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Testimony

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Water Development, Committee on
Appropriations, House of Representatives

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ADVANCED ENERGY TECHNOLOGIES

Key Challenges to Their Development and Deployment

Statement of Jim Wells, Director
Natural Resources and Environment





Highlights of [GAO-07-550T](#), a testimony to Subcommittee on Energy and Water Development, Committee on Appropriations, House of Representatives

Why GAO Did This Study

For decades, the nation has benefited from relatively inexpensive energy, but it has also grown reliant on fossil fuels—oil, natural gas, and coal. Periodic imported oil supply disruptions have led to price shocks, yet the nation's dependence on imported energy is greater than ever. Fossil fuel emissions of carbon dioxide—linked to global warming—have also raised environmental concerns. The Department of Energy (DOE) has funded research and development (R&D) on advanced renewable, fossil, and nuclear energy technologies. GAO's report entitled *DOE: Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs* examined the (1) R&D funding trends and strategies for developing advanced energy technologies; (2) key barriers to developing and deploying advanced energy technologies; and (3) efforts of the states and six selected countries to develop and deploy advanced energy technologies. GAO reviewed DOE R&D budget data and strategic plans and obtained the views of experts in DOE, industry, and academia, as well as state and foreign government officials.

What GAO Recommends

GAO's report recommended that the Congress consider further stimulating the development and deployment of a diversified energy portfolio by focusing R&D funding on advanced energy technologies.

www.gao.gov/cgi-bin/getrpt?GAO-07-550T.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Jim Wells, at (202) 512-6877 or wellsj@gao.gov.

ADVANCED ENERGY TECHNOLOGIES

Key Challenges to Their Development and Deployment

What GAO Found

DOE's budget authority for energy R&D, when adjusted for inflation, fell 85 percent from its peak in fiscal year 1978 to fiscal year 2005. Energy R&D funding in the late 1970s was robust in response to constricted oil supplies and an ensuing energy crisis, but R&D funding plunged when oil prices returned to their historic levels in the mid-1980s. DOE's R&D efforts have resulted in steady incremental progress in reducing costs for renewable energy, reducing harmful emissions of coal-fired power plants, and improving safety and efficiency for nuclear energy. Nevertheless, the nation's dependence on conventional fossil fuels remains virtually the same as 30 years ago.

Further development and deployment of advanced renewable, fossil, and nuclear energy technologies face several key challenges:

- **High Capital Costs.** The high capital costs of advanced energy technologies worry risk-averse investors. For example, solar cells made to convert solar energy into electricity for homeowners and businesses have been typically too expensive to compete with fossil fuels. DOE's R&D efforts include developing new materials for solar cells that could decrease manufacturing costs.
- **Environmental Concerns.** Advanced energy technologies need to address harmful environmental effects, including bird and bat fatalities cause by wind turbines, carbon dioxide and mercury emissions by coal-fired power plants, and spent nuclear fuel from nuclear power reactors.
- **Technology-Specific Challenges.** Challenges that are unique to each technology also create barriers to development and deployment. Ethanol, for example, will need to be manufactured with more cost-competitive technologies using agricultural residues or other cellulosic materials in order to expand beyond corn. Other challenges include developing new wind technologies to expand into low-wind and offshore locations; developing advanced coal gasification technologies to further reduce harmful emissions and high capital costs; and working with the nuclear power industry to deploy a new generation of reactors and develop the next generation to enable reactors to reprocess highly radioactive spent nuclear fuel or produce hydrogen.

Many states and foreign countries have forged ahead of the federal government by successfully stimulating the deployment of renewable energy technologies. For example, renewable energy accounts for 3 percent of Texas' electricity consumption because Texas enacted legislation in 1999 and 2005 requiring its electric utilities to meet renewable energy capacity standards. Similarly, Denmark has used mandates and financial incentives to promote wind energy, which provided 19 percent of its electricity in 2005.

