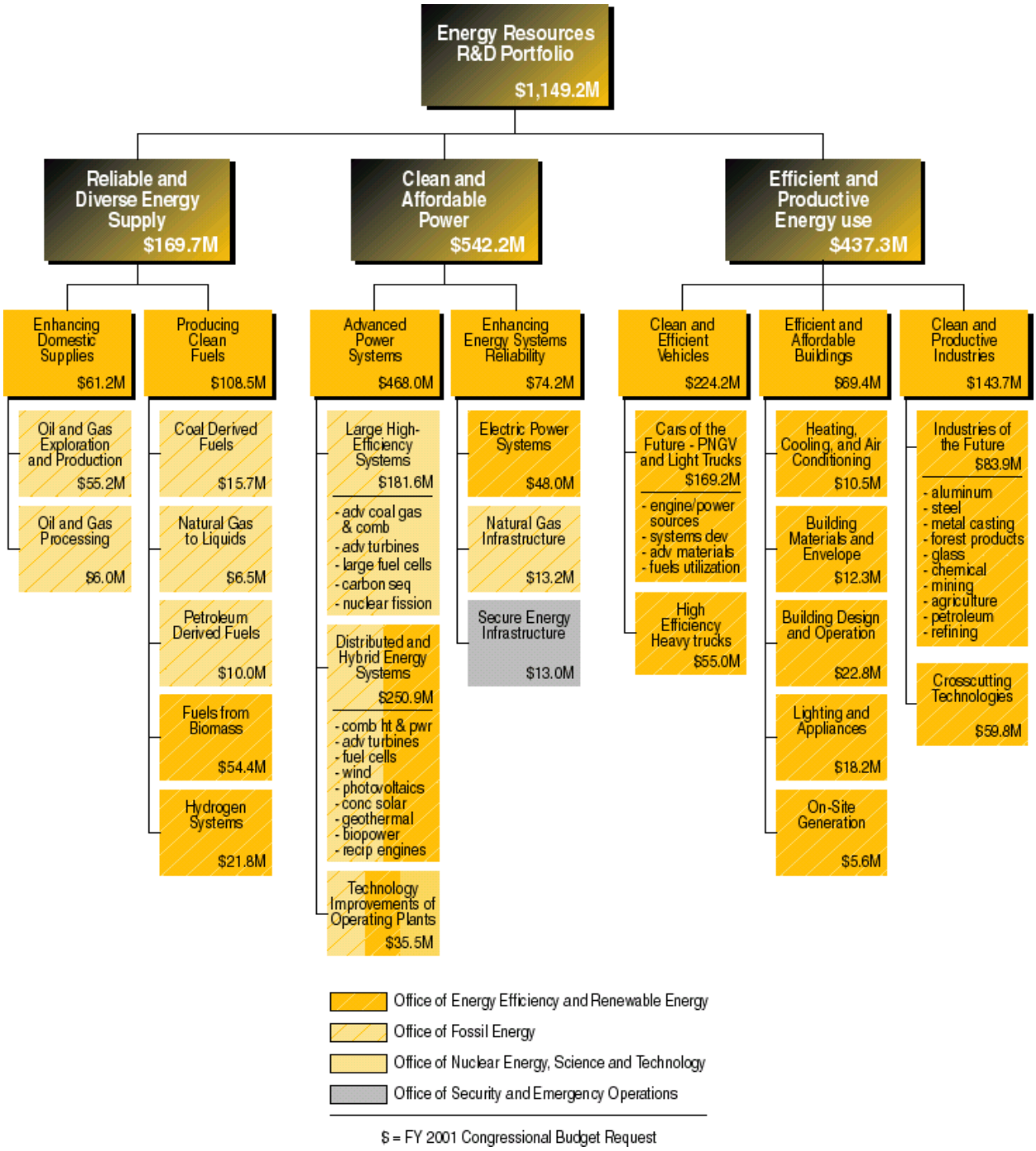
Chapter 2
Portfolio Analysis



Chapter 2
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Table of Contents

Page

Overview 15
The Context for the Energy Resources R&D Portfolio 15

The Energy Resources R&D Portfolio in Brief 19
DOE and Private Sector R&D Funding 19
DOE Energy Resources R&D Portfolio Budgets.....21
Types of Energy R&D 24
DOE Energy R&D Performers 26

