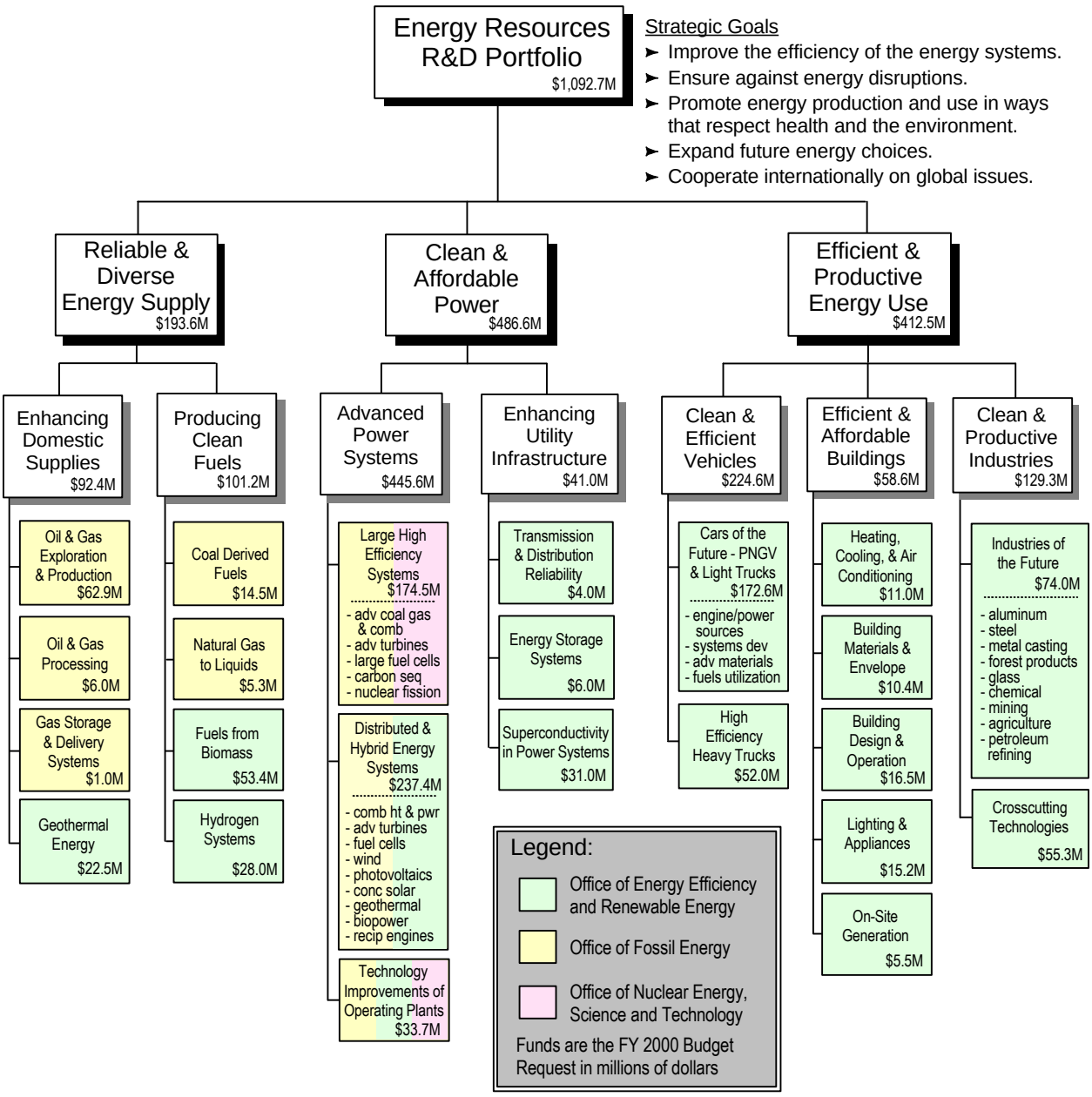
Chapter 2
Portfolio Analysis



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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 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 also limiting or reducing environmental damage.

One example of the impact of the technological advances is the fact that 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 7). 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. Technological advances that led to improvements in primary energy production, energy conversion and delivery, and energy end use in our buildings, industrial sector, and transportation systems have been a key driver of the decrease in energy intensity.

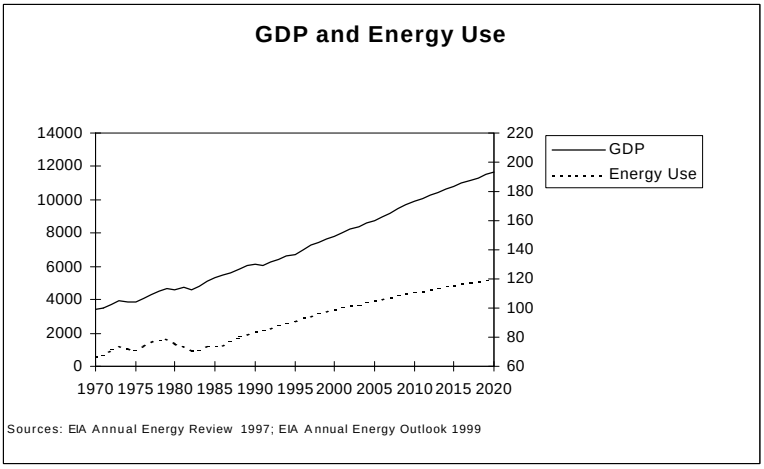
While energy use per GDP has been decreasing, energy use per capita has been increasing in the 1990s due to low energy prices and changing consumer habits and preferences (e.g., suburbanization, larger vehicles and buildings), as well as an increase in the use of electrical appliances in our homes and 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 technological advances (see Figure 7). 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 7). If this situation occurs, America will be increasingly reliant upon energy imports, particularly oil 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 sectors (see Figure 8):

