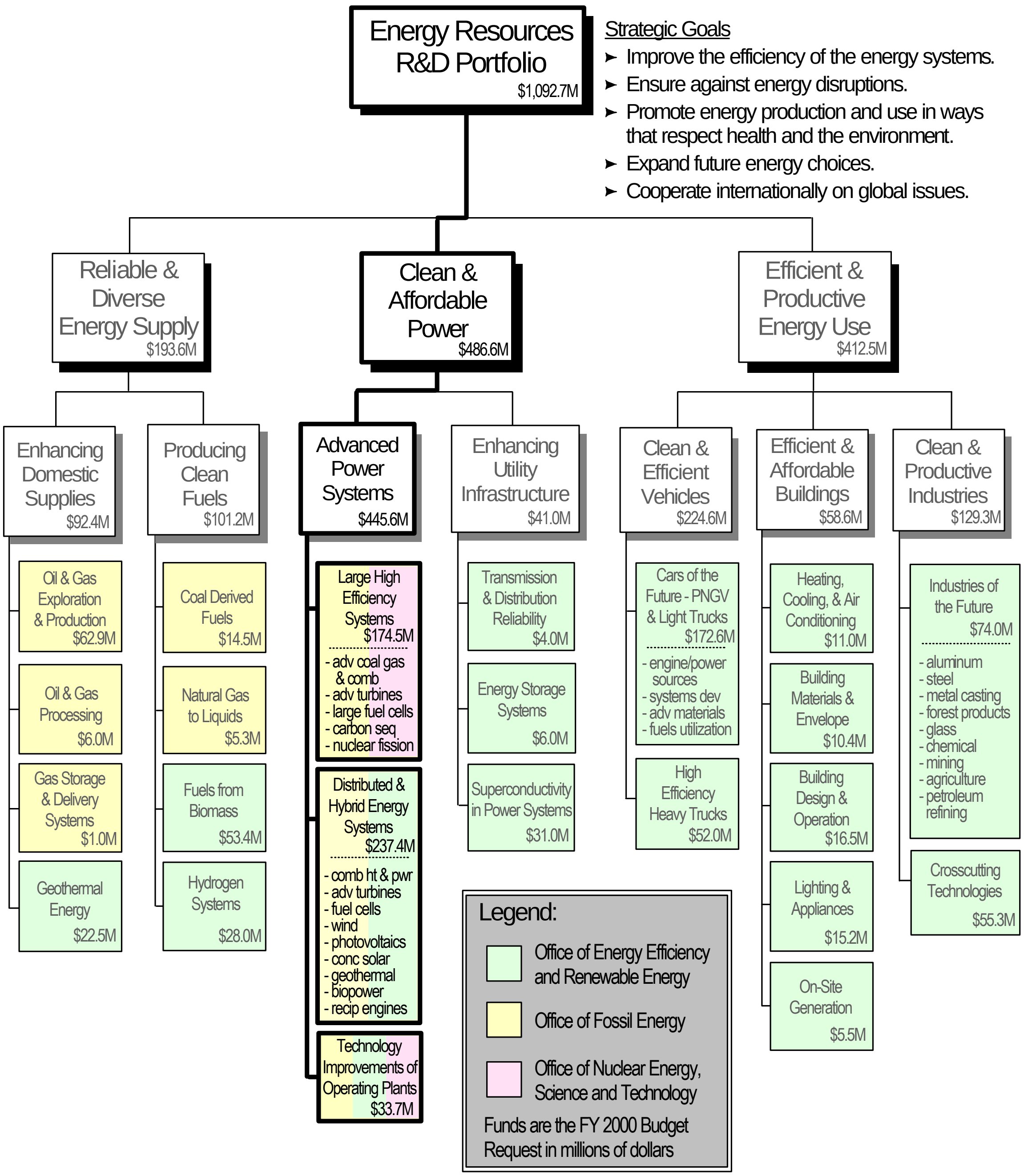
Chapter 5
Advanced Power Systems



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Overview

Definition of Focus Area

The Department's advanced power systems research and development portfolio is comprised of a broad range of power generation technology options that utilize fossil fuels, renewable energy resources, and nuclear power in both large, high efficiency energy systems and in distributed and hybrid energy systems to deliver affordable, reliable, and clean electric power. The work is principally applied R&D which is cost-shared with industry, supported by basic and enabling research activities, managed by Federal personnel, and performed primarily by industry, National Laboratories, and universities. Longer-term R&D includes a modest investment in carbon sequestration and a more significant investment in the Science and Technology program in nuclear fusion.

National Context and Drivers

The electric power sector is the largest direct consumer of energy in the United States. It used 36 percent of all primary energy consumed in the country in 1996, while providing power worth approximately $200 billion annually to fuel myriad essential functions in our homes, businesses, and industries. Most energy projections show the United States requiring an increase of 100,000 to 200,000 megawatts of additional power generation capacity between now and the year 2010.

About 68 percent of the electrical power generated in the United States is fueled by coal, natural gas, and oil; the balance is provided by nuclear (20 percent), hydroelectric, and renewable technologies. Due to the reliance on fossil fuels, power generation currently contributes substantially to the pollutants and greenhouse gas emissions in the United States, at a time when world concern continues to grow regarding global climate change. Meeting the projected significant increase in demand for electric power without compromising the Nation's environmental standards is therefore essential to sustaining the Nation's economic growth while at the same time protecting human health and the environment.

Nearly 95 percent of the electricity consumed annually in the United States is generated by large (greater than 30 megawatt) power plants. Because of the significant capital investment in large plants, the existing residential, commercial, and industrial infrastructure connected to the plants, and the Nation's dependence on the large amounts of electricity they produce, large plants will continue to produce the majority of the Nation's electric power for the foreseeable future.

Under current market and regulatory trends, coal and, increasingly, natural gas, will continue to be the primary fuels for large systems, well into the 21st century. No significant new additions of nuclear, hydroelectric, or oil capacity are expected, and existing nuclear plants in the United States are expected to be retired over the next 50 years.

However, many power generators, either in response to public pressure or State and Federal regulatory trends, are seeking to diversify their fuel choices and add renewable energy resources to their fuel mix. Environmental concerns, ample supplies of cheap natural gas (the cleanest fossil fuel), current and potential constraints of large system power transmission and distribution, and technological advances are causing distributed and hybrid systems and technologies such as combined heat and power systems, gas turbines, photovoltaics, wind turbines, and solar, geothermal, and biomass systems gradually to augment and sometimes to replace conventional, large-scale generating technologies.

Linkage to CNES Goals and Objectives

There are three strategic ends for advanced power R&D:

1. Ensure the availability of large-scale, advanced technologies to: (1) reduce both fuel use and the volume of pollutants and greenhouse gases emitted per unit of useful electric power produced; and (2) maintain an adequate, reliable and affordable supply. This end supports:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(improve the efficiency of the energy system)*
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.
- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.

2. Ensure the availability of a portfolio of advanced power technologies utilizing renewable and hybrid energy systems that will increase the flexibility, capacity and reliability of the U.S. power system. This end supports :

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.
- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.
- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe , and efficient energy systems.

3. Protect the Nation's investment in existing baseload power plants through the development of improved information management systems, sensors and controls, aging management, and regulatory compliance programs. This end supports:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(improve the efficiency of the energy system)*

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe , and efficient energy systems.

Uncertainties

Renewable energy sources, nuclear power, and fossil fuel with sequestering (direct or indirect) are insurance against the possible occurrence of climate change. Government investment at this time is prudent as the country and the world face major environmental and energy security challenges and domestically the electrical power sector is dealing with the issues of restructuring.

The following major planning assumptions are implicit in the attainment of our strategic goals.

- Robust U.S. Economy Depends on Low Cost Energy.
  The continued strength of the U.S. economy depends on the availability of low-cost energy. It is virtually assured that there will be continued growth in demand for electricity and transportation fuels. Fossil fuels will meet much of the demand.

  Americans want secure energy supplies, and the associated economic benefits, achieved in an environmentally responsible manner. The public supports ongoing efforts to reduce the environmental impacts of fossil energy production, transportation, and use. The combined benefits of a secure energy supply and environmental stewardship can be achieved by the use of advanced, more efficient power generation and conversion systems.

  Changes in electricity prices have significant effects on the economy. For example, an increase in the cost of electricity of 4 to 5 cents per kilowatt-hour (more than a 50 percent increase in the national average delivered price) leads to the same inflationary impacts as a 30-cent-per-gallon rise in gasoline price (about a 25 percent increase in delivered price.) Therefore, low cost electricity is essential to economic growth.

- Electric Utility Deregulation Leads to Competition.
  Deregulation of the electric utility industry and the resultant increase in competition will lead to lower electric bills for large consumers. This is evidenced by the Comprehensive Electricity Competition Plan (CECP), a proposal published by the Administration that is expected to result in lowered prices for electricity and a cleaner environment. Cost savings of $10 billion per year and greenhouse gas emissions reductions of 25 to 40 million metric tons are anticipated.

These lower costs could increase demand. In the near term, most new capacity will be characterized by the lower-capital-cost technologies that use natural gas. In the longer term, this demand will be satisfied by using clean and efficient technologies being developed by the Department and others.

- Public Wants Environmental Issues Addressed.
  Significant environmental issues have been, are being, and will be addressed. Sulfur dioxide (SO_2) emissions have been capped. It is expected that permissible nitrogen oxide (NO_x) emissions will be lowered. Allowable levels of particulate and hazardous air pollutants (HAPs) emissions will be further reduced because of health considerations. Limitations on land use will increase pressure to reduce the quality of waste generated.

- International Community Urges the United States to Reduce Greenhouse Gas Emissions.
  The effort to reduce greenhouse gas emissions, principally carbon dioxide (CO_2), will continue to increase. A major driver for the Office of Fossil Energy's research program is a reduction of CO_2 emissions with the vision of zero emissions in order that fossil fuels can be used in a greenhouse gas constrained economy. Nuclear power can provide electrical power on a large scale without harmful air pollutants. The Office of Nuclear Energy, Science and Technology is charged with maintaining the viability of this important technology.

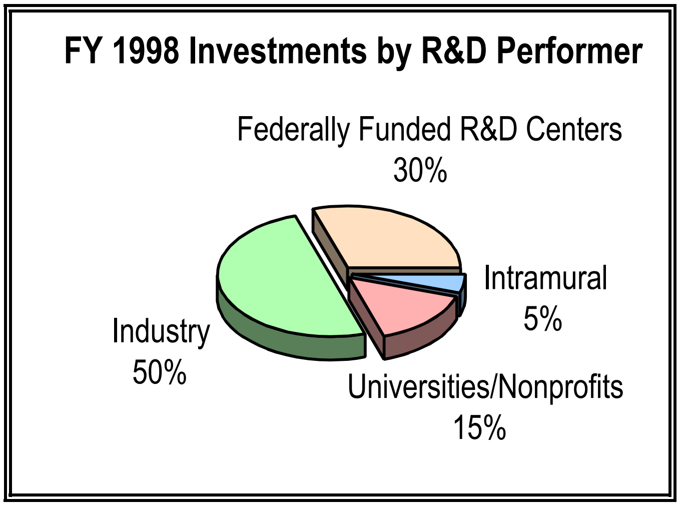
- Imported Oil Remains a National Security Issue.
  National security concerns will be exacerbated by the ever-increasing reliance on potentially unstable, non-domestic sources of oil. The technology to produce alternate transportation fuels (e.g., coal-based) at competitive prices can reduce this concern and ensure national security.

