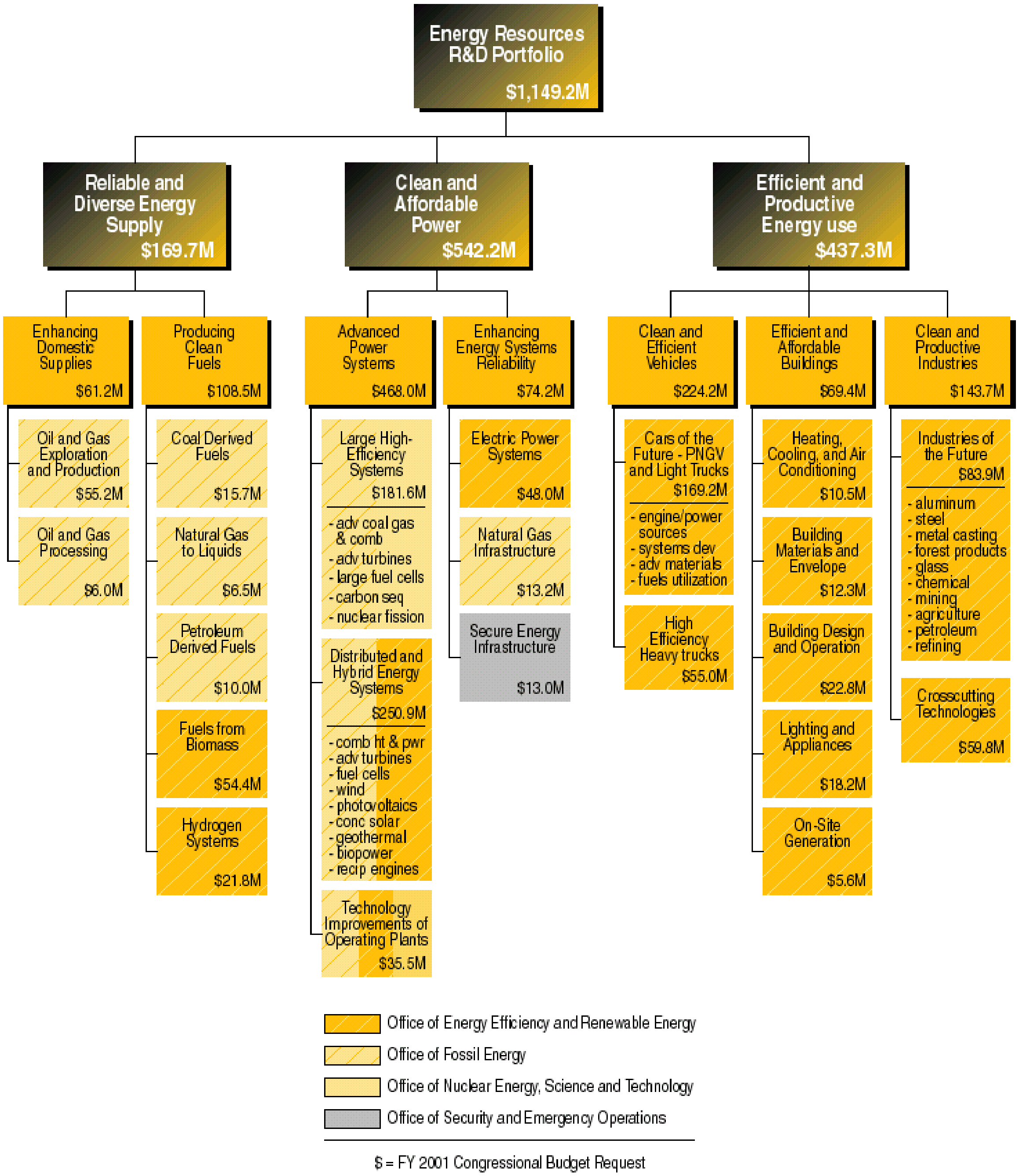
Chapter 1
Introduction



Chapter 1

Introduction

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Background

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

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

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

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

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

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

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

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

Comprehensive National Energy Strategy

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

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

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

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

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

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

From Strategic Planning to R&D for Required Technologies

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

The Comprehensive National Energy Strategy at a Glance

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The Energy Resources R&D Portfolio

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

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

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

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

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

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

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

Reliable and Diverse Energy Supply

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

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

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

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

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

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

Clean and Affordable Power

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

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

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

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

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

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

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

Efficient and Productive Energy Use

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

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

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

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

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

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