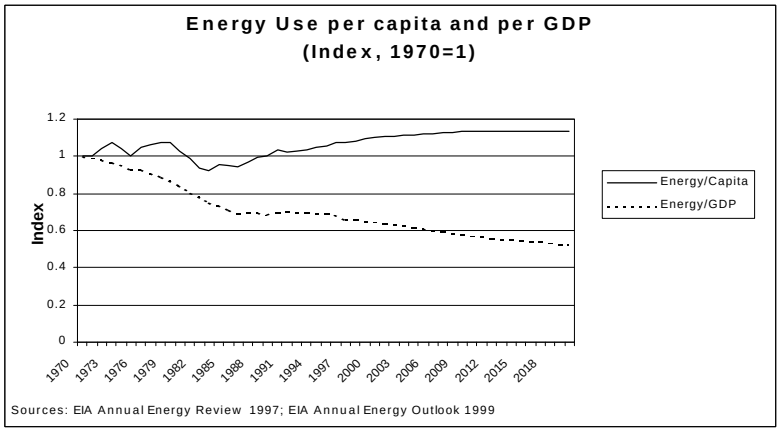
- In buildings, to energize expanding building stocks for the commercial services and in the home, comfort and entertainment of an increasing population.
- In industry, to power the industrial production for expanding GDP.
- In transportation, to meet the Nation’s increasing household and industrial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

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

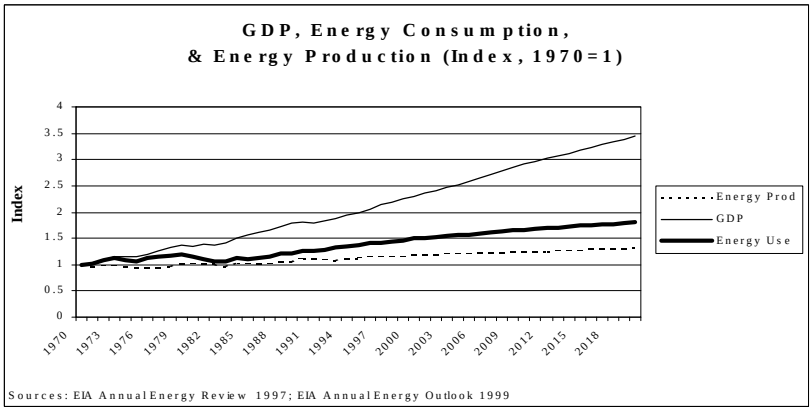
production, conversion, delivery and storage, and end-use technologies to meet the growing energy needs of the buildings, industrial, and transportation sectors.



GDP growth is expected to continue at approximately the level of the past 2 decades. Energy use is also expected to increase, at a somewhat lower rate than GDP.

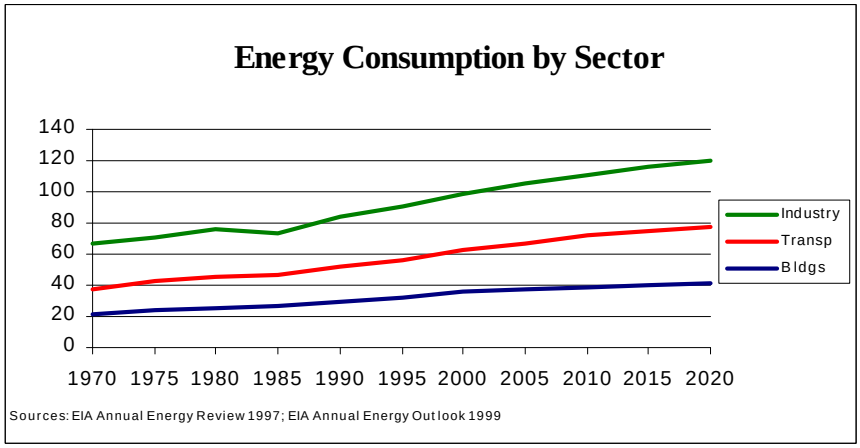


Energy use per unit of GDP is projected to continue to decrease. Advancing technology and shifts to less energy intensive industries are the primary contributors to that decrease. However, energy per capita is expected to continue to grow slowly.

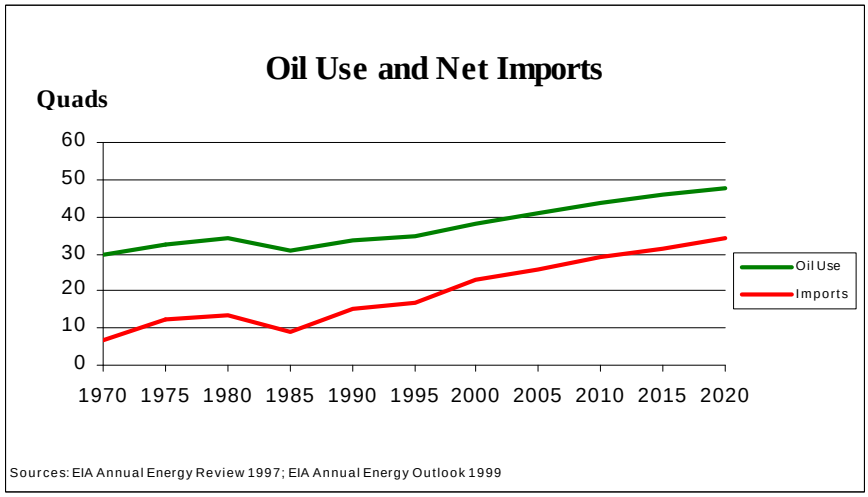


Domestic energy production is projected to continue to lag energy consumption, implying an increasing dependence on imports.

