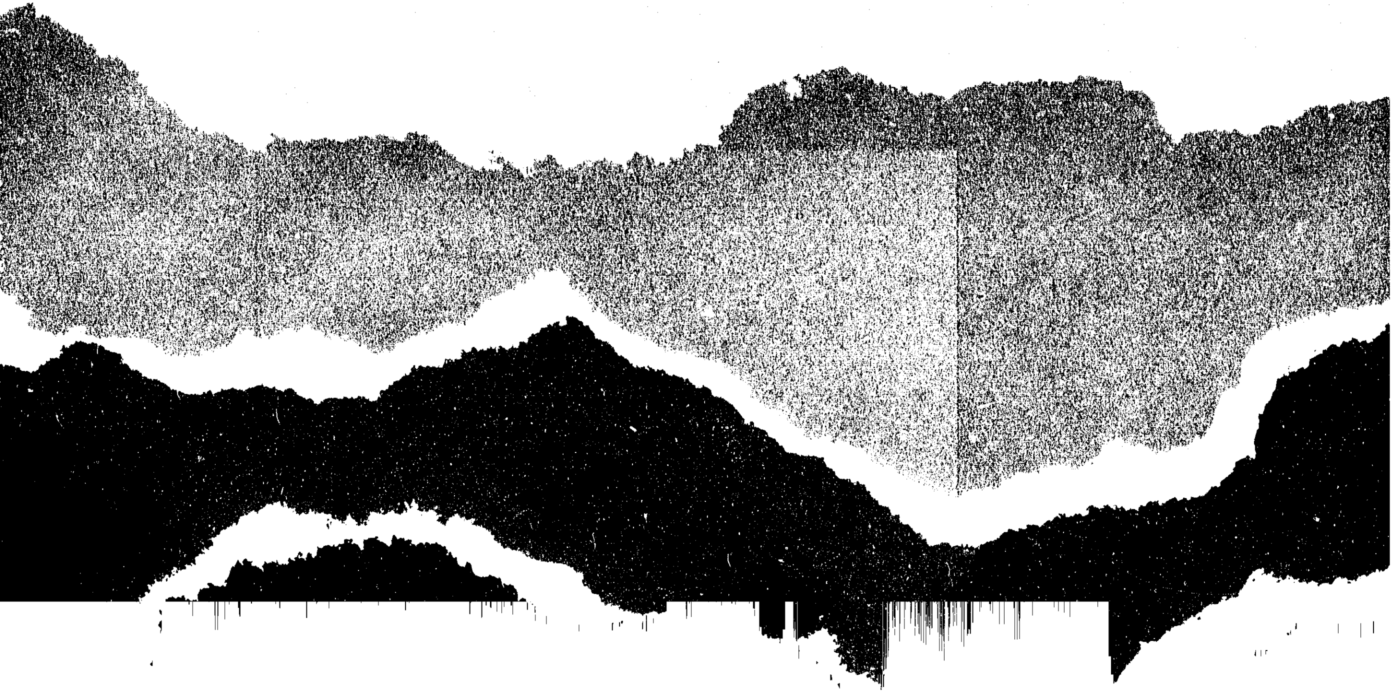
Department of Energy
Washington D.C. 20585



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Research, development, and demonstration efforts in Clean Coal Technology are driven by national objectives related to both the economy and the environment.

Throughout the industrial world, the availability of reliable, low-cost energy supplies is a major determinant of economic competitiveness and quality of life. Relatively low energy costs enable a nation to produce goods and services that compete favorably in both the domestic and international marketplaces. Strength in the global market, in turn, fosters growth across all sectors of a nation's economy, increasing employment opportunities and standards of living.

In the United States, fossil fuels — coal, petroleum, and natural gas — have been central in filling the need for reliable, low-cost energy for more than a century. Today, fossil fuels remain the energy mainstays of the United States, supplying almost 90 percent of the nation's primary energy consumption.

Economic Goals

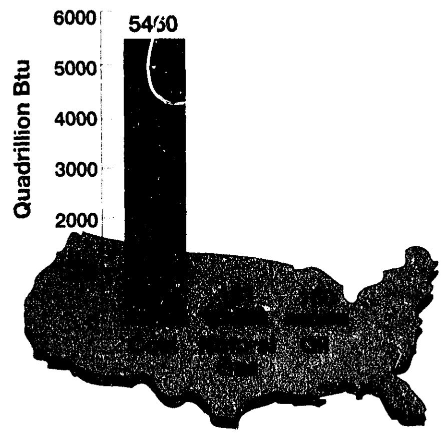
Ensuring reliable supplies of low-cost energy in the future has been the focus of numerous legislative and policy initiatives of the U.S. government. These initiatives encourage more effective use of domestic energy resources and reduced dependence on imported oil. In particular, key initiatives target more effective conservation of energy; accelerated use of renewable energy sources; expanded utilization of natural gas; maintenance of the nuclear energy option; and optimal use of coal, which accounts for over 94 percent of proven domestic fossil energy reserves.

Environmental Goals

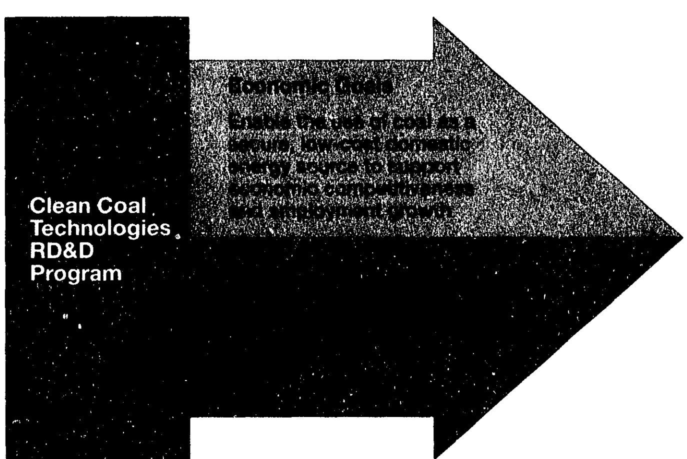
At the same time, significant efforts are being made at the federal, state, and local levels to enact and enforce environmental protection measures. Strategies for utilizing all forms of energy must support the national commitment to achieving a cleaner environment. Coal-based power generation, specifically, is subject to the provisions of the Clean Air Act Amendments of 1990 and other regulations.

The U.S. Department of Energy, Office of Fossil Energy, has structured an integrated program for research, development, and demonstration of clean coal technologies that will enable the nation to use its plentiful domestic coal resources while meeting environmental quality requirements. The program provides the basis for making coal a low-cost, environmentally sound energy choice for electric power generation and fuels production.

Proven U.S. Fossil Energy Reserves



▲ **Coal is the nation's most abundant domestic energy resource, constituting over 94 percent of proven U.S. fossil energy reserves. Our nation's recoverable coal reserves are the energy equivalent of about one trillion barrels of crude oil.**
Source: Energy Information Administration (Annual Energy Review 1992, June 1993)



Power Generation

In power generation, clean coal technologies will enable the coal-fired plants of the future to produce low-cost electricity with minimal environmental impact, high efficiency, and high reliability.

Fuels Production

In fuels production, clean coal technologies will be capable of producing secure domestic supplies of clean liquid transportation fuels, chemicals, and other products that can compete with petroleum-derived products, thereby reducing the nation's dependence on imported oil.

The Coal RD&D Program

The coal RD&D program spans the full cycle of technology development, as illustrated in the "Clean Coal RD&D Logic Diagram" below. The program consists of the following elements:

Base Research

Base research focuses on the development of enabling science and technology critical to the development of advanced power systems and fuel systems. The program advances the scientific and technical knowledge required to understand the physical, chemical, biological, and thermodynamic mechanisms that control the behavior of coal-fueled systems, and develops the means to overcome technological barriers that impede the realization of system goals. Research areas include advanced materials, biotechnology, and the physical and chemical properties of coal systems. Collaborative research between academic institutions and industry plays an important role.

RD&D efforts in clean coal technology are driven by national objectives related to both the economy and the environment.

Crosscutting Technologies

In addition to crosscutting applied research, crosscutting technology development activities are also performed. These activities are grouped into four different coal technology program areas: coal preparation, alternative fuels utilization, flue gas cleanup, and waste management. Developments in each of these crosscutting technologies are of benefit to virtually all advanced power systems and fuel systems.

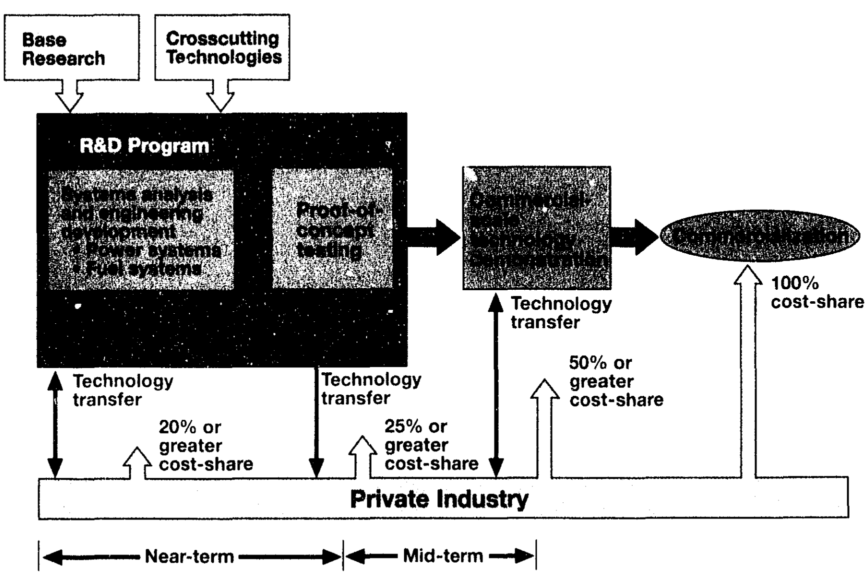
Systems Analysis and Engineering Development

Promising technologies are advanced to the proof-of-concept (POC) test stage through systems analysis and engineering development efforts. These activities translate theoretical understanding into the preliminary design of systems and processes, address key questions about the behavior and properties of the systems and processes, and determine ways to predict and model behaviors over a wide range of conditions. At this scale of development, the majority of costs are assumed by the federal government, due to the relatively high technical risks of the early stages of RD&D.

