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Report to Congressional Requesters

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DEPARTMENT OF ENERGY

Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs

GAO-07-106

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Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs

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Highlights

Highlights of GAO-07-106, a report to congressional requesters

Why GAO Did This Study

Despite periodic price shocks and related energy crises, the United States is even more dependent on crude oil and natural gas than it was almost 30 years ago. And, without dramatic change, the nation will become ever more reliant on imported oil and natural gas with attendant threats to national security. The nation has also become concerned about global warming, which has been linked to carbon dioxide emissions from burning coal and oil. To address these concerns, the Department of Energy (DOE) has funded research and development (R&D) on advanced renewable, fossil, and nuclear energy technologies. GAO 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 interviewed DOE officials and scientists, U.S. industry executives, independent experts, and state and foreign government officials.

What GAO Recommends

GAO suggests that the Congress consider further stimulating the development and deployment of a diversified energy portfolio by focusing R&D funding on advanced energy technologies. DOE had no comment on this recommendation.

www.gao.gov/cgi-bin/getrpt?GAO-07-106.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Jim Wells at 202-512-3841 or wellsj@gao.gov.

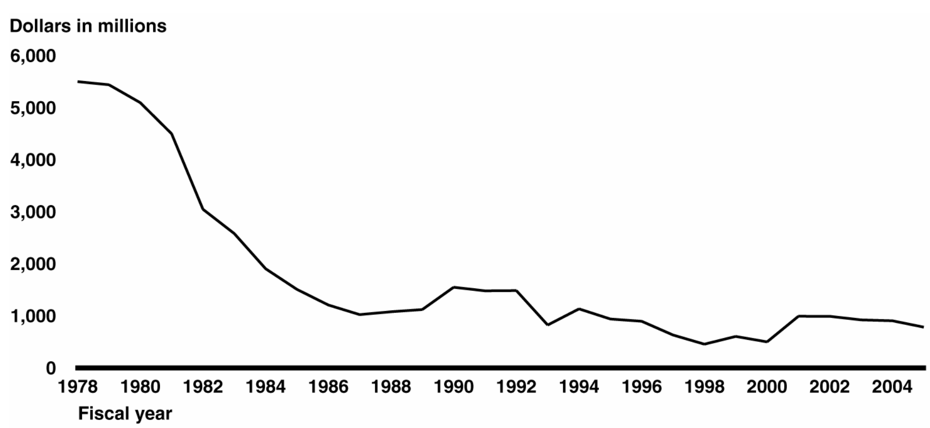
What GAO Found

DOE's total budget authority for energy R&D dropped by over 85 percent (in real terms) from 1978 to 2005, peaking in the late 1970s but falling sharply when oil prices returned to lower levels in the mid-1980s (see table). DOE's R&D efforts have resulted in steady incremental progress in reducing costs for renewable energy technologies, reducing harmful emissions of coal-fired power plants, and improving safety and efficiency for nuclear power plants.

Further development and deployment of advanced renewable, fossil, and nuclear energy technologies face several key challenges. Challenges for renewable technologies include developing (1) cost-effective technologies to produce ethanol using agricultural residues and other biomass materials as well as the infrastructure for distributing ethanol, (2) new wind technologies to expand into low wind and offshore locations, and (3) improved solar technologies that can better compete with conventional technologies. Challenges for fossil technologies are primarily associated with developing advanced coal gasification technologies to further reduce harmful emissions and reducing their high capital costs. Challenges for advanced nuclear technologies include uncertainty about the Nuclear Regulatory Commission's revised licensing process, investor concerns about high capital costs, and the disposal of a legacy of spent nuclear fuel.

Many states have successfully stimulated the deployment of renewable energy technologies by using standards, mandates, and financial incentives that require, for example, power companies to provide small producers with access to the power transmission grid and purchase their excess energy. Each of the six countries GAO reviewed 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.

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.

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Abbreviations

AFCI	Advanced Fuel Cycle Initiative
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
GNEP	Global Nuclear Energy Partnership
IGCC	integrated gasification combined cycle
MIT	Massachusetts Institute of Technology
NRC	Nuclear Regulatory Commission
RPS	renewable portfolio standards
R&D	research and development

GAO
Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, DC 20548

December 20, 2006

The Honorable Bart Gordon
Ranking Member
Committee on Science
House of Representatives

The Honorable Michael M. Honda
Ranking Member
Subcommittee on Energy
Committee on Science
House of Representatives

Since 1974, the nation has been subjected to periodic disruptions of crude oil imports resulting in price shocks and related energy crises. Oil prices doubled in 1974 and doubled again between 1978 and 1980. These price shocks alerted the nation to our growing dependence on imported oil and the need to conserve energy and develop alternative energy sources. Yet, when world crude oil prices plunged in the mid-1980s, the United States continued to rely on oil, and U.S. energy companies reduced their investments in developing alternative energy technologies. More recently, crude oil prices more than doubled—gasoline prices exceeded $3 per gallon in August 2006—as a result of increased world consumption, hurricanes in the Gulf of Mexico, and instability in the Middle East and other oil producing regions. However, by October 2006, crude oil prices had once again declined, though at higher levels than previously. Despite these periodic price shocks and related energy crises, the United States' dependence on imported crude oil and natural gas continues to increase—crude oil imports have grown from 40.5 percent of the U.S. supply in 1980 to 65.5 percent of the U.S. supply in 2005, according to the Energy Information Administration (EIA), within the Department of Energy (DOE). Without dramatic change, the United States is likely to become ever more reliant on imported oil and natural gas with all the attendant threats to the U.S. economy and national security.

EIA projects that total U.S. energy demand will increase by about 28 to 35 percent between 2005 and 2030. Specific sectors reflect even more dramatic growth in energy demand: (1) the transportation sector is expected to grow by 43 percent, with annual crude oil consumption increasing from about 4.8 billion barrels in 2004 to about 6.8 billion barrels by 2030 (a barrel of oil is equivalent to 42 gallons of gasoline), and (2) the electricity sector is expected to grow by 50 percent, with electricity consumption increasing from about 3.6 billion megawatt-hours in 2004 to about 5.3 billion megawatt-hours by 2030 (a megawatt-hour is sufficient to meet the demand of 750 households for 1 hour). EIA projects that the proportions of energy derived from renewable, fossil, and nuclear sources for both transportation and electricity generation will remain about the same through 2030.

Since its creation in 1977, DOE has had leadership responsibility for energy research, development, and demonstration programs (R&D) to enable the nation to deploy advanced energy technologies for meeting future demands and diversifying 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] Specifically:

- DOE's renewable energy R&D program has primarily focused on (1) developing cost-effective technologies for producing ethanol from biomass sources, such as agricultural residues and forest waste, and (2) making wind and solar energy technologies more cost-competitive sources of electricity. DOE has also funded R&D for geothermal and hydropower energy technologies and, in 2003, accelerated the R&D funding for developing hydrogen technologies.

- DOE's fossil energy R&D program has primarily focused on reducing emissions of harmful pollutants from coal-fired power plants, particularly sulfur dioxide and nitrogen oxide in the 1980s and early 1990s. More recently, DOE has concentrated on developing (1) coal gasification technologies to improve efficiency and reduce mercury and carbon dioxide emissions and (2) sequestration technologies for the long-term storage of carbon dioxide.

- DOE's nuclear energy R&D program has focused primarily on improving nuclear power plant safety—in response to the March 1979 accident at the Three Mile Island plant near Harrisburg, Pennsylvania—and efficiency.[3]

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

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

[3]The Three Mile Island accident, which involved one of the plant's two reactors, was the most serious incident at a U.S. commercial nuclear power plant. While there were no deaths or injuries, the reactor's core began to melt down, creating widespread concern about health and safety.

More recently, the program has focused on developing technologies and designs for new generations of nuclear reactors —so-called Generation III and Generation IV. Beginning in October 2007, electric power companies are expected to apply for the first licenses to construct nuclear reactors since 1979. These reactors will use Generation III technologies. DOE's nuclear R&D program is developing Generation IV technologies for deployment after 2020.

The market has been slow to embrace advanced energy technologies because they typically are not economically competitive with conventional energy sources such as oil, natural gas, and coal. In part this is because the prices U.S. consumers pay for conventional energy do not reflect their true costs, including the costs of certain adverse environmental impacts; economists refer to these hidden costs as negative externalities. For example, we continue to rely on electricity generated from coal-fired plants because coal is plentiful and inexpensive in the United States. However, carbon dioxide emissions from coal-fired power plants—a key concern for global warming—are not currently regulated, and thus potential environmental costs associated with global warming are not reflected in the electricity prices that consumers pay. In contrast, renewable energy sources, such as wind farms, and nuclear reactors do not produce carbon dioxide emissions in generating electricity.

The American Jobs Creation Act of 2004 stimulated the deployment of ethanol by providing a 51-cent tax credit through December 31, 2010, for every gallon of ethanol blended into gasoline.[4] The act also provides tax credits that expire on December 31, 2006, for every gallon of biodiesel and agri-biodiesel. Similarly, the Energy Policy Act of 2005 promoted a diversified U.S. energy portfolio by reauthorizing DOE's R&D funding and providing tax incentives for stimulating investment in advanced renewable, fossil, and nuclear energy technologies.[5] Specifically, the Energy Policy Act of 2005 extended the production tax credit established in the Energy Policy Act of 1992 for renewable technologies for 2 years until January 1, 2008. The act also added a new (1) investment tax credit of up to $1.3 billion for constructing new clean-coal power plants and (2) production tax credit of 1.8 cents per kilowatt-hour for up to 6,000 megawatts of new nuclear power capacity lasting 8 years after each qualifying nuclear reactor begins service. These tax credits and other tax

[4]Pub. L. No. 108-357.

[5]Pub. L. No. 109-58.

incentives are legally known as tax expenditures;[6] revenue losses from these tax incentives can be viewed as spending channeled through the tax system. Historically, the tax subsidies that the U.S. government has provided to the energy sector have been directed toward the conventional energy sector. More recently, tax incentives available in fiscal year 2006, such as the new technology tax credits, have also been directed toward stimulating the development and deployment of advanced energy technologies (see app. I).

You asked that we assess the nation's ability to meet its energy needs through 2030 by examining DOE's efforts to diversify the nation's energy portfolio and reduce its dependence on oil and natural gas. Specifically, we examined (1) DOE's R&D funding trends and strategies for developing advanced renewable, fossil, and nuclear energy technologies; (2) the key barriers to developing and deploying technologies that will address the nation's future energy needs; and (3) the efforts of states and selected countries to develop and deploy renewable, fossil, and nuclear energy technologies that address future energy needs.

To ensure that we obtained a balanced view of future U.S. energy challenges, we reviewed documents and interviewed DOE officials, including program managers and laboratory scientists; senior industry executives; independent experts; officials of several state governments and states' associations; and representatives of foreign governments and industry associations. More specifically, to review DOE's R&D funding trends and strategy for developing advanced energy technologies, we analyzed DOE's (1) budget authority data for renewable, fossil, and nuclear energy R&D from fiscal year 1978 through fiscal year 2006, adjusted for any advanced appropriations and rescissions, and (2) strategic plans for developing and deploying new energy technologies. For perspective, we also reviewed revenue losses due to energy-related tax expenditures for fiscal years 2000 through 2006. To assess the key technological, economic, and other barriers, we analyzed various energy studies and interviewed senior officials at DOE and the Nuclear Regulatory Commission (NRC), which regulates the construction and operations of nuclear power plants, industry executives, and independent experts. To examine the efforts of states and selected countries to develop

[6]Tax expenditures result in forgone revenue for the federal government due to preferential provisions in the tax code. See GAO, *Government Performance and Accountability: Tax Expenditures Represent a Substantial Federal Commitment and Need to Be Reexamined*, GAO-05-690 (Washington, D.C.: Sept. 23, 2005).

and deploy advanced energy technologies, we identified their use of mandates, financial incentives, and other actions. We selected Brazil, Denmark, France, Germany, Japan, and Spain because they have initiated major nationwide programs to stimulate the deployment of advanced energy technologies that have changed, or could change, their energy portfolios. We found that the data we used to examine trends and states' efforts to develop and deploy energy technologies to be sufficiently reliable for our purposes. We conducted our work from October 2005 through October 2006 in accordance with generally accepted government auditing standards. (See app. II for further information about our scope and methodology.)

Results in Brief

Despite growing dependence on foreign energy sources, DOE's R&D budget authority for renewable, fossil, and nuclear energy technologies declined by over 85 percent (in real terms) between fiscal years 1978 and 2005. Specifically, DOE's R&D budget authority dropped from about $5.5 billion (in real terms) in fiscal year 1978 to $793 million in fiscal year 2005. Budget authority for renewable, fossil, and nuclear energy R&D peaked in the late 1970s before falling sharply in the mid 1980s when crude oil prices returned to lower levels. As funding has shrunk, DOE's R&D focus has narrowed. For example, DOE's renewable R&D program has focused on ethanol, wind, and solar technologies, making steady incremental progress in reducing their costs over the past 29 years. DOE's fossil R&D program has focused primarily on reducing harmful emissions of coal-fired power plants, working with industry to make significant progress in reducing sulfur dioxide and nitrogen oxide pollution during the 1980s and 1990s. Currently, DOE is using coal gasification technologies to reduce mercury and carbon dioxide emissions and achieve the long-term goal of a "near-zero emissions" power plant. From 1978 through 1998, DOE's nuclear R&D program focused on making incremental improvements in nuclear power plant safety and efficiency. Since 1998, DOE's nuclear R&D program shifted its focus to developing "next generation" nuclear facilities for reprocessing spent fuel, developing advanced nuclear reactors that produce hydrogen and reduce waste, and producing more efficient nuclear fuels. Faced with competing R&D priorities and budget constraints, DOE's fiscal year 2007 budget proposed eliminating R&D funding for its geothermal, hydropower, oil, and natural gas programs.

Advanced renewable, fossil, and nuclear energy technologies all face key barriers to their development and deployment. Among renewable energy technologies, for ethanol to garner a significant share of the U.S. gasoline market, ethanol producers need to deploy cost-competitive technologies for processing agricultural residues and other biomass materials; it is unclear whether ethanol from corn alone can achieve this result. Widespread deployment of ethanol also faces infrastructure challenges—in particular, transporting and storing ethanol and retrofitting gasoline station pumps. Barriers to electricity generation from renewable sources—primarily wind and solar—include the difficulty of efficiently converting renewable energy into electricity, high up-front capital costs, including connection to the electric power transmission grid; the intermittent nature of wind and solar energy; and the higher financial risks associated with gaps in the renewal of the production tax credit. In addition, renewable energy technologies must compete with traditional fossil energy sources whose greater environmental costs are not reflected in the price paid by consumers, and renewable energy R&D budgets have been subject to growing congressional earmarks in recent years. For advanced fossil technologies, the primary challenge continues to be controlling emissions of mercury and carbon dioxide generated by conventional coal-fired plants. However, reducing these emissions requires plants to use new coal gasification technologies, which cost about 20 percent more to construct than conventional coal-fired plants and carry higher perceived investment risk as new technologies. Furthermore, DOE and industry have not demonstrated the technological feasibility of the long-term storage of carbon dioxide captured by a large-scale, coal-based power plant. For advanced nuclear technologies, investors face uncertainties about whether NRC's revised review process for new reactors will effectively reduce regulatory delays and minimize added costs to address safety concerns. While public opposition previously was a primary barrier, the nuclear industry reports that public opinion, particularly in the southeast United States, is more favorable reflecting the increased demand for electricity, perceived advances in safety, and growing concerns about global warming. Investors also face higher financial risk because of nuclear reactors' high capital costs and long construction time frames, as well as environmental and nonproliferation concerns about spent nuclear fuel.

While federal R&D has declined and the government has relied on the market to determine whether to deploy advanced energy technologies, 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. In particular, 22 states have established renewable portfolio standards requiring or encouraging that a fixed percentage of the state's electricity be generated from renewable sources; 39 states have established rules for electric power companies to connect renewable energy sources to the power transmission grid and credit producers for excess generation; and 45 states offer tax credits, grants, or loans to stimulate the deployment of renewable energy. Examples of state initiatives include the following: Since 1980, Minnesota has enacted various mandates and production incentives to stimulate the use of ethanol. Minnesota had displaced nearly 10 percent of all of its gasoline consumption with ethanol by June 2006 and had nearly one-third of the nation's ethanol fueling stations in September 2006. Texas' 2005 legislation extended the state's 1999 renewable portfolio standard to require the installation of 5,000 megawatts of new renewable capacity by 2015. As of September 2006, electric power companies had installed over 1,900 megawatts of new renewable capacity in Texas—approximately 3 percent of its total electricity consumption. California's Solar Initiative called for 3,000 megawatts of new solar capacity by 2017. In response, 150 megawatts of new solar capacity have recently been installed. Some states have also established mandates and financial incentives to stimulate advanced fossil and nuclear technologies. For example, 2002 legislation in Indiana established investment tax credits for advanced coal power plants to encourage cleaner coal technologies. Similarly, Calvert County, Maryland, recently offered a 50-percent, 15-year property tax credit to the owner of the Calvert Cliffs nuclear power plant if an additional nuclear reactor is built.