Investment Trends and Rationale

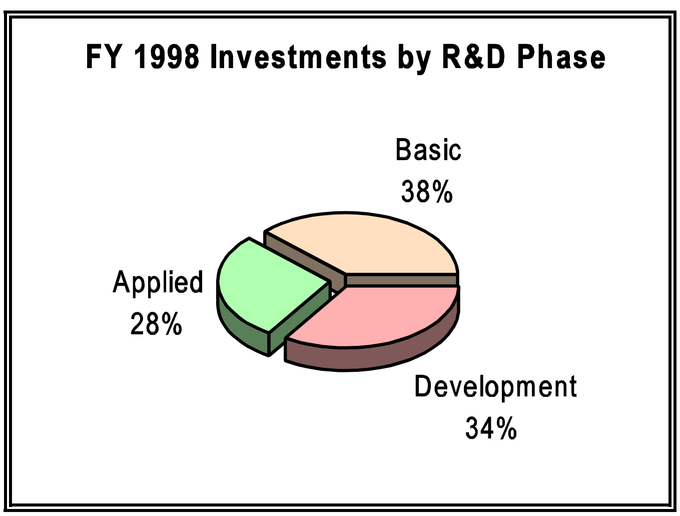
Domestic utilities are perceived to be in a "wait-and-see" mode, given the uncertainties associated with the restructuring of the power generation industry, uncertainties about recovery of new expenditures during the transition to retail deregulation, and competition from other entities such as independent power producers (IPPs) and energy service companies. It is expected that reserve margins will shrink before new facilities will be built. Utilities are currently pursuing life extension and asset management to optimize utilization of existing capacity, thereby delaying the need for new generating capacity. Under current conditions, these utilities foresee an extended period of operation for older units over the next two decades.

Utilities are concerned about proposed, tougher environmental regulations for NO_x, SO_2, particulates, and HAPs. They also are concerned about the treatment of assets in which they invested as a "regulated" industry. The trend in the industry is to focus on the "market clearing price" rather than the "obligation to serve." In the preparation for competition, some are planning to provide other energy services, shed assets, or enter into joint ventures. These competitive pressures and uncertainties, as well as the lack of demand for additional baseload capacity, limit U.S. private-sector R&D investment in advanced power systems.

As a response to the above, the Department spends $350 million on advanced power systems. Advanced power R&D is performed cooperatively with industry, National Laboratories, universities, and State/local governments. The percentage split among these organizations is shown in the chart below.



The next chart shows the investment by R&D phases, that is, the type of R&D. The chart includes fusion from Science and Technology. Fundamentally, fusion accounts for the basic research performed in advanced power systems.



In FY 1998, the Department invested 42 percent, 53 percent, and 5 percent of the $350 million dollars for advanced power systems in large high efficiency systems, distributed and hybrid systems, and technology improvements of operating plants, respectively. These proportions don't change materially in FY 1999 and FY 2000. However, the year to year funding increases are approximately 18 percent and 5 percent for FY 1998 to FY 1999 and FY 1999 to FY 2000, respectively. Additionally, there are no foreseen factors that would alter substantially the current mix of R&D performers and types of R&D. In large high efficiency systems, the investment is in coal- and gas-fired systems (including sequestration).[1] The Department does not invest in advanced oil-fired power systems because no large oil-fired facilities are expected to be constructed in the United States in the foreseeable future. As work in other coal combustion systems is completed, the early stages of the concept for the Vision 21 PowerPlex will begin. Approximately $53 million for the Vision 21 PowerPlex concept will be spent in FY 2000. The Vision 21 PowerPlex seeks to integrate advanced systems in order to achieve higher efficiency, product flexibility, reduced emissions, and lower cost. In distributed and hybrid systems, wind energy, photovoltaic, and bio-power receive more focus and resources. These alternate electricity sources present choices in meeting the challenges offered by a restructured power industry and the goals in the CNES.

Federal Role

Regulated utilities have traditionally invested significantly in power generation R&D, either individually or through industry R&D organizations like the Electric Power Research Institute. However, the U.S. electric power industry is restructuring in response to changes in State and Federal regulations requiring increased competition in the industry. In response to increased competitive pressures, utilities and other companies that traditionally have invested in research have reduced or eliminated their R&D budgets.

Moreover, while global concern over the environmental impact of power generation is growing, most U.S. power generation facilities are in compliance with existing environmental regulatory requirements. At the same time, the prices of fossil fuels, particularly oil and natural gas, are at historic lows. There is little immediate market incentive for investment in cleaner power generation technologies. To the contrary, an increasingly competitive market in power generation could well accelerate the decline in private sector investment in power generation R&D in the United States.

Concern for the environment and electric industry restructuring create a significant public interest challenge: how can the Nation mitigate and possibly eliminate the adverse environmental impact of power generation while ensuring the availability of affordable electricity to continue to grow our economy? An appropriate Federal role in addressing this challenge is to invest in advanced power generation technologies where the market will not support industry's incurrence of all of the costs of the long-term, high-risk, and/or high-cost R&D required to develop those technologies, or when the Government has unique R&D capabilities.

Accordingly, there is a significant gap between the level of advanced power generation R&D that the market will support and the level needed to address current and future concerns about the steady increase in the demand for electricity worldwide and the resulting impact of power

[1] In addition, the Department, in the Science and Technology budget, is proposing $223 million for both FY 1999 and FY 2000 in the fusion program.

generation on human health and the environment. The Department's advanced power systems research and development portfolio is designed to help bridge that gap.

Key Accomplishments

Considerable progress has been made through DOE support toward achieving the advanced power systems goals:

- A new generation of higher-efficiency, cleaner, coal-fueled technologies is currently being demonstrated (e.g., integrated gasification combined cycle) that will also be attractive in hybrid applications when combined with ongoing advances in coal power R&D, turbines, and fuel cells.

- R&D has continued to reduce the cost of renewable systems suitable for distributed applications:

  – Biomass power is being demonstrated at scales from 10-75 MWE for dedicated feedstocks and for co-firing with coal.

  – Recent advancements in geothermal technology have reduced costs by increasing power plant efficiency 5-10 percent for certain key resources.

  – Concentrating solar power has been combined with thermal storage to produce more competitive levels of cost.

  – The cost of producing photovoltaic modules has decreased 50 percent since 1991, making it cost-competitive in certain applications.

  – The cost of wind power has decreased by 85 percent since 1980, making it competitive in some areas that have good wind resources.

- Fuel cells and turbines have reached the stage where they are expected to achieve significant deployment in distributed and hybrid applications in the next decade:

  – Phosphoric acid fuel cells are commercially available, and molten carbonate fuel cells are being successfully tested at full scale.

  – An advanced, cleaner, higher-efficiency industrial turbine is nearing commercial readiness, including a 1999 demonstration.

- Numerous technologies have been deployed/demonstrated and actions taken to help protect the Nation's investment in existing power plants:

  – Test data has been used to help shape environmental regulation.

- Reductions have been achieved in sulfur dioxide, nitric oxides, fine particulates and associated trace toxic substances.

- New alloys and ceramics have increased equipment life.

- Research on hydropower turbines is improving the understanding of advances needed to incorporate "fish-friendly" features.

- Fusion research has continued to raise the power achieved in test reactors (the Princeton Tokamak reached 10 MW in 1996) and increased the understanding of how to control plasma conditions and improve energy confinement.

Large High Efficiency Systems

Budget: FY98-$148.0M, FY99-$182.1M, FY00-$174.5M

Background

Out of a total of about 750,000 megawatts of generating capability in the United States, large electric utility generating capability totaled about 710,000 megawatts in 1996. Coal and natural gas fueled about 65 percent of this capacity.

Large Plant Generating Capacity in 1996

Primary Energy Source	**Capacity** (Megawatts)	**Percent of Total Capacity**
Coal	322,000	45.6
Gas	131,000	18.6
Nuclear	109,000	15.4
Conventional Hydroelectric	76,000	10.8
Petroleum	62,000	8.8
Renewable and Waste Heat	6,000	0.8

Large systems will continue to be needed to satisfy the majority of the Nation's increasing demand for electricity, and fossil energy-based systems are expected to continue to predominate the market. Conventional fossil plants, however, are extremely fuel inefficient, wasting as much as 70 percent of the energy that is used in the generation process. Moreover, these systems create the vast majority of the environmental impacts resulting from power generation in the United States.

Nuclear power plants do not emit air pollutants or greenhouse gases such as carbon dioxide, and are the largest non-emitting electricity supply technology used in the United States. These plants currently produce about one-fifth of the Nation's electricity. The country, however, is at a critical juncture with regard to the continued operation of its nuclear power plants. While many of the 105 existing nuclear power plants will continue to produce electricity well into the next century, licenses for existing U.S. nuclear power plants will begin to expire in large numbers in 2010. However, nuclear plants can be re-licensed for an additional 20 years under current regulations. Two plants have already applied for an extended license and expect approval from the Nuclear Regulatory Commission within the next 2 years. Also, competitive pressures resulting from electricity deregulation could result in the premature closure of some nuclear power plants with relatively high production costs. There have been no new orders for nuclear power plants in the United States since the 1970s, and this is likely to remain the case unless issues of plant economics, spent fuel disposal, and safety and proliferation are successfully

addressed. As a result, nuclear units are projected to provide one-tenth of total electricity generation in 2015.

Linkage to CNES Goals and Objectives

The Department invests in large, high efficiency systems to ensure the availability of large-scale, advanced technologies to (1) reduce both fuel use and the volume of pollutants and greenhouse gases emitted per unit of useful electric power produced, and (2) maintain an adequate, reliable and affordable supply. These ends support:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.
- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.

Program Description

The Department invests in the development of a number of large, high-efficiency systems including coal and natural gas power generation technologies and systems, as well as nuclear fission and fusion systems. Nuclear energy's continued role in electricity production provides for our economic and energy security, and is a critical element of our Nation's global climate change responsibilities. Nuclear power plants currently produce about 20 percent of all U.S. utility-generated electricity without emitting carbon dioxide, a greenhouse gas, and sulfur and nitrogen oxide pollutants associated with the combustion of fossil fuels.

For coal and natural gas systems, a program called "Vision 21" aims for the upper end of performance efficiencies, 60 percent to over 70 percent, at near zero emissions. It features the capability of power generation systems to have fuel flexibility while generating a variety of energy products along with low-cost electricity. Due to the inherent fuel flexibility of gasification and coal-based combustion systems, they may be synergistically integrated into industrial processes (e.g., refineries, paper mills, food processing plants), delivering even greater economic and environmental benefit by converting process waste to electricity, steam, and chemical products as needed. The resulting fleet of large, high-efficiency power systems included in Vision 21 would perform well below the New Source Performance Standards (NSPS) for SO_2, NO_x, and particulates emissions, with the most advanced systems achieving near zero emissions of regulated pollutants.

DOE and its predecessor agencies played a significant role in development of nuclear fission power in the United States. The most recent example is the Advanced Light Water Reactor program that resulted in the design certification of new evolutionary and passive light water reactor technology. However, in light of the uncertainties facing nuclear power, the President's Committee of Advisors on Science and Technology (PCAST) and the Directors of seven National Laboratories recommended that DOE reestablish a strong nuclear energy R&D portfolio. Although there were no nuclear fission programs in FY 1998, in FY 1999, Congress funded the Department's proposed Nuclear Energy Research Initiative (NERI). NERI will sponsor innovative scientific research and technology development to address the longer-term issues facing the future use of nuclear energy, namely proliferation, waste, and economics.

The Department's nuclear fusion program is conducted by the Office of Science. The Fusion Energy Sciences program conducts basic research in plasma science and alternative confinement concepts to understand the physics of plasma (the fourth state of matter), identify and explore innovative and cost-effective development paths to fusion energy, and explore the science and technology of energy producing plasmas, the next frontier in fusion research.