Proof-of-Concept Tests

POC tests are performed to confirm the validity of system concepts, and to provide the data necessary for commercial-scale demonstrations. As technologies mature to POC scale, less promising lines of development are phased out, and private industry assumes a progressively larger share of development costs.

Clean Coal RD&D Logic Diagram



◄ **The DOE Coal RD&D Program involves private industry at every stage of technology development in order to facilitate progress from the laboratory to commercial use.**

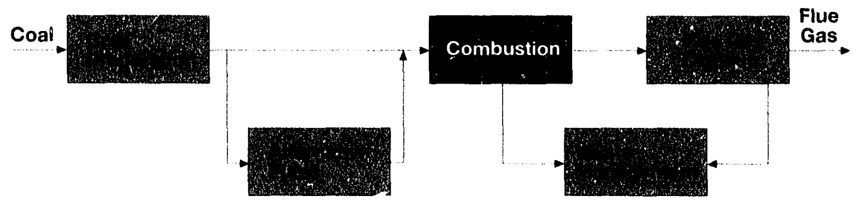
Technology Demonstration

Once a technology passes the POC stage, an industry partner can be selected via competitive procurement to demonstrate the technology at or near full commercial scale. For these large-scale demonstrations, a significant cost-share, normally 50 percent or greater, is assumed by private industry. Demonstration activities are currently being performed under the Department of Energy's Clean Coal Technology Demonstration program for systems that show the greatest potential for fully meeting technical and market requirements. The demonstrations yield the technical, environmental, economic, and operational data needed by the private sector as the basis for sound and confident decisions about using the technologies.

The Role of Private Industry

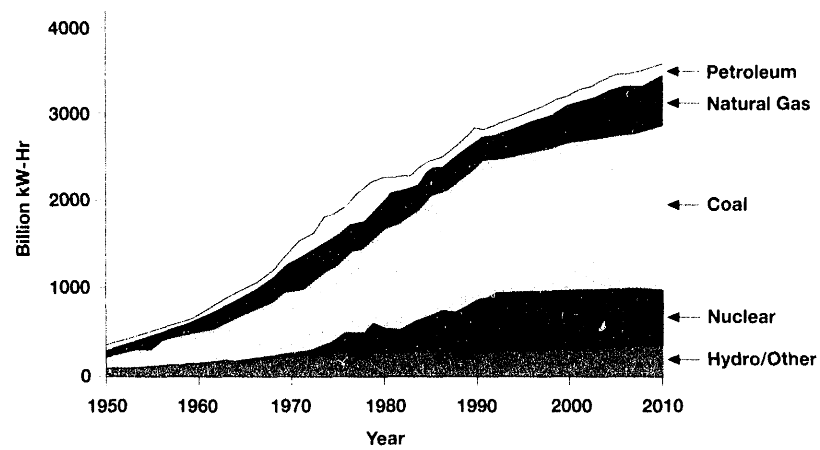
At every stage, private industry has a strong role in conceiving, directing, and implementing coal RD&D activities. Private industry involvement generally begins at the systems analysis and engineering development stage. Research and development at this stage may be performed under DOE sponsorship at private, university, or government research facilities, with the industry partners typically contributing 20 percent or greater share of costs. The industry cost-share increases to 25 percent or greater at the POC test stage. Projects selected for commercial-scale demonstration under the Clean Coal Technology Demonstration Program must have at least a 50 percent cost-share participation by private industry. The industry partners are often granted patent rights for inventions developed during demonstrations.

Crosscutting Technologies



▲ Crosscutting technology development activities are performed in four different coal technology program areas: coal preparation, alternative fuels utilization, flue gas cleanup, and waste management. These technologies benefit more than one advanced power or coal-based fuel system under development.

U.S. Electricity Generation by Utilities, 1950-2010



▲ Since 1950, coal-based electricity generation by U.S. utilities has increased about tenfold, from approximately 150 billion kilowatt-hours in 1950 to over 1.5 trillion kilowatt-hours today. Under current projections, the use of coal for electricity generation is expected to continue to expand through the early decades of the next century. By the year 2010, if there are no changes in current energy policies, nearly 2.0 trillion kilowatt-hours of electricity could be generated annually from coal.

Environmental Performance

Growing demand for electricity, coupled with increasingly strict emissions standards, creates the need for coal-based power systems with substantially improved environmental performance.

Because of its abundance and low cost, coal now accounts for about 56 percent of the electricity generated in the United States, and for over 20 percent of the nation's primary energy.

Coal is expected to continue to have a major role in meeting U.S. energy requirements. According to current projections, even with aggressive conservation measures and sizable expansion in the use of renewable energy and natural gas, coal use will increase significantly by 2010 to keep pace with our nation's energy and economic needs.

The increasing use of coal will be driven largely by growth in demand for electric power. Total consumption of electricity in the U.S., including power from both utility and non-utility producers, is expected to rise from 3.0 trillion kilowatt-hours in 1990 to as much as 4.2 trillion kilowatt-hours in 2010, and to more than 5.8 trillion kilowatt-hours in 2030. Coal-fueled power plants are expected to continue to provide about half of the nation's electricity from now through 2030. Clean coal technologies will be essential in enabling the U.S. to expand coal-fueled electric power generation while meeting environmental standards.

Domestic Fuel Production

Clean coal technologies can be used to produce domestic substitutes for imported petroleum-based products.

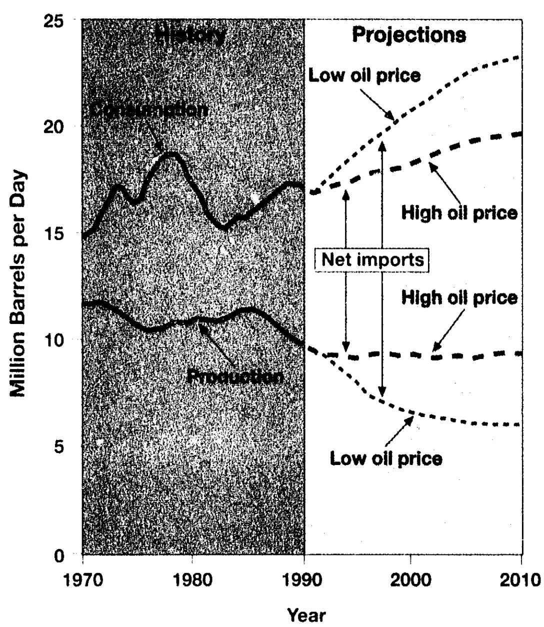
In addition to its importance in fueling electric power generation, coal also has a potentially valuable role as a domestic source of liquid fuels, chemicals, and other products that could serve as replacements for imported petroleum-based products. Petroleum currently provides more than 40 percent of U.S. primary energy needs, and supplies over 95 percent of the energy used for U.S. transportation.

The use of petroleum within the U.S. has increased dramatically over the past 40 years, and is expected to continue to rise into the next century. The growing dependence of the U.S. on imported oil raises concerns about energy security, and also worsens the nation's international trade deficit. The cost to the U.S. for imported crude oil, currently about $48 billion per year, could increase to almost $75 billion per year by the year 2000. By the year 2010, the cost could exceed $100 billion annually.*

Clean coal technologies such as liquefaction processes can transform coal into a liquid fuel for transportation uses and other applications. Current RD&D efforts are focused on developing systems that will produce clean-burning, coal-derived liquid fuels at a cost that is competitive with petroleum prices, to provide the U.S. with an economically viable and environmentally acceptable alternative to imported oil.

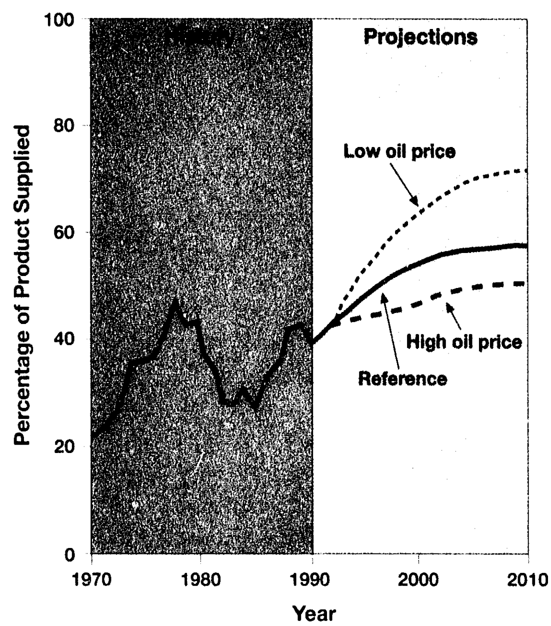
* Figures in 1990 dollars. Source: Table D8, Energy Information Administration 0383 (93).

U.S. Petroleum Production and Consumption, 1970-2010



▲ Since the mid-1980s, the amount of petroleum consumed in the United States has increased, while domestic petroleum production has steadily declined. *Source: Energy Information Administration (Annual Energy Outlook 1993)*

Percentage of U.S. Oil Consumption Supplied by Net Imports, 1970-2010



▲ In 1990, crude oil imports accounted for over 40 percent of domestic petroleum use. The use of imported oil is expected to increase into the next century. *Source: Energy Information Administration (Annual Energy Outlook 1993)*

Policy and Marketplace Drivers

Federal policies and marketplace requirements determine the mission of the clean coal technologies RD&D program.

The coal RD&D program of the U.S. Department of Energy is designed to accelerate the progress of clean coal technologies from the laboratory to the marketplace. The program consists of two main components: Advanced Power Systems and Coal-Based Fuel Systems.