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss the challenges that our nation faces in meeting its future energy needs. The United States has primarily relied on market forces to determine its energy portfolio. These market forces have generally succeeded in providing us with plentiful, reliable, and generally inexpensive gasoline to power our vehicles and electricity to run our homes and businesses. However, most of this energy comes from conventional fossil fuels—oil, natural gas, and coal—the dependence on which has brought increased economic and national security risks and adverse environmental impacts. In 1973, 1979, 1991, and 2005, the nation's crude oil supplies were constricted contributing to major energy price shocks. Despite these price shocks and related energy crises, the United States is even more dependent on imported crude oil and natural gas today than it was 30 years ago. And, without dramatic change, the nation will become ever more reliant on imported oil and natural gas with corresponding threats to the U.S. economy and national security. Perhaps equally important, the growing recognition that global warming is linked to carbon dioxide emissions from burning coal and oil will need to be addressed. Given these threats, the nation will almost certainly need to make much more tangible progress than has been achieved to date to diversify our energy portfolio by reducing conventional fossil fuel usage and developing and deploying advanced energy technologies.

Since its inception in 1977, the Department of Energy (DOE) has had leadership responsibility for energy research, development, and demonstration (R&D) that enable the nation to deploy advanced energy technologies for meeting future demands and diversify its energy portfolio.¹ During the past 29 years, the Congress has provided DOE about \$50 billion for R&D in renewable, fossil, and nuclear energy technologies.² Regrettably, however, the nation is still not currently positioned to deploy alternative energy technologies in the next 25 years that will reverse our growing dependence on conventional fossil energy.

¹DOE is also responsible for energy efficiency programs, which are integral to addressing future energy challenges by reducing demand.

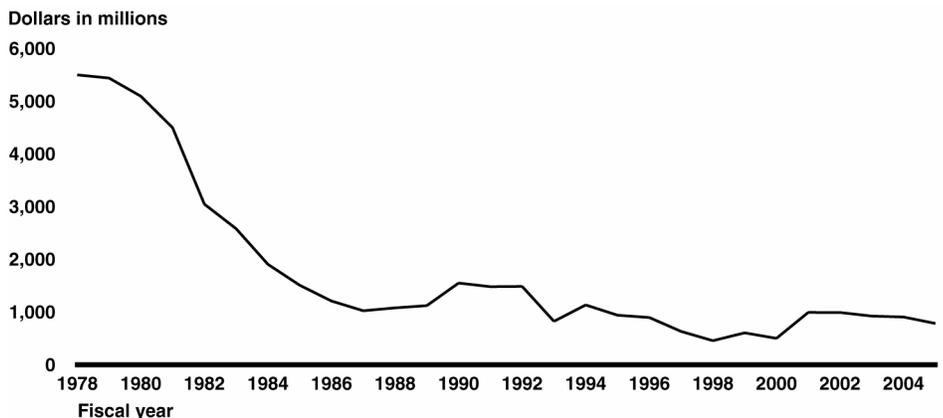
²All historical DOE R&D budget authority totals are presented in real terms by adjusting them to fiscal year 2005 dollars to account for inflation.

My testimony today is based on our December 2006 report on key challenges to developing and deploying advanced energy technologies.³ Specifically, my testimony will address (1) funding trends for DOE's energy R&D program, (2) key barriers to developing and deploying advanced energy technologies, and (3) efforts of the states and six selected countries to develop and deploy advanced energy technologies.

Summary

DOE's budget authority for renewable, fossil, and nuclear energy R&D declined by over 85 percent (in inflation-adjusted terms) from 1978 through 2005, dropping from about \$5.5 billion in fiscal year 1978 to \$793 million in fiscal year 2005.

Figure 1: DOE's Budget Authority for Renewable, Fossil, and Nuclear R&D, Fiscal Years 1978-2005



Source: GAO analysis of DOE data.

Note: Budget authority is in real terms, adjusted to fiscal year 2005 dollars to account for inflation.

DOE's R&D efforts have made renewable technologies more cost competitive, reduced harmful sulfur dioxide and nitrogen oxide pollution by coal-fired power plants, and improved the safety and operating efficiency for nuclear reactors. However, DOE and the energy industry still need to overcome enormous technological and financial challenges before advanced energy technologies are likely to supplant fossil fuels on a

³GAO, *Department of Energy: Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs*, [GAO-07-106](#) (Washington, D.C.: Dec. 20, 2006).

