DOE Research and Development Portfolio

Energy Resources

Volume 2 of 5

April 1999

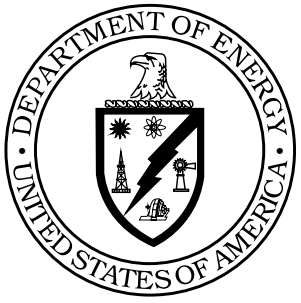
U.S. Department of Energy

DOE Research and Development Portfolio

Energy Resources

Volume 2 of 5

April 1999



U.S. Department of Energy

Department of Energy

Washington, DC 20585

April, 1999

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.

Over the past year, the Department of Energy (DOE) has undertaken a major effort to ensure that our research and development programs are balanced and that our Federal investments are appropriately coordinated with the needs of the public and the marketplace. To do this, we have begun instituting a new portfolio approach to managing our R&D activities. This entails building a comprehensive document that, for the first time, provides in one place, a clear description of our entire $7 billion research portfolio. Following is DOE's *Energy Resources R&D Portfolio*. It is Volume II of the DOE's five volume R&D Portfolio.

This document is intended 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 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 successfully. It is our hope that this document will provide the means for illuminating our proposed investments for Fiscal Year 2000 and beyond, as a unified portfolio and serve as a useful framework and resource for further analysis and dialogue among all interested parties.

Ernest J. Moniz
Under Secretary

Dan W. Reicher
Assistant Secretary for Energy
Efficiency and Renewable Energy

Robert W. Gee
Assistant Secretary for
Fossil Energy

William D. Magwood, IV
Director, Office of Nuclear
Energy, Science and Technology

Martha A. Krebs
Director
Office of Science

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.

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 attempts to describe 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; energy from geothermal sources; clean, alternative liquid fuels from coal, natural gas and biomass; and hydrogen fuels.

- **Chapters 5 and 6** deal with ***Clean and Affordable Power*** activities, the largest portfolio area. These chapters describe the broad range of generation technology needed to deliver affordable, reliable, and clean electric power. 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 details on R&D for advanced delivery and control systems that will help ensure the availability of a robust, reliable electricity infrastructure required to serve emerging, competitive regional and interregional markets.

- **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 is summarized in **Chapter 10**.

Table of Contents

Executive Summary

Introduction

Energy needs of the United States are diverse and extensive. Energy is the vital force powering business, 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 (40 percent), gas (24 percent), coal (24 percent), nuclear (8 percent), and renewable sources (4 percent). The Energy Information Administration's 1999 Annual Energy Outlook (AEO99) 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).

AEO99 projects that by 2015, U.S. consumption of oil will increase more then 20 percent to over 23 million barrels per day, of which 60 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 nearly double by 2015, with the Middle East controlling nearly 70 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 AEO99 to increase over 33 percent by 2015 to nearly 31 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 at these

[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.

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 roughly one-tenth of this production to a variety of markets. It uses almost 90 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 more than 20 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 wood and waste), 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, more electricity than Europe and Japan combined. AEO99 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 36 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 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 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.

Energy prices, particularly for oil, are now relatively low, and electric utility restructuring is expected to support this general trend by subjecting the pricing of electricity to the discipline of market forces. If energy prices remain low for the near future as many project, private sector investments in energy R&D could be reduced and introduction of new, commercial-scale technologies into the market delayed or deferred. But R&D and adoption of new technologies is

a long-term process. The size and complexity of the U.S. energy system, and the large capital requirement of many energy investments are such that the transition to new energy sources and fuels has historically taken from several decades to half a century. A substantial period of R&D, in some cases decades, may be needed to ensure that robust technological and energy options are available when the need inevitably arrives.

Federal Role and Linkage to Comprehensive National Energy Strategy

The Department's energy R&D portfolio is keyed to national needs regarding energy security, environment, and economic prosperity. DOE is the lead Federal agency working to assure clean, affordable, and dependable supplies of energy for our Nation. The Federal government's energy role is articulated through the goals, objectives, and strategies in the April 1998 Comprehensive National Energy Strategy (CNES)[2], that was developed by the Department and other Federal agencies with input from many stakeholders. The CNES includes actions that help increase energy supply diversity and fuel choices, bring renewable energy sources into the market, strengthen domestic production of oil and gas, support commercial nuclear energy research, and increase the efficiency of both power and end use technologies. The Department is also the lead agency for the Administration's strategy to bring competition to the electricity industry.