Growing demand for electricity, coupled with increasingly strict emissions standards, creates an urgent need for advanced coal-based power systems.

The Advanced Power Systems Mission:
To accelerate commercialization of affordable, highly efficient, low-emission, coal-fueled, electricity-generating technologies.

The Coal-Based Fuel Systems Mission:
To support the development and advance the commercialization of clean, cost-effective coal processing technologies for production of coal-derived fuels, chemicals, and other products for the transportation, utility, commercial, and residential sectors.

These missions have been largely determined by four driving forces:

- Federal energy policy initiatives.
- Federal environmental policy initiatives.
- U.S. marketplace requirements.
- Potential applications in the global marketplace.

Federal Energy Policy Initiatives

Title XIII of the Energy Policy Act of 1992 states that DOE shall "conduct programs for research, development, demonstration, and commercial application in coal-based technologies." This authorizing legislation reinforces the missions for Advanced Power Systems and Coal-Based Fuels Systems, in that it sets goals of increasing U.S. energy efficiency, securing reliable electricity and energy supplies, enhancing environmental quality, and fortifying U.S. preeminence in energy research.

The RD&D efforts in clean coal technologies described in this Program Plan further these goals in several important ways. First, the efforts focus on significantly increasing the efficiency of coal-based power generation and minimizing associated environmental emissions. They also enable the use of coal as a domestic source of alternative transportation fuels, chemicals, and other products to replace imported-petroleum-based products. Finally, clean coal technologies initiatives further fundamental science and engineering research in the United States.

Federal Environmental Policy Initiatives Affecting Power Generation

Federal environmental standards are another key driver of clean coal technologies RD&D. In particular, many of the RD&D efforts address the needs of electric power producers in meeting requirements of the Clean Air Act. These requirements, which apply to both existing and new coal-fired power generation plants, mandate the reduction of atmospheric emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx), two gases identified as precursors to acid rain. Other clean coal technologies RD&D efforts address air toxics emissions. In addition, due to their superior system efficiencies, clean coal technologies will enable substantial reductions in carbon dioxide emissions. These technologies also minimize the generation of coal-derived solid waste.

Reduction of Acid-Rain-Forming Gases

Governmental regulation of acid-rain-forming gases was first formalized by the Clean Air Act of 1970, which introduced the concept of New Source Performance Standards (NSPS) to regulate the utility industry. In 1978, the NSPS were amended, with more stringent emissions standards for utility boilers constructed after 1978. These NSPS limits did not set boiler emissions limits in terms of absolute tonnages, but instead based emissions ceilings on the amount of heat released by the fuel consumed in the power plant: the greater the amount of heat generated in the boiler, the greater the allowable emissions of SO_2 and NOx. The annual emissions limits for SO_2 and NOx were not absolute, but instead depended on the amount and kinds of fossil fuels consumed for that year.

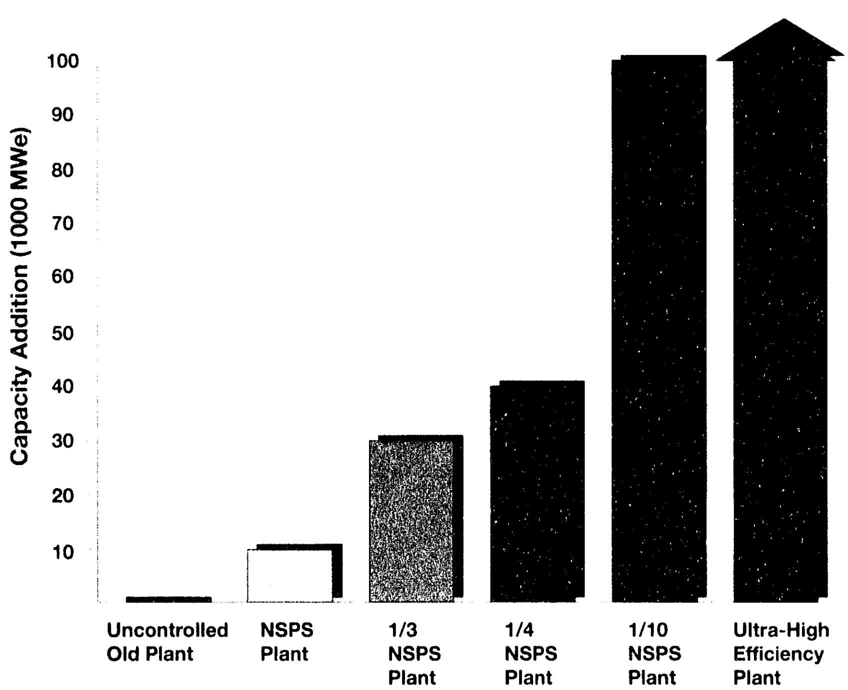
Federal policies and marketplace requirements determine the mission of the clean coal technologies RD&D program.

Title IV of the Clean Air Act Amendments of 1990 changed the basis for calculating allowable nationwide emissions of acid-rain-related gases. The intent is to:

- Reduce annual utility SO_2 emissions in the U.S. by ten million tons from 1980 levels.
- Limit utility SO_2 emissions in the U.S. to approximately 8.9 million tons per year by the year 2000.
- Reduce annual utility NOx emissions in the U.S. by approximately two million tons from 1980 levels.

Under the Amendments, utilities will be assigned system-wide absolute sulfur dioxide emissions caps, based on the megawatt capacity of the system and type of fuel consumed. Utilities that do not meet their sulfur dioxide emissions caps can come into compliance in a number of ways: by changing to a lower sulfur-content fuel from a different source, or one produced by beneficiation of the existing fuel supply; by retiring high-emissions generating units in favor of power purchases from other utilities; by installing post-combustion flue gas scrubbers on selected generating units; by repowering one or more high-emissions units with advanced low-emissions technologies such as fluidized-bed combustion or coal gasification combined cycle; or by purchasing "emissions allowance" credits from any utility that already betters its own sulfur dioxide emissions requirements.

Potential Capacity Additions with CAAA Sulfur Limits*



◄ The Clean Air Act Amendments of 1990 limit sulfur dioxide emissions to 8.9 million tons per year after 2000. Based on current technology that would operate at NSPS emissions levels, only 10,000 megawatts could be added to U.S. generating capacity without exceeding this limit. In contrast, clean coal technologies can deliver much greater capacity and still not exceed the sulfur dioxide limit.

* A combination of efficiency and desulfurization capability determines allowed capacity additions.

Reduction of Air Toxics

In addition to acid-rain-related gases, the Clean Air Act Amendments of 1990 cover the control of air toxics. Title III of the Amendments targets reductions in atmospheric emissions of 190 toxic pollutants from industrial sources. The United States Environmental Protection Agency will conduct a study of utility air toxics emissions and will promulgate new regulations if appropriate.

Reduction of Carbon Dioxide

Emissions of carbon dioxide, a greenhouse gas, are not currently regulated in the United States. If control requirements are imposed on CO_2 in the future, clean coal technologies would provide power-generating utilities with the basis for effective approaches for reducing these emissions. Specifically, since CO_2 formation is inversely related to power plant efficiency, the replacement of aging, lower-efficiency power plants with advanced, high-efficiency power systems of equal capacity would result in significantly lower atmospheric emissions of CO_2.

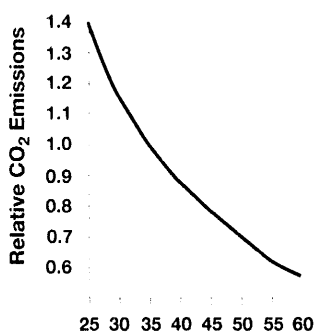
Traditional Controls

Clean coal technologies RD&D supports the development of practical, economical, and effective approaches to meeting the environmental requirements governing power-generating utilities. A number of clean coal technologies will offer more efficient, lower-cost alternatives to conventional scrubbers and other traditional emissions-control methods. These traditional controls, which are generally built as facility additions to power plants, reduce emissions by cleaning up the flue gases produced during combustion. Because these controls add to the expense and complexity of the power plant and reduce its efficiency, they result in increased electric power costs to consumers. In addition, traditional controls produce solid and liquid wastes that require disposal.

Advanced Controls

In contrast, advanced power systems using clean coal technologies focus on total system improvements that will yield far lower emissions and, at the same time, far higher efficiencies. Since increased efficiency means that the power plant will produce more electric energy per ton of coal burned, each step up in efficiency not only conserves fuel, but also reduces emissions and wastes. In addition, clean coal technologies will reduce waste disposal requirements by producing solid wastes that are marketable by-products.

Relative Dependence of CO_2 Emissions on Power Plant Efficiency
(35%=Unity)



▲ The higher the efficiency of a power plant, the lower its rate of carbon dioxide formation. As an example, a 100-megawatt power plant of 50 percent net efficiency will emit 30 percent less CO_2 than a 100-megawatt power plant of 35 percent net efficiency that uses the same fuel supply.

Federal Environmental Policy Initiatives Affecting Liquid Fuels

Federal environmental policies also affect RD&D efforts related to systems for the production of coal-derived liquid fuels. Transportation fuels from coal, used either as refinery feed or without additional processing, will have to meet post-2000 standards of the Clean Air Act, and may be subject to other future fuel specifications promulgated by the Environmental Protection Agency.

Post-2000 standards for transportation fuels are not yet formulated, but are expected to be more stringent than those proposed by the Clean Air Act. Title II of the Clean Air Act covers mobile sources of pollutants with the intent of legislating fuel changes that will result in reduced hydrocarbon and carbon monoxide emissions. The Clean Air Act Amendments of 1990 specifically require reformulated gasoline for nine high ozone non-attainment areas, and fuels containing oxygenates for carbon monoxide non-attainment areas. Other proposed requirements are reduced vapor pressure for gasoline to limit vapor emissions, and stringent sulfur restrictions and a minimum cetane number for diesel fuels.

