised.

Accomplishments. The Transmission Reliability program has published six white papers to identify issues and R&D needs for electric power systems under restructuring. The white paper titled “Real-Time Security Monitoring and Control of Power Systems” outlines the issues, challenges and opportunities in the area of real-time monitoring and control of power systems in the restructured electricity industry. In the earlier research program, in addition to the WAMS project discussed above, which proved its worth during the summer 1996 western system outages, important successes were achieved in initial steps toward automated system control. A neural network-based voltage controller was developed that could simultaneously optimize the voltage profile and minimize system losses using only a single system measurement point. A multi-path fiber optic communications network for distribution system use was developed that could automatically route messages through damaged and reconfigured networks. The system was licensed to a utility who is currently using it as part of a wide area distribution automation scheme.

Distributed Resource Integration

Budget: FY99-$0.9M, FY99-$0.8M, FY00-$2.0M

Description, Objectives and Performers. Distributed resources include a variety of energy production and storage devices, such as microturbine generators , building-integrated photovoltaics, fuel cells, and energy storage systems with capacities from 1 kW to 10 MW. Another distributed resource is direct control of customer load for system and local benefits. Deployment of such resources on distribution networks could both defer investment in distribution and/or transmission facilities, and increase the reliability of power delivery by placing energy sources (either generation or storage) nearer to demand centers. By providing localized reactive power support, distributed resources could improve power quality. By supplementing conventional power delivery systems, distributed generation and storage could offer supply flexibility, including greater use of environmentally benign renewable energy.

This program area will support the integration of distributed resources into the larger power system. Proposed tasks focus on methods to integrate distributed resources into the power system to achieve their full value for reliable system operation, and for operation of efficient competitive markets. In addition, this element addresses redesign of the distribution system to accommodate active distributed power sources. Research will be performed through National laboratories and electricity industry partners. Some of the initial effort will identify the steady-state and dynamic characteristics of active distributed resources, and create scenarios and models for simulating their performance under system loads. National Laboratory and/or university expertise will be utilized to develop the theoretical bases for modeling and control.

R&D Challenges. The principal system integration barriers to large scale deployment of distributed resources are:

- Lack of modeling, monitoring and control methods for planning and operating systems composed of a large number of sources which must be dispatched in accordance with reliable system operation practices, and the economics of the larger marketplace, as well as with consideration for local system constraints.

- Lack of an economic approach to distribution system protection and reliability for distributed resources.

R&D Activities. Research activities under this program area will stretch the new paradigm even further, and require examination of technical, economic, institutional, safety, and other issues. More detailed guidance from stakeholders is continually sought to completely define this program area as distributed resources are developed and introduced. The following elements are proposed as initial areas for investigation in support of near- and mid-term goals. Distributed resources can provide a significant alternative to central station reactive power support, and the evaluation of such options is a near-term recommendation of the SEAB Task Force. In the mid-term, distributed resources offer the potential for increased customer choice and improved reliability of the larger system.

Control and protection of distributed resources: This program element will develop high speed multi-variate constrained optimization strategies for dispatching and control of large numbers of distributed resources. It will also assess the availability of cost-effective communications strategies that can accurately and securely exchange data at high speed to economically control large numbers of dispersed resources. This project will also explore options for protective systems that can be retrofitted to existing distribution systems economically and reliably.

Feasibility case studies: A key recommendation of the SEAB Task Force was the evaluation of alternatives to central station reactive power support. Distributed resources offer an important mechanism for supplying reactive support close to the load. Cooperative efforts with industry will develop case studies assessing the feasibility of distributed resources in specific electric systems. Potential partners would include energy producers, distributors, and users such as commercial building owners as well as equipment manufacturers. Case studies would identify the operational characteristics, reliability issues, control system requirements, and system-related economic benefits, as well as the potential for reactive power support from distributed generation or storage technologies in an application environment.

Electric and gas systems integration: Most distributed generation is expected to rely on natural gas, at least in the near term. Examples include microturbines and fuel cells, both of which may be applied either as cogeneration in commercial buildings or as stand-alone electricity sources. Gas infrastructure and supply will therefore be as important as electric system issues in determining the success of large-scale application of these technologies. A series of regional studies will be conducted with industry to examine the interactions of the gas and electric delivery systems from the perspective of each as a component of an integrated energy system, with special emphasis on decreasing overall emissions and minimizing the cost of the delivered energy services to the customer. This activity will be closely coordinated with the Department's Distributed Power program.

Accomplishments. The Transmission Reliability white paper, "Interconnection and Controls for Reliable, Large Scale Integration of Distributed Energy Resources" identifies, defines and prioritizes R&D needs for this program area. From DOE's earlier reliability research program, two reports were prepared at the request of Congress that used case studies with actual utilities to determine the potential for integration of renewable resources into the electric power transmission and distribution system. The 1994 report assesses the cost and benefits of integrating wind and solar electric generation resources into the electric power distribution system. A 1995 report assess the capacity of the existing transmission system to accommodate delivery of large blocks of energy generated by renewable resources from remote, resource-rich areas of the country.

Reliability and Markets

Budget: FY99-$1.0M, FY00-$0.8M, FY01-$3.0M

Description, Objectives and Performers. The driving principle underlying restructuring is that markets will make more efficient and more equitable decisions regarding the generation and utilization of electric power than the current system of command and control. Markets for electricity are rapidly developing around the country. Many believe separate markets can and should be created for reliability, and that many reliability and security problems are amenable to market solutions. Yet, electricity has unique physical characteristics (supply and demand must be matched instantaneously, parallel routes may become congested unintentionally, and stability must be maintained in response to disturbances). Traditional approaches to efficient market operation developed for other commodities must be modified to reflect these realities. Early efforts to create markets for a handful of ancillary, reliability-related services in California are not functioning well in their present form. At the same time, many believe that the option of using existing command and control approaches to ensure system reliability protocols are inefficient and inappropriate for the new markets that are being created. The objective of research on Reliability and Markets is to determine the appropriate balance between ideal economic market mechanisms and traditional utility operating practices that will provide inexpensive and reliable energy for consumers. Interdisciplinary research involving power system engineering and market economics is needed. The research must consider both: (1) how market participants will respond to the incentives created under different market structures and the impacts of these responses on reliability; and (2) how market-based power flows are currently affecting system operation and reliability, and how incorporation of technological advances in real-time system control and distributed technologies might affect future systems. This program area requires a strong Federal role and will be led by National laboratory and university researchers.

R&D Challenges.

- Determine the potential of, methods for, and constraints on increased reliance on market forces to maintain or enhance the reliability of the electric power system
- Determine how the design and operation of electricity commodity markets affect reliability, which aspects of reliability, and to what extent efficient markets for them can be designed and operated
- Rethink system reliability standards and identify what is and what is not amenable to market solutions
- Explore, test, and demonstrate both theoretical and experimental economic approaches that simulate market performance in ways that accurately reflect the physical capabilities and limitations of the electric power system and the risks inherent in linking it to volatile markets

R&D Activities. In a restructured electricity industry, market adoption of new generation, reliability, and end-use technologies will depend on the operation of well-functioning markets that provide meaningful pricing information to all market participants. Markets must be both credible through adequate compliance and monitoring, and transparent in reflecting the true scarcity of resources. This activity will perform R&D to improve the design and operation of markets for the provision of ancillary (reliability) services in a restructured electricity industry. The structures for bulk-power markets have substantial effects on reliability and on consumer costs for electricity (as well as affecting the profitability of generators, power marketers, and other market participants). Ancillary services are provided by the same resources that participate in energy markets, so the markets are inherently linked. Definition of types, pricing and compliance monitoring of ancillary services markets are presenting real challenges for deployment and for system reliability. Timely and reliable ancillary service supplies are key for maintaining system reliability. However, the transition of ancillary service provision from traditional vertically integrated utilities to new energy merchants is making supply difficult to manage, and compliance difficult to track.

Modeling of specific market implementations: Preliminary modeling has shown that conflicting goals significantly complicate the problem of designing market structures. The Independent (transmission) System Operator (ISO) tries to maximize reliability at minimum cost by purchasing a range of services from a fleet of resources. Individual resources try to maximize profits from the sale of a range of services. Even relatively simple market rule sets can result in perverse and unexpected incentives. This activity will utilize both experimental economics and computer based modeling to determine how market participant behavior changes under different conditions of supply and demand. Actual data will be collected to verify the models and to address current problems in the specific markets. Results will be applicable to other current implementations.

Ancillary service prediction requirements: To complement the broader modeling effort, real time actual and committed ancillary services related data will be identified, collected and archived from the California ISO. California is the first location to operate open ancillary service markets. Consequently, California is the first location to experience the practical problems associated with running real markets. It is also the first location where real economic pressures are influencing operating decisions in a competitive market. The data collected will be used to research and implement ancillary service prediction requirements in near real time and identify the most appropriate user interfaces for reliability monitoring, and efficiently managing ancillary service provision. This will benefit the remainder of the modeling effort but, more importantly, should benefit ISO's directly.

Accomplishments. The Transmission Reliability program white paper "Review of the Structure of Bulk Power Markets" provides an understanding of the needs of a restructured electricity market, and some of the market methods and systems that have developed to address these needs. In addition, the Program, through a National lab, is participating on a NERC Policy 10 Operating Committee to support technology-neutral definitions of ancillary services which would allow for participation of demand-side management in these services.

Distributed Power

Budget: FY99-$1.2M, FY00-$3.5M, FY01-$3.0M

Background

Interest in the use of distributed generation and storage has increased substantially over the last 5 years because of their potential to provide (particularly with customer-sited generation) increased reliability and lower cost of power delivery to the customer. The advent of competition in the electric power industry and customer choice have, in part, been a stimulus for this increased interest. Also contributing to this trend has been the development of small modular generation technologies, such as photovoltaics, micro-turbines and fuel cells. Industry estimates that distributed resources will account for 20 percent of new generation by 2010. The potential environmental benefits of distributed power employing, for example, renewable resources or combined heat and power, are substantial.

Although the application of distributed generation and storage can bring many benefits, the technologies and operational concepts to properly interconnect them with the power system must be developed to realize these benefits and avoid negative impacts on system reliability and safety. The power distribution system was not designed to accommodate active generation and storage at the distribution level, particularly to supply energy to other distribution customers. The technical issues to allow this type of operation are significant. An interconnection standard to allow distributed generation to deliver energy safely and with acceptable power quality is the high priority issue.

Electricity regulation, zoning and permitting processes, business practices developed under the framework of an industry based on central station generation and ownership of generation facilities by a regulated monopoly can be barriers to the orderly development of market opportunities for distributed power. The institutional and regulatory regimes must be redesigned to accommodate markets for distributed power in a restructured electric power industry.

The Federal government has a interest in the systems aspects of distributed power because of the impact on competition in the electric industry, the reliability and security of the electric power supply and the environment, and because of Federal investments in the distributed generation and storage technologies.

A state public utility commissioner has observed that there will be no true retail competition in the electric industry if there is not significant penetration of distributed power technologies. It is not likely that market power for electricity supply will be concentrated in the hands of a few if there is a robust market for distributed generation, compared to the real possibility that this could occur if self-generation is not a viable option for consumers. Even if the wholesale electricity market is dominated by a few generating companies, the cost of self-generation sets the upper limit for the price consumers need to pay for electricity, if that option is available to them.

The Federal government has and will spend billions of dollars on R&D for distributed generation and storage technologies, photovoltaics, wind, fuel cells, microturbines, combined heat and power, batteries, etc., and would therefore be prudent to invest additional resources to address the systems issues that are fundamental to the large-scale deployment of these technologies.

Finally, the systems issues related to distributed power are national issues that cut across a number of industries. There is a Federal leadership role in bringing together the various stakeholders - hardware manufacturers (photovoltaic, wind, fuel cell, gas turbine, batteries, etc.), utilities, energy service companies, codes and standards organizations, state regulators and legislators, and others, to address the technical, institutional and regulatory barriers to distributed power. These stakeholders have in fact requested the Department to serve this role. States have begun a piecemeal approach to addressing these issues, but neither the states nor industry see this as a satisfactory course of action, and feel a national approach is essential to creating a viable market for distributed power.

Linkage to CNES Goals and Objectives

The research and development program in Distributed Power would contribute to the following CNES goals and objectives:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

Program Description

Working with its industry and state and local government partners, the Distributed Power program will conduct R&D to address the technical, institutional, regulatory, and financial issues that are critical to realizing the full potential of the use of distributed generation, energy storage, and demand-side management on the power distribution system. The Distributed Power Program focuses on system integration and crosscutting issues that impact several or all distributed power technologies relative to their deployment in the power system, and realization of their full market potential.

The program performs analysis and develops technologies in three program areas: Strategic Research, System Integration, and Regulatory and Institutional Issues.

Strategic Research

Budget: FY99-$0.2M, FY00-$0.5M, FY01-$0.7M

Description, Objectives and Performers. This activity will develop new system operational concepts for distributed power that would be enabled by advanced distribution system control technologies needed to safely interconnect small, modular generation and storage technologies such as fuel cells, microturbines, photovoltaics, batteries and flywheels into the distribution system. Advanced device technologies will be adopted that will lead to development of interconnection devices with advanced capabilities. The potential benefits of distributed power are enhance power system reliability, provide ancillary services, and improve energy efficiency. Strategic research also includes the development of strategies and multi-year R&D plans.

R&D Challenges. The vision for distributed power is of an electric power system substantially different from today's in which the full value of distributed power will be captured in an electricity market in which customers can sell power, load management, and operations support services (ancillary services) as easily as the utility. This will be an automated, adaptive, intelligent electric power system in which distributed power provides 40 to 50 percent or more of the nation's electric energy, increases competition in electric power markets, and enhances the reliability, power quality, security and environmental friendliness of the electric power system. To accomplish this vision, innovative operational concepts and technology solutions will be developed.

R&D Activities. This activity addresses longer-term program objectives. With the limited funding available in FY99, the program's first year, efforts under this activity were limited to initial work by several of the national laboratories, led by NREL, to develop a five-year R&D plan. The plan is expected to be completed in the second quarter FY2000, and is being developed with major stakeholder and industry input through workshops and individual meetings. R&D on advanced operations concepts and innovative device technologies is expected to begin in FY2000 as a result of the competitive solicitation.

Accomplishments.

- Held a workshop with 120 stakeholders on 12/02/99 to identify barriers to distributed power, and determine industry priorities for DOE in addressing these barriers.

- Held a program review and planning meeting in October 1999, attended by over 130 stakeholders.

System Integration

Budget: FY99-$0.7M, FY00-$2.7M, FY01-$2.0M

Description, Objectives and Performers. Interconnection and integration of distributed resources with the power system was identified as the number one near-term priority by industry. The lack of a national interconnection standard and conforming interface devices was stated to be the most important market barrier to distributed power. Much of the program's activities in FY99 have been devoted to initiating efforts to develop an interconnection standard on a fast track.

Working with industry and the national laboratories, system interconnection issues, including safety, reliability, power quality, and environmental issues related to distributed generation and storage, will be identified through modeling and other engineering analyses, case studies and hardware system integration testing and demonstration. Technologies and approaches to address these issues will be developed. The interactions of the gas and electric delivery systems from the perspective of each as a component of an integrated energy system will also be examined.

R&D Challenges. Near-term R&D challenges include development of a national interconnection standard, and testing and certification methodologies and processes for implementation of the standard. In the longer term, in order to realize the full benefits of distributed power, hardware and software for modular, intelligent power system interface units that conform to the interconnection standard will be developed. These interface units will support a plug-and-play environment for automated control and operation of distributed generation and storage across all technologies, i.e., microturbines, fuel cells, photovoltaics, wind, batteries, fly wheels, etc.

R&D Activities. Development through the Institute of Electrical and Electronics Engineers (IEEE) of a national standard for interconnecting distributed generation and storage with the power system has been initiated and will continue through FY 2002 when the standard is expected to be approved and published. At least one revision of the standard, probably in about

FY 2005, will be necessary as substantial amounts of distributed power is deployed and experience with the standard is obtained. Testing and certification activities as well as R&D on interface devices will likely begin in FY 2000 as a result of the competitive solicitation, along with preparation of a plan for demonstration of the integration of distributed power with the grid at the Nevada Test Site.

Accomplishments.

- Initiated development through the IEEE of a national standard for interconnection of distributed power with the electric power system. The initial draft standard has been written, with more than 200 representatives from industry participating in the IEEE working group developing the standard. The program goal, with DOE's continued support and leadership, is to reduce the time to establish the standard in half, and have a standard in place in late 2001.

- NREL issued a competitive solicitation for R&D on interconnection hardware and software, tests and procedures for equipment certification, and modeling and analysis to address technical, regulatory and institutional barriers to distributed power.

Regulatory and Institutional Issues

Budget: FY99-$0.3M, FY00-$0.3M, FY01-$0.3M

Description, Objectives and Performers. The Distributed Power Program works with industry, state legislators, regulators and energy officials, as well as federal agencies to address regulatory and institutional market barriers to distributed power. These barriers include current business practices, planning methodologies, power systems engineering training, policies, regulations, ownership structures.

R&D Challenges. Accelerating the development, adoption, and implementation of regulatory utility policies, technical standards, local codes and permitting processes will allow distributed power to compete fairly in the market without compromising consumer protections, environmental values, health, and safety.

R&D Activities. The Distributed Power Program is working with industry to document the nature and impact of market barriers, particularly related to utility requirements for interconnection of distributed power resources to the grid, including rates and non-technical requirements, and the impact these have on the economic viability of distributed power projects. Several workshops will be held with state legislators and regulators to examine these issues.

Accomplishments.

- Information has been collected on 60 case studies, and will be published in a report which documents the barriers to interconnection due to current utility business practices and interconnection requirements.

- Awarded grant to conduct workshops for state regulators to address regulatory barriers to distributed power, and a grant to the National Conference of State Legislators to conduct a workshop for state legislators on legislative issues impacting distributed power.

Energy Storage Systems

Budget: FY99-$4.5M, FY00-$3.4M, FY00-$5.0M

Background

Competitive electric market pricing structures will stimulate development of new strategies for controlling electricity use and cost. Sophistication of both high-tech and manufacturing industries makes power quality increasingly important to U.S. productivity. As transmission networks more frequently operate at their stability limits, network operators search for means to increase network capacity at minimum cost. Energy storage systems could effectively address all of these issues. In addition, energy storage increases the value of electricity generated by renewable resources by making it available at any time. Accordingly, the Energy Storage Systems (ESS) Program focuses on three technological thrust areas: reliability, renewables, and productivity.

The ESS Program addresses the multi-billion dollar national power quality problem by developing systems that enable electricity providers to correct instantaneously for power variations. Power quality systems can be installed at a customer site or at a utility substation near customers in need of guaranteed quality power. Larger versions can improve stability and selectively increase capacity of the transmission system.

Large electricity users and providers can achieve important productivity gains and increase competitiveness through distributed siting of storage systems. Often, a single storage system can be used for multiple purposes and result in substantial cost savings and improved operational efficiency through avoidance of monthly peak demand charges, power quality-induced equipment failure, and peak period overload of utility equipment.

The President's Committee of Advisors on Science and Technology (PCAST) stated that "if intermittent renewable energy technologies are to make very large contributions to electricity supplies in the longer term. .... technologies are needed that would make it possible to store energy for many hours at attractive costs." The ESS Program works with renewable energy system suppliers to optimize storage systems integrated with Photovoltaics (PV) and wind generators.

Linkage to CNES Goals and Objectives

The Energy Storage Systems program supports the following CNES goals and objectives:

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems. *(by working with other countries through the International Energy Agency to promote communications and collaborations)*

Focused on the three thrust areas of reliability, renewables and productivity, the ESS Program will continue to team with industry in highly-leveraged agreements to develop improved, integrated, cost-effective storage systems with multiple benefits for electricity providers and users at scales ranging from small remote installations to large industrial facilities.

Application of energy storage technologies will be driven by reduced costs and improved flexibility as the Program develops systems that meet the cost goal of $700 per kW and the energy density goal of 5 kWh per sq. ft. of system footprint while meeting customer needs in the rapidly changing electricity marketplace.

Program Description

Research and development in the ESS Program is organized around three objectives: (1) integration—supporting the near- and mid-term development of complete energy storage systems for diverse applications that make use of modularity, factory integration, and transportability for cost reduction; (2) components—supporting the design, research, and long-term development of batteries, superconducting magnetic energy storage systems (SMES), flywheels, and other advanced energy storage devices along with improved, multi-use power electronics, controls and communications components; and (3) analysis—improving the understanding of application requirements, assisting U.S. industry in identifying high-value energy storage sites through modeling and engineering assessment, and identifying national benefits of storage in a restructured utility industry.

Integration

Budget: FY99-$2.2M, FY00-$1.6M, FY01-$2.5M

Description, Objectives, and Performers. By viewing a storage system as a single product, rather than a custom designed project composed of parts procured from various sources, major savings in construction cost and improvements in performance can be achieved. Benefits include cost savings of 30 to 50 percent through reduction of custom engineering and on-site installation labor, as well as reduced start up times. Standardized components, designed to optimize system performance, offer the potential for further cost reduction and longer life. Integrated hybrid systems, consisting of a renewable generator (PV or wind), storage system, and a diesel generator or gas turbine, offer increased flexibility to meet energy supply needs. Development of multiple integrated systems in a coordinated effort allows the program to leverage private and public resources through coordination of parallel R&D activities.

R&D Challenges. Experience has proven that good integration leads to optimal performance at the lowest cost compared to off the shelf or one-of-a-kind engineered designs. The major obstacle to greater levels of integration is the cost associated with low production volumes. Without further support for high-cost, high-risk prototypes and demonstrations, it will be impossible to generate the wide-spread interest and support necessary to optimize designs at a low enough cost to reap reliability and productivity benefits.

R&D Activities. *Advanced battery systems:* The ESS Program continues to work on development of zinc-bromine battery systems, which have 4 times the energy density of lead acid batteries. The Advanced Battery Energy Storage System (ABESS) is a high-risk, 3-year, 50-50 cost-shared project with ZBB to develop a transportable, modular zinc/bromine battery storage system, scheduled to begin a multi-year test at a utility or customer site by 2000.

Advanced batter-renewable systems: Another zinc-bromine battery system is being fielded with Powercell Corporation in a community theater project. A 200kWh capacity battery is combined with 70kW of photovoltaic generation, allowing the theater to be a net producer of green power. The ESS program completed a system analysis and will be collecting data from the project.

Renewable generation and storage: The ESS Program works with the photovoltaic and wind industries to improve the compatibility and reliability of hybrid renewable generation and storage (RGS) systems while lowering system cost and maintenance requirements. Studies will define the present and future needs of users of RGS systems, determine their application requirements, and help guide development of integrated system components.

Accomplishments. The PQ2000 system developed by the ESS Program and its industrial partners earned an R&D 100 Award as the first installation of a complete integrated power quality protection system with master control by the electric utility. The system meets the power quality needs of one of Oglethorpe Power Corporation's industrial customers, a lithography plant in Homerville, GA. During the first six months of operation, the system corrected over 90 percent of the plant's power quality events.

A mobile version of the PQ2000 factory integrated battery-based power quality system has been developed in collaboration with Omnion Power Engineering Co. The 2MW/15-second system was tested by the Virginia Power Company, and is now installed at the S&C plastics extrusion plant in Chicago.

A factory integrated 1.4 MWh, multiple benefit storage system by was developed by ESS and an industrial partner. Installed on the Annette Island Reserve, in southeast Alaska, the system absorbs the large load spikes caused by the local lumber mill. By displacing the output of a 3.3 MW diesel engine formerly operated at light load to control power swings, it reduced diesel fuel use by 180,000 gallons and cost by $310,000 in the first 8 months of operation. It greatly improved power quality for the island residents, the 1,700-member Tsimpshian Native American Indian tribe.

A 3.5 MWh storage system co-developed by the ESS Program and GNB provides multiple benefits at a lead-acid battery recycling plant in Vernon, California. The system's primary benefit is its ability to carry critical loads during power outages, ensuring that pollution control equipment remains operational. Additional benefits include peak-shaving and uninterruptible power.

Components

Budget: FY99-$1.4M, FY00-$1.0M, FY01-$1.6M

Description, Objectives, and Performers. The ESS Program works with industry and university partners to carry out fundamental research on advanced storage elements and power conversion equipment components that cost less, have higher performance, are smaller, and are better integrated with the other parts of the system. A great deal of the evaluation of prototype energy storage components is conducted in-house at Sandia National Laboratories. The Program also draws on the expertise and resources of a diverse group of partners including representatives from industry and an industry research association, a utility trade association, two engineering and consulting firms, and several university groups.

R&D Challenges. Materials and processing limit the life, and hence, the cost effectiveness of advanced storage equipment. For example, work must be done to identify electrochemical failure mechanisms in valve regulated lead acid (VRLA) batteries and find ways to delay failure. Key issues include loss of cell seal integrity, loss of conductivity due to changes in separator mechanical characteristics, and sensitivity to temperature extremes. Similarly, successful commercialization of advanced zinc bromine batteries requires improvements in the microporous polyethylene separator, increases in the rate capability of the bromine electrode activation layer, and in the robustness of the electrochemical cell stack.

Research is also needed on SMES, flywheels and power conversion systems. SMES requires low cost materials and cryogenics. Flywheels need high strength composite rotor materials and improved bearings. Power conversion systems require development of advanced, high power, low cost semiconductor switches, hybrid power controller software, and advanced converters.

R&D Activities. *VRLA batteries:* Low-maintenance, spill-proof, and more compact than conventional batteries, VRLA batteries have been commercially available for more than ten years. The ESS Program, using the extensive field data now available, will build on past work with industrial partners by collaborating on a VRLA reliability improvement project with the International Lead Zinc Research Organization. Studies will be conducted to define opportunities in existing VRLA designs for further improvement under typical utility battery operating conditions and use modes. Similar projects are in the planning stages for SMES and flywheels.

Power conversion systems (PCS): The ESS Program is teaming with power electronics firms, universities, and energy research institutions to develop power controller electronics and software for use in several advanced storage applications such as remote backup systems. The ESS Program supports testing at the Arizona Public Service Solar Test and Research Center of a state-of-the-art PV/battery hybrid controller developed by Trace Technologies. Results from the characterization testing will be used to develop operation strategies for village hybrid systems. ESS is also participating with the International Lead Zinc Association in a cost shared effort to develop testing requirements for remote area power systems. This project will greatly improve the reliability of modular renewable energy systems not tied to electric grids.

Accomplishments. Recently, the ESS Program completed development of a prototype 33 kW, 3-hour prototype zinc/bromine battery that exhibits four times the energy density of current lead acid batteries. This highly successful prototype is the basis for the ESS Program's ongoing ABESS project that will result in the development and demonstration of a transportable 300-kW/2-hour integrated system designed to showcase the potential of zinc bromine technology for peak shaving and other customer-side applications.

In 1998, the ESS Program completed an assessment of system configurations, cost, and standards for PCS use in the utility industry with recommendations for future R&D activities. This report will form the basis of future R&D work on a single PCS topology to serve the needs of batteries, flywheels, SMES, and renewable generation sources.

Analysis

Budget: FY99-$0.9M, FY00-$0.8M, FY01-$0.9M

Description, Objectives, and Performers. Projects conducted within the analysis program area are designed to improve the understanding of application requirements and assist industry in identifying high-value energy storage sites using models and engineering assessment tools. This work often forms the basis for R&D projects undertaken by the ESS Program and/or its partners.

R&D Challenges. Currently, the greatest source of uncertainty in the development of energy storage and other distributed resources is the future of the electricity industry. The emergence of a competitive marketplace for electricity will bring about many technological changes in the way electricity is generated, delivered and sold. A restructured electricity marketplace is expected to lead to many opportunities for increased efficiency, resource utilization, flexibility and reliability through energy storage as utilities begin to tap the potential benefits of distributed resources. Understanding how the dynamics of this new marketplace will drive end user needs and quantifying the many potential benefits of energy storage are the major challenges confronting the energy storage community.

R&D Activities. *Transmission Power Quality Project:* The next generation of power quality correction devices is expected to be placed at the substation level. These systems will be large (4-10MW) and will protect entire plants or Premium Power Parks from power quality problems. Most of these customers are fed directly from the transmission grid. This project will measure the power quality of the transmission grid in one region to provide specifications for the substation power quality project. This project will also tie in with the DOE Transmission Reliability Program by producing baseline data on reliability of the current state of the regulated utility network.

Energy storage in a restructured environment: As electric industry restructuring proceeds, it will become increasingly important that electricity providers and related service companies understand the role energy storage can play in maintaining the reliability of the electricity infrastructure. The ESS Program will conduct a quantitative analysis of the impact of energy storage on reliability. This study will help determine the direction of development of integrated energy storage systems for reliability applications.

Non-grid applications: The need for distributed energy storage technology is particularly acute in remote areas not connected to utility grids. Congress highlighted this need in 1998 by requesting that DOE develop and demonstrate cost competitive, modular renewable energy technologies to "focus near-term research on the development of reliable systems for remote applications in occasionally hostile climates." The ESS Program is currently working with the International Lead and Zinc Research Organization on a feasibility study of hybrid photovoltaic/storage systems for use in remote villages in Peru. Results from this study will be used to assist in conducting a series of demonstration projects showcasing this technology.

Accomplishments. Recent progress in the development of both superconducting magnetic energy storage (SMES) and flywheel energy storage has made these technologies increasingly viable energy storage options in the United States. In order to further development of these advanced storage technologies, the ESS Program completed an analytical study that identifies areas of analysis and R&D necessary to advance SMES and flywheel technologies. Included in the study is a modeling tool that links cost and performance of SMES and flywheels over time and an updated definition of application requirements and potential markets.

A recent survey by Arizona State University supported by ESS and the Photovoltaic Program quantified sales of photovoltaic batteries domestically and world-wide in 1995, identifying market weaknesses and information needs. The information contained in the report has helped to improve the information exchange between the various industry groups involved in the development and manufacturing of PV/storage hybrid systems.

Superconductivity in Power Systems

Budget: FY99-$32.1M, FY00-$31.4M, FY01-$32.0M

Background

High temperature superconductivity (HTS) or the ability of some ceramic materials to become lossless carriers of electricity when cooled to the temperature of liquid nitrogen, was discovered in 1986. Materials that become superconducting at the much lower temperature of liquid helium are used in medical applications, but costs of refrigeration have made them unattractive for power equipment applications. HTS not only presents opportunities for constructing compact, high efficiency, high capacity power equipment but also opens possibilities for development of equipment, such as fault current limiters, that offer entirely new capabilities. HTS, in fact, has the potential to impact the production, delivery, and use of electricity as profoundly as fiber optics has impacted communications. Superconducting wires, with 100 times the current carrying capacity of copper wires, will result in transmission cables with five times the capacity of conventional cables. HTS motors, generators, and transformers will have half the energy losses and be half the size and weight of conventional systems. Superconductivity in Power Systems constitutes the principal long-term development effort for the Enhancing Utility Infrastructure program.

HTS offers many national benefits. HTS cables offer an alternative to new rights of way for overhead lines which are difficult to obtain, without the oil spill exposure that limits interest in conventional oil filled cables. Retrofitting HTS cable into existing ducts could increase transmission capacity of rights of way by up to five times with no environmental risks.

HTS motors and generators pack nearly three times the power into the same space as conventional machines and coordinate well with power electronic inverters to provide a double benefit of controllability as well as increased power density.

HTS fault current limiters ameliorate concern for added short-circuit current caused by system growth. Limiting fault currents to lower levels also enhances system stability, reliability, and safety, and improves power quality. The ability to efficiently control currents also offers new operating possibilities for power flow control.

HTS transformers offer utilities oil-free, fire-proof performance and the absence of a thermal aging mechanism, as well as high efficiency. HTS transformers can also be operated for long periods at up to double their rated capacity without loss of life, a capability not available in conventional units. Finally, the HTS transformer will likely have low-impedance, making it easier for utilities to maintain output voltage levels over a wide range of power levels, and they will incorporate fault current-limiting winding concepts to provide additional benefits. HTS transformers truly represent the first major hardware innovation in this mature industry since the development of oriented core steel.

HTS bearings for flywheel systems could be attractive to tomorrow’s utilities and large industrial customers seeking diurnal storage efficiencies approaching 90 percent.

HTS magnetic separator technology is important both for the chemical industry and for hazardous waste processing.

The annual world market for HTS power technologies is estimated to be at least $30 billion by 2020. DOE leads the world in superconductor technology development and with the SPI projects described below, DOE and U.S. industry are partnered to move a step closer to being the world leader in sales.

Linkage to CNES Goals and Objectives

The Superconductivity in Power Systems program supports the following CNES goal and objective:

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

In 1988, DOE mobilized the resources of U.S. industry, National Laboratories and universities to accomplish two major technological goals: (1) solve the difficult problem of manufacturing electrical wires from the family of brittle ceramic superconducting materials discovered in 1986, and (2) develop practical equipment designs for efficient, pre-commercial electric equipment such as motors, transmission cables, generators, transformers, and current limiters that use these wires.

To accomplish these program objectives, specific goals must be met for superconducting wire, as well as for pre-commercial prototypes of power equipment using the wires. The wire goal is to achieve an operating capacity of 1000 amperes per square millimeter of wire cross-sectional area at a cost of 1 cent per ampere-meter. Goals for equipment are specific to individual technologies, but are met through operational tests of prototypes that prove the technology is ready to provide the specified performance advantages. Generally, devices will have only half the energy losses of conventional alternatives. In addition, it is the goal of the Superconductivity Program that, by 2004, U.S. industry will begin supplying the international electric power sector with the first HTS transmission cables, transformers, motors, and current controllers.

Program goals are achieved through a national effort that partners Federal and State agencies, universities, National Laboratories, and private industry in cost shared, industry led consortia focused on producing marketable products. HTS equipment will achieve market penetration not only based on efficiency, but also on superior performance, small size, and environmental benefits when compared with conventional equipment.

Program Description

The Superconductivity Power Systems program marries the entrepreneurial drive of high-tech companies with the vast technological resources of DOE's National Laboratories to meet the complex research challenge of long-term development of HTS technology for electric power. The HTS program contains three program elements: The Superconductivity Partnership Initiative (SPI), The Second Generation Wire Initiative, and Strategic Research.

The Superconductivity Partnership Initiative (SPI)

Budget: FY99-$14.5M, FY00-$14.0M, FY01-$14.0M

Description, Objectives, and Performers. The SPI competitively solicits aggressive industry-led projects to design and operate pre-commercial HTS electric power equipment. SPI projects include transformers, motors, cables, current limiters, flywheel energy storage, generators, and magnetic separation systems. A unique SPI feature is that each project must be carried out by a vertically integrated team, typically including an electric utility, a system manufacturer and a superconducting wire supplier, and National Laboratories. This vertical integration has proven to be a powerful way to quickly develop mature end user systems while leveraging resources.

The SPI program promotes cost-shared development by manufacturers of equipment design technologies necessary to take commercial advantage of advances in HTS wire technology. By the end of the program, it is expected that SPI teams will have built and operated refined HTS versions of all of the major power equipment technologies that could represent a significant benefit for the electric utility infrastructure.

A total of 9 SPI projects either are or will soon be under way. Performance teams include 17 manufacturers, 6 utilities, 2 utility research associations, 5 National Laboratories, and a State research organization. Projects cover the entire program range including a 15kV current limiter, a 5000 Hp motor, 2 power transformers and 2 cables, as well as a magnetic separator and a flywheel energy storage system.

R&D Challenges. SPI teams must resolve a number of key technical challenges including:

- Conductor availability, performance, configuration, and cost.
- Electrical and thermal insulation performance and durability.
- Interface between the ambient environment (room temperature, atmospheric pressure) and the cryogenic temperature, high-pressure environment.
- Cooling system research, design, reliability, and performance.

R&D Activities. *Cable projects:* Activities are underway to determine the optimum configuration for wrapping the HTS tapes to assure the lowest possible alternating current (ac) losses. Such losses can add substantially to the heat load of the cryogenic system required to keep the cable cold. In addition, two candidate dielectric systems are being evaluated by different teams. One system, based on room temperature, extruded dielectric material, takes advantage of the large base of conventional cable experience, while another, based on a novel cryogenic temperature dielectric, offers potential for reduced ac losses.

The characterization and measurement of ac losses is complex for cables and the SPI cable teams are developing two alternative methods for these measurements. Either a transport or a calorimetric method is used and the teams have made good progress toward developing a detailed understanding of the ac loss phenomenon.

Low cost, reliable cryogenic systems to keep the cable cold are of crucial importance to the success of HTS cable technology and both teams are also evaluating options for increasing the cable length between cooling stations.

Terminations and splices are a special topic of research in the cable SPI projects. Most failures in today's conventional cables occur in either the terminations or the splices. Electrical, thermal, and mechanical stresses on materials must be balanced.

Transformer projects: Research activities in the transformer SPI projects include the development of appropriate conductor geometries, dielectrics, and the cooling system. Investigation of low-loss conductor and winding configurations are essential as ac losses, like thermal losses, must be carried away by the cryogenic refrigeration system. The core design and core cooling systems are active areas of research.

HTS motor project: The SPI motor team is focusing on innovative fluid transfer coupling technology for entry and exit of cryogen at the motor/refrigerator interface. They are also developing the wire and motor coil technology necessary for cost-effective, 3-Tesla operation at temperatures near 30°K. Another active area of research is the concept of cryocooling in a rotating reference frame. Sophisticated high power test beds have also been developed for full scale characterization of HTS motor performance.

Accomplishments. World record performances were achieved by SPI teams. The 200-horsepower motor exceeded the design goal by 50 percent during tests in 1997, and the world's first superconducting current limiter met its technical goals during testing at a utility substation in FY 1998. The next version will feature the world's largest HTS coil and operate long-term on a utility grid, a first for the SPI program. The world's largest HTS transformer commenced testing in FY 1998, and the world's longest HTS cable completed its tests successfully.

The Second Generation Wire Initiative

Budget: FY99-$8.0M, FY00-$8.0M, FY01-$8.0M

Description, Objectives, and Performers. The Second Generation Wire Initiative is exploiting 1996 research breakthroughs at Los Alamos and Oak Ridge National Laboratories that promise unprecedented current-carrying capacity in high-temperature superconducting wires. These breakthroughs, which made headlines worldwide, will allow long wire lengths to behave as a single crystal, thus eliminating internal barriers to current flow that may limit use of wires now being manufactured. The interest in second generation wires for energy applications is enormous. A total of nine high-performance project teams involving six national labs and nine industrial partners are at work to further develop the wire technology.

R&D Challenges. Moderate lengths (1 to 10 meters) of coated conductors are needed for use in coils and device prototypes during FY 1999-2000. The performance goals for such moderate length wires are: critical current (I_c)= 50 amps and engineering current density (J_e) =20,000 amps per sq. centimeter. R&D challenges include scale-up of promising short sample results to produce substrates, verification of superconductor film growth by a number of industrially scalable techniques, demonstration of adequate texture and epitaxy over length, and development of simpler, and more robust buffer layer systems.

R&D Activities. *Substrate development:* This project investigates two methods of making buffered, textured metallic substrates, ion-beam assisted deposition ("IBAD"), and rolling-assisted, biaxially-textured substrates ("RABiTS"), both developed by National Laboratories. An industrial partner is developing electron-beam evaporation for depositing the superconducting layer upon either of two substrates. Concerns are process conditions for buffer layer deposition, adequate texture in the rolled nickel metal foil, and thickness of the superconducting layer while maintaining acceptable levels of critical current density.

Buffer layer development: A team led by an industrial partner is developing a non-vacuum buffer layer technology for deformation textured metal substrates. Such a structure could offer cost and performance advantages over conventional vacuum deposition of these layers. The work includes measurement of buffer layer texture, deposition of buffers and superconductor, and electrical characterization.

Alternative superconductors: A team of National Laboratories and industrial partners have also been working together to scale up yttrium-based (YBCO) coated conductors. Tasks include nonmagnetic deformation textured substrate development, substrate preparation, buffer layer development, IBAD sample testing, investigation of strain tolerance, statistical analysis of defects, environmental stability, microstructural studies, and measurements of critical current and critical current density. Near-term goals are a critical current density of 1 MA/cm^2 at 77°K on a nonmagnetic, deformation textured substrate 1 meter long. The team has the ultimate goal of demonstrating the commercial feasibility of the coated conductor technology.

Accomplishments. Initial FY 1998 scale-up goals were met for wire processing breakthroughs. The first 2-cm lengths of coated conductor were produced in FY 1998 using an *ex-situ* deposition process.

Strategic Research

Budget: FY99-$9.6M, FY99-$9.4M, FY00-$10.0M

Description, Objectives, and Performers. The Strategic Research R&D area focuses on developing underlying knowledge needed for the success of industry-led projects. The Second Generation Wire Initiative evolved from five years of strategic research that achieved world record performance in short wire samples. In addition, research and analysis will be conducted on issues associated with integration of superconducting systems into an increasingly competitive and restructured industry framework. Strategic Research performers include four DOE National Laboratories, two Department of Commerce labs, sevenuniversities, and two industrial partners.

