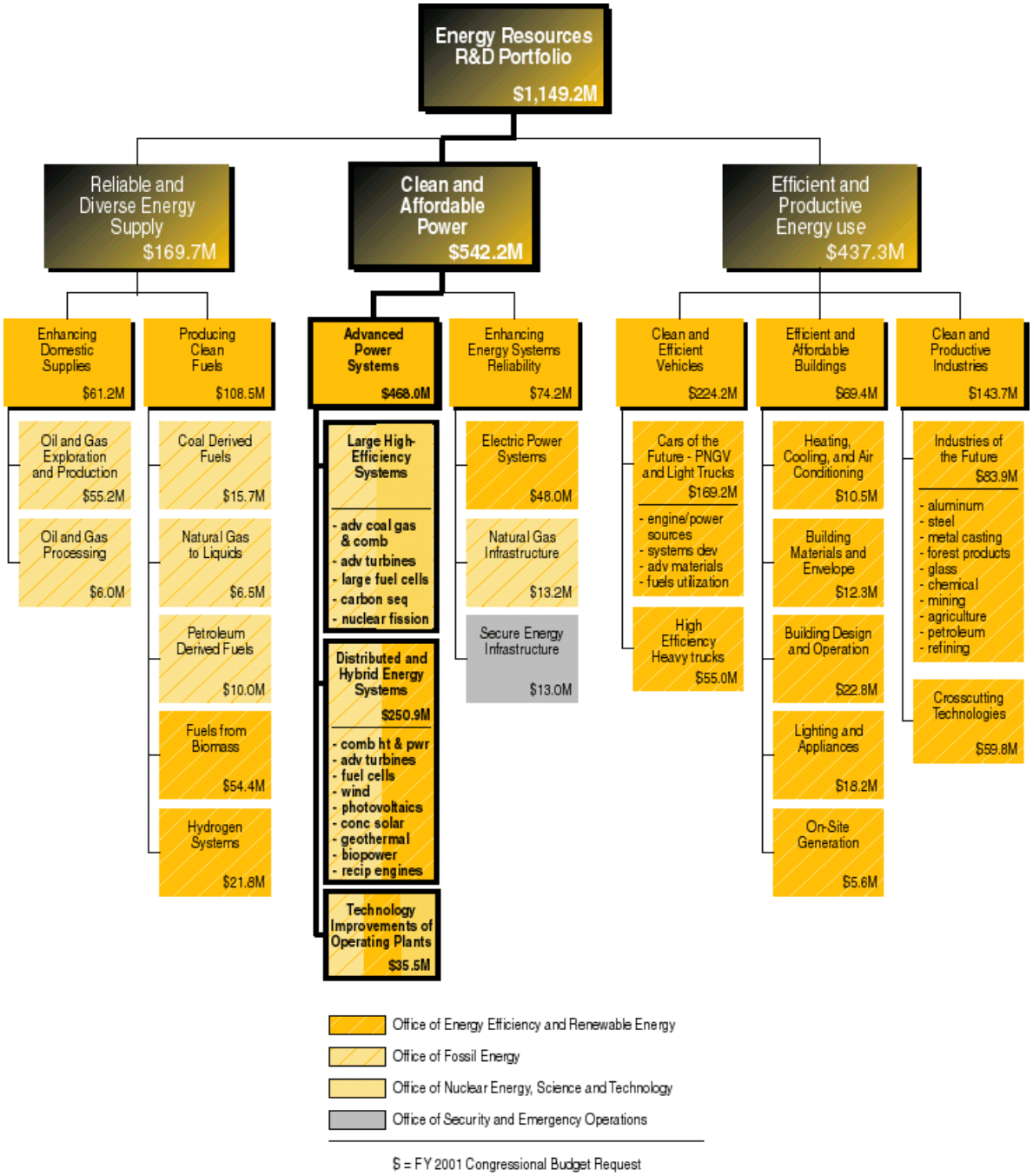
Chapter 5
Advanced Power Systems



Chapter 5
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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 37 percent of all primary energy consumed in the country in 1998, 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 70 percent of the electrical power generated in the United States is fueled by coal, natural gas, and oil; the balance is provided by nuclear (19 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, 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 sequestration (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.

  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 Restructuring Leads to Competition*
  Restructuring of the electric power industry and the movement towards competition will lead to lower electric bills for all 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 $20 billion per year and greenhouse gas emissions reductions of 40 to 60 million metric tons are anticipated from implementation of the proposal. .

  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 quantity 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 Department's fossil energy research program is a reduction of CO_2 emissions, with the vision of ultimately achieving near-zero emissions so 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.