The Department's energy R&D portfolio supporting the CNES is managed by three principal organizations: the Office of Energy Efficiency and Renewable Energy, the Office of Fossil Energy, and the Office of Nuclear Energy, Science and Technology. Their combined R&D portfolio is centered on developing the technologies in support of the 3 energy R&D goals and 7 objectives shown in Figure 1. R&D associated with the 7 objectives is shown in Figure 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 3 provides examples of why and where the private sector has underinvested in strategically important energy R&D.

[2] The five CNES goals are:

1. Improving the efficiency of our energy systems.
2. Ensuring against energy disruptions by reducing the threat of supply interruptions and increasing the security and reliability of our energy infrastructure.
3. Promoting energy production and use in ways that protect our health and environment.
4. Expanding future energy choices.
5. Cooperating internationally on energy issues.

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

Figure 1

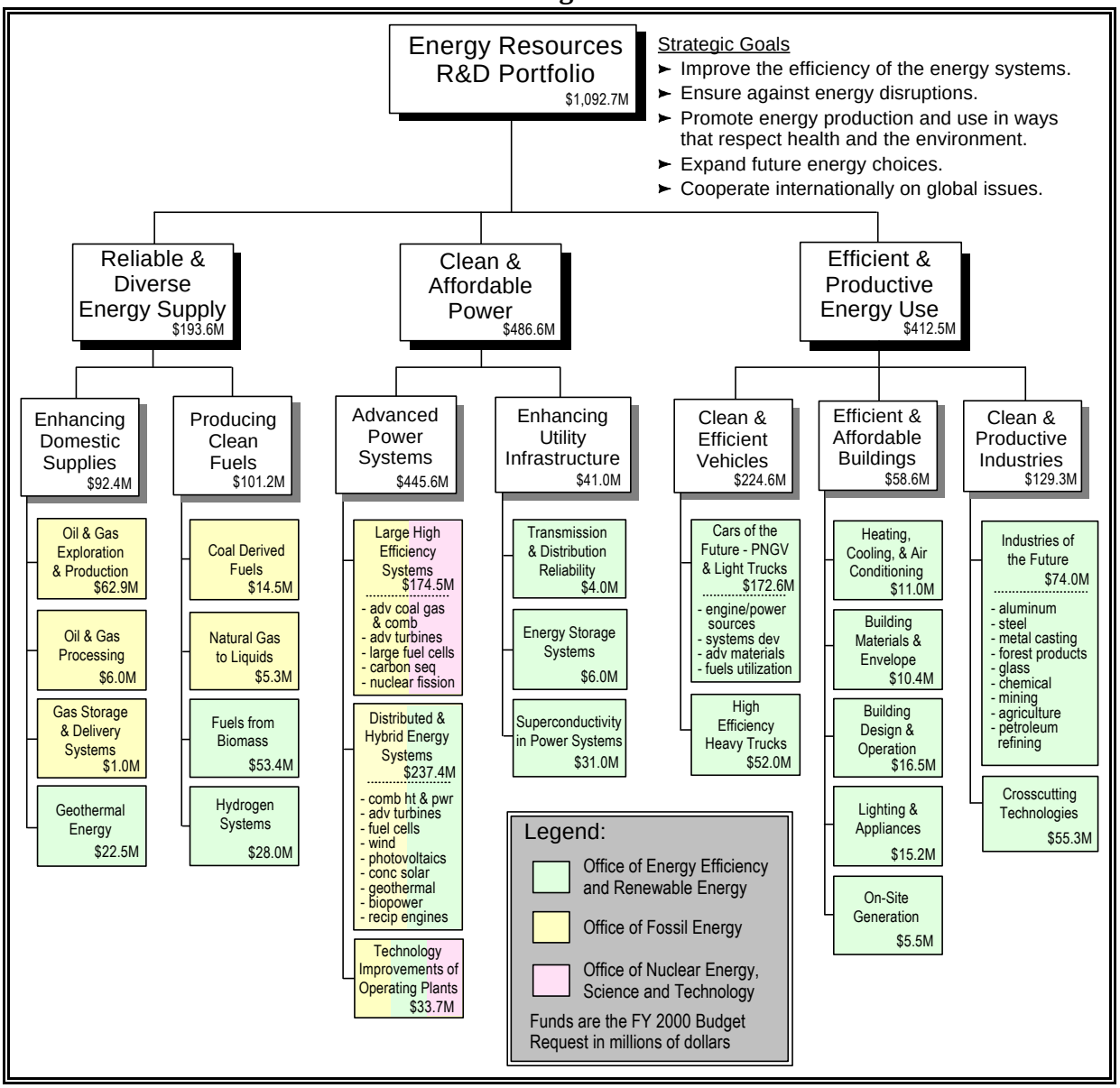


Figure 2

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

Figure 3

Portfolio Summary, Trends, and Accomplishments

Funding and Characteristics

Funding shares for DOE's FY 2000 Energy Resources R&D portfolio of applied research and development activities are shown in Figure 4 for 2 levels of detail. Shares of the overall FY 2000 budget request of $1.07 billion are 17 percent for energy supply, 44 percent for power, and 39 percent for energy use.

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.

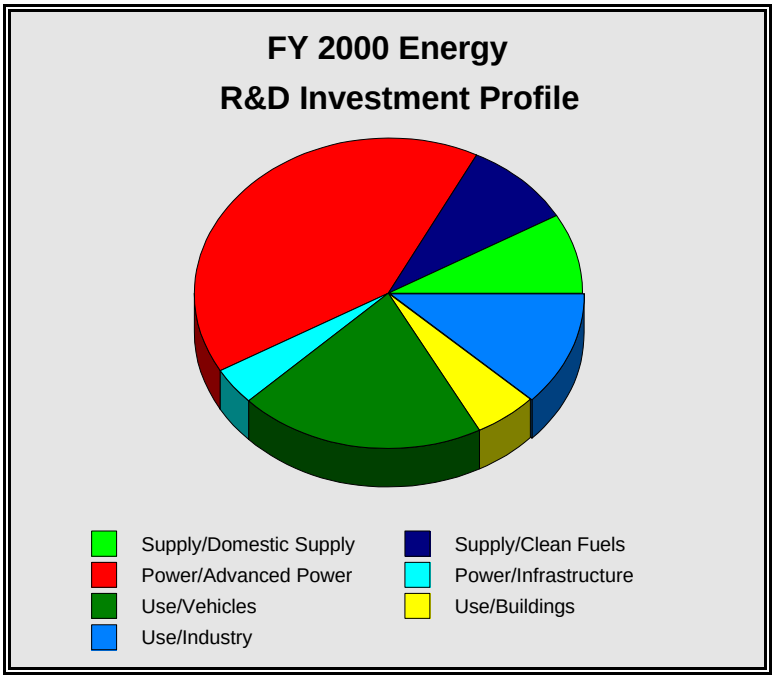


Figure 4

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., 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

The major components of the energy R&D portfolio shown in Figure 2 are discussed below, along with selected accomplishments that reflect progress toward goals.

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; energy from geothermal sources; clean, alternative liquid fuels from 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 of activities for clean, alternative fuels is fuel additives to solve environmental problems. R&D for liquids from coal and natural gas includes diesel additives to reduce emissions in high efficiency engines. 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 thought to be depleted.