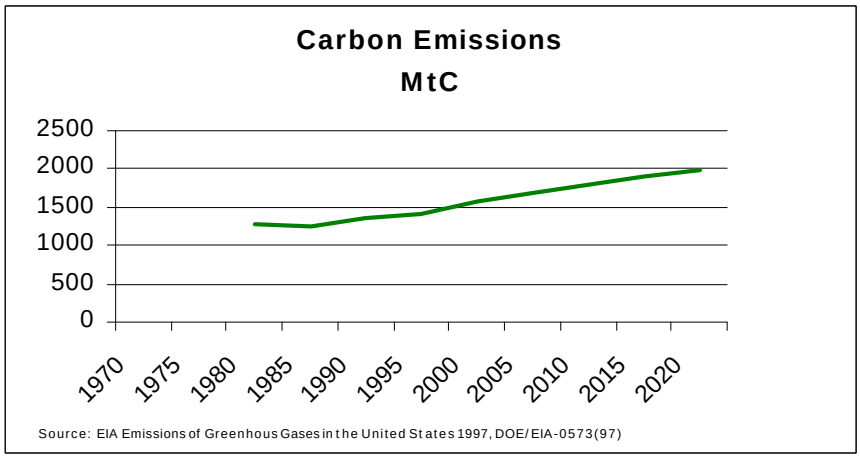
Figure 7



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



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



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

Figure 8

A second energy challenge facing the Nation is the forecast growth in oil imports, up from about 50 percent of total use today to 65 percent in 2020 (see Figure 8). 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 dependent upon foreign oil reserves in the 21st century, should recent trends continue. This challenge makes the Department's R&D activities that are designed to increase the availability of low-cost domestic oil or alternative fuels (e.g., biofuels) a prudent investment for the country's continued economic well-being and national security.

A third energy challenge facing the Nation is reflected in the growing concerns about the emissions associated with the current approaches to fossil energy recovery and use, both locally as smog and regionally through transmission by winds, and even globally in the form of emissions of greenhouse gases. 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 the buildings, industry, transportation, and utility sectors.

The composition of the Energy Resources R&D Portfolio has evolved over the past few decades as our understanding of energy system challenges and technological opportunities have developed. For example, 10 years ago the concerns about carbon emissions were not widely shared. Today, however, advances in our scientific understanding of global warming have raised a number of concerns about carbon emissions that have led to an R&D investment in a number of carbon management technology options. As another example, conversion of natural gas to liquid fuels is receiving increased attention because it could enable use of large, remote domestic natural gas supplies to alleviate our need for imported oil. Finally, R&D on technologies such as fuel cells is increasingly emphasized today with our expanding appreciation of the conversion efficiency and low emissions potential of that technology for both stationary and transportation power systems.

In summary, the Nation is facing a range of serious challenges associated with our future energy economy. The Department's Energy Resources R&D Portfolio, which is described in detail in this report, 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 those 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. While DOE has a large energy R&D program, it represents less than one-half of what is spent by the private sector, and probably considerably less than that given limitations in data availability of private sector R&D activities (see Figure 9). This perspective has a bearing on the appropriate Federal role, areas of focus, and approaches to Federal and Federal-private sector collaborative R&D.

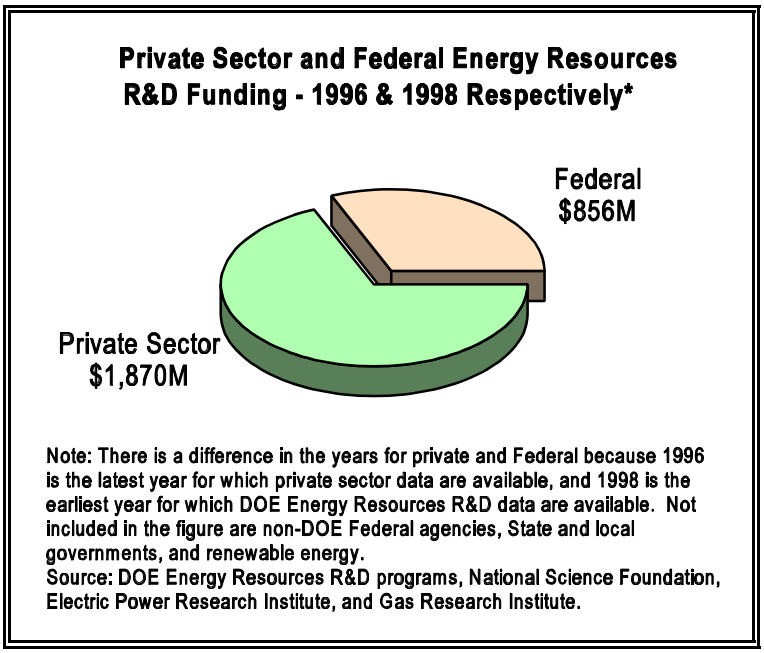


Figure 13

There are several considerations that are important for understanding the roles of the private sector and the Federal government in 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 imperfections in the marketplace, 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 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.[5] 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 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 9. 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 9; however, the

[5] 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.

ratio of DOE to other funding sources would not be significantly affected by inclusion of these expenditures.

Energy Resources R&D and Energy Services

The Energy Resources Business Line of the Department—the Offices of Fossil Energy; Nuclear Energy, Science and Technology; and Energy Efficiency and Renewable Energy—support both R&D programs and efforts providing other energy services. These energy service activities are beyond the definition of R&D in the rigorous sense as defined by OMB, and as utilized in this report. Research and development programs constitute approximately 60 percent of the DOE

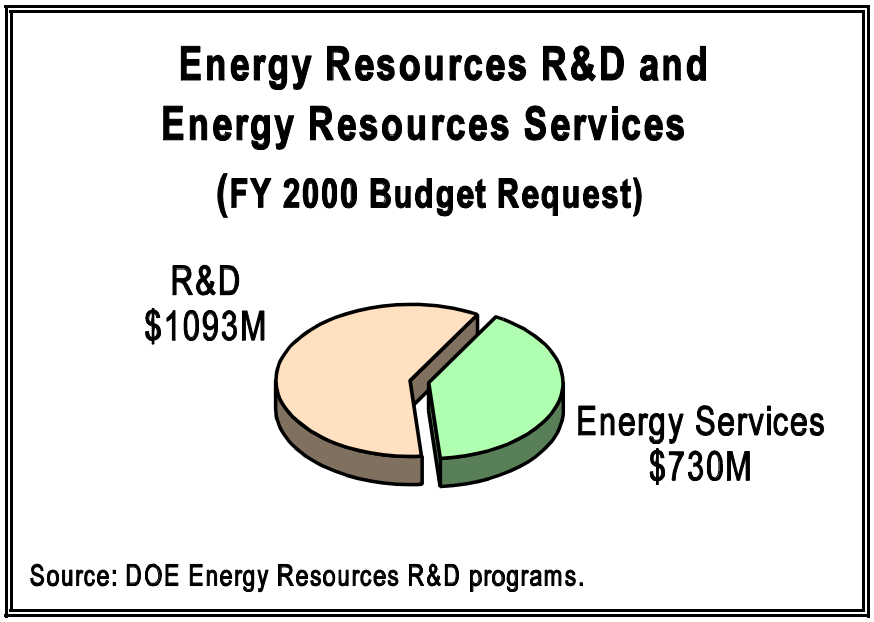


Figure 14

Energy Resources R&D budget and energy services represent the remaining 40 percent (see Figure 10).