R&D Challenges. Strategic research challenges include development of powder-in-tube wire that meets cost and performance needs of pre-commercial prototype developers, novel processing to increase pinning and connectivity to raise field and temperature operating windows for the HTS wire. Coils must be fashioned from the first lengths of second-generation wire, and the properties of these coils must be measured to provide input to system developers. An understanding of HTS material phase assemblage is critical to developing cost-effective HTS wire processes.

R&D Activities. Strategic research activities include bismuth/oxide (BSCCO) wire development research by two teams. The research includes development of novel means to produce high critical current density HTS tapes, including the new "coated BSCCO" approach that already has demonstrated over 40,000 A/cm^2 in short samples. The group studies the effects of processing conditions on the critical current and microstructure of the resultant wires.

Efforts to scale up the short sample BSCCO results to long lengths are conducted under several CRADAs. This research enables U.S. industry to use the National Laboratories' special facilities and staff resources to solve key technical issues of filament uniformity, grain growth (bridging) between filaments, ac conductor losses, and others.

Research is also conducted by the laboratories and several universities to exploit the higher critical temperatures of the thallium and mercury compounds. National Laboratories and universities, for example, are working to deposit and characterize thallium HTS on RABiTS. Results of the order 0.5 MA/cm^2 have been obtained on short samples.

Phase diagram research enables the National Laboratories and industry to understand the physical and chemical properties of HTS compounds. This research is cost-shared with the Department of Commerce. In another cost-shared effort, the mechanical properties of the new laboratory-developed coated conductors are being examined, with plans underway to measure the private industry materials, as well, starting with the BSCCO tapes.

Strategic research also includes the fabrication and testing of small research magnets using the BSCCO compound (now) and the coated conductors when lengths of material become available. The understanding of normal zone propagation and quench characteristics of the new coated conductor in coil form will be needed if these wires are to be useful in electrical devices.

University research explores the physics of deposition of buffer layers and superconductor by electron beam evaporation, including the development of rate-monitoring apparatus, the nature of current flow through grain boundaries, and novel, high rate deposition of buffer layers.

Accomplishments. In FY 1998, the industry-led Wire Development Group achieved a record critical current density in BSCCO powder-in-tube wires of 71,500 A/cm^2. The average critical current in HTS wire made in FY 1998 for cables exceeds 100 amperes per tape in liquid nitrogen, a new record for commercially available wire.

Program participants have won five R&D 100 awards in the last 4 years, and have set most of the world's records for superconducting motors, transmission cables, and transformers.

Natural Gas Infrastructure

Budget: FY99-$1.0M, FY00-$1.0M, FY01-$13.2M

Background

The expansion of the North American gas markets to meet a 30 Tcf market by 2015 will require that new sources of supply be characterized, developed, and connected to new and existing gas system infrastructures. The gas industry and its suppliers face significant technology, market, and regulatory challenges to reach the 30 Tcf market. Regulatory constraints in the expansion of transportation and distribution pipeline systems and storage facilities could impede industry progress, harm the economy, and weaken the environment. Government funding of "public benefit" R&D will become more critical as private firms lose incentives for long-term, public service R&D. Technology constraints could lead to increased fugitive emission methane leaks from the aging gas transmission and distribution system. Market constraints could lead to higher gas prices for consumers and power generation sectors. The integrity of the gas delivery and storage infrastructures will be important in maintaining system throughput and in meeting future gas demands.

The natural gas delivery and storage system provides a vital link between production and end use. Natural gas supplies are transported through a nationwide pipeline network to move large volumes of gas from producing wells to consumers. Gas storage serves as the primary means of managing fluctuations in supply and demand. Gas from storage can supply up to 30 percent of daily gas demand in winter and summer months for heating and power. Storage enables greater delivery system efficiency by allowing more level production and transmission flows throughout the year. Without this leveling effect, the amount of transmission pipeline would need to be increased by 50 percent to connect the producing regions to the marketplace. Government funding of “public benefit” R&D will become more critical as R&D funding by private firms and the Gas Research Institute (GRI) declines.

The Natural Gas Infrastructure program includes the Gas Storage Technology program initiated in 1993 and two new programs for FY 2001--Enhancing Infrastructure Reliability and International Infrastructure Integrity. These two new program support DOE’s activities and goals to enhance the reliability of existing and new pipeline infrastructure and to remediate greenhouse gas emissions in the gas industry. Significant methane emission reduction opportunities exist in Russia and other countries through the accelerated international deployment of advanced methane emission detection and repair technology for oil and gas pipelines.

Linkage to CNES Goals and Objectives

The program supports the following CNES goal and objective:

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability. (oil and gas transportation and storage)

Program Description

DOE is working with GRI and industry to ensure that the gas delivery and storage system continues to provide a reliable, cost-effective supply of natural gas well into the next century.

Gas Storage Technology

Budget: FY99-$1.0M, FY00-$1.0M, FY01-$2.2M

Description, Objectives, and Performers. This program includes cooperative efforts with industry to help ensure the safe, reliable, and cost-effective supply of natural gas, and will enhance gas storage system deliverability, reservoir management, and operational flexibility. Through its Gas Storage Program, DOE supports the development of advanced technologies and methods to enhance deliverability, increase efficiency, and reduce the costs of operation and maintenance. Program drivers include:

- Federal Energy Regulatory Commission (FERC) regulatory changes increased system deliverability requirements.

- Projected increased gas demand in the South Atlantic and New England Regions and gas production shifting towards the western producing basin create a critical need for delivery and storage system expansion.

- The aging delivery and storage system infrastructure requires re-engineering for increased operational flexibility.

- Human health and safety concerns due to aging pipeline system and distribution system

- Increased constraints on the infrastructure operation systems due to environmental regulations and gas and electric deregulation

- Funding for long-term public benefit storage and infrastructure technology R&D is decreasing

R&D Challenges. Depleted oil and gas reservoirs are used for interim storage of natural gas primarily to meet the large increase in natural gas demand during the winter and for peaking services for power generation. Each reservoir has characteristics that determine the limits of injection and withdrawal rates and total storage capacities that can be achieved. Improved methodologies and technologies must be developed through rigorous R&D to prevent the loss of deliverability from these fields and to better remediate lost deliverability when it occurs. Natural gas storage is a critical segment of the Nation's overall energy system, and innovative gas storage methods are required to meet the projected increase in gas demand, especially in the power generation sector and in areas where conventional underground storage-depleted oil and gas reservoirs are unavailable (South Atlantic and New England Regions).

R&D Activities. DOE, in collaboration with industry, is conducting storage research in the following areas:

- Advanced storage technologies that will meet the specific storage needs of new and growing industrial and power generation markets, specifically the short-term or hourly requirements of the power generation sector. To provide science and engineering solutions for the development of gas storage facilities in regions without conventional storage options, and to ensure gas system infrastructure reliability, deliverability, and operational flexibility.

- Novel and advanced fracture simulation technologies and improved remediation treatments that will increase storage reservoir deliverability and help to offset the reported 5.2 percent annual loss in deliverability.

- Improved real-time storage measurement technologies and gas flow metering (e.g. ultrasonic meters, direct energy meters) and energy measurement technologies that will provide real time, automated monitoring of pipeline gas flow and energy content, increasing system deliverability and optimizing gas sales to customers and to reduce uncertainties in storage inventories attributable to storage metering biases.

- Re-engineering underground gas storage reservoirs to increase operational flexibility, extend the useful life of underground storage reservoirs using horizontal wells, and lower costs for storage.

Development of advanced technologies that meet industry needs would result in a more efficient natural gas storage system and benefit both industry and consumers. The gas storage industry would benefit from improved storage efficiency through increased deliverability, decreased deliverability revitalization costs, and increased operating efficiency. Local distribution companies would gain from improved system reliability and flexibility. Industrial and power generation end users would benefit from advanced storage concepts, and residential customers would benefit from lower costs for service.

Accomplishments. Program accomplishments include:

- Northern Indiana Public Service Company (NIPSCO) partnered with DOE and GRI to demonstrate the use of geological modeling and seismic survey techniques to optimize the development and operation of gas storage fields. Based on the results of this integrated study, NIPSCO drilled a horizontal well at the Royal Center field in Indiana. Initial flow tests indicate that the well will significantly enhance deliverability from the field and allow the utilization of gas from an area of the storage field that was not accessible from the existing vertical wells.

- Universal Well Services, located in Wooster, Ohio, pumped the first ever CO_2/sand fracture stimulations in a gas storage field to determine the applicability of a totally nondamaging fracturing fluid. The deliverability from two underground storage wells at the Galbraith field in Pennsylvania, operated by National Fuel Gas Supply Company, increased by 600 percent

Enhancing Pipeline System Reliability

FY99-$0.0M, FY00-$0.0M, FY-$5.0M

Description, Objectives, and Performers. This is a new program for FY2001. The program includes cooperative efforts with industry to help ensure pipeline system reliability. The existing pipeline infrastructure is limited and there is increasing concern about restricted deliverability of the pipeline system and the high cost associated with system expansion, maintenance, and enhancements to serve growing gas demand. Better methods are needed to monitor, protect, maintain, and repair existing pipelines to ensure the integrity of the gas delivery system. Through its Natural Gas Infrastructure Program, DOE supports the development of advanced technologies and methods to enhance deliverability, increase efficiency, and reduce the costs of operation and maintenance. Program drivers include:

Federal Energy Regulatory Commission (FERC) regulatory changes increased system deliverability requirements.

- Projected increased gas demand in the South Atlantic and New England Regions and gas production shifting towards the western producing basin create a critical need for delivery and storage system expansion.

- The aging delivery and storage system infrastructure requires re-engineering for increased operational flexibility to maintain system throughput and meet growing gas demand.

- Human health and safety concerns due to aging pipeline system and distribution system

- Increased constraints on the infrastructure operation systems due to environmental regulations and gas and electric deregulation

- Funding for long-term public benefit infrastructure technology R&D is decreasing industry and energy service providers

R&D Challenges. There is a need to minimize threats to pipelines from mechanical damage by construction equipment and weather related landslides, flooding and washouts to ensure the reliability of the gas transmission and distribution network and increase the operational efficiency of the pipeline system. Current technologies have very limited success in locating underground facilities and detecting and characterizing mechanical damage, especially for those pipelines which cannot accommodate in-line inspection tools.

R&D Activities. DOE, in collaboration with industry, will initiate pipeline infrastructure research research in the following areas:

- Natural Gas Transmission System: including: design and engineering studies for program development work in real-time controls, meters, and sensors that are capable of monitoring pipeline integrity and are capable of managing delivery of gas to customers; development of advanced models, engineering tools, and pipeline and data visualization and communication technologies to lower barriers to distributed power generation and increase the efficiency of the pipeline system; gas system reliability analysis and distributed resource system integrated modeling; and modeling high deliverability gas storage system to serve the power generation marketplace

- Natural Gas Distribution System: Research directed to ensure the reliability and optimization of the distribution network, including development of longer life, high-strength, non-corrosive pipeline materials and research on obstacle detection systems for horizontal boring applications for laying distribution pipelines.

- Leak Detection: Development of pipeline leak and intrusion detection system using optical visualization methods. Development of a portable, hand-held and aircraft mounted, real-time natural gas visualization remote sensing technology to detect fugitive emissions during leak surveys in natural gas distribution systems and gas transmissions systems.

International Infrastructure Program

FY99-$0.0M, FY00-$0.0M, FY-$6.0M

Description, Objectives, and Performers. This is a new program for FY2001. This program is initiated in response to the June 1999 President's Committee of Advisors on Science and Technology report entitled *"Powerful Partnerships-the Federal Role in International Cooperation on Energy Innovation"*.

R&D Challenges. A natural gas leak visualization device is needed that is sufficiently compact and electrically efficient to allow operation in a hand-held format, as well as a remote leak visualization system with sufficient standoff range to operate from a low altitude aircraft. This will require development of a laser source that has sufficient power to accommodate the standoff range and two dimensional area coverage required, and optical receiver hardware capable of the required gas detection sensitivity.

R&D Activities. DOE, in collaboration and partnership with other Federal Agencies, industry, and host country government will initiate international pipeline infrastructure research oriented toward gas leak detection. Activities will include development of: a pipeline leak and intrusion detection system using optical methods; a portable, natural gas video imaging system that has application as a aircraft survey device for natural gas pipelines; improved corrosion-inhibition treatment alternatives in gas gathering and gas transmission lines; and pipeline inspection sensors with internal leak sealing capabilities.

Secure Energy Infrastructures

Budget: FY99-$0.0M, FY00-$2.1M, FY01-$13.0M

Background

The nation's energy infrastructure, which is composed of industries that produce and distribute electric power, oil, and natural gas, is susceptible to threats from natural, accidental, and intentional sources. The threats are directed at both physical and cyber assets of the energy sector. Recent trends toward increasing complexity and interconnectedness of the energy sector serve to increase the potential for significant disruptions to the energy grid and the other critical national infrastructures that the grid supports (i.e., information and communications, banking and finances, transportation, water, emergency services, and government services).

In order to effectively carry out DOE's role as the lead federal agency for the energy infrastructure under Presidential Decision Directive 63, this program is being undertaken to assure the continuity and viability of the nation's critical energy infrastructures and the elimination of any significant vulnerability of that sector to physical and cyber disruptions. This will involve leveraging and developing essential energy infrastructure protection, mitigation, response, and recovery methodologies, analytic tools, and technologies. It will also involve collaboration between DOE and the major stakeholders including private sector owners of energy infrastructure elements, other federal agencies involved in critical infrastructure protection, and state and local governments. The national laboratories, academia, and private research organizations will participate in developing and implementing the research program.

Linkages to CNES Goals and Objectives

The Secure Energy Infrastructures Program supports the following CNES goals and objectives:

- CNES Goal II, Objective 2 – Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 2 – Develop technologies that expand long-term energy options.

Focused on the thrust areas of Analysis and Risk Management and Protection and Mitigation Technologies, the Secure Energy Infrastructures Program will result in real-time control mechanisms, integrated multi-sensor and warning systems, and risk management and consequence analysis tools that will help the national energy sector address the physical and cyber threats to, and vulnerabilities of, the energy infrastructures. Infrastructure interdependence methodologies, architectures, analytic tools, and technologies will also be developed that will improve the capability to assess the technical, economic, and national security implications of energy technology and policy decision designed to ensure the reliability and security of the nation's interdependent energy grid.

Program Description

The Secure Energy Infrastructure program will collaborate with industry, academia, and other federal agencies to conduct research that will enhance the protection of the nation's energy infrastructure from disruptions, the mitigation of potential disruptions that do take place, the response to potential disruptions, and the restoration the energy infrastructure to normal operation following a disruption. The program develops methodologies, architectures, analytic tools, and technologies in two program areas: Analysis and Risk Management and Protection and Mitigation Technologies.

Analysis and Risk Management

Budget: FY99-$0.0M, FY00-$2.1M, FY01-$10.3

Description, Objectives and Performers. To adequately determine the susceptibility of the energy infrastructure to disruption, critical assets (both physical and cyber) need to be identified, vulnerability assessments of those assets need to be conducted, and critical consequence analyses to determine the impacts (on public health and safety, on national security, and on economic well-being) of the loss of those assets need to be carried out. To date, there has been no systematic, comprehensive effort to cover all these issues for the energy infrastructure. Some individual energy companies have carried out analyses of their own assets. However, it is not a widespread industry practice to carry out regular, comprehensive, and detailed analyses of physical and cyber asset security. Further, there has been no attempt to systematically evaluate the security of the energy infrastructure on a regional or national scale. This is becoming increasingly important with the greater degree of interconnectedness, both physical and cyber, of the energy system. With the increasing interconnectedness of the energy system, it is no longer possible for an individual company to address all the critical assets that its own system depends on.

The objective of this program element is to develop a better understanding of the nature and extent of the energy infrastructure's vulnerability to disruption and of the consequences of disruptions. The performers include private sector owners of energy infrastructure elements, other federal agencies involved in critical infrastructure protection, state and local governments, the national laboratories, academia, and private research organizations

R&D Challenges. The challenges to understanding energy infrastructure vulnerabilities and risks include:

- Lack of an effective methodology for processing and analyzing threat information.
- Rapidly changing vulnerabilities of the energy infrastructure, particularly in the cyber area.
- Increasing interdependence of energy infrastructure and other infrastructures.
- Increasing system interconnectedness and complexity of the energy system.

R&D Activities. The following R&D activities are designed to address the challenges.

Infrastructure Interdependencies: Develop, demonstrate, and deliver analytic capabilities and supporting knowledge bases that will significantly improve understanding of, and the ability to comprehensively study, the interdependent nature of the U.S. energy infrastructures. This will involve: (1) enhancing existing and developing new analytical tools that treat infrastructure interdependencies explicitly; (2) enhancing early alert screening tools that provide infrastructure stress indicators; (3) coordinating with other Federal agencies to link to models and simulations of other critical infrastructures; (4) enhancing existing and developing new policy and impact analysis tools; and (5) developing an integrated architecture for analyzing the technical, economic, and national security implications of energy technology and policy decisions.

Vulnerability Assessments: Expand upon previous infrastructure assurance efforts (in the electric power and, to a lesser extent, natural gas infrastructures) to work with utilities to identify and evaluate the threats to and vulnerabilities of the natural gas and oil infrastructures. This includes both cyber (information) and physical infrastructure components. One assessment of the natural gas infrastructure and three assessments of the oil infrastructure would be conducted at various utilities. A summary of lessons learned and recommended practices for the energy industry would be developed.

Scale and Complexity Analysis: Characterize the large, complex, non-linear energy infrastructures, focusing on stability, countermeasures, complexity reduction, uncertainty effects, and personnel behavior.

Critical Consequence Analysis and Tool Development: Develop the data, methodologies, and tools to evaluate the public health and safety, national security, and economic consequences of disruptions to energy infrastructures and the processes to assist in restoration and reconstitution.

Risk Management Tools: Develop tools to assist decision makers in planning and implementing protection and mitigation strategies and predictive risk management tools allowing for real-time, accurate interpretation of system monitoring information.

Evaluating Policy Effects and Institutional Barriers: Evaluate the cause-and-effect relationships between specific public policies, institutional barriers, and energy infrastructure vulnerabilities.

Accomplishments. This is a new program and is just starting.

Protection and Mitigation Technologies

Budget: FY99-$0.0M, FY00-$0.0M, FY01-$2.7M

Description, Objectives and Performers. Response and recovery procedures and technology are not adequate for dealing with the rapid changes in threats and with the changes in the structure of the energy system. This is especially true when dealing with deliberate threats (as opposed to natural and accidental threats) and is particularly true with regard to cyber assets. Technology and procedures that can detect emergency conditions before they become critical (e.g., sensors), that can be deployed quickly to reduce the impact of an emergency (e.g., rapid repair technology), and that can expedite restoration (e.g., information sharing among companies and emergency responders) are needed. The response and recovery technology and procedures used for physical damage are, in general, much better developed than those used for cyber damage. The objective of this activity is to develop energy system protection and mitigation technologies that are suitable for use in the rapidly changing, restructured energy markets.

The performers in this program element are in the national laboratory system, academia, and private research organizations. The work will leverage research in other parts of DOE by adding the security considerations to the development of related technologies.

R&D Challenges. The R&D challenges include the following:

- Technologies that can process large quantities of energy system information in real-time and can analyze the information to provide system operators with the ability to detect and react quickly to potentially destabilizing conditions

- Sensors that can respond in real-time and that can detect emergency conditions before they become critical

R&D Activities. The following R&D activities are designed to address the challenges.

Development of Real-Time Control Mechanisms in the Energy Infrastructure: Identify the vulnerabilities of real-time control systems and develop technologies that protect against unauthorized control of, or intrusion into the system.

Integrated Multi-Sensor and Warning Technologies for the Energy Industry: Develop an integrated, corroborative system of overlapping technologies, including sensors, designed to warn of attacks and impending failures at critical points in the energy system. The focus would be on tamper detection and failure warning technologies such as acoustic instrumentation, electronics signals, biological and chemical toxin sensors, video imaging, satellite oversight, remote methane detection (hand-held and airborne), expert system data interpretation, and standards development. Advanced technology approaches and cost regulation will be the focus of the R&D.

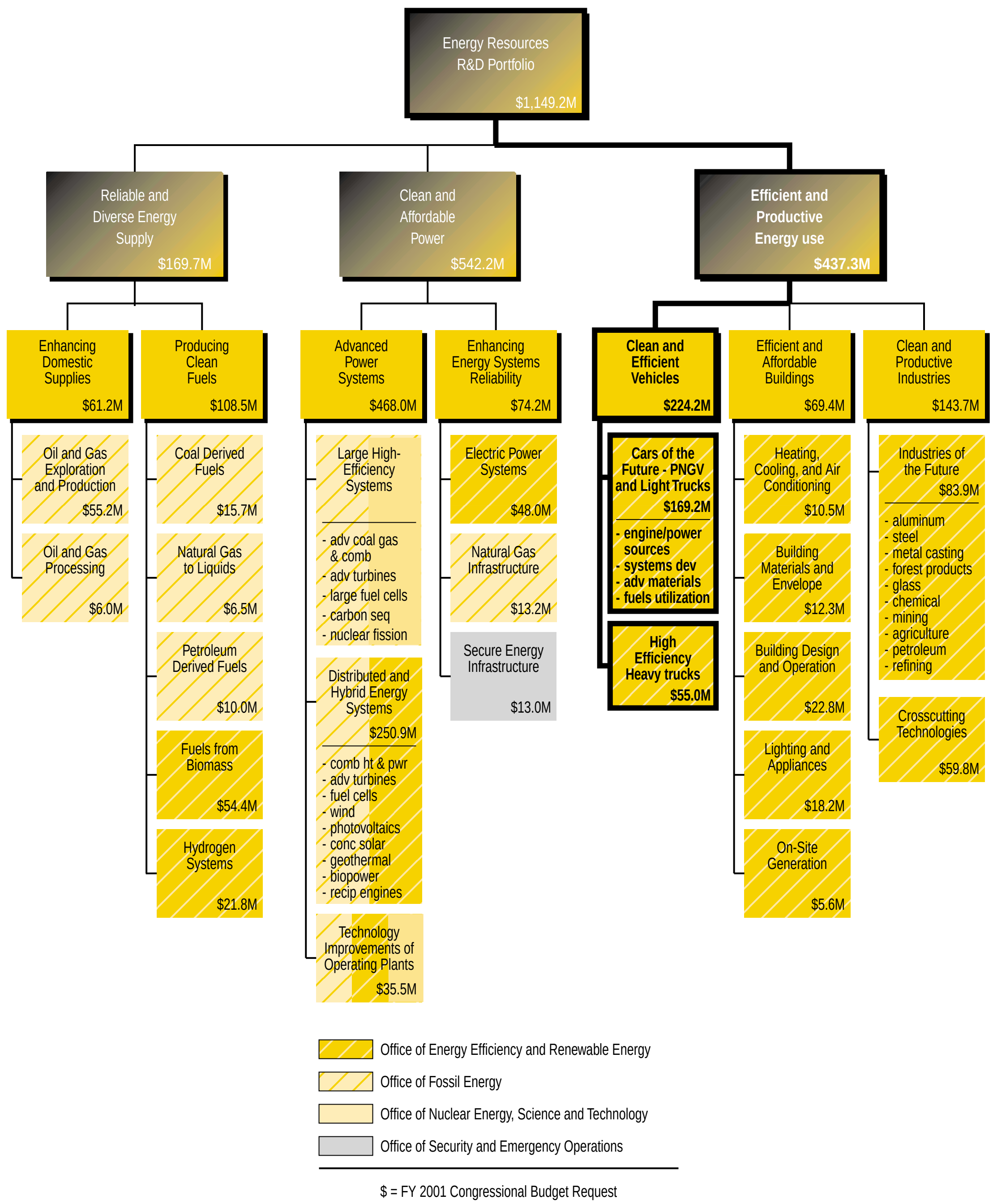
Geomagnetic Interference Warning Systems: Develop a methodology that would enable electric power system operators to establish emergency operating procedures for electric power systems under the influence of intense geomagnetic disturbance. This will provide a cost-effective approach to reduce power system vulnerability to predictive increases in sunspot activity in the next few years.

Accomplishments. This is a new program that is just being started.

Summary Budget Table (000$)

Enhancing Energy System Reliability Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Transmission Reliability	**3,019**	**2,455**	**8,000**
Real Time System Control	1,169	855	3,000
Distributed Resource Integration	900	800	2,000
Reliability and Markets	950	800	3,000
Distributed Power	**1,200**	**3,500**	**3,000**
Strategic Research	200	500	700
System integration	732	2,700	2,000
Regulatory and Institutional Issues	300	300	300
Energy Storage Systems	**4,445**	**3,429**	**5,000**
Integration	2,170	1,640	2,500
Components	1,384	1,000	1,600
Analysis	891	789	900
Superconductivity in Power Systems	**32,100**	**31,408**	**32,000**
The Superconductivity Partnership Initiative	14,500	14,000	14,000
The Second Generation Wire Initiative	8,000	8,000	8,000
Strategic Research	9,600	9,408	10,000
Natural Gas Infrastructure	**975**	**1,000**	**13,200**
Gas Storage Technology	975	1,000	2,200
Enhancing Pipeline System Reliability	0	0	5,000
International Infrastructure Integrity	0	0	6,000
Secure Energy Infrastructures	**0**	**2,100**	**13,000**
Analysis and Risk Management	0	2,100	10,300
Protection and Mitigation Technologies	0	0	2,700
Total	**41,739**	**43,892**	**74,200**

Chapter 7
Clean and Efficient Vehicles



Chapter 7
Clean and Efficient Vehicles

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Overview

Definition of Focus Area

Highway vehicles currently account for approximately 50 percent of daily domestic petroleum consumption (about 9.2 million barrels per day). Through significant efficiency increases in passenger cars and trucks, and development of cost-effective alternative fuels, the clean and efficient vehicles R&D portfolio seeks to reduce the growth of highway vehicle petroleum consumption.

National Context and Drivers

The U.S. transportation sector is dependent on petroleum for nearly 97 percent of its energy. In 1997, the transportation sector consumed 12.1 million barrels per day (MBPD) of petroleum products; highway vehicles account for 75 percent of transportation energy use with passenger vehicles alone using nearly 60 percent of the total. Without the increased technological progress and adoption of advanced transportation technologies supported by this program, the Energy Information Administration projects that by 2020, the energy demand in the transportation sector will increase by 45 percent to 17.6 MBPD.

Transportation accounts for 65 percent of the U.S. annual petroleum consumption and uses 88 percent more petroleum than the United States produces. Currently, about half of the petroleum used in the United States is imported with U.S. dependence on imported petroleum growing. Annually, the cost of oil imports is one of the largest components of the U.S. balance of trade deficit. In 1997, oil imports were 34 percent of the merchandise trade deficit. The United States also remains vulnerable to future oil price shocks and periods of high prices connected to world events.

The explosive popularity of low fuel-economy pickup trucks, vans, and sport utility vehicles used for personal transport, coupled with a growing economy, falling fuel prices, increasing numbers of drivers, and increasing miles traveled by each vehicle is pushing transportation fuel consumption higher. This situation will not change without a major advance in vehicle fuel efficiency. This could occur through regulatory or tax policies on vehicles or fuels and/or through technology improvements in the Nation's vehicles.

The Department of Energy's (DOE's) clean and efficient vehicles portfolio is the technological cornerstone for the Nation's initiative to significantly improve transportation energy efficiency.

Linkage to CNES Goals and Objectives

Technological developments from the clean and efficient vehicles R&D portfolio will contribute to meeting objectives contained within four of the five major CNES goals.

- CNES Goal I, Objective 2 - Significantly increase the energy efficiency in transportation, industrial, and buildings sectors by 2010.

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

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(pursuing research aimed at major improvements in vehicle efficiency, resulting in major reductions in greenhouse gas emissions, while meeting significantly improved emissions standards)*

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options. *(expanding long-term energy options such as hydrogen-based vehicle systems, enabling educational research opportunities, and building capabilities at educational institutions)*

By meeting OTT's goals and objectives, the Nation will reduce its dependence on oil and achieve energy savings as well as reduced carbon emissions. DOE, in the Quality Metrics Program Analysis, has estimated that by 2010, 1.8 quads of primary oil will be displaced, increasing to 3.7 quads by 2020. (For reference, 3.7 quads equals 638 million barrels of oil; highway vehicles currently use about 19 quads of energy annually). This will result in energy cost savings of nearly $10 billion in 2010 and over $20 billion by 2020; carbon reductions are estimated at 25 and 60 million metric tons in 2010 and 2020. (Motor gasoline use in the United States produces about 302 million metric tons of carbon per year).

Uncertainties

The technologies needed for the Cars of the Future and Heavy Trucks programs offer technical challenges identified in the technical roadmaps that provide the approach, milestones, and tasks needed to resolve the technical uncertainties. In addition to the uncertainties in technology development (the risk of being able to resolve technical barriers in a timely fashion), market and political uncertainties also exist. With low oil prices, fuel economy ranks low on the list of vehicle attributes that new car buyers desire. Consequently, one of the technical challenges is a result of market uncertainty—with an uncertain market for energy-efficient transportation technologies, efficiency needs to be produced with little to no incremental cost. In addition, there are some political uncertainties. For example, the regulatory process may establish extremely strict emissions standards that could preclude the adoption of some energy-efficient technologies.

Investment Trends, Initiatives, and Rationale

Because 75 percent of transportation energy use is consumed by highway vehicles, virtually all of the DOE transportation technology R&D budget is directed at cars and trucks. And with 80 percent of highway vehicle energy use being passenger vehicles, the majority of the R&D budget is in the Cars of the Future (the major effort being the Partnership for a New Generation of Vehicles) and Light Trucks (which includes pickup trucks, vans, and sport utility vehicles). The area of heavy trucks accounts for the remainder of the DOE transportation R&D investment.

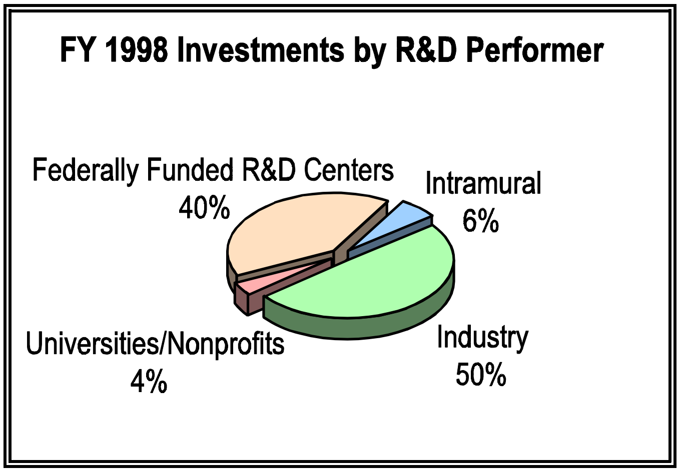
The Office of Transportation Technologies and its predecessor organizations have worked with the U.S. auto industry and engine manufacturers for over two decades to develop energy efficient technologies. Often the research was driven by Congressional mandates and various Administration priorities. Since the advent of the Partnership for a New Generation of Vehicles, DOE has worked even closer with the industry during the planning process to develop common technical roadmaps that would enhance the probability of commercial success. Technical roadmaps were developed first for the auto area and later for the heavy truck sector. Research and development plans were produced by OTT's Office of Advanced Automotive Technologies (OAAT) and the Office of Heavy Vehicle Technologies (OHVT). These plans underwent extensive external review. To assure the quality of the automotive R&D plan, the National Research Council (NRC) conducted an independent, comprehensive review of the OAAT plan last year, while the OHVT plans will be reviewed by the NRC this year.

Major program thrusts are developed in cooperation with industry in order to maximize the likelihood of commercialization of the energy-efficient technologies. Consequently, budget changes tend to be characterized as "mid-course corrections" rather than radical adjustments. One area of increased emphasis is compression-ignition, direct-injection (CIDI) engines, commonly called diesel engines. CIDI engines have the highest thermal efficiency of any internal combustion engine and offer the greatest near-term potential for reducing transportation energy use and greenhouse gas emissions. The primary focus of DOE's R&D is reducing emissions of particulates and oxides of nitrogen, which are the major technical challenges for CIDI engines.

One way that risk can been reduced is to explore a broad range of technologies. For this reason, the Office of Transportation Technologies has a diverse research portfolio. Periodically, a technology selection process is used to evaluate research progress against established milestones and reduce the number of technologies to the most promising ones. The most recent example occurred with the Partnership for a New Generation of Vehicles at the end of 1997. Program diversity also occurs with respect to time horizons, research stage, and research performers.

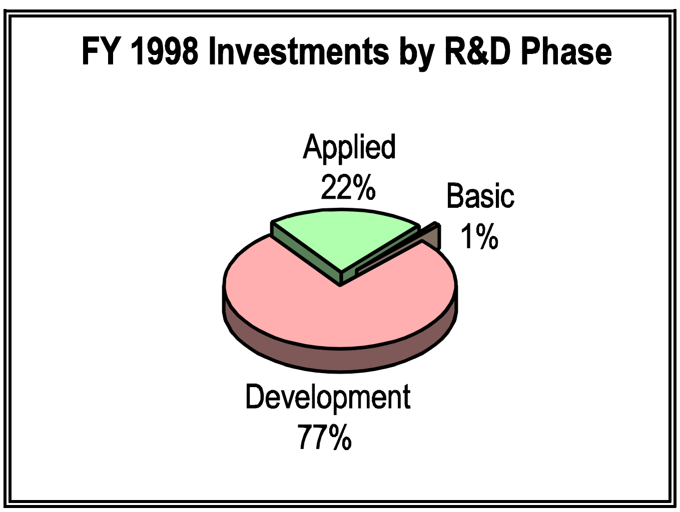
By design, the OTT research programs have been long-term, i.e., typically ten years or longer. DOE transportation research in the 1980s on alcohol fuels has resulted now in commercially available flexible-fueled (gasoline or alcohol) vehicles. Current research into energy storage, fuel cells, and hybrid vehicle systems also has a long-term horizon, although industry will often "harvest" DOE-supported technologies before the technology development for an integrated vehicle system has been completed. Consequently, it is difficult to delineate with any precision whether the research fits within a near-, mid-, or long-term horizon for anticipated commercialization.

The portfolio consists of two main entities, Cars of the Future, which includes PNGV and light trucks, and High Efficiency Heavy Trucks. FY 1998 funding for Cars of the Future totaled 84 percent of the portfolio, with High Efficiency Heavy Trucks supporting the remaining 16 percent. As shown in the figure below, half of the research is performed by the private sector, either funded directly or through DOE laboratories. Approximately 40 percent of the research is performed by the DOE laboratories themselves. A relatively minor amount of research is performed by other government agencies (6 percent) or universities (4 percent). The charts showing Investments by R&D by Performer and Investments by Phase reflect recent experience and are not expected to change significantly over the FY 1999 - 2001 period.



Research is often classified by stage—basic research, development, and applied research. Very little basic research is performed by the clean and efficient vehicles portfolio. Development is defined in the OMB Circular No. A-11 as, "...systematic application of knowledge toward the production of useful materials, devices, and system or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."

As the next figure shows, the bulk of the research dollars are devoted to development with the majority of the balance spent on applied research, and a minute portion on basic research.



Given the limitations of Federal resources, the clean and efficient vehicles portfolio is allocating its budget consistent with the opportunities for having the greatest impact on transportation energy use (cars, light trucks, and heavy trucks) and with the technical priorities established with DOE's cost-sharing partners.

While budget constraints pose significant problems in allocation of resources, two special initiatives have been identified that take advantage of activities in other organizations, by conducting collaborative research.

The Enhanced Ultra Clean Transportation Fuels Initiative focuses activities within the Fossil Energy (FE) and Energy Efficiency (EE) areas of the Department of Energy, and involve the U.S. petroleum industry and motor vehicle (auto and truck) manufacturers. Because petroleum-based fuels will dominate the market in the near-term, research will focus on the development of ultra-clean petroleum fuels that will enable the use of the high-efficiency, low-emissions engine technologies being developed in the PNGV and heavy truck programs. A near-term strategy will also be to use blends derived from domestic resources of natural gas and coal. For the long-term, a sustainable and environmentally-beneficial option involves the research to develop renewable fuels, and the necessary infrastructure, that would make alternative fuels economically competitive. The FE area of responsibility would be to develop improvements in fuel production while EE concentrates on engine performance improvements and emissions reduction. Both organizations would share responsibilities in fuels characterization, testing, and evaluation.

The 21st Century Truck Initiative is led by the Army with participation from the Department of Energy, Department of Transportation, and the Environmental Protection Agency. The goal of the Initiative is to form a government-industry partnership to develop truck and engine technology that can enhance the mobility of goods while further reducing the impact of trucks on the environment and the Nation's dependence on imported petroleum. The technical goals are to achieve, by 2010, 3X fuel economy improvement for light-heavy duty (Class 2b) and medium duty (Class 6) trucks and 2X fuel economy improvement for heavy over-the-road (Class 8) trucks while attaining very low emissions levels. Enhanced truck safety is also a key goal of the program. The government-industry partners will conduct research in areas such as diesel engine combustion and emission control technologies, hybrid vehicle designs, light-weight materials, reduction of parasitic energy losses, regenerative braking, more efficient transmissions, and alternative fuels.

Federal Role

The primary government R&D role is to support long-range, high-risk activities where breakthroughs offer large potential payoffs to the Nation, but are not reflected in current market pricing. This support includes funding, as well as access to unique R&D capabilities within the Federal laboratory system. With fuel prices at historic lows, the transportation sector has little or no incentive to undertake high risk research on its own to achieve breakthrough efficiency improvements. The DOE role is to conduct R&D, with cost-sharing industry partners, that would achieve the national goals of:

- Reducing the Nation's dependence on petroleum.

- Decreasing vehicle exhaust emissions, thereby improving urban air quality.

- Having a positive economic impact on the Nation's transportation sector, which accounts for one out every seven American jobs.

Key Accomplishments

The auto industry is already beginning to use many of the technologies developed in the Cars of the Future, Partnership for a New Generation of Vehicles (PNGV), and Light Truck Programs. Beginning with the 1998 North American International Auto Show in Detroit, several hybrid and other advanced vehicles, including the Chrysler ESX2, Ford P-2000, and the General Motors EV-1 platforms, showcased DOE-funded technologies. OAAT-supported technologies that were integrated into these concept vehicles included advanced compression-ignition, direct-injection (CIDI) engines, parallel-hybrid vehicle configurations, a proton exchange membrane (PEM) fuel cell, a methanol reformer, and a nickel-metal hydride battery. While considerable R&D remains to make these technologies commercially viable, these public demonstrations clearly demonstrate the interests of the U.S. auto companies in bringing these DOE-supported technologies to market. In 1999, Ford delivered to DOE its P2000 LSR (Low Storage Requirement) hybrid vehicle designed for a fuel economy of 60 mpg.

Cars of the Future, PNGV, and Light Trucks:

Budget: FY99-$147.3M, FY00-$155.3M, FY01-$169.2M

Background

The Partnership for a New Generation of Vehicles (PNGV) is a cooperative research and development (R&D) program between the Federal government and the United States Council for Automotive Research (USCAR) that was announced by President Clinton and the CEO's of Chrysler Corporation, Ford Motor Company, and General Motors Corporation (GM) on September 29, 1993. The three major domestic automakers are working with the Federal government, labor, suppliers, and universities, to develop efficient, low-emission vehicles for the 21st Century.

The PNGV has 3 goals:

- To develop manufacturing techniques to reduce the time and cost of automotive development.
- To improve fuel efficiency and emission performance of conventional vehicles.
- To develop a new family of vehicles with up to triple the fuel efficiency (i.e., 80 miles per gallon) of today's mid-size cars (i.e., Ford Taurus, Chrysler Concorde, and Chevrolet Lumina) while maintaining or improving safety, performance, emissions, and price.

The initiative represents a priority approach of the Administration to protecting the environment, improving the competitiveness of U.S. companies, and reducing the economic and geopolitical risks that result from this Nation's rising dependence on petroleum. Government is working with industry to develop the required technologies, and industry will make the choices necessary to meet America's transportation needs. Together, they will achieve important social and economic objectives for the Nation. Seven Federal agencies participate in the Partnership for a New Generation of Vehicles under the leadership of the Department of Commerce.

Currently the Administration is discussing expansion of the Partnership for a New Generation of Vehicles to include multi-purpose vehicles (Class 1 and 2 trucks which include pickups, vans, and sport utility vehicles). Sales of multi-purpose vehicles have increased dramatically in the past 13 years from approximately 3 million vehicles in 1983 to over 6.9 million in 1997 (from 25 percent to over 45 percent of the foreign and domestic sales in the United States). Consequently, the industry is shifting substantial manufacturing emphasis to light trucks.

Sales in the light truck segment are shifting towards the heavier Class 2 trucks, reducing the average fuel economy for this segment. As a result, the U.S. auto manufacturers are having difficulty meeting current light truck Corporate Average Fuel Efficiency (CAFÉ) standards. Both GM and Chrysler failed to meet the 20.6 mpg standard for the 1995 model year. GM's truck fleet must exceed the CAFÉ standard of 20.7 over the next 3 years or face a prospective penalty for its 1995 shortfall.