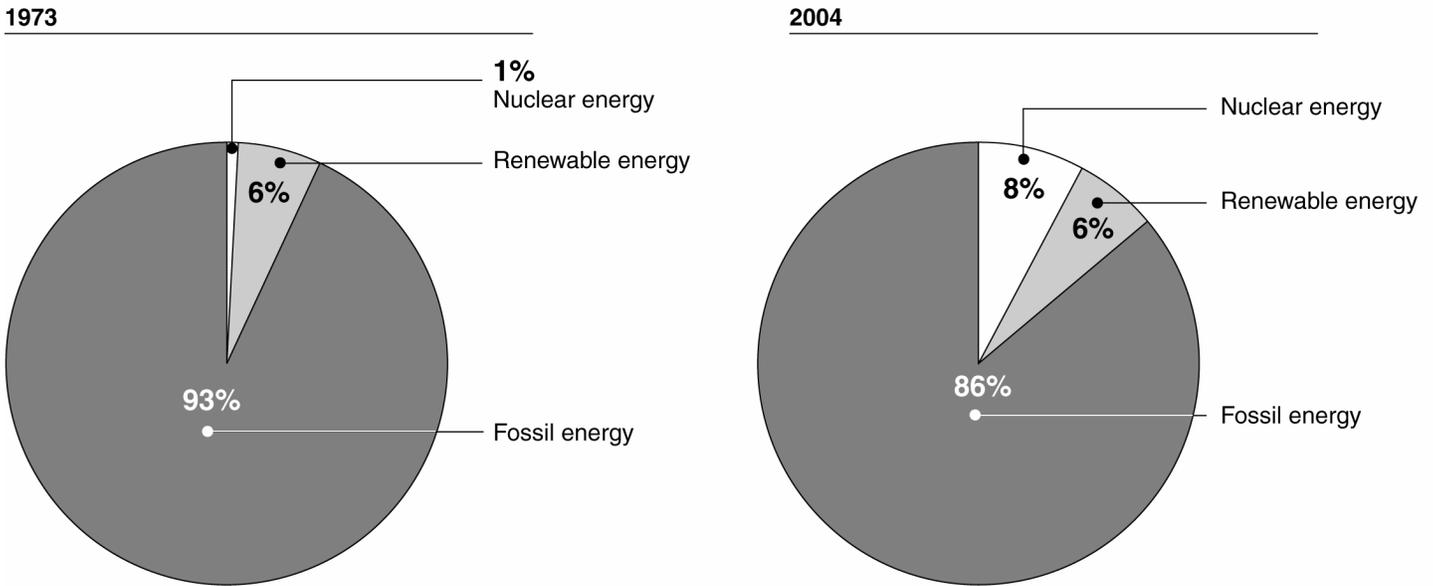
national scale. For example, because many high-wind sites have been developed, for the wind industry to expand, it will need to develop low-wind and offshore sites that require new designs, technologies, and materials, and will face higher upfront capital costs. Similarly, development and use of advanced coal gasification and carbon sequestration and storage technologies to control harmful carbon dioxide emissions is dependent upon additional technological breakthroughs and lowered costs.

While federal R&D funding has declined and the government has relied on the market to make advanced energy technology deployment decisions, many states have assumed higher profile roles by enacting standards, mandates, and financial incentives primarily to stimulate renewable energy technologies that address their growing energy needs and environmental concerns. For example, in Texas over 1,900 megawatts of new renewable capacity was installed and renewable energy now accounts for 3 percent of electricity consumption because legislation enacted in 1999 and 2005 requires Texas' utilities to meet renewable energy capacity standards. In addition, each of the six countries we reviewed—Brazil, Denmark, Germany, Japan, Spain, and France—has used mandates and/or financial incentives to deploy advanced energy technologies that are providing, or are expected in the future to provide, significant amounts of energy. For example, Brazil has replaced all of its imported oil with ethanol, wind energy provides 19 percent of Denmark's electricity, and Germany's renewable energy technologies generate 10 percent of its electricity.