Advanced Coal Gasification and Combustion Systems

Budget: FY98-$61.3M, FY99-$68.5M, FY00-$60.9M

The coal gasification and combustion program is part of the Vision 21 program plan described above. Its overall goal is to make available, by 2010, coal-fueled power technology: (1) with a net electricity system efficiency of at least 60 percent (new plants are currently about 35 percent); (2) that reduces emissions to less than 1/10 of New Source Performance Standards and CO_2 emissions 45 percent below conventional plants; and (3) achieves a cost of electricity below that of conventional new pulverized coal power plants. There are 3 technologies addressing this area.

Advanced Coal Combustion - LEBS/HIPPS

Budget: FY98-$21.0M, FY99-$21.5M, FY00-$10.0M

Description, Objectives, and Performers. This program is re-engineering today's pulverized coal boiler to incorporate advanced combustion and innovative flue gas cleaning into the original design, rather than adding them after the plant is built. The low emissions boiler system (LEBS) has been underway since 1992 and builds on earlier research in the areas of emission control, materials, and combustion. The program will be completed in FY 2001 with operation of a small proof-of-concept plant. The program objective is, by the year 2001, to make available technology: (1) with a net plant system efficiency of at least 42 percent; (2) that reduces emissions to 1/6 of the Clean Air Act's New Source Performance Standards (NSPS) for SO_2 and NO_x and 1/3 the NSPS for particulates; and (3) that achieves a capital cost of less than $1,000 per kilowatt and a cost of electricity 10 percent lower than a conventional pulverized coal power plant. The program is a cost-shared partnership with industry, supported by university and National Laboratory research.

Also as part of advanced pulverized coal combustion, a program to develop an indirect fired cycle having (1) a net plant system efficiency of at least 47 percent; (2) emissions 1/10 of the Clean Air Act's NSPS for SO_2, NO_x, and particulates; and (3) a capital cost 20 percent lower than that of a conventional pulverized coal power plant. In addition to inherently high system efficiency, indirectly fired cycles have other advantages that include no requirements for an oxygen plant or hot gas cleanup, and fuel flexibility, since the products of coal combustion do not contact the gas turbine. This high performance power system (HIPPS) program is also a cost-shared partnership with industry supported by university and National Laboratory research. The engineering development and testing associated with this program ends in 2001, with designs for large commercial plants, prototype plants, and repowering for existing coal-fired plants. The next phase, if undertaken, would be the operation of a prototype HIPPS by 2006.

R&D Challenges. To achieve the more aggressive performance levels, there must be advances in the areas of combustion, heat transfer, and materials. These advances are needed in order to develop the high temperature air furnace, the coal pyrolyzer, and the char burner required in the indirect fired cycle.

R&D Activities. Two different concepts for an indirectly fired cycle are being pursued, but both require R&D necessary for technology and systems development to support the design and operation of the major subsystems, particularly, a high temperature air furnace. Designs for these subsystems will be verified in test facilities. Equipment to be developed includes radiant and convective air heaters, coal burners, integrated slag removal and slag handling components, and char combustors. Research in high-temperature ash deposition, materials, and CO_2/O_2 recycle combustion is required in order for this effort to meet its objectives.

Accomplishments. Successes include the development of new combustion technology (so-called U-fired combustors) capable of reducing NO_x emissions below 0.2 lbs per million Btu at very low cost. NO_x levels approaching natural gas firing are achieved with the addition of a copper oxide cleanup unit. The U-fired combustors produce a granular slag by-product that is preferable to flyash. A HIPPS 2000°F radiant air heater has been tested successfully.

Pressurized Fluidized Bed (PFB) Combustion

Budget: FY98-$17.9M, FY99-$14.6M, FY00-$12.2M

Description, Objectives, and Performers. The PFB program is developing an advanced combustion system capable of utilizing a wide variety of coals (including very low quality coals) to generate electricity cleanly and efficiently. The highly effective mixing of coal particles in the boiler allows combustion temperatures to be kept below the point where most nitrogen pollutants form. Elevated pressures produce a high-pressure gas stream that can drive a gas turbine, and steam generated by the boiler powers a steam turbine. The program has progressed from its basic research or idea stage to the commercial demonstration stage today. A large commercial scale PFB plant is now being designed under the Clean Coal Technology Demonstration Program. This first generation plant will have efficiencies in the 40 percent range and will lay the engineering foundation upon which further technology advances now in the R&D pipeline will be made to achieve the program's 2010 goals. The program objective is, by the year 2010, to make available technology: (1) with a net electricity system efficiency of at least 50 percent; (2) that reduces emissions to 1/10 of the New Source Performance Standards for SO_2, NO_x, and particulates; and (3) that achieves a capital cost of less than $1000 per kilowatt and a busbar cost of electricity that is 10-20 percent below that produced by a new conventional pulverized coal power plant.

The PFB program is a 20-60 percent cost shared partnership with industry, supported by university and National Laboratory research.

R&D Challenges. The key R&D challenge for PFBC is a reliable, available, maintainable, and affordable hot gas cleanup system. Hot gas cleanup systems for advanced high efficiency PFBC power systems remove virtually all particulate matter that would otherwise enter the gas turbine. These filter systems operate under high temperature conditions (e.g., 1400°F to 1700°F). Advanced high efficiency PFBC power systems of the future will include supercritical power conversion systems (PCS) steam conditions, fuel cells, and higher temperature gas turbines. These PFBC systems will necessitate that gas streams be free from impurities (e.g., sulfur, alkalies, and particulates) in order to provide for long term, reliable, trouble free operation.

R&D Activities. The thrust of the research is in hot gas particulate filtration, critical to advanced PFB systems, and improvements in subsystems and their interfaces to enhance system efficiency and reduce cost and pollutant emissions necessary for market entry.

Accomplishments. The program has already succeeded in developing and commercially deploying very clean, but lower efficiency (36 percent) atmospheric fluidized bed systems globally—over $8 billion in sales have been reported.

Integrated Gasification Combined Cycle (IGCC)

Budget: FY98-$22.3M, FY99-$32.4M, FY00-$38.7M

Description, Objectives, and Performers. In the IGCC program, a coal gasifier (which generates a synthetic gas by means of "partial combustion" of coal) is used instead of a traditional combustor and is coupled with an advanced gas turbine. This combination of technologies gives the advantage of adding steam power generation to gas power generation along with new coal gasification processes and breakthrough gas cleanup technologies. IGCC is unique in that it is highly flexible for all coals, liquids, and waste or other opportunity fuels; it can produce high value co-products; and its electricity is predominantly extracted from the more efficient gas turbine portion of the combined cycle. IGCC is the most efficient and cleanest of the available technologies for coal-based power generation. The objective of the program is, by the year 2010, to make available technology: (1) with a net electricity system efficiency up to 55 percent; (2) that reduces emissions to less than 1/10 of the NSPS for SO_2, NO_x, and particulates; and that (3) achieves a capital cost of less than $1,000 per kilowatt with a cost of electricity 80-90 percent of that produced by a new conventional pulverized coal power plant.

The DOE IGCC program is a 20-60 percent cost-shared partnership with industry, supported by university and National Laboratory research.

R&D Challenges. The key R&D challenge for IGCC is to reduce capital and operating costs while simultaneously lowering risk, increasing plant efficiency, and further reducing emissions. To accomplish these goals, the IGCC program has diversified its activities to include a range of technology options to meet existing and future market requirements for electricity and other high-value products. These activities are also consistent with the goals and objectives of the Vision 21 Energy-Plex.

DOE is investing in the development of novel air separation technologies that have potential for significantly reducing capital cost while simultaneously improving efficiency.

To employ advanced technologies such as fuel cells, to convert synthesis gas to other products, and to meet the environmental goals of Vision 21, the gas exiting the gasifier must be cleaned of all impurities such as sulfur, mineral matter, and other toxic materials. The development of reliable, affordable, and high efficiency gas cleanup technologies is, therefore, another major technical challenge for IGCC. First-generation hot gas cleanup technologies have been developed and are being demonstrated under the Clean Coal Technology Demonstration Program. Although suitable for power generation, these technologies must be extended to meet the stringent gas quality requirements for fuel cell and co-production applications. Novel approaches for achieving this, while simultaneously reducing cost and improving efficiency, are also being explored.

To meet the goals of Vision 21 for high efficiency and reduced emissions of greenhouse gases, low-cost technologies for hydrogen and CO_2 separation from the synthesis gas stream are required. Advanced technologies using membranes are being investigated to accomplish the desired separation, as well as novel chemical approaches to separating CO_2 the gas.

R&D Activities. Currently, the focus of the program is centered around four primary activities: (1) Advanced Gasification, that includes accelerating development of the transport-bed gasifier and associated control devices, investigating cofiring of coal with other low-cost feedstocks, improvements in refractory design, and high temperature instrumentation; (2) Gas Stream Clean-Up that enables the production of ultra-clean syngas for fuel cell and co-production applications, novel gas clean-up technologies that minimize consumables and waste streams, and more sorbent development work to meet the need of more stringent applications; (3) Gas Separations that are aimed at enabling the development of new air separation technologies for producing low cost oxygen and enriched air, novel hydrogen separation technologies capable of operating at high temperatures and pressures in the presence of chemicals and particulate contaminants, and technologies for mitigating, separating and utilizing CO_2 emissions; and (4) Products/By-Products Utilization that is looking into aspects of improving slag/ash quality and direct sulfur recovery processes.

Accomplishments. The program has progressed from the basic research or idea stage 20 years ago to the early stages of commercial introduction. Three first-generation (42 percent efficient) commercial demonstration plants are now operating under the DOE's Clean Coal Technology Demonstration Program. In this 20-year time period, which is a typical lead time for developing new power systems, the program has been highly successful in developing the critical components of IGCC systems (e.g., gasifiers, gas stream clean-up subsystems, coal-fuel compatible turbines, and others), some of which have already been commercialized (e.g., the Texaco gasifier).

Advanced Gas Turbine Systems

Budget: FY98-$45.0M, FY99-$44.5M, FY00-$41.8M

Description, Objectives, and Performers. A gas turbine is a major component used in the generation of electricity. Advanced turbines are initially being developed using natural gas as the fuel, but will later be designed for use with other fuels derived from coal, biomass, etc. In the turbine, the high-temperature, high-pressure gases rushing out of the combustor push against the turbine blades, causing them to rotate. The turbine is connected by a shaft to a generator that turns to produce electricity. Much of the remaining heat supplied by the gas can be converted to useful energy in a steam bottoming cycle (i.e., a second lower temperature power generator).

The Department's Advanced Turbine Systems (ATS) program is developing ultra-high efficiency gas turbines for utilities, independent power producers, and industrial markets. The objective is to break the 60 percent barrier in net thermal efficiency for gas turbine systems and reduce SO_x emissions to zero and NO_x emissions to 9 parts per million or less, while achieving operating costs 10-20 percent lower than conventional power systems. The potential domestic and global markets for advanced turbines are large. At least half of all new power generating capacity to be added between now and 2010 is likely to use gas turbines. EIA forecasts over 200 gigawatts of new gas capacity additions in the United States between now and 2015. If ATS were to capture half of this market, it would result in 0.43 quads less fuel use and 94,000 tons less NO_x in 2015 compared to using current systems that operate at an electric efficiency of 50 percent and generate about 10 to 24 parts-per-million of NO_x (without external controls). Because of their high efficiency, advanced turbines will emit less CO_2.