Linkage to CNES Goals and Objectives

The R&D goals of DOE's programs in advanced vehicle technologies are to research, develop, and validate technologies that enable development of production prototypes of light-duty vehicles (automobiles, pickups, vans, and sport utility vehicles) which have (1) for automobiles, up to 3 times the fuel economy of comparable conventional vehicles; (2) for light trucks, 35 percent improvement in fuel efficiency (engine replacement only); (3) fuel flexibility; (4) emissions that at least comply with the most stringent statutory limits projected to be in the marketplace; and (5) other attributes, such as price, safety and performance, that render them competitive with conventional products.

This effort supports objectives contained in four of the five CNES goals:

- CNES Goal I, Objective 2 - Significantly increase the energy efficiency in transportation, industrial, and buildings sectors by 2010. *(developing more efficient transportation technologies)*

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply. *(helping reduce the consumption of petroleum)*

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(pursuing research aimed at major improvements in vehicle efficiency, while meeting significantly improved emissions standards)*

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options. *(expanding long-term energy options such as hydrogen-based vehicle systems, enabling educational research opportunities, and building capabilities at educational institutions)*

Program Description

Seven Federal agencies are collaborating with the U.S. auto companies in pre-competitive research to significantly improve automotive fuel economy. DOE's R&D program, which represents the majority of the Federal effort in PNGV, is conducted in partnership with the U.S. auto industry and the U.S. diesel engine industry. Research to overcome barriers to automotive technology development and utilization draws upon the unique capabilities of a dozen National Laboratories, combined with research facilities at universities, the major automakers and their suppliers. Coordination and prioritization of research portfolios is undertaken by technical teams comprised of representatives from industry, government, and National Laboratories. The technical areas include fuel cells, electrochemical energy storage, system analysis, manufacturing, four-stroke direct injection engines, materials and structures, electrical and electronics, and vehicle engineering.

Through consensus, each team develops a technical roadmap to overcome the barriers in its particular technology area. The teams review research progress and results, and recommend priorities for further research.

Research in the Cars of the Future, PNGV and Light Trucks Program Area can be grouped into four programs:

Engine/Power Sources

Budget: FY99-$94.3M, FY00-$109.7M, FY01-$123.4M

Advanced engine and power systems are critical to dramatic improvements in the fuel economy of automobiles and light trucks. Because the government does not manufacture vehicles, development of these technologies (which include advanced combustion engine R&D, fuel cells, high-power batteries, power electronics and electric machines, and electric vehicle batteries) will occur through a process that focuses on the research, development, and validation of hardware or prototypes to meet performance and cost goals. This collaborative process between the U.S. automakers, diesel engine manufacturers, and DOE follows technology roadmaps that have been developed, and are periodically updated, for each technology area.

Advanced Combustion Engine R&D

Budget: FY99-$33.5M, FY00-$39.7M, FY01-$41.9M

Description, Objectives, and Performers. The Advanced Combustion Engine R&D effort seeks to significantly improve the fuel efficiency of conventional piston engine technologies while cost-effectively meeting projected emissions regulations. The primary focus is on developing and validating compression-ignition, direct-injection (CIDI) engine technologies. In its 1997 technology selection, the PNGV identified direct injection engines as the most promising near-term energy conversion technology. Additional resources were requested in the FY 1999 and FY 2000 budgets to overcome the significant barriers that remain for this technology to meet anticipated emissions requirements. With the stringent emissions regulations proposed for particulates and nitrogen oxides, a secondary focus will be to enhance the performance of spark-ignition, direct-injection (SIDI) technology as a power system alternative to meeting the PNGV goals.

CIDI (diesel) engines have the highest thermal efficiency of any proven heat engine (brake thermal efficiency of 32-42 percent) and are excellent propulsion system candidates for both conventional drive systems and hybrid configurations. However, the use of CIDI engines in the automobile and light truck markets has been limited by shortcomings in performance, weight, size, noise, cost, and emissions. The greatest barrier to the future viability of CIDI engines for light-duty vehicles is the lack of effective, affordable emissions control technologies.

SIDI engines are being developed to support Goals 2 and 3 in the PNGV program. The status of current development and the potential of the SIDI engine suggest that it is a likely candidate for the incremental improvement of passenger car fuel economy (Goal 2), and a potential enabling technology for a three-times more fuel-efficient vehicle (Goal 3). The SIDI engine appears to be a viable alternative to the CIDI engine if, for a variety of reasons such as emissions, refueling, and service infrastructure, the latter is determined to be unable to achieve all the PNGV requirements.

R&D Challenges. Current NO_x emissions exceed the target (0.2 g/mile) by a factor of two and the proposed research target (0.05 g/mile) by a factor of eight. NO_x catalysts that operate with lean-burn engines are not available. Catalyst materials must be developed that operate in the presence of oxygen in the exhaust and that can perform over a wider temperature range. Other aftertreatment technologies are underdeveloped, costly, and do not have proven reliability and durability. Current particulate emissions exceed the research target (0.01 g/mile) by a factor of six. Particulate traps are costly (as much as 30 percent of the engine cost), energy-intensive (about 10 percent of fuel consumption), and have unproven reliability. Other aftertreatment devices (e.g., non-thermal plasma) are not adequately developed. In addition to the emissions problem, CIDI engines are about twice as expensive as conventional, port-injected, spark-ignition engines, principally because of the sophisticated fuel injection equipment. Higher operating temperatures and pressures also increase the cost of the engine structural components. Additional emissions controls (in-cylinder or aftertreatment) will simply add to the cost of the CIDI engine.

The key challenges for SIDI include reduction of NO_x, plus the reduction of unburned hydrocarbons (HC), and further reduction in particulates. The remaining challenge for SIDI is to improve the thermal efficiency (36-37 percent), which is better than the current port fuel injection engines (25-30 percent), but lower than CIDI engines.

R&D Activities. CIDI engine technology R&D focuses on in-cylinder and aftertreatment methods to reduce NO_x and particulate emissions as the primary barriers. NO_x reduction will target in-cylinder combustion control, catalysts, low-temperature plasma, and fuel modification and additives. Particulate reduction will target combustion control (such as variable air composition), traps, low-temperature plasma destructive technologies, and fuel and lubricant modifications. Research utilizes standard U.S. diesel fuel, low-sulfur California diesel fuel, and ultra-low sulfur European diesel fuel. Additional fuels that may have potential, such as dimethyl ether, are being evaluated. Design teams are focused on a 55 kW engine for hybrid applications in automobiles and a 150-200 kW engine for light trucks. The SIDI development effort is similar in approach, but smaller in scope.

Accomplishments. Program accomplishments include:

- In a joint DOE/industry hybrid propulsion program, two different CIDI engines were designed and developed. One engine was developed by Ford Motor Company and FEV Engine Technology, the other by Chrysler and Detroit Diesel Company.

- Completed initial performance specifications of critical enabling technologies, as well as cost goals, for the high efficiency diesel engine to replace the lower efficiency spark ignition gasoline engine for light truck applications (sport utility vehicles, vans, pickup trucks).

- Initiated two industry, cost-shared programs with engine manufacturers and catalyst suppliers to develop and demonstrate emissions control systems for PNGV CIDI and SUV-sized engines that will enable achievement of proposed Tier 2 standards.

- Initiated testing of light truck diesel engine in vehicles and demonstrated 35% efficiency improvement.

Fuel Cells

Budget: FY99-$33.9M, FY00-$37.0M, FY01-$41.5M

Description, Objectives, and Performers. Fuel cells have emerged in the last decade as a potential replacement for the internal combustion engine in vehicles because they are clean, energy efficient (with a part-load system efficiency goal of over 50 percent and a full-load system efficiency goal target of 45 percent), and fuel flexible. Fuel cells offer the desirable attributes of low emissions, quiet and continuous operation, and modularity. Any hydrogen-rich material can serve as a potential fuel source for this rapidly developing technology. This includes fossil-derived fuels, such as natural gas, methanol, petroleum distillates, liquid propane, and gasified coal, or renewable fuels, such as ethanol or hydrogen (produced from renewable energy sources). The proton exchange membrane (PEM) fuel cell is the focus of current development efforts because it is capable of higher power density and faster start-up than other types of fuel cells.

R&D Challenges. Stack systems, fuel-flexible fuel processors, hydrogen storage, and power system integration are technical barriers for fuel cell development. Although fundamental scientific breakthroughs are not required to meet the program goals, substantial improvements are also needed in the areas of catalyst carbon monoxide (CO) tolerance and low-cost fabrication.

Long-term durability and the efficiency of the integrated power system have not yet been demonstrated.

R&D Activities. Particular emphasis is placed on research to achieve high efficiency, quick start-up, long life, and low manufacturing costs. The R&D is focused towards development of low cost fuel cell components, fuel processor subsystem development, and integration of stacks, fuel processors, and balance of plant components. Methanol, ethanol, natural gas, and gasoline are being evaluated as fuels for on-board reforming. Industry teams led by Plug Power, International Fuel Cells, Allied Signal, and Energy Partners are completing development of 50 kW fuel flexible fuel cell systems under cost-shared contracts.

Accomplishments. Program accomplishments include:

- Conducted the world's first gasoline-fueled proton exchange membrane (PEM) fuel cell power demonstration with Epyx Corporation, Plug Power, and Los Alamos National Laboratory, integrating fuel-flexible fuel processing technology with carbon monoxide clean-up and fuel cell stacks to produce power from both ethanol and gasoline.

- Under a program with Ford Motor Company and International Fuel Cells, completed laboratory validation tests on hydrogen-fueled 50 kilowatt (commercial-scale) PEM fuel cell propulsion systems including testing under automotive drive cycle requirements.

- Under a program with General Motors Corporation and Ballard, completed testing of a 30 kW methanol fuel cell system that demonstrated extremely low emissions.

- Evaluated fuel cell membrane electrode assemblies manufactured under a continuous process, incorporating less precious metals and a unique catalyst structure.

High-Power Batteries for Hybrid-Electric Vehicles

Budget: FY99-$12.5M, FY00-$14.0M, FY01-$18.3M

Description, Objectives, and Performers. A lightweight, compact, high-power energy storage device is one of the critical component technologies for a viable hybrid propulsion system. The primary functions of this device are to load-level the demand on the prime power source to maximize efficiency and minimize engine weight, volume, and cost; recapture the vehicle kinetic energy through regenerative braking; and capture the energy from the prime power source during braking and idle periods. In contrast to the high-energy requirement of electric vehicles, the energy storage device for hybrid vehicles must have high specific power (about ten times greater for hybrids than for electric vehicle batteries). Technologies that have the potential to meet the requirements for hybrid vehicles include: advanced high-power batteries, ultracapacitors, and flywheels. Currently only high-power batteries are considered sufficiently developed to have the potential to meet the schedule requirements of PNGV.

R&D Challenges. Batteries with power-to-energy ratios greater than 20kW/kWh and also have long cycle life, are needed. Electric and mechanical safety devices are needed to prevent overcharge or over-discharge. The candidate batteries all have operating temperature ranges that do not cover the entire operating temperature range required for automotive applications. Cost is too high by several factors, calendar life is unknown, and recyclability of the components is not known (the target is 80 percent recyclability at the vehicle level).

R&D Activities. Through a cooperative agreement between the United States Advanced Battery Consortium (USABC) and DOE, the USABC is focusing on the development of high-power batteries for PNGV. Two candidate battery chemistries have been identified as the most likely to succeed in meeting the requirements—nickel-metal hydride and lithium ion. The first of these offers relatively good power capability as a result of the good ionic conductivity of the aqueous potassium hydroxide electrolyte. The second offers excellent energy density that can be traded for higher power. Both chemistries are being investigated under the USABC program, initially to establish the basic performance and life capabilities in small laboratory cells, and then to demonstrate the best of these technologies in full-size modules. Ultimately, full-capacity battery energy storage subsystems will be engineered for delivery and operation with technology-validation test-bed vehicles.

Four USABC subcontracts to establish baseline cell chemistries and electrode designs were completed in 1997 and two of the contractors were awarded follow-on subcontracts (one for lithium-ion cells and the other for nickel-metal hydride cells) to develop and demonstrate their high-power battery technologies at the nominal 50-V module level with electronic and thermal management. In addition, the USABC awarded two other subcontracts to further explore alternative lithium-ion technologies. Performance and cycle life testing of deliverable cells are being conducted by selected National Laboratories under a Cooperative Research and Development Agreement (CRADA) with USABC.

Accomplishments. Program accomplishments include:

- Completed cycle testing of first-generation 50-volt nickel metal hydride high-power module.

- Completed first-generation 50-volt high-power lithium-ion module development and initiated performance characterization and life-cycle testing at DOE laboratories.

- Developed abuse test requirements and protocols, and completed assessment of the high-power energy storage lithium-ion safety performance envelope.

Power Electronics and Electric Machines

Budget: FY99-$6.8M, FY00-$10.0M, FY01-$12.0M

Description, Objectives, and Performers. Power conditioning for motor controllers, chargers, and other interface electronics is a key enabling technology for hybrid electric vehicles.

Development of electronic components and systems for vehicle applications has progressed from replacing mechanical systems to making features available that can only be realized through interactive controls and devices. Currently, the application of power electronics in conventional vehicles is aimed at integrated powertrain controls, integrated chassis system controls, multiplexing, and navigational and communications systems. In addition to these requirements for conventional vehicles, hybrid vehicle electric powertrains will require control devices with faster semiconductor chip operation, higher power density, and more power dissipation per device.

Electric machines in use today are typically driven by induction motors, which are inherently difficult to optimize for power and efficiency. Replacing them with permanent-magnet, switched-reluctance, or other advanced machines will result in lighter weight, more cost-effective systems with higher efficiency and power density needed for hybrid electric vehicles. Research and development is therefore needed to produce power electronics and electric machines for automotive applications that are efficiently packaged, lightweight, low-cost, and reliable.

R&D Challenges. The primary barriers include: (1) Cost - materials, processing, and fabrication technologies for both power electronics and electric machinery are too expensive (by factors of 3 to 4) for automotive applications; (2) Volume - power electronics and electric machines are too large for automotive use; (3) Weight - electric machinery and power electronic controllers are too heavy and the extra component weight requires additional structural mass; and (4) Reliability and Durability - controllers have not been developed that meet 150,000 mile vehicle lifetime targets and existing electric machinery is not sufficiently rugged to operate in an automotive environment.

R&D Activities. For power electronics, OAAT is focused on developing technologies for automotive integrated power modules (AIPM) suitable for automotive applications. Baseline requirements for automotive controllers incorporating this power module architecture have been developed through close coordination with Chrysler, Ford, and General Motors. Additionally, OAAT is supporting development in the industry with the competitive award of 2 contracts at $10 million each to develop AIPM. OAAT work in this area is leveraged through an interagency agreement with the Office of Naval Research to jointly develop Power Electronic Building Blocks for use in automotive as well as military applications. The government-funded component development and testing is primarily being performed by DOE National Laboratories and U.S. Navy laboratories. In the electric machines area, OAAT is also supporting research to develop advanced technologies. Presently, industrial development is focused on induction motors, but weight, volume, efficiency, and cost goals are more likely to be met by switched-reluctance or permanent-magnet technologies if the existing technical barriers are resolved. OAAT plans for a similar solicitation effort to aid industry development of electric machinery for traction drives. A specification has been developed in a coordinated effort with Ford, GM, and Chrysler for traction drives. OAAT is also supporting laboratory R&D to improve materials useful in attaining the PNGV goals for power electronics and electric machinery.

Accomplishments. Program accomplishments include:

- Developed novel inverter topologies capable of meeting size, weight, reliability, and performance requirements for PNGV.
- Developed dc-dc converters with enhanced performance, size, and weight necessary in fuel-cell powered vehicles.
- Initiated fabrication and testing of advanced carbon foam heat sinks for thermal management of power electronics, with an increase in effective heat transfer by up to 4 orders of magnitude, a factor of 10 reduction in heat exchanger volume, and 20 to 25 percent of the cost reduction necessary to meet the target of $7/kW for the power electronics.

Electric Vehicle Batteries

Budget: FY99-$8.7M, FY00-$9.0M, FY01-$9.7M

Description, Objectives, and Performers. The California zero-emission vehicle requirements formulated in 1990, strengthened the interest of the auto industry in developing and introducing electric vehicles (EVs) into the automotive market. The key to market success of EVs has always been battery technology. Vehicle range is limited by battery performance, and battery cost remains high. For the past eight years, DOE's EV battery research and development has been conducted under a cooperative agreement with the USABC. Currently, research is directed toward completing the nickel-metal hydride technology (that doubles the range of EVs) and the lithium-ion technology, as the most promising mid-term technologies, and toward the lithium polymer technology for the long term.

R&D Challenges. While the technical barriers are specific to the type of battery being developed for electric vehicle application, the general areas are similar, and include for the long-term lithium-polymer battery: power density (which needs to be improved from 250 to 450 W/l), specific power (targeted at 300 W/kg versus the current 200), energy density (which needs to reach 195 Wh/l compared to the present 110) and specific energy (from the current 75 Wh/kg to a goal of 135). Cost, safety, recycling/disposal, and manufacturability are also barriers.

R&D Activities. The development of advanced batteries involves battery developers and suppliers, small businesses, National Laboratories, and universities. These activities are coordinated by DOE through the EV Battery Exploratory Technology Research Program and by USABC through its Technical Advisory Committee. Key barriers (and attendant research) for lithium batteries are large cell safety, overcharge damage, electrolyte oxidation, and cathode limitations. The technical barriers requiring research for the development of the lithium polymer battery include material degradation, electrode and electrolyte performance, projected battery performance and cost, thermal and electrical management, safety, disposal, and manufacturability.

Accomplishments. Program accomplishments include:

- Demonstrated 500 cycles for the lithium-polymer battery at the electrochemical cell level.

- Nickel-metal hydride battery packs, provided by two separate developers, are currently powering electric vehicles in introductory market programs.

Systems Development

Budget: FY99-$24.4M, FY00-$16.6M, FY01-$16.8M

Description, Objectives, and Performers. Systems development provides the focus and guidance for the OAAT vehicle systems research and development activities. Work in this area provides development and validation of required propulsion subsystem technologies; validation of vehicle system component and subsystem technologies in the context of a vehicle operating environment; feedback to enhance predictive models; and validation at the vehicle level of the achievement of objectives.

In this context, the systems development objectives are:

- By 1998, develop and validate production-feasible propulsion subsystem technologies that will enable the achievement of 50 mpg in test-bed six-passenger sedans that meet EPA Tier 2 emissions requirements, and retain all the attributes of comparable competitive production vehicles.

- By 2004, develop and validate propulsion subsystem technologies and validate technologies that will enable the achievement of 80 mpg in test-bed six-passenger sedans that retain all the attributes of comparable competitive vehicles, including emissions controls.

- By 2011, develop and validate production-feasible vehicle subsystem technologies that will enable the achievement of 100 mpg in test-bed six-passenger sedans emphasizing non-petroleum-based fuels and zero emissions, and which retain all the attributes and features of competitive vehicles.

The 1998 objective has already been met. In October 1999, Ford delivered a vehicle (P2000) which met the fuel economy goal of 50 mpg and the default Tier 2 emissions requirements (those standards which were included in the 1990 Clean Air Act Amendments as possible emission goals). Research targets are being revised and resources reallocated to address EPA's final Tier 2 emission standards.

The P2000 sedan is not being produced, but it incorporates technologies that "enable" it to meet the 50 mpg goal. Similarly the objectives for 2004 and 2011 focus on the development of "enabling" technologies which the auto industry may chose to include, or not, in their final products. As evidenced by the Year 2000 North American International Auto Show, each auto company is likely to use distinct mixes of the technologies developed through government-sponsored research as well as those developed internally.

R&D Challenges. The technical barriers are defined for the engine/power sources, materials, and fuels programs. In the systems development program, the technologies produced in the other programs are brought together as a system, i.e., into a testbed vehicle or propulsion system in the laboratory.

R&D Activities. To overcome the technical barriers, technology requirements were first defined. Requirements were developed through coordination with industry and derived from a common vehicle systems perspective. A vehicle system computer modeling capability (ADVISOR) was developed in the first phase of the program. The propulsion subsystem performance models embedded within the vehicle system models are being validated and refined using data generated by the test and evaluation activities of both the Hybrid Program (50/50 cost-shared contracts with Chrysler, Ford, and General Motors) and the vehicles developed in the advanced vehicle competitions by a number of university engineering schools. Technology validation will occur within a total vehicle systems context. This activity can involve either actual testing and evaluation of technology-representative point designs in complete test-bed vehicles or simulation of the operation of such point designs using subsystem/component models embedded in a total automobile system model.

Accomplishments. Program accomplishments include:

- Completed the validation of the hybrid vehicle ADVISOR model against data from the four existing university-developed hybrid vehicles from the Advanced Vehicle Competition.

- Ford Motor Company developed, and delivered to DOE, the P2000 LSR (low storage requirement) hybrid vehicle employing advanced automotive technologies to achieve fuel economy of more than 60 miles per gallon.

- Completed development and testing of 50 mpg hybrid propulsion systems for mid-size vehicles, and continued technology development and integration activities aimed at 80 mpg vehicles.

- Concluded in 1998, the GM hybrid propulsion development program demonstrated the achievement of a Stirling-powered series hybrid configuration in a mid-size Chevrolet Lumina. Because of its series hybrid configuration, the vehicle also demonstrated a zero emissions capability for errands and short commutes. Compared to prior technologies, substantial improvements were achieved in developing affordable battery packs specifically designed for hybrid vehicles, and reducing the cost of the electric motor and the complexity of the motor's power electronics, as well as improving thermal control for the battery pack.

- A major success for the Chrysler hybrid propulsion development program in FY 1998 was the rapid design, development, and testing of the first generation parallel hybrid propulsion configuration. The program began in March 1996, and in just over 18 months succeeded in demonstrating a production based test-bed vehicle and an advanced lightweight concept vehicle, the ESX-2. The concept vehicle is an operational parallel hybrid system using an advanced three cylinder diesel engine. Both vehicles are paving the way for Chrysler's 2^{nd} generation of hybrids that will address issues of manufacturing, cost, weight, accessory power requirements, emissions, durability, and reliability. Initial tests show the fuel economy and emissions targets will be exceeded.

- Launched the CARAT program which provides small businesses and universities an opportunity to solve critical technology barriers as part of the PNGV. Received 133 competitive proposals and have awarded 26 Phase 1 CARAT cooperative agreements.

- A unique university program was initiated with ten schools developing curricula in five advanced technology areas include: fuel cells, advanced energy storage, lightweight and propulsion materials, direct injection engines, and hybrid electric drivetrain and control systems. Approximately 40 GATE fellowships were awarded at these universities.

Advanced Materials

Budget: FY99-$22.3M, FY00-$22.0M, FY01-$21.0M

Description, Objectives, and Performers. The advanced materials research conducted by OAAT has two closely coordinated elements. The first is propulsion subsystem materials, which is focused on developing materials for propulsion components and subsystems to facilitate higher efficiencies, lower emissions, improved alternative fuel capabilities, and lower specific weight and volume, without compromising other factors such as cost, safety, and reliability. Research activities in this area are defined under the appropriate engine/power source. The other research element encompasses lightweight vehicle systems materials, where reduction of body and chassis weight is the focus of the research activities. Both the propulsion subsystem materials work and the lightweight vehicle system materials research are closely coordinated with materials R&D for heavy vehicle technologies.

The major goals in the lightweight vehicle systems materials area are to develop and validate cost-effective lightweight material technologies that could significantly reduce vehicle weight without compromising vehicle cost, performance, safety, or recyclability. Research objectives include:

- A 25 percent reduction in the weight of the body and chassis by 2000.

- A 50 percent reduction in the weight of body and chassis components contributing to a 40 percent reduction in vehicle weight by 2004.

- A 60 percent reduction in the weight of body and chassis components, necessary to achieve 100 mpg fuel economy, by 2011.

R&D Challenges. Cost is the single greatest barrier to the use of lightweight materials in automotive applications. In terms of life-cycle cost, aluminum is about 50 percent (or less) as expensive as steel and polymer composites are 3 times (or less) as costly. Methods for high-volume production of automotive components from lightweight materials have not been adequately developed, and design data and test methodologies are inadequate. High-volume, high-yield joining technologies for lightweight and dissimilar materials do not exist. Technologies for cost-effective recycling and repair of advanced materials are lacking.

R&D Activities. The DOE research is focused on specific classes of materials using representative, nonproprietary components. As technical barriers are removed, the technologies are made available for industry to take in-house to perform proprietary, application-specific research. The technology development areas and individual projects have been identified through workshops, white papers, planning studies, and assessments. The lightweight materials of interest include aluminum, magnesium, titanium, and carbon-fiber and metal matrix composites.

Accomplishments. Program accomplishments include:

- Demonstrated a four-minute cycle time for glass-fiber preforms to enable high-volume production of glass-reinforced composite automotive components.

- Developed test methodologies for characterizing the Mode II response of adhesive bonding joints for automotive applications. Standardized test procedures and fracture-based guidelines were developed and have been transferred to industry.

- Demonstrated the technical feasibility of producing carbon fiber using microwave radiation with significantly reduced processing times and costs.

- Demonstrated new processing technology for the fabrication of pump components using particulate reinforced aluminum alloys, resulting in weight savings and improved performance.

- Developed non-heat treatable aluminum sheet with yield strength exceeding 35,000 psi.

- Developed lightweight carbon composite bipolar plate materials in the laboratory that meet fuel cell requirements, and transferred a material recipe and manufacturing process to industry for scale-up.

- Demonstrated low-cost casting methods to produce structural light metal castings for automotive applications.

- Completed development of the process for casting ultra-large vehicular components; cast prototypes for laboratory testing and evaluation by original equipment manufacturers; field tested qualified components under service conditions.

- Extended the successful development of metal compression forming, for solid solution and precipitation-hardenable aluminum alloys, to metal matrix composites and magnesium alloys.

Fuels Utilization

Budget: FY99-$6.3M, FY00-$7.0M, FY01-$8.0M

Description, Objectives, and Performers. DOE supports fuel R&D in two major areas: (1) alternative fuels for conventional engines, and (2) fuels for advanced engines in support of the PNGV program. Alternative (i.e., non-petroleum) fuels have the potential to displace significant amounts of petroleum, providing energy security benefits, and reduced emissions. Alternative fuels are at varying stages of development for use in vehicle engines, and the additional research needed to increase their viability for conventional vehicles varies accordingly. Research is also being conducted to address the potential of new fuels to ensure compliance with emissions regulations in high-efficiency advanced engines. Fuel composition changes may facilitate the effective use of aftertreatment/cleanup devices and enable advanced engines to minimize emissions while maximizing fuel economy objectives.

R&D Challenges. *Compressed Natural Gas (CNG):* The most critical barrier to retail consumer acceptance of the CNG vehicle is the high initial vehicle cost, due primarily to the high fuel tank cost. In addition, refueling infrastructure expansion is hindered due to the high cost of compressors and auxiliary equipment, resulting in CNG fueling stations that cost five times as much as gasoline stations. The third technical barrier is limited vehicle range (about half that of conventional vehicles) due to the mass and volume of the on-board gas storage tanks.

Ethanol: This renewable fuel has the potential to displace imported oil and reduce the transportation sector’s contribution to criteria pollutants and greenhouse gases. The current ethanol R&D needed for long-term biomass production is described in the Producing Clean Fuels chapter of this document.

Dimethyl Ether (DME): Although not currently used as a transportation fuel, dimethyl ether is being considered because of its high cetane number and inherently low particulate emissions, which make it attractive for high-efficiency compression-ignition engines. The principal technical barriers for DME exist because its supporting fuel systems (fuel storage, fuel delivery/injection) are in a very preliminary design stage; therefore the costs, reliability, durability, and safety are not known. Further, large-scale production, distribution, and refueling infrastructures do not exist.

R&D Activities. For CNG, several interrelated tasks will develop lower-cost, lighter-weight materials for the different types of CNG storage tanks and integrate these improvements into acceptable vehicle storage systems. The cost and reliability of fueling stations will be improved through compressor and auxiliary component technology development, with an emphasis on materials and design concept refinements. Vehicle range will also be addressed through improvements to achieve a high-efficiency engine. Research into the use of dimethyl ether will require development of fuel storage, fuel delivery, and fuel injection systems. Fuel infrastructure issues will also be evaluated.

In the future, the Fuels Utilization program for light duty vehicles and trucks will increase focus on development and evaluation of advanced petroleum based fuels to be used in direct injection engines and fuel cells. A major concern for these advanced engines is to be able to meet future emission requirements and efficiency goals. It will be necessary to work with energy and automotive companies to develop fuels that will meet these goals and that can be effectively introduced into the market. Testing of various fuels with advanced direct injection engines is underway. Future programs will evaluate the effect of oxygenates as an additive to diesel fuel to help with reducing particulate matter (PM) emissions, analysis of PM with regard to toxicity, and determining the impact that lubrication oil has on the formation of PM in the exhaust. Fuels for fuel cells will also be a major part of the program. Projects to identify major contaminants in advanced petroleum based fuels and their impact on fuel cell performance is underway. The tolerance level of these contaminants will be determined in future programs. In addition, testing of fuels in fuel processors to optimize the use of fuel constituents will be started.

Accomplishments. Program accomplishments include:

- Completed tests on 7 fuels (DMM [dimethoxymethane], Fischer-Tropsch neat, Fischer-Tropsch 20, biodiesel, EPA-2D, CARB diesel, regular diesel) in an advanced direct injection, diesel engine, aimed at determining emission effects. Positive effects were observed on particulate emissions with up to 50 percent reduction gained from DMM blended with low-sulfur diesel.

- Completed test and evaluation of an advanced compression-ignition direct-injection (CIDI) engine, representative of PNGV size, using conventional fuels blended with alternative fuels to reduce NOx and particulate emissions.

- Completed development of a prototype fuel injection system for an automotive application using DME.

- Demonstrated the Generation I integrated storage system (ISS), utilizing lower-cost, lighter-weight, Type II compressed natural gas tanks.

- The second annual Ethanol Vehicle Challenge in 1999, involving 14 U.S. and Canadian engineering schools, demonstrated 30 percent better fuel economy than gasoline pickups or exceeded EPA's Low Emission Vehicle standards. The ethanol-powered trucks also out-performed conventional trucks in the acceleration and hill climbing events. .

- Thirteen U.S. and Canadian engineering schools participated in the fourth and final FutureCar Challenge (with vehicle goals similar to those in the PNGV program). The highest on-road efficiency was 63 mpg. with a diesel hybrid propulsion system. Another school successfully demonstrated a fuel cell in a passenger car and scored first in emissions.

High-Efficiency Heavy Trucks

Budget: FY99-$30.7M, FY00-$50.2M, FY01-$55.0M

Background

The health and continued growth of the U.S. economy are dependent on maintaining the energy security and profitability of the trucking industry, now and into the foreseeable future. Trucks are the mainstay for trade/commerce and economic growth. The gross domestic product (GDP), and hence, economic activity, is linked to freight transport. Total highway freight transportation expenditures (local and intercity trucks) were over $348 billion, accounting for 79 percent of the Nation's freight bill and approximately 4.8 percent of the GDP (1995). Meeting energy demand for movement of goods is, therefore, critical to the economy.

Linkage to CNES Goals and Objectives

Three goals for heavy truck technology have been established according to truck class because of the vastly different use patterns across the weight classes.

(1) Develop by 2004, the enabling technologies for a Class 7 & 8 truck with a fuel efficiency of 10 mpg (at 65 mph) which will meet prevailing emission standards.

(2) For class 3-6 trucks operating on an urban driving cycle, develop by 2004 commercially viable vehicles that achieve at least double the fuel economy of comparable current vehicles (1999), and as a research goal, reduce criteria pollutants to 30% below EPA standards.

(3) Develop by 2004 the diesel engine enabling technologies to support large-scale industry dieselization of Class 1 & 2 trucks, achieving a 35% fuel efficiency improvement over comparable gasoline-fueled trucks, while meeting applicable emissions standards.

This effort supports objectives contained in three of the five CNES goals:

- CNES Goal I, Objective 2 - Significantly increase the energy efficiency in transportation, industrial, and buildings sectors by 2010. *(developing more efficient transportation technologies)*

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply. *(helping reduce the consumption of petroleum)*

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(pursuing research aimed at major improvements in vehicle efficiency resulting in major reductions in greenhouse gases)*

Program Description

Research and development plans developed by OTT's Office of Heavy Vehicle Technologies (OHVT) were extensively reviewed by industry partners (truck manufacturers, diesel engine manufacturers, and their suppliers), fuel suppliers, other DOE organizations, other Federal agencies, National Laboratories, and other Federal research centers. The OHVT plans and programs were reviewed by an independent industry/government peer review panel and will undergo National Research Council review during 1999. Consequently, the research activities described in this portfolio are the result of rigorous planning processes and can be referenced in the OHVT Technology Roadmap and in the Multi-Year Program Plan. Research and development for the Office of Heavy Vehicle Technologies is carried out largely in cooperative programs between the DOE laboratories and industry, by universities, and by independent research institutions.

The High Efficiency Heavy Truck efforts can be grouped into four major categories:

Heat Engine R&D

Budget: FY99-$3.5M, FY00-$8.1M, FY01-$12.0M

Description, Objectives, and Performers. Heavy trucks rank closely behind passenger cars and light trucks in the Nation's annual fuel utilization. Their relatively high fuel consumption per vehicle provides an incentive to utilize more efficient technology as it becomes available, even in times of low fuel prices. Engine R&D for heavy vehicles focuses on advancements in fuel economy for petroleum savings and on emissions control technology to maintain compliance with increasingly stringent regulations. Mainstream R&D activities in engine technology are carried out in cooperative agreements with the major domestic engine manufacturers, with enabling technology R&D conducted in the National Laboratories. Targeted engine efficiency is 55 percent or higher, with the direct-injection diesel engine being the incumbent, and still most viable candidate, for highway truck applications. Engine efficiency improvement is a major contributor to overall goals of increasing class 7-8 truck fuel economy from nominally 7.5 mpg to over 10 mpg at 65 mph. Innovative and improved designs for higher cylinder pressures, improved exhaust heat utilization, and lower engine friction are key aspects of the technology roadmap. Emissions control R&D emphasizes a three-pronged approach: combustion systems, aftertreatment, and fuel formulation. Engine compatibility and optimization for non-petroleum diesel fuels is an additional objective to augment petroleum savings. These efforts are shared and coordinated with the fuels R&D projects in heavy vehicles.

R&D Challenges. Best current engines have efficiencies of nominally 46 percent. In order to achieve the fuel economy targets for heavy trucks, engine efficiency must be on the order of 55 percent or higher, requiring a 20 percent advancement. Improvements, focused on the direct injection, "diesel-cycle" engine, are needed in a number of integrated technology areas including increased peak cylinder pressure, additional exhaust heat recovery through improved turbo systems, improved thermal management, less heat rejection, reduced parasitic friction loss, and improved combustion.

The greatest barrier for this high efficiency engine class is emission control, particularly NO_x and particulate matter (PM). Emissions reduction requires a systematic approach encompassing three areas of activity: (1) in-cylinder processes (combustion, air handling), (2) exhaust aftertreatment, and (3) fuels properties.

Success is dependent on advancements in basic engine design, in key subsystems such as turbocharging and fuel injection, and in supporting technologies like materials.

R&D Activities. Tasks are in progress to improve fuel injection systems, along with more fundamental research to improve the understanding of key parameters of the in-cylinder processes. New models of how NO_x and particulates form in engines have been developed. Research and development on exhaust aftertreatment includes particulate filters, NO_x catalysts, and plasma systems, plus improvement in the measurement and analysis tools needed to accurately determine what compounds the devices are reducing and what byproducts they may be producing.

Accomplishments. Program accomplishments include:

- A new type of particulate filter has been developed through the prototype stage.
- Small prototypes of NO_x catalysts have exceeded 50 percent reduction of NO_x and non-thermal plasmas devices have exceeded 70 percent reduction on a small scale.
- Developed zeolite-based lean NOx catalysts which achieved greater than 90% conversion efficiency in laboratory bench tests.
- To date, engine efficiency of approximately 52 percent has been achieved in test engines, compared to 44 percent in production engines when the program began, and 46 percent today.
- The program has assisted manufacturers in reducing NO_x emissions by over 50 percent and PM by over 80 percent in production engines.
- New prototypes of diesel engines for sport utility vehicles have been built and are undergoing evaluation in test cells as well as in vehicles. Fuel economy improvements are expected to exceed 50 percent compared to gasoline engines.

Systems Development

Budget: FY99-$1.5M, FY00-$7.0M, FY01-$9.0M

Description, Objectives, and Performers. For class 7-8 highway trucks, systems R&D encompasses the reduction of aerodynamic drag and rolling resistance in heavy trucks, as well as reduction of parasitic losses related to auxiliaries and operating modes. In order to achieve the truck fuel economy goals, for example, aerodynamic drag coefficients will need to be lowered from today's typical value of 0.60 to less than 0.50. The challenge is to make the cab and trailer modifications cost effective, while not hindering maintenance, reducing payload, nor violating regulations that govern the overall size of the unit. A detailed plan on aerodynamic drag has been developed with industry participation, and a similar activity is underway on rolling resistance. One part of the aero effort will be to advance the computational tools used for cab/trailer development. In particular the trailer has received much less attention in aerodynamic development. It will be the focus of near-term analysis using existing computational tools.

R&D Challenges. The trucking industry is reluctant to accept new technology unless it meets all State and Federal regulatory standards, standard trucking practices, and the return on the investment is realized within 2 years.

R&D Activities. DOE is fostering a proof-of-principle project to reduce truck idling that can save up to 3 billion gallons of fuel per year (reducing petroleum consumption by nearly 200,000 barrels per day). Several industry firms have agreed to make cab heater/cooler units available to truck operators who will record data on time in use and fuel consumed. The data will be disseminated in order to encourage the use of the devices. A substantial improvement in local air quality could also result.

For class 6 and lighter trucks (urban delivery trucks), the primary focus in systems R&D is on hybrid-electric technology. In a conventional vehicle powered by an internal combustion engine, the engine must deliver short bursts of high power for acceleration and also long duration steady-state power at lower levels for constant speed highway cruising. The variability in power requirement causes vehicle manufacturers to provide engines that are sized to meet the maximum power requirement. These "oversized" engines are less fuel efficient at low loads and idling and they produce higher emissions. Also, in conventional vehicles, mechanical friction braking is used to slow the vehicle when necessary, resulting in the conversion of kinetic energy into heat.

The use of a hybrid electric propulsion system allows the vehicle to have a smaller prime power source that can be optimized for efficient, clean operation while the hybrid system can still meet the high power requirements for acceleration. Also, regenerative braking can be easily incorporated into the hybrid system. Hybrid electric propulsion systems are ideally suited for use where the power demand is non-constant, such as in city driving where frequent starts and stops are required. The hybrid electric propulsion system is a natural replacement for the gasoline engine in medium duty urban delivery trucks. The attainment of a fully cost-effective technology is one of the hybrid's greatest challenges. Hybrid systems are being developed in the PNGV program for cars, and these systems should be applicable to light trucks.

Accomplishments. Program accomplishments include:

- A detailed R&D plan on heavy vehicle aerodynamic drag has been developed with industry. Efforts are started to improve computational tools for aerodynamic design of the tractor/trailer.

- Initiated active projects in the computational simulation and manipulation of air flow fields which create the energy-consuming aerodynamic drag of heavy vehicles.

- Initiated programs for reducing heavy vehicle energy consumption due to rolling resistance, onboard thermal management, and auxiliary power systems.

- Developed a joing program with DOE to determine safety impacts to the truck system by changes adopted to achieve operational energy efficiencies.

- A program has been started to compile data on the fuel savings from use of truck cab heaters/coolers to avoid truck idling. The continued outreach of the data is expected to promote the use of these fuel-saving devices.

Advanced Materials

Budget: FY99-$14.6M, FY00-$20.5M, FY01-$17.5M

The major program elements in heavy truck advanced materials are (1) propulsion system materials, (2) high strength weight reduction materials, and (3) the High Temperature Materials Laboratory.

Propulsion System Materials

Description, Objectives, and Performers. The purpose of the Heavy Vehicle Propulsion System Materials Program is to develop enabling materials technology to support fuel flexible low emission, high efficiency diesel engines for medium and heavy duty trucks.

The design of advanced components for high efficiency diesel engines has, in many cases, pushed the performance envelope for engine materials past the point of reliable operation. Higher mechanical and tribological stresses and higher temperatures of advanced designs limit the engine designer. Advanced materials allow the design of components that may operate reliably at higher stresses and temperatures, thus enabling more efficient engine designs. Advanced materials also offer the opportunity to improve emissions, noise, vibration, harshness (NVH), and performance of diesel engines for pickup trucks, vans, and sport utility vehicles.

R&D Challenges. Component cost and reliable cost-effective processes and manufacturing procedures for advanced materials present substantial barriers to their commercialization.

R&D Activities. New forms of materials, such as nanophase structures in both metals, ceramics, and alloys in the amorphous condition, are being investigated to determine if their unique properties such as high hardness, strength, corrosion resistance, and low coefficient of friction can stand up to the rigors of the new power plants.

Accomplishments. Program accomplishments include:

- Developed cost-effective technologies to manufacture thick thermal barrier coated pistons for the 55 percent efficient (LE-55) engine to enable use of lower cost alloys for pistons and demonstrated over 2,000 hours durability.