Background

For the past several decades, the United States has enjoyed relatively inexpensive and plentiful energy supplies, relying primarily on market forces to determine the energy mix that provides the most reliable and least expensive sources of energy—primarily oil, natural gas, and coal. In 1973, oil cost about \$15 per barrel (in inflation-adjusted terms) and accounted for 96 percent of the energy used in the transportation sector and 17 percent of the energy used to generate electricity. As shown in figure 2, the 2004 U.S. energy portfolio is similar to the 1973 energy portfolio. In 2004, oil accounted for 98 percent of energy consumed for transportation, and coal and natural gas accounted for about 71 percent of the energy used to generate electricity. Renewable energy—primarily hydropower—remains at 6 percent of U.S. energy consumption.

Figure 2: Comparison of the U.S. Energy Portfolio in 1973 and 2004



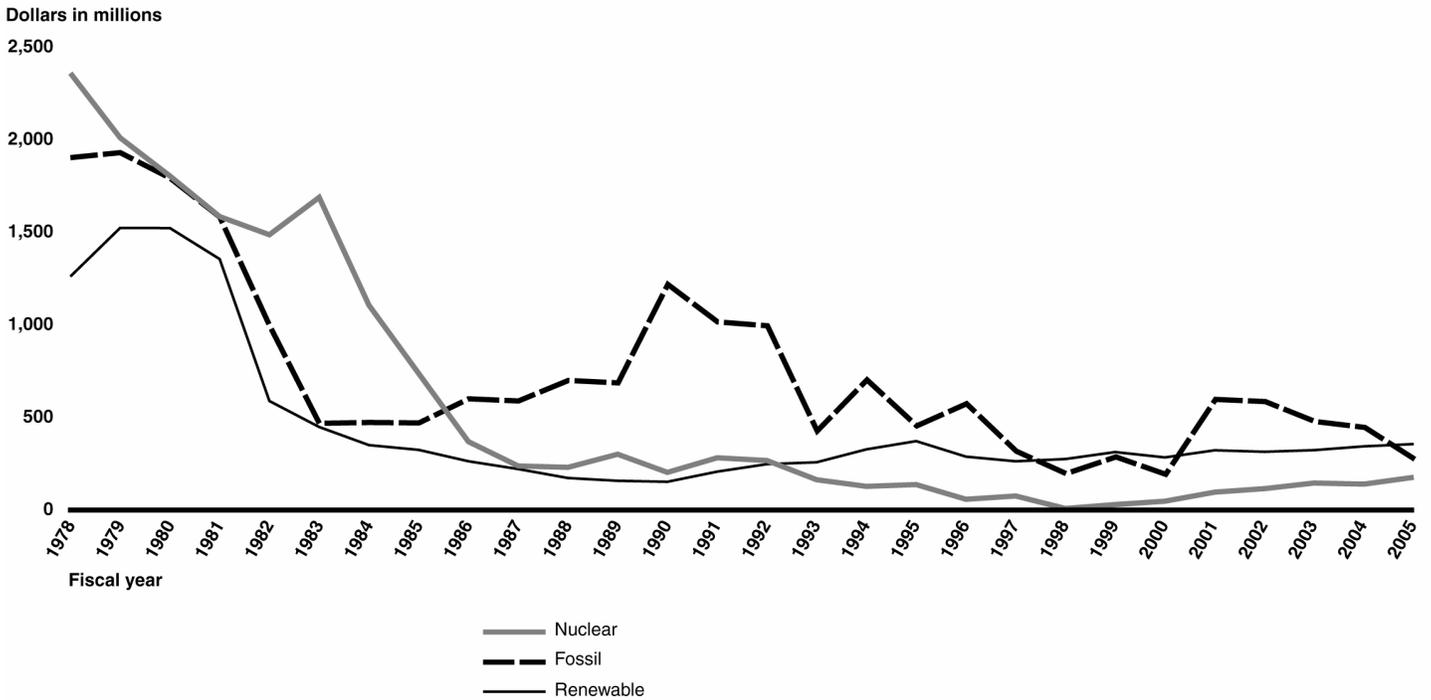
Source: GAO analysis of EIA data.

However, since 1973, U.S. crude oil imports have grown from 36 percent of consumption to 66 percent of consumption today, and crude oil prices have jumped particularly in recent years to today's \$60 per barrel level.