This program is an innovative partnership between DOE, State governments, gas turbine manufacturers, universities, natural gas companies, National Laboratories, and electric power producers for developing lower cost, higher efficiency gas turbines that have better environmental performance than existing machines, to meet current and projected power generation needs. A university consortia works directly with industry to resolve key technical problems encountered in the program. Current industry cost sharing is up to 70 percent.

Supporting research and development is performed as part of the ATS Program. This technology base effort includes the Advanced Gas Turbine Systems Research (AGTSR) managed by the South Carolina Energy Research and Development Center (SCERDC), Federal Energy Technology Center (FETC) research, Department of Energy Combustion Systems Cooperative Research and Development Agreements, research on advanced alloys, thermal barrier coatings, and catalytic combustion, and small business and innovative research.

The AGTSR, a national industry-university R&D consortium, is currently in its sixth year of operation. AGTSR is dedicated to supporting the advancement of land-based gas turbines for future power generation systems which include both the ATS and post-ATS technology programs. The major goals of AGTSR are to promote multi-disciplinary engineering education to realize gas turbine challenges for the 21st century and industry-oriented collaborative R&D with U.S. universities. There are 95 universities which qualify to participate in the consortium and 9 industrial review board members. Over the past 5 years, AGTSR has supported 51 research subcontracts at performing member universities. Ten new projects were selected in 1997. These selections include 3 projects in combustion, 4 in aerodynamics and heat transfer, and 3 in materials.

In advanced materials development, research to develop advanced alloys for ATS hot gas path components has continued. Advanced single crystal alloy developments are enabling the scale up of technologies used to produce high-temperature blades and vanes for the aircraft engines. Recent accomplishments have reduced levels of sulfur and defects in large production castings of these components. Future emphasis is being placed on the cost-effective manufacturing of these components. Projects have recently been initiated to develop advanced casting and fabrication methods to increase the yield rates to reduce the production costs of these components. Successful commercialization of these new processes is critical to achieving the cost of electricity goals of the ATS Program. Currently, the teams of Howmet Corporation-General Electric Company-Solar Turbines Incorporated and General Electric Company-PCC Airfoils Inc. are participating in the new casting projects under the advanced alloys program.

R&D Challenges. Technological advances in the turbine components and systems, such as cooling system design, materials development, and thermal barrier coatings, will permit higher gas turbine combustor firing temperatures that are necessary to reach program efficiency goals. Other design advances are needed to reach NO_x emissions goals and carbon monoxide and unburned hydrocarbon emissions of less than 20 parts-per-million without post-combustion cleanup.

R&D Activities. R&D activities focus on materials science advances, integral thermodynamic changes, base technology research, systems design, development, and integration. Solicitation and awards were made for "Advanced Turbine Airfoil Manufacturing Technology" to develop advanced manufacturing methods in order to increase the yields of turbine blades from low sulfur content, single crystal materials.

Accomplishments. Many technological advances have been achieved since 1992, when the ATS program was initiated. Howmet Corporation developed a single crystal material with a sulfur content significantly below 1 ppm in a non-production size heat and in production size heats (5,000 pounds) with a sulfur content around 0.5 ppm. They were able to produce utility size blades with acceptable grain defects. PCC has produced products with the grain defects contained only in the tips and platforms, has identified and partially eliminated core break locations, and has produced a single crystal of material with a sulfur content of 0.3 ppm using a melt desulfurization process. As a result, U.S. turbine manufacturers will be ready to supply the first ATS machines early in the next century (with expected further improvements afterwards including the incorporation of aeroderivative designs).

Under the industry-university consortium, significant accomplishments were made in the areas of heat transfer, combustion, materials and aerodynamics, providing many design methods, models, and concepts for the gas turbine industry. Faculty principal investigators completed sabbaticals at gas turbine manufacturers and successful workshops were conducted in areas of specific need or emphasis. Numerical models were developed for lean premixed combustion, simplified chemistry, unsteady aerodynamics, and heat transfer for designing advanced gas turbines. Novel probes and control strategies were developed for improving lean premix combustion processes, and advanced coating and materials development processes were produced.

DOE's Federal Energy Technology Center completed tests on new combustor lean pre-mix configurations using liquid fuels, tests of a novel low-NO_x burner developed by Alzeta Corporation that showed very low emissions performance, and a series of tests for humid air turbine configurations. The humid air turbine tests verified that very low NO_x and CO emissions can be achieved with high steam loadings in the combustor.

Under the Small Business and Innovative Research Program, Precision Combustion Incorporated of New Haven CT was awarded the Tibbetts Award in recognition of their unique contributions as an "SBIR Model of Excellence" in developing and commercializing important environmental technologies.

Advanced Large-Scale Fuel Cell Power Systems

Budget: FY98-$40.2M, FY99-$44.2M, FY00-$37.6M

Description, Objectives, and Performers. Over the longer-term, quiet, virtually non-polluting fuel cells could become a new option for electric utilities. Unlike conventional power generation technologies, fuel cells work without combustion and the associated environmental side effects—atmospheric emissions of sulfur and nitrogen compounds. Instead, fuel cells act like continuously fueled batteries, to produce electricity using an electrochemical process. In a fuel cell power plant, natural gas or coal gas is first cleaned, then converted to a hydrogen-rich gas by a fuel processor or by an internal catalyst. This fuel is then fed along with air to a fuel cell power section to generate high quality electricity. Fuel cell power plants can be built by combining cells into stacks to obtain the needed voltage and power output in a wide range of sizes—from 200 kilowatt units suitable for powering commercial buildings, to 100 megawatt plants that can add baseload capacity to utility power plants.

The program objective is to make available, by 2003, fuel cells for electricity production with up to 60 percent efficiency and negligible emissions of regulated pollutants. This performance, coupled with the quietness, small size and modularity of the technology, make fuels cells an attractive option for meeting fast-growing demand in global markets.

R&D Challenges. The challenges for advanced, large-scale fuel cells are, in the near-term, reducing costs and extending cell life and reliability. Longer-term challenges are the solution of integration issues related to combining fuel cells with turbines and gasifiers for hybrid fuel cell/turbine systems and for Vision 21 applications.

R&D Activities. DOE is continuing its industry cost-sharing partnerships to develop advanced, next generation fuel cells, with support from the National Laboratories. Molten carbonate and solid oxide fuel cell technology is being tested at full-scale. Supporting research is focused on improved electrodes, electrolytes, interconnects, materials and seal, and thin film advanced cell processing techniques.

Studies are being conducted on various fuel cell/turbine combined cycle configurations, and investigations will focus on pressurization, the design of fuel cell gas passages to allow integration with turbines, high temperature seals, reliability, fuel gas cleanup, improved thermal cyclability, and high temperature material issues. Hybrid system studies will investigate system reliability and operability, control, dynamic response, matching of gas flow rates, system optimization, mode of operation, and cost and ease of installation.

Accomplishments. The DOE, in partnership with industry, has cost-shared (30-50 percent industry contribution) the development of fuel cells since the mid-1970s. The first generation fuel cell products, phosphoric acid fuel cells (PAFC), entered the commercial market in 1992. More than 160 PAFC power plants have been delivered to sites in the United States, Europe, and Asia. The current fleet has an impressive availability above 95 percent, and demonstrates reliable, safe operation in a variety of climates, applications, and service scenarios. The electric efficiency of these natural gas fired plants is in the 40-45 percent range. Early versions of molten carbonate systems have been tested at the 250 kilowatt and at the megawatt size, while solid oxide fuel cells are being tested at the full-size 100 kilowatt unit module.

Carbon Sequestration

Budget: FY98-$1.5M, FY99-$5.9M, FY00-$9.1M

Description, Objectives, and Performers. Fossil fuel-fired power plants emit about one-third of the Nation's CO_2 emissions. Moreover, these plants account for 70 percent of U.S. electricity generation, and are projected to dominate generation for the foreseeable future. If dramatic reductions in CO_2 emissions are to occur, it appears necessary that technologies will be required to sequester (capture, store, or transform) at least a portion of these emissions of CO_2. Sequestration has the potential to offset a large portion of the 1.6 billion tons per year of U.S. carbon emissions attributable to human activities. It is estimated that achievement of program goals can lead to sequestration of about 200 million tons per year of carbon in 2015, increasing to nearly 3 billion tons per year in 2100. The program objective is to develop sequestration technologies which make it possible to offset all growth in CO_2 emissions in the United States after the year 2015, for $5-10 per ton of carbon reduced, without introducing new environmental damages.

Compared to most research in the Department, sequestration research is a relative newcomer. Nevertheless, sequestration techniques are already being implemented on a very limited scale in promoting enhanced oil recovery, and to dispose of CO_2 associated with natural gas production. In addition, a number of reforestation projects have been implemented. It should also be noted that CO_2 injection into unmineable coal seams has been used to promote methane production, and efforts are underway to reduce the cost of this technology to make it economically practical at more sites. Most sequestration research in the Department is at a fairly fundamental level, as evidenced by the recent solicitation and selection of projects to identify "novel concepts" to sequester greenhouse gases.

R&D Challenges. The challenge is to find sequestration approaches which are both low in cost and which do not introduce new environmental problems.

R&D Activities. The Office of Fossil Energy is examining approaches which capture and store (e.g., in depleted oil or gas reservoirs) emissions from advanced power cycles, technologies which enhance natural processes for removing CO_2 from the atmosphere, and novel concepts which transform CO_2 to a valuable resource or a benign material

Accomplishments. The Office of Fossil Energy (FE) conducted a competitive procurement to solicit proposals pertaining to novel concepts to sequester greenhouse gases. In April 1998, 12 potential breakthrough research projects were selected form the 60 proposals that were submitted. FE has, and will continue to sponsor several workshops to bring together the experts on sequestration to advance the most promising R&D pathways and to develop a roadmap that will lead to sequestration becoming a viable commercial technology. FE and DOE's Office of Science have also developed a formal working group on carbon sequestration research. The group held workshops at the Massachusetts Institute of Technology in June 1998, and at FETC in July 1998. The workshops respectively focused on (1) identification of priority research needs by major DOE stakeholders from the coal, oil and gas, electric utility, and other industries, and (2) coordination of Federal agency and National Laboratory programs to address gaps in current research activities. Subsequent workshops on topics ranging from CO_2 utilization to storage in geological structures will be conducted over the next year.

Nuclear Fission Systems

Budget: FY98-$0.0M, FY99-$19.0M, FY00-$25.0M

Description, Objectives, and Performers. The Nuclear Energy Research Initiative (NERI) complements Nuclear Energy Plant Optimization by addressing our Nation's nuclear energy future. Despite nuclear energy's advantages, unless issues such as plant costs and spent fuel disposal are successfully addressed, the United States is unlikely to see new orders for nuclear power plants. NERI, started in FY 1999, funds investigator-initiated research and development at universities, National Laboratories, and industry to advance nuclear power technology, paving the way for expanded use of nuclear energy in the future.

Science and engineering research is needed to develop new, innovative, and advanced reactor designs in three distinct areas: proliferation resistant reactor technology, high efficiency reactor concepts, and low output reactor applications. The overall objective is to develop new reactor designs that offer improved economics, reduced waste generation, increased safety, and proliferation resistance. Research proposals are solicited from a broad range of researchers, including universities, National Laboratories, and industry. International collaboration will be encouraged in order to leverage Federal research funds, although no Federal funds will be used to directly support research outside of the United States.