To meet expected Clean Air Act standards, fuels produced from coal must result in lower emissions on use than existing petroleum-based fuels. The processes for producing these fuels must also be environmentally benign in terms of gaseous, liquid, and solid waste emissions. One goal is to develop highly efficient processes and coproduction techniques that will minimize CO_2 emissions in the production of coal-derived fuels.

New Source Performance Standards

Particulates	SO_2	NOx
0.03 pounds per million Btu	1.2 pounds per million Btu* and 90 percent reduction in potential emissions	0.6 pounds per million Btu*

* Exceptions apply for certain fuels.

U.S. Marketplace Requirements

U.S. marketplace requirements continue to be a central consideration in determining the mission, strategy, and structure of the coal RD&D program.

Advanced Power Systems

In power generation, the focus is on demonstrating systems that will enable utilities to meet stringent environmental requirements while keeping electricity prices stable. The new systems must produce significantly lower emissions of acid rain gases and air toxics species than the present generation of coal-fueled power plants. They must also compete economically with the current generation of pulverized coal power plants. Advanced power systems technologies are being developed not only for new capacity additions, but also for repowering of existing plants through the replacement of major subsystems, such as boilers.

In comparison with current coal-fueled power plants, the higher efficiencies of advanced power systems will contribute to both environmental performance improvements and lower overall life cycle costs. Reductions in capital costs are also targeted through efforts to simplify process design, increase the modularity of plant design, and reduce power plant land area requirements.

Commercial availability of advanced power systems technologies in the United States is targeted for early in the next century, a period when replacement of aging power generation facilities is expected to accelerate, and when substantial new baseload capacity additions are anticipated.

Fuel Systems

RD&D efforts in liquid fuels are aimed at developing systems that can produce coal-derived transportation fuels, chemicals, and other products that will be cost-competitive with oil-derived products. Cost is currently the single major obstacle to introduction of these fuels in the U.S. energy supply system. Other key marketplace considerations, such as the integration of coal-derived fuels within existing fuel refinery, transportation, and distribution systems, are addressed by the systems under development.

Coal makes up 70 percent of the world's proven fossil energy reserves, and significant international demand for clean coal technologies is projected in the near future.

Potential Applications in the Global Marketplace

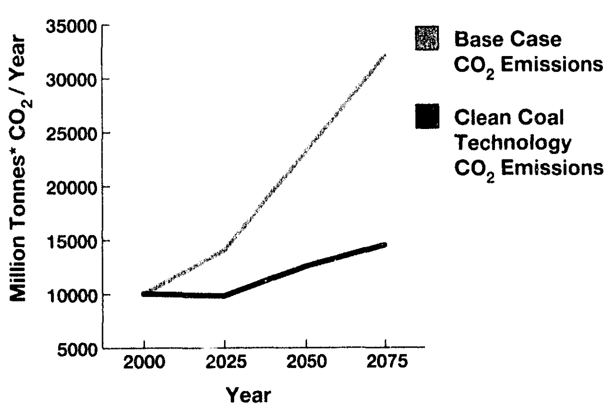
While the focus in both advanced power systems and fuels systems is on domestic U.S. applications, it is important to recognize that significant international demand for clean coal technologies is projected in the near future. The same dynamics that make clean coal technologies attractive in the United States will apply in many other regions of the world. Worldwide energy demand is expected to rise dramatically over the next two decades, particularly the demand for low-cost electricity in developing nations and Eastern Europe. Coal, which makes up 70 percent of the world's proven fossil energy reserves, is likely to be the primary fuel source for many nations.

Clean coal technologies offer a means to minimize the environmental impact of economic growth or previous environmental neglect. In addition, by accommodating low-grade domestic coal, these technologies enable nations to increase their fuel flexibility and self-reliance.

The growing demand for energy, coupled with increasing environmental concerns, will create a sizable global market for clean coal technologies. Projections are that, through 2010, this world market will total between $270 billion and $750 billion.

As the current world leader in clean coal technologies development, demonstration, and production, the U.S. is positioned to serve a large segment of the export market for these technologies. Exporting clean coal technologies could also enable the U.S. to increase the value of its annual coal exports from $4.5 billion today to between $13 billion and $18 billion by 2010.

Potential for Worldwide CO_2 Reduction



◄ **If all power producers were to use clean coal technologies, global carbon dioxide emissions could be cut by more than half, compared with the levels that would be produced by existing power plant technologies.**

*1 tonne=1.10 tons

Program Structure and Objectives

Clean coal technologies RD&D combines the efforts of government, academia, and private industry.

The U.S. Department of Energy has a mission to advance the commercialization of new clean coal technologies that have the highest efficiency, lowest emission characteristics, and lowest cost of all alternatives available. To accomplish this mission, DOE has structured an integrated research, development, and demonstration program that involves the coordinated efforts of government, industry, and academic organizations. The RD&D program involves private industry in cost-shared development of advanced power and liquid fuels systems. These partners help to ensure that coal RD&D is directed toward fulfilling the ultimate requirements of the marketplace.

Cost-shared development of clean coal technologies is accomplished at several different levels. DOE sponsors the research and development of many potentially promising areas; these initial efforts may be in the form of in-house research, or contracted/cooperative activities with industrial and utility groups, national laboratories, and universities. As technologies begin to mature, less promising lines are discarded, and the most promising technologies progress through proof-of-concept testing to commercial demonstration. The industrial cost-share increases at progressively larger scales of development.

In addition to its responsibility for the RD&D program, DOE has a role in promoting the export of coal and clean coal technologies by U.S.-based industries. Key activities include supplying market information to U.S. companies, supporting feasibility studies, and conducting overseas technology demonstrations.

DOE Research Goals for Clean Coal Technologies

Advanced Power Systems

❶ **By the year 2000:** Demonstrate an advanced coal technology with 42 percent or greater system efficiency. The system must also control sulfur dioxide, nitrogen oxides, and particulates to less than one-third of the current New Source Performance Standards (NSPS) set by the Clean Air Act Amendments of 1990.

❷ **By the year 2005**: Demonstrate systems with efficiencies of at least 47 percent, while controlling sulfur dioxide, nitrogen oxides, and particulates to less than one-quarter of current New Source Performance Standards.

❸ **By the year 2010:** Demonstrate advanced coal-fired power systems with more than 55 percent efficiency, while controlling sulfur dioxide, nitrogen oxides, and particulate emissions to less than one-tenth of the New Source Performance Standards.

❹ **By the year 2015:** Demonstrate systems with efficiencies of more than 60 percent, while controlling sulfur dioxide, nitrogen oxides, and particulate emissions to less than one-tenth of the New Source Performance Standards.

All of these systems must be capable of producing electricity at a 10 to 20 percent lower cost than currently available pulverized coal technology that would meet the same emission standards.

Fuel Systems

❶ **By the year 2010:** Demonstrate advanced concepts for the clean and safe production of coal-based transportation fuels, chemicals, and other products that can compete with petroleum-derived products, at a cost of less than $25 per barrel of oil equivalent in 1991 dollars.

Advanced Power Systems Development

To meet the varying needs of power producers, DOE is active in the research, development, and demonstration of a number of advanced power systems. These systems, which include both coal-combustion-based and coal-gasification-based technologies, have different emissions and efficiency characteristics and will become commercial in different time frames.

The seven power systems under development by DOE are:

- Advanced Pulverized Coal (APC) Systems
- Indirectly Fired Cycle (IFC) Systems
- Direct Coal-Fired Heat Engines (DCFHE) Systems
- Pressurized Fluidized-Bed Combustion (PFBC) Systems
- Magnetohydrodynamics (MHD) Systems
- Integrated Gasification Combined Cycle (IGCC) Systems
- Integrated Gasification Fuel Cell (IGFC) Systems.

Advanced power systems are projected to have substantially better emissions and efficiency performance than current coal-fired systems. By reducing sulfur dioxide and nitrogen oxide emissions, clean coal technologies have the potential to make coal-fired power plants nearly as clean as plants that burn natural gas. These technologies will also enable coal-fired plants to be just as efficient as natural-gas-fired plants.

Detailed descriptions of the seven advanced power systems are provided in this Program Plan. Each description includes program goals, a diagram of program elements interaction, a system components diagram with a technology description, a development cycle timeline, a major activities description with a map showing geographic distribution, and a milestone chart.

Fuel Systems Development

Coal-based fuel systems provide a broad spectrum of fuels, including specification transportation fuels, alternative fuels such as methanol, slurry boiler fuels, and industrial value-added products. Several different approaches to coal-based fuel systems are being undertaken by DOE to support this diversity of products and to enable the economic integration of coal-based fuels into the U.S. fuel supply and distribution system.

Clean coal technologies RD&D combines the efforts of government, academia, and private industry, in an integrated research, development, and demonstration program.

Processes under development by DOE include:

- Direct Coal Liquefaction Systems
- Indirect Coal Liquefaction Systems
- Hydrogen/Synthesis Gas Systems
- Mild Gasification Systems.

Detailed descriptions of fuel systems technologies are provided in this Program Plan. Each description includes program goals, a diagram of program elements interaction, a system components diagram with a technology description, a development cycle timeline, a major activities description with a map showing geographic distribution, and a milestone chart.

Building-Block Technologies

The advanced power systems being developed under DOE sponsorship have a number of technical challenges in common. These challenges are being addressed through work on "building-block" technologies: advanced combustion, advanced gasification, hot gas cleanup, advanced furnace/heat exchanger, advanced turbines systems, flue gas cleanup, and waste management.

Similarly, several building-block technologies are key to fuel systems development: advanced gasification/pyrolysis, gas separation/ cleanup, reactor systems/catalysts, and product upgrading.

Progress in any of the building-block technologies can yield improvements in the efficiency, environmental performance, and life cycle costs of multiple advanced power systems or fuel systems. Coordination of RD&D efforts in these technological areas contributes to the most effective possible use of funding and other resources.