Analysis of the Portfolio 27
Federal Energy R&D for the Challenges of the 21st Century (PCAST-Federal) 27
Energy Resources R&D Portfolio Analysis 28
Powerful Partnerships: The Federal Role in International Cooperation and Energy Innovation (PCAST-International) 30

Other Reports Related to Portfolio Analysis 31

R&D Portfolio Responses 34
Summary 38
References 40

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.

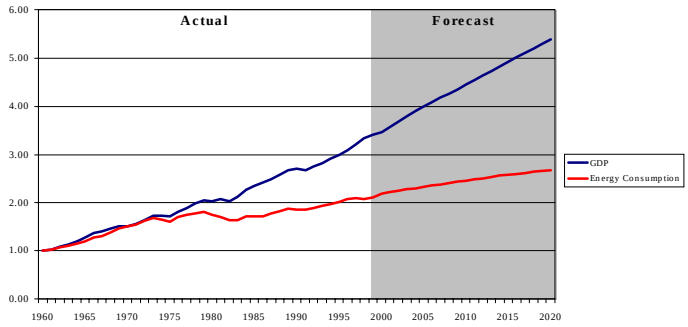
It is generally accepted that while shifts in the makeup of energy supplies and use patterns will occur, there are no "silver bullet" technologies to address the energy demands across the three sectors. Instead, the Nation will continue to require a broad portfolio of economically productive and reliable 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.

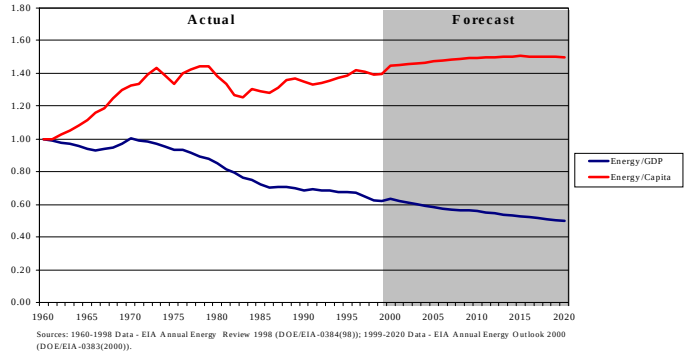
A fourth energy challenge facing the Nation is the electricity industry's transition from a regulated monopoly to a restructured electricity market. This transition poses new challenges to the continued reliable transmission and distribution (T&D) of electricity; the market penetration of advanced energy 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)



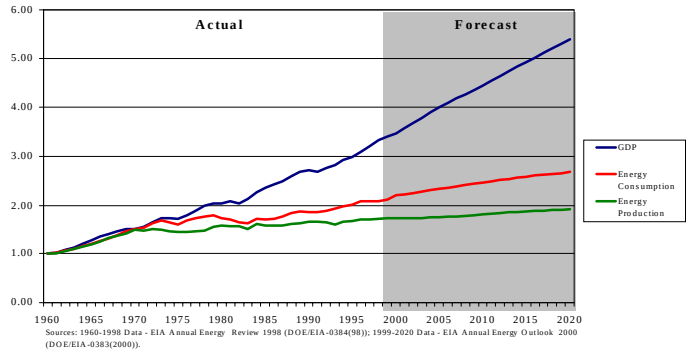
GDP growth is expected to continue at approximately the level of the past two decades. Energy use is also expected to increase, at a somewhat lower level, however, than the GDP.