Important examples of energy service activities include the Strategic Petroleum Reserve ($164 million) that provides a reserve supply of oil to support national security. Another large energy services program is the Weatherization Assistance program ($191 million), wherein the Department provides funding to State agencies which, when supplemented by State and other funding sources, finance energy efficiency improvements for low income households to help reduce their energy costs. Other examples include the development of appliance, equipment, and building codes and standards and consumer information.

DOE Energy Resources R&D Portfolio Budgets

The Energy Resources R&D Portfolio diagram (Figure 11) organizes the portfolio into three broad strategic areas.

- Reliable and Diverse Energy Supply

- Clean and Affordable Power
- Efficient and Productive Energy Use

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

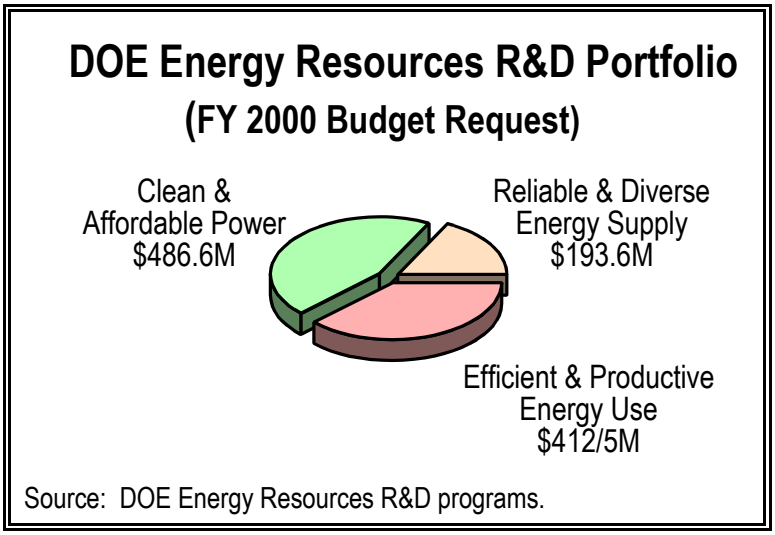


Figure 15

allocation to these strategic areas is displayed in Figure 11.

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

- Eighteen 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 44 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 were 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 38 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 funds 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 12 shows a breakout of the DOE budgets for the seven portfolio areas shown as the second row of the Energy Resources R&D Portfolio diagram for the FY 2000 request. This figure also shows the more important roles of each of the portfolio areas.

Budgets for 3 years, FY 1998, FY 1999, and the President's request for FY 2000, are provided in Figure 13. This figure indicates that the budgets for 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.