In several cases, including advanced gasification, building-block technologies are relevant to both advanced power systems and fuel systems. This commonality between advanced power and fuel systems has commercial as well as technological development implications. There is significant market interest in several systems that combine power and fuel production into multiproduct systems. Economic analyses indicate that since these systems may be more advantageous than single-product systems in certain instances, they may be among the first commercial applications of clean coal technologies.

Self-Assessment of Ongoing Program Plan Activities

Self-assessment plans have been devised and implemented to aid in achieving Program Plan goals and objectives while ensuring compliance with DOE Environmental, Safety and Health (ES&H), and Safeguards and Security (S&S) requirements. These plans are ongoing processes for identifying ES&H and S&S deficiencies, determining root causes, ensuring that corrective actions are taken, and communicating the trends and lessons learned. Responsibilities for implementing and appraising the effectiveness of these self-assessment plans have been assigned to both DOE headquarters and field organization management.

Building-Block Technologies for Advanced Power Systems

Advanced Power Systems	Advanced Combustion	Advanced Gasification	Hot Gas Cleanup	Advanced Furnace/Heat Exchanger	Advanced Turbines Systems	Flue Gas Cleanup	Waste Management
APC	■					■	■
IFC	■			■	■	■	■
DCFHE			■			■	■
PFBC		■	■		■		■
MHD	■			■		■	■
IGCC		■	■		■		■
IGFC		■	■				■

Building-Block Technologies for Fuel Systems

Advanced Fuel Systems	Advanced Gasification/ Pyrolysis	Gas Separation/ Cleanup	Reactor Systems/ Catalysts	Product Upgrading
Direct Liquefaction			■	■
Indirect Liquefaction	■		■	■
Synthesis Gas/ Hydrogen	■	■		
Mild Gasification	■			■

▲ DOE efforts focus on the advancement of building-block technologies that will form the basis for advanced power systems and fuel systems utilizing clean coal technologies.

Important milestones have been reached in a number of coal RD&D programs, as technologies near the point of commercial availability.

DOE will continue its efforts to accelerate the commercialization of efficient, environmentally sound advanced power systems and coal-based fuel systems, building on the foundation of its successes in research, development, and demonstration. Important commercial or near-commercial milestones have been reached in a number of programs, including:

Important milestones have been reached in a number of coal RD&D programs, as technologies near the point of commercial availability.

Atmospheric Fluidized-Bed Combustion

The Department of Energy's AFBC program initiated the concept of burning high-sulfur and/or low-quality fuels (like gob and culm, wastes from the mining of bituminous and anthracite coals) in AFBCs. After technical feasibility was proven, contracts were awarded that allowed a number of boiler companies — including Foster Wheeler, Combustion Engineering, Tampella Keeler (initially Dorr-Oliver), and FluiDyne — to introduce their initial AFBC products into the commercial market. Foster Wheeler has licensed its AFBC technology to four offshore companies. Work sponsored by DOE at Battelle resulted in licenses to Riley-Stoker Corporation, Foster Wheeler UK, Struthers-Wells, and Mitsui, which in turn have made commercial boiler sales based on Battelle's AFBC technology. At least 61 AFBC commercial units, with an installed value of approximately $700 million (1990 dollars), are directly related to the R&D work done in the DOE program.

Direct Coal-Fired Turbines and Diesels

For the past decade, the Department of Energy has sponsored projects to develop diesel and gas turbine engines capable of operating on low-cost, coal-based fuels. The program began as an exploratory effort and grew into a proof-of-concept (POC) program that has included major U.S. manufacturers of both diesel engines and turbines. The turbine manufacturers have included Allison Gas Turbine Division of General Motors, Solar Turbine Incorporated, and Westinghouse Electric Corporation. Diesel manufacturers have included General Electric and Cooper-Bessemer under subcontract to Arthur D. Little. (POC) systems operating on coal-water slurry fuel have achieved power outputs ranging from 2 to 5 megawatts, with combustion efficiency of over 99 percent. Potential applications for these engines range from transportation (locomotive and marine uses) to industrial, cogeneration, and utility systems.

Phosphoric Acid Fuel Cells

Fuel cells, because of their high electrical conversion efficiencies and superior environmental performance, are attractive energy conversion devices. DOE and its predecessor agencies have funded the development of fuel cells since the 1970s. Phosphoric Acid Fuel Cells were the primary focus of the early program. Power plant systems based on this technology are now in the initial stages of commercialization.

International Fuel Cells Corporation manufactured the stacks for an 11-megawatt power plant for the Tokyo Electric Power Company. This unit, the world's largest fuel cell power plant, is currently being successfully operated. For distributed electrical power and heat cogeneration, IFC has engineered and is producing a line of 200-kilowatt packaged fuel cell power plants. Nearly 60 of these units are or will be operated in the U.S., Japan, and Europe. Gas and electric utilities are evaluating these fuel cell units as future power plants for their systems.

Coal Preparation

Through the Acid Rain Initiative, carried out under the Coal Preparation Program, the technology and design base has been developed for three advanced coal preparation technologies — advanced froth flotation, selective agglomeration, and advanced cycloning — that will efficiently reject pyritic sulfur and thereby significantly reduce the release of acid-rain precursors during combustion.

To demonstrate the capabilities of these three techniques, contracts for POC testing have been awarded to ICF Kaiser Engineers for advanced flotation, Southern Company Services for selective agglomeration, and Coal Technology Corporation for advanced cycloning. In addition, development work on a coal preparation process flowsheet simulation has begun at Aspen Technology. This simulator will be applicable to all three advanced coal-cleaning processes.

Industrial/Commercial-Scale Advanced Combustion Systems

The development of five coal-fired combustion systems intended for use in the industrial and commercial market sectors is nearing completion. These systems, which can be fired on a variety of coal-based fuels, are extremely versatile with respect to type and size of application, and rival natural-gas-fired systems in efficiency, simplicity, reliability, small size, and low cost. Low emissions are achieved by a combination of low-NOx combustion systems, flue gas controls for SO_2 and particulates, and use of beneficiated coals.

Long-term POC testing under "real world" conditions is now under way. Test applications include providing space heating for university buildings and large industrial warehouses. When these tests are complete, a new generation of advanced coal-fired combustion systems will be ready to compete in the industrial and commercial markets both within the U.S. and abroad.

Advanced Mild Gasification Processes for the Production of Co-Products

Two advanced mild gasification systems for the low-cost production of value-added co-products from coal are ready for large-scale demonstration. Mild gasification, an advanced low-temperature coal carbonization process, yields char and liquid co-products that can be upgraded to such marketable products as form coke, smokeless fuel, activated carbon sorbents, commercial chemicals, and blending stocks for transportation fuels.

One system — developed by the Institute of Gas Technology, Peabody Holding Company, and Bechtel Group — uses a combined fluidized-bed/entrained-flow reactor to process caking bituminous coals without the use of an oxidant. The system has been successfully tested in a process research unit with a coal feed capacity of 100 pounds per hour. A team led by Kerr-McGee Coal Corporation was selected in 1992 to design, construct, and operate a one-ton-per-hour process development unit, through a cooperative agreement with the Department of Energy.

The second system involves the reconfiguration and scale-up of the Hayes Retort, a facility that was operated commercially for several years around 1930 in Moundsville, West Virginia. The system, being developed by Coal Technology Corporation, has successfully performed up to design expectations for a 1000-pounds-per-hour feed throughput, and has attracted the interest of potential commercial partners.

Clean Coal Technology Program

The DOE Clean Coal Technology program is a technology development effort jointly funded by government and industry. In this program, the most promising of the advanced clean-coal-based technologies are being moved into the marketplace by a process of demonstration.

Demonstrations are performed at a scale large enough to generate all the data needed to judge the commercial potential of the technologies involved, which were selected in five rounds of competitive solicitations between 1986 and 1993.

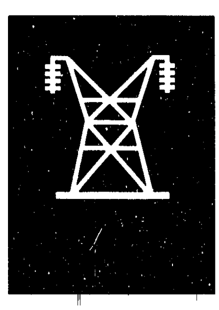
Technologies being demonstrated in the Clean Coal Technology program are representative of the three main divisions of this Program Plan: systems for the production of power, systems for the production of coal-based fuels, and crosscutting technologies. Upon conclusion of these demonstrations, successful commercial introduction of many of these technologies is expected to occur.

Advanced Power Systems

The clean coal technologies RD&D program supports the development of several advanced power systems based on coal combustion or coal gasification, which will become commercial in different timeframes. The goal of the program is to enable the coal-fired plants of the future to produce low-cost electricity with minimal environmental impact, at high efficiency and reliability levels, and to accelerate commercialization of these technologies.

Advanced Pulverized Coal (APC) systems take pulverized coal combustion — the most widely accepted technology for coal-fired power generation at the present time — one step further, by refining the process to gain major performance improvements. APC systems offer a method of cleaner, more efficient coal-fired power generation that will soon be available on the commercial market.

U.S. businesses are leaders in pulverized coal combustion technology and world suppliers of PC systems. The marketplace is now ready for APC systems, which are expected to be available by the end of this decade.



APC RD&D Program Description

APC technologies are being developed for both electricity generation and cogeneration applications.

- Low Emission Boiler Systems (LEBS) are applicable to electricity generation, generally at 250 MWe or larger.
- Coal-Fired Cogeneration (CGEN) Systems involve the generation of both electricity and heat, usually at smaller size plants of 100 MWe or less.

Low Emission Boiler System

LEBS integrates methods of emission control at the outset of design and development, instead of adding them to a completed system. This results in a power plant with very low emissions and higher efficiency than a conventional pulverized coal power plant. High system efficiency is achieved by using advanced steam cycles which employ supercritical steam conditions, reducing in-plant parasitic losses, and recovering more low-temperature heat. Emission control is achieved by:

- A combustion system that may incorporate staged air firing, reburning, selective noncatalytic reduction, and other advanced techniques for reducing emissions of NOx.
- An advanced flue gas cleanup system for reducing emissions such as SO_2, NOx, particulates, and air toxics.