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)

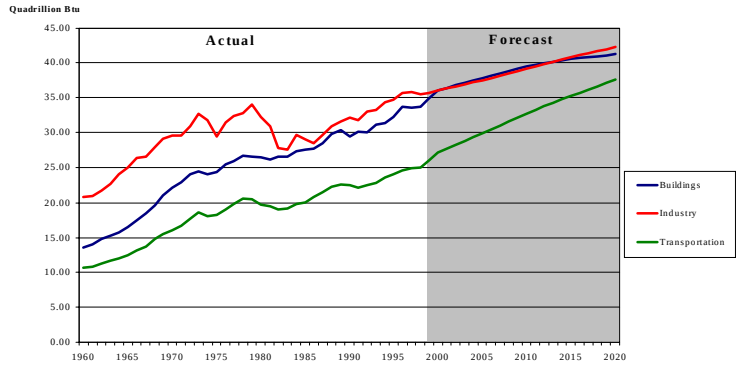


GDP Domestic energy production is projected to lag energy consumption, implying an increasing dependence on imports.

Energy Trends

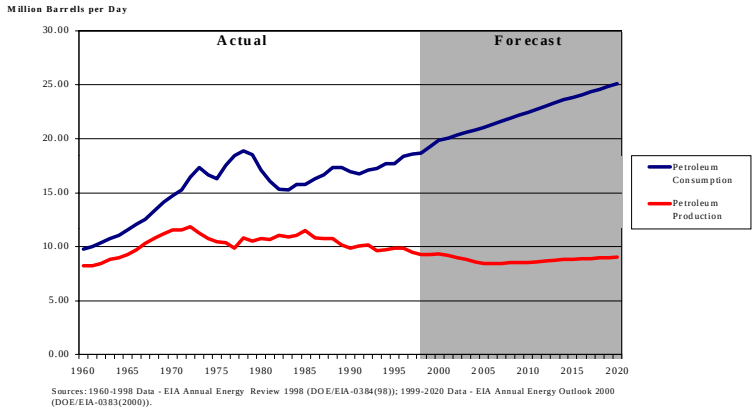
Figure 2-1

Energy Consumption by Sector



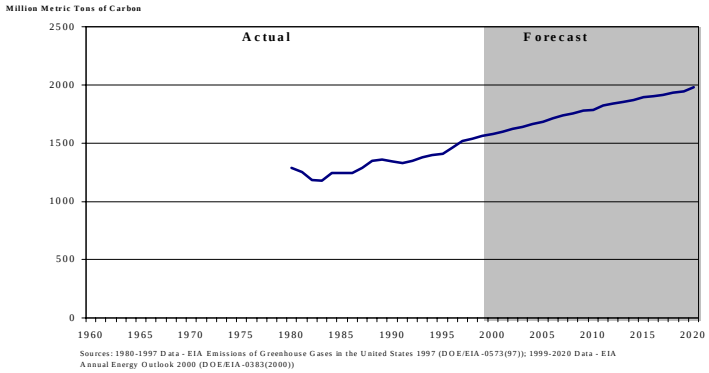
The growth in energy consumption is occurring across all three energy sectors.

Petroleum Consumption and Domestic Production



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

Carbon Emissions



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

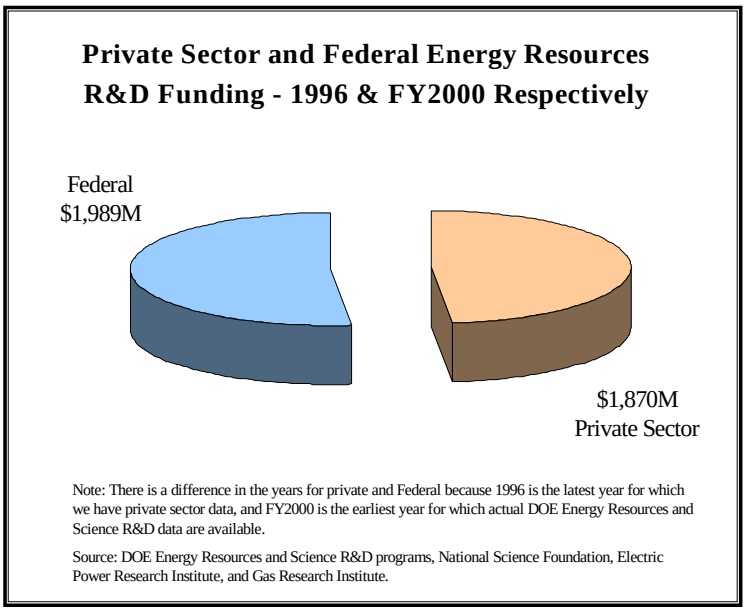


Figure 2-3

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.