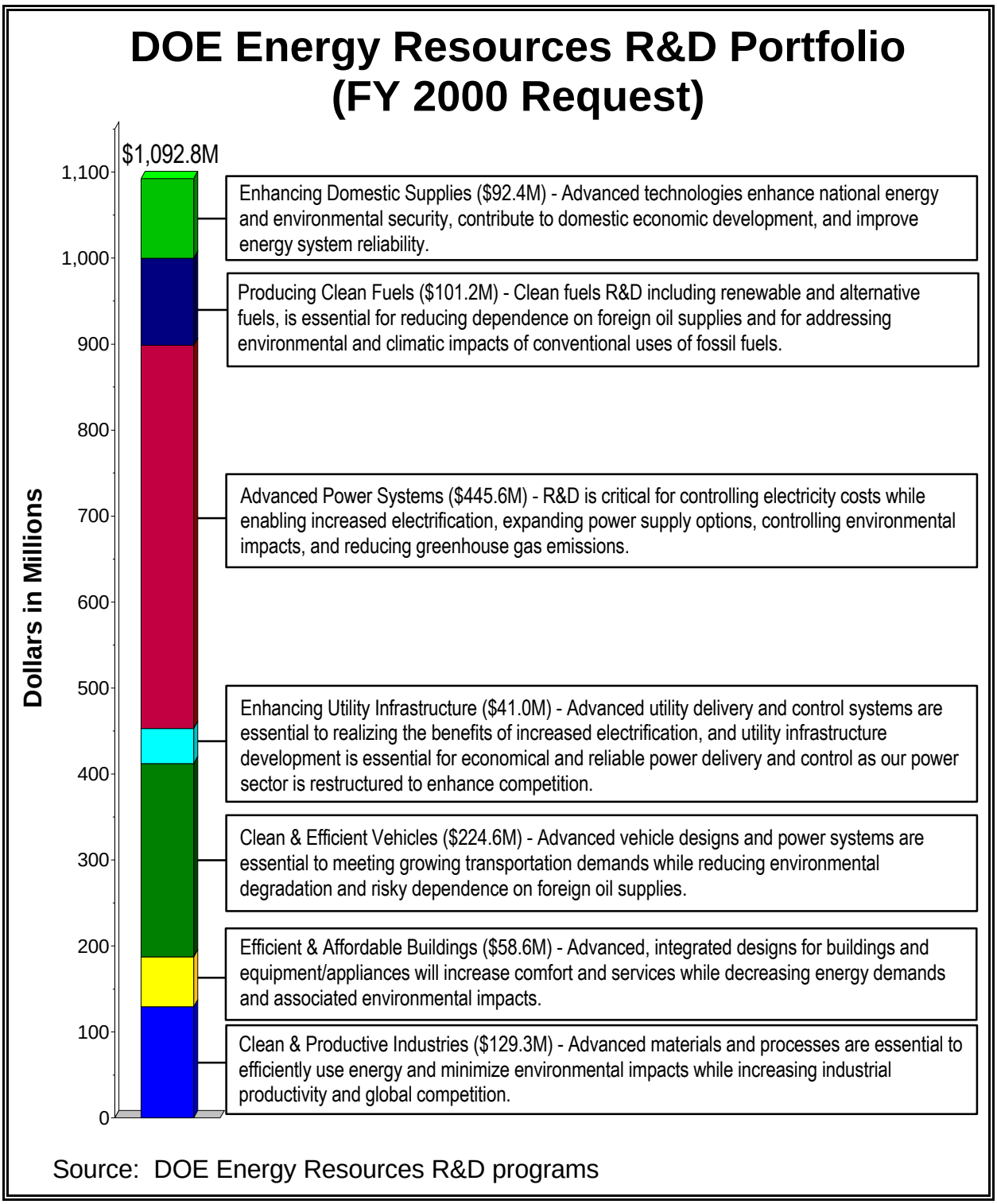

DOE Energy Resources R&D Portfolio
(FY 2000 Request)
$1,092.8M
Dollars in Millions
1,100
1,000
900
800
700
600
500
400
300
200
100
0
Enhancing Domestic Supplies ($92.4M) - Advanced technologies enhance national energy and environmental security, contribute to domestic economic development, and improve energy system reliability.
Producing Clean Fuels ($101.2M) - Clean fuels R&D including renewable and alternative fuels, is essential for reducing dependence on foreign oil supplies and for addressing environmental and climatic impacts of conventional uses of fossil fuels.
Advanced Power Systems ($445.6M) - R&D is critical for controlling electricity costs while enabling increased electrification, expanding power supply options, controlling environmental impacts, and reducing greenhouse gas emissions.
Enhancing Utility Infrastructure ($41.0M) - Advanced utility delivery and control systems are essential to realizing the benefits of increased electrification, and utility infrastructure development is essential for economical and reliable power delivery and control as our power sector is restructured to enhance competition.
Clean & Efficient Vehicles ($224.6M) - Advanced vehicle designs and power systems are essential to meeting growing transportation demands while reducing environmental degradation and risky dependence on foreign oil supplies.
Efficient & Affordable Buildings ($58.6M) - Advanced, integrated designs for buildings and equipment/appliances will increase comfort and services while decreasing energy demands and associated environmental impacts.
Clean & Productive Industries ($129.3M) - Advanced materials and processes are essential to efficiently use energy and minimize environmental impacts while increasing industrial productivity and global competition.
Source: DOE Energy Resources R&D programs

Figure 16

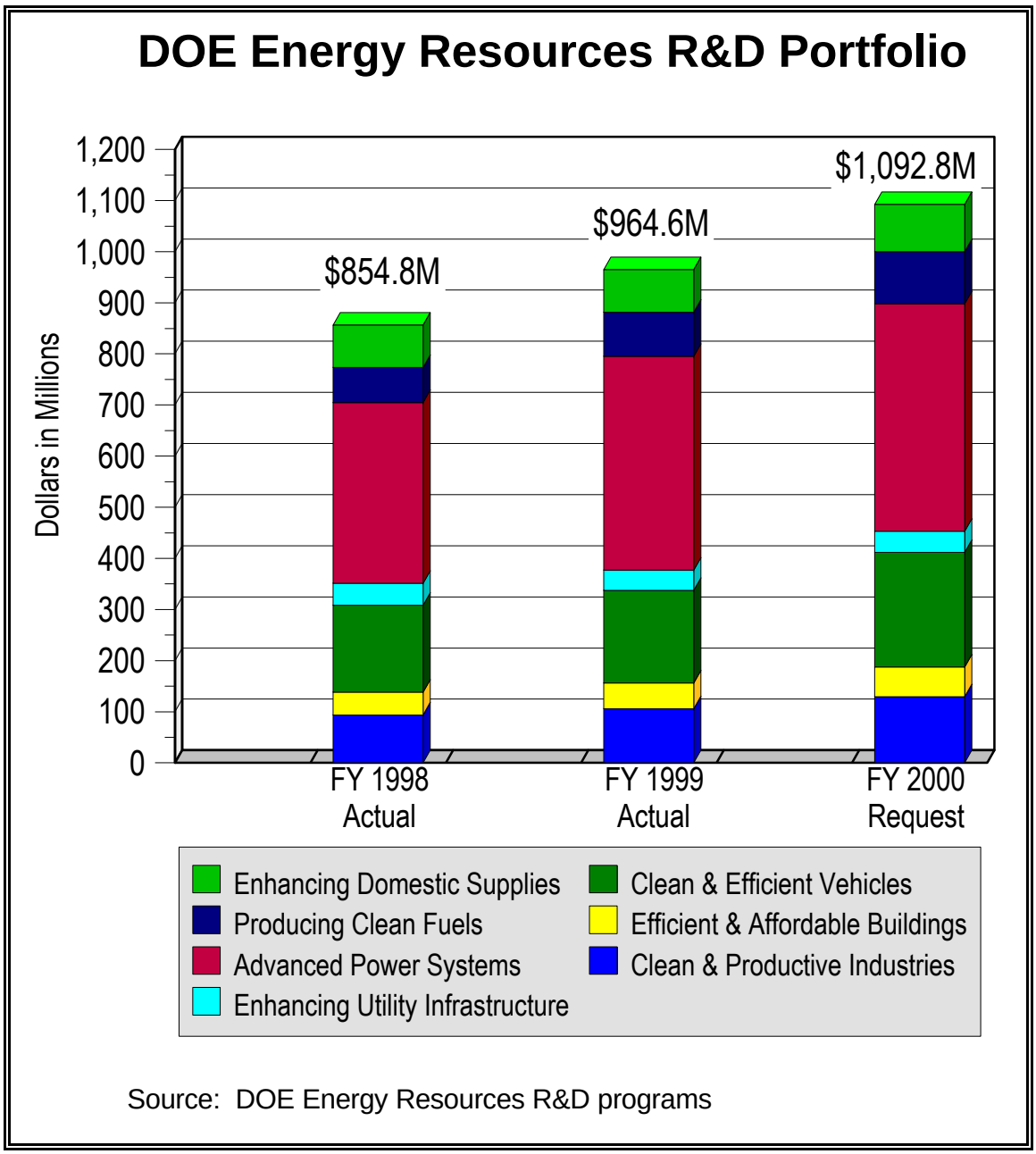


Figure 17

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, and other governmental agencies. The budget levels for each of these performers in FY 1998 are displayed in Figure 14.[6]