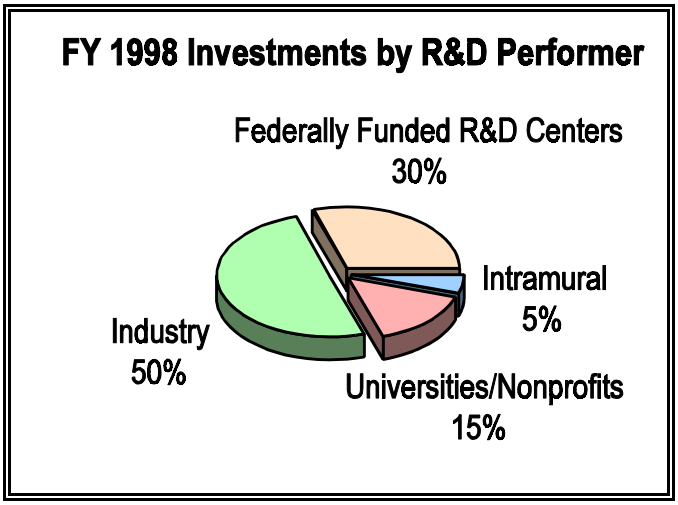
Investment Trends and Rationale

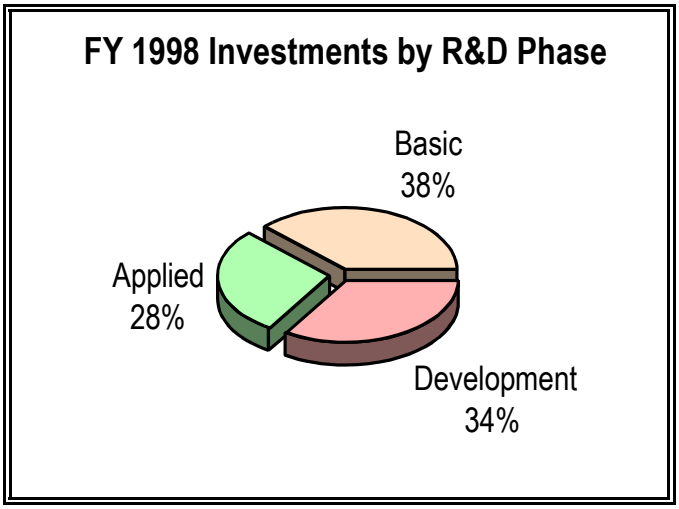
Domestic utilities are perceived to be in a "wait-and-see" mode, given the uncertainties associated with the restructuring of the power generation industry, uncertainties about recovery of new expenditures during the transition to retail deregulation, and competition from other entities such as independent 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 is proposing to spend $451 million on advanced power systems in FY 2001. Advanced power R&D is performed cooperatively with industry, National Laboratories, universities, and State/local governments. The FY 1998 percentage split among these organizations, which not expected to change significantly in the FY 1999-2001 period, is shown below.

Also shown below is a chart showing 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.





There are no foreseen factors that would alter substantially the current mix of R&D performers and types of R&D in the near term, so the FY 1998 breakdown is expected to be valid for the FY1999-20001 period.

Two significant trends are evident in advanced power area. The first is the move toward enhancing economics and environmental performance through the development of multi-product systems. For example, the gas and coal technologies in the large high efficiency systems can potentially be integrated into energy complexes consistent with the *Vision 21* concept, where the products could include power, clean fuels and chemicals. Such complexes could take advantage of opportunity fuels (e.g. agricultural wastes) and employ carbon capture and sequestration to minimize greenhouse gas emissions.

A second trend is the increased emphasis on environmental technologies with major application in domestic and international markets. These include wind, photovoltaic and biopower

renewable energy systems, and carbon sequestration. The FY2001 request for these areas is $201 million, versus a FY 2000 appropriation of $139 million.

The following two FY2001 initiatives are also relevant to the Advanced Power portfolio:

Biobased Products and Bioenergy Initiative
Funding associated with biopower are included in this is a government wide, integrated research, development and deployment effort in bio-based technologies that convert crops, trees, and other "biomass" into a vast array of fuels and products. Biobased industries use agricultural, forest, and aquatic resources to make commercial products including fuels, electricity, chemicals, adhesives, lubricants, and building materials. The initiative supports the President's August 1999 Executive Order 13134 and Memorandum on Promoting Biobased Products and Bioenergy, aimed at tripling the use of biobased products and bioenergy in the United States by 2010. The major goal of this initiative is to make biomass a viable competitor to fossil fuels as an energy source and chemical feedstock, while protecting the environment.

International Clean Energy Intiative
The June 1999 report by President's Committee of Advisors on Science and Technology (PCAST) titled "Powerful Partnership – The Federal Role in International Cooperation on Energy Innovation," addresses ways to improve the U.S. program of international cooperation on Energy R&D to best support U.S. priorities and address the key global energy environmental challenges of the next century. The report includes funding recommendations for a variety of initiatives that include approaches such as tax credits, regulatory assistance, training and Federally-supported R&D. In response, the Department is proposing a variety of international activities in FY 2001 that total $46 million, span most of the seven Energy Resources objectives, and include R&D and other forms of international collaboration. Potential R&D areas relevant to Advanced Power include solar/renewable technologies, hydrogen production via gasification and advanced separation, improved efficiency of operating fossil plants, and nuclear fission.

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 relatively low by historic standards. 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 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: FY99-$176.3M, FY00-$190.2M, FY01-$181.6M

Background

Of the 770 gigawatts of generating capability in the United States shown below for 1998, most are associated with larger, central station facilities. Actual generation (kilowatt hours) in 1998 breaks out differently since some plants are used more than others, and includes coal (52%), nuclear (19%), natural gas (14%), hyrdo/renewable (11%) and petroleum (3%).

Electricity Generating Capacity in 1998		
Primary Energy Source	**Capacity (Gigawatts)**	**Percent of Total Capacity**
Coal	305	40
Oil/Gas Steam	138	18
Gas Combined Cycle	20	3
Combustion Turbine/Diesel	73	9
Nuclear Power	97	13
Conventional Hydroelectric	77	10
Other Renewable	10	1
Cogenerators (60% gas)	50	6
Total Capacity	770	100

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 have emissions well below the New Source Performance Standards (NSPS) for SO_2, NO_x, and particulates, 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 sponsors 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: FY99-$65.5M, FY00-$69.9M, FY01-$58.9M

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: FY99-$21.0M, FY00-$9.0M, FY01-$2.0M

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 2000ºF radiant air heater has been tested successfully.

Pressurized Fluidized Bed (PFB) Combustion

Budget: FY99-$14.4M, FY00-$12.2M, FY01-$11.2M

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 and temperatures produce a high-pressure gas stream that can drive a gas turbine, and steam generated by the combined cycle system 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 Advanced Circulating Pressurized Fluidized Bed Combustion (APFBC) combined cycle power system is capable of achieving efficiencies of 46% or higher and is highly suited for repowering as well as greenfield site applications. 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 completing a first generation 80 MW_e 40% efficient pressurized fluidized bed demonstration project in Brillant, Ohio (TIDD Plant) . The program also succeeded in developing and commercially deploying very clean, atmospheric fluidized bed systems globally—over $8 billion in sales have been reported.

Gasification Technologies

Budget: FY99-$30.2M, FY00-$48.7M*, FY01-$45.7M*

*Includes $13.5M in FY00 and $13.7M in FY01 for gasification related to pulp/paper

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.

In FY 2000, a major new initiative focusing on the application of gasification to the pulp and paper industry is being implemented. The objective is to develop safer, less expensive, and environmentally friendly alternatives to conventional pulping liquor processing and wood residual combustion. Gasification has the potential for achieving higher thermal efficiency, exceeding known and anticipated emissions standards for SO_2 and NO_x, enhanced separation and regeneration of pulping chemicals, higher electric power generation, and improved safety.