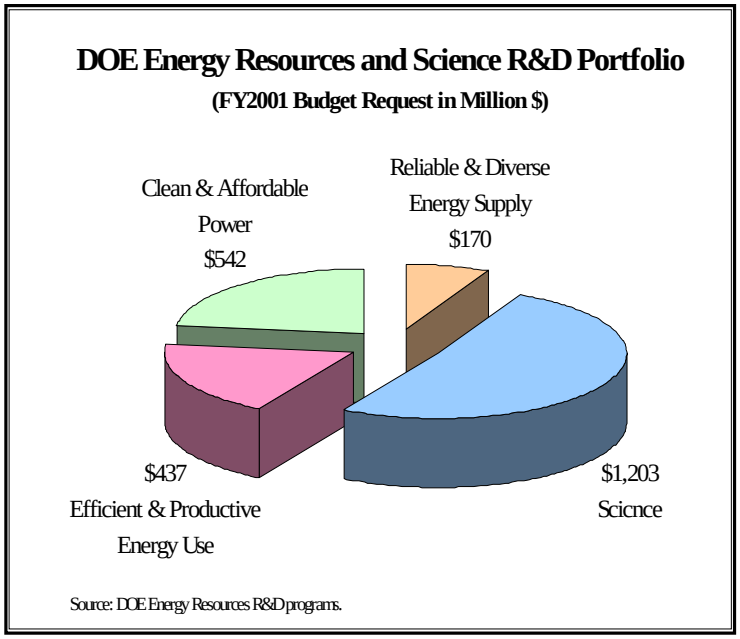


Figure 2-4

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.