The LEBS program consists of:

- System analysis, component definition, and preliminary commercial generating unit design.
- Engineering development and subsystem testing.
- Revised design of commercial generating unit and preliminary design of a proof-of-concept (POC) test facility.
- Detailed design, construction, and operation of the POC test facility.

During the preliminary design phase of LEBS, promising concepts are being evaluated and the research, development, and testing that is required to turn the best concepts into a commercial plant design are being identified. Following engineering development and POC tests to prove the validity of LEBS technology, the first commercial plant can be built.

LEBS is part of the Advanced Combustion program, and is supported by other projects within this program, as well as by efforts in the Alternative Fuels, Coal Preparation, and Flue Gas Cleanup programs.

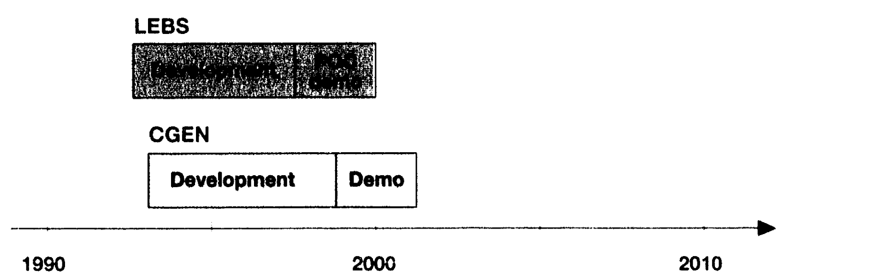
Coal-Fired Cogeneration

CGEN produces both steam for power generation and heat for process and space heating. Utilizing the low-grade steam produced as a by-product of power generation can result in plant efficiency of over 70 percent. Potential applications for CGEN systems include medium- to large-size industrial facilities and institutions such as hospitals and universities.

Typical cogeneration systems are small, less than 100 MWe, and are often located in urban areas, where there are frequently constraints imposed on the use of coal. These can include environmental performance constraints, fuel delivery restrictions (fugitive dust and traffic), space difficulties (fuel storage and handling), and waste removal and disposal considerations. The CGEN program will focus on development of a system that uses coal-water fuel in order to avoid many of these constraints.

➤ The LEBS program is currently in the development stage. Over a two-year period ending in 1996, experimental testing, engineering analysis, and modeling will take place to develop and evaluate each of the subsystems that make up LEBS. This process will result in the design and operation of a POC test facility. Development of a preliminary cogeneration plant will begin in 1994, and a 5 MWe demonstration facility will be constructed by 2001.

Development Cycle



The CGEN program consists of:

- System design and analysis.
- Engineering analysis and testing.
- Commercial plant design, and POC test facility design, fabrication, and preliminary tests.
- Demonstration testing of a 5 MWe CGEN POC facility.

Crosscutting Technologies

There are several crosscutting technologies that are integral to this program. CGEN system development will rely heavily on concurrent efforts in coal preparation, fuel formulation and handling, advanced coal combustion, environmental controls, and waste management. Advances in these technologies in support of LEBS and the commercial- and industrial-scale coal-fueled systems have also helped to lay the groundwork for CGEN.

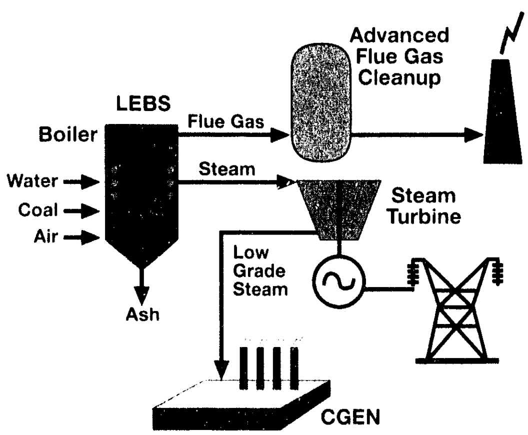
RD&D Program Goals

APC Systems	LEBS	CGEN
Net system efficiency	42%	70%
SO_2 emissions relative to current NSPS or local regulations	1/3	to meet
NOx emissions relative to current NSPS or local regulations	1/3	to meet
Particulate emissions relative to current NSPS or local regulations	1/2	to meet
Cost of electricity relative to current NSPS conforming plant	better than	N/A
Air toxics emissions relative to 1990 CAAA	to meet	to meet
Solid waste	minimized/ saleable	minimized/ benign
Capital cost, $ per kW	$1,400	N/A

NSPS=New Source Performance Standards

CAAA=Clean Air Act Amendments

System Components



▲ An Advanced Pulverized Coal (APC) System uses a Low Emission Boiler System (LEBS) to generate power, while also utilizing the low-grade steam produced as a by-product for manufacturing and heating (CGEN). APC technology aims at improving on pulverized coal technology currently in use, by employing advanced combustion, steam generation, and emissions-control technology to achieve lower SO_2 and NOx emissions while gaining greater thermal efficiency.

In an APC system, pulverized coal cleaned to specific levels is entrained by preheated air, injected into a furnace, and burned. Some systems may also have the capability to cofire with alternative coal-based fuels such as coal-water fuels or coal-waste fuels. Steam generated inside tubes that form the furnace walls is superheated in convective tube banks at the furnace exit. This steam drives a turbine to produce electricity. Heat is recovered from the flue gas to preheat combustion air and boiler feed water.

APC Program Activities

Low Emission Boiler System

There are four major phases to the LEBS program, which take place in sequence.

Phase 1. Systems Analysis, R&D Plan Formulation, Component Definition, and Preliminary Commercial Unit Design

Different industry teams will select and evaluate candidate technologies and subsystems (such as boilers and flue gas cleanup systems), identify design uncertainties and development needs, and formulate a comprehensive research, development, and test plan. Initial definition and development of components will follow, which will include activities such as engineering analysis, modeling, and preliminary experimental work. Then a preliminary design and economic assessment of a commercial-scale LEBS plant will be made.

Phase 2. Engineering Development and Testing

Over a two-year period ending in 1996, experimental testing, engineering analysis, and modeling will take place to develop and evaluate each of the subsystems that make up LEBS. The results will be used to support the design of the commercial generating system and the POC test facility. Phase 2 is likely to include subsystem testing at a scale of approximately 5-10 MWe.

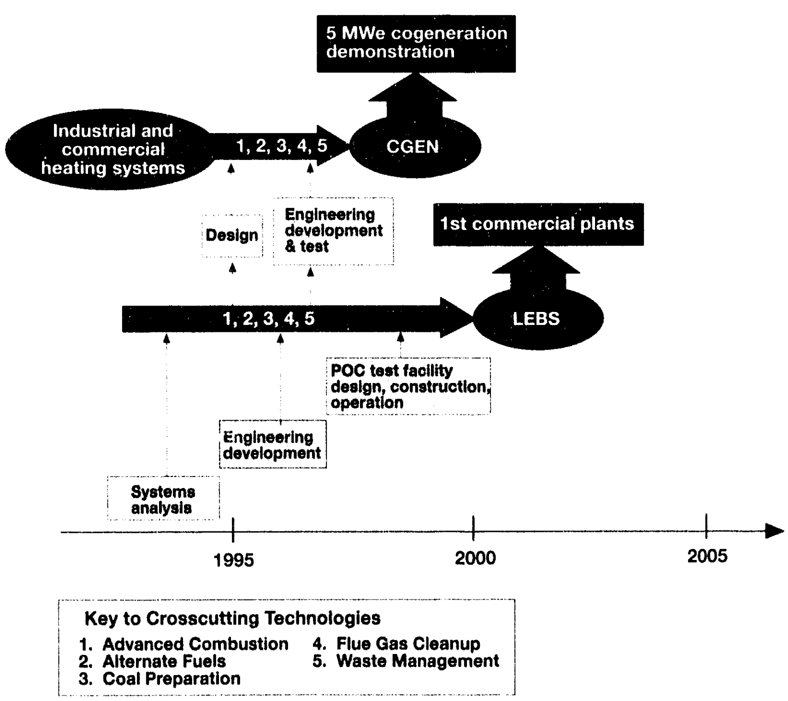
Phase 3. POC Test Facility Design

The most promising LEBS technologies evaluated and tested will be selected for incorporation in the design of the 20-30 MWe POC test facility. Engineering designs that incorporate Phase 2 results will be completed by 1997.