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

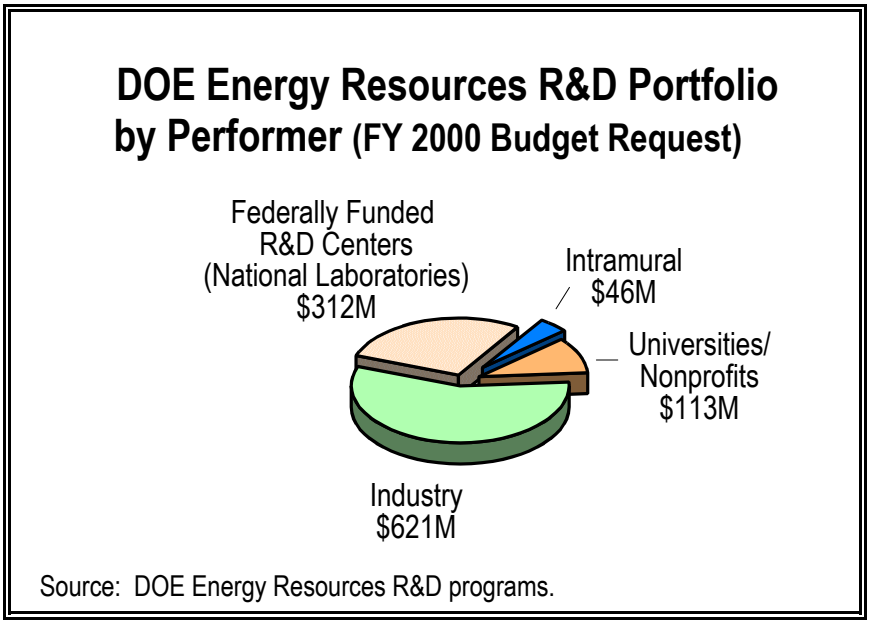


Figure 18

Industry plays the major role, 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 are used because of 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 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.

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 (see

Figure 15). 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.

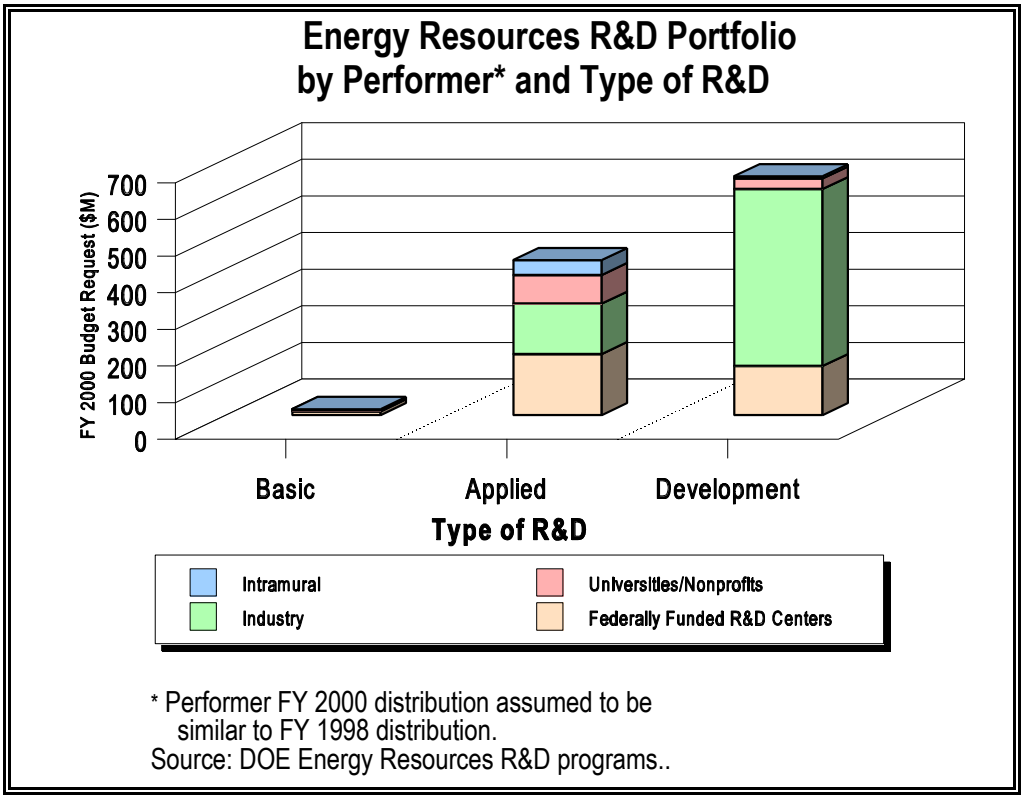


Figure 19

The majority of the Energy Resources R&D funding, 61 percent ($663 million), is devoted to technology specific developmental work, and the bulk of this work is performed by industry and National Laboratories (see Figure 16). 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. The cornerstone to this development effort is the LaPorte, Texas, proof-of-concept facility where successes in the laboratory are

transferred into the production of fuel, as was demonstrated in the FY 1998 F-T operation where more than that fuel was produced in the advanced slurry reactor for further evaluation.