Each of the six countries we reviewed—Brazil, Denmark, Germany, Japan, Spain, and France—has sustained long-term efforts using mandates and/or incentives to deploy advanced energy technologies that are providing, or are expected in the future to provide, significant amounts of energy. For example, by 2005, Brazil had eliminated its need to import crude oil for gasoline by using mandates and price subsidies to stimulate the development of an ethanol industry that uses domestic sugarcane. Similarly, Denmark's stimulation of renewable energy has resulted in wind energy generating 19 percent of total electricity consumed in 2005. Denmark's support of wind energy has also created a thriving domestic wind turbine industry, which grew from about 200 megawatts to more than 3,000 megawatts in annual global sales over the past decade. To develop a sustainable energy supply and protect the environment, Germany established a goal to increase the share of renewable energy consumption to at least 4.2 percent of its total energy requirements by 2010 and to 10 percent by 2020. The 2010 target was exceeded in 2005, when renewable technologies accounted for 4.6 percent of consumption. To reduce its reliance on imported energy, Japan initiated a 10-year program subsidizing the cost of residential solar systems. As a result, solar systems were installed on more than 253,000 homes and the price of residential solar systems was cut by more than one-half. Spain, supported in part by a European Union program to promote cleaner energy technologies, is successfully operating a 320-megawatt coal gasification plant—the largest such plant in the world—designed to run more efficiently with fewer emissions than conventional coal-fired plants. France leads the United States in deploying an advanced Generation III nuclear reactor—the European Pressurized Reactor—which is designed to be safer, more efficient, and less susceptible to terrorist attacks than older reactors, and will also generate nearly 80 percent more electricity.

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, we suggest that the Congress consider further stimulating the development and deployment of a diversified energy portfolio by focusing R&D funding on advanced energy technologies.

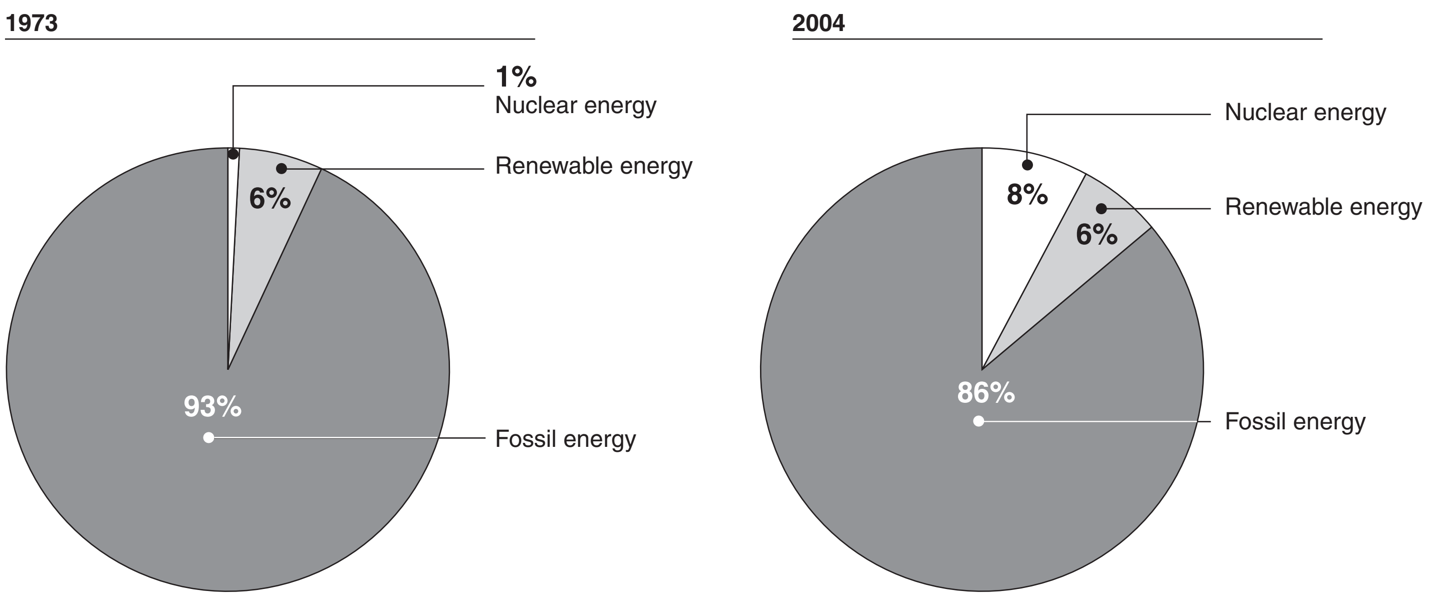
Background

For the past several decades, the United States has enjoyed relatively inexpensive and plentiful energy supplies, relying 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 real terms) and accounted for 96 percent of the energy used in the transportation sector and 17 percent of the energy used to generate electricity.

In 1973, the Organization of Arab Petroleum Exporting Countries embargoed nations that it believed supported Israel during the Yom Kippur War. The disruption of oil supplies caused oil prices in the United States to double between 1973 and 1974, resulting in long gasoline lines and rationing by the U.S. government. Natural gas price spikes followed a pattern similar to that of oil. Since oil and natural gas accounted for about 35 percent of electricity generation in 1973, electricity prices soared, and consumers experienced periodic brown outs. Oil disruptions reoccurred with the 1979 Iranian Revolution and the 1979 to 1981 Iran-Iraq War, which caused oil prices to double once again from the already record-high prices, adversely affecting the U.S. economy. Oil and natural gas prices fell in the mid-1980s, and U.S. reliance on fossil fuels and, in particular on imported oil, continued as the U.S. economy expanded and domestic sources of oil declined. By 2004, about 63 percent of U.S. oil was imported and cost $38 per barrel (in real terms);[7] 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.

As shown in figure 1, the current U.S. energy portfolio is similar to the energy portfolio in 1973. The primary change is the growth of the fledgling nuclear energy industry during the 1970s and 1980s, as new nuclear power plants came online and efficiency improved. However, because nuclear power plants currently operate at about 90 percent capacity, new growth will occur only when new reactors are built. In addition, while hydropower makes up the bulk of energy generated from renewable sources, its share of the renewable energy has declined because new wind, geothermal, and solar-generating capacity has been added while hydropower generation has remained unchanged.

Figure 1: Comparison of the U.S. Energy Portfolio in 1973 and 2004

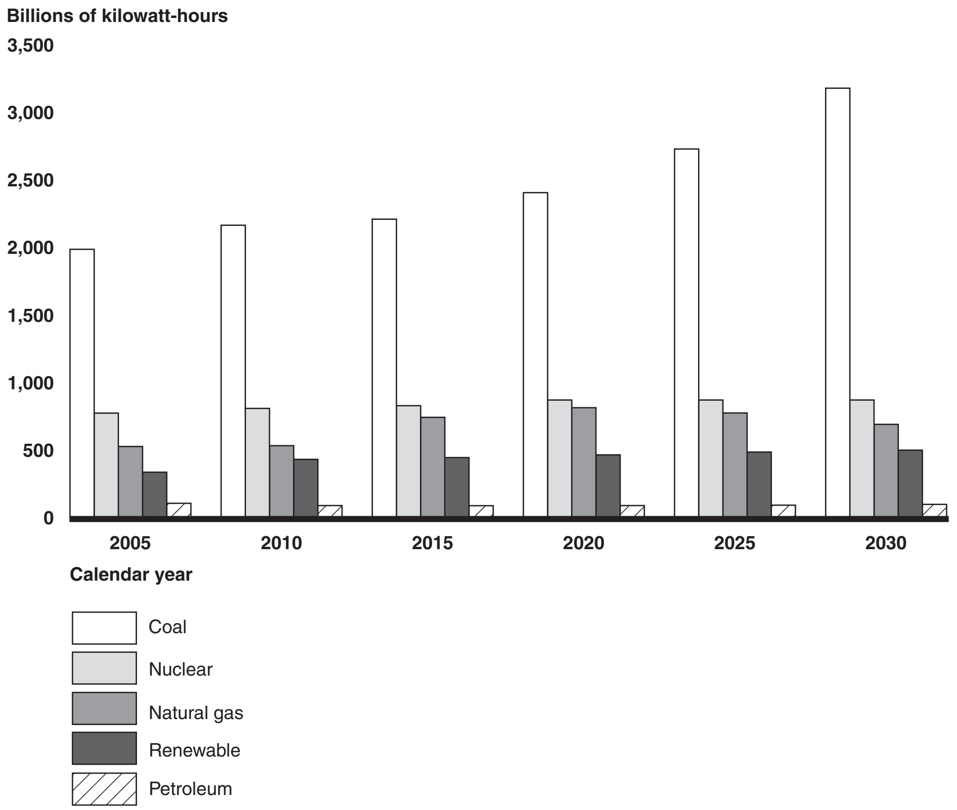


Source: GAO analysis of EIA data.

[7]In 2006, crude oil prices peaked at nearly $70 per barrel in the United States.

EIA's model of energy generation in 2030 projects that the United States will continue to primarily rely on oil to provide most of the energy in the transportation sector and coal to provide most of the energy for generating electricity. EIA projects that U.S. electricity generation will grow from 3,900 billion kilowatt-hours in 2005 to 5,500 billion kilowatt-hours in 2030 (see fig. 2).

Figure 2: Projected U.S. Electricity Generation by Energy Source, 2005-2030



Source: EIA.

Note: EIA projects a greater reliance on coal to generate electricity if oil prices exceed $90 per barrel by 2030 and less reliance on coal and a slight reduction in renewable energy if oil prices are less than $30 per barrel by 2030.

In addition to funding energy R&D to develop advanced energy technologies, DOE has funded efforts to improve energy efficiency and reduce energy demand. For example, DOE has encouraged energy efficiency by, for example, establishing energy efficiency standards for home appliances and air conditioners, and the federal government provides tax credits for purchasing energy-efficient equipment.

The federal government also provides the energy industry and consumers with 23 tax expenditures affecting energy supply, some of which are incentives designed to stimulate the development and deployment of advanced technologies. From a budgetary perspective, most tax expenditures are comparable to mandatory spending for entitlement programs because they require no further action. Tax expenditures do not compete directly in the annual budget process and, in effect, receive a higher funding priority than discretionary spending subject to the annual appropriations process. Some tax expenditures are enacted on a temporary basis, providing an opportunity for scrutiny before they can be extended.

Currently, the United States does not regulate carbon dioxide emissions, which contribute to global warming. In 1992, the United States ratified the United Nations Framework Convention on Climate Change, which was intended to stabilize the build-up of greenhouse gases, but did not impose binding limits on greenhouse gas emissions. In 1997, the United States participated in drafting the Kyoto Protocol, which established some limits on greenhouse gas emissions but did not ratify the protocol. Many DOE officials and industry executives told us, however, that the federal government might begin to regulate greenhouse gas emissions in the future to address global warming concerns. The Energy Policy Act of 2005 authorized R&D funding for the capture and long-term storage—or sequestration—of carbon dioxide.

DOE's Budget Authority for Renewable, Fossil, and Nuclear Energy R&D Has Declined by over 85 Percent in Real Terms Since 1978; DOE Is Narrowing Its R&D Focus

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. Energy R&D budget authority peaked in the late 1970s in response to the Organization of Arab Petroleum Exporting Countries' oil embargo of 1973 and fell sharply as crude oil prices plunged in the mid 1980s. However, since fiscal year 2000, federal support for the energy industry—through DOE's R&D budget authority and federal revenue losses from energy-related income tax expenditures—has grown. Since 1978, DOE's renewable energy R&D program has made incremental progress in making renewable technologies more efficient and reducing their costs. DOE's fossil energy R&D program has focused primarily on reducing harmful emissions by coal-fired power plants. During the 1980s and 1990s, the program made significant progress in demonstrating technologies that reduce sulfur dioxide and nitrogen oxide pollutants, and DOE's current objective is to develop a "near-zero emissions" power plant by targeting mercury and carbon dioxide emissions. In response to the Three Mile Island accident in

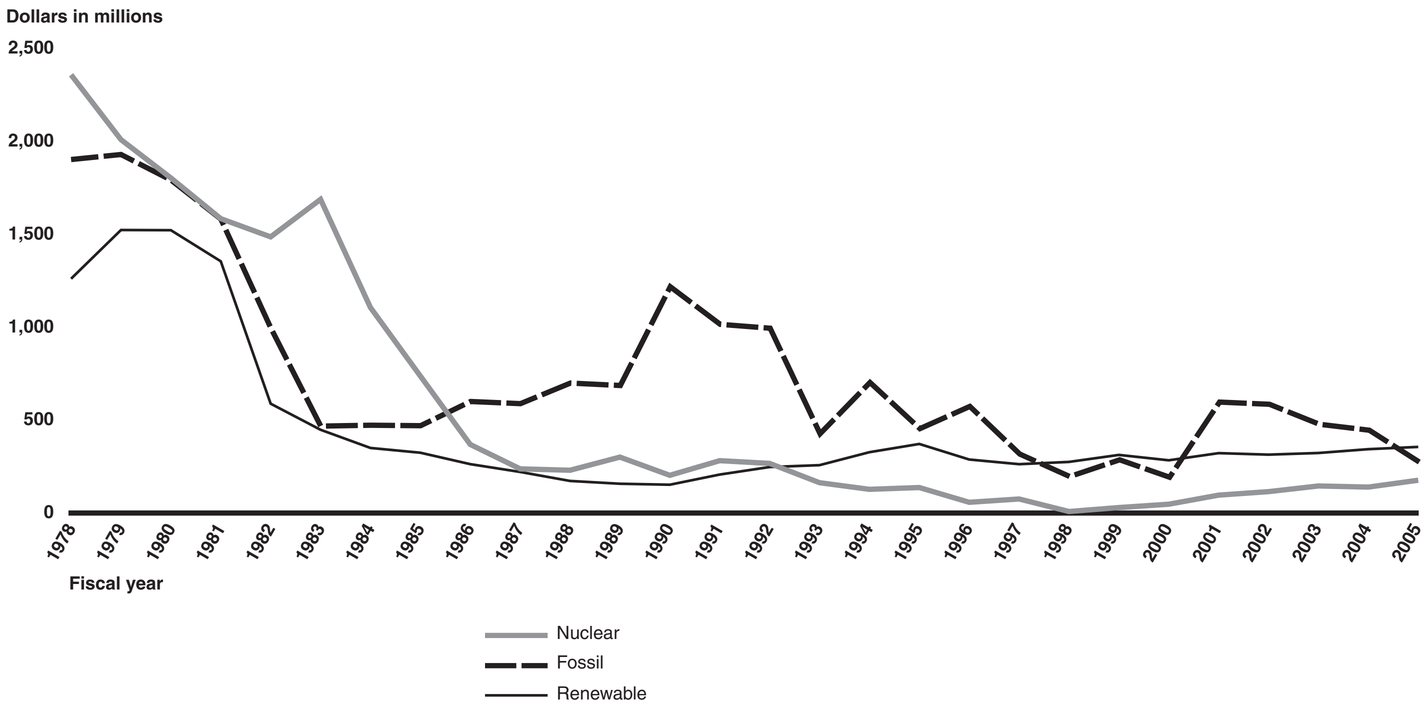
1979, DOE's nuclear energy R&D program focused on improving the safety and efficiency of nuclear reactors. More recently, the nuclear energy R&D program has given priority to (1) encouraging electric power companies to submit the first applications to NRC in over 30 years for combined licenses to build and operate a nuclear reactor to generate electricity, (2) developing technologies for reprocessing spent nuclear fuel that minimize the threat of spent fuel being used to make nuclear weapons and reduce highly radioactive waste, and (3) developing advanced Generation IV reactor technologies. Faced with competing R&D priorities and budget constraints, DOE has proposed in recent years to concentrate its R&D funding on key technologies for meeting the nation's growing energy demand while eliminating funding for geothermal, hydropower, oil, and natural gas technologies.

DOE's Budget Authority for Renewable, Fossil, and Nuclear Energy R&D Has Substantially Fallen Since 1978

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. Similarly, energy R&D funding as a percentage of total nondefense R&D expenditures fell from about 20 percent in the late 1970s to less than 5 percent in fiscal year 2006, according to the American Association for the Advancement of Science. More recently, total budget authority for the three energy R&D programs has risen after bottoming out in fiscal year 1998. Budget authority for renewable energy R&D peaked at $1.5 billion (in real terms) in fiscal year 1979, with most of the funding directed toward solar energy. Subsequently, renewable R&D budget authority fell, hitting its lowest point of $144 million (in real terms) in 1990. Fossil energy R&D budget authority peaked at $1.9 billion (in real terms) in fiscal year 1979 and then has fluctuated. In particular, the Clean Coal Technology Program, a joint DOE-industry effort to demonstrate technologies that reduce sulfur dioxide and nitrogen oxide emissions, began in 1985 with high levels of DOE budget authority in the late 1980s and early 1990s. Fossil energy R&D budget authority rose in fiscal year 2001, and the administration introduced its "clear skies" initiative to further reduce pollution in fiscal year 2002. DOE's nuclear energy R&D program peaked at $2.4 billion (in real terms) in fiscal year 1978 and then fell through fiscal year 1998, when the nuclear R&D program received no budget authority. Since fiscal year 1998, budget authority for nuclear energy R&D has gradually increased. Similar to DOE's budget authority for energy R&D, estimated federal revenue losses from energy-related tax expenditures grew from nearly $2.2 billion (in real terms) in fiscal year 2000 to nearly

$4.9 billion in fiscal year 2005.[8] While many of the new tax expenditures are for developing and deploying advanced energy technologies, tax expenditures for conventional energy remain among the largest in terms of revenue loss. The alternative fuels production credit is the largest energy-related tax expenditure, with estimated revenue losses of about $2.4 billion in fiscal year 2006.[9]

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.