- Geothermal drilling-related advances led to a 30 to 50 percent reduction of geothermal exploration drilling costs.

- 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.

- Over the last 2 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 is R&D on advanced delivery and control systems to ensure the availability of the robust, reliable electricity infrastructure required to serve emerging, competitive regional and interregional markets.

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, product flexibility, reduced emissions, and lower cost. Carbon sequestration is seen as an increasingly important option for coping with greenhouse gas emissions. The Nuclear Energy Plant Optimization program, proposed for FY 2000, will help ensure that nuclear plants can deliver affordable supplies beyond their initial 40 year license period. Effort on distributed and hybrid systems, that includes renewable technologies, the industrial cogeneration turbine and fuel cell technology, continues to expand in recognition of potential environmental benefits and advantages of increasing distributed generating capacity. R&D for enhancing utility infrastructure is phasing out electric and magnetic fields activities and increasing emphasis on power system and energy storage technologies.

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.

  - 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.

- 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 2000. Technology roadmapping carried out by industry continues to drive DOE's R&D agenda for clean and productive industries. Mining and agriculture (particularly the bioproducts area) have been added to the industries R&D portfolio, bringing the industries total to nine. 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. Ford and other major manufacturers have begun mass marketing vehicles that can use ethanol, a biofuel.

- 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. There has been a continuing increase in the use of more advanced lost foam processes and by 2010 it is expected to be used for 29 percent of aluminum and 15 percent of steel castings, saving 4.6 trillion Btus/year of energy and 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.