- Demonstrated an intelligent grinding process for ceramic engine components; demonstrated manufacturing of products such as valves and fuel injector components with this process.

- Development and commercialization of scuff-resistant ceramic components for Cummins Engine Company fuel injectors that allow Cummins to meet EPA standards for particulate emissions.

- Successful development and testing of durable ceramic valves for a Detroit Diesel Corporation heavy duty engine.

High Strength Weight Reduction Materials

Description, Objectives, and Performers. The objective of the High Strength Weight Reduction Materials Program is to develop advanced materials and materials processing technologies leading to reductions in vehicle weight that enable heavy vehicles (trucks and buses) to be more energy efficient. The focus is on body and chassis components which are light weight while still meeting performance requirements in a cost effective way. Weight reductions will be achieved through the increased use of improved conventional materials and new, advanced materials and by developing low-cost, high volume manufacturing processes. When implemented, these materials technologies will reduce the weight of unloaded heavy duty tractor-trailer units by 20-30 percent, resulting in 10-18 percent reduction in fuel use and emissions. These goals are achieved through partnerships between government laboratories, industry, and universities.

R&D Challenges. High costs and component reliability and durability are major issues in the commercial truck market.

R&D Activities. Development of the technology to cast ultra-large aluminum components; application of metal compression forming to produce high integrity structural cast aluminum components; and the development of metal matrix composites are other avenues of attention for heavy vehicles.

Accomplishments. Program accomplishments include:

- Design of all major components of the Ultra-large Casting System including primary and holding furnaces, press, mold system, and caster cell was completed and fabrication of a major component is nearing completion. Installation and initial trials are scheduled for early FY 1999. Successful development will result in low-cost, high-volume production of single large components, thereby reducing the number of parts and corresponding assembly steps.

- Demonstrated a new casting process for aluminum alloys and metal matrix composites (MMC) which will enable the substitution of low cost cast components with significantly less weight than cast iron components while offering considerable cost savings over forged aluminum components.

High Temperature Materials Laboratory

Description, Objectives, and Performers. The High Temperature Materials Laboratory (HTML) is a national user facility, offering opportunities for American industries, universities, and other Federal agencies to perform in-depth characterization of advanced materials under the auspices of its User Program. Available are electron microscopy for microstructural and microchemical analysis, equipment for measurement of the thermophysical and mechanical properties of materials to elevated temperatures, x-ray and neutron diffraction for structure and residual stress analysis, high speed grinding machines, and measurement of component shape, tolerances, surface finish, and friction and wear properties.

The User Program began in 1987, and has expanded over the intervening years from a few user projects per year to a current range of 80 to 110 project per year. In the eleven years between 1987 and 1998, a total of 819 projects were performed, with users from several hundred industries, colleges and universities, and other Federal agencies. The HTML focuses on materials for transportation, especially structural materials, with work being performed on engine and fuel system materials, chassis materials, and brake system materials. Cummins Engine Company, Detroit Diesel Corporation, and Caterpillar Inc. are frequent users. HTML also supports their suppliers, and especially catalyst materials developers and suppliers, since catalysts will play such an important role in the success of diesels in the future. Automobile manufacturers similarly work with HTML, especially Ford Motor Company. Projects involving non-transportation research are also undertaken at HTML, as long as they have a relationship to energy efficiency or renewable energy.

R&D Challenges. The HTML attempts to resolve materials issues at the atomic level. The primary barrier to that approach is the capability of the available equipment to provide adequate analysis.

R&D Activities. This year, HTML researchers and users spent considerable effort on characterization of catalyst materials, including use of transmission electron microscopy to evaluate several-atom clusters of Os species on substrates, and novel catalysts from Ford Motor Company. Much of the catalyst examination was performed via remote microscopy, wherein the user simply logs onto the HTML computer controlling the microscope and runs it from his/her home institution. This process is extremely cost-effective, avoiding the expenditure of both the user's travel time and money. Research was also directed at development of advanced materials for diesel engine fuel injection systems.

Accomplishments. Program accomplishments include:

- In an on-going HTML User project with Ford Research Laboratory, conducted via remote microscopy, Dr. C. K. Narula used the Hitachi HF-2000 transmission electron microscope to study experimental catalysts comprising Pt clusters on alumina, titania, and mixed Al-Ti oxide support materials.

- A basic catalyst research HTML user project has been initiated with Professor Bruce Gates and his students at the University of California at Davis. Professor Gates is preparing and studying catalysts comprising clusters of heavy atom species on a variety of substrates.

- Several Cooperative Research and Development Agreements (CRADAs) are now underway with major U.S. diesel engine manufacturers to apply the unique capabilities of the HTML to specific materials problems.

Fuels Utilization

Budget: FY99-$11.0M, FY00-$14.6M, FY01-$16.5M

Description, Objectives, and Performers. DOE has both near term and long range objectives and efforts in fuel utilization. For class 7-8 trucks, the most viable alternative substitute fuel in the near term is liquefied natural gas (LNG). Several LNG trucks are undergoing field trials, and have demonstrated NO_x and PM levels over 80 percent lower than similar vehicles operating on standard diesel fuel. A challenge remains to elevate the efficiency and power of the natural gas engines closer to that of the diesel engines they replace.

Natural gas engines, because of their demonstrated low PM and NO_x, are particularly attractive for urban delivery vehicles in class 3-6 trucks. These vehicles provide an excellent application for natural gas since most are operated as fleets with central refueling. Natural gas engines in class 3-6 need significant improvements in part-load efficiency since they normally operate with a lighter load factor than larger highway trucks. Urban delivery vehicles are prime targets for hybrid vehicle technology with the potential for up to 3 times today's fuel economy. Hybrid vehicles, for lowest emissions, will need a natural gas engine designed especially for the hybrid system.

R&D Challenges. Cost - the industry is reluctant to accept any new engine/fuel system which is not clearly cost attractive; Infrastructure - unavailability of an adequate number of fueling stations is a significant barrier to widespread use of alternative fuels; Operation, Maintenance and Reliability - the diesel engine is noted for its reliability and durability, and the industry is cautious about use of new fuels and engines due to concerns that reduced reliability will adversely impact operations.

R&D Activities. To meet this challenge, DOE, the Gas Research Institute, and the South Coast Air Quality Management District have jointly instituted projects with major engine manufacturers. The project teams will work to make incremental improvements to today's natural gas engines to help maintain a market for the technology. The teams will also develop stretch technology like direct injection natural gas engines to achieve efficiency goals of up to 55 percent.

The program strategy includes research and development of natural gas storage to complement these engines. One specific project focuses on the development of onboard high pressure fuel delivery systems for direct natural gas fuel injectors. Other projects include testing of conformable tanks, developing smart tank technologies, developing low pressure storage, studies on natural gas storage for heavy vehicle market penetration, and demonstrating the advantages of LNG/CNG refueling. Performance measures for this activity are developing safe, reliable, cost efficient components for heavy vehicle fuels storage. Performance goals are as follows:

- Use conformable tanks to achieve 40 percent more onboard storage than conventional compressed gas cylinders.
- Reduce life cycle cost by 25 percent for natural gas storage for heavy vehicles.
- Increase hold times, reliability and reduce boil-off for LNG storage.
- Conserve 15 percent of the energy fuel value of natural gas by improving storage tank design, fuel delivery systems and fuel integration strategies.

The second major fuel thrust for heavy vehicles is alternate-feedstock liquid diesel fuels. Fuels with excellent qualities for high-efficiency compression ignition engines can be produced from biomass, natural gas, and in the long term, other vast resources such as coal and oil shale. These fuels have value in displacing petroleum consumption, and their typically low levels of sulfur and aromatic hydrocarbons, offer some inherent benefit for engine emissions. The low sulfur content may enable use of certain aftertreatment technologies (e.g. NO_x traps) for near-zero emissions. Oxygenated fuels such as biodiesel and dimethoxymethane are proven for lowering PM and are generally miscible with conventional diesel fuel. Even without optimizing an engine for the specific fuel, Fischer-Tropsch diesel fuel has been found to lower PM by over 30 percent. Most of these diesel-like fuels are also advantageous in being compatible with today's fuel distribution infrastructure.

Compression-ignition fuels can possess similar physical properties (density, viscosity) yet vary widely in chemical composition (aliphatic/aromatic ratio, oxygen content). Compression ignition engines also have particular design features depending on the manufacturer and application of the engine. Correlations relating fuel properties to engine efficiency and emissions are empirical and not very accurate, making the optimization of fuel and engine properties difficult. A two pronged approach has been initiated to remedy the situation and help fully exploit new fuels. First, research has been started to improve the fundamental understanding of the effects of fuel properties on emission formation. Optical access research engines and combustion vessels are being used to characterize how fuel properties affect spray and atomization, soot formation, and NO_x. For the present, we must continue to rely on test programs with experimental matrices of fuel parameters and engine designs. This program element is called the “Performance and Emissions Data Base for New Diesel Cycle Fuels,” and was planned with participation of the engine manufacturers as well as fuel producers.

In addition to improving the utilization of conventional and alternative fuels in a diesel cycle engine, the program includes activities to improve the understanding of the effects of diesel engine emissions on air quality and human health. This will largely be accomplished by (1) participation and support for studies of diesel emissions and their health effects, (2) identification of major air quality problems affected by fuel-related sources, (3) examination of emissions from heavy vehicles run on diesel, biodiesel, CNG, LPG, methanol, ethanol, and other fuels of interest, and (4) the study of the transport and fate of the pollutants and/or their precursors.

The Office of Transportation Technologies (OTT) is also collaborating with Fossil Energy and its Federal Energy Technology Center (FETC) to advance the development and deployment of cost competitive fossil-based replacement fuels. Four types of activities are being conducted under this collaboration: (1) production, characterization, and testing of Fischer-Tropsch diesel fuel and additives made from syngas for petroleum diesel blending; (2) small-scale, high-efficiency Liquified Natural Gas (LNG) production technology for remote site natural gas production and fleet LNG fuel production; (3) incorporation of renewable feed streams to refinery systems for carbon reduction; and (4) process economics to identify technical and market barriers for the deployment of replacement fuels additives. These activities are being coordinated by the OTT Fuels Crosscut Coordinating Team (FCCT).

Accomplishments. Program accomplishments include:

- Assisted industry in introducing and certifying alternative fuel heavy-duty engines in numerous applications. Includes natural gas engines for urban buses and alcohol-fueled engines for trucks and buses.

- Demonstrated 40% energy conversion efficiency in a heavy-duty engine operating on natural gas.

- Demonstrated LNG powered trucks with 80 percent less NO_x and PM than conventional diesel powered vehicles.

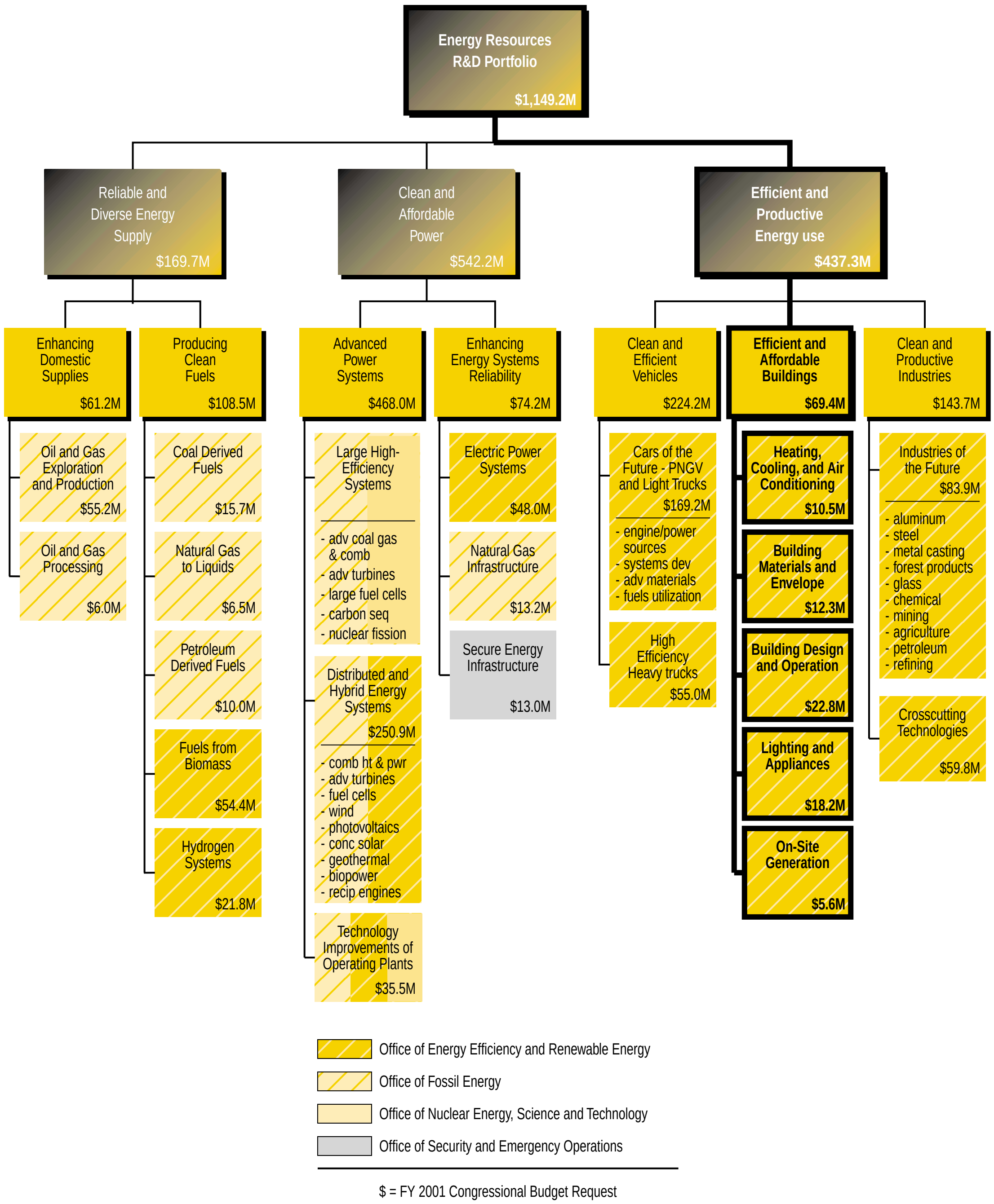
- Developed and demonstrated a multi-cylinder heavy duty diesel engine operational on M85 and diesel fuel interchangeably.

- Characterized the performance and emissions from diesel engines operating on advanced petroleum-like fuels such as biodiesel and Fischer-Tropsch diesel fuel.

Summary Budget Table (000$)

Clean and Efficient Vehicles Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Cars of the Future - PNGV and Light Trucks	**147,338**	**155,300**	**169,220**
Engine/Power Sources	94,320	109,700	123,420
- *Advanced Combustion Engine R&D*	*33,476*	*39,700*	*41,920*
- *Fuel Cells*	*32,909*	*37,000*	*41,500*
- *High-Power Batteries for Hybrid-Electric Vehicles*	*12,520*	*14,000*	*18,300*
- *Power Electronics and Electric Machines*	*6,751*	*10,000*	*12,000*
- *Electric Vehicle Batteries*	*8,664*	*9,000*	*9,700*
Systems Development	24,408	16,600	16,800
Advanced Materials	22,265	22,000	21,000
Fuels Utilization	6,345	7,000	8,000
High Efficiency Heavy Trucks	**30,679**	**50,200**	**55,000**
Heat Engine R&D	3,500	8,100	12,000
Systems Development	1,500	7,000	9,000
Advanced Materials	14,551	20,500	17,500
Fuels Utilization	11,128	14,600	16,500
Total	**178,017**	**205,500**	**224,220**

Chapter 8
Efficient and Affordable Buildings



Chapter 8

Efficient and Affordable Buildings

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Overview

Definition of Focus Area

The focus of the efficient and affordable buildings R&D portfolio is on buildings in both the residential and commercial sectors. Residential construction includes single-family, multi-family, and "industrial" (manufactured) housing. Commercial construction includes buildings used for commercial business such as offices, restaurants, hospitals, schools, warehouses, etc. Research and development (R&D) in the buildings sector ranges from improvements to the building shell (i.e., walls, windows, foundations) to improving the equipment used for heating and cooling the space or for providing building services like lighting and appliances, to methods of integrating all of these through "whole building" design techniques.

National Context and Drivers

The United States consumed roughly 94 quadrillion Btus (quads) of primary energy in 1996. The Nation's 100 million households and 4.6 million commercial buildings consume 36 percent or 34 quads of this total. Buildings also use two-thirds of all electricity generated nationally. More than $230 billion is spent each year in the United States to provide heating, cooling, lighting and related energy services for buildings. Even if the energy intensity of buildings remains constant, as more buildings are constructed, energy consumption and associated economic and environmental costs will continue to escalate. Energy consumption in buildings is a major cause of acid rain, smog, and greenhouse gas emissions in the United States, representing 35 percent of carbon dioxide emissions, 47 percent of sulfur dioxide emissions, and 22 percent of nitrogen oxide emissions.

One of the primary challenges to achieving efficiency in the building sector is its fragmentation. To start with, the building construction industry encompasses literally thousands of different businesses and millions of individual decision makers. Developers, designers, builders, utilities, engineers, and occupants pursue objectives which often are at cross-purposes. Also, unlike the transportation sector that is dominated by a few major firms responsible for final assembly and product delivery, the building sector has hundreds of thousands of builders who assemble individual components into complete structures. Furthermore, vast variability exists within the constructed structures themselves, so that even a single community might contain hundreds of building styles and sizes. One result of all this diversity is that product integration is less than optimal and buildings are typically designed and constructed as complex amalgamations of individual technologies, each of which carries out its intended function largely independent of (or even in spite of) others, rather than as a tightly integrated system of interrelated components. Inefficiencies and lost energy opportunities are frequent consequences of this situation.

Unfortunately, the number of decision makers that must be influenced and the effort required to pursue a change in the current predicament is high. The buildings sector is a risk-averse industry that has been slow to adopt new technologies that are more efficient than conventional ones. Although not a focus of this paper, Federal efforts in the buildings sector therefore also place a fair emphasis on activities that are designed to encourage the deployment of new energy efficiency technologies through education, training, and related efforts across the buildings community.

A third consequence of fragmentation is that the building industry spends relatively little on R&D. The industry is dominated by small firms that can ill afford research programs, and competition effectively prevents coordinated or integrated research. R&D expenditures for the buildings sector as a whole are an order of magnitude less than the national average. Given the importance of current energy consumption and projected growth in the buildings sector, maintaining and growing a vital research program for efficient buildings is critical to the success of the Department's overall strategic goal of increasing the efficiency and productivity of energy use.

Another significant element of the Department's R&D program is making homes more affordable for all Americans. Increased affordability is achieved by developing technologies and techniques which can either reduce the amount of energy used or improve the efficiency of its use in buildings at little or no net consumer cost. Such techniques are demonstrated, for example, by the Building America program which strives to increase a home's energy performance 50 percent over the Model Energy Code at little or no additional cost. The Building America program employs strategies such as improved design techniques that greatly reduce thermal leakage through the building envelope, or improved insulation and windows whose costs are offset by resulting reductions in the size of required space conditioning equipment. Other R&D efforts are focused on low-cost technology developments that offer sizable enough returns to justify their use within one or two years of implementation. One example is a thermal duct-sealing technology that can be used as part of the low-income Weatherization Program. This technology reduces leakage of thermal conditioning air by up to 30 percent and yet only costs a few hundred dollars to apply.

Linkage to CNES Goals and Objectives

The efficient and affordable buildings R&D portfolio directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.

DOE's portfolio emphasizes areas where the opportunity for cost-effective energy reductions are greatest, such as heating and cooling, lighting, and systems integration. DOE estimates that successful realization of its R&D portfolio will reduce buildings energy use by 0.6 quads per year in the year 2010, and by 2 quads per year in 2020.

Uncertainties

The present R&D portfolio is a mixture of near and longer term research efforts. All R&D entails some measure of risk in that not all efforts are likely to come to fruition in terms of achieving the ultimate goal. Risk increases as endeavors become longer-term. Technical problems, both known and unknown, may arise that are insurmountable with current know-how and are hence candidates for longer-term, investigative research. Spreading risk across such a portfolio increases the likelihood of technical success in at least some subset of the endeavors.

In the current context of the building marketplace, the ultimate goal is reducing energy consumption. However, even if technical capability is achieved, market barriers such as declining real energy prices or conservatism on the part of building designers or builders may still impede market penetration, hence reducing success in achieving this goal.

Finally, there must be sustained commitment with budgets sufficient to continue R&D at a minimum threshold to achieve any measure of success within a reasonable time frame. The minimum funding threshold for any given effort varies as to the program's technical goals, necessary time frame, number of related efforts elsewhere, number of participants, and other factors. Below that level, an R&D program essentially becomes a maintenance program where researchers can keep up with innovations being achieved elsewhere but are unable to achieve much success in their own endeavors. Uncertain or widely varying budgets from one year to the next have similar impacts as researchers and their invested experience move on to more consistent and reliably funded activities.

Investment Trends and Rationale

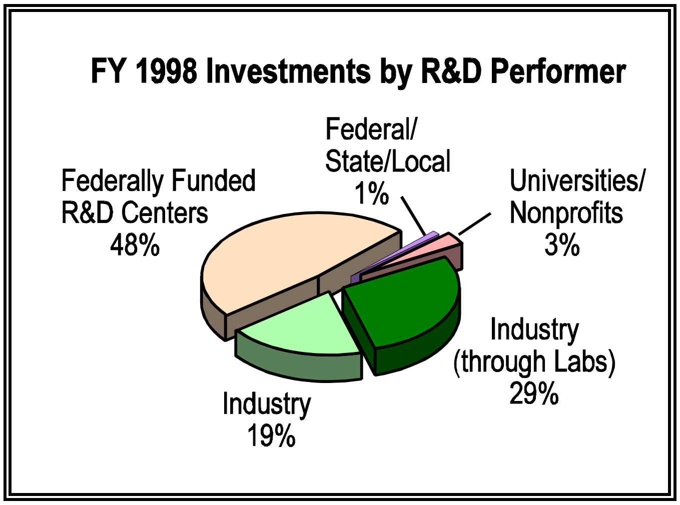
The current portfolio of investments is driven by both the energy use and market characteristics of the buildings sector. The Energy Information Administration (EIA) projects that the United States will add 28 million households and about 16 million square feet of commercial floor space between now and 2020. Once built, these homes and buildings will last 50 years or longer, so the impacts of buildings design, construction, and equipment decisions cast very long shadows into the future. Fully 30 percent of commercial floor space and 40 percent of all housing currently in use were built prior to 1960. Therefore, the portfolio must not only address new buildings, but existing buildings through retrofit and renovation.

The potential savings impacts to the Nation's projected energy use in buildings are great—the Department projects that from 10 to 30 percent savings are cost-effective in existing buildings and from 30 to 70 percent in new construction. These savings will not only be realized in consumer's pocketbooks but also in reduced environmental impacts of energy production and use.

This paper presents an overview of the R&D portfolio for the buildings sector. R&D areas include (1) Heating, Ventilation, and Air Conditioning; (2) Building Materials and Envelope; (3) Building Design and Operation; (4) Lighting; (5) Appliances; and (6) On-Site Generation.

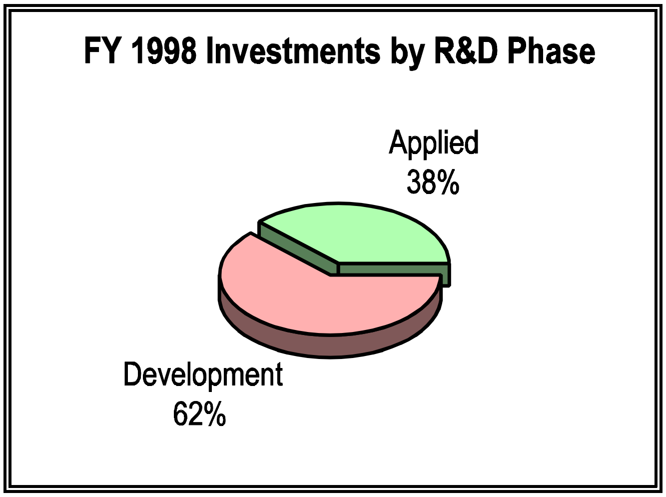
The first three areas target energy saving opportunities in heating, cooling, and ventilation, which account for 40 percent of building energy consumption on a primary basis. Areas 4 and 5 target the next largest areas of consumption. The final research area, On-site Generation, has the potential for addressing both electric and thermal needs of buildings.

As shown in the figure below (which is representative for the FY199-FY2001 period), the buildings R&D portfolio is performed by two main entities, with monies spread roughly equally between them. About half (48 percent) of the research is performed by the private sector, either funded directly or through DOE laboratories. An equal amount of research is performed by the DOE laboratories themselves. Only a minor amount of the Department's research is performed by universities (3 percent) or other government agencies (about 1 percent).



Cost-sharing with the private sector varies greatly among research programs, but typically averages between 50 to 75 cents of private contribution for each dollar of public expenditure. Much of this cost-sharing takes place through Cooperative Research and Development Agreements (CRADA) and other types of cooperative research through the National Laboratories, as highlighted in the figure below.[1]

[1] The breakout of research, development, and demonstration (RD&D) by performer is based on the FY 1995 budget. However, the performer mix has not changed greatly since that time.



The next figure illustrates the funding divisions between stages of research—development versus applied R&D ("buildings" R&D is by definition does not include basic research). For these purposes, development is defined as enhancements to the performance or operation of a product or practice, with an emphasis on commercialization. An example might be the independent and objective testing or evaluation of a completed system under various operating regimes. Applied R&D examines broader research issues, such as materials compatibility or corrosion.

As the figure shows, the bulk of Departmental research dollars are devoted to development with the balance spent on applied research. This division is consistent with the primarily near- and mid-term focus of the current research portfolio.

Future Trends in Investment. The buildings R&D portfolio is undergoing a fundamental change. In the spring of 1997, it was recognized, with Congressional concurrence, that there was a need for broader industry input, increased competition and less fragmentation, and greater focus in the portfolio. The Office of Building Technology, State, and Community programs (BTS), which manages the bulk of the Efficient and Affordable Buildings research done by the Department, initiated a strategic planning process that is realigning the research in this sector.

In concert with the recently released Strategic Plan, BTS has initiated an effort to bring stronger focus and relevancy to the buildings R&D portfolio. The plan establishes a new way of doing business:

- Stronger and more effective partnerships with industry, including jointly developed government-industry technology roadmaps that incorporate consumer and end-user perspectives.

- A culture of competitively selected and peer reviewed projects.

- Establishment of BTS as the integrator of cost-effective, technology based, highly efficient energy consuming products and practices.

- An organization that is customer focused, highly productive and results driven.

In consultation with industry and other stakeholder organizations, BTS is developing technology roadmaps to define the future portfolio and to develop strategic alliances with industry. In 1998-1999, roadmaps are being developed for lighting; windows; heating, ventilation, and air conditioning (HVAC) equipment; and commercial and residential buildings (buildings systems integration). Additional roadmaps began in 1999 and 2000. The roadmaps had an impact in the FY2000 budget process and will continue to will have an impact on the FY 2001 budget as it evolves.

The recent analysis of the Energy Resources R&D portfolio has also impacted the Building portfolio. Gaps and opportunities identified in the analysis process have been addressed in subsequent budget requests. The findings of the analysis panel were reported in the budget documentation to Congress. The program element discussions below include mention of where this process has resulted in enhanced budgets.

Federal Role

Research by the Department in the buildings area fills four needs. First, the Department can provide the critical mass necessary to accelerate progress in an area in which the private sector does limited research. Second, in many cases, important research would not occur at all in the absence of the Department's efforts due to the fragmented nature of the buildings marketplace. Third, it provides industry with objective analysis on new technologies and techniques to reduce barriers to new technology adoption. Finally, buildings research can reduce the huge energy costs incurred by the Federal Government—the single largest consumer of energy in the United States.

Key Accomplishments

The Department has a history of supporting RD&D in the area of buildings efficiency technology that has paid off handsomely for the Nation. The net result of just 5 Federal investments made back in the 1970s-80s[2] have resulted in present value savings in the U.S. economy totaling nearly $33 billion through 1997, while simultaneously eliminating more than 60 million metric tons of cumulative carbon emissions. These case study results were reviewed in detail by the General Accounting Office and reflect their conservative accounting methods.

[2] The five technologies include the Flame Head Retention Oil Burner, Advanced (Low-E) Glass, Electronic Fluorescent Ballasts, the Efficient Refrigerator Compressor, and the DOE-2 Building Design Software.

Heating, Cooling, and Air Conditioning

Budget: FY99-$15.4M, FY00-$10.9M, FY01-$10.5M

Background

The demand for HVAC in homes and commercial buildings consumes nearly 14 quads of primary energy per year—40 percent of the primary energy in buildings and 15 percent of U.S. primary energy totals—amounting to $90 billion annually. Buildings consume 4.1 quads of primary fuel to make electricity and 1.85 quads of electricity directly, 5.4 quads of natural gas, 1.2 quads of fuel oil, and 1.2 quads of other fuels (e.g., wood) for thermal comfort services. Space heating and cooling dominate, accounting for over one-third (37 percent) of total energy usage in buildings.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(increase efficiency of space conditioning, ventilation, and thermal distribution equipment; reduce peak-load electricity demand; and enhance indoor air quality)*

Program Description

A variety of equipment provide space conditioning services, including heat pumps, furnaces and boilers, chillers, and others. Thermal distribution systems include fans, ducting, piping, heat exchangers, and controls and can also be the means of primary ventilation. More highly advanced systems incorporate computers, sophisticated building sensors, and complex control strategies.

The equipment used in a given building is determined by building size, function, geographic region, availability of fuel types, consumer preferences, and other factors. Opportunities for the most cost-effective energy savings and improved performance in a given application vary by technology. Therefore DOE has a number of technology development activities underway.

In 1998 the Department joined with the Air Conditioning and Refrigeration Institute (ARI) in developing a roadmap for HVAC research for the future. The ARI initiative, HVAC&R Research for the 21st Century (known as "21-CR") is a comprehensive, industry-generated research agenda. Its major elements include improved equipment efficiency and new refrigeration cycles development, building systems integration, and new working fluids. This effort will help define the next generation of research with implementation beginning in FY 2000.

Geothermal Heat Pumps

Budget: FY99-$6.5M, FY00-$0.0M, FY01-$0.0M

Description, Objectives, and Performers. The geothermal heat pump (GHP), also known as a ground-source heat pump (GSHP) works on the same principle as a conventional (air source) heat pump of transferring heat from a cooler temperature to a warmer temperature. But whereas conventional heat pumps transfer heat to and from outside air, GHPs transfer heat to and from the earth. While this technology typically has a low life-cycle cost and is more efficient than conventional HVAC technology, first costs are high. DOE funds geothermal heat pump research and development and technical assistance programs at the International Ground Source Heat Pump Association (IGSHPA), consisting of 24 utilities, and Oak Ridge National Laboratory (ORNL).

R&D Challenges. The objective of the DOE activity is to reduce the initial cost of the system. Research is needed to reduce the cost of installing the underground heat exchanger, the costliest portion of a GHP system. Reduction of costs in other system components also need attention. Goals include a 40 percent reduction in ground loop heat exchanger cost.

R&D Activities. Research is focused on developing methods to properly assess the thermal characteristics of the installation site to reduce the installation cost of the underground heat exchanger. There is also ongoing research on other system components and system integration, such as developing hybrid systems using small cooling towers, snow melt, and passive surface heat exchangers to reduce operating and capital costs.

Accomplishments. Among the DOE successes in this area were the use of improved simulation models to develop a "rule of thumb" for ground loop design that resulted in 40 to 50 percent shorter loops, and hence, lower first cost.

Absorption Technologies

Budget: FY99-$5.9M, FY00-$6.4M, FY01-$6.3M

Description, Objectives, and Performers. Absorption technologies are being pursued for both residential and commercial applications. The commercial research is focused on alternative working fluids and system enhancements to improve energy efficiency. The residential effort is centered around development of an absorption heat pump (AHP).

An AHP differs from an engine-driven heat pump in the way the refrigerant is compressed. An AHP absorbs the refrigerant vapor from the evaporator in a solution rather than using a mechanical compressor. The refrigerant is then separated from the solution by heating it with natural gas. A natural gas-fired absorption heat pump has the potential to have substantially lower (40 to 50 percent) operating costs compared to conventional heating and cooling systems and also offers an opportunity to serve cooling needs with natural gas. AHPs also have more uniform temperature distribution, can be operated at variable speeds, and provide significantly warmer air than that produced by electric heat pumps. An additional objective of the DOE effort is to help U.S. manufacturers recover a technical advantage in large commercial chiller applications by ultimately developing a gas absorption heat pump with a coefficient of performance of 1.8 in heating and 0.8 in cooling. The work is carried out through industry cost-shared programs with a major manufacturer and 3 small business establishments, 1 university and ORNL in close coordination with the Gas Research Institute (GRI) and major gas utilities. The program is 35 percent cost-shared.

R&D Challenges. The R&D challenge is the development of materials that will not corrode from the use of non-ozone depleting working fluids.

R&D Activities. Two different gas-fired absorption heat pump concepts are being researched. The Generator Absorber Heat Exchange ("GAX") is intended for markets where heating dominates energy use while the "Hi-Cool" unit is targeted towards cooling-dominated markets. In 1999, the first GAX prototype was tested. This design uses a non-ozone depleting working fluid consisting of an ammonia/water mix. "Hi-Cool" research has advanced to initial stages of system development and is in the process of developing a prototype. Absorption chiller research continues with field testing of a lithium/bromide triple-effect chiller for cooling commercial buildings. Laboratory tests of this cycle have demonstrated significant (30-40 percent) improvements in energy efficiency of chiller applications.

Accomplishments. A complete residential GAX heat pump assembly was put into full operation and laboratory-tested in 1998. Measured heating efficiency was found to be 100 percent better than the best existing gas-fired condensing furnace.

Desiccants

Budget: FY99-$2.5M, FY00-$4.0M, FY01-$4.3M

Description, Objectives, and Performers. Desiccant systems take advantage of thermodynamic relationships between air temperature and humidity. Desiccant materials have a higher affinity for water than does air and can therefore be employed to absorb moisture and lower air humidity. Once the air is dried, cooling it requires less energy than if it were still humid. Energy and cost savings (as well as precise humidity control and alleviation of moisture-related indoor air problems) are thereby possible with proper desiccant system design. Desiccant systems are complex and not fully understood. The objective is to develop and disseminate credible information on desiccant systems operation and design in order to ensure their use where economically advantageous from an energy efficiency perspective or to address problems of indoor air quality. The National Renewable Energy Laboratory (NREL) and ORNL assist 2 industry teams consisting of a major HVAC manufacturer and desiccant wheel manufacturers. This activity focuses on the continued development and integration of desiccant wheel and complete system testing of new designs and materials as they emerge from manufacturers. The program is 40 percent cost-shared.

R&D Challenges. The R&D challenges are to better understand the properties of solid desiccant materials and system operation, thereby developing the information needed to achieve optimal system design. With liquid desiccants, the challenge is to reengineer the absorber to increase the stability of the liquid/air interface and reduce the potential for droplet formation and carryover into indoor air.

R&D Activities. R&D activities include objective testing, analysis and feedback to industry on the design, performance, and durability of prototype solid desiccant wheels and humidity control systems. There is also ongoing field testing to integrate prototype desiccants into conventional HVAC systems. Research continues with industry on a cost-shared project to develop high efficiency liquid dehumidifiers.

Accomplishments. A highly successful testing and evaluation program of solid desiccant wheels with industry was achieved.

Furnaces and Boilers

Budget: FY99-$0.5M, FY00-$0.5M, FY01-$0.0

Description, Objectives, and Performers. Oil furnaces and boilers provide heat and hot water in over 10 million buildings. Oil-heating is provided by heating air or through hydronics (water radiating heat through a piped system). An oil burner system delivers and disperses the fuel, and ignites and monitors the flame used to heat the air or water. The objective of the DOE effort is to reduce oil consumption through improved burner design. The program works with three equipment manufacturers and the New York State Energy Research and Development Agency (NYSERDA), and is cost-shared with about 60 percent of funds coming from industry. Future plans are to have the program become 100 percent funded by industry.

R&D Challenges. The challenge is to develop low-cost, low NO_x emission burner technologies.

R&D Activities. DOE research focuses on improvements to burner design and operation. DOE is testing a prototype low NO_x version of the fan atomized burner. Research is also underway on a second generation burner that will be lower cost and include self-tuning features to maintain efficiency.

Accomplishments. DOE funded earlier development of the flame retention head oil burner which now dominates the marketplace resulting in $5.0 billion in cumulative consumer cost savings.

Building Materials and Envelope

Budget: FY99-$10.7M, FY00-$11.7M, FY01-$12.3M

Background

The building envelope is the barrier between the interior and exterior environment. It consists of the walls, windows, roof, foundation, and doors. Energy demand for heating, ventilation, and air conditioning is determined by the thermal integrity of the building envelope, “air-tightness,” and by occupant behavior. There is much interaction between building envelope, lighting, and HVAC components. DOE conducts a diversified portfolio of research into components and systems.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(increase the thermal performance of the building envelope, increase indoor air quality, reduce the environmental impact of building construction, and increase occupant comfort)*

Program Description

Component research includes advanced materials and insulations, high-performance windows, and innovative components such as self-drying roofs. DOE works with industry to develop systematic and objective evaluation methods for all envelope components. These range from thermal control windows ("superwindows") to dynamic wall systems, and from highly-reflective building surfaces designed to reduce cooling loads to energy efficient and durable commercial roofing systems. This research also provides the technical foundation for the industry consensus process for building standards and guidelines, such as those of American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) and the American Society for Testing of Materials (ASTM).

Windows and Glazings

Budget: FY99-$6.8M, FY00-$6.9M, FY01-$7.3M

Description, Objectives, and Performers. Windows are major determinants of heating needs, due to conductive losses, air infiltration, and solar gain; and to cooling needs, largely due to solar gain. As such, improving the thermal performance of window systems is an important element in reducing the energy required to provide consistent thermal comfort. The Department's goal is to conduct research and development on advanced window technologies and to develop design, rating, and information tools needed to optimize the use of these technologies. The program works with three manufacturers, two research institutes, an industry association, one university, and three National Laboratories in its research program. Roughly 80 percent of the funding goes to the National Laboratories.

R&D Challenges. Coating design, performance, and durability are technical barriers for electrochromic and other advanced window concepts. First costs for advanced window systems will also be barriers to market acceptance without substantial engineering improvements.

R&D Activities. Research on windows and glazing systems focuses on development of advanced materials, devices, and technologies as well as creating the analysis, simulation, and test procedures needed to accurately characterize performance. Electrochromic research continues on improving coating design and performance and durability of window that can be switched from clear to opaque to control cooling loads and manage daylight levels. This technology offers large energy savings potential, and the ability to shave peak electricity demand in the "Sunbelt," where much of the Nation's construction is occurring. DOE also provides testing of prototype high performance windows with superior thermal qualities using computer simulation, infrared, and thermal performance test facilities. Finally, DOE develops performance data, procedures, and tools that underlie the highly successful National Rating Fenestration Council windows rating system.

In 1998, the Department joined with industry partners in developing a vision and a roadmap for windows research for the future. This is the first portion of a broader building envelope roadmap. This effort will help define the next generation of research with implementation beginning in FY 2000.

Accomplishments. The low-emissivity (Low-E) window, which reduces the transfer of long-wave, infrared radiation was developed in the early 1980s. Currently, this technology accounts for 35 percent and 18 percent of residential and commercial window sales, with cumulative consumer savings of about $5 billion.

Walls, Roofs, and Foundations

Budget: FY99-$3.9M, FY00-$4.8M, FY01$-5.0M

Description, Objectives, and Performers. About 40 percent of the 34 quads of building energy use serves space conditioning and ventilation needs. The thermal performance of the building envelope is a major determinant of this energy use. The Department conducts research and development to significantly improve the thermal performance of walls, roofs, and foundations, and to investigate the effects of reflective surfaces and vegetation on building demand for cooling energy. In addition to the opportunity to lower energy use, other benefits include the increased durability of building envelope systems and materials and environmental improvements such as reduced construction waste, decreased use of ozone-depleting insulations, possible increased use of indigenous materials, and decreased summer temperatures (and air pollution) in urban areas through mitigation of the “urban heat island” effect. Major performers include ORNL, which hosts the Buildings Technology Center— a user facility that enables users (nearly 300 organizations) to share research costs with DOE. Lawrence Berkeley National Laboratory (LBNL) is the research organization for highly reflective surface research.

R&D Challenges. The lack of objective, widely available information on “whole-wall” and thermal reflective surface field performance, hinders market acceptance of novel, high performance technology. Uniform and comprehensive metrics are also needed to assess the environmental impacts of alternative insulation blowing agents. Durability of high performance roofing systems is another challenge.