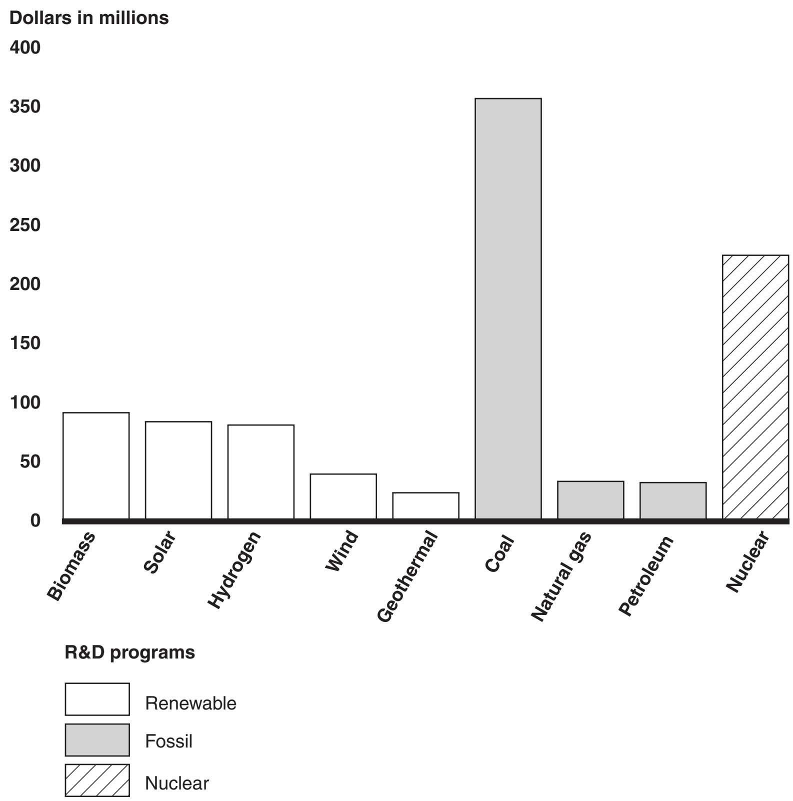
In fiscal year 2006, the Congress provided about $982 million in budget authority for energy R&D, including $324 million for renewable energy R&D, about $434 million for fossil energy R&D, and about $224 million for

[8]Summing tax expenditure estimates is useful to gauge their general magnitude but does not take into account interactions between individual provisions.

[9]The alternative fuels production credit is a tax credit of $3 per oil equivalent barrel (in 1979 dollars) for gas produced from biomass or synthetic fuels produced from coal.

nuclear energy R&D (see fig. 4). The biomass, solar, and hydrogen energy programs received about 80 percent of the renewable energy R&D budget authority. Similarly, coal R&D programs received more than 80 percent of the fossil energy R&D budget authority, particularly for developing and demonstrating advanced gasification technologies—including integrated gasification combined cycle (IGCC)—mercury capture, and sequestration technologies. DOE's top nuclear energy R&D priority is to encourage electric power companies to submit applications to NRC for licenses to build and operate Generation III nuclear reactors by competitively awarding funds for preparing early site permits and NRC combined license applications. The nuclear R&D program also is developing Generation IV nuclear reactor technologies, especially ones that can reprocess spent nuclear fuel that reduce both proliferation risks and the amount of waste generated.

Figure 4: DOE's Budget Authority for Renewable, Fossil, and Nuclear R&D, Fiscal Year 2006



Source: GAO analysis of DOE data.

Note: Budget authority is in fiscal year 2006 dollars. Excludes DOE program management costs, indirect facilities costs of DOE laboratories, and funding for fuel cells—historically, an energy efficiency program.

DOE's Renewable R&D Focuses on Innovations in Ethanol, Wind, Solar, and Hydrogen Energy Technologies

Over the past 29 years, DOE has made steady incremental progress in making each of the renewable energy technologies more cost-competitive; for example, DOE and its industry partners have reduced wind energy costs by more than 80 percent. DOE's renewable energy R&D efforts have focused on developing ethanol, wind, and solar energy technologies. More recently, in January 2003, the administration announced the Hydrogen Fuel Initiative and proposed spending $1.2 billion over 5 years to support research in hydrogen and fuel cell technologies. While DOE has conducted R&D in geothermal and hydropower technologies since the late 1970s, the administration's 2007 budget proposed to eliminate both programs.

Ethanol

DOE's ethanol R&D program, the primary component of its biomass R&D efforts, is developing technologies to reduce the cost of producing ethanol, which can be blended with gasoline to reduce harmful exhaust emissions. In the early years of the biomass program, DOE focused on developing biofuels and biomass energy systems that primarily relied on corn as the energy source. As the biomass program evolved, it sought to make biorefinery-related technologies cost- and performance-competitive. As of October 2006, 106 biorefineries were operating throughout the United States to supply (1) oil refineries with ethanol to oxygenate gasoline—ethanol is a substitute for methyl tertiary-butyl ether (MTBE), which some states have banned because of concerns about groundwater contamination, and (2) fuel suppliers with ethanol to produce E85, a blend of 85 percent ethanol and 15 percent gasoline that can be used in flex fuel vehicles.[10]

The long-term goal of DOE's biomass R&D program is to enable U.S. industry to produce enough biofuels equivalent to 30 percent of current gasoline demand—about 60 billion gallons of biofuels per year—by 2030. To meet this goal, the biomass program is focused on developing additional sources of ethanol from cellulosic biomass, such as agricultural residues, forest wastes, and energy crops. According to DOE, producing cellulosic ethanol is difficult because it requires a complex chemical process to convert the plant material into a simple sugar to use for

[10]Flex fuel vehicles operate on any blend of ethanol and gasoline, from 0 percent ethanol and 100 percent gasoline, up to 85 percent ethanol and 15 percent gasoline.

ethanol. The biomass program is also working with industry to demonstrate biorefinery technologies and assess infrastructure needs.

Wind

DOE's wind R&D program primarily is focused on developing efficient wind turbines that convert the wind's power into electrical power. Historically, DOE's wind program focused on developing wind turbines for high-wind sites because it was the easiest way to achieve significant levels of electric power generation. High-wind sites—referred to as Class 6—typically are located in areas where the wind regularly blows from 18 to 20 miles per hour. During the past 29 years, DOE and its industry partners have made technological improvements that reduced the cost of wind energy by more than 80 percent, and industry has built wind farms on many of the high-wind sites that are easily accessible.

DOE's wind R&D program primarily is seeking to develop new cost-effective technology for deploying wind turbines for low-wind areas in the United States and exploring the possibility of offshore wind development. Low-wind sites—referred to as Class 4—generally are located in areas of sustained winds of 16 to 17 miles per hour and primarily are located in the Midwest from Texas to the Canadian border. The advantages of developing low-wind resources are that 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. DOE's R&D program is focused on developing wind turbine technology for low-wind sites because easily accessible high-wind sites are becoming scarce. Specifically, the turbine rotor diameter must be much larger to harvest the low-energy winds without increasing costs, and the tower must be taller to take advantage of the increasing wind speed at greater heights. DOE is using public/private partnerships to improve wind turbine designs and components and demonstrate full-scale prototypes. DOE's goal is to reduce the cost of low-wind generated electricity from about 4.5 to 5.5 cents per kilowatt-hour in 2002 to 3.6 cents per kilowatt-hour by 2012.

DOE's wind R&D program is also exploring wind energy technology for the distinct needs of offshore wind sites. While the United States currently has no offshore wind farms, several projects have been proposed in the waters off the Northeast and Gulf coasts. DOE estimates that there are over 900,000 megawatts of potential wind energy off the coasts of the United States, roughly between 6 and 58 miles offshore. Several European countries, including Denmark, Ireland, and the United Kingdom, have deployed wind farms in the shallow (less than 100 feet deep) waters off their coastlines using wind turbine designs adapted from land-based versions. However, the European offshore sites are different from potential U.S. offshore wind sites, which are generally located in deeper waters and expected to have more severe wind, wave, and ice conditions. As a result, many U.S. sites will require new technologies. DOE's offshore wind R&D activities include mapping coastal wind resources, organizing workshops for knowledge sharing, and collaborating with industry in developing offshore technologies to address design, offshore transmission, and interconnection issues. DOE is also collaborating with European nations on deep-water wind energy and with states to identify the regulatory, environmental, and technical issues facing offshore wind energy. DOE's goal is to reduce the cost of electricity generated by offshore wind farms located in water 100 to 200 feet deep from an estimated 12 cents per kilowatt-hour today to 5 cents per kilowatt-hour by 2016.

Solar

DOE's solar R&D program is working to make solar energy technologies a more cost-competitive source of electricity. Specifically, DOE's extensive work has advanced solar technologies, improved efficiency and reliability, lowered costs, and resulted in more than 235 patents. While solar energy technologies have evolved and costs have decreased, DOE is focused on further reducing solar energy costs to compete in the residential, commercial, and industrial energy markets and for solar technology to penetrate the market sufficiently to create a sustainable solar industry. Currently, DOE's solar R&D program focuses on developing advanced photovoltaics, also called solar cells, that produce electricity directly from absorbed photons from sunlight; solar heating and lighting systems; and utility-size, solar-power plants.

DOE's photovoltaic R&D program is designed to increase performance, reduce costs, and enhance the reliability of photovoltaic systems. DOE initially focused on using crystalline-silicon, which continues to hold the majority of the photovoltaic market today. DOE's second generation of photovoltaic R&D focuses on thin-film technology, which is designed to use less materials to reduce costs and can be made into a variety of forms. DOE's goal is to lower the cost of photovoltaics so that they are an affordable alternative to traditional electricity sources across all sectors. DOE is working to reduce the costs of photovoltaics from about 18 to 23 cents per kilowatt-hour in 2005 to about 5 to 10 cents per kilowatt-hour by 2015.

DOE's solar heating and lighting R&D program is developing technologies that use sunlight for various thermal applications, particularly space heating and cooling, water heating, and to illuminate building interiors.

DOE's R&D program is focused on advancing materials, design, and manufacturability that will lower costs of solar water heaters, improve their performance, and ease installation. DOE seeks to reduce the costs of solar water-heating systems operating in cold climates from about 11 to 12 cents per kilowatt-hour today to about 5 to 6 cents per kilowatt-hour by 2011. DOE is also working with industry to fully commercialize solar lighting systems. However, the administration's fiscal year 2007 budget proposed eliminating funding for the solar heating and lighting R&D program.

DOE is also working with industry and southwestern states to develop utility-size solar power plants that use two types of concentrating solar power technologies: trough systems and dish/engine systems. These technologies use various mirror configurations to convert the sun's energy into high-temperature heat that is used to generate electricity in a steam generator. DOE's goal is to reduce the cost of utility-size solar power plants in the Southwest from 12 to 14 cents per kilowatt-hour in 2005 to 10 to 12 cents per kilowatt-hour by 2010.

Hydrogen

In January 2003, the administration announced the Hydrogen Fuel Initiative and proposed spending $1.2 billion over 5 years to support research in hydrogen and fuel cell technologies. The initiative's objective is to accelerate the development of technologies to produce and distribute hydrogen to power fuel cells to replace the internal combustion engine in vehicles. While hydrogen is used as a fuel for aerospace and rocket propulsion applications, it is primarily used in the petroleum refining and fertilizer industries. DOE's hydrogen R&D program is focused on developing technologies for production and delivery, storage, conversion, and end-use applications and on standards formulation and other research. The program's goal is to develop the technology needed to allow industry to make a technology readiness decision in 2015 and introduce new hydrogen vehicles by 2020. However, these technologies are not expected to penetrate the market or significantly displace oil before 2030.

Geothermal

DOE's geothermal R&D program is developing technologies to improve the efficiency and cost competitiveness of geothermal technologies, which currently provide about 0.3 percent of total U.S. electricity and heating needs.[11] DOE's R&D program has changed over time from a resource-

[11]See also GAO, *Renewable Energy: Increased Geothermal Development Will Depend on Overcoming Many Challenges*, GAO-06-629 (Washington, D.C.: May 24, 2006).

oriented, long-term, high-risk program to a cost-shared, competitively selected R&D program to meet immediate industry needs in geosciences, drilling, resource engineering, and energy conversion technologies. The program has developed drilling tools that oil and gas companies have adapted for exploration and helped introduce geothermal heat pumps into the market.[12] The current goals of the geothermal R&D program are to (1) decrease the cost of geothermal electricity from about 8 to 9 cents per kilowatt-hour in 2004 to about 3 to 5 cents per kilowatt-hour by 2010; (2) improve hydrothermal technologies by increasing the productivity and lifetime of reservoirs, improve technology performance, and reduce the costs associated with drilling geothermal wells; (3) develop additional geothermal resources; and (4) explore the technical feasibility of mining heat from hot dry rock and magma. However, the administration's fiscal year 2007 budget proposed eliminating funding for the geothermal R&D program.

Hydropower

Since 1991, annual budget authority for DOE's hydropower R&D program has not exceeded $6 million (in real terms) for developing cost-effective technologies to improve the operation of hydropower facilities and address environmental concerns. Hydropower is currently the largest source of renewable energy, generating as much as 10 percent of U.S. electricity. The most common type of hydropower plant uses a dam on a river to store water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which, in turn, activates a generator to produce electricity. Current hydropower technologies can have undesirable environmental effects, such as fish injury and mortality from passage through hydropower systems, and negative impacts on the quality of water downstream. DOE has been working with industry to improve the environmental and operational performance of hydropower systems. DOE's goal is to demonstrate advanced turbine technologies that will enable a 10 percent growth in generation at existing hydropower plants and enhance environmental performance by 2010. However, the administration's fiscal year 2007 budget proposed eliminating funding for the hydropower R&D program.

[12] Geothermal heat pumps are used for space heating and cooling, as well as water heating. The heat pump transfers heat stored in the earth or in groundwater into a building during the winter and transfers it out of the building and back into the ground during the summer.

DOE's Fossil R&D Program Has Focused on Reducing Harmful Emissions and Improving the Efficiency of Burning Coal

DOE's fossil energy R&D has focused primarily on reducing emissions and increasing the efficiency of coal-fired power plants. DOE also has supported oil and natural gas R&D through cost-shared partnerships with industry, with most funding focused on advanced drilling and piping technologies for exploration and production.

Coal

In the 1980s and early 1990s, DOE's clean coal technology programs used cost-shared cooperative agreements with power companies to demonstrate technologies for reducing sulfur dioxide and nitrogen oxide emissions from coal-fired power plants. In part as a result of concerns about acid rain and transboundary pollution, the 1990 Clean Air Act amendments required that the U.S. Environmental Protection Agency (EPA) regulate hazardous air pollutants, including sulfur dioxide and nitrogen oxide emissions.[13] Technologies demonstrated by the clean coal technology program contributed to a 98-percent reduction in sulfur dioxide and similar targets for nitrogen oxide emissions from coal-fired power plants from 1986 to 2005.

While DOE's fossil R&D program seeks to further reduce sulfur dioxide and nitrogen oxide emissions, its overall objective is to drive all coal-fired power plant emissions to "near-zero" levels by 2020. To enable industry to meet Clean Air Act standards, as well as new goals set out by the administration's Clear Skies Initiative and EPA regulations,[14] DOE has focused on reducing mercury and carbon dioxide emissions—significant contributors to health hazards and global warming, respectively. DOE's objective is to reduce mercury emissions by 95 percent and capture and store—or "sequester"—up to 90 percent of carbon dioxide emissions by 2020. Carbon dioxide capture and storage technologies would separate carbon dioxide from other gases produced during the combustion process and would transport the captured carbon dioxide to a suitable long-term storage site, such as geologic repositories or in the deep ocean.

[13]Under the Clean Air Act, EPA sets limits on how much of a pollutant can be in the air anywhere in the United States, which it can enforce by fining companies that violate air pollution limits.

[14]EPA has promulgated a Clean Air Mercury Rule for mercury and a Clean Air Interstate Rule for sulfur dioxide and nitrogen oxide reductions across the states.