R&D Challenges. The new reactor design challenge is to bring the capital cost of nuclear power in line with other electricity supply options while also reducing the amount of spent nuclear fuel produced per kilowatt-hour of electricity generation. Internationally, several developing countries expect to see rapidly growing electricity demand over the next few decades and are looking to nuclear power as an option for meeting those needs. In those markets, issues of plant safety and proliferation risk are also of concern. The challenge in those areas will be to develop reactor designs that require a minimum of maintenance, operator action, and refueling during the lifetime of the reactor.

R&D Activities. Activities planned under NERI would focus on scientific and/or engineering research to further reduce the potential for proliferation of nuclear fuel materials and increase the efficiency of nuclear energy systems. Research into new fuel types and fuel cycles that reduce plutonium buildup, produce less waste, and improve efficiency will be studied.

Innovative research could be conducted on reactor designs offering improved thermal-to-electric efficiencies or specialized, new applications such as cogeneration process heat/electricity systems to compete in the global market. Research would include technologies, design concepts, and approaches that incorporate construction and operations simplicity and cost reduction features.

Finally, research and development of innovative, low power reactor designs employing passive safety systems, and long life cores for electricity generation or process heat use in developing countries could be conducted. The ultimate objective is to develop small reactor systems, primarily for export, that need no on-site refueling for the life of the reactor, employ high safety margins, automated operation, minimized waste production, and cost effectiveness.

Accomplishments. The NERI program is a new start in FY 1999, so that program has no accomplishments to date. The first group of R&D grants and contracts selected from solicited, peer-reviewed research proposals will be awarded in May 1999.

Nuclear Fusion Systems

Budget: FY98-$226.6M, FY99-$228.2M, FY00-$190.2M
(These funds are part of the Science Portfolio and are repeated here for information purposes only)

Description, Objectives, and Performers. Nuclear fusion has the potential of being one of the best long-term means to meet future needs for a safe, clean, environmentally benign, and abundant energy source. The process of nuclear fusion—evident in stars, including the sun—releases enormous amounts of energy. It occurs when the nuclei of lighter elements (such as hydrogen) are fused together at extremely high temperatures and pressures to form heavier elements (such as helium). The program objective is to advance plasma science, fusion science, and fusion technology to establish the knowledge base necessary for the future development of economically and environmentally attractive nuclear fusion energy systems.

The Department's fusion program performers include numerous National Laboratories, universities, and industrial firms. The allocations of funds for FY 1998 is 44 percent for National Laboratories, 28 percent for universities, and 22 percent for industrial firms, with the remaining 6 percent applied toward educational programs, Departmental program direction, and other activities. The Princeton Plasma Physics Laboratory, the Department's only laboratory dedicated to fusion research, is the largest of the performer institutions.

R&D Challenges. The primary scientific challenge facing fusion energy development is advancing the understanding of high power density plasmas. This understanding, which will guide the development of innovations and concept improvements, will result from an integrated program of experiments and advanced theory and computational capability. The development of theory based computational tools with predictive capability will be an increasingly important part of the development of future experimental systems which are becoming more costly. Innovations and concept improvements will contribute to demonstrating the scientific and technical attractiveness of fusion power plants. Significant technical challenges also exist in the development of low-activation materials, which are required to enhance the environmental attractiveness of fusion energy.

R&D Activities. Research activities supporting the program are designed to advance plasma science in pursuit of national science and technology goals; develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program; and pursue fusion energy science and technology as a partner in the international effort.

While fusion power outputs can be sustained now for only a few seconds, successes with the Tokamak Fusion Test Reactor (TFTR), the Joint European Torus (JET) project, and other elements of the United States and worldwide fusion research effort have provided confidence in the ability to pursue a scientific and technological feasibility demonstration experiment. Toward this end, the United States is collaborating with Japan, the European Union, and the Russian Federation on the design of, and supporting R&D for, the International Thermonuclear Experimental Reactor (ITER). If constructed, ITER would produce 100s of megawatts of fusion power for possibly 100s of seconds and would test the plasma physics operating modes and technologies needed for steady-state operation and efficient extraction of fusion energy for electricity generation.

The fusion research technical infrastructure that is needed to sustain the science objectives supported by Congress will also provide the basis for expanding fusion energy development activities in the future, as either research results or energy needs dictate that the Department should do so.

Relative to innovation, the Department's fusion program has substantially increased its efforts toward proof-of-principle experimentation on promising new fusion concepts and toward advanced energy technologies. The National Spherical Torus Experiment (NSTX), which will become operational at the Princeton Plasma Physics Laboratory in 1999, is the first in a series of new proof-of-principle experiments, with others now being planned through a competitive selection process that will identify the most promising concepts. Also, technology initiatives begun in 1998 are now aimed at proving the feasibility of advanced concepts for handling the high levels of particle and heat fluxes that will be produced in the high performance plasmas needed to achieve an attractive fusion energy source.

At a constant level of funding, the program will focus on fusion's underlying scientific foundations. This will enable the United States to exert leadership in selected areas of expertise in the international effort to develop fusion energy. Although the United States will be unable to pursue an independent fusion energy development program, it will attempt to remain a credible partner in the international fusion program that remains aimed at long-term energy development. Because Europe and Japan have energy situations different from that of the United States, fusion energy R&D has a higher priority in those countries. Europe's fusion program is about 2½ times the size of the U.S. program and Japan's fusion program is about 1½ times the size of the U.S. program.

Accomplishments. Substantial technical progress has been made in domestic and worldwide fusion programs. In 1996, the Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory, became the first fusion device in the world to produce 10 megawatts of fusion power. This power was produced in a plasma with a deuterium-tritium fuel mix that is expected to be used in fusion energy sources. More recently, the Joint European Torus in England has produced even greater levels of fusion power than the 10 megawatts produced in TFTR. Substantial progress also has been made in the last 3 years in understanding and controlling plasma conditions to improve the energy confinement capability of Tokamaks. By selectively heating the plasma and shaping the current, the thermal energy of the plasma is better contained which would lead to a smaller and more efficient advanced Tokamak power plant.

Distributed and Hybrid Energy Systems

Budget: FY98-$188.3M, FY99-$212.8M, FY00-$237.4M

Background

The U.S. electric industry is undergoing fundamental change due to restructuring and the addition of new electric generation power suppliers and products, as well as the changing nature of decision making. Grid-sited, large central power plants have long dominated electric utility technology decisions and today these plants remain the backbone of the power system. However, market factors—including ample supplies of cheap natural gas, constraints at the transmission and distribution level, environmental considerations, and technological advances—are causing alternative, modular technologies such as fuel cells, gas turbines, photovoltaics, wind turbines, solar, geothermal, and biomass systems gradually to augment and sometimes to replace conventional, large-scale generating technologies. In particular, gas turbine technology has a dominant role in both distributed energy and hybrid systems.

Renewable resources, such as hydroelectric, wind, solar, photovoltaics, geothermal, and biomass, are abundant. Hydropower provided about 10 percent of the electricity consumed in the United States in 1996, while the remaining renewable resources supplied 1.3 percent. The primary advantage of these renewable resources in power generation is they produce virtually no harmful emissions or solid wastes. Their primary disadvantages are the cost of producing power (with the exception of hydropower) compared to coal and natural gas, and the need to create the infrastructure required to deliver electricity to the market. Because hydropower already has a well developed market and infrastructure, the Department currently does not invest significantly in hydropower technologies. The Department focuses instead on improving the performance and lowering the costs of the technologies using other renewable resources.

Where these technologies are available locally, the cost of infrastructure development on the transmission and distribution system is reduced, and a reliable power supply system is made available at critical times in those locations. In a recent study, the Electric Power Research

Institute indicated that these small modular units, located primarily on the distribution system, would capture at least half of all new U.S. electric capacity needs between now and 2020. These distributed and hybrid power systems using renewable and fossil energy sources have many benefits such as improving environmental quality, short construction lead time, modular installation, and low capital expense, which all contribute to their growing popularity.

The portfolio of technologies represented by distributed and hybrid systems have numerous applications, for example, at customer sites, to provide both heat and power; on the distribution system, to provide high value electricity and deferral of costly line upgrades and replacement; off-grid in stand alone power applications; and for electricity supply to the bulk power market.

Linkage to CNES Goals and Objectives

The Department invests in distributed and hybrid energy systems to ensure the availability of a portfolio of advanced power technologies utilizing renewable and hybrid energy systems that will increase the flexibility, capacity and reliability of the U.S. power system. This end supports:

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 1 - Increase domestic energy production in an environmentally responsible manner.
- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.
- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe , and efficient energy systems.

Program Description

The Department is developing a suite of distributed and hybrid power systems to significantly contribute toward the goal of providing reliable and affordable power generated in an environmentally benign manner. Technologies being developed include renewable energy (wind, photovoltaics, concentrating solar power, geothermal, and biomass), combined heat and power (cogeneration), smaller fuel cells, and small combustion turbines and reciprocating engines.

Combined Heat and Power Systems

Budget: FY98-$1.0M, FY99-$1.5M, FY00-$2.0M

Description, Objectives, and Performers. Combined heat and power, or cogeneration, involves capturing the waste heat and putting it to some useful purpose at the customer site.

The development of combined heat and power systems for generation systems has the potential for over 85 percent fuel utilization efficiency in industrial, commercial, and residential applications. With conventional power generation systems, up to two-thirds of the energy is lost as waste heat. The program objective is to eliminate the barriers of combined heat and power technologies to increase the overall power industry efficiency and reduce atmospheric emissions.

With utility restructuring and competition in the power generation market and new environmental regulations on the horizon, the market landscape for energy production and use is likely to change. Government and industry, in partnership, have the opportunity to address the technology challenges associated with optimizing heat and power systems for on-site usage, as well as addressing technical issues associated with infrastructure development for energy transport and storage.

A related new initiative is the Combined Heat and Power Challenge (CHP) that addresses major existing barriers to the implementation of combined heat and power systems, including:

- Environmental permitting that is complex, costly, time consuming and uncertain.

- Environmental regulations that do not recognize the overall energy efficiency of CHP or credit emissions avoided from displaced electricity generation.

- Utilities that charge (or threaten to charge) prohibitive exit and/or stranded asset fees for customers wanting to build CHP facilities, or charge unreasonable rates for use of the distribution grid, and/or prevent the use of alternative backup and supplemental power suppliers.

- Long and varied Federal tax depreciation schedules for CHP investments that differ depending on system ownership.

The CHP Challenge will assist plants that experience the above problems when implementing CHP systems through assessments of future combined heat and power facilities, State outreach, modeling, and technology verification. The program has provided several grants to California, Vermont, Indiana, and Washington to initiate case studies to implement advanced combined heat and power technologies. The program is also investigating the use of biomass and black liquor (produced in the paper-making process) for large-scale combined heat and power systems that are synergistic with industrial processes and district heating/cooling needs.

R&D Challenges. R&D challenges include prime mover (fuel cell, turbines, etc.) technology development, related low emissions, cost effective technology development, and long-term materials development.

R&D Activities. Some of the power generation technologies being developed by DOE and industry such as gasification, combustion, and fuel cells are aimed at fuel flexibility and other modifications to accommodate a variety of energy needs. For example, combined heat and power is included as part of the Vision 21 Energy Plex development program currently underway in the Office of Fossil Energy.

Accomplishments. In FY 1999, the program will hold a national workshop and aid in the technology demonstration of a ceramic combustor liner.