DOE's Budget Authority for Renewable, Fossil, and Nuclear Energy R&D Has Declined by Over 85 Percent in Real Terms Since 1978

Despite growing dependence on foreign energy sources, DOE's budget authority for renewable, fossil, and nuclear energy R&D dropped from \$5.5 billion (in real terms) in fiscal year 1978 to \$793 million in fiscal year 2005—a decline of over 85 percent. As shown in figure 3, renewable, fossil, and nuclear energy R&D budget authority each peaked in the late 1970s before falling sharply in the 1980s. Total budget authority for the three energy R&D programs has risen after bottoming out in fiscal year 1998.

Figure 3: DOE's Budget Authority for Renewable, Fossil, and Nuclear R&D, Fiscal Years 1978 through 2005



Source: GAO analysis of DOE data.

Note: Budget authority is in real terms, adjusted to fiscal year 2005 dollars to account for inflation. Excludes DOE program management costs and indirect facilities costs of DOE laboratories.

DOE's renewable R&D program has focused on ethanol, wind, and solar technologies, making steady incremental progress over the past 29 years in reducing their costs. DOE's goal is for biofuels production in 2030 to replace 30 percent of current gasoline demand, or about 60 billion gallons per year. In 2005, ethanol refiners produced 3.9 billion gallons of ethanol, primarily from corn, that was used (1) as a substitute for methyl tertiary-butyl ether, known as MTBE, which oil refineries have used to oxygenate gasoline and (2) to make E85, a blend of 85 percent ethanol and 15 percent gasoline for use in flex fuel vehicles. To achieve its production goal, DOE is developing additional sources of cellulosic biomass—such as agricultural residues, energy crops, and forest wastes—to minimize adverse effects on food prices. In recent years, DOE's wind program shifted from high-wind sites to low-wind and offshore sites. Low-wind sites are far more plentiful than high-wind sites and are located closer to electricity load centers, which can substantially reduce the cost of connecting to the electricity transmission grid. Low-wind and offshore-

wind energy must address design and upfront capital costs to be competitive. DOE's solar R&D program focuses on improving photovoltaic systems, heat and light production, and utility-size solar power plants. DOE is exploring thin-film technologies to reduce the manufacturing costs of photovoltaic cells, which convert sunlight into electricity. Similarly, DOE's solar heating and lighting R&D program is developing technologies that use sunlight for various thermal applications, particularly space heating and cooling. DOE is also working with industry and states to develop utility-size solar power plants to convert the sun's energy into high temperature heat that is used to generate electricity.

Beginning in the mid-1980s, DOE's fossil energy R&D provided funding through the Clean Coal Technology Program to demonstrate technologies for reducing sulfur dioxide and nitrogen oxide emissions. DOE also has focused on developing and demonstrating advanced integrated gasification combined cycle (IGCC) technologies. More recently, DOE proposed a \$1 billion advanced coal-based power plant R&D project called FutureGen—cost-shared between DOE (76 percent) and industry (24 percent)—which will demonstrate how IGCC technology can both reduce harmful emissions and improve efficiency by integrating IGCC with carbon capture and sequestration technologies for the long-term storage of carbon dioxide. According to DOE, FutureGen is designed to be the first “zero-emissions” coal-based power plant and is expected to be operational by 2015.

Beginning in fiscal year 1999, DOE's nuclear energy R&D program shifted from improving safety and efficiency of nuclear power reactors to developing advanced reactor technologies by focusing on (1) the Nuclear Power 2010 initiative in an effort to stimulate electric power companies to construct and operate new reactors; (2) the Global Nuclear Energy Partnership, or GNEP, to develop and demonstrate technologies for reprocessing spent nuclear fuel that could recover the fuel for reuse, reduce radioactive waste, and minimize proliferation threats; and (3) the Generation IV Nuclear Energy Systems Initiative, or Gen IV, to develop new fourth generation advanced reactor technologies intended to reduce disposal requirements and manufacture hydrogen by about 2020 to 2030.

