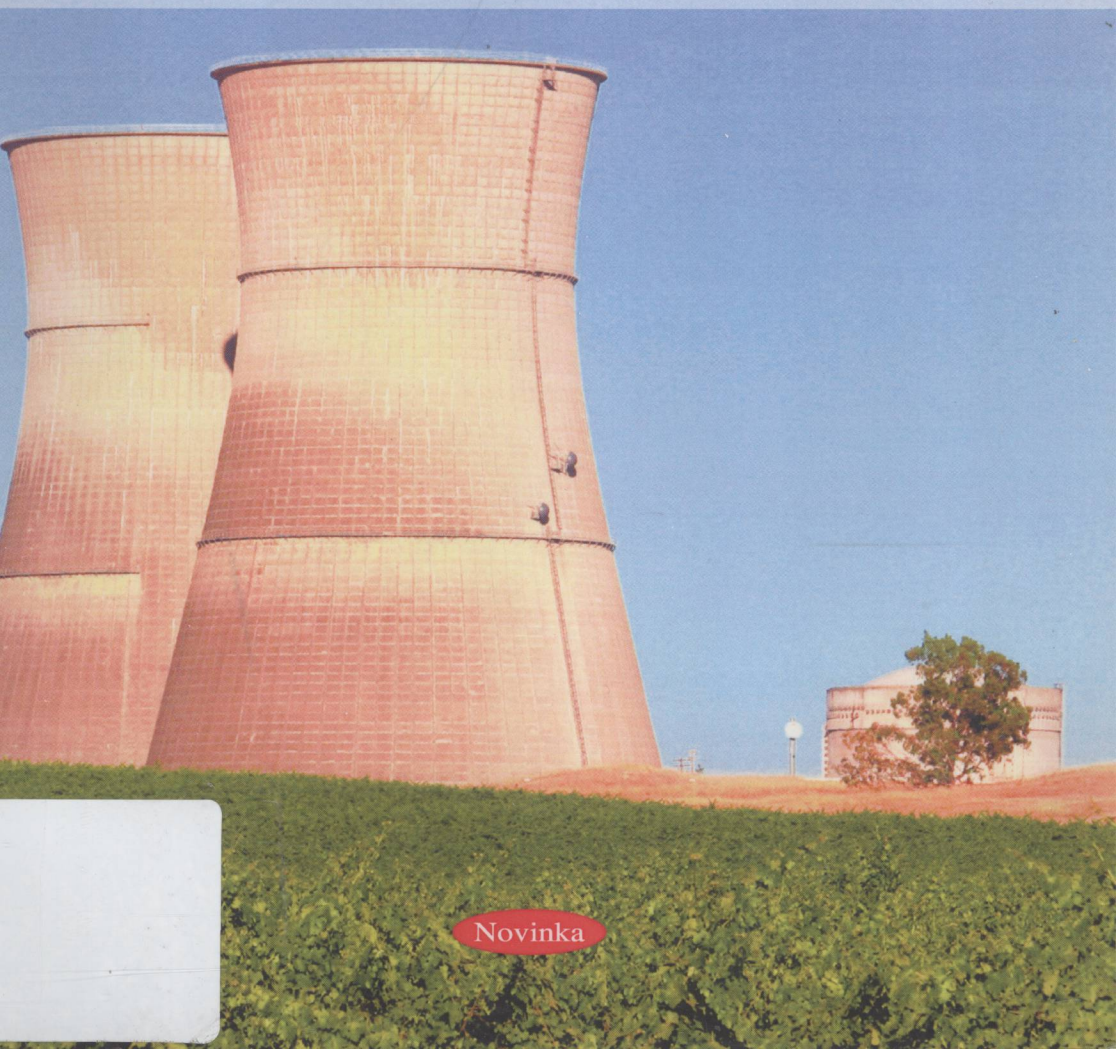
Deployment of Advanced Energy Technologies

Zachary T. Williamson
Editor



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PREFACE

For decades, the nation has benefited from relatively inexpensive energy, in the process growing heavily reliant on conventional fossil fuels—oil, natural gas, and coal. However, in the current wake of higher energy costs and environmental concerns about fossil fuel emissions, renewed attention is turning to the development of advanced energy technologies as alternatives. In the United States, the Department of Energy (DOE) has long conducted research, development, and demonstration (R&D) on advanced renewable, fossil, and nuclear energy technologies. DOE's Office of Science has also funded basic energy-related research.This book presents important information of developments in this essential field.