DOE is also working to improve the efficiency of coal-fired plants by up to 50 percent by 2010 and 60 percent by 2020. According to DOE, pulverized coal-fired plants using currently available technology are only about 35-percent efficient—meaning about 65 percent of the energy generated by the plant is lost during the conversion process, mostly as heat that is not converted to electricity. Several of DOE's current fossil R&D projects aim to develop coal-based plants that employ new, more efficient gasification technologies. Rather than burning coal directly, gasification breaks coal down into a synthesis gas, comprised primarily of carbon monoxide and hydrogen, which is combusted to turn a gas turbine, generating electricity. Heat from the combustion process is captured and directed toward a steam turbine, which also generates electricity. According to DOE, industry, and association officials, power plants using an IGCC configuration for gasification increase the efficiency of electricity generation and substantially reduce harmful emissions in comparison with conventional pulverized coal technology (see table 1).

Table 1: Comparison of Conventional Pulverized Coal and IGCC Technologies

		IGCC		
Performance characteristic	New conventional pulverized coal plant	current	near future	2020
Mercury emissions (pounds/year)	45	29	29	26
Sulfur dioxide emissions (tons/year)	3,027	566	276	250
Nitrogen oxide emissions (tons/year)	1,412	1,094	219	198
Carbon dioxide emissions (tons/year)	3,700,000	3,600,000	3,500,000	3,200,000
Potential for carbon capture and sequestration	Limited	Yes	Yes	Yes
Plant efficiency (percent)	38.6	39.7	45-50	50-60

Source: The Electric Power Research Institute and DOE.

Note: DOE is the source of plant efficiency data for the "near future" and 2020. The Electric Power Research Institute provided all other data.

Coal-based power plants that employ IGCC technologies break down coal into its basic chemical elements, allowing for the capture of carbon dioxide as a concentrated gas stream. In contrast, conventional pulverized coal plants burn coal directly, creating a more diluted stream of carbon dioxide that is much more costly to separate from the larger mass of gases flowing from the combustor. As such, IGCC plants offer greater potential for carbon capture and sequestration to reduce carbon dioxide emissions. Moreover, according to international climate change experts at the United Nations Environment Programme and the World Meteorological Organization, carbon dioxide capture and sequestration technologies have the most potential for significantly mitigating climate change when applied in IGCC plants. Currently, only two coal-based IGCC plants in the United States are fully operational and produce electricity, and an additional 28 coal gasification plants are planned for operation by 2030.

To meet its emissions and efficiency goals, DOE recently 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 emissions and improve efficiency by integrating IGCC with carbon capture and sequestration technologies. According to DOE, FutureGen is designed to be the first “zero-emissions” coal-based power plant and is expected to be operational by 2015. In addition to producing electricity and capturing and storing 1 million metric tons of carbon dioxide, the 275 megawatt plant also will be capable of producing hydrogen.

Oil and Natural Gas

Since 1978, DOE has supported oil and natural gas R&D, mainly through cost-shared partnerships with industry. Historically, DOE’s R&D funding for oil and natural gas was principally divided among specific resources, such as gas shales and coal-bed methane. In the mid-1980s, however, DOE switched its focus to developing energy technologies that cross multiple resources. Recently, DOE’s R&D has focused on improving oil exploration technologies, extending the life of current oil reservoirs, and developing drilling technology for tapping into deep deposits of natural gas. For example, DOE is working with industry to develop (1) a composite drill pipe that is lighter, stronger, and more flexible than steel to improve oil and natural gas extraction and (2) technology for tapping into the vast amount of natural gas available in naturally occurring methane hydrate found on land in permafrost regions and beneath the ocean floor at water depths greater than 1,600 feet. In fiscal year 2005, exploration and production and methane hydrate R&D received almost two-thirds of DOE’s funding for oil and natural gas R&D. While DOE’s fiscal year 2006 budget proposed terminating the oil and natural gas R&D program, the Congress provided $65 million. DOE’s fiscal year 2007 budget again proposed terminating the oil and natural gas R&D program. In addition to the appropriated funds that oil and natural gas R&D program receives, section 999A-H of the Energy Policy Act of 2005 established a program for R&D and commercialization of technologies for ultra-deepwater and unconventional natural gas and other petroleum resource exploration and production through September 2014 and authorized the use of $50 million per year from federal oil and gas lease income for an 11-year period.

DOE's Nuclear R&D Goals Recently Have Focused on Restarting the U.S. Nuclear Power Industry, Reprocessing Spent Nuclear Fuel, and Developing New Reactor Designs

The commercial nuclear energy industry experienced substantial growth during the 1960s and 1970s. By 1974, the federal government had approved operating licenses for 52 nuclear reactors with plans for dozens more. However, the energy crisis in the 1970s led to a significant reduction in orders for new reactors and, coupled with concerns about reactor safety and performance resulting from the 1979 accident at Three Mile Island, the industry canceled the application process for 93 other reactors. DOE began to focus on short-term R&D, working specifically to restore public trust and regulator confidence by improving safety and efficiency of operations. By the mid-1990s, the industry had dramatically improved its safety record, and the performance of nuclear power exceeded that of any other source of energy, reaching 90 percent of total potential capacity. Left with only incremental improvements in operations and uncertain economics, the Congress began to phase out funding DOE's nuclear energy R&D and terminated nuclear R&D funding altogether in fiscal year 1998.

In fiscal year 1999, DOE crafted a long-term nuclear energy R&D agenda that focused on developing more efficient systems and proliferation-resistant fuel cycles, devising new technologies for managing nuclear waste, and designing a fourth generation of nuclear reactors that would not use conventional light water reactor technology. In fiscal year 2001, DOE prioritized its R&D program to focus on (1) the Nuclear Power 2010 program, (2) the Advanced Fuel Cycle Initiative (AFCI), and (3) the Generation IV Nuclear Energy Systems Initiative.

DOE's Nuclear Power 2010 initiative has shared the costs that participating power companies have incurred in preparing either an early site permit or an application for an NRC license to construct and operate an advanced Generation III nuclear power reactor. In the years after the Three Mile Island accident, the nuclear power industry stated that NRC's regulatory process had become too cumbersome, leading to costly delays in construction and licensing and becoming a major stumbling block to investing in a new nuclear reactor. In response, NRC promulgated regulations in 1989 that established a single combined license to construct and operate a new reactor, replacing its prior requirement that companies obtain both a construction permit and an operating license.[15] More recently, in fiscal year 2002, to encourage power companies to apply to NRC for a combined construction and operating license, DOE initiated a

[15]See 54 *Fed. Reg.* 15383 (1989).

demonstration program with three power companies seeking early site permits for potential nuclear reactor sites in Illinois, Mississippi, and Virginia. The permits, applications for which were submitted to NRC in 2003, would allow the sites to be used for nuclear power plants, but the power companies still would have to apply to NRC for a combined license to construct and operate any reactors later built on these sites. In fiscal year 2004, DOE began a demonstration program with two industry consortia to develop applications for NRC licenses to build and operate two additional reactors at existing nuclear power plants. These applications may be submitted to NRC next year. Even if NRC approves the licenses, which NRC estimates will take 42 months, the industry consortia have not committed to constructing the new reactors. The industry has, however, received license extensions for 44 of the 103 operating nuclear reactors. DOE allocated $65.3 million to the Nuclear Power 2010 program in fiscal year 2006 and requested $54 million for fiscal year 2007.

The AFCI program is designed to develop and demonstrate technologies for reprocessing spent nuclear fuel that could recover the fuel for reuse, minimize proliferation threats, and reduce the long-term hazard and disposal requirements of spent nuclear fuel. In the 1970s, the United States pioneered reprocessing technologies, but it abandoned the concept because of concerns about nuclear proliferation—plutonium could be separated to manufacture nuclear weapons.[16] Current R&D efforts focus on reprocessing spent fuel without separating the plutonium, with the goal of rendering it virtually useless to potential proliferators. Much of the reprocessed fuel could be reused in commercial reactors to generate electricity.

In February 2006, DOE announced the Global Nuclear Energy Partnership (GNEP) program, characterizing it as an extension of the AFCI program. GNEP furthers the R&D goals of the AFCI program, accelerating the R&D efforts and introducing a global component. DOE’s intent is to work with other nations that reprocess spent fuel to supply fuel to countries for the purpose of generating electricity. The countries then would return the spent fuel to the supplier nations for reprocessing. Once reprocessed, this fuel would be returned to the countries for reuse. The intent of the program is to encourage these “reactor-only” countries not to develop

[16]In 1977, President Carter announced plans to indefinitely suspend U.S. reprocessing efforts.

their own independent nuclear technologies, thereby reducing proliferation risks. Details of the program are still being developed. DOE requested $243 million for the combined AFCI and GNEP programs in fiscal year 2007. According to DOE officials, the GNEP program would need about $5 billion over the next 5 years.

The Generation IV program focuses on developing new, fourth generation, advanced reactor technologies intended to be commercially available by about 2020 to 2030. The program, including the United States and 12 international partners, identified six advanced reactor designs from which DOE has focused on two reactor designs: (1) a sodium-cooled fast reactor and (2) a gas-cooled very high temperature reactor. A fast reactor manages nuclear reactions somewhat differently than current commercial reactors, in which neutrons interact with the low-enriched uranium fuel atoms to induce fissions—or the splitting of the uranium atom—that emits more neutrons and leads to a self-sustaining chain reaction. The fissioning of uranium releases large amounts of energy that is captured as heat to drive turbines and generate electricity. Because the fission neutrons are born at high energy, they are not inherently efficient at causing more fissions, so commercial nuclear reactors are filled with water that functions both to slow the neutrons down and act as a coolant and heat removal system. The lower energy neutrons in current commercial reactors are much more effective at sustaining the uranium fission chain reaction. In contrast, a fast reactor manages these nuclear reactions at a higher energy level. Fast reactors use coolants such as liquid sodium metal that do not slow down the neutron energy. Because fast reactors are more effective than current commercial reactors at inducing fissions in a wider variety of nuclear materials, including plutonium and other materials that might otherwise become wastes from the current commercial reactor fuel cycle, they can potentially reduce the total amount, temperature, and radiotoxicity of the fuel that might otherwise have to be stored for many thousands of years in a geologic repository. The lower temperature may also allow more spent fuel to be stored at a deep geologic repository, delaying the need for additional repository requirements. This continuous recycle and burning of spent nuclear fuel materials is key to the GNEP program.

The gas-cooled very high temperature reactor is also being developed through DOE's Next Generation Nuclear Plant program because the high temperature allows for the efficient production of hydrogen by splitting water. U.S. industries annually produce over 9 million tons of hydrogen to, for example, manufacture fertilizer and refine petroleum. Very high temperature reactors may become an efficient and emissions free alternative source of hydrogen, which is made primarily from natural gas.

The very high temperature reactor can be more efficient than current reactors and is designed to be versatile, capable of generating small or large amounts of electricity. DOE requested $31.4 million for fiscal year 2007 for the Generation IV R&D efforts.

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. Renewable technologies face technological and market barriers—such as efficiency and high up-front capital costs—to substituting for oil and for generating electricity. Advanced fossil technologies also face key challenges—such as controlling harmful emissions—to deploying advanced technologies for generating electricity. Similarly, advanced nuclear technologies face key challenges—such as public opposition and high capital costs—that must be addressed as the industry considers constructing new nuclear power reactors for the first time in nearly 30 years.

Renewable Energy Technologies Face a Variety of Technical and Deployment Barriers

The primary renewable energy technologies with the potential to substantially expand their existing production capacity during the next 25 years are biomass, a partial substitute for gasoline in transportation, and wind and solar energy technologies for generating electricity.

Ethanol

In 2005, 95 ethanol refineries located in 19 states produced 3.9 billion gallons of ethanol—an increase of 17 percent over 2004 and 126 percent over 2001. The United States will consume about 5 billion gallons of ethanol in 2006, according to the industry's September 2006 projections. Ethanol is blended in 30 percent of the nation's gasoline and is primarily produced in the Midwest because of the abundant supply of corn. Ethanol demand is expected to continue to grow as a result of the national renewable fuels standard,[17] enacted by the Energy Policy Act of 2005, and the decision of many oil refineries to switch to using ethanol instead of

[17]The national renewable fuels standard establishes a baseline for renewable fuel use, beginning with 4 billion gallons per year in 2006 and expanding to 7.5 billion gallons by 2012.

MTBE as a fuel additive in gasoline that improves its octane and clean-burning properties.[18]

One of ethanol's biggest challenges is how to cost-effectively expand the supply of biomass, in addition to corn, to enable the total ethanol market to grow. DOE scientists are exploring technologies that can cost-effectively use cellulosic biomass—low-value residues such as wheat straw and corn stover or bio-energy crops such as fast-growing grasses and trees. Some bio-energy crops, such as switchgrass, require less fertilizer than corn and can be grown in many U.S. regions. While cellulosic ethanol requires less fossil energy than corn ethanol on a total life-cycle basis, capital costs are substantially higher for cellulosic ethanol plants than for corn ethanol plants. In addition, cellulosic ethanol producers need to reduce costs for (1) harvesting and handling cellulosic feedstock, (2) enzymes for converting cellulose to fermentable sugars, and (3) novel fermenting micro-organisms that can convert these biomass-derived sugars to ethanol. Cellulosic ethanol currently costs at least twice as much to produce as corn ethanol, according to DOE officials.

A related challenge is producing sufficient biomass levels without disrupting current production of food and forest products. In 2005, 1.43 billion bushels of corn—nearly 13 percent of the U.S. corn crop—were used for ethanol production. In a 2005 report, the U.S. Department of Agriculture and DOE estimated that the nation is capable of producing enough ethanol to replace 30 percent of the U.S. oil consumption by 2030 and still meet food, feed, and export demands.[19] However, some experts have expressed concern that large-scale diversion of agricultural resources to generate ethanol could result in higher food prices for people and livestock. There are also questions about the amount of land that will be needed to produce higher levels of ethanol, whether vast preserved areas will be transformed into farmland, water quality issues, and soil sustainability. In addition, scientists have debated whether ethanol is an effective petroleum substitute because of the amount of energy needed to produce it—a significant amount of energy is used because (1) fertilizer

[18]According to EIA, oil refineries decided to eliminate MTBE primarily because (1) many states have banned MTBE because of water contamination concerns, (2) industry's liability exposure by adding MTBE to gasoline, and (3) industry's perception that liability exposure increased because the Energy Policy Act of 2005 eliminated the oxygen content requirement for reformulated gasoline.

[19]DOE and USDA, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005.

made from fossil fuels is used to grow the corn, (2) most U.S. biorefineries use natural gas to convert biomass into ethanol, and (3) the corn and the ethanol need to be transported.

A third challenge is the distribution of ethanol from the biorefinery to the consumer, according to DOE officials. Ethanol cannot use the same infrastructure as gasoline because it has corrosive qualities and is water soluble.[20] As a result, an independent infrastructure system for transporting and storing ethanol would be needed throughout the United States. In particular, no pipelines exist to distribute ethanol from the Midwest, where it is mainly produced, to major markets on the East and West coasts. In addition, infrastructure constrains the distribution of E85—a blend of 85 percent ethanol and 15 percent gasoline—because regular gas stations must have separate tanks for storing E85 and specialized pumps for dispensing it. Currently, fewer than 1,000 fueling stations provide E85 nationwide, compared with 176,000 gas stations. These ethanol fueling stations are concentrated in the upper Midwest, and about 75 percent of ethanol is transported by rail and 25 percent is moved by truck. U.S. consumers have bought more than 5 million flexible fuel vehicles that can run on E85; however, without a ready supply of E85, many of these vehicles will continue to operate using gasoline.

Ethanol also faces the challenge of becoming more price-competitive with gasoline. Currently the market for ethanol relies on federal tax incentives. One such incentive is the volumetric ethanol excise tax credit, enacted in 2004, which provides a 51-cent tax credit for every gallon of ethanol used to produce a fuel mixture through December 31, 2010. Even with tax incentives for ethanol producers, the fuel has been more expensive than gasoline, in part because ethanol's energy content is lower than gasoline's. According to DOE and EPA, flex fuel vehicles require about one-third more ethanol to match gasoline's energy content. Similarly, in October 2006, Consumer Reports, estimated that drivers paying $2.91 per gallon for E85 in August 2006 actually paid about $3.99 for the energy equivalent of a gallon of gasoline because the distance vehicles traveled per gallon declined by 27 percent.

[20]It is a normal occurrence for water to accumulate in oil pipelines. In most cases, water enters the system through terminal and refinery tank roofs or can be dissolved in fuels during refinery processes. Introducing ethanol into an oil pipeline risks rendering it unusable as a transportation fuel.

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.[21] DOE program officials told us that the rising number of biomass earmarks shifted funding away from DOE's R&D program, causing the biomass program to change its program priorities and terminated some of its cost-shared projects. Congressionally earmarked projects typically are not subject to peer review, are not selected on either their technical merits or their contribution to meeting program goals, and are only voluntarily accountable for reporting results.

Wind and Solar

Both wind and solar technologies have experienced substantial growth in recent years; they have benefited from federal and state financial incentives, DOE's R&D programs that decreased costs and improved efficiencies, and environmental and energy security concerns. For example, U.S. wind electric generation capacity has grown from 2,000 megawatts in 1999 to 10,000 megawatts by August 2006, enough energy to power about 2.5 million homes[22] with electricity on a typical day. Similarly, the total photovoltaic market has grown, on average, about 30 percent per year over the past 10 years, according to a solar manufacturer. In 2005, the United States had an estimated 475 megawatts of installed photovoltaic capacity, enough to power about 240,000 homes. EIA data show that in 2005 domestic shipments of solar photovoltaic solar technology increased by 72 percent over 2004.