R&D Challenges. The key R&D challenge for IGCC is to reduce capital and operating costs while simultaneously improving both the reliability and overall system availability, 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 Vision 21.

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

To employ advanced technologies such as fuel cells, to convert synthesis gas to other products (i.e., chemicals and fuels) 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, cost-competitive 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 from 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 Cleaning and Conditioning 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 to promote utilization and direct sulfur recovery processes.

This new government/private sector pulp and paper initiative is focusing on the commercial demonstration of gasification-based technologies at existing U.S. mills. Successful demonstration of these technologies will provide the industry with the information needed to make informed capital budgeting decisions regarding the replacement of existing technologies with technologies that are far superior in complying with emissions regulations.

Accomplishments. The program has progressed from the basic research or idea stage over 20 years ago through large-scale demonstration to the early stages of commercial operations. Three first-generation (42 percent efficient) commercial demonstration plants are now operating under the DOE's Clean Coal Technology Demonstration Program and one which is in the design/engineering phase is estimated to commence operation in 2002. During this time period, which is atypical for developing new power systems, the program has been highly successful in developing the critical system components (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: FY99-$43.4M, FY00-$44.2M, FY01-$26.0M

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 National Energy Technology Laboratory 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: FY99-$43.1M, FY00-$44.5M, FY00-$42.2M

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, natural gas 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: FY99-$5.8M, FY00-$9.2M, FY01-$19.5M

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. Increased concentrations of CO_2 due to carbon emissions are expected unless energy systems reduce the carbon load to the atmosphere. Accordingly, carbon sequestration–carbon capture, separation, and storage or reuse–must play a major role if we are to continue to enjoy the economic and energy security benefits which fossil fuels bring to the nation's energy mix. 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.

The program vision is to possess the scientific understanding of carbon sequestration and develop to the point of deployment those portfolio options that ensure environmentally acceptable sequestration. The long-term program cost goal is to reduce the net cost of sequestration to $10 per ton or lower by 2015.

Compared to most research in the Department, the sequestration research portfolio is a relative newcomer. In the near- and mid-term, the program will examine science-based sequestration approaches that have the greatest potential to yield cost effective technologies. This includes "value-added" approaches with multiple benefits, such as in promoting enhanced oil recovery while sequestering CO_2, sequestering CO_2 associated with natural gas production, and enhancing recovery of coal bed methane. Longer-term, the technology products will be more revolutionary, relying less on site-specific or application-specific factors to ensure economic viability. The program's research portfolio is closed linked to the Vision 21 program. For example, many of the advanced energy technologies being developed as part of the Vision 21 Program produce a relatively new stream of CO_2 that is amenable to capture and storage.

The program selects research topics and projects through competitive solicitations involving industry, universities, and national laboratories. International collaboration is extensive, and includes work with the International Energy Agency (IEA) Greenhouse Gas R&D Programme and the Climate Technology Initiative of the Framework Convention on Climate Change.

R&D Challenges. The challenge is to develop technologies and practices to sequester carbon that (1) are effective and cost-competitive, (2) provide stable, long-term storage, and (3) are environmentally benign.

R&D Activities. The program is examining approaches which separate, capture, and store (in geologic formations, the oceans, and vegetation and soils in terrestrial ecosystems) emissions from advanced power cycles, including 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. Since the initiation of the program in 1998, extensive stakeholder outreach and planning exercises have been conducted to help determine the appropriate R&D focus and direction. In particular, in collaboration with the DOE Office of Science, the report *Carbon Sequestration: State of the Science* was developed. It identifies the five major areas of needed R&D that are the basis of the program. Subsequently, focused workshops are being held on specific technical topics. For example, a September 1999 workshop in CO_2 Capture and Geologic Sequestration was cosponsored by DOE, the IEA, and BP/Amoco, an industry leader in reducing CO_2 emissions. In late 1999 the Office of Fossil Energy issued two related solicitations: One limited to National laboratory proposers and another aimed at academia and industry. Both solicitations are broad-based, covering the five program areas of interest: capture and separation, ocean sequestration, geologic sequestration, terrestrial sequestration, and

advanced chemical, biological, and other concepts. Selections under the two solicitations will be made in early 2000. In addition, 6 of the 12 projects which were funded under the Novel Concepts procurement in 1999, were chosen for continued research under a down-selection procedure in late 1999.

Nuclear Fission Systems

Budget: FY99-$18.5M, FY00-$22.4M, FY01-$35.0M

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.

The International Nuclear Energy Research Initiative (I-NERI) provides for world-wide R&D of new technologies to address the key issues affecting the future of nuclear energy, in particular, the economics of nuclear plants, safety, proliferation, and waste management issues. I-NERI will give the U.S. a key "seat at the table" at on-going international discussions regarding the future implementation of nuclear technologies and those areas that are important to U.S. policy objectives.

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.

I-NERI will include foreign collaborative research focused on advanced technologies for improving the cost, safety, waste management, and proliferation resistance of advanced nuclear energy systems through specific cost-sharing arrangements with each participating country. Long-term nuclear technology research will be in the areas of new and innovative reactor designs, proliferation-resistant fuel cycles, nuclear science and engineering with particular countries under bilateral agreements.

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. In FY 1999 initial R&D procurement was completed by soliciting research proposals, conducting proposal peer-review and awarding the first research grant and contracts in May 1999. NERI initiated innovative scientific and engineering research and development projects at universities, national laboratories, and industrial organizations that will enhance the performance, efficiency, reliability, proliferation resistance, and economics of nuclear power. A total of 46 proposals were selected for award.

Nuclear Fusion Systems

Budget: FY99-$216.1M, FY00-$237.7M, FY01-$240.1
(These funds are part of the Science Portfolio and are repeated here for information purposes only)

Description, Objectives, and Performers. The process of nuclear fusion - evident in stars, including the sun - releases enormous amounts of energy. The three goals of the program are to advance plasma science, identify and explore innovative and cost-effective development paths to fusion energy, and explore the science and technology of energy producing plasmas as a partner in an international effort. The mission is to advance the knowledge base needed to make fusion an economically and environmentally attractive power source for the future. This research is conducted at national laboratories, universities, and industrial firms.