Advanced Turbine Systems (Industrial and Microturbines)

Budget: FY98-$34.7M, FY99-$51.0M, FY00-$31.3M

Description, Objectives, and Performers. Advanced turbine systems, with their wide range of potential sizes, are particularly attractive for distributed generation applications. Competition and emerging technologies are causing the power generation industry to abandon its larger-is-more-efficient philosophy for a customer-based, tailored energy mindset. In the competitive environment, electric power suppliers will need to pay more attention to customers needs in order to retain them. The result will be a growing demand for custom power plants designed to most efficiently meet the end-use residential/commercial/industrial customer's specific needs. DOE's Advanced Turbine Systems (ATS) Program is focusing on this market through it objective to make available turbine systems for distributed applications, including: (1) industrial gas turbines that are 40 percent efficient with single digit emissions and provide a 10 percent reduction in the cost of electricity while maintaining the reliability, durability and availability of today's industrial turbines, and (2) advanced microturbines with 40 percent efficiency and emissions of less than 10 parts per million NO_x and CO_2 at an equivalent reliability and reduced cost compared to today's technology.

Partners in the Advanced Turbine Systems Program include over 150 suppliers, universities, and National Laboratories. The program is a joint effort between the Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy.

R&D Challenges. Meeting the goals for the industrial turbine part of the Department's Advanced Turbine Program (begun in 1994) will require advancements in engine and component design, including innovations in cooling, materials, and coatings. The environmental goals will require the use of new combustion techniques such as the use of ceramics and catalytic combustion.

Currently, distributed microturbines are approximately 23 percent efficient. Meeting program goals will require the development of advanced materials such as ceramics and coatings, combustion systems, and recuperation technologies. Advanced ceramics and coatings will enable engines such as microturbines to have low emission levels, have long life (>18,000 hours), be highly efficient targets, and be fuel flexible. Microturbines can be coupled with a fuel cell resulting in a system efficiency ranging from 70 to 80 percent.

R&D Activities. DOE work on small turbine systems includes industrial and microturbine R&D. The Advanced Turbine Program funds major work in ceramics. Because of their superior high temperature durability, the application of ceramics as structural materials for gas turbine hot section components will enable a significant increase in the turbine rotor inlet temperature of current all-metal industrial gas turbines, resulting in improved thermal efficiency, greater output power, and reduced emissions of NO_x and CO_2.

In the microturbine area, the program is working with the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), and Edison Technology Solutions to test the current state-of-the-art microturbines available, a ceramic recuperator development effort with DuPont Lanxide Composites Inc., Rensellaer Polytechnic Institute, and Teledyne Ryan Aeronautical and a hybrid turbine/fuel cell system. In FY 1999 and beyond, funding will continue the design and development of microturbines, advanced recuperators, and ceramic components.

Accomplishments. An early success of the program is the announcement by Solar Turbines, Inc. of the demonstration of the "Mercury 50" advanced turbine set for 1999. A second success is, with DOE support, Solar Turbine's ceramic development effort to replace cooled metallic hot section parts (combustor liner, vanes, and nozzles) with uncooled ceramic parts. To date, a ceramic composite combustor liner and silicon nitride blades have been run for approximately 2000 hours in an industrial gas turbine at ARCO Western Energy in Bakersfield, CA. The goal of the effort is to run the ceramic components (blades, vanes, and nozzles) for 4000 hours.

Distributed Fuel Cell Power Systems

Budget: FY98-$6.4M, FY99-$0.0 M, FY00-$0.0M

Description, Objectives, and Performers. Fuel cell power systems do not rely on combustion, but rather produce electricity from power plants based on electrochemical power conversion of a carbon-rich fuel. These modular systems are among the most efficient and cleanest power plants being developed. They can be deployed in applications ranging from small distributed systems (several kilowatts) to utility scale (multi-megawatts). The program seeks to help bring this promising alternative to combustion-based fuel cycles to the marketplace, and to ultimately ensure that renewable energy serves as the source of hydrogen fuel. The objective is to (1) lower the cost and improve the performance of fuel cells to meet the competitive market challenges of less than $1000 per kilowatt, and (2) develop an integrated fuel cell/turbine hybrid system for small-scale applications that promise system efficiencies of over 70 percent and costs below $700 per kilowatt. The Department is partnering with industry (supported by university and National Laboratory research) on a cost-shared basis (currently at 30-50 percent industry funding) to develop fuel cell technology for the restructured energy market.

R&D Challenges. R&D challenges for the fuel cell program include improving key advances to enhance the fuel cells output performance (cell voltage degradation), enhance longevity (minimum 5 years operation), and develop lower cost materials and components.

R&D Activities. R&D supporting these efforts is aimed at extending cell life, improving reliability, and reducing costs. Activities include advanced manufacturing techniques; improved electrodes, electrolytes, interconnects, materials, and seals; and thin film advanced cell processing techniques.

Accomplishments. The DOE fuel cells program has run over the last 20 years from fundamental research to stack and full scale prototype systems that are modules for larger size applications. The first generation fuel cell products, phosphoric acid (PAFC) fuel cells, entered the commercial market in 1992. More than 160 PAFC power plants have been delivered to sites in the United States, Europe, and Asia. The current fleet has an impressive availability above 95 percent, and demonstrates reliable, safe operation in a variety of climates, applications, and service scenarios. Early versions of molten carbonate systems have been tested at the 250 kilowatt and in the megawatt-size range.

Wind Energy Systems

Budget: FY98-$32.1M, FY99-$33.2M, FY00-$45.6M

Description, Objectives, and Performers. Wind turbines convert the kinetic energy in the wind into electrical energy. Most turbines today employ two or three propeller-like blades mounted on a rotor connecting to an electric generator that typically is 500-1000 kilowatts in output. Larger sizes that have been tested are just now entering the commercial marketplace. Because they are modular, wind turbines can be sited either individually, grouped in small clusters, or in larger windfarms totaling 10 to 50 megawatts or larger. In 1997, 3.2 billion kilowatt-hours of electricity were produced by 16,000 wind turbines in the United States.

The program's near-term objective is to develop advanced wind turbine technologies capable of bringing the costs down to $0.025/per kilowatt-hour by 2002 compared to today's cost of $0.04-0.05 per kilowatt-hour. In the longer term, R&D will focus on turbine systems, component materials, electronic controls, and wind forecasting combined with hybrid systems to expand wind energy applications. The target is 10,000 MW of wind energy installed in the United States by 2010, by combining a vigorous technology development effort with activities to reduce barriers and to promote supportive energy policies.

The program conducts R&D with significant cost-sharing through industry partnerships and collaboratives. Partners working collaboratively with DOE include the wind and electric utility industries, National Laboratories (National Renewable Energy Laboratory [NREL], Sandia National Laboratory [Sandia]), and universities.

R&D Challenges. Wind has proven to be an extraordinarily complex energy resource. To be cost-effective, a wind turbine must have high aerodynamic efficiency and must be durable and reliable, while also having minimal weight and complexity. The challenge for the wind program, therefore, is to assist industry in bringing the cost of wind technology to a level where it can compete with traditional energy sources.

R&D Activities. The wind program has three R&D thrusts. The first, the Applied Research program, focuses on basic issues of wind characterization, aerodynamics, structural dynamics and fatigue, hybrid systems, and advanced components and controls. The second, Turbine Research, includes five distinct efforts to develop advanced deployable technology. These efforts include next generation technology development for both utility-scale and small systems and field verification tests at actual operating locations. The third thrust encompasses a number of activities that support the development of certification and standards, technical assistance for industry's international programs, and operation of the National Wind Technology Center at Rocky Flats, CO.

Accomplishments. The DOE wind program has been increasingly successful in improving the performance and decreasing the cost of wind systems and subsequently enhancing its commercial prospects. Today, in areas with ideal wind resources, electricity can be produced for less than $0.05 per kilowatt-hour compared to wind energy in 1980 at $0.35 per kilowatt-hour—a decrease of 85 percent in just 15 years. Recent partnerships with DOE have produced 3 commercially-offered wind turbines, with another 8 now under development.

Photovoltaic Systems

Budget: FY98-$64.7M, FY99-$72.2M, FY00-$93.3M

Description, Objectives, and Performers. Photovoltaic (PV) solar technology uses semiconductor-based cells to directly convert sunlight to electricity. The greater the intensity of the light, the more power that is generated. PV can be used to produce electricity on almost any scale, depending only on how many PV modules are connected together. The worldwide market for PV is growing rapidly, with the United States retaining the largest market share in 1997.

The objectives of the PV program are: (1) by 2000, reduce the price of commercial modules by 15 percent from current average costs of about $4.25 per watt and increase annual sales of commercial modules from 225 megawatts in 1996 to 500 megawatts; and (2) by 2004, increase the efficiency of both thin film and crystalline silicon PV cells, reduce the retail sales price of commercial modules by 40 percent, increase lifetimes to greater than 25 years, and increase annual U.S. industry sales to 1 gigawatt.

Partners working collaboratively with DOE include the PV and electric utility industries, National Laboratories (NREL, Sandia), and universities. Almost all work with industry is heavily cost-shared.

R&D Challenges. Even though the cost of PV is rapidly decreasing, it is currently too high for the bulk power market. R&D challenges to reduce costs include improving the fundamental understanding of materials and processes to provide a technology base for advanced PV options, optimizing cell and module materials and design, scaling up cells to product size, validating performance in outdoor and accelerated conditions, and improving manufacturing processes.

R&D Activities. The Photovoltaic R&D program is divided into three areas. The first, Fundamental Research, includes the measurement and characterization of cell materials and devices. Work is also performed to improve cell structure and materials processing for thin film technologies. As part of the second area, Advanced Materials and Devices, the Thin Film Partnership Program is a government/industry/university partnership to accelerate development of cost-effective thin-film technologies. The program also operates a core research effort in high efficiency III-V gallium arsenide (GaAs) materials and devices for concentrator and flat plate applications. Finally, under the third area, Collector Research and Systems Development, the Photovoltaic Manufacturing Technology Project (PVMaT) is improving manufacturing processes for thin-film technologies and assisting industry in the development of advanced techniques for producing higher performance and lower cost commercial products. The program is continuing R&D on advanced PV Building products, concepts, tools, and modeling procedures in support of industry efforts for technology development/deployment. The Million Solar Roofs Initiative will increase outreach activities to establish partnerships with communities, cities, builders, Federal and State agencies, corporations, and financial institutions across the Nation.

Accomplishments. The program has contributed to a 50 percent reduction in the cost of producing PV modules since 1991, resulting in the technology being used in grid-connected, distributed power, and off-grid, remote electric power. A recent success is the development, in partnership with industry, of a Photovoltaic roofing shingle that is now on the market and can replace conventional roofing shingles to generate clean electricity.

Concentrating Solar Power Technology

Budget: FY98-$16.3M, FY99-$17.0M, FY00-$18.9M

Description, Objectives, and Performers. Concentrating solar power (CSP) systems use sun-tracking mirrors to reflect and concentrate sunlight onto a receiver where it is converted to high-temperature thermal energy. The high-temperature heat is then used to drive a heat engine and electric generator.

The CSP program has recently reviewed its objectives to ensure that the program is focused on the needs of the evolving utility marketplace. By 2004, the program will, in collaboration with industry, help develop a reliable (4000 hours mean time between failures) distributed power system and a competitively priced dispatchable power system. that will enable full participation by CSP systems in domestic generation markets, prompted by the restructuring activities in various States.

The Program has cost sharing with industry of roughly 50 percent. R&D partners working collaboratively with DOE include the solar thermal and electric utility industries, National Laboratories (NREL, Sandia), and universities.

R&D Challenges. The program is addressing the challenges of harnessing an intermittent resource, i.e., sunlight, and cost-effectively converting that resource into electricity that has high value to the utility supply system. One approach is to store thermal energy for later conversion into electricity as utility system demand dictates. A second approach is to produce electricity whenever sunlight is available, and to supply that electricity to the grid either in high-value peak periods or in applications where the price of alternative power supplies is high. Because thermal conversion efficiencies are greatest at higher temperatures, the program is seeking advanced materials and heat receivers that operate at higher temperatures.