Advanced Renewable, Fossil, and Nuclear Energy Technologies Face Key Barriers to Market Deployment

Advanced renewable, fossil, and nuclear energy technologies all face key challenges to their deployment into the market. The primary renewable energy technologies with the potential to substantially expand their existing production capacity during the next 25 years are ethanol, a partial substitute for gasoline in transportation, and wind and solar energy technologies for generating electricity. For advanced fossil technologies, the primary challenge is controlling emissions of mercury and carbon dioxide generated by conventional coal-fired plants by using coal gasification technologies that cost about 20 percent more to construct than conventional coal-fired plants and demonstrating the technological feasibility of the long-term storage of carbon dioxide captured by a large-scale coal-fired power plant. For advanced nuclear technologies, investors face substantial risk because of nuclear reactors' high capital costs and long construction time frames and uncertainty about the Nuclear Regulatory Commission's (NRC) review of license applications for new reactors.

One of ethanol's biggest challenges is to cost-effectively produce ethanol while diversifying the biomass energy sources so it can grow from its current 3-percent market share. DOE is exploring technologies to use cellulosic biomass from, for example, agricultural residues or fast-growing grasses and trees. In addition, ethanol requires an independent transportation, storage, and distribution infrastructure because its corrosive qualities and water solubility prevent it from using, for example, existing oil pipelines to transport the product from the Midwest to the east or west coasts. As a result, fewer than 1,000 fueling stations nationwide provide E85 compared with 176,000 stations that dispense gasoline. Ethanol also needs to become more cost competitive. Even with the recent spikes in gasoline prices, ethanol producers rely on federal tax incentives to compete. In October 2006, *Consumer Reports* estimated that drivers paying \$2.91 per gallon for E85 actually paid about \$3.99 for the energy equivalent amount of a gallon of gasoline because the distance vehicles traveled per gallon declined by 27 percent. Finally, congressional earmarks of DOE's biomass R&D funding rose from 14 percent of the fiscal year 2000 funds to 57 percent (\$52 million) of the fiscal year 2006 funds, according to a DOE program official.

Both wind and solar technologies have experienced substantial growth in recent years, but both wind and solar technologies face important challenges for future growth. In particular, wind investors pay substantial upfront capital costs to build a wind farm and connect the farm to the power transmission grid, which can cost \$100,000 or more per mile on average, according to DOE officials. Because both wind energy and solar

energy are intermittent, utilities have been skeptical about using them, relying instead on large baseload power plants that operate full time and are more accessible to the transmission grid. In contrast, wind turbines operate the equivalent of less than 40 percent of the hours in a year because of the intermittency of wind. In addition, the electricity that is generated must be immediately used or transmitted to the grid because it cannot be cost effectively stored.

For the wind industry to expand from high-wind sites to low-wind and offshore locations, DOE needs to also develop bigger wind turbines with longer blades mounted on taller towers, requiring improved designs and materials for blade and drive train components. In addition, offshore wind development faces such technical challenges as understanding the effects of wave and ocean current loads on the base of the structures. The wind industry also faces concerns about environmental impacts, including bird and bat fatalities caused by wind turbines. Finally, investors interested in developing wind energy have relied on the federal production tax credit as a financial incentive to construct wind farms. The credit has periodically expired, resulting in a boom-and-bust cycle for the wind power industry.

Solar energy also faces a challenge of developing inexpensive photovoltaic solar cells. As a result of R&D efforts, photovoltaic cells, consisting mostly of crystalline-silicone materials, are becoming increasingly efficient, converting nearly 40 percent of sunlight into electricity for some applications, but the cells are expensive for the typical homeowner. DOE is exploring how to reduce manufacturing costs through thin-film technologies, but at a cost of efficiency. DOE's challenge is to increase efficiency and reduce costs in the thin-film technologies.

Reducing emissions from coal-fired power plants continues to be the priority for DOE's fossil energy R&D. Having significantly reduced sulfur dioxide and nitrogen oxide, DOE is now focusing on reducing mercury and carbon dioxide emissions. Gasification technologies, such as the IGCC configuration, holds the most promise, but at a 20 percent higher cost than conventional coal-fired power plants. To address global warming concerns, DOE's challenge is to reduce the cost of gasification technologies and demonstrate the large-scale sequestration and long-term storage of carbon dioxide.