Research Challenges. There are two promising approaches to achieving fusion energy: magnetic and inertial confinement. Theory and simulation of plasma behavior in both magnetic and inertial fusion is complex because of the many orders of magnitude in spatial and temporal scales involved. It is further complicated by the need to understand electromagnetic wave/plasma interactions and plasma material interactions. Magnetic confinement experiments require innovative configurations of magnetic field lines to contain the hot fusion plasmas. Inertial

fusion experiments require simultaneous illumination of the full surface of fusion fuel pellets by high-energy beams to create the needed inertial confinement.

The long-term potential for successful commercialization of fusion energy could radically change the overall pattern of electricity generation. Because fusion power plants would not produce air pollutants that contribute to acid rain and that may contribute to global climate change, they could minimize the environmental risks associated with the burning of fossil fuels. Further, because fusion power plants would contain only small quantities of fuel at any time, they could eliminate the potential for runaway reactions that might lead to accidents. The development of low-activation materials or advanced fuel cycles for fusion reactors could make the amounts of high-level radioactive waste that result from fusion-produced energy far smaller than those produced by fission reactors-thus simplifying waste disposal problems.

Although the burning of fusion fuels (deuterium and tritium) does not produce radioactivity, the tritium itself is radioactive, and the neutrons produced by fusion will induce radioactivity in surrounding materials.

Although fusion has great potential as a safe and environmentally benign source of energy, there are safety and environmental issues associated with radioactive materials in future fusion devices; these issues will need to be addressed Developing an attractive fusion energy source requires major advances in technologies for plasma and neutron-interactive fusion power core components and in neutron-interactive structural materials with the potential for superior performance in fusion energy systems. The hostile neutron irradiation environment of future fusion power cores will place unprecedented demands on structural materials.

Research Activities. Theoretical and computational research in plasma science provides the predictive capability needed to make progress in plasma and fusion science. Current research areas include plasma turbulence and its effect on the transport of particles and energy in plasmas, macroscopic equilibrium and stability of confined plasmas, edge plasma physics and plasma material interactions, plasma heating and current drive with radio-frequency waves, and understanding the characteristics of innovative confinement configurations. Plasma theory and simulation are also key to understanding other scientific phenomena, such as magnetic reconnection in solar and magnetospheric plasmas or turbulence, chaos, and self-organized behavior in complex systems. Finally, simulation in plasma physics is similar to and promotes progress in fields such as computational fluid dynamics and climate modeling.

The plasma technologies program provides the technology tools needed to create, control, and understand the high-temperature plasma state in fusion experiments. Collaborative experiments with our major international partners are under way in magnetic fusion research. The experimental program with heavy ion drivers for inertial fusion energy shows promise for significantly advancing inertial fusion science.

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: FY99-$224.1M, FY00-$201.8M, FY01-$250.9M

Background

The U.S. electric industry and natural gas industry are undergoing fundamental change due to restructuring and the addition of new electric generation power suppliers and products and gas transmission, 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 low-cost 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 and I.C. engine technologies have 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 1998, while the remaining renewable resources supplied is nearly 2 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 heat, power, and cooling and improved indoor air quality in buildings; on the distribution system, to provide high value electricity and deferral of costly power line upgrades and replacement; off-grid in stand alone power applications; and for electricity supply to the bulk power market.

Diesel electric generators currently provide electrical power in remote villages. These generators are reliable if properly maintained, and the low cost of oil make them relatively economical. In their most efficient use, the waste heat is recovered and used for space heating (usually for a large building, such as a school) with total system efficiencies of about 60%. The cost of producing electricity is high in the villages for several reasons. Transporting diesel fuel to the village is the most obvious cost. Since there are no roads, fuel must be barged or flown into the village. Building and operating an electrical utility also requires skilled labor, both for linemen to string wires between houses, and also for mechanics to maintain the diesel engines. As the villages grow smaller, it becomes less and less likely that a person with these skills will be found in the village, so technicians must be brought in from outside, at considerable expense. Since each village is isolated and not connected to a grid, backup power must be provided within the village, by redundancy in the diesel generators, resulting in high capital costs. And furthermore, as the villages become smaller, the per residence cost rises simply due to the reverse of the economies of scale: fixed costs are distributed over fewer users. In addition, because the generators need to be sized for peak demand the generators are most frequently operated significantly below the optimal efficiency

The hydrogen program promotes the development of distributed electric power systems using hydrogen-powered fuel cells. These systems are expected to have many long-term benefits: increased energy efficiency through cogeneration; reduced pollution through the use of hydrogen-powered fuel cells; and increased energy independence by enabling renewable energy sources that produce hydrogen as an energy carrier. The near-term goal of this program is the advancement of this technology by proving that current technologies can be used for distributed, proton exchange membrane fuel cell (PEMFC) energy generation in remote locations. Of specific interest here is the development of systems several kilowatts in size, optimized for and located in individual homes that are not connected to an external electric grid. The power systems under development are comprised of a fuel reformer for conversion kerosene or diesel into hydrogen for use in a fuel cell, a PEMFC, and utilization of waste heat from the PEMFC for residential space and water heating.

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, photovoltaic, concentrating solar power, geothermal, and biomass), and in the area of co-generation, both Industrial Combined Heat and Power (ICHP) and Buildings Cooling Heating and Power (BCHP), with smaller fuel cells (25-50kW), and small gas turbines and reciprocating engines. Emerging technologies in the BCHP programs will significantly contribute to electric peak shaving during the cooling season, when cooling energy is dominant, in buildings comfort conditioning using desiccant systems, and gas heat pumps and chillers.

Industrial Combined Heat and Power Systems

Budget: FY99-$0.2M, FY00-$3.0M, FY01-$1.0M

Description, Objectives, and Performers. Industrial Combined Heat and Power (ICHP) is not a new technology, especially for large industrial applications. With the passage of the Public Utilities Regulatory Act of 1978 (PURPA), new rules were put into effect designed to increase the efficiency of fuel use by removing regulatory and institutional barriers to the development of CHP. PURPA required utilities to interconnect with qualified CHP facilities, provide back up power at reasonable rates, and purchase any excess electricity at the same rate the utilities would have had to pay to generate it themselves. Additionally, on average, two-thirds of the fuel used to make electricity in the U.S. is wasted. 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.