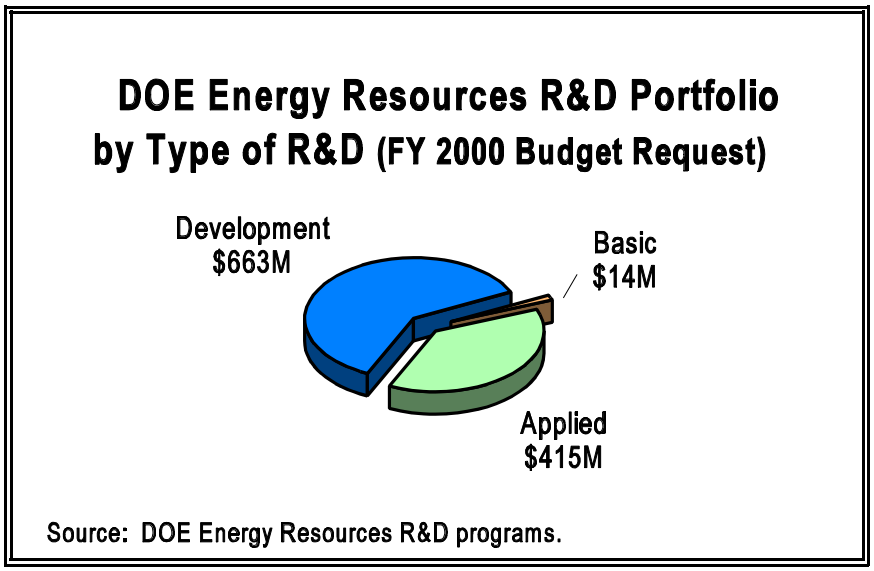


Figure 20

Approximately 38 percent ($415 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 16). 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.

Only 1 percent ($14 million) of the Energy Resources 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 16). 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.

Energy Resources R&D Portfolio Relation to CNES Goals

The 5 major goals of the Comprehensive National Energy Strategy address the major energy issues discussed in section I. Figure 17 displays the relevance of the 7 Energy Resources R&D Portfolio areas to these 5 CNES goals. The purpose of this chart is to convey in general terms the degree of relevance of each of the seven portfolio areas to each of the CNES strategic goals. The indicators used were developed through a Delphian Technique. Because much of this energy R&D has a mid-to long-term focus, progress in these R&D areas toward CNES goal achievement will also be more substantial over a longer period and less likely in a shorter period such as 5 years.

Clearly, a key characteristic of the energy portfolio is its multi-dimensional interrelationships. More specifically, accomplishing any of the CNES goals requires progress in several of the 7 energy portfolio areas, and, conversely, each of these 7 areas contributes to achievement of several of the CNES goals. This multivariate relationship between strategic energy goals and the DOE Energy Resources R&D Portfolio results from a portfolio design that is intended to simultaneously address several issues, as well as reflecting the complexity and interrelationships of different parts of the energy economy. In short, the whole is greater than the sum of its parts.

Energy Resources R&D Portfolio Relevance to CNES Goals and Objectives

	Improve the efficiency of the energy system.			Ensure against energy disruptions.		Promote energy production and use in ways that respect health and environmental values.		Expand future energy choices.		Cooperate internationally on global issues.	
	Support competitive and efficient electric systems.	Significantly increase energy efficiency in the transportation, industrial, and buildings sectors by 2010.	Increase the efficiency of Federal energy use.	Reduce the vulnerability of the U.S. economy to disruptions in oil supply.	Ensure energy system reliability, flexibility, and emergency response capability.	Increase domestic energy production in an environ-mentally responsible manner.	Accelerate the develop-ment and market adoption of environmen-tally friendly tech-nologies.	Maintain a strong national knowledge base as the foundation for informed energy decisions, new energy systems, and enabling technologies of the future.	Develop technologies that expand long-term energy options.	Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.	Promote foreign regional stability by reducing energy-related environmental risks in areas of U.S. security interest.
Enhancing Domestic Supplies	◎			●	●	●	●	(1)	●	◎	(2)
Producing Clean Fuels	○	○		●	◎	●	●	(1)	●	◎	(2)
Advanced Power Systems	●		◎	○	●	●	●	(1)	●	◎	(2)
Enhancing Utility Infrastructure	●	○	○		●		●	(1)	●	◎	(2)
Clean and Efficient Vehicles		●	●	●	●		●	(1)	●	◎	(2)
Efficient and Affordable Buildings	○	●	●	○	○		●	(1)	●	◎	(2)
Clean and Productive Industries	◎	●	◎	○	◎	○	●	(1)	●	◎	(2)

● = Strong Relationship

◎ = Moderate Relationship

○ = Weak Relationship

(1) The majority of this research is basic science

(2) All R&D generically supports this objective.

Note: This chart reflects the relevance and degree to which the R&D activities are aligned with the CNES objectives. It does not predict the ultimate benefits or outcomes of the research and development.

Source: DOE Energy Resources R&D programs.

Figure 17

External Views on Energy Resources R&D Portfolios

An energy R&D program must provide the continuity necessary to bring R&D activities to fruition. At the same time, the Energy Resources R&D Portfolio must change over time to respond to changing national needs and market realities, technology opportunities, and the appropriate government responsibilities. DOE continually modifies its Energy Resources R&D Portfolio through portfolio planning and analysis, technology roadmapping, and budget planning activities. Even with these efforts, it is very appropriate to ask whether the current portfolio and the portfolio planning processes are appropriate.

There have been several studies in recent years that have provided important comments on DOE's Energy Resources R&D Portfolio. Overall, these studies provide a good benchmark for the portfolio. The first is the recently published *Federal Energy Research and Development for the Challenges of the Twenty-First Century* (November 1997). This study, conducted by an Energy R&D Panel appointed by the President's Council of Advisors on Science and Technology at the request of President Clinton, reports on a thorough review of DOE's Energy Resources R&D Portfolio. The study states that "energy R&D … is vital to the future of the United States and the world." It suggests that four criteria be applied in gauging the effectiveness of the work. These are:

- Strategic criteria—How well does the portfolio address energy related economic, environmental, and national security challenges, and how well does it strengthen science and technology leadership?