A significant obstacle facing nuclear power is the high upfront capital costs. No electric power company has applied for a NRC license to construct a new nuclear power plants in almost 30 years in large part because of a long legacy of cost over-runs, schedule delays, and

cancellations. Industry officials report that new nuclear power plants can cost between \$1.5 billion and \$4 billion to construct, assuming no problems in the licensing and construction process, with additional expenses for connecting the plant to transmission lines. In addition, investors have grown concerned about the disposal of a legacy of spent nuclear fuel. While NRC has revised its licensing process to address past concerns over licensing delays and added costs because of requirements to retrofit plants, investors are uncertain of the effectiveness of the revised regulations. Recently, the Massachusetts Institute of Technology (MIT) and the University of Chicago issued studies comparing nuclear power's costs with other forms of generating electricity.⁴ Both studies concluded that, assuming no unexpected costs or delays in licensing and construction, nuclear power is only marginally competitive with conventional coal and natural gas and, even then, only if the nuclear power industry significantly reduces anticipated construction times. MIT also reported, however, that if carbon were to be regulated, nuclear energy would be much more competitive with coal and natural gas.

The States and Countries We Reviewed Have Implemented a Variety of Initiatives to Encourage the Development and Deployment of Advanced Energy Technologies

While federal R&D has declined in recent years, the states have enacted legislation or developed initiatives to stimulate the deployment of renewable energy technologies, primarily to address their growing energy demands, adverse environmental impacts, and their concern for a reliable, diversified energy portfolio. As of 2006, (1) 39 states have established interconnection and net metering rules that require electric power companies to connect renewable energy sources to the power transmission grid and credit, for example, the monthly electricity bill of residents with solar-electric systems when they generate more power than they use; (2) 22 states have established renewable portfolio standards requiring or encouraging that a fixed percentage of the state's electricity be generated from renewable energy sources; and (3) 45 states offer various tax credits, grants, or loans. For example, renewable energy accounts for 3 percent of Texas' electricity consumption because Texas enacted legislation in 1999 and 2005 that created a renewable portfolio standard requiring electric utilities to meet renewable energy capacity standards.

⁴MIT. *The Future of Nuclear Power* (Cambridge, MA: July 2003); University of Chicago, *The Economic Future of Nuclear Power* (Chicago, IL: August 2004)

We identified six countries—Brazil, Denmark, Germany, Japan, Spain, and France—that illustrate a range of financial initiatives and mandates to stimulate the development and deployment of advanced renewable, fossil, and nuclear energy technologies. Through mandates and incentives, Brazil initiated an ethanol program in 1975 that eventually led to an end to Brazil’s dependence on imported oil. Denmark focused on wind energy and, in 2005, derived 19 percent of its electricity from wind energy. Germany began a more diversified renewable energy approach in 2000 and has a goal to increase the share of renewable energy consumption to at least 50 percent by 2050. Japan subsidized the cost of residential solar systems for 10 years, resulting in the installation of solar systems on over 253,000 homes and the price of residential solar systems falling by more than half. Spain hopes to lead the way for European Union investments in an IGCC coal power plant, improving efficiency and generating fewer emissions than conventional coal-fired plants. Finally, France has led Europe in nuclear energy and plans to deploy new nuclear power plants within the next decade.

Concluding Observations

The United States remains the world’s largest oil consumer. In the wake of increasing energy costs with the attendant threat to national security and the growing recognition that fossil fuel consumption is contributing to global climate change, the nation is once again assessing how best to stimulate the deployment of advanced energy technologies. However, it is unlikely that DOE’s current level of R&D funding or the nation’s current energy policies will be sufficient to deploy advanced energy technologies in the next 25 years. Without sustained high energy prices or concerted, high-profile federal government leadership, U.S. consumers are unlikely to change their energy-use patterns, and the United States will continue to rely upon its current energy portfolio. Specifically, government leadership is needed to overcome technological and market barriers to deploying advanced energy technologies that would reduce the nation’s vulnerability to oil supply disruptions and adverse environmental effects of burning fossil fuels.

To meet the nation’s rising demand for energy, reduce its economic and national security vulnerability to crude oil supply disruptions, and minimize adverse environmental effects, our December 2006 report recommended that the Congress consider further stimulating the development and deployment of a diversified energy portfolio by focusing R&D funding on advanced energy technologies.

Contacts and Acknowledgments

For further information about this testimony, please contact me at (202) 512-3841 or wellsj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Richard Cheston, Robert Sanchez, and Kerry Lipsitz made key contributions to this statement.

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