Since the oil price shocks of the 1970s there have been impressive energy efficiency gains in many sectors of the economy , but the introduction of state-of-the-art (more efficient) fossil fuel power plants has been slow. The result is that the average plant efficiency of power generation in the U.S. has increased very little. However, there has been a dramatic increase in the use of combined heat and power systems at large industrial plants. 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, as well as field-test innovative CHP systems.

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 even more. Government and industry, in partnership, have the opportunity to address the technology challenges associated with optimizing heating, cooling, and power systems for on-site distributed use for both industrial and buildings applications. These new government-industry partnerships should be in addition to those that are already addressing the 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, to achieve a goal of doubling the amount of CHP in the United States (46 GW) by 2010. Some of the barriers addressed follow:

- 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 ICHP 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 will field-test innovative CHP technology solutions for the industrial, residential, and commercial systems. 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 technology development and technology integration into the end-use sector.

R&D Activities. Some of the power generation technologies being developed by DOE and industry such as microturbines, reciprocating engines, and fuel cells are aimed at fuel flexibility and other modifications to accommodate a variety of energy needs. CHP is an energy efficiency strategy that includes the Offices of Building Technologies (and??), Power Technologies, and Industrial Technologies.

Accomplishments. In December 1998, the program held a national workshop. In August 1999, the program initiated a technology demonstration of a ceramic combustor liner CHP system in the industrial sector; and facilitated industry in developing a vision for advanced power generation systems. In addition, three regional workshops were held. In February 2000, an international workshop will be held to address the issues of reducing global emissions and increasing efficiency in developing countries (in support of PCAST).

Buildings Cooling Heating and Power (BCHP) Systems

Budget: FY99-$0.0M, FY00-$0.0M, FY01-$3.0M

Description, Objectives, and Performers. The Department of Energy has embarked on significant partnerships with industry with the intent of creating meaningful research, development and commercialization program plans. Reviewing progress among these important efforts, the natural gas industry together with manufacturing trade allies in the onsite power generation and thermally activated HVAC industry concluded that a significant technology synergism opportunity exists. To address this opportunity, the DOE with industry has created the BCHP Initiative and is proposing BCHP 2020 Vision in support of the Department's ICHP program in the Buildings Sector.

New and emerging BCHP system choices include a spectrum of technologies, such as fuel cells, micro turbines and the about-to-be commercialized industrial advanced turbine system (ATS), which are more economically attractive, reliable, and versatile and should open new markets for both BCHP and ICHP. New thermally driven cooling and humidity control technologies are likewise being developed and demonstrated which can potentially utilize the heat output very effectively.

BCHP along with ICHP offers great potential for the environment. A September 1997 study in which five DOE laboratories examined more than 200 technologies, entitled *Scenarios of U.S. Carbon Reductions*, found that just three BCHP and ICHP type applications –advanced turbines, fuel cells, and integrated combined cycle technologies – accounted for nearly 10 % of the projected carbon savings. The next generation of turbines, fuel cells, and reciprocating engines offer efficiency at reduced size, versatility in the ratio of electric or mechanical energy to thermal energy, and can be combined with advanced heat recovery-driven cycles for the highest possible overall source energy efficiency and lowest carbon emissions.

Energy is used to provide a wide variety of services in buildings including occupant comfort (temperature and humidity control), desiccants, lighting, water heating, and power to drive appliances and other miscellaneous electrical devices. The US consumed almost 93 quadrillion

BTUs (Quads) of energy in 1996. Of this total, commercial buildings accounted for over 15 Quads. This is equivalent to the amount of gasoline consumed in a year.

There is a distinct opportunity to significantly conserve resources and reduce climate change gas emissions by accelerating the use of Building Cooling, Heating and Power systems in commercial buildings. Good planning and development in the area of building envelopes and windows will yield a 15% benefit. Historically research, development and commercialization efforts have been focused on individual equipment (e.g. cooling, thermal storage, ventilation air systems, power generation and cooling). BCHP now focuses on building power and HVAC system optimization and integration using efficient equipment. This yields remarkable building level energy efficiency gains and emission reduction achievements

Today, electric power industry restructuring, coupled with the unbundling of various components of electric service, is ushering a new era in which customers will have greater opportunities to optimize their energy services than ever before.

Many of the same barriers that confront the implementation of ICHP confront the implementation of the BCHP.

- Environmental permitting, codes and standards, regulations.
- Energy incentives, tax credits
- Cost of fuel
- Cost of new and emerging technologies

BCHP has the potential to reduce carbon and air pollutant emissions and increase source energy efficiency dramatically. BCHP produces both electricity and useable thermal energy onsite for input to thermally activated heat pumps, chillers or desiccant regeneration, converting as much as 90% of the fuel into useable end use energy. This is compared to conventional central station power plants, which convert only about a third of the fuel's available energy into useable electric power energy. New and emerging BCHP system choices include a spectrum of technologies, such as fuel cells, micro turbines and the about-to-be commercialized industrial advanced turbine system (ATS), large commercial chillers, residential heat pumps which are more economically attractive, reliable, and versatile and should open new markets for BCHP. New thermally driven cooling and humidity control technologies are likewise being developed and demonstrated which can potentially utilize the BCHP heat output very effectively.

R&D Challenges. R&D challenges include cost effective, advanced absorption commercial chillers, higher temperature PEM fuel cells, residential chillers/heat pumps, advanced desiccant materials and systems.

R&D Activities: R&D in small-scale (25 – 50 kW) PEM fuel cells for buildings, large commercial building LiBr/H20 chiller, residential NH3/H2O absorption heat pumps, liquid and solid advanced desiccant systems.

R&D Accomplishments. In FY1999, the program held three workshops for BCHP, fabricated two gas fired Ammonia/Water prototype absorption heat pumps for residential application. Tested several desiccant systems in high occupancy buildings.

Advanced Industrial Turbine Systems Budget: FY99-$49.4M, FY00-$22.3M, FY01-$13.3M

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 9 parts per million NO_x and CO_2 at an equivalent reliability and reduced cost compared to today's technology.

There are over 150 partners in the Advanced Turbine Systems program that represent 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 advanced industrial turbines will require advancements in engine and component design, including innovations in cooling, heat recovery, combustion, materials, and coatings. For advanced turbines improved and new ceramics and coatings will enable turbines to have higher efficiency, lower emissions, longer life, and to be fuel flexible.