R&D Activities. The Department’s “Buildings Technology Center” tests, models, and rates whole wall systems for thermal resistance, thermal mass benefit, and air leakage. Simplified tools are maintained on the Internet that allow building professionals to design energy efficient and durable wall and roofing systems. Research is targeted towards the development of advanced manufacturing processes for “next generation” insulation alternatives such as aerogels, evacuated panels, and non-HCFC foams. Commercial roofing systems typically have an installed R-value of 10 and a service life of 15 years or 30 percent of the remainder of the building envelope. DOE is performing laboratory and full-scale field testing of advanced roofing systems that are significantly more durable and energy efficient. To reduce cooling loads, buildings can incorporate highly reflective surfaces and roofing materials but a key issue is establishing field performance levels. DOE is therefore working to develop standardized protocols for measuring the energy performance of a variety of highly reflective roofing and pavement materials.

Accomplishments. Program accomplishments include the creation of a vacuum insulation panel that offers R-values an order of magnitude greater than that of standard insulation products.

Building Design and Operation[3]

Budget: FY99-$13.0M, FY00-$19.2M, FY01-$22.8M

Background

Buildings, although often "simple" in appearance, are in fact complex and dynamic systems made up of numerous components and subsystems. The interaction of these components and systems can have a profound impact on energy consumption, cost, and related pollution. Furthermore, because buildings differ greatly in size, shape, function, and intensity of use, these system interactions change from one building to the next.

The overall design and orientation of buildings have a substantial impact on energy consumption. The "pieces" of a building most relevant to an analysis of energy consumption are the building envelope (foundation, walls, windows, and roof); the heating, ventilating and air-conditioning subsystem; the lighting subsystem; the water heater and other appliances, including refrigerators, computers, and clothes washers and dryers; the energy controls associated with the HVAC and lighting subsystems; and the building occupants themselves. The energy requirements of a building or home depend not only on the *individual* performance of these components and subsystems but also on their *combined* performance when integrated into a unique building and how the building - as a system - is operated. There are large differences between building types in terms of systems design and operation considerations. For instance, in large office buildings, the interaction between lighting and other internal loads and HVAC is a very important design consideration, whereas this is not true in homes because lighting is a small energy user and is typically used in the evening hours when cooling loads are less.

An example may be useful for illustrating the importance of systems design approaches. In homes, the thermal integrity of the windows, walls, and roofs determines the heating and cooling loads the HVAC system must meet to keep occupants comfortable. A well-built home designed and oriented to take advantage of "passive" solar heating in heating climates, or incorporating "superwindow" technology that admits light but not heat in cooling climates, can meet its lowered thermal load with smaller and less costly heating and cooling systems, and perhaps without such systems altogether.

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[3] This area includes research activities from "Building Integration" and "Design Tools and Strategies" budget categories.

Due to industry fragmentation, the Department has a key role as an integrator in optimizing the design, installation, and operation of energy related building components using a systems approach. Because a systems approach may be nonintuitive and not lend itself well to simple design guides and checklists, much of the effort focuses on development of interactive, user-friendly design tools for use by the buildings community.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(reduce energy consumption through energy-efficient design techniques, reduce construction waste, increase use of passive solar in building designs, and reduce operation and maintenance costs)*

Program Description

The Department's research activities center on both building design and construction, as well as operation and maintenance (O&M). During building design and construction, subsystem, and component choices are made and actual construction begins. During the O&M phase, the building is occupied and in use. DOE develops tools and protocols for building design and operation as well as providing the technical basis for the industry consensus process for standards and guidelines, such as those of ASHRAE and ASTM.

Commercial Buildings

Budget: FY99-$5.2M, FY00-$7.7M, FY01-$9.6M

Description, Objectives, and Performers. DOE's commercial building research focuses on integrating technologies and practices to optimize whole building energy performance both during renovation and new construction. The objective of the research is to lower energy use by 25 percent or more, relative to conventional approaches, while increasing occupant comfort and productivity. DOE funds joint research with an industry consortium on integrated buildings designs and systems that are adaptable to changes in building use. Partners include National Laboratories and a consortia of universities, industry, and government organizations.

R&D Challenges. The R&D challenges are developing commercial whole building approaches for both new and existing buildings that are simple to integrate and that integrate simply with other building systems. They must be economically and ecologically sustainable, be acceptable to their community, and must easily adapt to a rapidly changing workplace. Addressing these challenges will in part require design tools and techniques which are robust, user-friendly, and accurately portray interactions between system components. These tools and techniques must be adaptable and transferable across design, construction, and operation stages of the building life-cycle.

R&D Activities. The Department's research on commercial building design and operation focuses on two areas: design strategies and energy performance tools that enable architects to optimize building performance at the point of design; and advanced building controls and diagnostics to optimize building operation once the building is occupied. Both approaches actively encourage the use of a "systems engineering" approach to the design and operation of commercial buildings, and thus the benefits are large, and cost-effective. Current Department research activities include development of software that incorporates consideration of passive solar options into small commercial buildings designs; new performance simulation software to replace DOE-2 ("EnergyPlus"); and the Whole Building Diagnostician, a hardware/software system to monitor real-time building performance. These tools and new technologies are field tested with the building industry in the context of real building projects via DOE's Commercial Exemplary Buildings Project. Measured energy cost savings of from 42 percent to 63 percent have been cost effectively achieved with no compromise of functionality or comfort.

In 1998, the Department joined with industry partners in developing a vision and a roadmap for commercial buildings design and operation research for the future. This effort will help define the next generation of research with implementation beginning in FY 2000. The 1999 portfolio analysis recognized commercial buildings R&D as a significant gap in the Efficient and Affordable Buildings technology category.

Accomplishments. A success in this area is "DOE-2," a widely used performance simulation tool that calculates energy use and cost from weather, building attributes, and other data. Approximately 15 percent of new commercial floorspace is designed with DOE-2 for cumulative energy savings to date of approximately $21.4 billion.

Residential Buildings

Budget: FY99-$7.8M, FY00-$11.5M, FY01-$13.2M

Description, Objectives, and Performers. DOE's residential systems research program focuses on accelerating the development of innovative residential energy systems by conducting full scale experiments on new residential buildings and manufactured homes. This industry consists of over 100,000 builders, and tens of thousands of component manufacturers. There is little integration or coordination of energy components in systems, and the industry is quite risk-averse in that it is very slow to adopt new technologies and embrace change. Through the Building America program, DOE facilitates integration of research and application in residential new construction. Experiments are conducted using an iterative design, test, redesign, retest sequence to ensure that technical barriers are fully identified and resolved during the research process.

The Building America program has established a unique arrangement with four consortia of private-sector firms in the residential building industry to carry out its research agenda. Each consortia is made up of a team of architects, engineers, builders, equipment manufacturers, material suppliers, community planners, mortgage lenders, and contractors, including more than 80 companies total. These four industry teams have committed $30 million over the next 3 years to implement full-scale systems engineering housing technology innovations. All projects are cost-shared between DOE and the Building America teams.

R&D Challenges. The challenges involve reducing the energy consumption of new residential buildings by 25 to 50 percent with little or no increase in construction costs. Achieving this will require development of building techniques that are quick and easy to implement, reliable, widely deployable, and inexpensive. One of the greatest barriers to implementation is overcoming worker reluctance to abandoning traditional building practices, thus new innovations must bear all of these qualities to be successful.

R&D Activities. DOE will test and evaluate alternative design and construction strategies. This includes analysis of alternative wall insulation designs on productivity in factory-built housing, air sealing strategies for modular housing, and development and testing of sheathing-integrated moisture and air barrier systems. Other activities include development of new low thermal loss duct designs, super-insulated ceiling systems, and AC control strategies for hot humid climates to maximize moisture removal during low load conditions. DOE develops and tests passive solar designs and phase-change materials. DOE develops computer simulation software and hardware to effectively monitor residential building energy performance. As part of this program, DOE has many partners including major builders, materials and equipment manufacturers, universities, research institutes, and industrialized home manufacturers. These partners contribute to research both through cost-sharing, research in-kind, or by sharing facilities.

Accomplishments. DOE worked with a manufacturer to design the first manufactured house to meet ENERGY STAR performance criteria and developed strategies to achieve 30-50 percent reductions in heating, cooling, and hot water energy use, the results of which, have been incorporated into new products by Carrier Corporation, USG Corporation, General Electric Company, Owens Corning, Tamarack Technologies, Inc., Ryan Homes, Pulte Homes, Beazer Homes, and others. To date, a total of 972 houses have been completed in Building America projects. Additional community-scale projects have been initiated in Denver, CO, Los Angeles, CA, Pittsburgh, PA, and Tucson, AZ.

Lighting and Appliances

Budget: FY99-$11.8M, FY00-$13.7M, FY01-$18.2

Background

In 1996, lighting in U.S. residential and commercial buildings used about 4.8 quadrillion Btu of primary energy, or about 14 percent of all energy used in buildings, at a consumer cost of $34 billion. In commercial buildings, lighting service demand represents one-fourth of total energy demand. Conventional lighting technologies still predominate throughout the economy—incandescent and standard fluorescent lamps account for almost two-thirds of the energy used to light buildings in the United States. Significant room for efficiency improvement exists. As artificial lighting is exclusively an electric technology, any savings achieved at the point of end use is tripled at the utility generation plant, bringing with it concomitant carbon reductions and other associated benefits.

Appliance technology comprises major building energy-consuming equipment other than that for space-conditioning and lighting. Appliances provide a variety of energy services, including water heating, food preparation and storage, clothes washing and drying, dish washing, and other services ranging from entertainment to security. Many smaller appliances present a difficult target for improved energy efficiency because of their low individual energy use and low frequency of use. The best candidates for efficiency improvements are those that involve transport, compression, heating or cooling of fluids (e.g., refrigeration, water heating), or involve significant use of transformers or electric motors. In some cases, process substitution (e.g., microwave drying in place of thermal drying) may offer additional alternatives for energy savings.

Water heating is the third largest end use for buildings in terms of magnitude, consuming about 3.9 quadrillion Btu in 1996 (11.3 percent of total buildings energy use), at a consumer cost of $25.9 billion. Refrigeration/freezers are also large energy users, about 2.2 quadrillion Btu in 1996 (6.4 percent of total buildings energy use) at a cost of $16.3 billion.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(reduce the first-cost of energy efficient light sources, develop new and innovative light sources and delivery systems, integrate natural light into lighting systems, and measure and assess the impact of alternative lighting regimes on worker health, safety, and productivity; increase energy efficiency of major energy consuming appliances, integrate appliances to capture and reuse waste heat, and develop appliances which use renewable energy sources rather than fossil fuels)*

Program Description

Electric lighting improvements underway include new and more efficient light sources, fixtures, light distribution systems, and improved ways of utilizing lighting based on the effects of lighting on vision and workplace productivity. Improved daylighting systems allow daylight to be used in buildings to offset electric lighting needs while achieving improved heating, cooling, comfort, and health performance. In 1998, the Department joined with industry partners in developing a roadmap for lighting research for the future. This effort will help define the next generation of research with implementation beginning in FY 2000.

Improved technologies underway include heat pump water heaters, improved insulations for refrigerators, and "integrated" appliances where, for example, waste heat from one serves as a heat source for another.

Lighting

Budget: FY99-$5.4M, FY00-$6.0M, FY-01$6.4M

Description, Objectives, and Performers. Lighting is responsible for 15 percent of energy use in buildings. Lighting systems include sources, fixtures and distribution systems, and controls. Artificial light sources include incandescent, fluorescent and High Intensity Discharge lamps (the "bulb"), while fixtures, by use of reflectors and diffusers, distribute the light. Lighting distribution systems can also include more advanced concepts, such as fiber optics, for distributing light from natural or artificial sources. Controls include occupancy detectors for automatically turning off light fixtures, discrete digital timer controls, and centralized computer controls. Lighting quality is also an area of intense interest, affecting worker productivity, comfort, and even health and safety. DOE's program is intended to help cut the energy used by lighting in half over the next 15 years. The Lighting program partners with numerous manufacturers, utilities, universities, and users in carrying out its research agenda. The program is 75 percent funded by industry.

R&D Challenges. The R&D challenges include optimizing component performance, size, and manufacturing processes to achieve cost-effective substitutes for conventional technology.

R&D Activities. Research includes a cost-shared effort with industry to develop a low-cost compact fluorescent lamp (CFL). This involves optimizing the power supply circuit, electrodes, phosphors, and ballast for performance and low-cost manufacture. DOE is also researching a new light source, the low-power sulfur lamp, which involves scaling down current technology to develop a smaller bulb as well as a solid-state source for microwave production. Fixture research is focused on efficient light distribution from non-linear sources (such as fluorescent), by redesigning fixtures traditionally used for (incandescent) point sources. DOE is developing expert controls systems to manage and control lighting subsystems. In addition, DOE is researching distribution systems for natural and artificial high-intensity, light sources. Finally, DOE conducts experiments and field tests that include testing high intensity outdoor lamps of different spectrums to produce a better quality light that improves vision while allowing lamps to be operated with less energy.

Accomplishments. Research on energy-efficient electronic ballasts in the late 1970s resulted in a product that captured 31 percent of sales, with up to 30 percent reduced energy use and cumulative energy savings worth $3.7 billion over the life of the technology.

Refrigeration

Budget: FY99-$2.8M, FY00-$4.2M, FY01-$4.2M

Description, Objectives, and Performers. Refrigeration includes both residential refrigerators/freezers, and commercial refrigeration uses such as in supermarkets. It encompasses not only component efficiencies, but also replacements for ozone-depleting substances used as working fluids. The objectives of the DOE activity are to eliminate all use of ozone-depleting chemicals while simultaneously increasing the operating efficiency of refrigeration equipment. Beginning in FY1999 DOE entered into a cooperative R&D program with the refrigeration industry. This group called Air Conditioning and Refrigeration Technology Institute develops and directs a research agenda of of pre-competitive research. Cost-sharing in this area is essentially 1:1 in matching funds.

R&D Challenges. The R&D challenges are to reduce the costs and ensure compatibility of alternative working fluids and equipment designs so that they are economically competitive with conventional technology for widespread application.

R&D Activities. For new refrigerants, DOE is completing the successful seven-year, industry-led, jointly-funded program of materials compatibility and lubricants research. This program has paved the way for a new generation of chlorine-free refrigerants to replace refrigerants which deplete the ozone layer. DOE is demonstrating supermarket refrigeration/HVAC energy savings in field tests of new systems with industry partners.

Accomplishments. A "fridge of the future" that uses half as much energy as today's refrigerator-freezers and a fifth as much as 1972 models was designed and demonstrated at a DOE National Laboratory during 1997. This reduction in energy use (from 2 to 1 kWh per day) exceeds the decrease called for in a 1997 rule, which requires refrigerators sold in 2001 to use 30 percent less electricity than those on the market today.

Heat Pump Water Heater and Appliances

Budget: FY99-$0.0M, FY00-$1.5M, FY01-$2.1M

Description, Objectives, and Performers. Appliances and hot water account for nearly one-fourth of energy use in buildings. Of this, hot water accounts for about half. Current research is focused on the heat pump water heater (HPWH) which offers performance improvements 2-3 times that of conventional electric resistance water heating.

R&D Challenges. The challenge is to reduce the cost of equipment and installation through design improvements.

R&D Activities. Residential HPWH have the potential to cut electric water heating bills in half. Research is underway to develop and begin field testing of innovative heat pump water heater concepts that have much lower cost and are easier to install than conventional technology. DOE will be developing and testing "drop-in" HPWH designs in conjunction with major manufacturers. In FY 2000, the appliance research effort will focus on development of prototypes of high efficiency laundry equipment.

Accomplishments. Accomplishments include performance testing and evaluation of energy and water savings of H-Axis washing machines.

Solar Water Heating

Budget: FY99-$3.6M, FY00-$2.0M, FY01-$5.5

Description, Objectives, and Performers. Solar heaters consist of a collection system that captures the sun's thermal energy, a distribution system, and a control system to regulate these functions. Some types of systems also include an energy storage system.

R&D Challenges. The challenges are to increase the durability and effectiveness of components while decreasing the component costs.

R&D Activities. Research efforts are focused on exploring the use of new materials (polymers) and components (heat pipes) to create the next generation system. The goal, by 2004, is to reduce system costs for solar water heating from $0.08/kWh to $0.04/kWh and for pre-heating of building ventilation air from $0.02/kWh to $0.005/kWh .

Accomplishments. Solar hot water systems research has resulted in a total reduction in cost from $0.20/kWh in 1980 to the current $0.08/kWh. A recent accomplishment is the development of a selective absorbing coating for solar collectors, *Black Crystal,* that has the potential to replace the industry standard material, black chrome. The transpired solar collector for pre-heating ventilation air won an R&D 100 Award and reduced costs to $0.02/kWh.

On-Site Generation

Budget: FY99-$1.8M, FY00-$3.6M, FY01-$5.6M

Background

Generating electric power at individual building sites versus at remotely-located central power plants offers a number of potential benefits to the Nation. First, on-site generation avoids many of the disadvantages associated with transmission and distribution—costly infrastructure and permitting, health and aesthetic externalities, and energy loss. Second, because distributed generation often takes place in close proximity to other thermal loads, such as space conditioning and water heating, the "waste" heat that is rejected from the generation process can be used by these other applications, i.e., cogeneration. This leads to very high system efficiencies, on the order of 80-90 percent (i.e., the electric and thermal output divided by the fuel input). These high efficiencies translate, in turn, into reduced emissions relative to conventional central station fossil generation.

Linkage to CNES Goals and Objectives

This program directly supports CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010. *(reduce overall energy consumption by eliminating line loss caused by electricity transmission, increase the use of natural gas as generation source for electricity, and increase opportunities for cogeneration of electricity and heat for building space conditioning)*

Program Description

On-site power plants can range in size from a few watts to several hundred kilowatts. Potential "distributed" generation technologies include fuel cells, photovoltaics, micro turbines, and reciprocating, and rotary engines. The Department's buildings research in this area is currently focused on fuel cells.

Fuel Cells

Budget: FY99-$1.8M, FY00-$3.6M, FY01-$5.6M

Description, Objectives, and Performers. Fuel cells are similar to batteries in that they produce electricity through electrochemical reactions. A battery depletes itself or must be recharged, but a fuel cell produces power continuously when supplied with an appropriate fuel and oxidant. A fuel cell consists of positive and negative electrodes immersed in an electrolyte. A hydrogen-bearing fuel is supplied to the anode along with oxygen, usually derived from air, to the cathode. During operation, the fuel is oxidized and the resulting chemical reaction produces direct current electricity. Waste heat from the reaction is available for recovery for thermal applications, from water heating to space conditioning, and in applications where all available heat is recovered, fuel cell system efficiencies—cogeneration—can exceed 85 percent. The objective is to develop the components and systems necessary to bring fuel cells to building applications. The BTS program works with five manufacturers and Argonne National Laboratory in carrying out its research agenda, with a cost-share of 40 percent.

R&D Challenges. The research challenges are fuel cell cost, longevity of components, and compatibility with various sources of hydrogen.

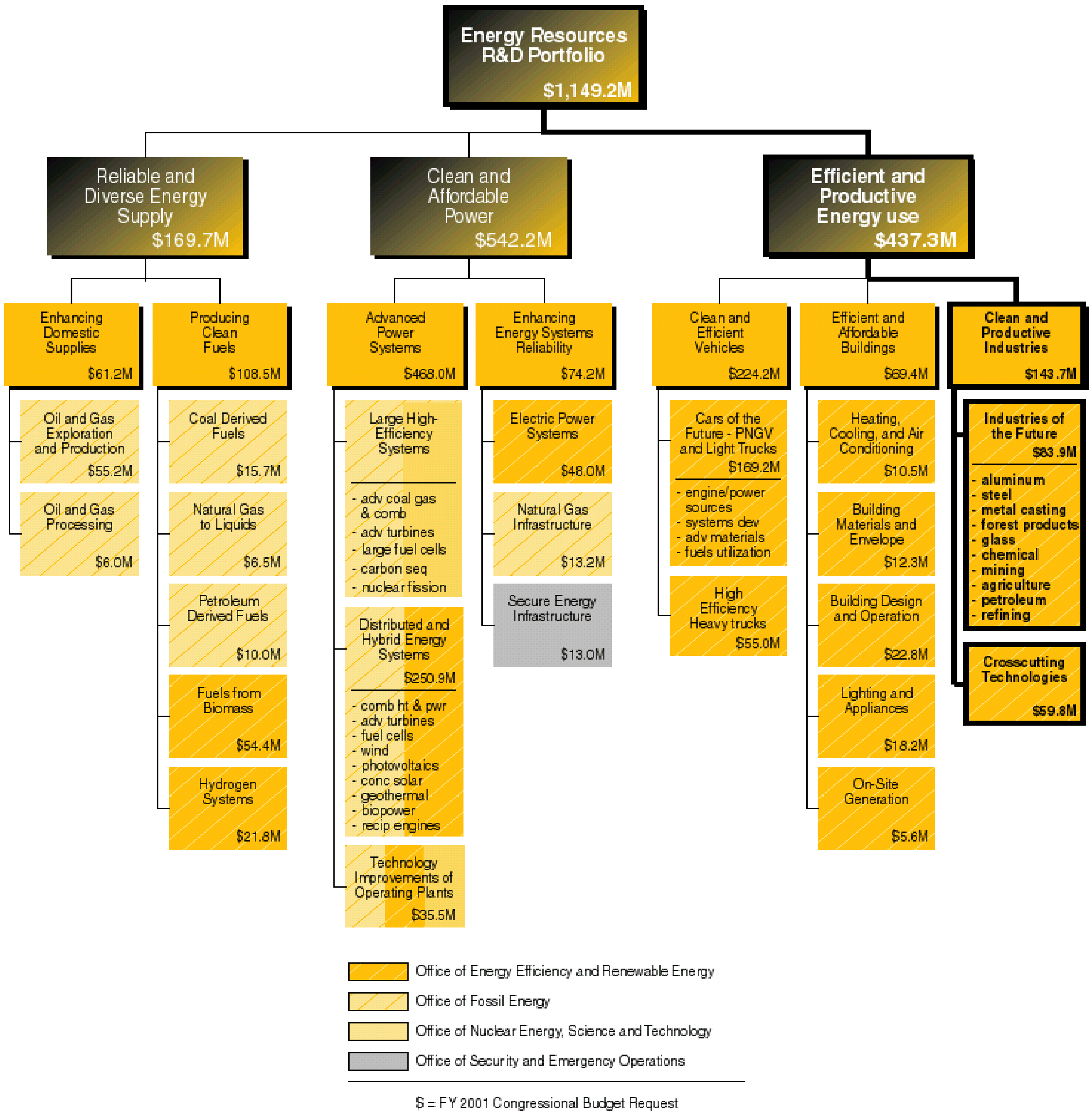
R&D Activities. The Department's research in buildings-applicable fuel cells, initiated in FY 1995, draws to the extent feasible on research in transportation and military applications, but focuses on the unique needs of buildings, that include lower noise levels, increased power densities, and durability in the 40,000 hour range (versus 3,000 for an automotive fuel cell). The Department's research is focusing on fabrication and testing of the prototype methane reformer and its incorporation into a Proton Exchange Membrane fuel cell. The Department's near-term R&D goal is to develop a first-generation prototype Proton Exchange Membrane fuel cell by FY 2002, and to demonstrate its performance in a commercial building.

Accomplishments. This is a new program so there are no accomplishment to date.

Summary Budget Table (000$)

Efficient and Affordable Buildings Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY2001 Request
Heating, Cooling, and Air Conditioning	**15,379**	**10,905**	**10,533**
Geothermal Heat Pumps	6,500	0	0
Absorption Technologies	5,910	6,365	6,260
Desiccants	2,480	4,040	4,273
Furnaces and Boilers	489	500	0
Building Materials and Envelope	**10,723**	**11,723**	**12,325**
Windows and Glazings	6,829	6,929	7,325
Walls, Roofs, and Foundations	3,894	4,794	5,000
Building Design and Operation	**12,970**	**19,163**	**22,790**
Commercial Buildings	5,200	7,700	9,610
Residential Buildings	7,770	11,463	13,180
Lighting and Appliances	**11,791**	**13,745**	**18,175**
Lighting	5,394	6,000	6,360
Refrigeration	2,797	4,245	4,230
Heat Pump Water Heater and Appliances	0	1,500	2,085
Solar Water Heating	3,600	2,000	5,500
On-site Generation	**1,750**	**3,550**	**5,550**
Fuel Cells	1,750	3,550	5,550
Total	**52,613**	**59,086**	**69,373**

Chapter 9
Clean and Productive Industries



Chapter 9

Clean and Productive Industries

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Overview

Definition of Focus Area

The clean and productive industries' research and development portfolio focuses on generic pre-competitive research concentrating on cooperative projects with nine of the major process and extraction industries in the industrial sector. These industries, referred to as the Industries of the Future, include aluminum, steel, metal casting, forest products, glass, chemicals, mining, agriculture, and petroleum. In addition, the portfolio includes crosscutting research and development efforts on technology needs which have been identified in technology roadmaps for multiple industries, and which form technology bases from which more industry-specific developments can derive. The crosscutting activities also include technical information and outreach programs, demonstrations, training, and tool development which assist industry in evaluating and adopting these new energy efficient and pollution preventing technologies and techniques.

National Context and Drivers

The industrial sector consumed almost 35 quads of primary energy in 1997—about 38 percent of all energy used in the United States. The industrial sector contains extraction industries, as well as materials processing and product manufacturing industries. Over 80 percent of the energy consumption in manufacturing (including feedstocks) occurs in only seven process industries: aluminum, steel, metal casting, forest products, glass, chemicals, and petroleum. Mining and agriculture are major energy users in the extraction industry. These nine industries are highly capital-intensive, produce significant emissions and waste products, have far larger energy and pollution abatement costs per unit sales than other industries, and typically invest far lower percentages of their sales in research and development than the average U.S. industry. Overall energy intensity (energy per unit output) decreased from 1973 through 1986, but has since remained nearly level, while pollution abatement costs have continued to grow, due in significant part to increased energy consumption.

The major process industries are becoming increasingly more capital-intensive. Markets are continuing to become more globally competitive. Many industries, such as steel, faced dire times in the 1960s and 1970s, but by restructuring and re-engineering themselves, became world leaders by the 1980s. By the late 1990s, a number of issues have again placed major strains on these industries. These include world financial markets, trade issues, increasing costs of environmental abatement and other costs not necessarily shared by foreign competitors, and generally soft markets. Reducing energy costs and waste, and reducing or eliminating environmental emissions upstream (closely related to energy use) are recognized as controllable costs that can increase U.S. industry's productivity, profitability, product quality, and global competitiveness.

Linkage to CNES Goals and Objectives

The program is in direct support of the following CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.

A reasonably ambitious goal for industry for the year 2010 is a 25 percent reduction in energy consumption per unit of output. The strategy to support the achievement of this goal, in addition to focusing resources on the most energy- and waste-intensive industries, is to form partnerships among industries, and invest industry and government resources in the areas of greatest need.

Uncertainties

In addition to the normal uncertainties in the R&D process, the timing of R&D is of particular importance in some industries. Many large plants and large equipment modules were installed in the period of rapid economic growth after WW II through the 1960s. This capital equipment will be reaching the end of its useful life by the end of the next decade. Hence, a window exists for rapid adoption of the new technologies that are ready for new or retrofit installations; if that window is missed, adoption will be slower in the face of high capital investments that were recently made in some facilities. In addition, several of the major process industries are experiencing very low or negative profit margins primarily because of low global prices associated with the current Asian and Eastern European economic situations. The restructuring of the utility industry, climate change, and emission requirements also have the potential to create uncertainties for industry depending on the details of these issues, many of which are also associated with State and local policies.

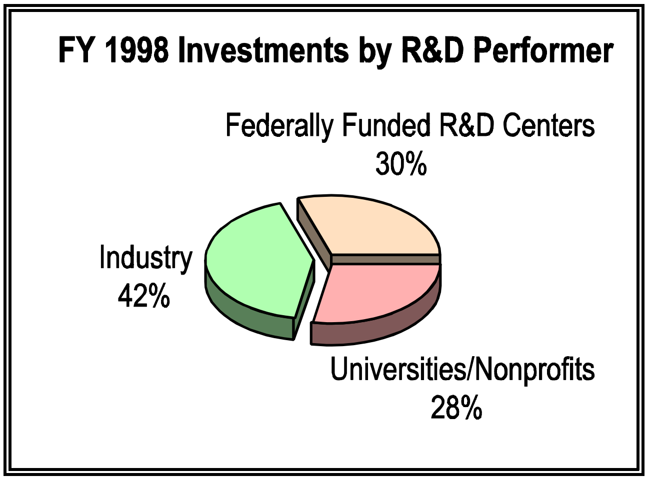
Investment Trends and Rationale

The Industries of the Future (IOF) program focuses its resources principally on the nine industries already mentioned. It supports collaborative research, development, and demonstration efforts to accelerate the development and adoption of energy efficient technologies and incorporation of "best practices" in industry.

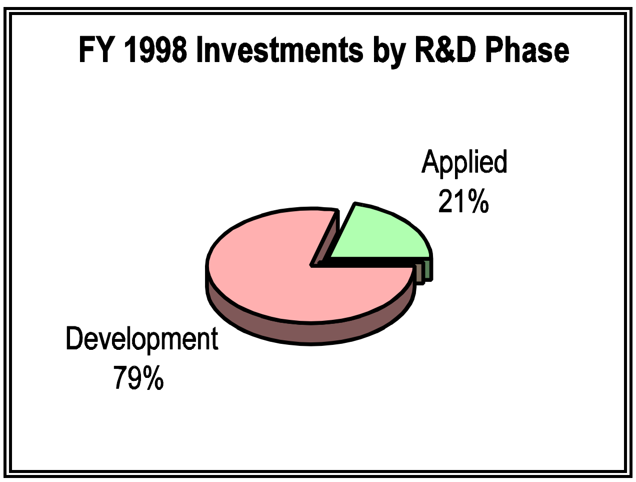
The IOF process includes the following:

- *Facilitate industry visions and technology roadmaps.* Industry leaders outline a future *vision* of their industry that is defined by explicit market, business, and technology goals. A *technology roadmap* is developed to articulate specific technology strategies and create a comprehensive R&D agenda. DOE's Office of Industrial Technologies (OIT) assists industry during this process and acts as a neutral party that can bring together competitors, suppliers, customers, and other key stakeholders.

- *Cooperatively fund strategic projects.* Once industry has developed its technology roadmap, OIT selectively cost-shares technology projects contained within the roadmap that are consistent with the Department's strategic goals and the government role. Essentially all research projects and their associated investigators are selected through a competitive DOE solicitation that includes industry's direct involvement, and with universities, DOE laboratories, and private sector companies performing the research. A significant number of efforts involve a mix of performers including industry-laboratory-university teams or combinations thereof. These mixes vary from industry to industry and the process is flexible to respond to the diverse nature of the different industries. The ratio of investments by the various R&D performers is shown in the figure below. (These estimates are based on the funding of the initial and primary recipients and do not reflect the sometimes significant percentage of funds flowing to subcontractors or collaborators, which may be in a different category of performer.)



The strategy also includes an integrated set of activities ranging from the applied research phase through technology development to activities to accelerate the continued development and/or adoption of energy efficient technologies. The latter may include demonstrations of advanced technologies, and tools and training on best practices at both an industry-wide and plant-floor level. An estimate of the ratio of investments by phase of research and development is shown in the figure below. The charts showing Investments by R&D by Performer and Investments by Phase reflect recent experience and are not expected to change significantly over the FY 1999 - 2001 period.



Research is conducted principally at the industry-wide, pre-competitive stage, with results available to all industry participants, rather than individual members of the IOF industries. Typically, the industry partnership is spearheaded by one (or occasionally more) industry trade association and/or professional society. The participation and consensus of the majority of the industry members are sought, with individual companies providing staff for technical roadmapping teams, peer and program reviews, and other support. Projects and programs are generally cost-shared with IOF industry collaboratives at an average level of at least 50 percent over the program's life.

Major program trends from FY 1997 to FY 2001 include the following:

- The program initially focused on seven major process industries, temporarily decreased to six when one industry was unable to reach a consensus. That industry has since reached a level of consensus and in addition, mining and agriculture (in particular the bioproducts area of agriculture) have been added to the Industries of the Future portfolio. This represents a balancing of available resources and the major energy consuming industries; further expansion at the Federal level is not anticipated at current resource levels in order to maintain that balance. However, the development of IOF programs has been initiated at the State level, providing closer relationships between State and Federal programs and promising more efficient development and adoption of technologies by local industries.

- The need for advanced sensors and controls and advanced combustion technologies has been identified as a high priority in many industry roadmaps; hence, new applied research efforts have been initiated in those areas to help provide the technology base from which industry-specific sensors and controls and combustion components can be developed. In addition, the research portfolios for each industry have been revised to match industry-developed technology roadmaps. Most recently, the chemical program has been reoriented and a catalysis program developed to support it.

- Integration of all the products and services provided by the industrial RD&D programs was fully implemented in FY 1999. Through this Integrated Delivery system, industrial customers are made aware of and encouraged to adopt technologies developed in other programs. For example, while the aluminum program is collaborating with the aluminum industry to develop advanced aluminum processing technologies, industrial customers are also being provided with more efficient technologies, tools, and/or techniques arising from other programs, such as those in electric motor systems, steam, and compressed air, and with an overall view of energy use and needs. Increasing collaborations with State organizations–energy technology institutes, energy and economic development agencies, and others–are also seen as an approach for assisting in the adoption of new technologies at the State and local levels and for incorporating State and local needs into the national roadmapping process.

Biobased Products and Bioenergy Initiative

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.

In FY2001 $43.8 million is included in the Industries area for this initiative. These activities are associated with Forest Products, Agriculture and Crosscutting Technologies.

Federal Role

Energy consumption by industrial processes is closely tied to emissions and other environmental impacts of industrial activity and has major implications for the state of the environment. It is tied as well as to industrial productivity and the economy, potentially affecting U.S. jobs and global competitiveness. This is particularly true in the major process and extraction industries, where global competition may not be based on completely free markets and where profitability as a function of sales is often relatively low. Low profitability leads in turn to relatively low private-sector investments in R&D (as a function of sales) by these segments of industry compared to industry as a whole.

The level of risk involved in the adoption of major new technologies in these industries is also relatively high. Most process plants operate continuously at very high throughputs; down-times and retrofits or repairs associated with a new technology could be financially critical. These processes are also highly capital-intensive and involve plants with generally very long, even half-century, lifetimes. Competition for capital and the nature of the risks involved further hinder adoption of many new technologies. Less capital-intensive advances such as process parameter changes or advanced sensing and controls and simulation capabilities suffer from a relatively limited capability to maintain intellectual property.

Collectively, these factors discourage individual companies from being able or willing to invest in many areas of advanced R&D. Thus, there is a need for a Federal role in helping to support primarily generic, pre-competitive R&D that can benefit the industry as a whole, which individual companies can then develop further in a competitive environment, but that would be unlikely to occur without such Federal involvement. This results in a need for testing, verification, demonstration, and information dissemination to provide the levels of information needed for critical investment decisions for the rapid adoption of advanced technologies.

The program acts initially as a facilitator, assisting industry in collectively identifying issues and developing an industry-wide vision of its long-term future. The program further facilitates and assists in the development of an industry technology roadmap, which identifies and prioritizes the research and development needed to achieve that vision. The program then collaborates with the private sector and cost-shares the generic pre-competitive research and development activities that meet industry's priority needs and the Department's key missions. This role also involves bringing to bear the unique expertise and facilities of the national laboratories to attack key technological and scientific problems.

Key Accomplishments

The industries participating in OIT's program are at some stage in developing a vision of where they want to be in 2020, and a roadmap for developing technologies in order to reach their goals. Some of the industries have embarked on R&D following their roadmaps, and have reported successful results from that R&D. The accomplishments of the nine current Industries of the Future include the following:

Aluminum Industry: The vision and roadmap documents, including an "Inert Anode Roadmap," are completed. Cathode research has achieved an 8 percent energy savings with a new cathode technology tested in a pre-bake cell, with no decrease in aluminum production.

Steel Industry: Efforts are underway to improve sensing and control, enhance recycling of processing byproducts, and improve processes. The program also wants to increase the use of near-net-shape casting processes. In collaboration with the Steel Manufacturers Association, research is being conducted on reducing refractory wear in electric arc furnaces.

Metal Casting: Work of the Lost Foam Consortium led to advances in reducing defects and producing higher-quality, higher precision lost foam castings. By 2010, use of the technology will save 4.6 trillion Btu of energy and prevent 0.45 million tons of waste. New procedures were introduced in lost foam casting as well as control technologies.

Forest Products: The implementation plan (roadmap) was published in 1999. New cleaning technology allows the use of lower grades of recycled paper by papermakers, permitting 50 percent recycling of all paper used, reducing energy used for recycling by 0.l quads/year and lowering CO_2 emissions by 0.6 million tons annually. A radio frequency-induced unit to remove VOCs from lumber prior to drying will reduce emissions, energy use, and industry's costs.

Glass: The vision document will be updated in FY 2000. Oxy-fuel firing for glass melting furnaces is in commercial use in 20 percent of glass furnaces, reducing a manufacturer's fuel use by 48 percent, NO_x emissions by 70 percent, and particulates by 60 percent, and increasing productivity by 25 percent. The glass portfolio has added 10 new technologies since FY 1998, including the development of an experimental glass furnace and a database of critical high-temperature mechanical properties of various glass compositions necessary to validate glass melts and combustion space models.

Chemicals: R&D in separations, catalysis, computational chemistry, and alternative synthetic pathways supports the vision. Four roadmaps have already been produced, because of the complexity of the industry. The 1999 Presidential Green Chemistry Challenge award was given to a technology that uses levulinic acid, which is derived from waste biomass, as a feedstock for producing chemicals such as succinic acid.

Mining: A compact was signed between DOE and the National Mining Association in June 1998. A vision document was published in September 1998, and a roadmap on crosscutting technologies was published in February 1999. Crosscutting research projects (benefitting both coal and hardrock mining) were initiated following a competitive solicitation in FY 1999, and work will begin on several new projects following the solicitation for FY 2000 funds currently in progress.

Agriculture: A vision document focused on plant-based renewable resources as a long-range goal. A compact was signed by representatives of the agricultural, forestry, and chemical industries, DOE, and the U.S. Department of Agriculture. A roadmap set forth the program's R&D goals, and six R&D projects were selected for funding following an FY 1999 solicitation. A second vision and roadmap will be developed based on the President's 1999 Executive Order and the National Bioenergy Initiative to develop and promote biobased products and bioenergy.

Petroleum: A vision document was printed, a technology workshop was held, and a compact will be signed with DOE. A solicitation will be issued in early 2000 based on the challenge areas identified in the vision and roadmapping workshop: energy and process efficiency, environmental performance, and materials and inspection technology. Biocatalytic desulfurization technology represents an energy efficient means to reduce the sulfur content of gasoline from the current average of 340 parts per million (ppm) to the level of 30 ppm proposed during 1999 by President Clinton. This approach will lower capital costs by 50 percent.

Accomplishments in the Crosscutting Technologies area:

Advanced Materials: Engineered ceramics are being tested and developed for high-temperature applications. The Advanced Industrial Materials (AIM) program is focused on advanced intermetallic alloys for high-temperature applications in aggressive industrial environments, and on new materials for membrane separations. A new class of nickel silicides and a new nickel aluminide alloy have been developed and will be tested in FY 2000 and beyond. A program plan has been written for integration of the CFCC area and AIM into a new materials program.

Combustion Technologies: A vision and a roadmap document were developed. The program is seeking significant gains in efficiency and emissions reductions in two projects based on goals of these documents. A packed media/transport membrane boiler may increase efficiency 10 percent, while lowering emissions. A new process heater using an original system design is projected to gain 10 percent in efficiency also. NOx emissions will be well below today's current state-of-the-art levels.

Sensors and Controls: The program will continue to advance sensors and controls that are significant to two or more Industries of the Future. Demonstration is planned of an on-line, laser-based ultrasonic system to measure wall thickness and eccentricity of steel seamless mechanical tubing during piercing, elongation, and rotary sizing operations. R&D will focus on selfdiagnostics and self-calibration of sensors, accurate high-speed measurements, and sensing in harsh environments.

Best Practices: Formerly called Technical Assistance, this program helps plants and manufacturing companies benefit from new technologies and well-proven, cost-saving opportunities in motor, steam, and other plant-wide systems. Additionally, the Industrial Assessment Center Program has analyzed opportunities in over 7,000 small manufacturing sites for saving energy, reducing pollution, and increasing productivity.

Financial Assistance: The Inventions and Innovation subdivision of this program is supporting Dieter Bryce, Inc., in developing a patented system for on-site, cost-effective removal of bark from tree stems that reduces energy use for debarking by 33 percent. A NICE[3] grant to Whyco Technologies, Inc., led to a plating technology that uses 15 percent less energy and reduces carbon dioxide emissions by about 12,800 tons annually.

Industries of the Future

Budget: FY99-$56.4M, FY00-$66.0M, FY01-$83.9

Background

The nine Industries of the Future have developed (or are in the process of completing) technology roadmaps addressing their industry vision and their major priority technological needs. Competitively selected projects and performers are underway to perform research and develop, test, and accelerate the adoption of new energy efficient technologies.

Linkage to CNES Goals and Objectives

The program is in direct support of the following CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.