The wind energy industry faces technological challenges to improve turbine design, performance, and reliability that will enable wind power to expand into low wind and offshore locations. These locations use bigger wind turbines with longer blades mounted on taller towers, requiring complex design improvements in such areas as blade development, advanced drive train and power electronics, and advanced controls to reduce system loads. For example, while traditional blade materials have used fiberglass technology, the next generation of turbines will need stiffer and stronger materials, such as carbon fiber, to make longer, thinner, but equally durable blades. Similarly, offshore wind development faces new technical challenges, such as understanding the effects of wave and

[21]Similarly, earmarks accounted for about $43 million, or 27 percent, of appropriated funds for DOE's hydrogen and fuel cell R&D program in fiscal year 2006.

[22]One megawatt of wind power generates about as much electricity as 240 to 300 households use each year.

current loads on the base of wind structures, connecting offshore wind farms to the electric transmission grid, and designing support structures for turbines located in deep water.

Solar technologies also face challenges of improving the scientific understanding of the electronic process of capturing and converting sunlight at the molecular level and technical challenges of improving performance and reliability. For example, DOE is pursuing thin-film photovoltaic technologies, which are designed to reduce material costs by using thin layers of semiconductor material. According to DOE, this technology is not as efficient in converting sunlight to electricity as conventional crystalline-silicon solar cells, but manufacturing costs are anticipated to be lower. The challenge is to increase their efficiency, while continuing to reduce the costs of manufacturing thin-film technologies. DOE scientists are also seeking to reduce failure rates for components in solar water-heating systems that are exposed to high temperatures and improve the 12-year tank life of current solar heaters in cold climates.

A second major challenge to deploying both wind and solar technologies is overcoming investors' concern about their higher up-front capital costs. In particular, wind investors pay substantial up-front capital costs to build a facility and connect it to the power transmission grid. Constructing a wind farm may cost less than connecting the facility to the power transmission grid, according to DOE officials who noted that the connection could cost $100,000 or more per mile, on average, depending on such factors as the project's size, the terrain, and the transmission line rating. In addition, in most areas, a wind farm's investors would pay for upgrading the power transmission grid to carry the extra load, which can be high because prime wind resources are often found far from large urban areas that need the electricity. Similarly, the primary barrier to deploying solar photovoltaic technologies is their up-front purchase costs, which continue to make them more expensive than traditional energy sources, according to DOE and industry executives.[23] More recently, the rapidly growing solar energy industry has experienced an industrywide shortage of solar-grade silicon—the principal material for making crystalline-silicon photovoltaic cells—because of competition from other industries, such as computer chip manufacturers. As a result, the price of silicon wafers on the market has doubled in each of the past 2 years, according to EIA. The tight silicon

[23]The Energy Policy Act of 2005 also established a new residential investment tax credit for solar energy systems that provides a 2-year tax credit through December 31, 2007.

supply has also created back orders of several months. Because photovoltaic manufacturing costs have risen sharply, manufacturers have changed their business strategies to maintain profits and continue to finance their plans to expand their production and strengthen their distribution capabilities.

Both wind and solar power also have unique intermittency characteristics that can constrain their use because the existing power transmission grid was built to accommodate large central-station power plants located near population centers that operate full time. This system relies on precisely predicting and controlling power plant output to avoid blackouts and other disruptions. However, wind and solar energy are intermittent energy sources because wind speed and sunlight vary, depending, for example, on the time of day and the weather—on average, wind turbines operate the equivalent of less than 40 percent of the hours in a year due to the intermittency of wind. Alternatively, the electricity generated must be immediately used or transmitted to the power transmission grid because no cost-effective means exists for storing electricity. DOE is conducting R&D in this area.

A recent challenge facing the wind industry is mitigating environmental and community concerns about its adverse effects. While wind energy does not create the pollution or greenhouse gas emissions associated with fossil fuel power generation, some wind farms have resulted in the death of birds and bats because they are located amidst migratory pathways or important habitats.[24] Our 2005 report found that impacts of wind farms on birds and other wildlife varied by region and by species, and the lack of comprehensive data on bird and bat fatalities from wind turbines make it difficult to make national assessments of the impact of wind turbines on wildlife.[25] In addition, wind energy may face community opposition because it affects visual aesthetics and landscapes. For example, the first proposed U.S. offshore wind project, consisting of 130 wind turbines off the coast of Massachusetts, ran into opposition from local residents and

[24]The Fish and Wildlife Service estimates that some of the leading sources of bird mortality per year are attacks by domestic and feral cats, hundreds of millions of bird deaths; collisions with building windows, 97 million to 976 million bird deaths; poisoning from pesticides, at least 72 million bird deaths; and collisions with communication towers, 4 million to 50 million bird deaths.

[25]See GAO, *Wind Power: Impacts on Wildlife and Government Responsibilities for Regulating Development and Protecting Wildlife*, GAO-05-906 (Washington, D.C.: Sept. 16, 2005).

organizations who oppose the appearance of wind turbines in Nantucket Sound.

Another challenge for wind energy is that the federal production tax credit—the primary federal financial incentive to stimulate the deployment of renewable energy systems—periodically must be legislatively extended, creating uncertainty among investors whether the tax credit will be extended. The federal production tax credit, initially established by the Energy Policy Act of 1992 for a limited duration, had expired before being renewed by subsequent legislation in 1999, 2001, and 2003. The Energy Policy Act of 2005 extended it an additional 2 years, until January 1, 2008. According to DOE officials and industry representatives, the production tax credit has helped to offset the significant higher capital costs per unit of generating capacity needed to start up wind power projects, compared with projects for fossil fuel power generation. However, the uncertainty about the production tax credit's availability has created a boom-and-bust cycle for installing new wind power capacity—installation of new capacity fell dramatically in years when the authorization for the tax credit expired and its renewal was delayed, as compared with years when it was available without interruption. Potential developers are reluctant to commit resources to the planning and construction of new capacity without the certainty that the tax credit will be reauthorized. Furthermore, according to the American Wind Energy Association, 4 to 6 months before the tax credit expires, financial lenders hesitate to provide capital for wind projects because of the uncertainty of whether the tax credit will be extended.

DOE officials and industry representatives believe the continued availability of the production tax credit, or other subsidy support, is vital to the potential future growth of the wind industry. According to an industry representative, a long-term production tax credit would facilitate steady market development for wind power and other renewable sources by encouraging companies to enter the market, allowing the industry to conduct long-term planning, and eventually help the industry stand on its own. According to some stakeholders, renewable energy sources require subsidies, such as the production tax credit, to level the playing field because various subsidies for fossil fuel and nuclear technologies have made it difficult for renewable energy sources to compete.

Both DOE's wind and solar R&D programs have experienced a large increase in the amount of congressional earmarks in recent years. Wind energy earmarks grew from 6 percent of funding in fiscal year 2004 to about 33 percent ($13 million) of funding in fiscal year 2006, according to a

DOE program official. Similarly, solar energy earmarks grew from 1 percent of funding in fiscal year 2004 to about 17 percent ($14 million) of funding in fiscal year 2006, according to a DOE program official. An industry association executive noted that congressional earmarks reduce DOE's ability to adequately fund its solar R&D programs and meet targets.

Barriers to Advanced Fossil Technologies Include Harmful Emissions and High Capital Costs of New Coal Gasification Plants

While coal-fired power plants have substantially reduced their sulfur dioxide and nitrogen oxide emissions, electric power companies face important challenges to deploying a new generation of advanced IGCC coal gasification power plants. These challenges are to further reduce mercury and carbon dioxide emissions and manage the risk associated with high construction and operating costs of new advanced coal technologies. The administration's Clear Skies Initiative set goals for coal-fired plants to cut their 2003 emissions—49 tons of mercury, 10.2 million tons of sulfur dioxide, and 3.9 million tons of nitrogen oxide—by an average of 70 percent by 2018. However, coal-fired plants also annually emit 2.1 billion tons of carbon dioxide—the most significant contributor to greenhouse gases and global warming—or 36 percent of the nation's total carbon dioxide emissions. EPA currently does not regulate carbon dioxide emissions but might do so in the future to address the growing concern about the harmful effects of greenhouse gases.

IGCC coal-gasification technology enables power plants to separate sulfur dioxide, nitrogen oxide, mercury, and carbon dioxide before the synthesis gas is burned, thus reducing their emission into the air. DOE and industry are conducting R&D to develop sequestration technologies for the long-term storage of carbon dioxide gas without the gas gradually leaking back into the atmosphere. DOE has funded 25 carbon-dioxide sequestration projects as of September 2006, but has not yet demonstrated the storage of carbon dioxide captured by a large-scale, coal-based power plant. Specifically, when carbon dioxide is compressed and stored in geologic formations, such as oil and gas reservoirs, its density is close to that of some crude oils, resulting in buoyant forces that tend to drive carbon dioxide upwards. It is unknown whether carbon dioxide will remain safely sequestered if pressure, temperature, or other conditions change. According to international climate change experts, leakages could significantly affect climate change or contaminate groundwater. Moreover, given the long-term nature of carbon dioxide capture and sequestration, storage sites may require monitoring for very long periods of time—possibly for "eternity," according to one DOE official.

New coal gasification plants also face the high costs associated with employing advanced energy technologies, such as IGCC and carbon dioxide capture and sequestration systems. In particular, IGCC plants are 20 percent more expensive—about $100 million more—than pulverized coal plants that use currently available technology, according to International Energy Agency, DOE, and industry officials. Moreover, carbon dioxide capture and sequestration technologies will further increase an IGCC plant's costs because capturing and sequestering carbon dioxide increases fuel consumption by as much as 25 percent. According to international climate change experts, an IGCC plant that employs carbon dioxide capture and sequestration technologies could increase the cost of electricity per kilowatt hour from 21 to 78 percent, depending on plant design, the cost of fuel, and the storage site characteristics.[26]

In addition to technological and cost barriers, the uncertainties surrounding new coal-gasification technologies create substantial investment risks that threaten to hinder development. Despite the greater efficiency, reduced emissions, and the ability to capture carbon dioxide, only four coal-based IGCC power plants currently operate worldwide. The unproven nature of IGCC technology creates uncertainty and reluctance among industry to invest in building a new coal-based IGCC power plant, particularly given the additional cost, according to DOE and industry officials. Furthermore, international climate change forecasting models predict that carbon dioxide capture and sequestration systems are unlikely to be deployed on a large scale without explicit government regulations that substantially limit greenhouse gas emissions to the atmosphere. In light of such technological uncertainties, industry officials noted that cost-sharing initiatives with DOE will continue to be an important factor in encouraging the demonstration and deployment of IGCC plants.

[26]The higher cost of electricity generated using IGCC technology in comparison with conventional coal-fired technologies more fully reflects the total cost of burning coal by including the cost of controlling the release of harmful emissions. Alternatively, several countries have enacted a carbon tax that puts a value on the carbon emissions that conventional coal-fired technologies generate.

Advanced Nuclear Energy Technologies Face Uncertainty about NRC's Regulatory Process, Public Opposition, High Capital Costs, and the Storage of Nuclear Waste

The nuclear energy industry, DOE, and NRC face important challenges in reinvigorating the nuclear power industry include an untried regulatory process, the public's concern about safe operations, investor concerns about high capital costs, and uncertainty about the long-term storage of nuclear waste. During the 1960s and 1970s, several nuclear power plants experienced construction costs that doubled and time frames that extended several years longer than anticipated—in one case, a project took nearly 20 years to build and begin operations, according to the Nuclear Energy Institute, an industry association. Since 1974, power companies have cancelled applications for 93 proposed reactors and have shut down 22 of 126 operating reactors before their 40-year license expired. NRC issued its last permit to construct a nuclear reactor in 1978, the year before the Three Mile Island nuclear reactor accident, which heightened public opposition to nuclear power and tightened NRC's oversight of nuclear power plant operations. More recently, however, NRC has approved a 20-year license extension for 44 of the 103 operating nuclear reactors in the United States and is reviewing applications to extend the licenses for 10 additional reactors.

Because NRC has not issued a construction permit in almost 30 years, investors worry that the problems that contributed to the schedule delays, cost overruns, and abandonment of many planned reactors may not be resolved. Among the reasons for these problems were that electric power companies custom-built many of the nuclear power plants, rather than using a standard design, and sometimes began construction with preliminary design information, only to resort to mid-construction retrofits as final design plans changed. In addition, NRC's regulatory process at that time required the applicant to obtain a construction permit first and apply for an operating license in the midst of construction. Final approval of the operating license sometimes hinged on time-consuming and costly retrofits, particularly if operational procedures conflicted with design features.

To reduce these high costs and long time frames, NRC streamlined its licensing process in 1989 by combining its construction and operating licenses into a single license that requires applicants to submit final design information, safety analyses, and environmental data in advance of or with the license application. While industry representatives generally agree that the revised licensing process reduces risk of costly retrofits, they are concerned that the new process has not been tested and could still lead to extensive delays. For example, some representatives noted that NRC has already fallen behind schedule in reviewing the early site permits that three electric power companies submitted as part of a DOE demonstration program to stimulate power companies to apply to NRC for a combined construction and operating license. The early site permits address site suitability matters such as safety and environmental issues and, once obtained, can be used as a reference in a combined license application to streamline the site suitability portion of the application.[27] NRC acknowledged the delays, attributing them to a learning process under new procedures and regulations; an unexpectedly large number of public comments received electronically; and, in one case, the applicant's decision to change the design. Electric power companies have notified NRC that they plan to submit license applications to build and operate at least 29 new reactors. To prepare, NRC has implemented a design-centered approach that encourages applicants to use a standardized design for each reactor manufacturer with variations only to address the site's local characteristics, such as environmental conditions. NRC also has created a separate Office of New Reactors to oversee the licensing process, plans to hire 400 additional staff by fiscal year 2008, and is developing a more robust system to handle electronic comments. NRC expects to review license applications and issue a decision within 42 months. However, while it has issued its draft regulatory guidance for submitting and reviewing the combined license applications, NRC does not expect to finalize the guidance until March 2007.

A second challenge that investors face is public opposition to nuclear power. According to the nuclear energy industry, public support for nuclear power has increased in recent years, primarily as a result of the industry's improved safety record and a growing awareness that nuclear power production releases few greenhouse gases.[28] Electric power companies plan to construct most of the announced new reactors at existing nuclear power plants in the southeast United States, where public opinion is more favorable toward nuclear power. Reactor projects at existing nuclear power plants also benefit from existing power transmission lines and historical environmental data for the required environmental impact assessment. However, industry officials acknowledge that public support is fragile and note that a nuclear accident anywhere in the world could undermine this support.

[27] *See* 10 C.F.R. pt. 52.

[28] Mining and processing of uranium and transporting of nuclear fuel result in some greenhouse gas emissions. In addition, greenhouse gas emissions result from site construction and worker transportation for both nuclear and renewable energy facilities.

A third challenge facing nuclear energy is the high capital costs to build new nuclear reactors and a potential shortage of skilled workers. Nuclear energy representatives expect a new nuclear power plant to cost between $1.5 billion and $4 billion—more than double the cost of a comparably sized conventional coal-fired plant. These costs may increase if (1) transmission lines need to be installed or upgraded, (2) significant delays occur during construction or start-up operations, and (3) lawsuits are filed resulting in higher legal costs and delays. Although nuclear power plants have relatively low operating costs and can operate at 90-percent capacity, the overall cost of construction makes nuclear energy a high-cost option. In addition, nuclear energy industry officials noted that a potential shortage of skilled workers creates additional uncertainties over construction schedules that could increase the cost of a new plant. With the hiatus in nuclear power plant construction, industry officials have expressed concerns that there may be a shortage of workers with the skills critical to the construction of new nuclear power plants, particularly if several utilities plan construction simultaneously.

The Energy Policy Act of 2005 has facilitated the construction of new nuclear power reactors by providing a 1.8 cents/kilowatt-hour tax credit for up to 6,000 megawatts of new nuclear energy capacity for the first 8 years of operation (up to $125 million per reactor). The Department of the Treasury is to prescribe the process for allocating the tax credit in consultation with the Secretary of Energy. In addition, the act authorizes the Secretary of Energy to enter into six contracts with sponsors of advanced nuclear facilities to ensure against certain delays in attaining full-power operation and provide indemnification of (1) 100 percent of covered costs, up to $500 million each for the first two reactors and (2) 50 percent of covered costs, up to $250 million each for the next four reactors after an initial 180-day delay.

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. [29] 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 costs. The nuclear power industry has

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

proposed constructing modular plants based on a set of reference designs in the hopes of reducing construction costs. New technologies that use more reliable and less expensive passive safety systems also can reduce costs considerably compared with active safety systems currently used. For example, several of the proposed nuclear reactors utilize less piping. Despite the projected cost reductions, the MIT authors suggested that investors would most likely prefer conventional coal or natural gas over nuclear energy for generating electricity. Table 2 shows that without substantial cost reductions, nuclear energy cannot compete with either conventional coal or natural gas.