R&D Activities. The Advanced Turbine program is developing industrial gas turbines and microturbines to meet goals previously mentioned. Additional work supports major component development in the combustor and power turbine. These elements include low-emissions technology development and advanced materials (e.g., ceramics, advanced coatings). Engine development and testing continues to improve gas turbine efficiency, environmental performance, and long-term durability.

In the microturbine area, the program is working with the Electric Power Research Institute (EPRI), the California Energy Commission (CEC), and Southern California Edison to test the performance characteristics of commercially available microturbines to establish a technology baseline. Additional information will be gained from a joint field test program with EPRI and the National Rural Electric Cooperative Association (NRECA) to site nine microturbines at cooperative locations across the United States. The development of ceramics and new corrosion-resistant metals for recuperators will continue, focusing on improving durability of the materials

in microturbine engine environments. A competitive solicitation will be released in FY 2000 for advanced microturbine projects including concept design, component and sub-component development, and testing.

Accomplishments. An early success of the program will be the demonstration of the "Mercury 50" advanced turbine by Solar Turbines, Inc., in early 2000. 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, ceramic composite combustor liners have been run for approximately 2000 cumulative hours in an industrial gas turbine at Texaco in Bakersfield, California. The goal of the effort is to run several ceramic components (blades, vanes, and nozzles) for 4000 hours.

Data reports on microturbine performance and operating and maintenance logs are being generated for the various microturbines tested under the Southern California Edison project. Work continues to develop a performance-based design database for silicon nitride ceramics and improve the durability in high-temperature water vapor environments. Advanced manufacturing, including automation, are being applied to the production of silicon nitride small turbine parts.

Hydrogen Fuel Cell Systems

Budget: FY99-$0.0M, FY00-$5.5 M, FY01-$8.8M

Description, Objectives and Performers. This is a three-year effort to develop distributed PEMFC technology and demonstrate its use in remote settings, specifically in Alaskan villages. This is being accomplished by fostering ongoing commercial activity in the areas of importance for this activity, including the development of diesel and kerosene reformers capable of producing useful hydrogen streams, efficient fuel cell systems in the several kilowatt range, and encouraging systems integration to achieve high overall system efficiencies through cogeneration.

The near-term objective of this program, which is being accomplished through a solicitation process, is to assemble teams of industrial partners that can supply field distributed, hydrocarbon fed, and fuel cell power systems. As many of the necessary components are in the development stage, the near-term goals are set to ensure that components with the necessary long-term specifications are being developed now, leaving system integration and fielding for later in the program.

This program is being executed in three phases. During the first phase, three PEMFC stacks and two reformers were delivered for evaluation. The second phase will focus on systems integration, with the components being integrated into hydrocarbon-fed, fuel cell powered, energy systems. The third phase will consist of field testing the completed distributed energy systems in a remote setting

The principle customer for this program is the residents of Alaskan Villages. The University of Alaska at Fairbanks (UAF) is a partner in this program and provides arctic engineering expertise.

The UAF will actually qualify these technologies for use in the remote village environment. Hence, UAF is the most immediate customer for this program.

The performers are Teledyne Brown Engineering, Schatz Energy Research Center, Schatz Energy Research Center and another team to be awarded in January, 2000.

R&D Challenges: A significant technical barrier is the development of a reformation technology that can suitably reform diesel and/or kerosene for use in PEMFC's and do so with a reasonable time between failure. In addition, the systems are being designed to be fully automated in the field.

R&D Activities: Steam reforming and auto-thermal reformers are being developed for this system that include the development of advanced catalysts that are resistant to sulfur and soot formation. Small-scale hydrogen fuel cells are being developed to operate off the gases produced by these reformers.

Accomplishments: A diesel reformer was operated in July 1999. A three to five kilowatt PEMFC using hydrogen reformed from diesel fuel operated in September 1999.

Wind Energy Systems

Budget: FY99-$34.1M, FY00-$32.5M, FY01-$50.5M

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: FY99-$70.6M, FY00-$65.9M, FY01-$82.0M

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 direct manufacturing cost of commercial modules by 15 percent from current average costs of about $4.25 per watt and increase annual U.S. sales of commercial modules from 40 megawatts in 1996 to 70 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 180 megawatts.

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: FY99-$16.8M, FY00-$15.2M, FY01-$15.0M

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 Energy

Budget: FY99-$21.7M, FY00-$23.6M, FY01-$27.0M

The accessible geothermal resource is the thermal energy contained in the rocks within the top three miles of the Earth's crust. This heat energy is carried by naturally occurring hot water or steam brought to the surface through deep wells, and the fluid is used to drive turbine-generator systems to produce electricity or heat is used directly for industrial, agricultural, or domestic purposes. The Department is working with industry to solve the major R&D challenges in the exploration, drilling, and reservoir management of geothermal resources. The goals are to reliably detect producing fractures in hydrothermal systems; to efficiently drill and complete wells under conditions of high temperature, hard rock, and corrosive fluids; and to economically operate production and injection wells for the maximum energy yield as a sustainable resource.

Geothermal Exploration

Budget: FY99-$5.4M, FY00-$6.0M, FY01-$6.0M

Description, Objectives, and Performers. To improve the detection of producing zones in geothermal reservoirs, the Department in partnership with the geothermal industry is augmenting the technology for 3-D seismic surveys and electromagnetic logging.

R&D Challenges. The major challenge in exploration for geothermal resources is the detection of producing zones deep in the subsurface so that drill holes can be directed from the surface to intersect them. Lower well costs would result in expanded use of geothermal power by making this environmentally-preferred alternative more economical.

Present exploration techniques are not specific enough to identify producing zones, and their application results in too many dry wells, driving up development costs. The industry needs better geological, geochemical, and geophysical techniques to identify and characterize the geothermal reservoirs. Technology improvements are needed to reduce the cost of drilling into hard rock at high temperatures which contain corrosive formation fluids, and cements must be developed to maintain well integrity in acidic conditions and high temperature.

R&D Activities. The geothermal reservoir contains steeply dipping faults and fracture zones which provide the high permeability pathways for geothermal fluid production, and the opposing rocks may have only a slight contrast in seismic velocity. Shear-wave generators are being tested to determine the best technique to provide the seismic energy needed for characterization of the geothermal production zones. Geophone array configurations will be tested in mathematical models to determine the optimal design for increased accuracy of location and decreased biasing of the data.