A reasonably ambitious goal for industry for the year 2010 is a 25 percent reduction in energy consumption per unit of output. The strategy to support the achievement of this goal, in addition to focusing resources on the most energy- and waste-intensive industries, is to form partnerships among industries and invest industry and government resources in the areas of greatest need.

Program Description

Research and development, along with testing, demonstration, and evaluation programs, are undertaken on a broad array of technologies that are identified by the Industries of the Future as priorities in their technology roadmaps and that meet the Department’s missions and goals. Individual projects range across the spectrum from small focused research tasks and activities of relatively short duration, to multi-year, major technology development projects. Research projects may focus on individual technical disciplines or on multi-disciplinary areas. The characteristics and needs of each industry vary, and determine the nature and balance of the activities in the individual portfolios. This is discussed further in the following sections on each of the Industries of the Future.

Aluminum

Budget: FY99-$7.9M, FY00-$11.2M, FY01-$11.0M

Description, Objectives, and Performers. Nearly 0.5 quad of energy is used in making primary aluminum and about 150 trillion Btu are used in secondary aluminum production and rolling, making products worth $35 billion per year. The industry spends nearly 7 percent of its product costs on energy, a larger portion than that spent by other industries. The production of primary aluminum produces 6 million metric tons of carbon equivalents (MMTCE) per year from energy use, mainly electricity. In addition, the basic smelting of alumina utilizes consumable carbon anodes, which contribute about 1.5 MMTCE. The process also produces over 4 MMTCE from perfluorocarbons.

The aluminum industry and DOE signed a compact in October 1996, having produced a vision document in 1996. A technology roadmap was published in May 1997. Because of the importance and difficulty of developing a replacement for the current carbon anodes, a follow-on Inert Anode Roadmap was published in February 1998 to address this complex area.

The vision and roadmaps identified specific goals adopted by the industry, which include the following:

- Improve the energy efficiency of the smelting process by 13 percent within 10 years and by 27 percent in the longer term.
- Eliminate (process-produced) CO_2 emissions in the long term.
- Develop new uses for wastes/byproducts to reduce waste emissions and improve efficiency and costs.

R&D Challenges. The aluminum industry roadmap organizes technology needs into three categories: Primary (including recycling) Aluminum Production; Semi-Fabrication Production (subdivided into Casting and Rolling/Extrusion); and Finished Products. (DOE will be supporting the first two categories; finished products are left for private sector R&D.) They are further prioritized and categorized into short-, mid-, and long-term needs. DOE’s overlaid priorities stress the smelting portion of primary aluminum production (since the majority of energy use and emissions occur in that process) as well as methods to improve production from recycled aluminum, which only consumes about 5 percent of the energy as primary production.

The main challenge involves eliminating the inherent deficiencies in the traditional Hall-Heroult process. The process involves a carbon anode with molten cryolite (a sodium-aluminum-fluorine compound) as the electrolyte and molten aluminum acting as the cathode in an electrolytic cell.

Electric energy plus consuming of the carbon anode leads to conversion of the raw alumina (Al_20_3) to aluminum plus CO_2. Variability in the process causes the emissions of perfluorocarbons. Electricity losses occur for several reasons including anode-cathode spacing requirements, partly due to undulating melt surfaces. The consumable carbon anode is also a major economic expense due to two- to three-week replacement. Improved cells in the short term leading to a totally new process in the longer term is the principal challenge.

R&D Activities. *Primary (including recycling) Aluminum Production*
Cathode research is investigating wettable TiB_2 cathodes and recent tests showed an 8 percent lower energy consumption over conventional cells. The wettable ceramic cathode, by eliminating the wavy irregular molten surface, allows the anode-to-cathode distance to be decreased, reducing electrical resistance. Research is continuing on materials, scaling issues, stability, and molten surface motions. If successful, commercialization by industry partners is expected by 2003.

Exploratory research on three advanced cell designs and several advanced anode materials was recently initiated. Statistical design and retrofit tests will be used to determine the most promising anode-cathode coupling and geometry. A retrofit advanced cell system will also require R&D on cell sensors and controls, advanced sidewall materials, new designs for cell heat control and management, as well as Bayer process improvements.

Other cell research including investigation of advanced sensors and probe coating materials to survive cryolite melt temperatures, improved potlining materials to enhance cell performance and pot life, and dynamic modeling to enable better control of cell and electric power load levels are all necessary to achieve significant cell improvements, stability, and reliability.

Some 1 million pounds of aluminum salt cake (spent salt fluxes, residue oxides, dross, etc.) could be reused and aluminum (and its energy content) and other byproducts reclaimed through reprocessing, which would provide major stimulus to aluminum recycling as well as aid secondary production. Four advanced processes have been examined and concentration is on an electrodialysis technique as the most promising. Studies of hydrometallurgical processes to improve the purity of nonmetallic byproducts (NMP) are also underway. Converting NMP to fiber insulation is in early commercialization by industry while research on alternative byproducts and electrodialysis is expected to reach pilot demonstrations by 2000-2001.

Several aluminum companies (Reynolds Metal Company, Aluminum Company of America (ALCOA), Northwest Aluminum, Kaiser Aluminum Corporation), other companies, ORNL, ANL, Ohio State University, and several other universities are involved in this program; several companies have developed commercialization plans pending successful R&D results.

Semi-Fabrication
The production of sheet, extrusions, and other intermediate products is a second area with potential for energy, waste, and environmental improvements. An innovative spray rolling technology to form sheets, in place of the current ingot casting, as well as near-net-shape products directly from the melt (reducing reheating steps), is under investigation by the University of California at Irvine. Better metallurgical and corrosion-resistant properties are possible due to

better microstructure control, and the technology requires less energy and generates less scrap than conventional processes. An oxygen-enhanced combustion melting system developed by Air Products & Chemicals, Inc., will be incorporated as a retrofit to reverberatory furnaces commonly used for melting recycled aluminum. The high-efficiency, high-capacity, low-NOx technology will also be applicable to other metal melting operations. The Innovative Vertical Flotation Melter (VFM) and Scrap Dryer will offer an advanced remelting process for recycled aluminum of various shapes and sizes that saves energy, reduces dross, and reduces air emissions from secondary aluminum melting. The Energy Research Company has led this design effort.

An additional method of producing near-net shapes is an innovative semi-solid material (SSM) process. Cast parts are produced from a slurry kept at a temperature between the solidus and liquidus isotherms exhibiting both solid- and liquid-like behaviors. It can combine the advantages of both liquid metal casting and solid metal forging. This is a longer term, more advanced technology and the current objective is to achieve a better understanding of the fundamental issues concerning material behavior. Research includes numerical simulation to predict die filling and, ultimately, die design optimization; fluid models modified to account for the two-phase nature, obtaining rheological data needed for the modeling; and the effects of slurry structure on flow behavior and separation. If successful, energy reductions due to lower temperature processing and increased productivity due to shorter solidification times and longer die life will occur; quantified goals await further research. Participants include MIT, Worcester Polytechnic Institute, and ORNL; a consortia of over 20 industrial partners are cost-sharing and will share research results.
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Accomplishments. An early version of a new technology cathode element was tested in a full-scale pre-bake cell in a collaborative project between DOE, Kaiser Aluminum Corporation, and the Reynolds Metals Company at a Kaiser plant. Test results showed an 8 percent energy savings compared to a conventional cathode with no decrease in aluminum production, although continued research is required to provide the required long-term material strength and longevity.

Steel

Budget: FY99-$10.3M, FY00-$10.6M, FY01-$10.9M

Description, Objectives, and Performers. The steel industry uses about 1.8 quads of energy and emits about 35 MMTCE to produce about 100 million metric tons of steel annually. This energy costs some $7 billion annually and represents 12 percent of total production costs. Over 50 percent of new steel production is made from recycled scrap. Steel production is a major generator of carbon dioxide and other pollutants, and the industry has invested more than $6 billion in control equipment in the last two decades.

The industry's vision document, "Steel: A National Resource for the Future," was released by the American Iron and Steel Institute (AISI) and Steel Manufacturers Association (SMA) in May 1995; an R&D compact was first signed by DOE and the AISI and SMA in May 1995, and was updated in February 1999. A technology roadmap was released by the steel industry, as represented by AISI and SMA, in March 1998. Research priorities emphasize energy efficiency, environmental protection, greater use of recycled steel, reduced capital intensity, less waste production, and improved productivity. Long-term goals of the industry include zero waste production, and recycling of 70 percent of scrap steel.

R&D Challenges. In the February 1999 compact, four key areas were identified by industry: (1) production efficiency, (2) environmental engineering, (3) recycling, and (4) steel processing efficiency. DOE collaborates in all of these areas. A long-term, high-priority challenge is the ability to develop alternative iron smelting processes that produce liquid iron directly from coal and ore fines or concentrate. This would eliminate the steps of cokemaking and blast furnace ironmaking, leading to larger reductions in costs, energy consumption, and emissions. Another major challenge is the need to develop net-shape casting processes that could enable the cast surface to become the finished part surface. This requires a degree of consistency and a nearly defect-free surface in continuous cast steel that is not achievable by current technology. To obtain this accuracy, there must be improvements in modeling and sensors and controls, including real-time optimized computer-based control of the entire production cycle.

R&D Activities.

Production Efficiency

Research in this area includes advanced process control projects to improve the efficiency and productivity of major pieces of process equipment though better sensors and more rapid and precise control of the process. For example, in "Microstructure Engineering in Hot Strip Mills," a computer tool is being developed by the University of British Columbia and the National Institute of Standards and Technology (NIST) to provide on-line control over the quality and yield of hot-rolled steel. Sandia National Laboratory, Berry Metal Company, and others are developing sensors for the basic-oxygen-furnace (BOF) capable of on-line measurement of off-gas temperature and composition and bath temperature from within existing oxygen blowing lances. Both these technologies are undergoing field testing at Bethlehem Steel's Sparrows Point, Maryland, plant. A temperature measurement technology using phosphor thermography developed at ORNL is being further developed by ORNL, the University of Tennessee, and Bailey Engineers to assure accurate on-line temperature control of galvannealing furnaces. Other efforts include research being conducted on reducing refractory wear in electric arc furnaces in collaboration with the Steel Manufacturers Association.

Environmental Engineering

Research is aimed at reducing NO_x emissions and increasing efficiency in combustors for various steel processing applications. Typical of the combustors under development is the "VISTA Combustor for Very Low NO_x Emissions in Furnaces and Boilers," which can theoretically reduce NO_x emissions to less than 10 ppm after the second stage. The low-emissions burner can be retrofitted to intermediate-temperature industrial systems to meet environmental standards, increase energy efficiency, and improve mill productivity. The Thermo Power Corporation and John Zink Company are conducting this research.

Recycling

Projects include "Atmospheric Gas Recovery and Regeneration in Heat Treating Operations," a membrane technology for recovering, cleaning, and reusing more than 90 percent of the furnace atmosphere gas discharged in present systems after carburization. The technology also removes air pollutants, avoids the production of waste, and offers the potential for heat recovery from the clean gas. Partners include the Dana Corporation and the State of Minnesota.

Accomplishments. Following the successful Burns Harbor Showcase of May 1998, a regional technology showcase has been scheduled for spring 2000 to support the steel industry in the Pittsburgh area. The showcase will publically celebrate the industry's national importance, and use of advanced technologies. Partners in the showcase are the State of Pennsylvania, American Iron and Steel Institute, and Steel Manufacturers Association. The Federal Government was awarded a small royalty check in 1999 as its 25-percent royalty share of an advanced process control system that has been commercialized. The technology was designed to measure the temperature of galvannealed strip, and was licensed to Bailey Engineering. It was the first royalty payment to the government under a DOE/industry partnership that provides public funding for R&D.

Metal Casting

Budget: FY99-$5.7M, FY00-$5.8M, FY01-$5.8M

Description, Objectives, and Performers. In the United States, castings are used to produce 90 percent of all manufactured durable goods and nearly all manufacturing machinery. The United States produces 20 percent of the world's cast products, and in 1997, shipped more than 14 million tons of castings, with sales worth $22.7 billion. Metal casting is highly energy-intensive, using 0.25 quads annually; energy expenditures in 1994 were $1.1 billion, equal to 5 percent of the value of that year's shipments. This industry recycles 15 to 20 million tons of scrap annually, generating $3.5 billion in cost savings, but spends more than $300 million on pollution control technologies and produces 1.6 MMTCE.

The industry's vision document, "Beyond 2000: A Vision for the American Metal Casting Industry," was printed in September 1995, and a compact between the industry and DOE was signed in October 1995. Seven critical areas were identified: market development; materials technologies; manufacturing technologies; environmental technologies; human resources, education, and training; health and profitability; and partnerships and collaboration. A series of key challenges included reducing energy consumption by 20 percent by 2020. Additional goals relevant to DOE included developing materials technologies; developing advanced manufacturing technologies to increase productivity 15 percent, and reduce average lead times 50 percent; developing environmental technologies to achieve 100 percent recycling of pre- and post-consumer waste, a 75 percent beneficial re-use of foundry by-products and total elimination of waste streams; and encouraging partnerships and collaborations.

The "Metal Casting Industry's Technology Roadmap Workshop," published in January 1998, identified top priority research needs including the development of low-cost, rapid tooling technology for both making and changing metal casting tooling, improvement in the ability to produce the desired size and dimension of castings, and development of modeling technology for casting processes to gain precise understanding of how die-casting dies actually fill. The Cast Metals Coalition (CMC) and the societies that comprise it–the American Foundrymen's Society (AFS), North American Die Casting Association (NADCA), and Steel Founders' Society of

America–have worked closely with DOE, industry, and researchers to implement a program of research for achieving the goals set forth in the vision and roadmap documents.

Since its inception, the Metal Casting program has awarded over 80 projects to address industry research priorities in the vision document. Nearly all of this research is performed at the university level, contributing to the education and human resource development goals stated by industry. There is also broad participation by industry. More than 250 industry partners from more than 30 states have taken part in these research efforts.

R&D Challenges. Current metal casting processes are diverse and vulnerable to stringent environmental regulations and increased global competition. The thermodynamics and fluid flow of molten metal into and throughout molds is a complex dynamic phenomenon with a multiplicity of poorly understood factors. Small variations in internal surfaces, mold materials, initial temperatures and cooling rates, internal geometry, the molten metal's specific properties, and many other conditions can have a significant effect on the end product. Moreover, the energy consumed in the overall process, as well as the embedded energy in the cast product and waste, including rejects and excess material (hence the importance of near-net-shape casting) is significant and can be reduced by having a better understanding of the complex molding process. Inclusions, product characteristics and tolerances, weaknesses, costs, reject rates, and throughput are all factors that affect the capability of the industry. Research in low-cost rapid tool making using superior materials, defect-free and dimensional control of castings, advanced sensing and modeling capabilities, improved design standards, and re-use of foundry sand and other solid wastes will make the metal casting industry the preferred supplier of near-net-shape metal components beyond the year 2000. Projected benefits by the year 2020 include a 10 percent market increase, 0.018 quads of energy savings, 100 percent pre- and post-consumer recycling, and 75 percent re-use of foundry by-products.

R&D Activities. The program is co-funding research in the areas of materials technologies, manufacturing technologies, products and markets, and environmental technologies.

In the area of *Materials Technologies,* the program is co-funding fundamental research to advance technology for producing clean, machinable gray iron, and ductile iron parts. By improving machinability, closer tolerances can be obtained between pistons and cylinder walls thereby improving fuel efficiency in automobiles and trucks. In another project, "Improve the Die Life of Die Casting Dies of H-13 Steel," researchers published a database of physical and metallurgical properties of H-13 steel to predict die properties during the heat treating cycle. They also developed a PC-based computer model for use in the die casting industry to optimize mechanical properties with minimal distortion.

In the area of *Manufacturing Technologies,* research is conducted on tools, sensors, and modeling to improve die-cavity filling for higher-quality castings, extend die life, and minimize part distortions for die-casting aluminum, magnesium, and zinc alloys. Guidelines are being developed for advanced casting technologies to produce higher-quality, higher-integrity castings.

In the area of *Environmental Technologies*, the program co-funded an evaluation of energy use in foundry industry processes including melting, molding, cleaning and finishing, and pollution control. An Energy Manual and Spreadsheet model were developed to assist the industry in identifying major energy load centers and to identify measures for reducing energy consumption.

In the area of *Products and Markets*, the program is co-funding research in the Development of Database Design Rules for Cast High Alloy Steel Components. These materials have properties that allow casting designers to use thinner walls, which will reduce energy costs in product markets.

Accomplishments. The Lost Foam process advantages of reducing machining, minimizing assembly operations, and reducing solid waste and emissions were never realized due to a lack of knowledge of the process and the absence of proper control measures. The Lost Foam Consortium, funded in part by the program, led to advances in controlling the lost foam process including new procedures introduced in lost foam casting as well as control technologies. These measures have been proven in the foundry in reducing defects and producing higher quality, higher precision lost foam castings. Specific developments include a single stage air gauging system followed by a 30-channel commercial air gauge for rapid determination of pattern dimensions, instruments and transducers for measuring vibrational frequencies and amplitudes, a distortion gauge to determine when and under what conditions pattern distortion occurs, instrumentation for measuring gas permeability of pattern coatings, and a procedure to measure liquid absorption characteristics of liquid pattern pyrolysis into castings. Since 1990, there has been a significant increase in the use of the process and by 2010, about 29 percent of aluminum castings and 15 percent of iron castings are expected to be cast using lost foam technology, equating to energy savings of 4.6 trillion Btus/year by 2010, environmental savings of 0.45 million tons of waste, and energy cost savings of $16 million.

Forest Products

Budget: FY99-$11.8M, FY00-$12.1M, FY01-$17.1M

Description, Objectives, and Performers. The U.S. forest products industry represents 8 percent of the manufacturing sector’s total annual output, and had shipments valued at more than $267 billion in 1996. With 1.4 million employees, the industry is a “top-10" manufacturing employer in 46 States. Although the industry uses renewable biomass fuel for 57 percent of its energy needs, it remains among the most energy-intensive of the Industries of the Future, consuming 3 quads of energy annually at a cost of $8 billion. Pollution abatement measures add about $3 billion annually in both capital and operating expenditures to the industry’s production costs. Annual production of hazardous wastes is more than 2l9,000 tons. Emissions of direct carbon equivalents were 36 MMTCE in 1994.

A compact for cooperative research with DOE was signed by the forest products industry in 1994. “Agenda 2020: A Technology Vision and Research Agenda for America’s Forest, Wood and Paper Industry” was prepared in November 1994. This vision document defined six areas that were considered high-priority for future R&D efforts: (1) Sustainable forest management, (2) environmental performance, (3) energy performance, (4) improved capital effectiveness, (5) recycling, and (6) sensors and control. The industry's "Agenda 2020 Implementation Plan" (roadmap) was published in 1999.

R&D Challenges. The forest products industry faces significant R&D challenges to meet changing standards and regulations while remaining economically viable and competitive. The industry's high capital intensity and the resulting economic consequences of equipment replacement tend to limit development and application of large, new core technologies. A major technical issue facing the paper industry is the environmental impact of mills. A zero discharge concept has been envisioned by the industry called "mill closure." Current separation technologies do not adequately control or remove the non-process elements that build up in the reused water streams. Inherently more efficient, safer, and lower-cost process technologies and systems are needed. Currently targeted is a replacement technology for the Tomlinson Chemical Recovery Boiler, one of the major components of current paper process technology. Existing recovery boilers are expensive to construct and operate and involve significant environmental and safety issues and costs. Most were constructed during the 1950s and 1960s and are nearing the end of their effective lifetimes; hence, a window of opportunity exists over the next decade in which to introduce major new approaches. Advanced black liquor gasification technologies hold the promise of significant improvements to performance, environmental and safety benefits, and energy and economic improvements, but will require advances in materials, sensors and controls, and system operating parameters.

R&D Activities. *Sustainable forest management*
R&D is being directed along four different "research pathways" to achieve more productive and environmentally sustainable tree stands: biotechnology, tree physiology, soils, and remote sensing. A current effort is the "Sustainability of High-Intensity Forest Management" project in which ORNL is quantitatively measuring the physical and chemical changes in farmland soils after they are converted to the production of intensively managed forests. The "Pine Gene Discovery Project" of North Carolina State University involves isolating and determining the functions of many of the genes expressed in loblolly pine, in order to improve the planting stock for the species.

Environmental Performance
DOE is supporting the research pathway to develop alternative pollution-prevention processes. Efforts include the project, "VOC Control in Kraft Mills," in which Georgia Institute of Technology is developing a computer model to predict the formation and release of VOCs in kraft mill waste streams and a membrane separation technology for VOCs, and Auburn University's work on a water recycling/removal process for the industry using hydrogels to absorb large amounts of water. Additionally, Auburn University and IPST are studying bio-bleaching technologies for producing a high yield of bleached kraft pulp cost-effectively, with few environmental effluents, using a laccase-mediator enzyme system that selectively removes 55 percent of the residual lignin.

Energy Performance
Research on manufacturing process efficiency and heat recovery includes the “Design and Demonstration of Multiport Cylinder Dryers,” involving cylinder redesigns with the potential to increase the drying rate of paper by 30 percent over that of existing dryers. Research has been funded in FY 2000 to look at the environmental impact of energy production and utilization and provide the industry with optional methods in such areas as combustion, the wider use of renewable resources, and fuel production and enhancement. A study in Black Liquor Gasification kinetics by Air Products & Chemicals, Inc. and IPST will develop a new energy efficient and low-carbon-emitting technology to replace older recovery boilers in the pulp and paper industry.

Capital Effectiveness
This pathway involves research on materials and coatings, and lower-cost process alternatives. The Institute of Paper Science and Technology (IPST) is studying the fundamental chemical and physical behavior of sodium carbonate and sodium sulfate, in order to minimize fouling problems in black liquor concentrators.

Recycling
Research on improved separations includes Thermo Black Clawson’s project on a revolutionary screening device to remove contaminants from pulp slurry with an energy savings of 80 percent compared to current techniques. Sparktec Environmental is studying the feasibility and economics of applying pulsed power technology to deliver a shock wave to the pulp slurry, generating hydroxyl radicals that oxidize stickies in the slurry as well as disperse them mechanically. For the longer term, research is expected to also include new technologies for sludge use and disposal, fiber-fiber bonding, and sorting and collection tools.

Sensors and Controls
Research is undertaken on control devices, process measurement and diagnostics, process and product models, data presentation and interpretation, and control system effectiveness. R&D on a “Distributed Web Sensor for On-Line Measurement of Paper Basis Weight” is part of a multi-faceted effort to provide the paper industry with real-time techniques to monitor the moving web. Nuclear instrumentation will detect beta particles transmitted by the web. The sensor for paper basis weight would improve product quality and productivity for the industry, and reduce its processing wastes. IPST’s project, “On-Line Fluidics Controlled Headbox with Coanda Jet,” uses the science of fluid dynamics to control the orientation of fibers when the pulp slurry leaves the headbox and enters the forming section of paper-making machines. This “conanda jet” concept will improve the structural formation of the sheet, create a better paper product, and reduce industry’s costs for energy, fiber, and water.

Accomplishments. The Black Clawson Company commercialized a cleaning technology for paper recycling that allows the use of lower grades of recycled paper without compromising the quality of new paper. This technology will help meet industry’s year-2000 goal of recycling 50 percent of all used paper. It also achieves greater efficiency while using less energy. By 2010, estimates are that energy used for processing recycled paper will be reduced by 0.1 quads/year, and CO_2 emissions will decrease 0.6 million tons. This research involved a 45 percent industry cost share.

"Low-VOC Drying of Lumber" is a successful project that is moving into the pilot stage. IPST has developed a pilot scale, radio frequency-induced unit to remove VOCs from softwood lumber prior to conventional drying. The technology reduces VOC emissions during the drying process as well as energy and other industry costs. The Institute of Gas Technology's METHANE de-NOx® technology is undergoing demonstrations in several commercial settings, using the industry's biomass by-products (e.g., wood waste and sludge) as fuel. Combustion systems are expected to operate more efficiently, require less maintenance, and emit significantly fewer emissions of NOx, VOCs, and CO compared to conventional reburning and cofiring methods using these fuels. NREL has adapted infrared technology to field-mobile and on-line sensors that monitor the manufacture of wood and paper products in real time. These "Feedstock-to-Product Characterization Tools" have been verified in a wood-chip stream at a demonstration plant. IPST's successful acoustic radiation technology is also being demonstrated in a mill, to separate fibers based on fiber width and clarify mill water streams.

Glass

Budget: FY99-$4.7M, FY00-$4.8M, FY01-$4.8M

Description, Objectives, and Performers. The glass industry produces 21 million tons of consumer goods annually valued at $22 billion. Glass making is highly energy-intensive consuming 170 trillion Btus in 1994, equal to about 15 percent of production costs. Theoretically, glass making requires 2.2 million Btu of energy to melt 1 ton of glass, but twice that amount is actually used because of inefficiencies and losses. Improvements in processing technologies have helped reduce energy consumption in glass making 25 percent in the last 15 years, and industry's goal is to reduce energy consumption by 50 percent (thus approaching the theoretical energy-use limits) by using more efficient technologies and processing operations, and increasing the use of recycled materials. The environmental impact of glass making is relatively benign, although the direct carbon emissions from the glass industry are 2.96 MMTCE annually.

The industry is divided into four specialized areas: glass/glass packaging, flat glass, fiberglass, and specialty glass. Recognizing the need for research partnerships and advanced technologies to ensure its future viability, the industry signed a compact with DOE and produced its vision document in 1996, entitled "Glass: A Clear Vision for a Bright Future." More than 60 priorities for R& D were identified at a Glass Technology Roadmap Workshop the following year, based on their potential for saving energy, increasing productivity, and enhancing environmental performance during the glass making process, and on developing innovative uses for glass. A solicitation for proposals has generated more than 50 responses from interested researchers since the workshop, and the R&D collaboration is moving toward implementation.

In addition to reducing energy use 50 percent, goals of the vision document include reducing production costs at least 20 percent below 1995 levels, recovering and recycling 100 percent of consumer glass products in the manufacturing process, lowering air and water emissions a minimum of 20 percent, improving quality control during production, creating innovative products and broadening the marketplace, and increasing supplier-customer partnerships.

Recently, the glass industry formed the Glass Manufacturing Industry Council (GMIC). This organization serves as the focal point for collaborative research and development efforts with the Department and is representative of all four segments of the glass industry.

R&D Challenges. Current sensors and control systems require significant advances to achieve energy and cost reductions as well as better product control. In particular, systems must be integrated across the overall process and also improved for both specific and integrating process components in order to improve efficiency. Sensors better able to survive the temperatures and environments in the process are needed to enable real-time control. High-temperature refractory and non-refractory materials beyond those available today, and which do not affect product properties, are also required. Progress is also hindered by a lack of understanding of some fundamental process mechanisms influencing particulates.

R&D Activities. The roadmap calls for technological improvements in four areas: production efficiency, energy efficiency and conservation, environmental protection and recycling, and innovative uses for glass. Key priorities of the industry include development of refractory materials, optimization of oxygen fuel, and modeling of furnace operations. A specific activity will be work on predictive tools for emissions modeling.

Production Efficiency

The "High-Heat Transfer Low-NO_x Natural Gas Combustion System" will optimize the oxy-fuel system already being implemented by many companies for glass-melting processes. The system offers good heat transfer, increases energy efficiency 20 percent, and enhances process efficiency. The technology involves increasing the flame luminosity by seeding the flame with soot particles that are burned out later in the flame. The project partner is AccuTru International Corporation.

Energy Efficiency and Conservation

A "Sensor Technology Advanced Research" effort is underway that will be applicable in all four segments of the glass industry. The new sensor will provide more accuracy, reliability, and ability to withstand thermal shock, and will be long-lived, easily replaced, and interchangeable. Improvements in energy efficiency, product quality, waste minimization, and cost efficiency are expected. The project has a refractory materials component that makes it useful for more efficient production. The material, molybdenum disilicide, has the potential to improve the inside walls of the glass furnace itself above and below the molten glass surface because it is resistant to corrosion. The research partner is AccuTru International Corporation. The Johns Manville Corporation studied the performance of molybdenum disilicide-coated refractory bricks in industrial oxyfuel melting furnaces.

Environmental Protection

"Glass Furnace Side Port Oxygen Enrichment" technology is being developed that will use a low-cost nitrogen oxide reduction technique on an industrial sideport furnace. (Sideport furnaces are used for 65 percent of U.S. glass production.) The system reduces the amount of oxygen available to the flame's high-temperature zone, improves the flame temperature's uniformity, and improves heat transfer to the glass, without interrupting furnace operation or affecting product quality negatively. Benefits of the technology include reduced energy use, waste and emissions production, and costs, and increased productivity. Several organizations are conducting this research, including the Institute of Gas Technology and Owens-Brockway Glass Container, Inc.

Innovative Uses of Glass
The "Development of Advanced Energy-Efficient Coatings for Sunbelt Low-E Coatings" has developed a method to apply coatings directly to glass, using a vapor deposition process. When installed in place of clear glass in windows, coated glass saves 1.4×10^{19} Btu/year of energy. Since it decreases UV transmission, there are also energy savings in the end-use market. The on-line deposition of coatings is faster than in batch coating, resulting in improved productivity. The glass is applicable to the residential, commercial, and automotive market. Sandia National Laboratories and Libbey-Owens-Ford Company collaborated on this research.

Accomplishments. Virtually all segments of the industry have implemented oxy-fuel furnace technology. The "Oxy-Fuel Firing,"or "Oxygen-Enriched Combustion System" for glass melting furnaces developed by Praxair, Inc. and OIT has been commercially successful. Companies adopting oxy-fuel firing in place of regenerative-type furnaces have reduced specific fuel use by 48 percent, NO_x emissions by about 70 percent, and particulate emissions by 60 percent, and increased their production rate by up to 25 percent. The quality of glass produced is more consistent, and furnaces converted to this type of combustion need to be replaced less frequently than regenerative systems. Over 20 percent of glass furnaces have converted to the technology.

"Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser" is a technology to replace conventional glass-cutting methods that may have resulted in an 80 percent loss of product. FETC, West Virginia University, and two manufacturers developed a laser-enhanced cutting and finishing method to reduce waste, energy use, and hazards to workers. A bench-scale prototype system is available to any company interested in testing it.

Chemical

Budget: FY99-$12.1M, FY00-$12.5M, FY01-$12.5M

Description, Objectives, and Performers. The chemical industry is the most diverse of U.S. industries, represented by about 10,000 corporations producing more than 70,000 different products that are classified under eight standard industrial classification codes. The industry consumes over 6 quads of energy annually. The industry's products fall into three categories: (1) basic chemicals, (2) chemical products needed in manufacturing processes, and (3) finished chemical products that will be consumed or supplied to other industries. As the world's largest producer of chemicals, the U.S. chemical industry shipped $372 billion worth of products worldwide in 1996, creating one of the largest trade surpluses of any industrial sector ($21.2 billion in 1996).

The industry prepared its vision statement, "Technology Vision 2020: The U.S. Chemical Industry," in 1996. Four technical disciplines were identified as crucial to the chemical industry: new chemical science and engineering technology, supply-chain management, information management systems, and manufacturing and operations. DOE research focuses principally on the first area. The vision process involved the American Institute of Chemical Engineers, the American Chemical Society, the Chemical Manufacturers Association, The Council for Chemical Research, and the Synthetic Organic Chemical Manufacturers Association, as well as a significant number of companies and research organizations.

The size and complexity of the industry make it impractical to develop a single technology roadmap. To date, three areas of the industry have been analyzed in depth under new chemical science and engineering, and roadmaps have been prepared for computational fluid dynamics (CFD) (1997); the separation technologies (adsorption, crystallization, distillation, extraction, membrane processes, and separative reactors) (1998); and computational chemistry (1998). Roadmapping was also completed for chemical process plant materials of construction, with emphasis on high-temperature, corrosive-resistant materials. Workshops were held on biocatalysis, sponsored by the Council for Chemical Research, and on reaction engineering, sponsored by the American Institute of Chemical Engineering. Roadmaps will be published on these meetings. Additional areas of high priority are catalysis, chemical synthesis, separations for industrial biotechnology, electrotechnology and alternative reaction mechanisms, and chemical measurement. Catalysis impacts about 90 percent of the chemical industry's processes.

R&D Challenges. Current technologies limit the ability to control major processes to the degree needed for significant improvement. In addition, several types of separation technologies, such as distillation, require considerable energy. Some processes involve the need for toxic solvents or involve such materials; new membranes and catalysts could lead to advances in using alternative products and feedstocks. Advanced mathematical modeling, particularly for multi-phase flows, and better real-time controls along with advanced sensors could enable much of what is today an "art" to become a much more highly and accurately controlled process.

R&D Activities. In February 1997, the Department signed a Memorandum of Understanding with the chemical industry for identifying appropriate areas for joint research with the focus on "New Chemical Sciences and Engineering" and the research areas described above.

Computational fluid dynamics (CFD) has become one of the more important engineering and analysis tools for the chemical industry over the past decade. As the result of many new developments, the predictive power of CFD for single-phase flow (for example, a single liquid) for process design and control is undisputed. The use of CFD for multi-phase flows (gas and solid together, for example) is far less well developed; however, industry believes the potential value would be at least as great as single-phase flow CFD. To achieve significant progress in the application of CFD to resolve difficult problems, such as flows in process equipment that cannot be seen, DOE has entered a partnership with seven DOE National Laboratories and industry for the development and commercialization of multi-phase CFD technology. A five-year development effort is underway.

Separations science and technology is of significant interest to the chemical industry. Separations processes represent up to 70 percent of capital and operating costs and account for nearly 45 percent of the energy used in the chemical processing industries. Investigators are studying the production of ethylene from ethane using a new catalytic autothermal oxydehydrogenation process that will be more cost-effective and produce less NOx and CO_2 than the conventional steam cracking method for olefin production.

Work in biocatalysis includes the development of active and stable biocatalysts as commercial alternatives to chemical processing. Manufacturers in several industries who require polyphenols or propylene oxide in processing will save costs by deriving them biocatalytically. Research is also underway to develop a catalyst to conduct oxidative dehydrogenation for producing ethylene, propylene, butenes, and olefin derivatives. This technology will produce energy and environmental benefits for the industry as well as savings in downstream processing. Another research effort would replace the current energy-intensive methanol synthesis process with alkane functionalization catalysis for direct conversion of alkanes.

Collaboration is underway between DOE's Office of Science and DOE's Office of Energy Efficiency and Renewable Energy in nearly a dozen Small Business Innovation Research projects for basic research in new and advanced membrane separation technologies. Projects were also awarded in two additional topic areas—reactive separations and alternative reaction conditions.

In the electrochemical field, Los Alamos National Laboratory is developing chlor-alkali electrochemical reactors that will potentially lower the chemical industry's operating costs. The research could result in a new electrochemical reactor that reduces total electric power consumption by the chlor-alkali industry by 30 percent and reduces CO_2 emissions from U.S. electric power generation by 0.6 percent.

In the catalysis field, the "Low Temperature, Aqueous Phase Catalytic Gasification" project has recently undergone a successful full-scale demonstration at the DuPont plant in Beaumont, Texas. The system is a catalytic process for destroying organic contaminants in industrial process streams and for producing clean water and a fuel gas. The process is an alternative to the deep-well injection of these wastes, and negotiations are underway between Battelle Memorial Institute and DuPont to optimize the application for future commercialization.

Accomplishments. The "Membrane Vapor Recovery System, VapoSep" for the recovery of VOCs from air was awarded the 34th Kirkpatrick Chemical Engineering Achievement Award by the American Institute of Chemical Engineers in 1997. This membrane system is starting to be widely used in the chemical, petrochemical, and pharmaceutical industries.

The "Novel Membrane-based Process for Producing Lactate Esters" received high recognition during this past year as winner of the 1998 Discover Magazine Award for Technology of the Year, winner of the 1998 Green Chemistry Challenge Award, and winner of the 1997 Thiele Award for Engineering. Developed by Argonne National Laboratory in collaboration with NTEC, Inc., this technology is an entirely new process for the production of marketable nontoxic solvents. This process has the potential for replacing 80 percent of the 3.8 million tons of halogenated toxic solvents used annually in the United States with biomass-based solvents.

The 1999 Presidential Green Chemistry Challenge, Small Business Award, was given to a technology utilizing levulinic acid, derived from waste paper sludge and other biomass at low cost, as a feedstock to synthesize chemicals such as succinic acid and methyltetrahydrofuran (a fuel additive to increase gasoline oxygenates). Biofine, Inc., NREL, and PNNL were partners in developing this technology, which has been commercialized.

Mining

Budget: FY99-$2.0M, FY00-$3.0M, FY01-$4.0M

Description, Objectives, and Performers. Essentially all manufacturing starts with raw materials which are mined and processed. Miners work in all 50 States, contributing $39 billion per year in economic value. Mining operations and processing of coal, metals, and industrial minerals (except for aluminum and steel) consume almost 1.2 quads of energy annually. Over 30 percent of the Nation's energy supply, including more than 75 percent of the energy used in electricity generation, comes from mining.

R&D Challenges. The key R&D challenges were identified during the development of the "Mining Industry Roadmap for Crosscutting Technologies" published in February 1999. Research pathways were established in three areas: Exploration and Resource Characterization, Mining and Extraction, and Mineral Processing. Goals will be further codified in future roadmaps focused on processing and mining technologies.

R&D Activities. The National Mining Association signed a compact with DOE in June 1998, and the mining industry published a vision, "The Future Begins with Mining," in September 1998. Research based on the "Mining Industry Roadmap for Crosscutting Technologies" was initiated following a competitive solicitation in FY 1999, and work will begin on several new projects following the solicitation for FY 2000 funds currently in progress.

Accomplishments. As a new initiative, accomplishments have been primarily in the areas of planning and outreach. Ten projects have been initiated, and some near-term successes are anticipated as soon as FY 2000.

Agriculture

Budget: FY99-$2.0M, FY00-$4.0M, FY01-$13.0M

Description, Objectives, and Performers. Agriculture represents about 14 percent of the U.S. GDP with exports worth $60 billion providing a trade surplus of $36 billion. The agriculture industry is extremely broad and diverse and has traditionally focused on producing wide varieties of food, feed, and fiber. Trees and plant matter have the potential to reduce fossil fuel consumption, as well as climate change effects, through their substitution for petroleum as feedstocks for producing products such as paints, plastics, and adhesives. These also provide additional markets for the agricultural industry, and it is believed that 0.35 quads of energy could be saved by 2020.

In 1995, a Memorandum of Understanding was signed by the Secretaries of DOE and the United States Department of Agriculture (USDA) to cooperate and coordinate technology research, development, transfer, utilization, and commercialization. The agriculture industry's first vision, "Plant/Crop-Based Renewable Resources 2020," was published in 1998, focusing on plant-based renewable resources as a long-range goal. A compact was signed by representatives of the U.S. agricultural, forestry, chemical communities, DOE, and USDA. This was the first time that this diverse set of American companies, nonprofit groups, trade associations, and academic institutions came together for a shared vision of the future for this emerging industry. The goal stated in the vision document is "to provide continued economic growth, healthy standards of living, and strong national security through the development of plant/crop-based renewable resources that are a viable alternative to the current dependence on non-renewable, diminishing fossil fuels."

The targets set in the vision document follow:

- At least 10 percent of basic chemical building blocks to be derived from plant-based renewables by 2020 (a five-fold increase).

- Plant-based systems to produce renewable feedstocks with efficient conversion processes for selected products by 2020.

- Collaborative partnerships among industrial stakeholders, growers and producers, academia, and Federal and State governments to help develop commercial applications and revitalize rural areas.

R&D Challenges. There is a need to identify genetic metabolisms and to be able to understand their pathways in order to effectively convert agricultural and forestry raw materials into chemical intermediates, in competition with hydrocarbons. To produce bio-based products, an understanding is required of how the fundamental properties of and variations in the agricultural raw materials relate to the industrial process needs. Increasing the productivity of fermenters while reducing their size, and increasing the efficiency of the separations process are also difficult technological steps.

R&D Activities. A primary barrier to using plant-based materials as feedstocks is the need to fit carbohydrate chemistry into processes based on hydrocarbons, that is, fossil fuels. Short-term R&D will call for modifying processes in order to economically use existing plant and crop materials. Longer-term R&D will apply recent advances in biotechnology to selected processing opportunities. Specific R&D goals were presented in the technology roadmap published in 1999. A solicitation was issued by DOE for selecting projects for FY 1999 funding based on the priorities identified in the roadmap. Six projects were funded in 1999–the first R&D projects for the Agriculture Team. They were all based on the processing and utilization barrier areas of the roadmap. Another solicitation will be run for FY 2000 funding.

The six projects include “Commodity Scale Thermostable Enzymatic Transformations” (Altus Biologics, Inc.), which will allow the direct conversion of glucose syrup to fructose syrup with significant energy savings. “Enhanced Utilization of Corn Based Polymer Materials” (Cargill Dow Polymers, Inc., NREL, and Colorado School of Mines) involves fundamental studies of a new environmentally benign plastic material, poly lactic acid (PLA). PNNL and Michigan State University will develop processes to convert corn-derived glucose to value-added chemicals through catalytic routes. A contract was awarded to PNNL, Pendleton Flour Mill, Inc., and Mennel Milling Company to develop an innovative process for recovering a starch-rich product from low-value mill feed and for converting it into a value-added product. Terresolve Technologies, Inc. will develop and screen a series of vegetable-oil-based, 2-cycle engine oils for use in water-cooled engines. The soy-based oils would protect sensitive aquatic environments when used in marine engines. The University of California, Davis, will develop a bioprocess that uses waste agricultural feedstocks to produce lactate ester.