R&D Activities. The CSP R&D program activities are categorized into four paths. The first path, Develop and Demonstrate High-Reliability Distributed Power Systems, focuses on reliability of dish/engine systems for emerging markets for distributed energy sources. The second path, Reduce Costs of Dispatchable Solar Power, is currently focused in two areas: advanced trough component R&D and the development of high-temperature CSP systems. Penetration of broad domestic and international markets will, however, require further significant technology advances addressed in path 3, Develop Advanced Components and Systems. A fourth path, Expand Strategic Alliances and Market Awareness, will keep technology efforts focused on the most critical needs of industry, ensure a technology capable of meeting market needs, and support domestic and international information flow and policy decisions favorable to renewable energy.

Accomplishments. The CSP program is concluding a decade-long program to develop a utility-scale dispatchable solar electricity system. The 10-MW Solar Two power tower concept, being demonstrated in Southern California, incorporates molten salt thermal storage to extend its operation into early evening hours at a more competitive level of cost.

Geothermal Systems

Budget: FY98-$5.1M, FY99-$6.0M, FY00-$7.0M

Description, Objectives, and Performers. Geothermal power plants use the natural heat in the earth's interior to drive a turbine generator and produce electricity. Currently, the installed commercial geothermal electric capacity in the United States exceeds 2,800 megawatts. Today, electricity is produced domestically only from hydrothermal resources (reservoirs of steam or hot water) in the western United States. In the future, hot dry rock resources, which are far more abundant, could contribute to clean power production.

The program objectives are: (1) by 2005, lower the cost of geothermal energy production to $0.035 per kilowatt-hour from typical geothermal resources, compared to current costs ranging between $0.05 and $0.08 per kilowatt-hour; and (2) by 2010, provide technology to facilitate increased geothermal power that will supply electric power to 7 million U.S. homes, and meet the needs of people in developing countries.

The DOE Geothermal Electric R&D program is implemented through a combination of contract research at National Laboratories (principally Idaho National Engineering and Environmental Laboratory, Sandia National Laboratory, and National Renewable Energy

Laboratory) and financial assistance to private companies whose proposals are selected by a competitive process of objective merit review.

R&D Challenges. Longer-term (beyond 2005) geothermal R&D challenges include improved methods for predicting reservoir performance and lifetime, innovative low-cost drilling technologies, improved conversion of energy from hot dry rock, and lowering equipment costs through materials science and process chemistry.

R&D Activities. The Geothermal Electric R&D Program focuses its efforts in three areas. Exploration and production technology work seeks new, more cost-effective ways to identify and exploit geothermal reservoirs. Support for drilling technology development includes drill bit development and advanced computerized well logging tools. Energy conversion technology focuses on advanced systems for controlling non-condensible fluids in geothermal fluids, and development of a small-scale demonstration plant at a remote location.

Accomplishments. The DOE Geothermal Electric R&D Program improved the flashed-steam cycle during the 1970s and 1980s by developing technology for managing solids, making possible exploitation of over 200 megawatts of the geothermal resources near the Salton Sea in California. More recently, it has developed technologies that have achieved 5 to 10 percent efficiency improvements of power plants operating with high non-condensible gas loading (at The Geysers, CA) and with reduced brine temperatures (at Mommoth, CA). The program was a key participant in the development of the polycrystalline diamond drill bits now used in about 40 percent of oil and gas drilling worldwide, and since then has demonstrated the use of slimhole drilling for geothermal exploration, reducing drilling exploration costs by 30 to 50 percent.

Biopower

Budget: FY98-$27.8M, FY99-$31.5M, FY00-$39.0M

Description, Objectives, and Performers. Biopower systems generate electric power from resources such as energy crops, agricultural residues, wood, and wood residues. These can be co-fired with coal, burned directly as a single fuel in new power plants, or converted through a gasification process to a high energy gas stream to be burned in an advanced, high efficiency gas turbine to produce electricity. Biopower systems can also be integrated in industrial processes such as paper and allied products.

Objectives of the program include: (1) develop advanced biomass conversion technology that, when combined with dedicated crop and tree feedstocks, will reduce the cost of electricity production by nearly 50 percent compared to current costs of $0.07-0.09 per kilowatt-hour for direct biomass-fired power plants now in the marketplace, (2) increase the viability of clean, efficient, biopower technologies for a variety of markets to achieve an additional 3,000 MW of new biomass power in the United States by 2004, and (3) develop integrated biomass/black liquor process streams for the manufacturing sector.

Biomass power research performers include industry partnerships and consortia, the National Laboratories (NREL, Oak Ridge National Laboratory [ORNL], Sandia), and other Federal agencies such as USDA. The program has significant cost-sharing with industry.

R&D Challenges. Short-term R&D challenges include finding ways to improve fuel feed systems, combustion characteristics, gas cleanup, effects on materials and component life and heat transfer performance, discharge handling, NO_x reduction potential, and ash chemistry. Regarding advanced gasification, near-term objectives focus on demonstrating the feasibility of various conversion technologies. Research challenges include demonstrating long-term operation of gas turbines on biogas, improving materials, developing sufficient energy crops for feedstocks, demonstrating advanced technologies, and integration into the forest products sector.

R&D Activities. The Biopower Program is pursuing the development and use of "dedicated" crops and trees which would be regrown to recapture the carbon dioxide emitted when the biomass is burned as a fuel in power plants, creating an energy cycle in which there is no net greenhouse gas emissions. Biomass gasification technologies are being developed through a program that examines advanced techniques for thermochemical conversion of biomass feedstocks and that demonstrate the use of gasifier technology in utility and industrial manufacturing settings. The development of biomass co-firing in existing coal power plants is being pursued in partnership with the utility industry.

Accomplishments. Program successes include the demonstration of the gasification process at the Vermont Biomass Indirect Gasification Project (8-12 megawatts). Three projects competitively awarded in 1996 to industry consortiums will validate integration of dedicated feedstocks with existing or new power plants. These are Niagara Mohawk/Salix Consortium Willow Cofiring Project—47-megawatts of biomass power in an existing coal plant, the Minnesota Valley Alfalfa Producers Gasification Project (MnVAP)—a new 75-megawatt alfalfa biomass-based power plant, and the Chariton Valley RC&D (Iowa) Switchgrass Cofiring Project—35-megawatts of biomass power cofired in an existing coal plant.

Reciprocating Engines

Budget: FY98-$0.3M, FY99-$0.4M, FY00-$0.4M

Description, Objectives, and Performers. Reciprocating engines are piston internal combustion engines (typically less than 20 megawatts) that are well known for their use in combined heat and power applications. Advantages of reciprocating engines are low capital cost, fuel flexibility, and easy maintenance and operation. These advantages will continue to make reciprocating engines the option of choice for onsite power production for the foreseeable future while more advanced technologies such as microturbines or fuel cells are under development. Primary markets include the chemicals, petroleum, natural gas, agriculture, metal refining and casting, and waste disposal industries. Reciprocating applications include cooling, power generation, backup power, compression, and transportation applications such as locomotive. The objective of this activity is to develop a

50 percent efficient natural gas fired reciprocating engine with emissions less than 5 parts per million NO_x (at 15 percent O_2).

R&D Challenges. Challenges include high emissions, low relative efficiency, ignition challenges, and the heavy use of lubricating oil.

R&D Activities. Begun in 1994, the Department's Advanced Reciprocating Gas Engine Technology Program is a key component to enhancing industrial power generation/cogeneration technologies through the development of ceramic technologies, advanced ignition systems, combustion development, sensors and controls, catalyst development, and oil reduction. Efforts include the development of a gas engine consortium with the Federal Energy Technology Center, Gas Research Institute, and Southwest Research Institute, and the testing of a ceramic engine valve.

Accomplishments. FY 1998 accomplishments will include the demonstration of a ceramic valve guide and the completion of the technology roadmap for reciprocating engines.

Technology Improvement of Operating Plants

Budget: FY98-$17.2M, FY99-$22.7M, FY00-$33.7M

Background

The existing fleet of operating plants include fossil, nuclear, and hydroelectric units, which make up over 98 percent of the power generated in the United States. The existing fossil fleet is aging, while the licenses for the fleet of operating nuclear plants will begin to expire in large numbers beginning in 2010. Environmental concerns created by hydroelectric plants, particularly with their impact on fish life, are increasing.

Despite expected energy efficiency measures, the projected growth in electricity demand coupled with expected plant retirements would require over 400,000 megawatts of new power capacity by 2020. It is critical, therefore, that the contribution of current fossil, nuclear, and hydroelectric powered plants be optimized. In order to do so, improved technology must be deployed in current power plants and a large percentage of existing nuclear power plants must achieve license renewal.

Linkage to CNES Goals and Objectives

The Department protects the Nation's investment in existing baseload power plants through the development of improved information management systems, sensors and controls, aging management, and regulatory compliance programs. This end supports:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems.

Program Description

DOE and industry are partners in the development of technologies to improve the operations of fossil energy plants, to provide for cost-effective compliance to new environmental regulations, to ensure acceptable levels of safety and reliability as these plants begin to age, and to improve efficiencies for their remaining life.

With respect to nuclear plants, the Department is conducting no R&D in FY 1998 or FY 1999, but has proposed for FY 2000 a new R&D initiative, the Nuclear Energy Plant Optimization (NEPO) program. The NEPO program will be 50-50 cost-shared with industry with a goal of ensuring that current nuclear plants can continue to deliver adequate and affordable energy supplies up to and beyond their initial 40-year license period. Technology improvements for both fossil and nuclear plants are targeted primarily in three areas: information management systems, aging effects in key components, and sensors and controls.

Regarding hydropower plants, the Department's work is focused on the development of improved hydropower turbines.

The continued operation of existing U.S. nuclear power plants avoids emission of over 620 million metric tones of carbon dioxide annually. Nuclear energy's continued role in electricity production is necessary so that our Nation can meet its global climate change commitment. In addition, the loss of nuclear power plants would not only have negative environmental impacts, but also threaten the reliability of the electric generation systems in several States.

Aging Effects in Key Components

Budget: FY98-$5.2M, FY99-$6.2M, FY00-$7.0M

Description, Objectives, and Performers. In coal-fired plants, technical issues related to plant aging include fouling, corrosion/erosion, fatigue, and creep life of components. The DOE and industry, with support from the National Laboratories and universities, are developing improved materials, developing fabrication techniques, and conducting research to gain a better understanding of the combustion science, corrosion, and transport mechanisms that impact the life of components. Although the research and development are aimed primarily at advanced coal power systems, these improvements would be applicable to components in existing plants and could be deployed at the time of scheduled maintenance and change out.

Degradation of materials in nuclear reactor plant structures and components caused by radiation, high temperatures, high pressure cyclic stresses, and a relatively corrosive environment costs utilities that operate light water reactors (LWRs) hundreds of millions of dollars each year. Not only does this degradation increase current operating costs significantly, but, if continued, material degradation could force the premature shutdown of some plants before the end of their initial 40-year license term. Even for plants that can operate until the end of their current license period, material degradation issues will strongly affect license renewal decisions. Work in this area under the NEPO program will be conducted by a combination of universities, National Laboratories, and industry.

R&D Challenges. The challenges are to develop improved materials and detection devices to reduce costs associated with component aging in coal and nuclear power plants.