Phase 4. Construction and Operation of the POC Facility

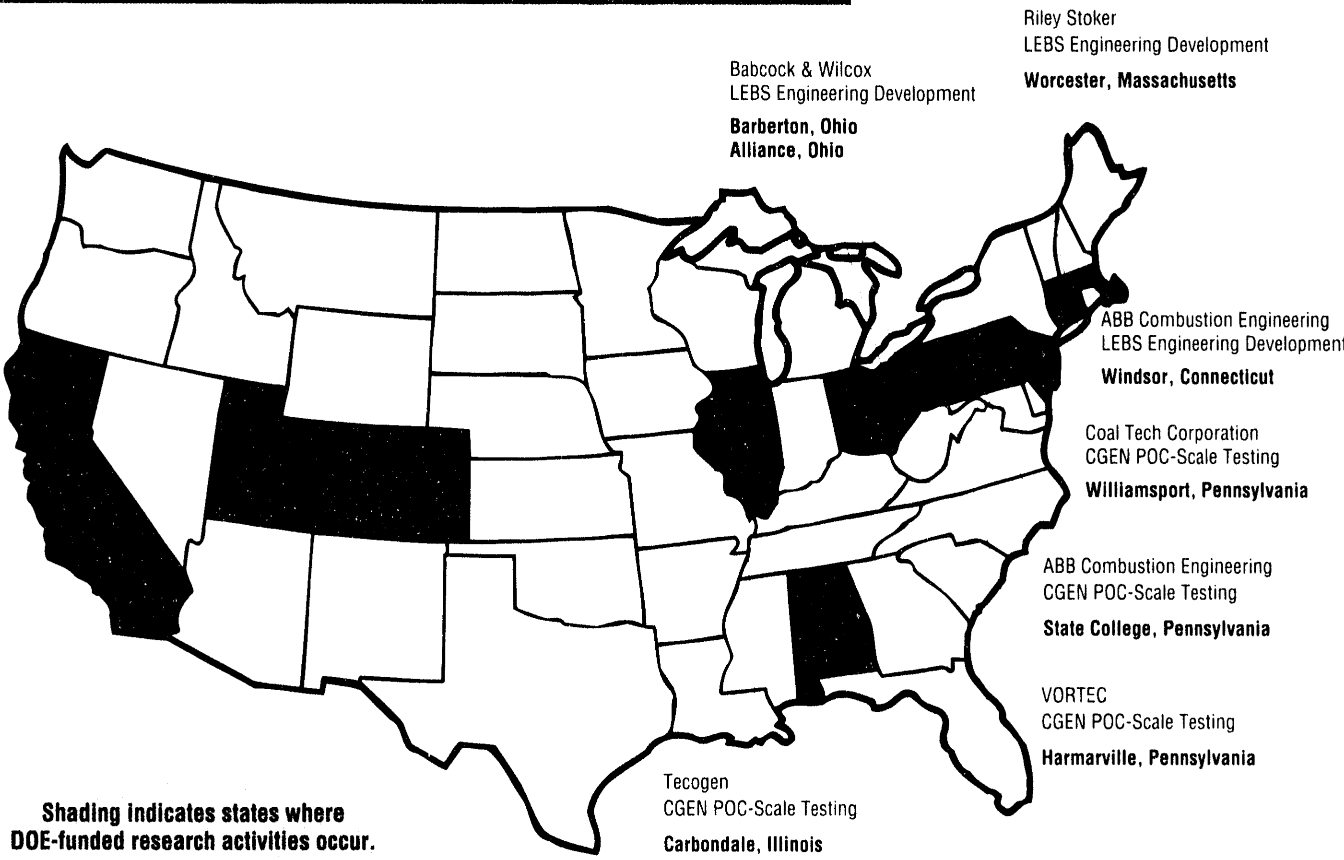
The POC test facility will then be designed in detail, constructed, and put into operation by the year 1999. Successful completion of the POC demonstration will make a verified design basis available for construction of the first commercial generating plants using LEBS technology.

Program Elements Interaction



◄ Interaction between the elements leading to commercial coal-fired cogeneration and commercial LEBS plants, and the crosscutting technologies associated with them, is essential to the design and construction of the first commercial plant.

Major Demonstrations and Activities



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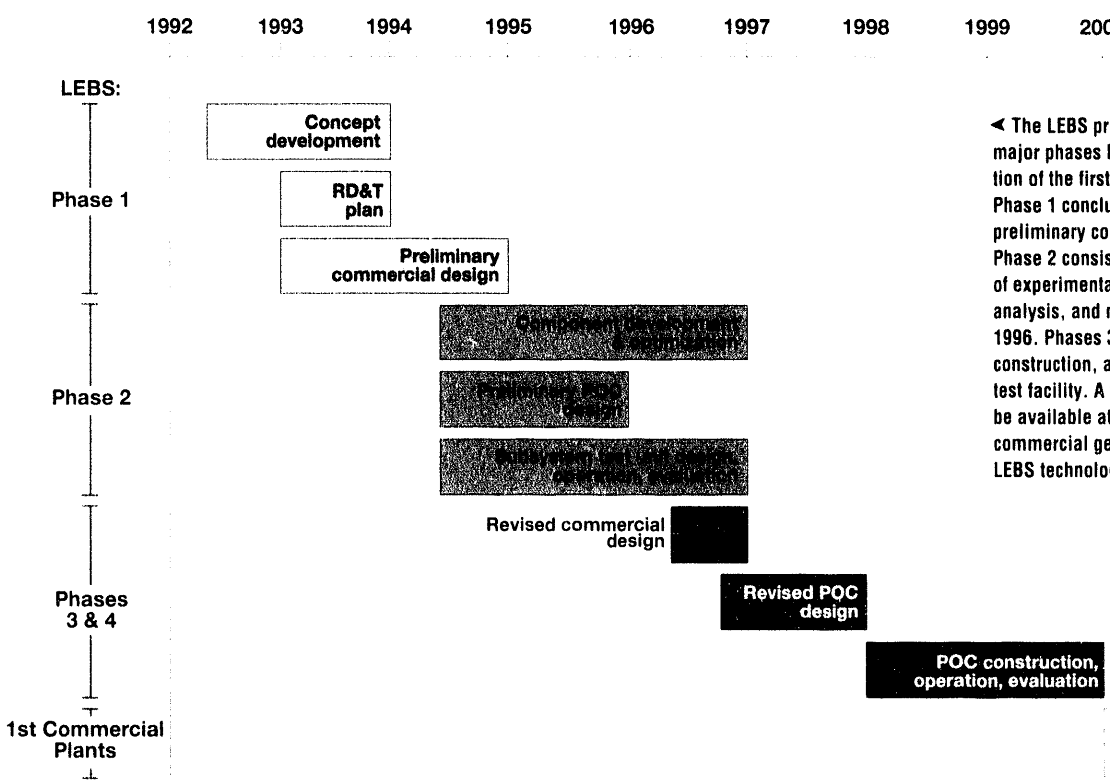
Major Activities and Milestones



◄ The LEBS program consists of four major phases leading up to the operation of the first commercial LEBS plant. Phase 1 concludes in late 1994 with a preliminary commercial unit design. Phase 2 consists of a two-year program of experimental testing, engineering analysis, and modeling, ending in 1996. Phases 3 and 4 cover the design, construction, and operation of a POC test facility. A verified design basis will be available at this time for the first commercial generating plants using LEBS technology.

Coal-Fired Cogeneration

There are four phases to the CGEN program. The program will take advantage of concurrent advances in coal preparation, alternative fuels, advanced combustion, flue gas cleanup, and waste management. The development of LEBS and advanced coal-fired industrial and commercial heating systems could also contribute to the CGEN program.

Phase 1. System Design and Analysis

Preliminary design of a commercial plant will focus on a system that can be introduced near a load center or urban area. System analysis will provide estimates of the CGEN's operating performance and indicate areas requiring R&D.

Phase 2. Engineering Analysis and Testing

Engineering analysis and testing will be performed on technologies integral to the CGEN system operation, including coal preparation, fuel formulation and handling, combustor and furnace design, gas cleanup, and waste management. This work will serve to close technology gaps, provide needed data and component designs, and resolve system integration issues. Work in Phase 2 will be completed by FY 1997.

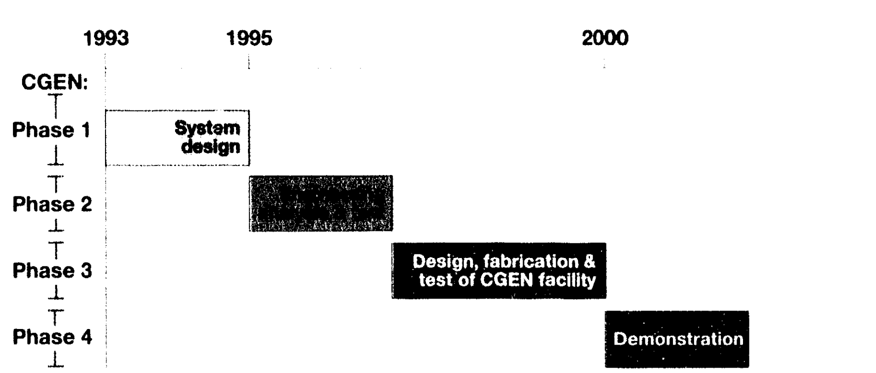
Phase 3. Commercial Plant Design and POC Facility Design, Fabrication, and Preliminary Testing

A final commercial CGEN plant design will be developed using the Phase 2 results. The design of a 5 MWe POC test facility will follow from the commercial plant design. Once the 5 MWe POC facility is designed, fabrication and shakedown testing will commence. Phase 3 will be completed by FY 2000.

Phase 4. Demonstration Testing of a 5 MWe CGEN POC Facility

The 5 MWe CGEN POC facility will be operated over a three-year period in order to evaluate system performance and resolve any technical issues with the integrated system. This demonstration will provide the design basis for commercialization by 2003.

Major Activities and Milestones



➤ **There are four phases to the CGEN program, involving several coal-based combustion system technologies. System design, engineering analysis, and testing precede the design of a commercial CGEN plant, and preliminary testing of a 5 MWe POC facility based on the commercial design. The CGEN system will be constructed by FY 2000, with cost-share from private industry.**

Indirectly Fired Cycle Systems

Indirectly Fired Cycle (IFC) systems are coal-fired, combined-cycle systems that produce energy as cleanly and efficiently as oil- or natural-gas-fueled systems. IFC power generation is well-suited to technology growth, and the fact that it uses conventional generating practices makes it readily acceptable commercially.

First-generation IFC power systems will have net system efficiencies of greater than 45 percent, and may see large-scale demonstration before the end of this decade. Advanced IFC power systems are capable of net system efficiencies approaching 50 percent, and are expected to see large-scale demonstration in the middle of the next decade.

IFC RD&D Program Description

The IFC program consists of:

- Near-term introduction of a coal-fueled IFC system that incorporates an advanced high-temperature ceramic heat exchanger, and existing or near-term environmental control technologies. This subprogram is designated as the Externally Fired Combined Cycle (EFCC).
- Post-2000 introduction of advanced IFC systems, a subprogram designated as the High Performance Power System (HIPPS). HIPPS is based on a new high-temperature advanced furnace (HITAF), which integrates the combustion, heat transfer, and emissions-control processes. This unified approach is expected to provide synergism with respect to cost, efficiency, and environmental performance.

Externally Fired Combined Cycle

EFCC has as its goal the near-term introduction of commercially viable IFC systems.