Agriculture is helping to implement the President’s recent Biobased Products and Bioenergy Executive Order. A vision document will be produced that integrates issues concerning power, fuels, chemicals, and other biobased products from plant materials. A roadmap will then be produced.

Based on prior research (in the chemical program), a collaboration between ORNL, ANL, and industry is examining modifying *Escherichia coli* strands for the production of succinic acid from biomass. This could lead to an efficient biomass conversion process, reducing petrochemical feedstocks and energy, and sequestering CO_2 into commodity products.

Accomplishments. The Agriculture Team has a vision document and a technology roadmap in print. It issued an FY1999 solicitation and chose six research projects, and is moving forward to issue solicitations in FY2000 for new R&D projects and a new education initiative to encourage multidisciplinary graduate-level research.

Petroleum

Budget: FY99-$0.0M, FY00-$2.0M, FY01-$3.0M

Description, Objectives, and Performers. The refining industry is the largest single industrial energy user, consuming 3 quads (over 20 percent of all manufacturing energy), and is also a major energy supplier vital to energy security. It also produces 180 million tons of waste and has the highest pollution abatement costs as a percent of sales, nearly 4 percent.

The industry represented by the American Petroleum Institute, joined by the National Petrochemical and Refiners Association, has produced a vision and has held a technology roadmap workshop. The industry is arranging to sign a compact with DOE.

R&D Challenges. The petroleum industry vision and roadmap workshop identified a number of areas of emphasis:

- Energy and process efficiency.

- Environmental performance.
- Materials and inspection technology.
- Refinery distribution system and retail delivery.

Appropriate topics for industry-government collaboration can be identified within each of these areas. A solicitation based on three of these four areas is planned for early 2000.

R&D Activities. Several projects are underway using prior-year funds. The FY 2000 solicitation will initiate projects reflecting the vision and roadmap workshop.

Accomplishments. The use of biocatalytic desulfurization technology represents an energy efficient means to reduce the sulfur content of gasoline from the current average of 340 parts per million (ppm) to the level of 30 ppm proposed during 1999 by President Clinton. This approach will lower capital costs by 50 percent and operating costs by up to 25 percent relative to conventional technology. New microorganisms have been identified that represent an advance over those previously available.

Another project is designed to speed the detection of "fugitive emissions" due to leaking refinery fuel gas and other leaking hydrocarbons through the development of a laser-based imaging system to replace the current "sniffer" now used. OIT funding is making the imaging system more portable. With this improved measurement capability, leaks can be detected and repaired more frequently, thereby reducing refinery energy loss and regulated fugitive emissions.

Crosscutting Technologies

Budget: FY99-$48.0M, FY00-$53.6M, FY01-$59.8M

Background

There are several enabling or supporting technology areas which have been identified as key or priority needs in multiple industry roadmaps. (Some, such as Advanced Turbine Systems and Combined Heat and Power for on-site industrial use, contribute directly to other strategic goals and are hence described under those goals.) The industry roadmaps have assessed future material needs; combustion processes, either for steam or heat or in the process itself; advanced sensors and controls, particularly real time measurements in hostile environments to improve process quality and productivity; and energy and environmental issues.

In addition, the vast number of factories and plants across the United States, operating diverse manufacturing processes and production systems, producing enormous numbers of materials and products, requires that an effective system be developed and utilized to ensure the rapid adoption of new technologies, advanced techniques, and best practices. Without integrating such approaches as part of an overall R&D results deployment system, many technologies are slow to be adopted and some wither. Small businesses and factories are particularly prone to being unaware of the potential of energy efficient technologies and practices. By providing demonstrations of selected emerging technologies, showcasing and documenting advances and economic advantages that can be obtained, and developing and actively providing tools and information through collaborations with industry, stakeholders can accelerate the reduction in energy use and emissions, and reduce carbon emissions over the next decade–opportunities that would otherwise be lost.

Linkage to CNES Goals and Objectives

The program is in direct support of the following CNES goal and objective:

- CNES Goal I, Objective 2 - Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.

The goal of the program is to produce a 25 percent improvement in energy efficiency and 30 percent reduction in emissions for the vision industries by 2020. The strategy to achieve this, in addition to focusing resources on the most energy- and waste-intensive industries, is to partner with and across industries, and align industry and government resources to areas of greatest need.

Program Description

Research and development are undertaken on critical crosscutting technologies identified in multiple industry roadmaps, focusing on sensors and controls and combustion processes as well as on advanced industrial materials such as engineered ceramics, intermetallic alloys, and membrane materials that have applications in many industries. Financial support is also provided, through competitive solicitations, to inventors and small businesses, and through State governments to local industries, for developing inventions and innovations and for testing and demonstrating new technologies that emphasize applications to the Industries of the Future. Information dissemination, training, and showcasing concerning advanced energy efficiency technologies help in completing their development cycle and in continuing their development by the private sector.

Enabling Technologies

Budget: FY99-$18.8M, FY00-$22.5M, FY01-$22.00M

Description, Objectives, and Performers. Technology-based R&D, needed by multiple industries, is linked to the more fundamental basic research supported by the DOE Office of Science, as well as with R&D performed by FE and other DOE programs, and at times by other agencies. Materials research is coordinated through the DOE Energy Materials Coordinating Committee (EMaCC) by the exchange of planning and budgetary information and through bimonthly technical meetings on selected topics involving DOE and major contractors. The Department's program managers also participate in information and coordination activities under the Materials Technology (MatTec) subcommittee of the National Science and Technology Council (NSTC) Committee on Civilian Industrial Technology. In addition, R&D results on enabling technologies may be applicable to other industries beyond the Industries of the Future portfolio. Where the requirements are sufficiently defined and specific to a given industry, they are part of that industry's portfolio.

R&D Challenges.

Engineered Ceramics

U.S. industry has a critical need for materials that are lightweight, strong, tough, corrosion-resistant, and capable of performing at high temperatures. The availability of such materials will enable substantial increases in energy efficiency, reduction in emissions (such as NO_x, particulates, CO_2, and heat), and a decrease in life-cycle costs. Continuous Fiber Ceramic Composites developed to date have not provided adequate durability and reliability for many key industrial applications. In the early 1990s, continuous fiber ceramic composites were at a very early stage of development and too immature as a technology to be useful to industry. A study conducted by DOE concluded that investing in the development of these materials could provide substantial benefits to the U.S. industrial sector.

Advanced Industrial Materials

According to the National Materials Advisory Board, corrosion of metals in the United States costs about 4 percent of the gross domestic product. Using current methods of corrosion prevention on existing alloys could save about 15 percent of that cost, but development of new, corrosion-resistant materials, particularly with high-temperature fatigue resistance, could save even more. It is estimated that energy and production losses of 10 percent result from scheduled down time for maintenance and repair. Separations is another huge energy- consuming process that is predominantly carried out by distillation or cryogenic recrystallization. New, more robust, membrane materials for high-temperature chemical separations could save at least half the energy currently used for separations by the U.S. industrial sector.

Combustion Technologies

Fossil fuel combustion in boilers, furnaces, and process heaters is still at much lower efficiencies than is theoretically possible and can be improved through better fundamental understanding, modeling techniques, and real-time sensing and control of both existing and additional variables, particularly on large-scale units. Oscillating combustion requires additional understanding and development for applications beyond its initial use. Reducing emissions and maximizing the use of multiple fuels also require such advances.

Sensors and Controls (S&C)

The development and delivery of sensor and control solutions are critical to achieving the targets of reduction in energy use and carbon emissions by the Industries of the Future. Identified needs include advanced sensor technologies; improved information processing; and open-architecture, intelligent control systems. Challenges of the S&C program are to develop and deploy integrated measurement systems for operator-independent control of manufacturing processes with broad applicability across multiple industry sectors. Through development of improved sensor technology and information processing capabilities, the intelligent control system will be smarter and faster than the systems currently in use. The open-architecture control system will allow integration of a variety of modular plug-and-play elements such as sensors, actuators, control algorithms, and signal processing/modeling/simulation software to be adaptable and cost-effective to a broad spectrum of manufacturing processes.

R&D Activities.

Engineered Ceramics

In the area of advanced materials, engineered ceramics are being tested and developed for high-temperature applications. For example, in 1998, field testing was initiated at several industrial sites to evaluate CFCC radiant burner screens and immersion tube burners. CFCC radiant burners were tested in a glass plant and CFCC immersion tubes were tested in an aluminum casting plant in 1999. Also in 1999, CFCC combustion liners were tested for more than 5000 hours in a field test and installed in a commercial turbine at Malden Mills. CFCCs, in particular, have the potential for superior high-temperature strength, and resistance to fatigue, corrosion, and wear. Research involves materials development and characterization, fabrication and joining techniques, long term testing in various corrosive environments and temperature regimes, and the development of testing methods and data bases to facilitate other technology and engineering development. In 1999, standards for use in design and testing will be published. The CFCC program involves collaboration between industry, national laboratories and universities. The DOE laboratories, led by ORNL, are developing supporting technologies such as material design and processing methods and conducting performance evaluations. Five industry teams comprising 35 members (led by AlliedSignal Composites Inc., McDermott Technologies, Inc., Engineered Composites, Inc., General Electric Company, and Textron Inc.) are developing more than 20 applications.

Advanced Industrial Materials

The program concentrates on the development of selected new and improved materials to support critical industry roadmap needs, utilizing prior research from Energy Science and elsewhere. The results are transferred to appropriate IOF industry programs for further technology development and demonstration. For example, developments in intermetallic alloys and membrane materials have been transferred to the Steel, Chemical, and Glass Industry Teams. Support of new R&D in these two areas is continuing in FY 2000. A new nickel aluminide alloy has been developed for use at higher temperatures, and is being tested in industry. A nickel silicide alloy with superior resistance to acids has also been developed and will undergo testing in a wide variety of industries, most notably the chemical and refining industries.

A new method for heat treating, using infrared and plasma processes, is also undergoing testing by industry. The same heating systems are being used to develop new coatings to improve wear and corrosion resistance in the metalcasting, steel, and other industries. Following successful transfer of zeolite membrane and electrochemical reactor technologies to the Chemical Industry Team, AIM is now funding development of new phosphate and chirality-specific membranes for chemical separations and further applications of conducting- polymer technologies. Research into a new class of composites, made by reaction of molten metal with a porous powder compact, is continuing, and knowledge gained in the project has led to collaborative efforts to develop better refractories for the aluminum industry. The Metals Processing Laboratory User Center (MPlus) at Oak Ridge National Laboratory, initiated by AIM, continues to be a mechanism of choice for collaboration of industrial partners and is now receiving funding from the Aluminum, Metalcasting, Steel, and Chemical Industry Teams to work with their particular industries.

Combustion Technologies
This program is now focusing on achieving significant gains in efficiency and emissions reduction in boilers and process heaters through the initiation of two new projects based on the DOE-facilitated combustion vision and roadmap. A packed media/transport membrane boiler is designed to increase efficiency by 10 percent above current levels while lowering emissions to meet the most stringent current targets. A process heater for use by the chemical, petrochemical, and petroleum industries will utilize an original overall system design, a new low-emissions burner, and a close-coupled control system to optimize efficiency and reduce emissions. A 10 percent efficiency gain is projected. Heaters used by the target industries consume about 40 percent of the total process heat energy used in the United States.

Sensors and Controls
More than 200 needs for improved sensors and controls have been identified in the Industries of the Future technology roadmaps. The S&C program aims at delivering these needed solutions with broad applicability across multiple industry sectors, focusing especially on high-risk and high-payoff technology research, development, and demonstration activities. The initial focus of the program is on developing improved technology components ion sensors, measuring instruments, information processing, and supervisory and communications systems. This focus will later shift toward advancing micro fabrication technologies and integrating components into smart, automated control systems to achieve improved throughput and productivity. By 2009, the underlying science and technology for intelligent control systems will be significantly advanced, with ensuing implementation of customized applications of intelligent systems by the industry-specific programs.

Accomplishments. Nickel aluminide research has been highly successful, with successful demonstrations in steel mill transfer rolls, commercialization as forging dies and heat treating furnace fixtures, and ongoing trials in more than 30 other applications.

Technical Assistance

Budget: FY99-$18.6M, FY00-$19.8M, FY01-$25.8M

Description, Objectives, and Performers. This program will bring the full range of OIT's technical assistance and technologies to thousands of plant sites in an integrated package that is easy for industrial partners to access. A recent, highly successful showcase at Bethlehem Steel's Burns Harbor, Indiana, plant demonstrated a large number of advanced energy-efficient technologies to representatives across the steel and other industries. Best Practices helps plants and manufacturing companies benefit from new technologies and well-proven cost-saving opportunities in motor, steam, and other plant-wide systems. Additionally, the Industrial Assessment Center Program has pinpointed and analyzed opportunities in over 7,000 small manufacturing sites for saving energy, reducing pollution, and increasing productivity.

This approach will have an important role in launching new industrial technologies from the research and development stage to the manufacturing plant where the technology can be used to boost the productivity and competitiveness of U.S. industry. The goal of the program is to facilitate and promote the introduction to industry of near-term and emerging energy efficiency, renewable energy, and pollution prevention technologies.

Industry partners have requested a simpler, integrated package of industrial energy efficiency technologies and technical and financial services that is both flexible and easy to access. The strategy and implementation plans for this coordinated, integrated-delivery approach will concentrate on outreach and technical assistance to IOF companies and plants. However, the techniques and technologies are expected to spread across the spectrum of U.S. industry. In addition to deploying specific emerging technologies from the IOF R&D technology portfolio, technology resources are provided from several Best Practices (technical assistance) programs.

R&D Challenges. The principal challenge is to make it possible for the vast and diverse U.S. industry to have access to valid data and tools for evaluating the multiple advanced energy efficiency technologies and techniques that are emerging from the R&D pipeline in order to accelerate their adoption in pilot and full-scale use.

R&D Activities. *Best Practices Activities* build upon the crucial, unbiased tools and information that assist plant managers in making decisions about energy efficiency. Tools such as the Motor Master+ software, 3E Plus Insulation software, the Industrial Assessment Center (IAC) self-assessment workbook, and the IAC database will be enhanced and delivered to industry through various means, including trade and technical organizations (e.g., the Technical Association of the Pulp and Paper Industry, and the Association of Iron and Steel Engineers) and the Internet.

The core of the Best Practices delivery is the development of one-on-one partnerships with individual plants to showcase and adopt a broad spectrum of advanced energy efficient technologies and techniques. The activities will build upon the successful collaborative showcasing of energy efficient steel production at Bethlehem Steel's Burns Harbor plant, where a spectrum of DOE-developed technologies and techniques were shown in operation or through demonstrations and presentations to visitors from the steel and other industries.

Industrial representatives at all levels will be exposed to the complete suite of IOF's information, tools, and technologies that are available to help implement clean, cost-effective strategies, while improving American industry's "bottom line." An additional objective of the Best Practices strategy is to allow direct interaction with and technical assistance from higher-level manufacturing personnel than was previously possible, and to have a positive influence on decisions concerning energy, waste, and productivity. Factory assessments are part of this system, performed by a network of trained university staff and students located around the country and aimed at small companies and plants who need evaluations and assistance at the local level.

In offering this technical assistance, the IOF Best Practices strategy relies on the existing tools, services, and technology resources of key program elements.

The *Industrial Assessment Center (IAC) Program* provides assessments to small manufacturers in order to pinpoint and analyze opportunities for cost-effective energy, waste, and productivity savings, and at the same time provides hands-on training to engineering students in energy, waste, and productivity management practices. It is also the only program that provides engineering students with both theoretical and practical plant experience. This university-based program serves parts of 43 States through 30 university engineering departments.

Accomplishments. As a precursor to Best Practices, the Motor Challenge Program delivered information and tools to 8,000 facilities to optimize and upgrade their industrial energy systems. The combined savings from Motor Challenge activities, which encouraged a systematic approach, have been $25 million per year.

The Industrial Assessment Center Program has provided industrial assessments to over 7,000 plants. At one plastic molding plant, an IAC team was able to make recommendations that, when implemented, cost-effectively saved the company approximately $134,000 per year, and significantly reduced the amount of waste plastic involved in the process.

Key partners include the 30 universities that currently deliver IAC assessments; numerous trade and professional societies; motor, controls, compressor and boiler manufacturers and distributors; and others that support the Motor Challenge, steam, and compressed air activities, and the IOF companies involved in showcasing and other efforts.

Financial Assistance

Budget: FY99-$10.5M, FY00-$11.4M, FY01-$12.0M

Description, Objectives, and Performers. OIT has traditionally relied on two separate financial assistance programs: (1) the Inventions and Innovation Program and, (2) the National Industrial Competitiveness through Energy, Environment, and Economics ($NICE^3$) Program. These programs were designed to speed the development of new energy efficient inventions, and to leverage industry and other resources to demonstrate and promote the benefits of advanced energy-efficient industrial technologies. The Inventions and Innovation Program provides support to individual inventors and small businesses for the development of new energy efficient technologies. The program was recently re-engineered to be performed through competitive solicitations. The $NICE^3$ Program provides funding also, on a competitive basis, to State and industry partnerships for projects that demonstrate energy efficient, clean production technologies that are emerging or ready for commercialization. In FY 2000, the Financial Assistance Program will provide an integrated delivery of these programs. In this way, selection of the most meritorious ideas and technologies is obtained through competition and an appropriate balance of the portfolio between short- and long-term technologies can be maintained.

R&D Challenges. These programs comprise competitively selected awards encompassing the industrial, buildings, power, and transportation sectors, but emphasize the Industries of the Future (IOF). The R&D challenges encompass those identified in the collection of IOF technology roadmaps.

R&D Activities. In FY 2000, the Financial Assistance Program will use competitive solicitations for both the Inventions Program and $NICE^3$ that will, for the first time, be issued on concurrent schedules. The program will continue to provide opportunities for inventors, innovators, and entrepreneurs to help make their energy-related ideas a commercial reality and will also continue to offer (on a competitive basis) cost-shared funding to State and industry partners to demonstrate advances in near-term, energy efficient, and clean manufacturing technologies that are just becoming available for commercialization. By reducing DOE overhead activities, a larger total number of worthy projects can be supported. Also, the new program will better support and target IOF sectors by using competitive solicitations that are designed to encourage and favor participation by energy- and waste-intensive industrial sectors. The impact of the new program will also be improved by working with regional centers to more effectively leverage local resources, and to better tailor assistance to specific regional/local needs and situations.

Accomplishments. The Inventions and Innovation Program awarded Dieter Bryce, Inc., $99,999 to help develop a technology to remove bark from delimbed tree stems. The new process involves a patented system called the Cradle Debarker™. Current debarking methods require the shipment of logs to a special facility to be debarked, and then they are shipped to sawmills for further processing. The Cradle Debarker™ can be used on-site, saving time and transportation costs. Another key feature of this technology is that unlike drum debarkers, which use a covered cylinder, the new technology has an open top, which allows more of the tree being debarked to be used, thereby saving trees. The open-top design also allows the debarking operator to tailor the process for the species of tree being debarked. Dieter Bryce developed this Cradle Debarker™ for the U.S. forest products industry, where almost 5,000 debarking units are in use. The new technology reduces energy requirements for debarking by 33 percent and increases the quality of the end product.

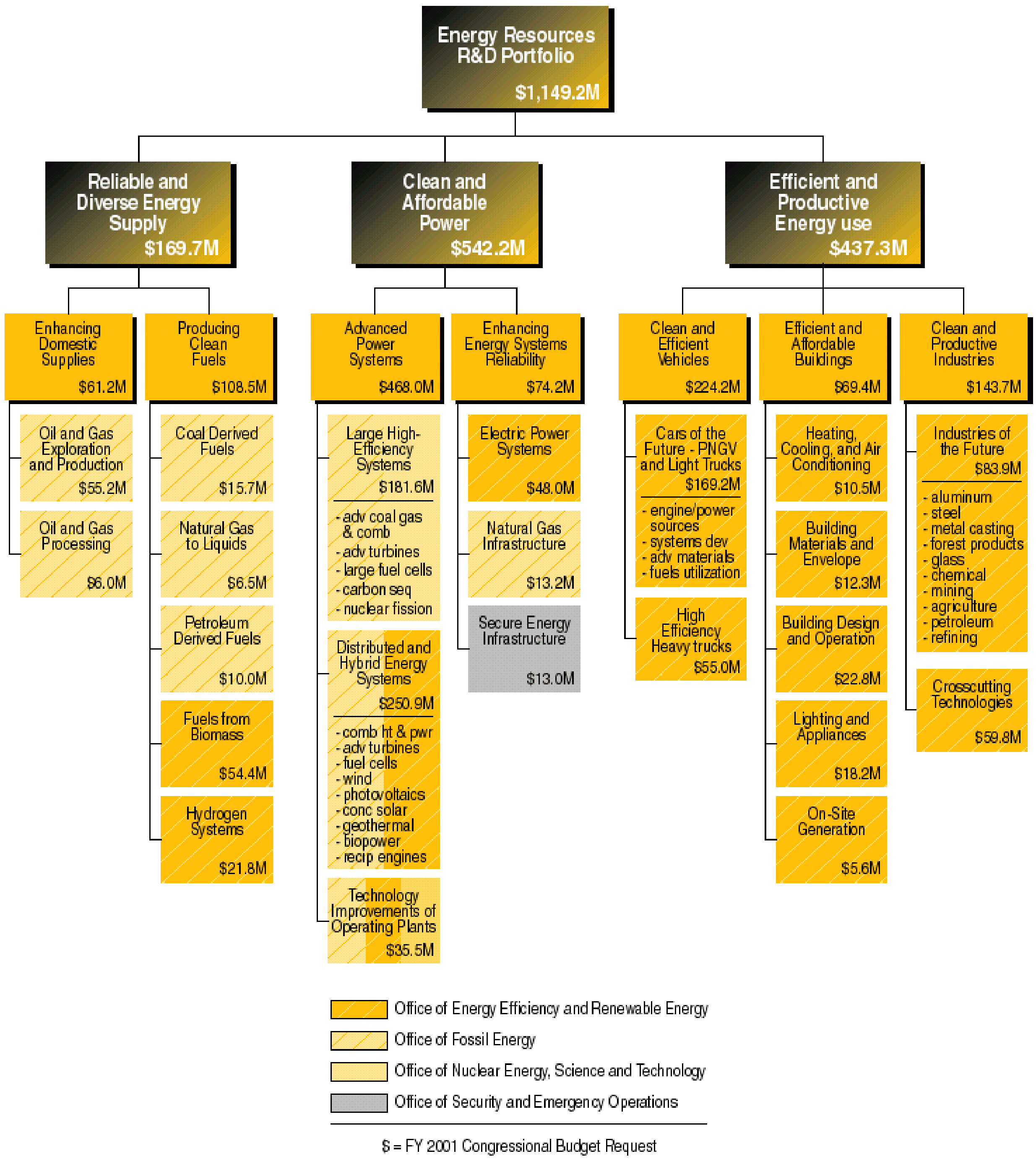
With the help of a competitive NICE^3 grant, Whyco Technologies, Inc. developed a new plating technology. The Whyco technology uses 15 percent less energy, and with more than 395 barrels in current use, the estimated energy savings are more than 195 billion Btu/year. This reduction in electricity use results in a drop in carbon dioxide emissions of approximately 12,800 tons/year. Assuming 50 percent of the 100,000 plating barrels in the United States are replaced with the Whyco barrel by the year 2010, the projected energy savings will be 25.1 trillion Btu/year, and the estimated reduction in carbon dioxide emissions will be more than 1.5 million tons annually.

With the assistance of DOE's NICE^3 program, Chrysler and its partners developed and implemented an innovative powder antichip painting process that contains no solvents and reduces energy requirements and solid-waste generation. The new process has been implemented in thirteen automobile paint shops, nine at Chrysler and four at shops of other auto manufacturers. The estimated yearly energy savings from the thirteen shops are 615 billion Btu/year. This process also has a beneficial effect on the environment by completely eliminating VOC emissions. Because of the reduced levels of solvents, 80 percent to 100 percent of the air in the powder booth can be recycled back into the booth.

Summary Budget Table (000$)

Clean and Productive Industries Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Industries of the Future	**56,447**	**66,000**	**83,900**
Aluminum	7,925	11,178	11,000
Steel	10,308	10,627	10,900
Metal Casting	5,675	5,797	5,800
Forest Products	11,753	12,076	17,100
Glass	4,701	4,830	4,800
Chemical	12,123	12,492	12,500
Mining	1,981	3,000	4,000
Agriculture	1,981	4,000	13,000
Petroleum	0	2,000	3,000
Supporting Industries	0	0	1,800
Crosscutting Technologies	**48,038**	**53,600**	**59,800**
Enabling Technologies	18,881	22,500	22,000
Technical Assistance	18,645	19,750	25,800
Financial Assistance	10,512	11,350	12,000
Total	**104,485**	**119,600**	**143,700**

Chapter 10
Basic Science



Chapter 10

Basic Science

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Overview

The Department of Energy maintains a sizeable portfolio of basic research that underpins DOE's applied R&D missions and explores broad frontiers in fundamental science, leading the Nation in the basic energy and physical sciences. Overall, this chapter addresses the contribution of basic science to the energy R&D mission, that is to say, the contributions of the DOE's Office of Science (SC) to applied energy R&D programs. A companion document to the overall Energy R&D Portfolio addresses the issues and implications of the Department's broader Science Portfolio.

In support of its basic science mission, DOE manages the most extensive and advanced complex of scientific facilities in the world. Such facilities, managed by SC, include powerful accelerators for high energy and nuclear physics, light and neutron beam facilities for the natural and life sciences, electron beam microcharacterization centers, multidisciplinary mission centers, and single purpose research facilities. Beyond DOE-sponsored research, the Department provides access to these facilities for the Nation's professors, students, and public and private-sector researchers.

Within the Department, the basic science programs are funded within SC at a total of $2.7 billion in FY 1999. This budget supports basic science, research facilities, and related infrastructure.

In pursuit of energy goals, research supports, as well as draws from, a broad spectrum of science disciplines. Most of these disciplines contribute directly to the applied energy R&D mission of the Department. These include:

- materials science
- environmental sciences
- fusion/plasma sciences
- energy technology research
- chemical sciences
- high energy and nuclear physics
- biological and biomedical sciences
- computational and math sciences
- engineering sciences
- geosciences
- energy biosciences

The National Laboratories, universities/colleges, and the private sector perform the research.

A distinguishing, general feature of basic science is that it is primarily knowledge rather than application driven. That is to say, one of its main purposes is to explore the complex phenomenon and processes that define our physical world, to determine what factors influence them, and to understand how we may ultimately control them. At this basic level, discoveries and insights usually have broad-reaching, diverse implications for many applied R&D and technology development programs, not just one.

Support for Energy R&D

Although most of the Department's basic science research has broad-based, generic implications for technology programs, some of this research aligns more strongly with particular energy technology applications, depending on the questions and phenomenon that the science addresses and the challenges inherent to the applied R&D area. For example, discoveries in the science of lightweight, high-strength materials, as well as advanced material joining techniques and properties align strongly with applications for next generation, efficient vehicles. To add perspective on how basic science supports applied energy R&D applications, additional examples are provided below in each of the seven other energy R&D areas:

- Enhancing Domestic Supplies.
- Producing Clean Fuels.
- Advanced Power Systems.
- Enhancing Utility Infrastructure.
- Clean and Efficient Vehicles.
- Efficient and Affordable Buildings.
- Clean and Productive Industries

Note that these examples are just that, examples. They are intended to illustrate the strong link that exists between the Department's basic science programs and innovation in DOE's applied energy R&D programs.

Enhancing Domestic Supplies

Examples of basic science that support Enhancing Domestic Supplies are provided below. Most of this research is carried out by the Office of Basic Energy Sciences, the Office of Biological and Environmental Research, and the Office of Computational and Technology Research.

- *Geosciences:* Basic research in Geosciences focuses on improving the level of understanding necessary for advances in, and choices among, current and emerging energy and environmental technologies. Primary research focus areas are geochemistry, geophysics, geomechanics, and hydrology. Additionally, research in chemistry focuses on fundamental molecular-level understanding of chemical interactions and chemical reactions, the development of new analytical tools and methods, and the physical and chemical interactions forming the bases for new membranes for separation processes. These programs also provide the fundamental thermal and physical properties that are the bases of all engineering applications. Research in materials sciences provides the knowledge for new materials impacting domestic supplies in every area from advanced materials for drill bits to new-concept storage methods. More directly, the basic research within geosciences efforts focuses on:

  – Improved fundamental research on mineral-fluid interactions will provide a better understanding of the origin, migration and localization of oil and gas resources, the location and management of geothermal resources, and the control of energy-related wastes in the vadose and saturated groundwater zones.

- New fundamental thermodynamic and physical property information on rocks, minerals, and geologic fluids are needed for resource recovery and contaminant assessment and monitoring.

- New and more sensitive isotopic tracer methods will contribute to evaluation of natural and anthropogenic processes in the geologic environment.

- Improved understanding of hydrologic processes, especially focusing on scaling and heterogeneity of porosity and permeability distributions will form the basis for more robust predictions of flow in reservoirs, aquifers, or in unconfined groundwater.

- Rock physics and geomechanics studies form the foundation for improved geophysical imaging, and for understanding fracture-mediated subsurface transport of fluids.

▪ *Environmental Sciences:* Within the Office of Biological and Environmental Research, there are research programs on global climate change, advanced sensors, and integrated assessment of the impacts of climate change.

▪ *Computational Sciences:* Within the Office of Computational and Technology Research, efforts at improving computational tools, developing the 2nd generation Internet, and providing the basis for massively parallel computation are critical to enhancing domestic supplies.

It is worth noting that beyond SC's contributing basic science, the Office of Environmental Management and the Office of Defense Programs both conduct basic research that impacts domestic supplies. The Office of Environmental Management conducts research that provides a sound scientific basis for assessing risks of various supply technologies. And, Defense Programs supports research in computing technology, computational modeling, instrumentation development, and geophysical studies that have both defense and civilian applications.

Producing Clean Fuels

Examples of basic science that support Producing Clean Fuels are provided below. Most of this research is carried out by the Office of Basic Energy Sciences and the Office of Biological and Environmental Research.

Efforts to develop cleaner fuels and reduce carbon emissions draw on many scientific disciplines. For example: biochemistry; catalysis; molecular, cellular and plant biology; structural biology; genome science; and solar photochemistry contribute, because the production of fuels and chemicals by plants and microorganisms and the interconversion of greenhouse gases requires a better understanding of metabolism, of the structure and function of sub-cellular components, and of enzymes. Similarly, the state-of-the-art in biochemistry, molecular biology, and ecology contribute. All of these biological processes are important in understanding the role of microorganisms in sequestering carbon. Improvements in combustion to reduce carbon emissions require a fundamental understanding in chemical dynamics, theoretical chemistry, and physics. Conversion of sunlight to energy requires an understanding in many areas of science, including photochemistry, photosynthesis, metabolism, and solid-state physics. The search for increased efficiency in energy production and use requires fundamental knowledge in ceramics, metals, polymers, solid-state chemistry, and condensed matter physics for materials that can withstand higher temperatures, have lower coefficients of friction, and are stronger and lighter. Enhanced recovery of fuel resources and of disposal of carbon dioxide requires a fundamental understanding of geometric, structural, and hydrologic properties of reservoirs and of multiphase, nonlinear transport of fluids in porous and fractured structures. Cross-cutting programs in nano- and meso-phase materials involve research at the forefront of materials science, chemistry, engineering, surface science, and semiconductor physics.

Office of Science fundamental research areas that underpin the Clean Fuels R&D Portfolio—and other DOE science and technology portfolios—include the following.

- *Microbial Genome Program:* Significant investments have been made in the technology that enables genome sequencing at rates previously unattainable. Capitalizing on these investments, the genomes of microbes that produce methane and hydrogen will be sequenced. This will enable the identification of the key genetic components of the organisms that regulate these gases. Once we identify and understand more fully how the enzymes and organisms operate, we will be able to evaluate the potential use of either the microorganisms or the relevant enzymes to produce methane or hydrogen from either fossil fuels or other carbonaceous sources, including biomass or perhaps even some kinds of waste products. For instance, recently discovered "extremophile" organisms could be used to engineer biological entities that could ingest a feedstock like methane, sequester the carbon dioxide, and give off hydrogen.

- *Microbial Conversion*: Basic research in microbial conversion focuses on examining the metabolism, biochemistry, genetics, and physiology of organisms and consortia of organisms that degrade lignin, cellulose, and/or hemicellulose into potential fuels. The fuels include ethanol, higher alcohols, and methane. While much of the activities involve anaerobic bacteria, fungi are also actively investigated. These studies form the foundation for the efficient conversion of lignocellulosics (biomass) into potential liquid and gaseous fuels, an important component of several technology programs in this portfolio.

- *Plant Biology*: Green plants and some bacteria use photosynthesis to capture solar energy and convert it into chemical energy that fuels metabolism and the biosynthesis of a broad range of storage compounds and structural components. For example, the chemical energy in firewood was the early energy source for mankind, and even today the worldwide combustion of plant biomass generates more energy than any other non-fossil fuel source. As a renewable resource, plant biomass potentially has enormously valuable uses when it is converted into specific materials, fuels, chemical feedstocks and petroleum replacing materials. Basic studies in plant biology are providing new insights into the genetic, metabolic, and enzymatic properties of plants that regulate the production of specific useful chemical compounds and materials. Similarly, studies on the regulation of the photosynthetic process that fuels metabolic biosynthesis are yielding new insights on how bacteria and plants channel photosynthetic energy into the production of renewable biomass materials.

- *Solar Photochemistry:* This research explores fundamental photochemical processes aimed at the capture and conversion of solar energy. This research program encompasses organic and inorganic photochemistry, electron and energy transfer in homogeneous and heterogeneous media, photocatalysis, and photoelectrochemistry. The photosynthetic reaction center is studied as a model for the design of efficient, photoinduced charge separation in biomimetic/ photocatalytic assemblies. The research provides the foundations for future solar technologies in which light-induced, charge-separation processes will convert light energy to chemical energy in such applications as the production of alcohols from carbon dioxide, hydrogen from water, or ammonia from atmospheric nitrogen.

- *Catalysis:* Catalysis is a chemical process found widely in nature and used extensively in industry because it removes energy barriers to chemical reactions. Catalysts used for the refining of petroleum or the manufacture of chemicals are important because they reduce process energy, speed up production, and make possible the manufacture of new materials. Despite their importance, catalytic processes are not sufficiently well understood to allow for rational design of new catalysts. Models for catalytic action are limited in scope and applicability. The Office of Science catalysis program seeks to gain understanding of catalysis at the molecular level to allow the development of general theories and models of catalytic action. The program includes both heterogeneous (multiple phases such as liquid/solid) and homogeneous (single phase) catalysis. Research in heterogeneous catalysis seeks to characterize the role of surface properties on molecular transformations and the structural relationships between oxide surfaces and reaction pathways, especially in the acid and redox catalysts commonly encountered in industrial applications. Research in homogeneous catalysis seeks to characterize the activation and subsequent reactions of carbon-hydrogen bonds and the role of bonding and molecular structure on the catalytic processes. The program constitutes the largest single component of the Nation's basic research portfolio focused on chemical catalysis.

The Department of Energy's Climate Change Technology Initiative has been developed as a partnership between the technology and research offices at DOE and representatives of the National Laboratories. A series of workshops have been held to identify basic science needs and opportunities for capturing and sequestering carbon, for fuel cell and hydrogen development, for enhancing the natural carbon cycle, and for biomass conversion. These workshops have included participants from the Offices of Science, Fossil Energy, and Energy Efficiency and Renewable Energy.

Advanced Power Systems

Examples of basic science that support Advanced Power Systems are provided below. Most of this research is carried out by the Office of Basic Energy Sciences, the Office of Biological and Environmental Research, and the Office of Fusion Energy Sciences.

Efforts to develop clean power and reduce carbon emissions draw on many scientific disciplines. For example: electrochemistry; combustion; materials - including welding, joining, and corrosion; photovoltaics and semiconductors; engineering research; geosciences; biology and genomics; and environmental sciences. These and other disciplines contribute, because power production, transmission, and storage as well as the interconversion of greenhouse gases requires a better understanding of the materials and processes that contribute to each phase. Similarly, the state-of-the-art in biochemistry, molecular biology, and ecology will be impacted. All of these biological processes are important, for example, in understanding the role of marine microorganisms in sequestering carbon. Improvements in combustion to reduce carbon emissions require a fundamental understanding in chemical dynamics and theoretical chemistry and physics. The search for increased efficiency in energy production and use requires fundamental knowledge in ceramics, metals, polymers, solid-state chemistry, and condensed matter physics for materials that can withstand higher temperatures, have lower coefficients of friction, and are stronger and lighter. Enhanced recovery of fuel resources, the disposition of nuclear power and other transuranic waste, and the disposal of carbon dioxide require a fundamental understanding of geometric, structural, and hydrologic properties of reservoirs and of multi-phase, nonlinear transport of fluids in porous and fractured structures. Cross-cutting programs in nano- and meso-phase materials involve research at the forefront of materials science, chemistry, engineering, surface science, and semiconductor physics. And efforts to understand fusion plasma science and concepts for engineering plasma confinement may someday make commercial nuclear fusion a reality.

Contributions to Advanced Power Systems include the following research areas:

- *Electrochemistry:* Fundamental research is supported in areas critical to understanding the underlying limitations in the performance of non-automotive electrochemical energy storage systems. Areas of research include the characterization of anode, cathode, and electrolyte systems and their interactions. The broad spectrum of research includes fundamental studies of composite electrode structures, failure and degradation of active electrode materials, and thin film electrodes, electrolytes, and interfaces. The aim is providing knowledge that will lead to improvements in battery size, weight, life, and recharge cycles.

- *Combustion:* Basic research in combustion provides knowledge on the rates and energetics of chemical reactions and on the interactions of fluid dynamics and chemistry. This knowledge is required by combustion models used for the design and optimization of energy-efficient, reduced-emission combustion devices. Knowledge gained consists of measured properties as well as theoretical constructs for the reliable prediction or extrapolation of such properties. SC supports the operation of the Combustion Research

Facility (CRF) at Sandia National Laboratories, California, where collocated research, supported by SC, the Office of Energy Efficiency and Renewable Energy (EE), the Office of Fossil Energy (FE), and industry, is conducted in a highly collaborative environment.

- *Photovoltaics and Semiconductors:* Semiconducting materials underpin virtually the entire “high tech” industry worldwide. They comprise the building blocks and components for several technologies within this portfolio, including photovoltaics, sensors, power electronics, and high speed computational systems. Research within this area includes synthesis of new and tailored semiconductor materials; characterization of structure, electronic structure, and stability of semiconductors; investigations of surfaces and interfaces; the influence of light on the behavior and properties of semiconductor materials; theory and modeling of properties and behavior; and the operation of facilities that support such research.

- *Ceramic Materials:* Ceramic materials play an integral role in the utility, automotive, and other energy-intensive industries. A fundamental understanding of their complex microstructure and behavior is essential for their successful implementation. The ceramic sciences research addresses the scientific issues underlying the synthesis, processing, behavior, and characterization of ceramic and non-metallic glassy materials. Focus areas include synthesis, processing, reactivity, and physical and mechanical properties, with emphasis on elevated temperature behavior. The technological areas impacted include high temperature structural materials (e.g., high temperature monolithic and composite ceramics and ceramic coatings), energy storage materials (e.g., solid electrolytes, batteries, and ultracapacitors), energy conversion materials (e.g., fuel cells), hazardous waste storage materials (glasses and ceramics), sensors, and environmentally benign synthesis techniques.

- *Radiation Materials:* There are approximately 70 nuclear power reactors in the United States that are over 20 years old. The time-dependent radiation-induced embrittlement of aging steel containment vessels and structural members defines a critical safety and environmental problem for these on-line facilities. Their continued safe operation requires a better predictive "early warning" or "retirement for cause" model for their behavior. Therefore, the Office of Science supported research in radiation materials includes synergistic relationships between neutron, proton, and ion irradiation with defects, composition, and physical and mechanical behaviors in metals, ceramics, intermetallics, polymers, and semiconductors. Emphasis is on surface modification, modeling of radiation induced damage, cascade formation, property changes, design of radiation-resistant materials, irradiation induced stress-corrosion cracking, changes in grain boundary microchemistry, crack tip phenomena, and evaluation of spallation neutron and high energy proton damage. There are three additional distinct motivations for SC activities in radiation materials sciences: (1) the safe containment, over many-generations, of radioactive wastes requires valid predictive models for their time-dependent degradation under conditions including self-irradiation, heat, and the time-dependent production of radio-decay products (this work supports the Department’s efforts in Environmental Management); (2) the development of fusion reactors will require an understanding and a modeling of the radiation induced behavior of insulator and first wall component candidate materials such as silicon carbide, high-chromium ferritic-martensitic steels, and vanadium; and (3) the energetic-ion-induced surface modification and implantation of metals, ceramics, polymers, and semiconductors is a continuously evolving science as well as an important technology that in turn underpins all energy conversion and conservation technologies.