R&D Activities. Advanced austenitic alloys will be developed to address the issue of stable alloys in super heaters and reheaters of advanced coal combustion plants with 1300 ^{o}F and 5000 psi steam conditions. Creep strengthening of promising alloys such as iron aluminites will be accomplished through oxide dispersion strengthening. A New generation of corrosion resistant high temperature alloys will be developed as hot components in advanced fossil energy combustion and conversions systems.

Research is planned in the NEPO program to understand, characterize, and manage service-induced degradation of steam generation tubes, reactor internals, primary system piping, electric cables, and safety-related structures. Technology development will be focused on timely detection, mitigation, and prevention of significant long-term effects of aging such as stress corrosion cracking, irradiation assisted stress corrosion cracking, reduction in fracture toughness due to neutron irradiation, thermal embrittlement of cast austenitic stainless steels, piping fatigue, and structure degradation. Research will involve laboratory tests, component inspections, and technology demonstrations.

Accomplishments. The development of the modified-9Chrome-molybdenum steel alloy by DOE and Oak Ridge National Laboratory over the last 20 years has been a resounding success for boiler tube applications in coal-fired power plants. The application of new alloys and ceramics or refractory materials can improve plant life and reduce the frequency of scheduled maintenance.

The NEPO program will be a new start in FY 2000, so the program has no accomplishments to date.

Nuclear Power Plants

Budget: FY98-$0.0M, FY99-$0.0M, FY00-$5.0M

Description, Objectives, and Performers. The United States is at a critical juncture with regard to the continued operation of its nuclear power plants. Faced with regulatory and economic uncertainties, some utilities already have closed nuclear facilities well before their license expiration dates. In the past 3 years, 6 reactors have closed. Licenses of U.S. nuclear power plants will begin to expire in large numbers in 2010, and licenses for 13 more plants will expire in 2014 alone. According to the Energy Information Administration's *Annual Energy Outlook 1999*, more than 80 percent of the nuclear power plants now operating in the United States will be retired in the first 2 decades of the 21st century if no action is taken.

The Nuclear Energy Plant Optimization (NEPO) program, part of the President's Climate Change Technology Initiative, is a new program proposed for the FY 2000 budget. The goal of NEPO is to cooperate with industry to develop advanced technologies that can help ensure that existing U.S. nuclear power plants continue to safely generate reliable and affordable electricity up to and beyond their initial 40-year license periods. Overall, NEPO aims to help increase the average capacity factor of existing nuclear power plants from 71 percent in 1997 to 85 percent by 2010.

R&D Challenges. NEPO will work with industry to develop and apply new technologies to improve plant economics, reliability, and availability. The program will work to resolve issues related to plant aging while maintaining a high level of safety.

The Department is well prepared to take on this challenge:

- NEPO will be guided by a chartered subcommittee of the Nuclear Energy Research Advisory Committee.

- The Department and the electric utility industry's Electric Power Research Institute have developed a Joint Strategic Research and Development Plan to prioritize and coordinate research and development needed over the next 7 to 10 years to sustain the operation of commercial nuclear power plants.

- The Department will continue to coordinate its program planning activities with the Nuclear Regulatory Commission to ensure that agency activities are not duplicated, but are complementary and performed in a cost-effective manner.

R&D Activities. Funds provided by the Department will be matched by industry in conducting peer-reviewed research and development to include: managing long-term effects of component aging, improving nuclear power plan capacity factors, and generation optimization through efficiency and productivity improvements. In FY 2000, NEPO will accomplish two major tasks that will contribute to improved nuclear power plant operating performance. The first is a laboratory benchmark of technology to reduce stress crack corrosion in nuclear plant components, and the second is demonstration of a prototypic method to non-destructively measure steam generator tube cracking. Both efforts are aimed to increase plant availability and capacity factors by reducing maintenance and outages.

Accomplishments. The NEPO program will be a new start in FY 2000, so the program has no accomplishments to date.

Regulatory Compliance

Budget: FY98-$11.2M, FY99-$13.3M, FY00-$14.7M

Description, Objectives, and Performers. Existing coal-fired power plants must comply with a number of existing EPA regulatory requirements. Additional requirements are being considered by the EPA, or have been proposed, but not promulgated. DOE research provides three types of inputs into this process. First, DOE contributes to the science base of regulations by collecting data on emissions and environmental quality near power plants, and by drawing on its knowledge base of mitigation technologies to identify the likely cost and performance of pollution control technology. Second, DOE develops emission control technology for major categories of pollution, such as sulfur dioxide, nitrogen oxides, particulate matter, and toxic air pollutants. Finally, DOE evaluates pending regulations which can significantly impact the electric power sector, and offers recommendations to EPA during the OMB-refereed interagency review process. Current goals for continued research in this area include the development of sound scientific data on which environmental regulations can be based, and the development of lower cost emission control technology to address current and future regulatory mandates.

The Nation's nuclear power plants are aging and approaching the end of their licensed period of operation. Extension of these licenses is critical if this carbon-free source of electric power is to continue beyond 2020. In order to continue to realize the benefits from operation of the current fleet of nuclear power plants, a viable, demonstrated process for license renewal is required within the next few years. Unnecessary costs and uncertainties associated with license renewal need to be eliminated, and practical, economic solutions to generic technical issues have to be developed today and confirmed through longer term R&D activities. The Department, working with the National Laboratories, universities, the Electric Power Research Institute, participating utilities, and other industry organizations, will help resolve the generic issues associated with license renewal and demonstrate a viable license renewal process.

R&D Challenges. During the 2003-2010 period, make technologies available for existing coal power plants that will significantly lower the cost of meeting more stringent environmental regulations.

R&D Activities. DOE is continuing development of technologies to reduce NO_x emissions from fossil-fueled power plants, primarily to reduce the cost of known technologies. In addition, DOE is pursuing several technologies to reduce mercury emissions from power plants, and technologies which simultaneously reduce multiple pollutants including particulates ($PM_{2.5}$), mercury, and SO_2.

Research under the NEPO program will address the three primary needs that nuclear utilities have with respect to license renewal: (1) generic license renewal technical issues need to be satisfactorily resolved now so that the costs of license renewal will be known with more certainty; (2) the entire license renewal process has to be successfully demonstrated, removing the economic uncertainties associated with preparation, approval and operation under a renewed license for plant designs that are representative of current operating plants; and (3) the utilities need a license renewal process that is efficient and relies largely on existing programs so that the cost of a renewed license does not make license renewal uneconomic for smaller, single unit nuclear power plants.

Accomplishments. This effort has met with major successes. For example, due to DOEsponsored stack testing of power plants, it was no longer necessary to use inaccurate estimates of emissions of toxic air pollutants. The better quality data resulted in decisions that further pollution controls for most of these pollutants would not be productive or necessary, saving perhaps billions of dollars per year. Technologies for conventional air pollutants emitted from power plants, developed over the past 25 years through collaboration between DOE, EPA, industry, and academia, are in use both in the United States and internationally. Currently, about one-fourth of all U.S. coal-fired power plants have been equipped with control hardware for sulfur dioxide; nearly all units will have nitrogen oxide controls by December 1999. Research by DOE and the private sector has roughly halved the cost of meeting related environmental regulations. Continued research in this area is projected to have an additional payoff of about $7 billion per year, in reduced compliance costs, by 2010.

The NEPO program will be a new start in FY 2000, so the program has no accomplishments to date.

Hydropower Turbines

Budget: FY98-$0.7M, FY99-$3.3M, FY00-$7.0M

Description, Objectives, and Performers. Hydropower currently contributes a carbon-free 10 percent of the Nation's electricity. However, existing generation is declining, due to a combination of real and perceived environmental problems, regulatory complexity and pressures at the Federal and State level, and changes in economics as a result. Potential hydropower resources are often not being developed for similar reasons.

Current hydropower technology, while emission-free, can have undesirable environmental effects such as fish injury and mortality from passage through turbines, as well as detrimental changes in the quality and quantity of downstream water. The Department's hydropower R&D program is therefore focused on developing advanced hydropower turbine technology which will allow the Nation to maximize the use of its hydropower resources, while minimizing adverse environmental effects.

Program activity is principally applied R&D, managed by Federal personnel and performed by industry partners and National Laboratories. FY 1998 biological testing and analysis activities were performed entirely by National Laboratories, while the proof-of-concept testing initiated in 1999 will be conducted with an industry partner, and the detailed design and model/prototype construction and testing activities in the out-years will be conducted with competitively-selected industry and university partners. The program will continue to be supported with environmental and engineering research and analysis by National Laboratories.

R&D Challenges. The challenges are to demonstrate turbine technology capable of maintaining a dissolved oxygen level of 6 mg/liter by 2005 (ensuring compliance with Federal and State water quality standards), and technology capable of reducing turbine-induced fish mortality to 2 percent or less by 2006, compared to current levels of 30 percent or greater.

R&D Activities. Experiments are currently under way to assess the effects of shear and turbulence on juvenile fish, with emphasis on juvenile salmonids and American shad. The fish will be exposed to levels of shear and turbulence that they might encounter during passage through a turbine and draft tube, and the biological effects will be quantified. The resulting data will be used to develop biological performance criteria for shear and turbulence for advanced hydropower turbine design.

Proof-of-concept testing of a conceptual design completed in 1997 will be initiated in 1999 in order to verify predicted biological performance. Detailed design and model construction and testing activities will begin in 2000, followed by full-scale prototype testing at operating hydropower facilities.

Accomplishments. In 1995, the Department, in collaboration with industry and other Federal agencies, initiated research and development to provide a biological and engineering basis for advanced hydropower turbines. Conceptual designs completed in 1997 incorporate “fish-friendly” features which (among others) minimize the number of blade leading edges, minimize the gap between the blade and blade housing, and maximize the size of flow passages, with minimal penalty on turbine efficiency. The conceptual design phase also revealed gaps in the knowledge of fish response to physical stresses experienced in the turbine environment. Research is now underway to understand these stresses and effects and provide biological performance criteria for advanced turbine detailed design.

Summary Budget Table (000$)

Advanced Power Systems Research Areas	**FY 1998 Appropriated**	**FY 1999 Appropriated**	**FY 2000 Request**
Large High Efficiency Systems	**147,989**	**182,116**	**174,456**
Advanced Coal Gasification & Combustion Systems	61,256	68,526	60,873
- Advanced Coal Combustion	*21,039*	*21,500*	*10,010*
- Pressurized Fluidized Bed Combustion	*17,875*	*14,638*	*12,202*
- Integrated Gasification Combined Cycle	*22,342*	*32,388*	*38,661*
Advanced Gas Turbine Systems	45,000	44,500	41,808
Advanced Large-Scale Fuel Cell Power Systems	40,210	44,200	37,649
Carbon Sequestration	1,523	5,890	9,126
Nuclear Fission Systems	0	19,000	25,000
Distributed and Hybrid Systems	**188,344**	**212,750**	**237,409**
Combined Heat and Power Systems	1,000	1,500	2,000
Advanced Turbine Systems - Industrial and Micro	34,650	51,000	31,300
Distributed Fuel Cell Power Systems (EE)	6,400	0	0
Wind Energy Systems	32,128	33,200	45,600
Photovoltaic Systems	64,691	72,200	93,309
Concentrating Solar Power Technology	16,317	17,000	18,850
Geothermal Systems	5,119	6,000	7,000
Biopower Energy Systems	27,789	31,450	38,950
Reciprocating Engines	250	400	400
Technology Improvement of Operating Plants	**17,165**	**22,735**	**33,744**
Aging Effects in Key Components	5,225	6,225	7,000
Nuclear Power Plants	0	0	5,000
Regulatory Compliance	11,211	13,260	14,744
Hydropower Turbines	729	3,250	7,000
Total	**353,498**	**417,601**	**445,609**