To increase the success of exploration wells intersecting productive fractures, joint Department-industry research is developing a deep-penetration electromagnetic logging tool. The initial activity will be development of the theoretical basis for the electrical response and the mathematical procedures for interpretation of the measurements. The major challenge will be the construction of a tool that will have sufficient signal strength and receiver separation distance to allow the imaging of potential producing fractures within a radius of 100 feet from the exploration well.

Accomplishments. Development of better interpretation methods for imaging logs have revealed the evolution of faults and fractures in relation to regional stresses in the Earth, and this has led to knowledge of the local control of fracture permeability in the geothermal reservoir. Research on surface electromagnetic survey methods has resulted in improved geothermal field definition with greater instrument reliability and more credible interpretation mathematics. Fluid inclusion studies of secondary alteration minerals from geothermal systems allow developers to determine the changes in salinity and temperature of geothermal fluids with time.

Geothermal Drilling and Completion

Budget: FY99-$4.9M, FY00-$5.5M, FY01-$5.5M

Description, Objectives, and Performers. Geothermal drilling R&D consists of two key components over the next 5-years: incremental improvements for geothermal drilling technology and a high-speed diagnostics-while-drilling (DWD) system.

R&D Challenges. Geothermal wells cost 35-50 percent of the costs of a typical geothermal electric power project. Geothermal well costs can be significantly reduced by improving the technology used in geothermal drilling. Reduced drilling costs is the key to the expansion of geothermal power from traditional hydrothermal resources to hot dry rock, the next generation of geothermal power.

R&D Activities. Activities include the application of advanced techniques, materials and equipment including: a core-tube data logger to collect downhole data while drilling; advanced

hard rock polycrystalline diamond compact (PDC) drill bits to drill harder rock; a dewared pressure/temperature/spinner logging tool to provide data in high-temperature wells; and development of slimhole drilling to reduce exploration costs by about 50 percent. The second involves the conceptual work, technology development, field testing necessary, and possible commercialization for the use of a high-speed DWD system. Real-time drilling and logging data, analyzed and used in real-time to control the drilling process, will result in dramatic improvements in drilling performance and reductions in well costs.

Accomplishments. Conducted initial design and testing of PDC drill bits now used in about 40 percent of drilling worldwide, an industry with annual sales in excess of $200 million. In addition, the program developed high-temperature drilling muds, high-temperature elastomers for downhole motors, advanced drilling fluid flow instrumentation, high-temperature memory logging tools; and fostered the use of slimhole drilling as an exploration tool for geothermal energy saving 30 to 50 percent of exploration drilling costs.

Geothermal Reservoir Technology

Budget: FY99-$5.4M, FY00-$6.0M, FY01-$5.5M

Description, Objectives, and Performers. The strong collaboration between the Department and industry in the areas of reservoir modeling, tracer technology, and the study of water absorption is the major focus of geothermal reservoir production.

R&D Challenges. The development of geothermal energy systems requires improved computer methods for modeling heat-extraction and water injection strategies from geothermal reservoirs. An entire suite of chemical tracers are needed to track the migration of injected water through the geothermal reservoir to the production zone to avoid premature breakthrough of cooled production fluid. It is necessary to quantify the relative permeabilities of water and steam in the geothermal reservoir to develop the best strategy for injection of cold water to avoid reservoir pressure loss. A knowledge of adsorption of water on mineral surfaces is important in low-pressure geothermal reservoirs to determine the amount of fluid reserves available for production.

R&D Activities. The possibility of water adsorption on mineral surfaces as a significant source of fluid in low-pressure geothermal reservoirs is being investigated by collaboration between Lawrence Berkeley National Laboratory and Stanford University through measurements of mass change in rocks as a function of water saturation in steam. This research will have important ramifications for the operating pressure of a geothermal reservoir and for the optimum conditions during water injection.

Collaboration between the Department and industry is enabling the development of chemical tracers that are compatible with the environment, do not react with the reservoir rocks, are thermally stable at reservoir temperatures, and can be detected in minute quantities. These tracers show the path of injection water through the reservoir, and they provide a measurement of transit time for a chemical front between injection and production wells. Operators can avoid the temperature drop that would result from rapid breakthrough of cold injection water into the

production zone of the reservoir. When cold injection water is used properly to maintain reservoir pressure, geothermal energy is sustainable over long periods of time.

Basic experimental laboratory studies are being conducted to determine the relative permeabilities of reservoir rock to steam and hot water. Empirical evidence has shown that the different phases travel through the reservoir at different rates, and this fundamental property is required for accurate reservoir modeling. Testing of potential tracers is continuing because different tracers are needed to identify the water from each injection well in an operating geothermal field with a large number of production and injection wells.

Accomplishments. Program accomplishments include:

- Demonstrated the application of reservoir modeling to geothermal systems to predict longevity and total energy recovery. Model improvements are underway to incorporate mineral precipitation in the prediction of reservoir permeability.

- Identified and tested chemical tracers for monitoring flow of injected water through geothermal reservoirs.

- Analyzed causes of reservoir pressure decline at the Geysers Geothermal Field and developed effective injection strategies to sustain reservoir productivity.

Geothermal Systems

Budget: FY99-$6.0M, FY00-$6.1M, FY01-$10.0M

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 Energy Systems

Budget: FY99-$30.8M, FY00-$31.8M, FY01-$48.0M

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: FY99-$0.5M, FY00-$2.0M, FY01-$2.3M

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 and back-up power generation. 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 transportation, residential, commercial, and industrial (chemicals, petroleum, natural gas, agriculture, metal refining and casting) sectors. Another application is gas compression. Reciprocating engines use a variety of fuel sources, including natural gas, diesel, waste fuels, and low-Btu fuels. The objective of this activity is to develop a 50 percent efficient natural gas fired reciprocating engine with emissions less than 9 parts per million of NO_x.

R&D Challenges. Challenges include developing low-emission technology solutions, obtaining efficiencies greater than 40 percent, fuel-flexible ignition systems, maintenance and operation, and the heavy use of lubricating oils.