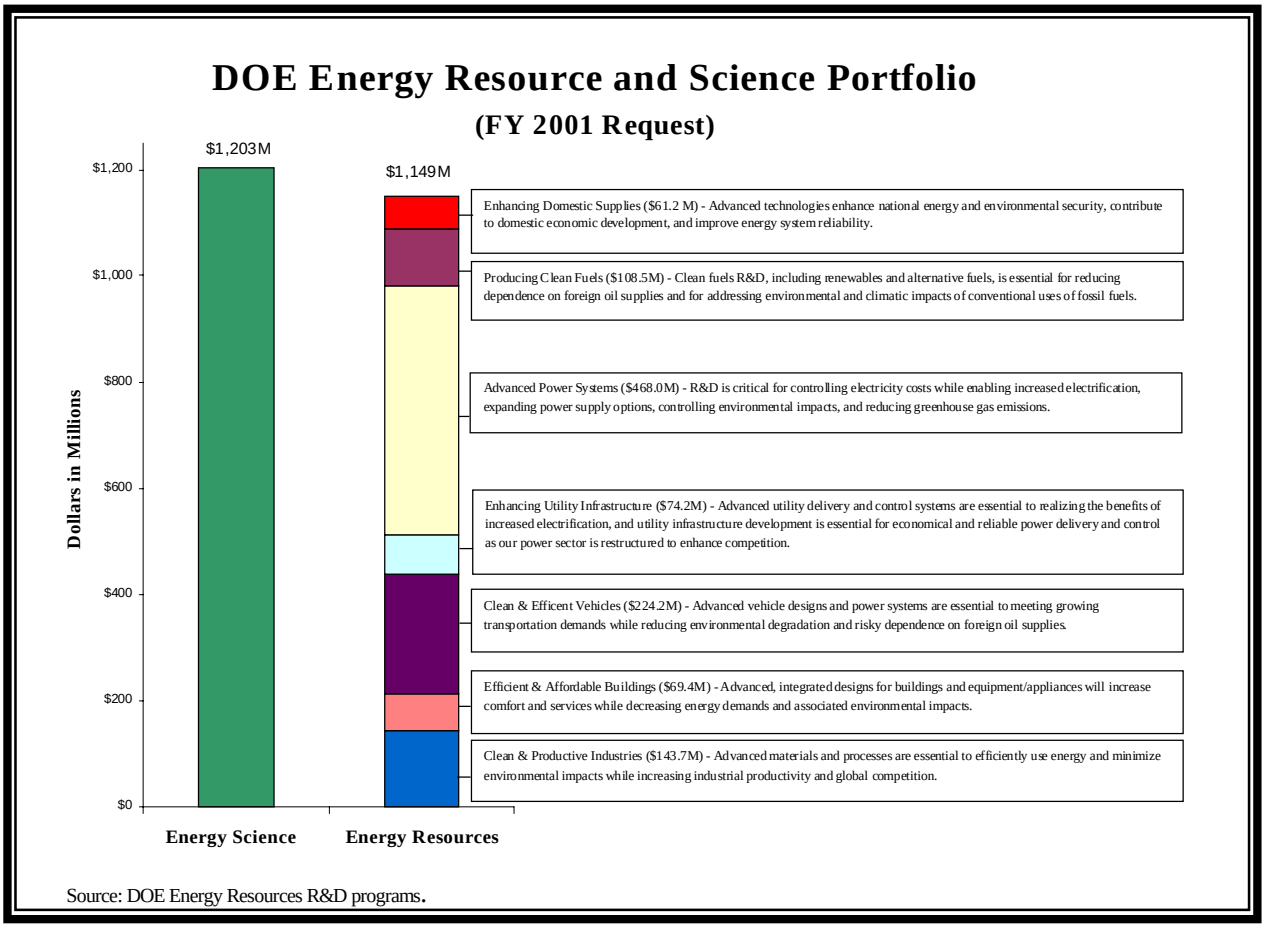


Figure 2-5

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.