Table 2: Comparison of Electricity Generating Costs Using Nuclear, Coal, and Natural Gas Energy Sources

Cents per kilowatt-hour

Energy source	25-year period	40-year period
Nuclear (base case)	7.0	6.7
Nuclear (best case)	4.7	4.4
Coal	4.4	4.2
Natural gas	4.9	5.1

Source: MIT.

Note: Costs were calculated using 2002 dollars and an 85 percent capacity factor using merchant plant financing, reflecting a risk premium for nuclear energy. The best case for nuclear energy assumes a 25-percent reduction in construction costs and a 12-month reduction in construction time. The natural gas case assumes combined cycle turbine technology and a price that starts at $4.50/million Btu and rises at a 2.5 percent rate over 40 years. Although natural gas prices were lower in 2002 than today, construction and other costs have risen, resulting in a good measure of relative costs, according to one of the MIT authors.

However, the MIT study found that if a tax on carbon emissions were introduced, nuclear energy could become much more competitive because conventional coal and natural gas power plants would be subject to the tax while nuclear reactors would not because they do not emit carbon dioxide during the generation of electricity (see table 3). Coal-based IGCC plants could perform better than the conventional coal-fired power plants in capturing and sequestering carbon dioxide emissions, but these plants are considerably more expensive to build and operate than conventional coal-fired plants. Part of DOE’s R&D efforts include reducing the cost of construction of coal-based IGCC plants.

Table 3: Comparison of Electricity Generating Costs Assuming a Carbon Emissions Tax

Cents per kilowatt-hour

Energy source	25-year period	40-year period
Nuclear (base case)	7.0	6.7
Nuclear (best case)	4.7	4.4
Coal ($50/ton carbon tax)	5.6	5.4
Coal ($100/ton carbon tax)	6.8	6.6
Natural gas ($50/ton carbon tax)	5.3	5.6
Natural gas ($100/ton carbon tax)	5.8	6.0

Source: MIT.

Note: Costs were calculated using 2002 dollars and an 85 percent capacity factor using merchant plant financing, reflecting a risk premium for nuclear energy. The best case for nuclear energy assumes a 25-percent reduction in construction costs and a 12-month reduction in construction time. The natural gas case assumes combined cycle turbine technology and a price that starts at $4.50/million Btu and rises at a 2.5 percent rate over 40 years. Although natural gas prices were lower in 2002 than today, construction and other costs have risen, resulting in a good measure of relative costs, according to one of the MIT authors.

The revival of the nuclear power industry is also challenged by uncertainty about long-term disposal of commercial reactors' spent nuclear fuel. DOE reports that about 55,000 tons of commercial spent nuclear fuel—enough to fill the area of a football field about 10 feet deep—currently sits in interim storage at 72 sites in 33 states, mostly at operating reactor sites. This spent fuel must be safely disposed of to protect the public and the environment from harm because it will remain highly radioactive for hundreds of thousands of years. The Atomic Energy Commission, DOE's predecessor, initially planned to recycle spent nuclear fuel to reduce the amount of waste for disposal, but the 1970s recycling technology did not address concerns that plutonium might be separated and diverted for use in manufacturing nuclear weapons. The Nuclear Waste Policy Act of 1982 determined that the spent fuel should be disposed of in a deep geologic repository; and, in 1987, an amendment to the act identified Yucca Mountain, about 100 miles northwest of Las Vegas, Nevada, as the one site that DOE should study further. However, DOE has extended the repository's commissioning date from the original 1998 target to 2017.[30] In

[30]The Nuclear Waste Policy Act of 1982 originally set 1998 as the date for DOE to begin accepting spent nuclear fuel for disposal. DOE has revised its estimate of the repository's opening first to 2010 and currently to 2017, characterized by DOE as a "best-achievable schedule."

addition, once the repository is completed, decades may be needed to transport the spent fuel from various locations across the country to Yucca Mountain. In the meantime, utilities continue interim storage of spent nuclear fuel at operating reactor sites.[31]

Many states have expressed alarm at the delays in opening Yucca Mountain, fearing that the repository will suffer continual delays or might never open, forcing the nuclear power plants to store the spent fuel indefinitely. While the states are concerned about the public health and environmental risks, especially with about 2,200 tons of spent nuclear fuel being added to the national inventory annually, DOE and NRC cite a long list of studies that indicate that the risks of radiation release from spent fuel in interim storage in pools or in dry storage casks is low.[32] The states are also concerned that Yucca Mountain project delays are resulting in ongoing costs for the consumer because, under the Nuclear Waste Policy Act, users of nuclear power generated electricity pay $0.001 per kilowatt-hour into a Nuclear Waste Fund, which is designed to pay for the permanent disposal of all commercial spent nuclear fuel and high-level waste, including the siting, licensing, and construction of a nuclear waste repository. In fiscal year 2006, DOE reported $19.4 billion in the fund. DOE reported that from project inception in fiscal year 1983 through fiscal year 2005 that it had spent approximately $11.7 billion (in real terms).[33] Recently, DOE revised the start date from 2010 to 2017 and estimated that the project would incur an additional $10.9 billion (in real terms) from fiscal year 2006 to fiscal year 2017. According to the National Council of

[31]NRC requires that utilities store spent nuclear fuel immersed in deep pools of water or in dry storage casks consisting of all steel or steel and concrete. Currently, 37 commercial dry storage facilities exist in 27 states. However, Private Fuel Storage in Utah, a facility licensed to take waste from a consortium of commercial reactors, is not yet operational. Two sites in Colorado and Idaho that are managed by DOE and store commercial spent nuclear fuel from the Fort St. Vrain and Three Mile Island reactors, respectively, are not included in this count.

[32]NRC has determined that there is reasonable assurance that a geologic repository will be open by 2025, giving it confidence that the nuclear waste issue will be resolved. In the meantime, NRC testified that continued interim storage is considered safe. In February 2006, NRC licensed a centralized interim storage facility in Utah that the electric power industry is pursuing to relieve congested spent fuel pools. However, there is no timetable for construction.

[33]Funding includes $8.3 billion from the Nuclear Waste Fund, $3 billion from defense waste, and the remainder from various reprogramming actions. Both commercial spent nuclear fuel and high-level defense waste are planned for disposal at Yucca Mountain.

State Legislatures, seven states have prohibited the construction of new nuclear plants, citing the need to resolve the spent nuclear fuel issue.

Nuclear energy representatives also told us that another barrier facing nuclear power is states' opposition to transporting spent nuclear fuel. Specifically, once Yucca Mountain opens, DOE expects to make about 175 shipments of spent nuclear fuel each year to Yucca Mountain, by both rail and truck, over at least 24 years. Some states and public interest groups have cited safety concerns if an incident occurred while the spent fuel was near populated or environmentally sensitive areas. DOE and NRC officials report that transportation casks have been certified to withstand severe accidents and, according to numerous studies, have also been found to withstand certain acts of sabotage and are considered safe for transporting spent nuclear fuel.

In fiscal year 1999, DOE began R&D to develop proliferation-resistant technology for reprocessing spent nuclear fuel. The new technology—called uranium extraction or UREX—strives to keep plutonium mixed with other highly radioactive elements. The resulting product can be used as fuel in a fast reactor, but it would be very unattractive to proliferators because the desired plutonium is mixed with thermally hot and highly radioactive elements. The technology still needs to be demonstrated to show that it can be cost competitive. In addition, while supporting the idea of reprocessing spent fuel, industry representatives noted that reprocessing technologies are technically challenging and very expensive and would make nuclear energy less economic. DOE and industry representatives have suggested that the reprocessing program, including development of a fast reactor, could cost about $5 billion by 2012 and could exceed $35 billion by 2050. DOE and NRC officials noted, however, that the reprocessing program could delay the need for a second repository, potentially saving money over the long term.

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

While federal R&D funding has declined and the government has relied on the market to determine whether to deploy advanced energy technologies, the states and countries we reviewed have enacted various standards, mandates, and financial incentives in an effort to deploy energy technologies that address their energy needs and environmental concerns. The states have focused their efforts on stimulating the deployment of renewable energy technologies; some states have also provided incentives for stimulating the deployment of advanced fossil and nuclear energy technologies. Each of the six countries we reviewed has sustained long-term efforts resulting in the deployment of one or more advanced renewable, fossil, and/or nuclear energy technologies. While the countries' initiatives have not been without difficulties, they have sustained long-term efforts using mandates and/or incentives to deploy advanced technologies that are providing, or are expected to provide, significant amounts of energy.

States Are Stimulating Renewable Energy through Standards, Mandates, and Financial Incentives

Forty-five states have enacted legislation or developed initiatives to stimulate the deployment of renewable energy technologies, primarily to address their growing energy demand, reduce adverse impacts on the environment, encourage local economic development, and/or provide a reliable, diversified supply of electricity for residents. (See app. III for states' use of five types of standards, mandates, and financial incentives for stimulating renewable energy.) 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;[34] (2) 22 states have established renewable portfolio standards (RPS) requiring or encouraging that a fixed percentage of the state's electricity be generated from renewable sources; and (3) 45 states offer various tax credits, grants, or loans including, for example, exemptions from the state sales tax for purchases of renewable energy equipment and low- or no-interest loans for the purchase of renewable energy equipment. As shown in figure 5, states in the West, Northeast, and Midwest are leading many of these efforts.

[34]The Public Utility Regulatory Policies Act of 1978, (Pub. L. No. 95-617, (1978)) requires that utilities buy excess energy generated by small energy producers. The states determine its minimum purchase price.

Figure 5: Distribution of State Incentives and Policies for Renewable Energy

Sources: GAO analysis of the Database of State Incentives for Renewable Energy maintained by the Interstate Renewable Energy Council and Map Resources (map).

Note: The map does not show the magnitude of state incentives. For example, while Minnesota has more types of financial incentives for renewable energy than California, California's rebate programs have a collective budget over 500 times greater than the budget for the single rebate program administered by Minnesota.

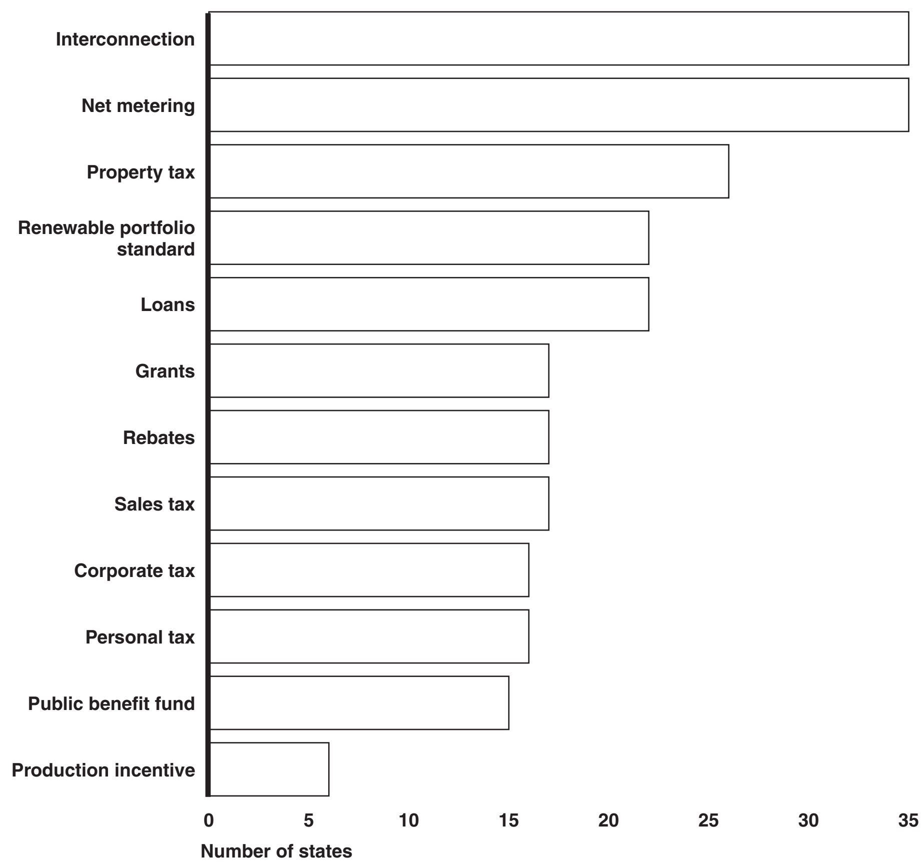
Many states have adopted various standards, mandates, and financial incentives to stimulate the deployment of renewable energy technologies by offsetting their high startup costs. The following are two examples of states' initiatives:

- In 2002, New Mexico enacted a production tax credit of 1 cent per kilowatt-hour for companies that generate electricity from wind, solar, or biomass. In February 2006, New Mexico enacted a 30-percent personal income tax credit (up to $9,000) for residents who purchase and install photovoltaic or solar thermal systems. New Mexico also has net-metering and interconnection rules, which address connecting renewable energy sources to the power transmission grid and crediting producers for excess power generation.

- Since 2004, Massachusetts has provided $2.5 million annually in grants to consumers who install qualified clean-energy technologies under the state's RPS. These technologies include solar thermal electric power, photovoltaics, and wind generation. Massachusetts also has net-metering and interconnection rules.

Figure 6 shows the number of states that provide each of 12 incentives we reviewed to stimulate renewable energy

Figure 6: Number of States Using Each of 12 Renewable Standards, Mandates, and Incentives



Source: Database of State Incentives for Renewable Energy maintained by the Interstate Renewable Energy Council.

Note: Net metering and interconnection refer to eligibility and pricing rules for connecting renewable energy sources to the power transmission grid and for crediting producers for excess generation. A public benefit fund is a general fund to support renewable energy resources, energy efficiency initiatives, and renewable energy projects for low-income residents, supported by a small surcharge on each consumer's electricity bill.

In addition to specific incentives and policies, some states have implemented statewide programs to stimulate the deployment of advanced renewable energy technologies. Three examples of states' efforts are described as follows (see app. IV for further details):

- Since 1980, Minnesota has provided mandates and production incentives to stimulate ethanol production. In particular, Minnesota (1) established an incentive in 1986 that paid ethanol producers 20 cents per gallon over 10 years and (2) mandated in 2003 that all gasoline sold in the state contain at least 10-percent ethanol. In 2004, Minnesota's governor proposed raising this mandate to 20 percent. As a result, the state is now home to one-third of the nation's E85 (85 percent ethanol and 15 percent gasoline) stations and has replaced nearly 10 percent of all its gasoline consumption with ethanol.

- In 2005, Texas enacted legislation that extended its 1999 RPS to require the installation of 5,000 megawatts of new renewable capacity—in addition to 880 megawatts of existing renewable capacity—by 2015. The Texas RPS represents 5 percent of the state's electricity demand. Electric power retailers that do not comply with RPS requirements are subject to penalties of up to $50 per megawatt-hour, or 5 cents per kilowatt-hour. Moreover, to ensure a wide variety of renewable projects, the Texas RPS requires that 500 megawatts of new capacity come from renewable sources other than wind. According to the Electric Reliability Council of Texas, Inc., as of September 2006, Texas had installed over 1,900 megawatts of new renewable energy, representing about 3 percent of its total electricity consumption.

- In 2006, California enacted a $2.2 billion solar initiative to support the governor's goal to install 3,000 megawatts of new solar energy by 2017. In particular, the initiative provides rebates for new photovoltaic and solar thermal systems, and pay-for-performance incentives that reward high-performing solar systems (greater than 100 kilowatts). The initiative also sets aside 10 percent of its funding to subsidize solar energy for low-income and affordable housing projects. According to a state official, California has already installed more than 150 megawatts of new solar energy capacity.

Some States Are Offering Incentives to Encourage the Deployment of New Fossil and Nuclear Energy Technologies

In addition to the investment tax credits and loan guarantees that the Energy Policy Act of 2005 authorizes for the deployment of fossil and nuclear technologies, some states have enacted financial incentives and requirements to further stimulate the deployment of advanced fossil and nuclear technologies that support state needs and goals. For example, Indiana enacted legislation in 2002 to provide financial incentives for clean coal projects using Illinois Basin coal or gas and extended these incentives in 2005 by establishing investment tax credits for state investments in IGCC power plants. Similarly, Pennsylvania's Energy Deployment for a Growing Economy program provides low-interest loans for IGCC plants in an effort to build advanced coal plants that use coals abundant to the state.

However, states provide far fewer incentives for fossil and nuclear technologies—both in variety and number—than for renewable energy technologies. As of 2006, only seven states had incentives for coal gasification and IGCC technologies, according to the National Conference of State Legislatures. We found no national database on states' nuclear incentives, although industry officials said that states or localities may offer a variety of economic incentives to attract large businesses, such as a nuclear power plant.