R&D Activities. Elements of this program are leveraging efforts performed in the Office of Transportation Programs, Diesel Engine program. A Stationary Engine program will be initiated in FY 2000 to develop an advanced reciprocating engine system as a key component to enhancing industrial power generation/cogeneration technologies. A research consortium is performing work on pre-competitive issues such as advanced materials, advanced ignition systems, combustion development, sensors and controls, catalyst development, and oil reduction. Partners in this gas engine consortium include the Federal Energy Technology Center, Gas Research Institute, and Southwest Research Institute.

Accomplishments. In December1998, a workshop was held to identify research needs and opportunities to meet stated goals. A program plan will be developed in FY 2000.

Technology Improvement of Operating Plants

Budget: FY99-$22.2M, FY00-$31.5M, FY01-$35.6M

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 363,000 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 conducted no R&D in FY 1998 or FY 1999, but is starting a new R&D initiative in FY 2000, the Nuclear Energy Plant Optimization (NEPO) program. The NEPO program is a 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 150 million metric tones of carbon annually. Nuclear energy's continued role in electricity production is necessary so that our Nation can meet its global climate change commitment. These plants are also critical to helping utilities meet state implementation plans and EPA requirements for Clean Air Act compliance. 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: FY99-$6.1M, FY00-$7.0M, FY01-$7.4M

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: FY99-$0.0M, FY00-$5.0M, FY01-$5.0M

Description, Objectives, and Performers. Over the last couple of years, there have been significant changes in the strategic landscape -- a growing recognition of the importance that our existing nuclear power plants play in meeting the needs of the nation for electricity during the first half of the next century and their importance in complying with our environmental laws and meeting international commitments on climate change. Two years ago, with electricity restructuring looming and concerns over regulatory uncertainty, the prediction was that the existing nuclear plants were doomed -- that fewer plants would seek license extensions and that many would shut down prematurely. Today, with consolidations in ownership occurring and several plants announcing their intention to seek license extensions, it is clear that there is a future for many of the U.S. nuclear power plants. However, for these plants to remain viable beyond 2020, both government and industry must take action – government reducing regulatory and other barriers to operation and industry, investing capital in the upgrading their facilities for

the future and investing in short-term R&D. Also, together, government and industry should explore intermediate-term evolutionary technologies to sustain these plants. For these reasons, the Department is initiating the Nuclear Energy Plant Optimization (NEPO) program, a new program in fiscal year 2000.

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 the long-term effects of nuclear plant aging.* R&D conducted under NEPO would provide a better understanding of material degradation mechanisms and how they occur, enabling development of cost-effective aging management strategies which will provide capabilities to easily prevent, detect, or repair the degradation.

- *Optimizing power generation through efficiency and productivity improvements.* Current nuclear plants were designed and are operating with technology developed over 25 years ago. As plants age, components and parts degrade or become obsolete, introducing inefficiencies, added costs, and unreliability. There have been significant technology advancements over the last 25 years that are applicable to power generation, particularly in computers, communications, materials, sensors and digital electronics, and artificial intelligence that provide more accurate, reliable and cost-effective technologies; however, most of these technologies are not qualified to meet Nuclear Regulatory Commission

requirements. Further R&D developments will produce new technology applications that meet regulatory requirements and that will improve plant operation and maintenance, increasing overall plant output. This initiative is focused on demonstrations of technologies necessary to achieve regulatory acceptance of the new technologies.

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

Regulatory Compliance

Budget: FY99-$12.9M, FY00-$14.6M, FY01-$18.2M

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.

DOE, under the International Clean Energy Initiative, will also seek opportunities to for international collaboration to optimize the performance of coal-fired plants in key developing countries. This will reduce greenhouse gases as well as other emissions.

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 DOE-sponsored 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: FY99-$3.2M, FY00-$5.0M, FY01-$5.0M

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. Biological testing and analysis activities are performed entirely by National Laboratories, while the proof-of-concept testing initiated in 1999 is being conducted with an industry partner, 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, turbulence, and pressure on juvenile fish, with emphasis on juvenile salmonids and American shad. The fish will be exposed to levels of stress 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 advanced hydropower turbine design.

Proof-of-concept testing of a conceptual design completed in 1997 was initiated in 1999 in order to verify predicted biological performance. Environmental testing of competitively-selected low head/low power turbines will be initiated in FY 2001.

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 (in $1,000)

Advanced Power Systems Research Areas	FY 1999 Appropriated	FY 2000 Appropriated	FY 2001 Request
Large High Efficiency Systems	**176,279**	**190,219**	**181,590**
Advanced Coal Gasification & Combustion Systems	65,491	69,923	58,890
- Advanced Coal Combustion	*20,967*	*9,010*	*2,000*
- Pressurized Fluidized Bed Combustion	*14,356*	*12,202*	*11,185*
- Gasification Technologies	*30,168*	*48,711*	*45,705*
Advanced Gas Turbine Systems	43,398	44,188	26,000
Advanced Large-Scale Fuel Cell Power Systems	43,069	44,499	42,200
Carbon Sequestration	5,825	9,217	19,500
Nuclear Fission Systems	18,496	22,392	35,000
Distributed and Hybrid Systems	**224,081**	**201,826**	**250,890**
Industrial Combined Heat and Power Systems	200	3,000	1,000
Buildings Cooling Heating and Power Systems	0	0	3,000
Advanced Industrial Turbine Systems	49,403	22,300	13,300
Hydrogen Fuel Cell Systems	0	5,530	8,770
Wind Energy Systems	34,076	32,481	50,500
Photovoltaic Systems	70,561	65,912	82,000
Concentrating Solar Power Technology	16,791	15,168	15,000
Geothermal Energy	21,734	23,600	27,000
-Geothermal Exploration	*5,400*	*6,000*	*6,000*
-Geothermal Drilling and Completion	*4,934*	*5,500*	*5,500*
-Geothermal Reservoir Technology	*5,400*	*6,000*	*5,500*
-Geothermal Energy Conversion Systems	*6,000*	*6,100*	*10,000*
Biopower Energy Systems	30,816	31,835	48,000
Reciprocating Engines	500	2,000	2,320
Technology Improvement of Operating Plants	**22,199**	**31,543**	**35,550**
Aging Effects in Key Components	6,066	7,000	7,350
Nuclear Power Plants (NEPO)	0	4,976	5,000
Regulatory Compliance	12,923	14,646	18,200
Hydropower Turbines	3,210	4,921	5,000
Total [Advanced Power Systems]	**422,559**	**423,588**	**468,030**