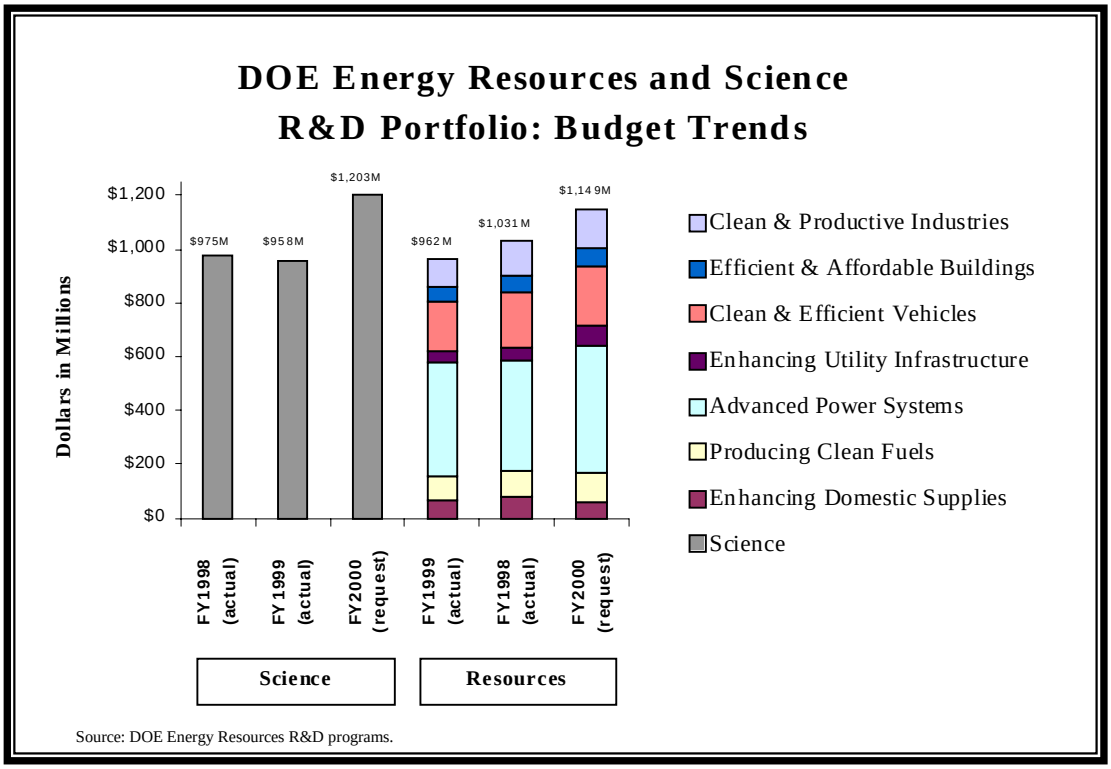


Figure 2-6

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.

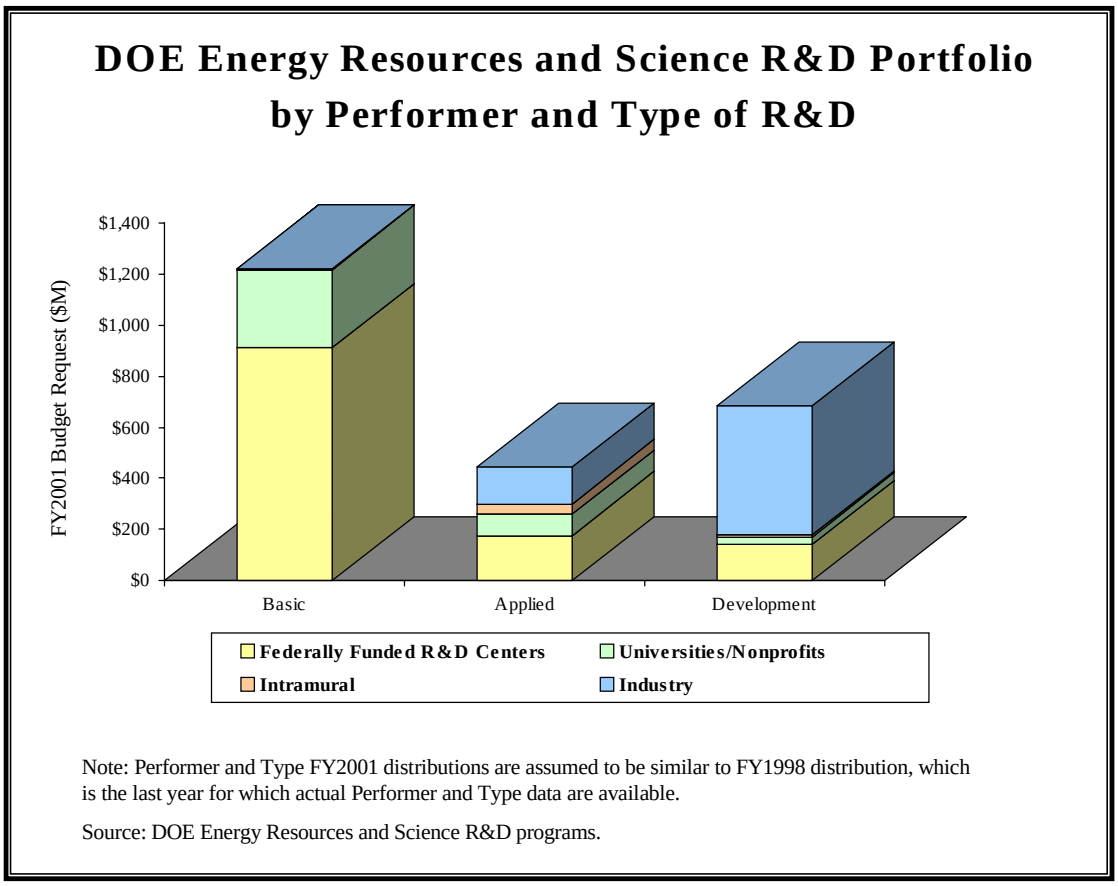


Figure 2-7

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

[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.

[*] 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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