- Diversity criteria—How well is the portfolio balanced across technologies, time frames, and degrees of risk?

- Public-private interface criteria—How effectively does it provide potential payoffs to society that will justify bigger R&D investments than industry would likely make on the basis of private return on investment? What is the potential for leveraging and partnerships?

- Other project criteria—How well do the projects within the portfolio exhibit strong technical merit, well-defined goals, and appropriate attention to cost, schedule, and performance?

This review found that, in general, the R&D activities as addressed in the current DOE program are appropriate. While the study proposed a variety of changes within the program, including some specific reductions, redirections, and increases, **their most important recommendation was for a substantial increase in energy technology R&D**. They further recommended that DOE expand and emphasize the use of portfolio analysis as an integral part of R&D portfolio planning efforts in the future. This should include increased emphasis on setting goals for all technologies and measuring progress toward these goals as well as application of the criteria listed above.

A second important benchmark for evaluating the current DOE Energy Resources R&D Portfolio is the 1995 report *Energy R&D: Shaping Our Nation's Future in a Competitive World*. This report resulted from a study commissioned by the Secretary of Energy's Advisory Board, and was conducted by a Task Force on Strategic Energy R&D which included leading energy experts from industry, academia, and research. DOE's Energy Resources R&D Portfolio is well in line with the key program recommendations of that report. For example, the report "recommends 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. Such support is essential to our Nation's future well-being." The report also recommends pursuit of a broad-based portfolio defined through a systematic portfolio planning and analysis process:

> *"The Task Force recommends 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 investment portfolio through:*
>
> - *A balance of basic research and applied R&D (including industry co-funded demonstrations.*
> - *Near- and long-term R&D to provide continuing return on investment and to contribute to the health and vitality of domestic energy industries.*
> - *A continuing commitment to support energy efficiency and renewable energy."*

Another important frame of reference is *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions*. This 1998 study by 11 DOE National Laboratories identified 47 technology pathways that offer significant potential to reduce greenhouse gas emissions. These pathways were grouped according to "Energy Efficiency" (buildings, industry, transportation, agriculture, and forestry), "Clean Energy" (fossil resource development, fossil power generation, nuclear energy, and renewables) and "Carbon Sequestration." The first 2 of these groupings map directly into the first 4 CNES goals and objectives, while the third represents a narrowly focused technology R&D effort aimed at dealing with long-term fossil-energy-based greenhouse gas emissions. These technology pathways were reviewed for their likely time profile of contributions toward reducing U.S. greenhouse gas emissions through 2030 (low, medium, or high potential). The report recommends collaborative R&D efforts involving both the private sector, universities, and government. The study concludes that the current Energy Resources R&D Portfolio is largely consistent with development of the range of advanced energy technologies that represent the best opportunities for reducing greenhouse gas emissions over time, and recognizes that the portfolio also addresses the multiple CNES objectives.

It is interesting to note that some traditional energy companies are moving toward strategic development of broader energy portfolios. One of these is British Petroleum (BP). In a recent article by Robert Shelton (*Sustainable Development: The Technology Management Implications and Opportunities*, P. 51, in PRISM, A.D. Little, Q 4 1998), the author points out: "BP noted

that the world has moved from solid (e.g., wood, coal) to liquid fuels (i.e., petroleum-related) over the past several hundred years, and that the next fuel transition will be from liquids to gas, as liquids become more expensive and gas remains plentiful and relatively inexpensive. Eventually, BP sees the energy business moving toward renewable energy in order to become sustainable. For BP, the sustainable development vision has identified the need to change from an oil company (with a primary focus on petroleum-related technologies) to an energy company with a portfolio of alternative technologies."

In 1994, Royal Dutch Shell conducted a study of the evolution of the world's energy system, including development of contrasting scenarios for future global energy consumption. An important conclusion of their study is that, even under quite different consumption scenarios, future energy supplies are likely to be more diverse. While fossil fuels today contribute over 75 percent of the world's energy supplies, the Shell study projects their contribution will begin to decrease in about 3 decades. By the middle of the 21st century, the world will be utilizing a range of energy resources, including significant contributions from renewables and nuclear as well as continuing reliance on important contributions from hydro, petroleum, natural gas, and coal (Reference: *The Evolution of the World's Energy Systems*, Group External Affairs, Shell International Limited, 1996).

To summarize, there have been a number of direct and indirect external comments on DOE's Energy Resources R&D Portfolio which support its basic features:

- The portfolio should be broadly-based in terms of energy resources and technologies.
- The portfolio should be balanced with respect to areas of research and development.
- The portfolio should draw upon the expertise of industry, universities, and the National Laboratories in collaborative efforts.
- The portfolio priorities should be continually reviewed and re-focused based on strategic planning and portfolio analysis.

Next Steps

What is described herein and in the following chapters represents a comprehensive description of the DOE Energy Resources R&D Portfolio, including supporting basic research. The relevance of each part of the portfolio to the common-sense goal of maintaining available and reliable low-cost energy services in the context of enhancing national security and environmental quality is explained. This thorough presentation of the portfolio contents and their relevance to these national interests is an important first step in portfolio development and analysis, but it is only a beginning. This document indicates that the DOE portfolio meets multiple objectives and demonstrates robustness for an uncertain future, but continuing and expanded planning and analysis is needed to insure appropriate prioritization and efficient utilization of taxpayer funds applied to these efforts. Future steps should include expansion of current technology and

program roadmapping to all areas as well as portfolio analysis that models R&D outcomes relative to R&D investments.

Future changes to the portfolio will also occur because of new opportunities, such as natural gas hydrates or fossil fuel decarbonization with CO_2 sequestration. Technological developments, such as methods for efficient conversion of coal or gas resources to liquid fuels, or economical methods for directly producing hydrogen from sunlight, will also drive portfolio shifts. Finally, institutional changes such as electricity re-structuring and international developments are likely to influence changes to the focus of DOE's energy R&D. Thus, strategic planning and portfolio planning and analysis will continue apace with the R&D programs.