An industry association official noted that states may have an important influence over regulatory incentives for fossil plants, such as requiring new coal-fired plants to employ mercury removal technologies. For example, Idaho has stopped construction on all conventional pulverized coal-fired power plants until the state finishes researching the possibility of building new gasification plants that significantly reduce mercury emissions. Similarly, while industry officials say state and local incentives for new nuclear plants—the most common of which are property tax breaks—do not significantly impact the high costs of plants, states may have an indirect impact on encouraging or discouraging the construction of new nuclear plants. For example, seven states specifically discourage or prohibit the construction of new nuclear plants until methods of waste disposal are determined. In contrast, some states and localities may send more positive signs about nuclear energy by offering economic enticements. For instance, Calvert County, Maryland, recently offered a 50-percent, 15-year property tax credit to the Calvert Cliffs nuclear power plant's owner if another nuclear reactor is built.

The Countries We Reviewed Have Stimulated the Development and Deployment of Advanced Renewable, Fossil, and Nuclear Energy Technologies

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. For example, successful use of financial incentives and/or mandates has enabled Germany to generate 10.2 percent of its electricity from renewable sources and Denmark to generate 19 percent of its electricity from wind technologies, surpassing the United States in the percentage of electricity derived from renewable sources.

Brazil Has Displaced 40 Percent of Its Gasoline Consumption with Ethanol

In 1975, in response to oil price shocks, Brazil initiated a program to replace imported oil with ethanol produced from domestic sugarcane to power vehicles. To stimulate its ethanol industry, Brazil (1) required its major oil company, Petrobras, to purchase a guaranteed amount of ethanol; (2) provided $4.9 billion in low-interest loans to the agricultural and industrial sectors to stimulate ethanol production for transportation use; (3) provided subsidies so ethanol's price at the pump was 59 percent of the price of gasoline; and (4) required that all fuels be blended with a minimum of 22 percent ethanol (called E22 fuel). Brazil removed its price supports for ethanol in 2000, when it deregulated the ethanol market, but still requires that all fuels be blended with 20 to 25 percent ethanol, depending on market conditions. Moreover, to receive an operating license, all fueling stations must provide an ethanol or ethanol-blend pump. In 2003, the Brazilian government introduced flex-fuel cars—which can run on ethanol, gasoline, or a blend of the two, thus allowing consumers to choose which fuel to use based on the current oil and ethanol prices—further encouraging the consumption of ethanol.

As of 2005, Brazil was the world's ethanol leader, producing 4.2 billion gallons of ethanol per year, or 47 percent of the world's supply. Brazil no longer needs to import crude oil for transportation, saving an estimated $1.8 billion per year by displacing 40 percent of its gasoline consumption—200,000 barrels of oil per day—with ethanol, according to Brazilian experts. In comparison, the United States produced 3.9 billion gallons of ethanol in 2005, displacing about 3 percent of gasoline consumption. By 2011, Brazil's ethanol production is expected to increase to 27 billion gallons per year—a more than 600 percent increase—from efficiency improvements and land expansion. With the introduction of flex-fuel cars, consumer confidence in ethanol consumption has grown significantly, according to Brazilian embassy officials. As a result, more than 70 percent of cars sold in Brazil today run on ethanol or ethanol blends, and according to Brazil's former Secretary of Environment, ethanol is now fully competitive with international gas prices—sold for 60 to 70 percent of the price of gasoline at the pump.

Brazil has also significantly improved its environmental profile by replacing oil with ethanol in the transportation sector. From 1975 to 2000, for instance, the use of ethanol in cars saved 100 million tons of carbon emissions, according to Brazilian authorities. In addition, ethanol production has helped Brazil become more self-sufficient in electricity. In particular, by burning sugarcane waste, mills have been able to generate energy surpluses of around 600 megawatts per crop season, allowing them to be completely self-sufficient in electricity, and in some cases, to export electricity abroad.

Denmark's Wind Energy Generates 19 Percent of Its Electricity

Successive Danish governments have committed to a series of national energy plans aimed at reducing dependency on imported fuels, improving the environment, and moving toward greater sustainability. As a result, since 1980 there has been general consensus in Denmark that renewable technologies—and especially wind energy—require special support to gain an advantage in the market. Specifically, the Danish government has (1) conducted R&D in wind turbine technologies since the 1970's; (2) provided investment subsidies for 30 percent of the installation cost of wind turbines until 1990; and (3) required that electric power companies purchase wind energy from private producers at a fixed price until 1999, when the obligation moved to electricity consumers paying for all increased costs associated with wind power. In addition, the government exempts wind generators from a carbon dioxide tax,[35] gives wind power priority access to the electric power grid, and has established regulations for building wind turbines.

In 2005, renewable energy accounted for approximately 28 percent of the Danish electricity supply, including 19 percent from wind power—the highest percentage in the world. Since 1980, more than 6,000 wind turbines have been established in Denmark. From 2001 to 2003, a repowering program led to approximately 1,500 smaller wind turbines being replaced by approximately 300 new and larger wind turbines, which together have tripled the capacity. At the end of 2005, Denmark had 3,122 megawatts of installed wind power capacity—more than the 2,631 megawatts of the installed capacity in Texas, the nation's leader in wind power.

Denmark's long-term support of wind energy has fostered a thriving wind turbine industry, with global sales increasing over the last decade from about 200 megawatts of capacity per year to more than 3,000 megawatts per year. Danish wind turbine manufacturers accounted for about 40 percent of global sales in 2004, providing about 20,000 jobs domestically, or 4 percent of Danish industrial production. In particular, Denmark is a world leader in offshore wind power development. Denmark built the first offshore wind farm in 1991 and had eight operating offshore wind farms by the end of 2005. Two additional offshore wind farms are planned to supply electricity to 350,000 to 400,000 households, or about 4 percent of the total Danish electricity consumption.[36] As a result of its experience, Denmark has gained extensive technical knowledge in how to integrate wind power into the overall electricity system, how to combine wind power with other sources of energy to maintain the electrical system's stability, and how to

[35]Renewable technology plants are exempt from taxes placed on power plants that emit carbon dioxide.

[36]One of the new offshore developments, Horns Rev II, is expected to be operational by 2009.

develop offshore wind farms—including the logistics of transporting, installing, and maintaining wind turbines at sea.

Germany's Renewable Energy Technologies Generate 10 Percent of Its Electricity

In 2000, the German government enacted the Renewable Energy Sources Act to accelerate the growth of renewable energy technologies in the German electricity market. It amended the act in 2004 to increase country targets for renewable technologies and further develop the framework conditions for renewable technologies.[37] The Renewable Energy Sources Act requires electricity grid operators to purchase electricity generated from renewable energy technologies and establishes minimum rates for it. Germany's goal is to increase the share of renewable energy consumption to at least 4.2 percent of its total energy requirements by 2010, 10 percent by 2020, and at least 50 percent by 2050. The target for 2010 was exceeded in 2005, when renewable technologies accounted for 4.6 percent of consumption. The German government is also offering tax relief for biofuels and financial support for constructing plants that generate heat and/or electricity from renewable energy sources. In response, Germany has more than doubled its electricity consumption from renewable energy sources—from 4.8 percent in 1998 to 10.2 percent in 2005. In particular, Germany generated about 1 billion kilowatt-hours of solar electricity in 2005, tripling the generation of electricity from solar cells in 2 years. Germany has also become the world leader in wind energy with 18,428 megawatts of installed wind capacity that produced 26.5 terawatt-hours of electricity in 2005.

Under the Kyoto Protocol and as a member of the European Union, Germany has committed to a 21-percent reduction in the 1990 baseline year's greenhouse gas emissions from 2008 to 2012. The German government believes the Renewable Energy Sources Act is one of Germany's most effective and efficient instruments for climate protection, stating that using renewable energy technologies prevented the emission of approximately 84 million tons of carbon dioxide in 2005. The government also states that renewable energy technologies have created jobs in Germany—the renewables sector had 157,000 jobs in 2004, including 64,000 jobs in wind power, 57,000 jobs in biomass, and 25,000 in the solar industry. The government estimates that renewable energy jobs

[37]The German government also amended the Atomic Energy Act in 2002, which will systematically decommission the nation's existing nuclear power plants once the volume of electricity specified for each plant is generated—the last nuclear power plant in Germany is estimated to shut down about 2020.

increased to 170,000 in 2005, and German industry estimates that this number will grow to more than 255,000 by 2010.

Japan Has Installed over 931 Megawatts of Residential Solar Systems

In 1994, Japan launched a 10-year residential solar project as part of its efforts to deploy domestic energy technologies that would diversify its energy portfolio and reduce its dependence on energy imports.[38] The goal of the residential solar project was to reduce the cost of photovoltaics and promote installation of solar systems in residential communities. Initially, the Japanese government provided a subsidy covering 50 percent of the cost of installing a residential solar system. This percentage subsequently dropped to 33 percent and eventually became a fixed amount as the 10-year project matured. As a result of the project, over 253,000 homes installed solar systems that collectively generate over 931 megawatts of power. Even though the government subsidy decreased, the number of systems installed increased considerably year by year, as the installation price decreased. According to a solar manufacturer, the cost of installing a solar system dropped from about $16,000 per kilowatt in 1994 to about $6,000 per kilowatt when the project ended. Due to the successful transformation of the photovoltaic market, Japanese homeowners continue to buy and install solar systems without the government subsidy.

The 10-year residential solar project has also helped create a Japanese solar industry that has become a world leader in the photovoltaic market. According to the European Commission, Japanese manufacturers' share of the world photovoltaic market is now greater than 40 percent. The residential solar project also enables the Japanese government to fulfill its commitment to increase its share of renewables in its energy portfolio to about 3 percent by 2010 and reduce its greenhouse gas emissions under the Kyoto Protocol.

Spain Began Operating an IGCC Coal Gasification Plant in 1997

In the early 1990s, the European Union and the Spanish government collaborated to construct the world's largest coal-based IGCC plant in Puertollano, Spain, to improve the efficiency, cost, and environmental profile of coal-based power plants. The 320-megawatt IGCC plant, which began generating electricity from coal in 1998, is operated by a consortium of eight utilities from France, Germany, Italy, Portugal, Spain, and the United Kingdom as part of a European Union program to demonstrate

[38] About half of Japan's total energy demand is for oil, which is primarily imported from the Middle East.

energy technologies that promote clean coal and reduce the European Union's dependency on natural gas.

The European Union and the Spanish government supported the construction of the Puertollano plant by subsidizing about 8.5 percent of its nearly $900 million cost. European consortium members noted that, in comparison, DOE can fund up to 50 percent of the cost of commercial IGCC demonstration projects. In 2000, the Puertollano plant produced nearly 1 million megawatts of electricity using synthetic gas. The Puertollano plant is expected to operate at over 45 percent efficiency and eliminate 99.9 percent of sulfur dioxide emissions. DOE plans to achieve efficiencies and emissions levels comparable to the Puertollano plant by 2010—currently, U.S. IGCC plants are about 40-percent efficient and eliminate 98 percent of sulfur dioxide emissions.

France's Advanced Nuclear Reactor Is Scheduled to Begin Operations in 2012

In response to the oil price shocks in 1973, France decided to reduce its reliance on oil-fired power plants to generate electricity by launching a nuclear initiative designed to make nuclear power a primary source of electricity. France built 56 nuclear reactors during the 1970s and 1980s and, according to the International Energy Agency, spent about 90 percent of its energy R&D funding on nuclear energy from 1985 through 2001. The French government reported that its R&D efforts during this time focused on technological improvements and safety, as well as development of a fast reactor. Today, France has 58 nuclear reactors generating 75 to 80 percent of its electricity.

France does not license reactors for a specific amount of time, but conducts reviews every 10 years to grant continued operational authority. Reactors are expected to operate for about 40 years. Some interest groups in France have called for an end to nuclear energy, citing radioactive waste and safety issues and noting that Germany has decided to phase out of nuclear energy and close down its reactors. However, the French government has maintained its support for nuclear energy, deciding in a 2005 law to keep the nuclear option open for the future and planning to potentially replace its current reactors with a new generation of reactors designed to be more efficient, safer, and less susceptible to external threats. As part of this effort, France has developed the European Pressurized Reactor, which uses Generation III technology and will be capable of generating 1,600 megawatts of electricity, a significant increase over the capacity of existing reactors, which range from 900 megawatts to 1,450 megawatts. Two European Pressurized Reactors are under construction—one in Flammanville, France, scheduled to be operational in 2012 and a second in Finland scheduled to be operational in 2009.

France is one of 13 partners in the Generation IV International Forum that collaborates on R&D to develop next generation nuclear reactor technologies. France is conducting R&D on several nuclear reactors, including the sodium-cooled fast reactor that is a critical element of the U.S. GNEP program. In addition, France has provided U.S. researchers with access to the French Phenix fast reactor to study how highly radioactive nuclear fuel might be converted to less radiotoxic material.

Conclusions

It is unlikely that DOE's current level of R&D funding or the nation's current energy policies will be sufficient to deploy alternative energy sources in the next 25 years that will reverse our growing dependence on imported oil or the adverse environmental effects of using conventional fossil energy. The United States has generally relied on market forces to determine the nation's energy portfolio, primarily conventional supplies of oil, natural gas, coal, and nuclear energy. In contrast, advanced energy technologies have higher up-front capital costs that make them less cost competitive than conventional technologies. As a result, despite periodic energy price spikes caused by disruptive world events and about $50 billion (in real terms) in energy R&D funding since 1978, the United States has made only steady incremental progress in developing and deploying advanced renewable, coal, and nuclear technologies that can compete with conventional energy technologies. However, continued reliance on conventional technologies leaves the United States vulnerable to crude oil supply disruptions, with economic, energy security, and national security consequences.

The nation is once again assessing how best to stimulate the deployment of advanced energy technologies in response to recent high energy prices—caused by the growing world demand for energy, wars in the Middle East, and last year's hurricanes—and concerns about the adverse environmental effects, particularly greenhouse gas emissions, of using conventional fossil energy. Reducing the nation's dependence on oil and carbon dioxide emissions in the next 25 years is not unlike the 1960s challenge to put a man on the moon. 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 the adverse environmental effects of burning fossil fuels.

The nation's current energy portfolio has raised concerns about the adverse environmental effects of energy generation—particularly greenhouse gas emissions from coal-fired and oil-fired power plants and the long-term storage of spent nuclear fuel. In addition, the duration of certain federal tax incentives has been insufficient to stimulate investment decisions to deploy advanced energy technologies. For example, renewable energy industry representatives have stated that the 2-year extension of the production tax credit in the Energy Policy Act of 2005 does not provide sufficient certainty to stimulate investment. In providing a production tax credit to stimulate the construction of projects using advanced technologies, the credit's duration is key to encouraging companies and their lenders to undertake the substantial investments and build an industry over time.

Several states have taken the lead in encouraging the deployment of advanced energy technologies, particularly in renewable energy. For example, in the past 7 years, Texas tripled its renewable energy use as a result of its renewable portfolio standard. Similarly, Minnesota's ethanol program has displaced 10 percent of gasoline consumption with ethanol. Many other states have initiatives to stimulate renewable energy generation as well. States' initiatives that diversify our energy portfolio and reduce harmful emissions are positive steps. Similarly, foreign countries, including Brazil, Denmark, and Germany, have sustained long-term efforts using 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. Approaches taken by these countries may provide useful insights and opportunities for fostering the deployment of advanced energy technologies.

Recommendation to the Congress

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, the Congress should consider further stimulating the development and deployment of a diversified energy portfolio by focusing R&D funding on advanced energy technologies.

Agency Comments

We provided DOE with a draft of this report for its review and comment. In its written response, DOE did not comment on our recommendation to the Congress. (See app. V.) DOE provided technical comments, which we have incorporated as appropriate.

As arranged with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the report date. At that time, we will send copies to interested congressional committees, the Secretary of Energy, the Director of the Office of Management and Budget, and other interested parties. We will also make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staffs have any questions about this report, 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. GAO staff who made major contributions to this report are listed in appendix VI.

Jim Wells

Jim Wells
Director, Natural Resources
and Environment

Appendix I: Estimated Federal Tax Expenditures Targeted at Energy Suppliers and Users, Fiscal Year 2006

Dollars in millions

	Federal tax expenditures targeted at energy suppliers and users[a]	Budget function	First year[b]	Estimated FY 2006 revenue loss
1	Capital gains treatment of royalties on coal	Energy	1974	$90
2	Excess of percentage over cost depletion, fuels	Energy	1974	670
3	Expensing of exploration and development costs, fuels	Energy	1974	680
4	New technology credits (addresses energy production from several technologies, including wind and solar energy)	Energy	1978	510
5	Alcohol fuel credits[c]	Energy	1980	40
6	Alternative fuel production credit	Energy	1980	2,390
7	Exclusion of interest on energy facility bonds	Energy	1980	90
8	Exception from passive loss limitation for working interests in oil and gas properties	Energy	1988	40
9	Tax credit and deduction for clean-fuel burning vehicles	Energy	1992	90
10	Enhanced oil recovery credit	Energy	1994	0
11	Credit for holding clean renewable energy bonds	Energy	2005	0
12	Deferral of gain from dispositions of transmission property to implement the Federal Energy Regulatory Commission's restructuring policy[d]	Energy	2005	620
13	Credit for production from advanced nuclear power facilities	Energy	2005	0
14	Credit for investment in clean coal facilities	Energy	2005	50
15	Temporary 50 percent expensing for equipment used in the refining of liquid fuels	Energy	2005	10
16	Pass through low sulfur diesel expensing to cooperative owners	Energy	2005	0
17	Natural gas distribution pipelines treated as 15-year property	Energy	2005	20
18	Amortize all geological and geophysical expenditures over 2 years	Energy	2005	40
19	30 percent credit for residential purchases/installations of solar and fuel cells	Energy	2005	10
20	Credit for business installation of qualified fuel cells and stationary microturbine power plants	Energy	2005	80
21	Alternative Fuel and Fuel Mixture tax credit	Energy	2005	170
22	Bio-Diesel and small agri-biodiesel producer tax credits	Agriculture	2004	90
23	Expensing of small refiner capital costs with respect to complying with EPA sulfur regulations	Natural resources and environment	2004	10
	Total estimated tax expenditures[e]			**$5,700**

Source: GAO analysis of tax expenditures reported by the Department of the Treasury.