- *High Temperature Superconducting Materials:* Research into the development of improved superconductors that can be used in the generation, transmission, utilization, and storage of electric power using high-T_c superconductors contributes to the efficient utilization of energy. Therefore, basic research is performed on the theory, synthesis, processing, structure, and physical properties of high temperature superconducting materials including the discovery of new classes of superconducting materials.

- *Intermetallics:* Intermetallic compounds are metal to metal compounds with definite stoichiometry. Intermetallic alloys made from these compounds constitute a unique class of high-temperature structural materials that posses the desired properties of high strength, oxidation and corrosion resistance, low density, and a high melting point. Such properties make them attractive as constituents for gas turbine engines, high-temperature coatings, and in dies and molds for ceramic and metallurgical processing. Intermetallic compounds may also be used in a variety of electromagnetic areas including both hard and soft magnets, superconductor, semiconductor, and optical applications.

- *Materials Welding and Joining:* Materials welding and joining are critical fabrication technologies that are used extensively in all energy, automotive, environmental, and electronic technologies. Weld failures are the most frequent reason for unscheduled and sometimes catastrophic outages in power plants with the cost of replacement power often exceeding $1 million dollars per day. Welding represents 10 percent of the cost of construction and 20 percent of the maintenance costs for a 500 megawatt fossil-fueled electric power plant. SC supported basic research includes understanding the microstructure and defects that develop as a consequence of temperature gradients; solid-state phase transformations in weld heat affected zones; thermal processes as applied to gas metal arc welding; molten metal droplet formation; plasma and arc physics; laser welding of automotive aluminum alloys; time-resolved X-ray absorption spectroscopy to directly determine rate of transformation of one phase to another phase under the highly-nonisothermal conditions that prevail during welding; welding of Al, Ti, and thin plates; coupling welding science and fracture mechanics modeling in response to the Northridge California earthquake experience; and critical issues in the non-welding joining of ceramics and dissimilar materials.

- *Corrosion:* The importance of the scientific understanding of corrosion is emphasized by the estimate that corrosion in the United States has an economic cost of 4 percent of the gross domestic product. Corrosion damage limits the performance of all energy conversion technologies. The basic research underlying the science of corrosion focuses on the formation, properties, and breakdown of passivating films; on a wide array of electrochemical phenomena involved in aqueous corrosion such as pitting and crevice corrosion; on high-temperature gaseous corrosion; and on new techniques to identify and study corrosion.

- *Engineering Research:* The SC Engineering Program supports fundamental research on broad, generic topics in energy related engineering topics. This includes research on fractals and porous media transport, nonlinear waves, traveling wave convection in fluid mixtures, wave turbulence interactions, multi-phase systems, gas and solids problems, the effect of different Reynolds numbers on turbulence, mixing and transport, gas-liquid flow in pipelines, lubricated transport of viscous materials, the rheology of concentrated suspensions, macrostatistical hydrodynamics, heat/mass transfer enhancement in separated and vortex flows, effect of forced and natural convection on solidification of binary mixtures, interfacial area and transfer in two-phase flow, and various diagnostics for analyzing fluids. An emphasis of the research is on complicated fluid dynamics because fluids are a part of most energy-related systems including pipelines, manufacturing processing, hydraulic systems, planes, trains, automobiles, ships, liquid metal handling, new materials synthesis, chaotic wave motion, weather prediction, environmental issues, and biological systems.

- *Geosciences:* Both geophysical and geochemical information is significant for current and future energy technologies, particularly geothermal energy, oil and gas, and understanding the disposition of wastes generated by the technological enterprise, including the by-products of nuclear energy. Rock mechanics, fracture, and fluid flow encompasses research on the response of rock to stress and the role of fluid flow as a cause and/or effect. The prediction and interpretation of rock response offers unique challenges because the scales involved range from the microscopic to hundreds of kilometers and from seconds to geologic times. The properties of rock are dominated by extreme heterogeneity, pressure dependence, the presence of natural fracture systems, and the coupling between thermomechanical properties, fluid flow, and geochemical processes. Geochemical research is supported in rock-fluid interactions to provide fundamental information on the governing mechanisms and rates of reactive geochemical processes that concentrate, transport, modify, and emplace energy resources and the by-products of energy use within the Earth's shallow crust. Other research in the Geosciences is focused on gaining a better understanding of the fundamental biological, chemical, geological, and physical processes that must be marshalled for the development and advancement of new, effective, and efficient processes for the remediation and restoration of contaminated sites. Research advances will continue to be made from pore to field scales, on genes and proteins used in bioremediation, in non-destructive, real-time measurement techniques, in overcoming physico-chemical impediments to bacterial mobility in the subsurface, on species interaction and response of microbial ecology to contamination, and in understanding microbial processes for altering the chemical state of metallic and radionuclide contaminants.

- *Fusion Energy Sciences:* Research is focused on fusion plasma science and engineering concepts and supporting science for plasma confinement. SC maintains a large research program aimed at unlocking the secrets to this potentially limitless supply of clean energy. Supporting computational sciences are developed within the Office of Computational and Technology Research. Materials and superconductivity research are critical to various confinement concepts.

- *Biology/Genomics:* The microbial genome program capitalizes on DNA sequencing technology from the human genome program to determine the complete DNA sequence of microbes with potential environmental, energy, or commercial applications. While the program has a principal emphasis on DNA sequencing it includes research on microbial diversity, to identify a broader array of potentially useful microbes; and novel strategies and tools for characterizing, manipulating, and modeling entire reaction pathways or regulatory networks of microbes or groups of microbes to maximize the usefulness of these newly characterized microbes.

- *Structural Biology:* Understanding and predicting the complex relationship between the DNA sequence of a gene and the structure and function of the protein it encodes is a critical first step in being able to reengineer genes and proteins for use in developing new strategies for improving or developing new fuels, reducing pollution from fuel use, and cleaning up the environment. Therefore, SC supports basic research in structural biology including instrumentation research and research that cuts across basic, molecular, and computational biology. For example, studies of inverse protein folding provide an understanding of the rules that proteins follow to acquire the three dimensional structures that give them their biological function while Proteomics research provides information that will lead to an understanding of the structure, function, and interactions of all proteins encoded by an organism's genome.

- *Environmental Sciences:* Research in the environmental sciences is focused on understanding the basic chemical, physical, and biological processes of the Earth's atmosphere, land, and oceans and how these processes may be affected by energy production and use, primarily the emission of carbon dioxide from fossil fuel combustion. A major part of the research is designed to provide the data that will enable an objective assessment of the potential for, and consequences of, global warming. Emphasis is given to understanding the radiation balance from the surface of the Earth to the top of the atmosphere (including the role of clouds) and on enhancing the quantitative models necessary to predict possible climate change at global and regional scales. The Atmospheric Radiation Measurement (ARM) program works to produce the experimental and modeling results that will be necessary to resolve the greatest uncertainty in climate prediction—the role of clouds and solar radiation. Climate modeling using massively-parallel supercomputers will simulate climate change, predict climate, and evaluate model uncertainties due to changes in atmospheric concentrations of greenhouse gases on decade to century time scales. The Carbon Cycle program studies the natural carbon cycle and assesses the potential impacts of climate change on terrestrial systems.

  Unique facilities at the Environmental Molecular Sciences Laboratory such as the Molecular Science Computing Facility, the High-Field Mass Spectrometry Facility, and the High-Field Magnetic Resonance Facility will be used to conduct a wide variety of molecular-level environmental science research, including movement of contaminants in subsurface groundwater and vadose zone sediments and atmospheric chemical reactions that contribute to global warming.

Capitalizing on activities in support of the U.S. Global Change Research Program, and stimulating a partnership between the technology and research offices at DOE and representatives of the National Laboratories, the Climate Change Technology Initiative supports research into the role that the terrestrial biosphere and human activities play on the state and quality of the global climate. The research seeks the understanding necessary to exploit the biosphere's natural processes for use in sequestration of atmospheric carbon dioxide including the roles of marine microorganisms in ocean carbon sequestration and the mechanisms by which forest ecosystems sequester carbon. A series of workshops have been held to identify the basic science needs and opportunities for capturing and sequestering carbon, for fuel cell and hydrogen development, for enhancing the natural carbon cycle, and for biomass conversion. These workshops have included participants from the Offices of Science, Fossil Energy, and Energy Efficiency and Renewable Energy.

In addition to interactions across the Department to develop the Climate Change Technology Initiative, the SC programs maintain significant interactions with other DOE offices and other agencies involved in environmental remediation, e.g., Office of Environmental Management, the Environmental Protection Agency, the Department of Defense, or other partners in the U.S. Global Change Research program.

Enhancing Utility Infrastructure

Examples of basic science that support Utility Infrastructure are provided below. Most of this research is carried out by the Office of Computational and Technology Research and the Office of Basic Energy Sciences.

- *Advanced Computing:* High speed computing and networking capabilities are critical to both modeling and control of the utility infrastructure.

- *Materials Science and Physics:* A wide range of advanced materials and materials processing technologies are required for high-performance low-cost semiconductors, superconductors, high-strength light-weight composites, and corrosion resistant materials. Physical understanding of the properties of these materials aids researchers in improving performance and reducing cost.

- *Power Electronics and Controls:* Research includes the development of advanced topology modeling methodologies and high speed switching devices based on silicon carbide and thin-film diamond which will have higher capacity, lower cost and lower losses.

- *Energy Storage:* Research in this area addresses advanced batteries, supercapacitors, flywheel technologies and their associated materials, and control technologies.

The performance parameters, economics, environmental acceptability and safety of all energy generation, conversion, transmission, and conservation technologies are limited by the performance of available materials. The BES Materials Sciences Program is concerned with understanding and exploiting the synergistic relationship between the synthesis, processing, structure, properties, behavior, in-service performance and lifetime, and recyclability of materials. Such understanding is necessary for the development of technologically and economically desirable new materials and cost-competitive and environmentally acceptable methods for their synthesis, processing, fabrication, quality manufacture, and recycling. The Materials Sciences program funds basic research in metallic glasses (for corrosion resistant, wear resistant, and low magnetic loss behavior); ceramics (energy storage technologies); high temperature superconductivity (for energy generation, transmission, and storage); hard and soft magnets (for low energy loss motors and transformers); and ordered intermetallic alloys (for heat, load, wear, and corrosion resistant applications).

Within the BES Chemical Sciences Program, the Advanced Battery Research program supports fundamental research in areas critical to understanding the underlying limitations in the performance of non-automotive electrochemical energy storage systems. Areas of research include anode, cathode, and electrolyte systems and their interactions with emphasis on improvements in battery size, weight, life, and recharge cycles. Although both primary and secondary battery systems are considered, the greatest emphasis is placed on rechargeable (i.e., secondary) battery systems. The program covers a broad spectrum of research including fundamental studies of composite electrode structures, failure and degradation of active electrode materials, and thin film electrodes, electrolytes, and interfaces. Problems of electrode morphology, corrosion, electrolyte stability, and the transport properties of electrode and electrolyte materials and surface films are also addressed.

In Superconductivity research particularly, the Office of Basic Energy Sciences (BES) plays a significant role. It funds research at the Oak Ridge National Laboratory (ORNL) to work with the 3M Company and develop a novel *ex situ* process for growing superconducting films. This work is conducted in collaboration with the Office of Energy Efficiency and Renewable Energy (EE) Second Generation Wire Initiative. The project included BES funding of $375,000 over 18 months, with a matching amount at ORNL from EE. Over the 18 month project time frame, 3M Company devoted over $1.5 million to research with both ORNL and Los Alamos National Laboratory (LANL) on aspects of the second generation wire initiative. EE and SC superconductivity research is coordinated through several workshop mechanisms, including a Wire Workshop jointly sponsored by EE/SC. The output is a jointly produced, publicly available document describing key science issues identified at the workshop. Teams of EE/BES staff have also been formed to focus on specific issues. In addition, SC maintains facilities on which advanced energy research can be carried out and a large communication network and computer facilities where information can be shared and simulations and analysis can be done.

Clean and Efficient Vehicles

Examples of basic science that support Clean and Efficient Vehicles are provided below. Most of this research is carried out by the Office of Basic Energy Sciences (BES).

- *Electrochemistry:* Within this topic area, the BES Advanced Battery Research program supports basic research critical to understanding limitations in the performance of electrochemical energy storage systems. Research addresses the characterization of anode, cathode, and electrolyte systems and their interactions, and includes fundamental studies of composite electrode structures, failure and degradation of electrode materials, and thin film electrodes, electrolytes, and interfaces. Close coordination with DOE's Office of Transportation Technologies' (OTT) battery programs is accomplished through joint meetings, program reviews, and strategy sessions.

- *Combustion:* Basic research in combustion provides knowledge on the rates and energetics of chemical reactions and on the interactions of fluid dynamics and chemistry. This knowledge is required by combustion models used for the design and optimization of energy efficient, low emission combustion devices. BES supports the operation of the Combustion Research facility at Sandia National Laboratory, which serves as the focus for the integration with the applied combustion programs in EE. Additionally, the EE Combustion Cooperative Research and Development Agreement (CRADA) is one of two pilot collaboratory projects in the Office of Science sponsored DOE 2000 Initiative.

- *Synthesis and Processing of Advanced Materials:* These essential elements of materials science and engineering deal with the assembly of atoms or molecules to form materials, the manipulation and control of the structure at all levels from the atomic to the macroscopic scale, and the development of processes to produce materials for specific applications. The goal of the basic research ranges from creating new materials, improving the properties of known materials, and improving the forming of metals to the understanding of such phenomena as diffusion, crystal growth, sintering, and phase transitions. Scientific results are translated into useful materials by developing processes capable of producing high quality cost-effective products including light weight alloys for vehicles.

- *Ceramics:* The BES Ceramics program addresses scientific issues related to the synthesis, processing, and characterization of ceramic and non-metallic glassy materials. The OTT technological areas impacted include high temperature structural materials (ceramic coatings), energy storage materials (batteries), energy conversion materials (fuel cells), and sensors.

- *Semiconductors:* This research includes synthesis and characterization of new semiconductor materials, electronic structure and stability studies, investigations of surfaces and interfaces, the influence of light on semiconductor properties, and theory and modeling. Semiconductors are the building blocks for photovoltaics, sensors, power electronics, and high speed computational systems.

- *Welding and Joining Sciences:* Welding and joining are critical fabrication technologies used in the automotive industry. BES research includes studies to understand the microstructure and defects that develop due to temperature gradients, solid-state phase transformations in weld heat affected zones, thermal processes as applied to gas metal arc welding, molten metal droplet formation, plasma and arc physics, laser welding of aluminum alloys, and joining of ceramics and dissimilar materials. These activities are directly related to the Transportation Materials program in OTT.

Many of the OTT/BES integration activities, especially those addressing materials research and development, occur through the Energy Materials Coordinating Committee (EMaCC).

Efficient and Affordable Buildings

Examples of basic science that support Efficient and Affordable Buildings are provided below. Most of this research is carried out by the Office of Basic Energy Sciences.

- *Electrochemistry:* Fundamental research is supported in areas critical to understanding the underlying limitations in the performance of non-automotive electrochemical energy storage systems. Areas of research include the characterization of anode, cathode, and electrolyte systems and their interactions. The broad spectrum of research includes fundamental studies of composite electrode structures, failure and degradation of active electrode materials, and thin film electrodes, electrolytes, and interfaces.

- *Combustion:* Basic research in combustion provides knowledge on the rates and energetics of chemical reactions and on the interactions of fluid dynamics and chemistry. This knowledge is required by combustion models used for the design and optimization of energy-efficient, reduced-emission combustion devices. Knowledge gained consists of measured properties as well as theoretical constructs for the reliable prediction or extrapolation of such properties. BES supports the operation of the Combustion Research Facility (CRF) at Sandia National Laboratories, California, where collocated research, supported by BES, the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy, and industry, is conducted in a highly collaborative environment.

- *Ceramic Materials:* Ceramic materials play an integral role in the utility, automotive, and other energy-intensive industries such as the building industry. A fundamental understanding of ceramic materials' complex microstructure and behavior is essential for their successful implementation. BES research addresses the scientific issues underlying the synthesis, processing, behavior, and characterization of ceramic and non-metallic glassy materials. The technological areas impacted include high temperature structural materials (e.g., high temperature monolithic and composite ceramics and ceramic coatings), energy storage materials (e.g., solid electrolytes, batteries, ultracapacitors), and energy conversion materials (e.g., fuel cells), sensors, and environmentally benign synthesis techniques.

- *Semiconductors:* Semiconducting materials underpin virtually the entire "high tech" industry worldwide. They comprise the building blocks and components for several technologies within this portfolio, including photovoltaics, sensors, power electronics, and high speed computational systems. Research within this area includes synthesis of new and tailored semiconductor materials; characterization of structure, electronic structure, and stability of semiconductors; investigations of surfaces and interfaces; the influence of light on the behavior and properties of semiconductor materials; theory and modeling of properties and behavior; and the operation of facilities that support such research.

Clean and Productive Industries

Examples of basic science that support Clean and Productive Industries are provided below. Most of this research is carried out by the Office of Basic Energy Sciences and the Office of Computational and Technology Research.

- *Combustion:* Basic research in combustion provides knowledge on the rates and energetics of chemical reactions and on the interactions of fluid dynamics and chemistry. This knowledge is required by combustion models used for the design and optimization of energy-efficient, reduced-emission combustion devices for most industrial processes. Knowledge gained consists of measured properties as well as theoretical constructs for the reliable prediction or extrapolation of such properties. The Office of Basic Energy Sciences supports the operation of the Combustion Research Facility (CRF) at Sandia National Laboratories, California, where collocated research, supported by SC, the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy, and industry, is conducted in a highly collaborative environment.

- *Catalysis:* Catalysis is a chemical process found widely in nature and used extensively in industry because it removes energy barriers to chemical reactions. Catalysts used for the refining of petroleum or the manufacture of chemicals are important because they reduce process energy, speed up production, and make possible the manufacture of new materials. Despite their importance, catalytic processes are not sufficiently understood to allow for rational design of new catalysts. Models for catalytic action are limited in scope and applicability. The SC catalysis program seeks to gain understanding of catalysis at the molecular level to allow the development of general theories and models of catalytic action. The program includes both heterogeneous (multiple phases such as liquid/solid) and homogeneous (single phase) catalysis. Research in heterogeneous catalysis seeks to characterize the role of surface properties on molecular transformations and the structural relationships between oxide surfaces and reaction pathways, especially in the acid and redox catalysts commonly encountered in industrial applications. Research in homogeneous catalysis seeks to characterize the activation and subsequent reactions of carbon-hydrogen bonds and the role of bonding and molecular structure on the catalytic processes. The program constitutes the largest single component of the Nation's basic research portfolio focused on chemical catalysis.

- *Synthesis and Processing of Advanced Materials:* These essential elements of materials science and engineering deal with the assembly of atoms or molecules to form materials, the manipulation and control of the structure at all levels from the atomic to the macroscopic scale, and the development of processes to produce materials for specific applications. The goal of the basic research ranges from creating new materials, improving the properties of known materials, and improving the forming of metals to the understanding of such phenomena as diffusion, crystal growth, sintering, and phase transitions. Scientific results are translated into useful materials by developing processes capable of producing high quality cost-effective products including light weight alloys for vehicles.

- *Ceramics:* Ceramic materials play an integral role in the utility, automotive, and other energy-intensive industries. A fundamental understanding of their complex microstructure and behavior is essential for their successful implementation. BES ceramic sciences research addresses the scientific issues underlying the synthesis, processing, behavior, and characterization of ceramic and non-metallic glassy materials. Focus areas include synthesis, processing, reactivity, and physical and mechanical properties, with emphasis on elevated temperature behavior. The technological areas impacted include high temperature structural materials (e.g., high temperature monolithic and composite ceramics and ceramic coatings), energy storage materials (e.g., solid electrolytes, batteries, ultracapacitors), sensors, and environmentally benign synthesis techniques.

- *Intermetallics*: These are metal to metal compounds with definite stoichiometry. Intermetallic alloys made from these compounds constitute a unique class of high-temperature structural materials that posses the desired properties of high strength, oxidation and corrosion resistance, low density, and a high melting point. Such properties make them attractive as constituents for high-temperature coatings and in dies and molds for ceramic and metallurgical processing.

- *Welding and Joining Sciences:* Welding and joining are critical fabrication technologies used in the automotive industry. BES research includes studies to understand the microstructure and defects that develop due to temperature gradients, solid-state phase transformations in weld heat affected zones, thermal processes as applied to gas metal arc welding, molten metal droplet formation, plasma and arc physics, laser welding of aluminum alloys, and joining of ceramics and dissimilar materials.

- *Corrosion:* The importance of the scientific understanding of corrosion is emphasized by the estimate that corrosion in the United States has an economic cost of 4 percent of the gross domestic product. Corrosion damage limits the performance of industrial processes. The basic research underlying the science of corrosion focuses on the formation, properties, and breakdown of passivating films on a wide array of electrochemical phenomena involved in aqueous corrosion such as pitting and crevice corrosion, on high-temperature gaseous corrosion, and on new techniques to identify and study corrosion.

- *Engineering Research:* The BES Engineering Program supports fundamental research on broad, generic topics in energy related engineering topics. An emphasis of the research is on complicated fluid dynamics because fluids are a part of most energy-related systems and industrial processes, including pipelines, manufacturing processing, hydraulic systems, liquid metal handling, new materials synthesis, chaotic wave motion, environmental issues, and biological systems. Engineering topics include fractals and porous media transport, nonlinear waves, traveling wave convection in fluid mixtures, wave turbulence interactions, multi-phase systems, gas and solids problems, the effect of different Reynolds numbers on turbulence, mixing and transport, gas-liquid flow in pipelines, lubricated transport of viscous materials, the rheology of concentrated suspensions, macrostatistical hydrodynamics, heat/mass transfer enhancement in separated and vortex flows, effect of forced and natural convection on solidification of binary mixtures, interfacial area and transfer in two-phase flow, and various diagnostics for analyzing fluids.

- *Plant Sciences:* Green plants and some bacteria use photosynthesis to capture solar energy and convert it into chemical energy that fuels metabolism and the biosynthesis of a broad range of storage compounds and structural components. For example, the chemical energy in firewood was the early energy source for mankind, and even today the worldwide combustion of plant biomass generates more energy than any other non-fossil fuel source. As a renewable resource, plant biomass potentially has enormously valuable uses when it is converted into specific materials, fuels, chemical feedstocks, and petroleum replacing materials. Basic studies in plant biology are providing new insights into the genetic, metabolic, and enzymatic properties of plants that regulate the production of specific useful chemical compounds and materials. Similarly, studies on the regulation of the photosynthetic process that fuels metabolic biosynthesis are yielding new insights on how bacteria and plants channel photosynthetic energy into the production of renewable biomass materials.

- *Biology/genomics:* The microbial genome program capitalizes on DNA sequencing technology from the human genome program to determine the complete DNA sequence of microbes with potential environmental, energy, or commercial applications. While the program has a principal emphasis on DNA sequencing, it includes research on microbial diversity, to identify a broader array of potentially useful microbes; and novel strategies and tools for characterizing, manipulating, and modeling entire reaction pathways or regulatory networks of microbes or groups of microbes to maximize the usefulness of these newly characterized microbes.

- *Structural Biology:* Understanding and predicting the complex relationship between the DNA sequence of a gene and the structure and function of the protein it encodes is a critical first step in being able to reengineer genes and proteins for use in developing new strategies for improving or developing new fuels, reducing pollution from fuel use, and cleaning up the environment. Therefore, the Office of Science supports basic research in structural biology including instrumentation research and research that cuts across basic, molecular, and computational biology. For example, studies of inverse protein folding provide an understanding of the rules that proteins follow to acquire the three dimensional structures that give them their biological function, while Proteomics research provides information that will lead to an understanding of the structure, function, and interactions of all proteins encoded by an organism's genome.

- *Computational Sciences:* The computational research area provides tools and methods to enable the wide spread use of massively parallel computers and the high speed network connections which underpin the computational needs common to many of the industry vision statements and their need for advanced computational capability for industry process understanding and control.

- *Chemical Sciences:* Research in chemistry focuses on fundamental molecular level understanding of chemical interactions and chemical reactions that provide the basis for new analytical tools and methods and the physical and chemical interactions that support the development of new membranes for separation processes.

- *Materials Science:* Basic research in materials enables technologies underpinning new aluminum alloys, the high rate sheet metal forming of aluminum alloys, and high strength and corrosion resistant intermetallic alloys. Part of this effort is carried out under the Design and Synthesis of Ultrahigh-Temperature Intermetallics project under the distributed DOE Center of Excellence for the Synthesis and Processing of Advanced Materials (CSP). Research is also underway, coordinated and carried out under the Materials Joining project under CSP, on the reliable joining of materials both for on-line repair and for the fabrication of new systems encompassing both metals and ceramics. Additional research involves efforts to advance materials requiring long-lifetime wear resistant surfaces, for example, to form boron nitride and diamond protective films on materials and investigating and understanding how to form oxide films as protective layers to prevent corrosion.

- *Advanced Sensors:* Research is conducted on innovative, more powerful sensors, including the understanding of the chemistry of molecular interactions that generate a chemical or physical response.

- *Computation:* The computational research area provides tools and methods to enable the widespread use of massively parallel computers and the high speed network connections which underpin the computational needs common to many of the industry vision statements and their need for advanced computational capability for industry process understanding and control.

Science Excellence and Research Integration

Recognizing that the basic sciences are the cornerstone for future technology innovation, it is important that DOE's basic science be well integrated with applied technology programs and that research be of the highest caliber. At the same time, consideration of needs and applications does not and should not constrain the scope of scientific inquiry—this is the hallmark of a basic science program and a fundamental tenet for truly crosscutting scientific discovery and innovation.

Consistent with the goal for science excellence, SC implements a highly effective scientific peer review process and is often called upon to conduct peer review for the rest of the Department. Additionally, and over the last few years, the Office of Science has strengthened its process for integration with the applied energy R&D programs, improving coordination and communication across a broad range of areas. Examples of some specific energy technology areas that have benefitted from recent strengthened integration include:

- Office of Energy Efficiency and Renewable Energy's Industries of the Future Program.
- Partnership for a New Generation Vehicle.
- Advanced Computation Initiative, that includes the Office of Energy Efficiency and Renewable Energy as well as the oil and gas industry.
- Advanced Turbine Systems Program.

Thus, with an eye toward research relevance and integration, SC sets strategic research directions through working relationships with other DOE programs, through research workshops involving input from the scientific and technical communities, through the promotion of open information transfer and exchange of ideas between the basic and applied research communities, and, finally, through the sponsorship of selected high-impact research collaborations and partnerships. Individual research projects are funded based on peer review by the members of the scientific community. These approaches to basic research funding have led to hundreds of Cooperative Research and Development Agreements, that extend the basic research to applications and development. In addition, there are many more collaborations between SC researchers and industrial researchers.

The resulting diverse portfolio of basic research programs and the combination of university and laboratory programs supports the institutional capacity for interdisciplinary research needed to solve the problems of energy production and use, and also integrates basic science with applied science and development activities. The Department's National Laboratory system plays a special role in the ability of SC to effectively integrate research and development by providing opportunities to collocate activities at these sites. And, because many researchers are also cofunded by SC as well as the applied energy technology programs, the Office of Science helps guarantee that energy technology development is being conducted with the benefit of advanced scientific knowledge and that the basic research programs are focused in areas directly relevant to energy systems.

Impacts—Select Examples

Against this backdrop, DOE's basic science programs have contributed substantially to the energy R&D mission of the Department. For example, in the past 50 years, 71 SC-supported researchers have received Nobel Prizes—a total that far surpasses that of any other public or private institution.

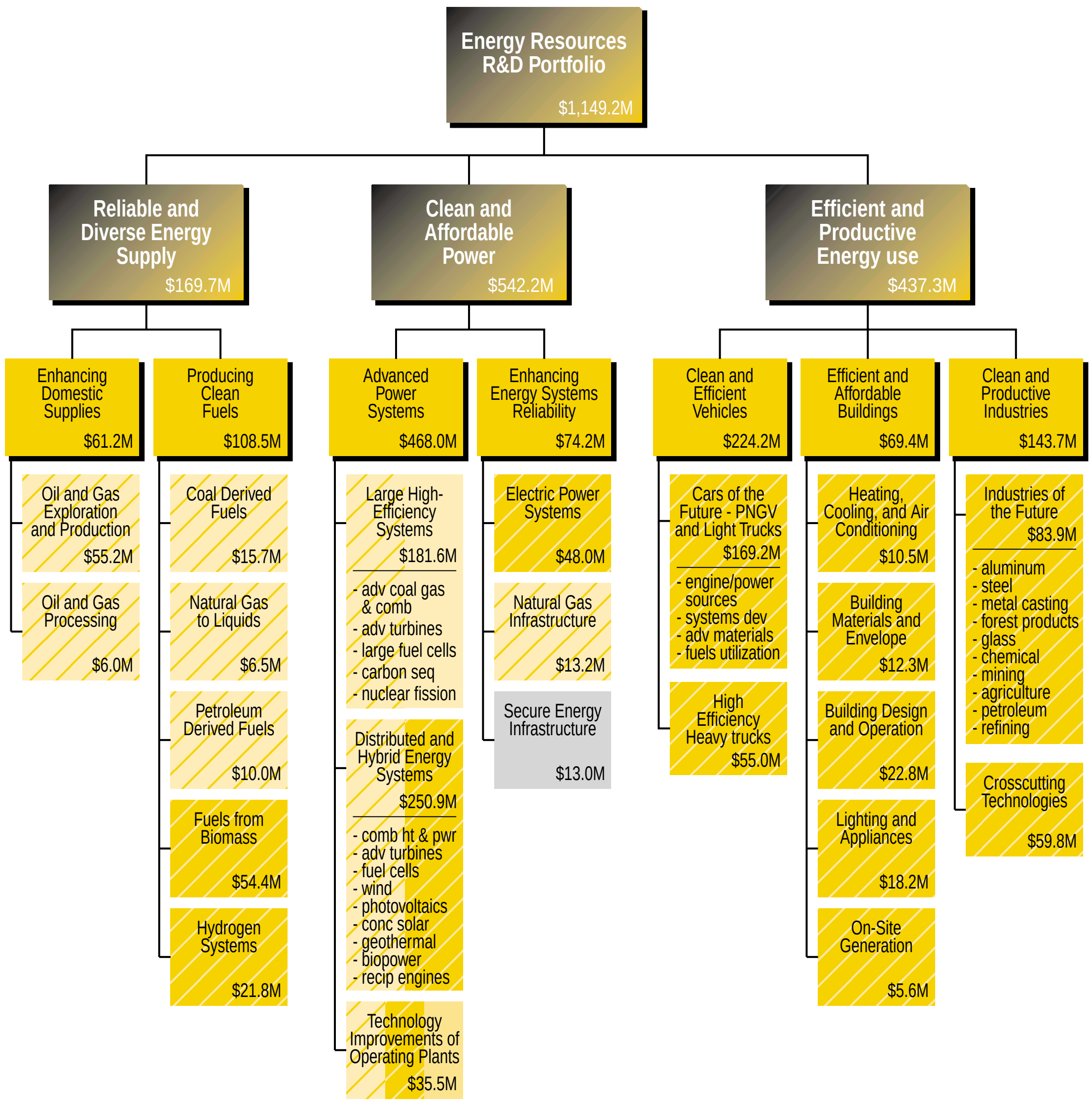
A long term study of R&D 100 Awards, considered the premier indicator of new technologies supported by private and public sector institutions, showed that SC-funded technologies dominate Award winners. During the period from 1963-1996, DOE received 62 percent of all R&D 100 Awards given to the Federal government. SC-funded research has received 177 awards (41 percent of the DOE total/25 percent of the Federal total), making the Office of Science the most frequent recipient in the Federal government. Comparisons with recipients in private industry and academia show similar results.

Below are some select examples that illustrate the energy impacts of SC-funded research in basic science:

- Development of the current generation of high energy and power lithium and lithium ion batteries from research into non-aqueous electrolytes.
- Batteries half the thickness of saran wrap stemming from research into ion transport in glassy solids.
- Improved natural gas separation processes stemming from research into reverse selectivity inorganic membranes.
- Enhanced separation of heavy elements in the nuclear industry from research on actinide separations and related research.
- Ability to produce new, valuable polymers from research into new metallocene catalysts.
- Original discovery of a new class of carbon materials—buckeyballs.
- Potentially new ways to store hydrogen through the discovery of new graphite nanofibers that can store three times their weight of hydrogen.
- Major improvements in the toughness of silicon carbide ceramics.
- Breakthrough processing of aerogel films, ideal insulating materials.
- Design of more reliable joints between ceramics and metals from improved finite element models.
- Research leading to the commercialization of gelcasting for molding near-net shape ceramic parts.
- New and better future diesel engine designs stemming from computational and technology research into models that predict soot generation.

- Discovery of a new marker for efficient combustion.
- Testing and development of nontoxic corrosion inhibitors using a special “vibration pole.”
- Breakthrough levels in energy production from fusion plasma experiments.
- New genetic manipulation techniques to improve the properties of bacteria that are capable of producing methane.
- Lignin depolymerizing enzymes with the potential for an effective “green” technology in pulp and paper production.
- Development of a new catalytic control system for a lean burn engine.
- Development of a photovoltaic cell that holds three world records for efficiency, stemming from collaborative research between EE and SC.
- Improved miniaturization through research into nanowires, “magic structures,” and conductance quantization.
- A tenfold increase in the electrical conductivity of semiconductors through research into gallium injection.
- Improved imaging of pore spaces in sandstone for oil recovery through research into synchrotron x-ray micro tomography.
- Artificial photosynthesis through research into light-matter interactions and proton motive force.
- Improved high temperature superconductors through research into pairing mechanisms and vortex physics.

Appendix
Budget Profiles



Office of Energy Efficiency and Renewable Energy
Office of Fossil Energy
Office of Nuclear Energy, Science and Technology
Office of Security and Emergency Operations

$ = FY 2001 Congressional Budget Request

Appendix

Budget Profiles (000$)

Enhancing Domestic Supplies Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Oil and Gas Exploration and Production	**60,757**	**69,967**	**55,219**
Diagnostics and Imaging	19,294	20,269	15,456
Drilling, Completion, and Stimulation	7,720	8,916	7,700
Reservoir Life Extension	24,514	28,164	21,840
Drilling and Production Env. Management	8,737	9,624	8,923
Gas Hydrates	492	2,960	2,000
Oil and Gas Processing	**6,225**	**6,015**	**6,015**
Low Quality Gas Upgrading	1,925	1,615	1,615
Air Emissions Detection and Control	4,300	4,400	4,400
Total	**66,982**	**77,948**	**61,234**

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**

Advanced Power Systems Research Areas	**FY 1999 Appropriated**	**FY 2000 Appropriated**	**FY 2001 Request**
Large High Efficiency Systems	**176,279**	**190,219**	**181,590**
Advanced Coal Gasification & Combustion Systems	65,491	69,923	58,890
- *Advanced Coal Combustion*	*20,967*	*9,010*	*2,000*
- *Pressurized Fluidized Bed Combustion*	*14,356*	*12,202*	*11,185*
- *Gasification Technologies*	*30,168*	*48,711*	*45,705*
Advanced Gas Turbine Systems	43,398	44,188	26,000
Advanced Large-Scale Fuel Cell Power Systems	43,069	44,499	42,200
Carbon Sequestration	5,825	9,217	19,500
Nuclear Fission Systems	18,496	22,392	35,000
Distributed and Hybrid Systems	**224,081**	**201,826**	**250,890**
Industrial Combined Heat and Power Systems	200	3,000	1,000
Buildings Cooling Heating and Power Systems	0	0	3,000
Advanced Industrial Turbine Systems	49,403	22,300	13,300
Hydrogen Fuel Cell Systems	0	5,530	8,770
Wind Energy Systems	34,076	32,481	50,500
Photovoltaic Systems	70,561	65,912	82,000
Concentrating Solar Power Technology	16,791	15,168	15,000
Geothermal Energy	21,734	23,600	27,000
-*Geothermal Exploration*	*5,400*	*6,000*	*6,000*
-*Geothermal Drilling and Completion*	*4,934*	*5,500*	*5,500*
-*Geothermal Reservoir Technology*	*5,400*	*6,000*	*5,500*
-*Geothermal Energy Conversion Systems*	*6,000*	*6,100*	*10,000*
Biopower Energy Systems	30,816	31,835	48,000
Reciprocating Engines	500	2,000	2,320
Technology Improvement of Operating Plants	**22,199**	**31,543**	**35,550**
Aging Effects in Key Components	6,066	7,000	7,350
Nuclear Power Plants (NEPO)	0	4,976	5,000
Regulatory Compliance	12,923	14,646	18,200
Hydropower Turbines	3,210	4,921	5,000
Total [Advanced Power Systems]	**422,559**	**423,588**	**468,030**

Enhancing Energy System Reliability Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Transmission Reliability	**3,019**	**2,455**	**8,000**
Real Time System Control	1,169	855	3,000
Distributed Resource Integration	900	800	2,000
Reliability and Markets	950	800	3,000
Distributed Power	**1,200**	**3,500**	**3,000**
Strategic Research	200	500	700
System integration	732	2,700	2,000
Regulatory and Institutional Issues	300	300	300
Energy Storage Systems	**4,445**	**3,429**	**5,000**
Integration	2,170	1,640	2,500
Components	1,384	1,000	1,600
Analysis	891	789	900
Superconductivity in Power Systems	**32,100**	**31,408**	**32,000**
The Superconductivity Partnership Initiative	14,500	14,000	14,000
The Second Generation Wire Initiative	8,000	8,000	8,000
Strategic Research	9,600	9,408	10,000
Natural Gas Infrastructure	**975**	**1,000**	**13,200**
Gas Storage Technology	975	1,000	2,200
Enhancing Pipeline System Reliability	0	0	5,000
International Infrastructure Integrity	0	0	6,000
Secure Energy Infrastructures	**0**	**2,100**	**13,000**
Analysis and Risk Management	0	2,100	10,300
Protection and Mitigation Technologies	0	0	2,700
Total	**41,739**	**43,892**	**74,200**

Clean and Efficient Vehicles Research Areas	**FY 1999 Appropriated**	**FY 2000 Appropriated**	**FY 2001 Request**
Cars of the Future - PNGV and Light Trucks	**147,338**	**155,300**	**169,220**
Engine/Power Sources	94,320	109,700	123,420
- *Advanced Combustion Engine R&D*	*33,476*	*39,700*	*41,920*
- *Fuel Cells*	*32,909*	*37,000*	*41,500*
- *High-Power Batteries for Hybrid-Electric Vehicles*	*12,520*	*14,000*	*18,300*
- *Power Electronics and Electric Machines*	*6,751*	*10,000*	*12,000*
- *Electric Vehicle Batteries*	*8,664*	*9,000*	*9,700*
Systems Development	24,408	16,600	16,800
Advanced Materials	22,265	22,000	21,000
Fuels Utilization	6,345	7,000	8,000
High Efficiency Heavy Trucks	**30,679**	**50,200**	**55,000**
Heat Engine R&D	3,500	8,100	12,000
Systems Development	1,500	7,000	9,000
Advanced Materials	14,551	20,500	17,500
Fuels Utilization	11,128	14,600	16,500
Total	**178,017**	**205,500**	**224,220**

Efficient and Affordable Buildings Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY2001 Request
Heating, Cooling, and Air Conditioning	**15,379**	**10,905**	**10,533**
Geothermal Heat Pumps	6,500	0	0
Absorption Technologies	5,910	6,365	6,260
Desiccants	2,480	4,040	4,273
Furnaces and Boilers	489	500	0
Building Materials and Envelope	**10,723**	**11,723**	**12,325**
Windows and Glazings	6,829	6,929	7,325
Walls, Roofs, and Foundations	3,894	4,794	5,000
Building Design and Operation	**12,970**	**19,163**	**22,790**
Commercial Buildings	5,200	7,700	9,610
Residential Buildings	7,770	11,463	13,180
Lighting and Appliances	**11,791**	**13,745**	**18,175**
Lighting	5,394	6,000	6,360
Refrigeration	2,797	4,245	4,230
Heat Pump Water Heater and Appliances	0	1,500	2,085
Solar Water Heating	3,600	2,000	5,500
On-site Generation	**1,750**	**3,550**	**5,550**
Fuel Cells	1,750	3,550	5,550
Total	**52,613**	**59,086**	**69,373**

Clean and Productive Industries Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Industries of the Future	**56,447**	**66,000**	**83,900**
Aluminum	7,925	11,178	11,000
Steel	10,308	10,627	10,900
Metal Casting	5,675	5,797	5,800
Forest Products	11,753	12,076	17,100
Glass	4,701	4,830	4,800
Chemical	12,123	12,492	12,500
Mining	1,981	3,000	4,000
Agriculture	1,981	4,000	13,000
Petroleum	0	2,000	3,000
Supporting Industries	0	0	1,800
Crosscutting Technologies	**48,038**	**53,600**	**59,800**
Enabling Technologies	18,881	22,500	22,000
Technical Assistance	18,645	19,750	25,800
Financial Assistance	10,512	11,350	12,000
Total	104,485	119,600	143,700