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Chapter 1

DEPARTMENT OF ENERGY: KEY CHALLENGES REMAIN FOR DEVELOPING AND DEPLOYING ADVANCED ENERGY TECHNOLOGIES TO MEET FUTURE NEEDS*

GAO

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 and D	research and development

December 20, 2006

* Excerpted from GAO Report GAO-07-106, dated December 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. 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 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 and 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 and D in renewable, fossil, and nuclear energy technologies.[2] Specifically:

- DOE's renewable energy R and 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 and D for geothermal and

hydropower energy technologies and, in 2003, accelerated the R and D funding for developing hydrogen technologies.

- DOE's fossil energy R and 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 and 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] 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 and 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 and 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 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 and 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 and 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 and 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 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 and 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 and 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 and 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 and D focus has narrowed. For example, DOE's renewable R and 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 and 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 and D program focused on making incremental improvements in nuclear power plant safety and efficiency. Since 1998, DOE's nuclear R and 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 and D priorities and budget constraints, DOE's fiscal year 2007 budget proposed eliminating R and 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 and 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 and 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 and D funding on advanced energy technologies.

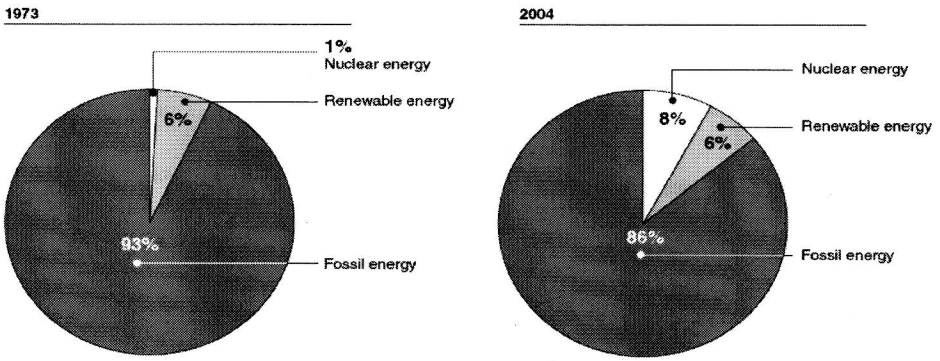
For the past several decades, the United States has enjoyed relatively inexpensive and plentiful energy supplies, relying on market forces to determine the energy mix that provides the most reliable and least expensive sources of energy—primarily oil, natural gas, and coal. In 1973, oil cost about $15 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.

BACKGROUND



Source: GAO analysis of EIA data.

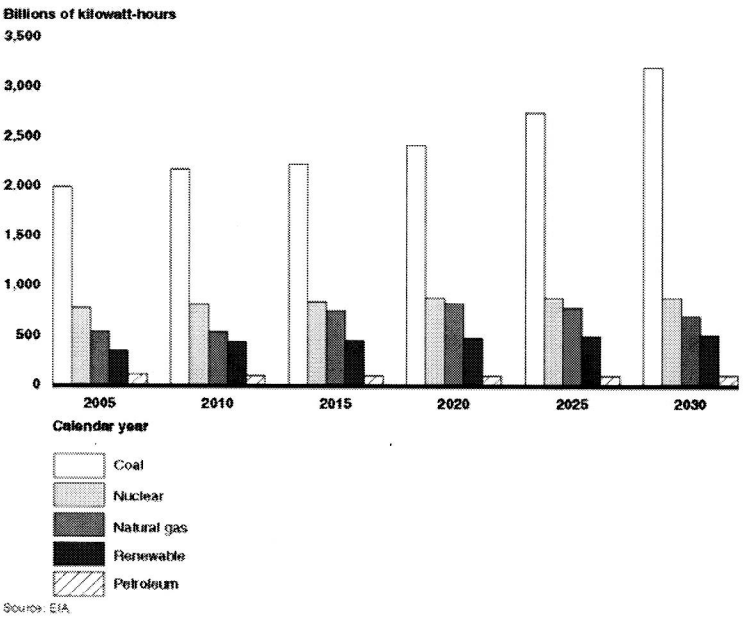
Figure 1. Comparison of the U.S. Energy Portfolio in 1973 and 2004.

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).

In addition to funding energy R and 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.



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.

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

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 and D funding for the capture and long-term storage—or sequestration—of carbon dioxide.