Note: For descriptions of tax expenditures, see Office of Management and Budget. Analytical Perspectives, Budget of the United States Government, Fiscal Year 2007, (Washington, D.C.: 2005).

[a]This list does not include five tax expenditures whose primary focus is energy conservation—exclusion of utility conservation subsidies, deduction for certain energy efficient commercial building property as well as tax credits for construction of new energy efficient homes, energy efficiency improvements to existing homes, and energy efficient appliances—with revenue loss estimates summing to $510 million for fiscal year 2006. This list also does not include tax incentives for general research and development available for all businesses. Also, the Department of Treasury does not report tax expenditures with revenue losses below $5 million.

[b]First year the Department of the Treasury reported expenditures.

[c]The alcohol fuel credit includes, among other things, the volumetric tax credit for ethanol, which was enacted in 2004. Treasury estimates a $2.1 billion reduction in excise tax receipts in fiscal year 2006 as a result of income tax revenue losses and reduced excise tax receipts.

[d]This tax expenditure was listed under the community and regional development budget function in 2004.

[e]Summing tax expenditure estimates does not take into account interactions between individual provisions.

Appendix II: Scope and Methodology

To review the Department of Energy's (DOE) research and development (R&D) funding trends, we analyzed DOE budget authority data for renewable, fossil, and nuclear energy R&D from fiscal year 1978 through fiscal year 2006. The data consist of DOE's annual appropriations, adjusted for any advanced appropriations and rescissions. To assess the reliability of these data, we interviewed DOE program managers and budget officials with oversight of each of the technologies. We asked DOE officials a series of data reliability questions, including questions covering data classification, particularly over time; program changes that could impact data classification or budget accounts; custody and maintenance of the data, including updates; quality control procedures; and accuracy and completeness of the data. Where appropriate, we adjusted the data to ensure consistency in reporting over time. We obtained historical documents, program plans, and assessments from other entities to corroborate the data. We determined that the data were sufficiently reliable for the purposes of this report. In addition to DOE's R&D funding, we reviewed revenue losses from energy-related tax expenditures for fiscal years 2000 through 2006 by reviewing tax expenditure revenue loss estimates prepared by the Department of the Treasury and published in the President's annual budget. While the aggregate value for energy-related tax expenditures is useful for gauging their general magnitude, summing does not take into account interactions between individual provisions. We excluded annual tax expenditures below $5 million because Treasury does not report them. To review DOE's strategy for developing advanced energy technologies, we reviewed DOE documents, including strategic plans, program plans, and studies on each of the technologies. We also collected and analyzed documents from industry and industry associations. In addition, we interviewed senior DOE managers, program managers and scientists at DOE laboratories, senior power company and industry association executives, and independent experts.

To assess the key technological, economic, and other barriers to developing and deploying new energy technologies, we analyzed various documents from DOE, including program plans, energy studies and assessments, and key budget documents, including supporting documentation justifying budget requests. We also analyzed documents from other federal agencies; utilities; industry associations; state utility commissions and associations; and independent experts, including studies from the Electric Power Research Institute, the Massachusetts Institute of Technology, and the University of Chicago. We interviewed DOE and NRC officials; program managers and scientists at DOE laboratories; executives of utilities, manufacturers, and industry associations; public utility commissions from various states; and selected state governments and government associations.

To examine the efforts of states to develop and deploy advanced energy technologies, we analyzed reports and assessments from DOE, various state governments and associations, industry and industry associations, and independent experts. We also used the Database of State Incentives for Renewable Energy, maintained by the Interstate Renewable Energy Council, to analyze state initiatives and select three states with successful initiatives—Texas' renewable portfolio standards, Minnesota's ethanol program, and California's solar programs. To assess the reliability of this database, we reviewed relevant documentation and obtained responses from the database administrator to a series of data reliability questions covering issues such as data entry, access, quality control procedures, and the accuracy and completeness of the data. We determined that the data were sufficiently reliable for the purposes of this report. In addition to the database, we collected documents and interviewed officials from DOE; industry and industry associations; and various state organizations, including the National Conference of State Legislatures and the Western Governor's Association; and selected public utility commissions.

To develop a nonprobability sample of countries that have developed and deployed advanced renewable, fossil, and nuclear technologies, we (1) reviewed the Energy Information Administration's (EIA) international data to identify significant changes in consumption patterns among renewable, fossil, and nuclear energy technologies; (2) examined other related information; and (3) interviewed cognizant DOE officials and independent industry experts.[1] We selected Brazil, Denmark, France, Germany, Japan, and Spain because they have initiated major efforts to deploy advanced energy technologies that could change their energy portfolios. To obtain information on each country's initiatives, we analyzed documents from EIA, the International Energy Agency, each of the countries, and independent experts. We also interviewed DOE officials; officials from each country, either at their U.S. embassy or by telephone or e-mail; and independent experts.

[1]Results from a nonprobability sample cannot be used to make inferences about a population because in a nonprobability sample some elements of the population being studied have no chance or an unknown chance of being selected as part of the sample.

We conducted our work from October 2005 through October 2006 in accordance with generally accepted government auditing standards.

Appendix III: The States' Use of Renewable Energy Incentives, Standards, and Mandates

State	Tax credits[a]	Rebates[b]	Public benefit funds[c]	Renewable portfolio standards[d]	Net metering & inter connection rules[e]
Alabama	•				
Alaska					
Arizona	•			•	
Arkansas					•
California	•	•	•	•	•
Colorado				•	•
Connecticut		•	•	•	•
Delaware		•	•	•	•
Florida					•
Georgia					•
Hawaii	•			•	•
Idaho	•				
Illinois		•	•	•	
Indiana					•
Iowa	•			•	•
Kansas					•
Kentucky					•
Louisiana					•
Maine		•	•	•	•
Maryland	•	•		•	•
Massachusetts	•	•	•	•	•
Michigan					•
Minnesota		•	•	•	•
Mississippi					
Missouri	•				•
Montana	•		•	•	•
Nebraska					
Nevada		•		•	•
New Hampshire					•
New Jersey		•	•	•	•
New Mexico	•			•	•
New York	•	•	•	•	•
North Carolina	•				•
North Dakota	•				•
Ohio	•		•		•

State	Tax credits[a]	Rebates[b]	Public benefit funds[c]	Renewable portfolio standards[d]	Net metering & inter connection rules[e]
Oklahoma	•				•
Oregon	•	•	•		•
Pennsylvania			•	•	•
Rhode Island	•	•	•	•	•
South Carolina		•			
South Dakota					
Tennessee					
Texas	•			•	•
Utah	•				•
Vermont		•		•	•
Virginia					•
Washington					•
West Virginia	•				
Wisconsin		•	•	•	•
Wyoming		•			•
Total	**21**	**17**	**15**	**22**	**39**

Source: GAO analysis of the Database of State Incentives for Renewable Energy, maintained by the Interstate Renewable Energy Council.

[a]Provided to corporations or individuals that purchase or install renewable energy equipment. For example, New Mexico offers a 30-percent personal income tax credit (up to $9,000) for residents who install photovoltaic or solar thermal systems. Tax credits are one of the most frequently used state-level financial incentives.

[b]Typically provided in the form of cash rebates to residents and businesses for the purchase and installation of renewable energy equipment. For example, New York provides $4 to $4.50 per watt to eligible installers for the installation of approved, grid-connected photovoltaic systems.

[c]A surcharge on each consumer's electricity bill that goes into a general fund to support renewable energy resources, energy efficiency initiatives, and renewable energy projects for low-income residents. For example, Connecticut residents are charged up to 0.1 cents per kilowatt-hour on their utility bills, which provides funding for Connecticut's Energy Efficiency Fund for energy efficiency and Clean Energy Fund for renewable energy.

[d]Require that a fixed percentage of the state's electricity be generated from renewable sources. For example, Texas enacted legislation in 2005 requiring the installation of 5,000 megawatts of new renewable capacity by 2015. According to the National Conference of State Legislatures, renewable portfolio standards have been particularly successful in encouraging wind power development.

[e]Eligibility and pricing rules for connecting renewable energy sources to the power transmission grid and crediting producers for excess generation. For example, the value of energy generated in excess of what is used is subtracted from the monthly utility bill of residents in Arizona with solar-electric systems.

Appendix IV: Three States' Initiatives to Stimulate the Use of Renewable Energy Technologies

Minnesota, Texas, and California have implemented programs to stimulate the use of renewable energy technologies. In response to various incentives and mandates, Minnesota now has one-third of the nation's ethanol fueling stations and had displaced nearly 10 percent of its gasoline consumption with ethanol by June 2006. Since Texas enacted renewable portfolio standards (RPS) in 1999, its electric power companies have installed over 1,900 megawatts of new renewable energy capacity—approximately 3 percent of the state's total electricity generation. Since California began its Solar Initiative in January 2006, over 150 megawatts of new solar capacity have been installed.

Minnesota's Ethanol Program

Minnesota's Ethanol Program began in 1980 as an effort to expand the state's farm economy by building a new market for corn, its largest crop; meet EPA standards for air quality in the Twin Cities area by reducing carbon monoxide emissions from cars; and reduce dependence on imported oil. To reach these goals, Minnesota established financial incentives and mandates to encourage the development of a state ethanol industry over a 17-year period. As of June 2006, ethanol had displaced nearly 10 percent of Minnesota's gasoline consumption.

The Minnesota Ethanol Program encouraged growth in the state's ethanol industry, primarily through the use of producer incentives and mandated ethanol blends. In particular, state legislation passed in 1980 provided a tax credit for gasoline that was blended with 10-percent ethanol, and in 1986, the state set up a producer payment incentive that paid ethanol producers 20 cents per gallon for a 10-year period. Legislation enacted in 1992 required that all gasoline offered for sale in the state be blended with 7.7 percent ethanol beginning in 1997. This provision was amended in 2003 to require blends to contain at least 10 percent ethanol. In 1995, Minnesota also established a statutory goal to develop over 200 million gallons of ethanol production. The tax credits were eliminated in 1997, and the producer incentive payments were phased out beginning in the late 1990s.[1] In 2004, Minnesota enacted legislation doubling the requirement to 20 percent by 2013.

[1] Some payments are still being made to producers that qualified for the program prior to 1999. However, these payments are now less than 20 percent and are being continuously phased out.

Currently, nearly all gasoline in Minnesota is blended with 10-percent ethanol, representing over $100 million in annual savings on oil imports. Ethanol production has expanded from 1.5 million gallons in 1987 to a current capacity of over 500 million gallons. Corn prices have also doubled to 30 cents a bushel, and the Twin Cities area is in compliance with EPA air quality standards, according to Minnesota officials. Minnesota is the nation's leader in the use of renewable fuels, with the highest renewable fuel use per capita in the nation. It is home to 32 percent of the nation's E85 stations.

Texas' Renewable Portfolio Standards

To reduce a growing dependency on imported fossil fuels, make better use of the region's natural renewable resources, and improve air quality profiles, Texas enacted legislation in 2005 that extended its 1999 RPS to require the installation of 5,000 megawatts of new renewable capacity, or about 5 percent of the state's electricity demand, by 2015. Texas has already tripled its use of renewable energy in the 7 years since its RPS was initially enacted.

Texas uses more total energy—including electricity, petroleum, natural gas, and coal—than any other state. In the early 1990s, Texas' use of renewable energy was less than 1 percent, the lowest in the United States. In 1992, Texas became a net importer of energy. Moreover, if Texas was a country, it would have ranked 7th in the world for greenhouse gas emissions in the early 1990s, according to climate change experts at the Pew Center on Global Climate Change. Despite these conditions, however, Texas also ranks first in abundance of U.S. solar and biomass resources, and second for wind resources. To encourage the use of the state's abundant renewable resources and improve its environmental profile, Texas' 1999 legislation established an RPS mandating that state utilities derive 2,000 megawatts of new generating capacity from renewable sources by 2009. When Texas had nearly reached this capacity by 2005, new legislation increased the mandate to 5,000 new megawatts by 2015. Electric power retailers that do not comply with RPS requirements are subject to penalties of up to $50 per megawatt-hour, or 5 cents per kilowatt-hour, as tracked by a renewable energy credit system. To encourage a wide variety of renewable developments, the Texas RPS also requires that 500 megawatts of total mandated new capacity come from renewable sources other than wind, because wind power is the most competitive renewable energy technology in Texas—98 percent of new installed capacity in Texas prior to 1999 was wind power. In addition, Texas' RPS set a nonbinding target of 10,000 megawatts of installed renewable capacity by January 1, 2025.

According to the Electric Reliability Council of Texas, Inc., as of September 2006, Texas had tripled its renewable energy capacity, installing over 1,900 megawatts of new capacity, representing about 3 percent of its total electricity consumption. During 2001 alone, Texas installed 912 megawatts of wind power—more than the entire country had installed in any previous year—and created 2,500 wind-power related jobs. Texas' 2025 goal would result in an estimated $5 billion in consumer electric bill savings and the creation of nearly 20,000 jobs, according to the Union of Concerned Scientists.

California's Solar Programs

Since 1998, California has supported the installation of solar systems—including photovoltaic systems and solar thermal systems—by establishing production incentives and rebates for solar energy generators and consumers. These programs are designed to reduce electricity demand and improve the reliability of the state's electricity system. In January 2006, California enacted a $2.2 billion Solar Initiative to install 3,000 megawatts of new solar energy by 2017, supporting the governor's 2006 "Million Solar Roofs Plan" to power 50 percent of all California homes—or 1 million roofs—with solar energy by 2019. As of January 2006, California had installed over 150 megawatts of new solar systems on over 20,000 homes, businesses, schools, and government buildings, according to California state officials and a California environmental group.

California established the Emerging Renewables Program in 1998. Implemented by the California Energy Commission, the program has encouraged the use of naturally abundant solar resources by allocating $118 million in rebates from 2002 through 2006 for the installation of new, primarily residential, renewable energy generating systems. In particular, for systems less than 30 kilowatts, the program offered $2.60 per watt for the installation of solar-cell systems and $3.00 per watt for the installation of solar-thermal systems. The Emerging Renewables Program also allocated $10 million toward a performance-based incentive option for photovoltaic installations, giving electricity generators $0.50 per kilowatt-hour over a 3-year period. In 2001, the California Public Utilities Commission initiated the Self-Generation Incentive Program, which offers rebates through 2007 for nonresidential distributed renewable generation for 30 kilowatt or larger systems. Since its inception, the rebate program has spent about $50 million per year, achieving 50 megawatts of installed solar capacity, with another 62 additional megawatts in progress. In 2006, the Public Utilities Commission introduced the California Solar Initiative, which will provide $2.9 billion in solar energy incentives over 11 years and support the governor's Million Solar Roofs Plan to install 3,000 megawatts of new solar energy capacity by 2017. By integrating California's existing Emerging Renewables Program and rebate solar programs, the initiative will continue to encourage new solar installations through rebate incentives for new photovoltaic and solar thermal systems, and pay-for-performance incentives that reward high-performing solar systems (greater than 100 kilowatts). To help sustain the solar industry, rebates for new solar systems will begin at $2.50 per watt, but will decline by about 10 percent annually over the next 10 years. In addition, the initiative sets aside 10 percent of program funding for low-income and affordable housing projects.

Appendix V: Comments from the Department of Energy

Department of Energy
Washington, DC 20585

December 11, 2006

Mr. Jim Wells
Director, Natural Resources and Environment
Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Wells:

Thank you for the opportunity to comment on the draft report GAO-07-106, *Department of Energy: Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs*. The Department of Energy's official technical corrections and comments are enclosed for your consideration. If you have any questions, please contact Mr. Thomas Shoemaker at: 202-586-7022.

Sincerely,

Rita L. Wells

Rita L.Wells
Deputy Assistant Secretary
Business Administration

Enclosure

Printed with soy ink on recycled paper

Appendix VI: GAO Contact and Staff Acknowledgments

GAO Contact

Jim Wells (202) 512-3841 or wellsj@gao.gov

Staff Acknowledgments

In addition to the individual named above, Richard Cheston, Assistant Director; Robert Sanchez, Kerry Lipsitz, Christina Connelly, Chuck Bausell, MaryLynn Sergent, Anne Stevens, and Alison O'Neill made key contributions to this report. Also contributing to this report were Doreen Feldman, Barbara Timmerman, and Jenny Chanley.

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