Major program elements include:

- The development and demonstration of a ceramic heat exchanger that maximizes the exit air temperature from the heat exchanger.
- A proof-of-concept (POC) demonstration of EFCC.
- Systems studies and support activities, including performance optimization of turbines, combustor, and post-combustion environmental controls.

High Performance Power System

The HIPPS program is aimed at developing an IFC system that meets strict limits on all system effluents while affording high cycle efficiency. HIPPS is based on a new high-temperature advanced furnace (HITAF), which fully integrates the combustion, heat transfer, and emissions-control processes. The benefits of this unified approach are expected to be significant in terms of increased efficiency and environmental performance of the system. Improved flue gas cleanup and waste management methods also form an integral part of the design.

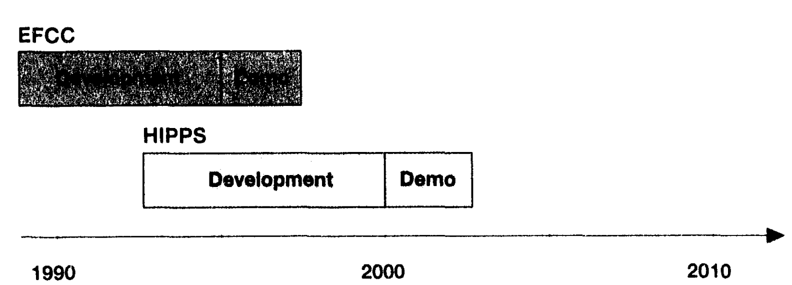
The HIPPS program consists of three phases:

- Concept definition and preliminary R&D.
- Engineering development, testing, and prototype plant design, including HITAF development, integration of post-combustion flue gas cleanup, and evaluation of advanced gas turbine cycles.
- Construction, operation, and evaluation of a commercial prototype IFC power plant.

Interaction of EFCC and HIPPS

All of the elements in both the EFCC and HIPPS programs are needed to push IFC power generation to commercial readiness. The two programs are complementary, and their elements interlock. The near-term introduction of IFC technology will come with the utility-scale demonstration of EFCC, and subsequent HIPPS development will bring efficiency and environmental performance to its full potential. The operation of a commercial-scale prototype HIPPS will demonstrate the readiness of a comprehensive IFC system, and lead to commercialization of advanced IFC power systems.

Development Cycle



➤ Currently under development, EFCC technology will introduce an IFC system by mid-1997 which incorporates an advanced high-temperature ceramic heat exchanger, and existing or near-term environmental control technologies. HIPPS development will conclude in 2000 with a demonstration of a commercial prototype plant.

Advanced Research

Progress in advanced base research and crosscutting technologies is also essential to the development of IFC systems. Greater thermal efficiency will result from RD&D conducted in the Advanced Turbines Systems program, and improved environmental performance will result from that conducted by the Coal Preparation, Advanced Combustion, Flue Gas Cleanup, and Waste Management programs. The input of these programs will support the introduction of EFCC, and the development of HIPPS. The development of advanced demonstration systems is dependent upon the work accomplished in these technologies.

Advanced Turbines Systems

A separate Advanced Turbines Systems crosscutting development program is being funded by the DOE Natural Gas program. This will develop and demonstrate next-generation gas turbine technology for use with natural gas and coal applications.

RD&D Program Goals

IFC Power Systems	
[illegible]	50%
[illegible]	1/10
[illegible]	1/10
[illegible]	1/4
[illegible]	90%
[illegible]	to meet
[illegible]	benign/saleable by-products
[illegible]	$1,200

NSPS=New Source Performance Standards

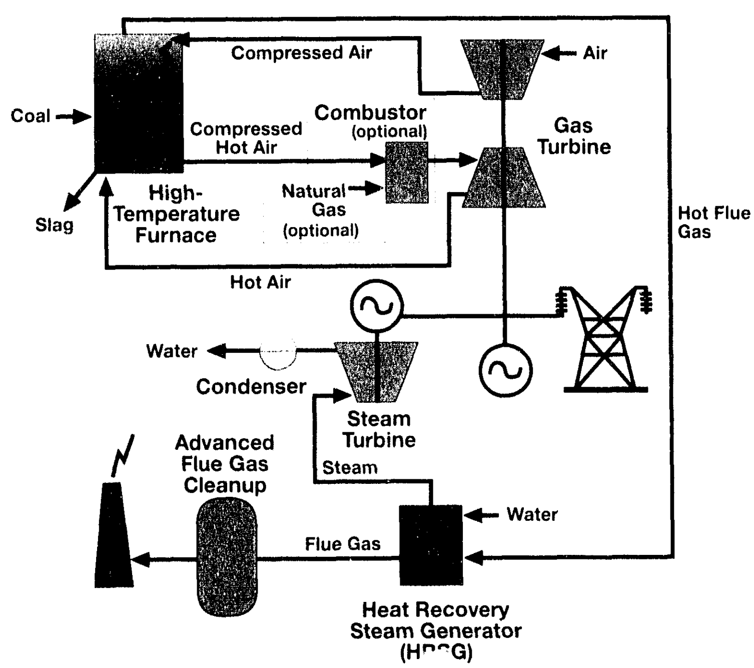
CAAA=Clean Air Act Amendments

System Components

➤ IFC power generation utilizes a combined cycle that transfers the heat produced by coal combustion across specialized heat transfer surfaces to a clean gas turbine working fluid (e.g. air). This working fluid can be further heated by burning natural gas. Energy from the gas turbine exhaust and from the coal flue gas raises steam, which adds a Rankine bottoming cycle to create a combined-cycle system.

Heat exchange surfaces isolate the corrosive, ash-laden combustion gases from the gas turbine, protecting the turbine from erosion and corrosion, and eliminating the need for high-temperature filters to clean hot gas entering the gas turbine.

Integration of the heat transfer, coal combustion, and emissions-control processes within the IFC design will improve its competitiveness in the power generation market.



IFC Program Activities

Externally Fired Combined Cycle

The elements of the EFCC program are being carried out concurrently.

Ceramic Heat Exchanger Development

A ceramic heat exchanger is being developed and demonstrated at industrial scale. Development of this heat exchanger demonstrates the key capability required for indirectly fired systems. EFCC testing will show that the heat exchanger can:

- Survive high operating temperatures.
- Resist corrosion.
- Withstand pressure differentials.
- Avoid seal leakage.
- Avoid catastrophic failure.

Tests will be conducted using a 2 MWe combustor, a ceramic heat exchanger, a slag screen for protecting the heat exchanger tubes, and other hardware.

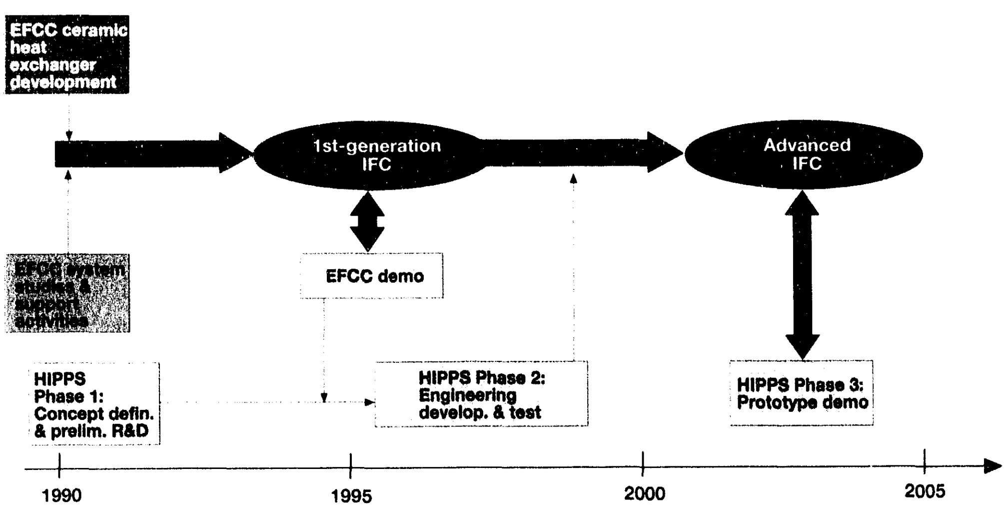
System Studies and Support Activities

- **Development of improved ceramics**. When the feasibility of the EFCC system has been proved, development will focus on integration, operation, and control of the EFCC system with a gas turbine. Improved heat exchanger materials and designs will also be investigated for their performance at very high temperatures and pressures.
- **Water or steam injection studies.** EFCC thermal performance will be optimized through studies on water or steam injection to achieve 50 percent or higher net system efficiencies, and significant increases in system power output.
- **Support activities**. Support activities are being conducted concurrently. These include screening studies of critical components, such as tests of the effect of moisture on advanced ceramics, and performance and cost tradeoffs for EFCC systems.
- **Development of improved heat exchanger materials.** Ceramic research by national laboratories, ceramic manufacturers, and universities may result in superior materials that will allow future heat exchanger performance improvements. Technologies developed in the Advanced Turbines Systems program will also be applied to IFC system concepts.

Utility-Scale Demonstration

This demonstration program element focuses on the design, construction, start-up, and operation of a first-generation IFC utility-scale power plant. This demonstration plant was selected by competitive procurement in the fifth round of the Clean Coal Technology program, and will have a 50 percent cost-share from a utility partner.

Program Elements Interaction



◄ Development of both the EFCC and HIPPS technologies and input from several crosscutting research programs are needed for IFC power generation to reach commercial readiness. First-generation IFC will follow development of a ceramic heat exchanger and EFCC system support activities. After integration of the EFCC and HIPPS programs in 1994, advanced IFC will demonstrate full efficiency and environmental performance. The design and operation of a commercial-scale prototype HIPPS will lead to commercialization of advanced IFC power systems.

High Performance Power System

There are three phases to the HIPPS program.

Phase 1. Concept Definition and Preliminary R&D

Phase 1 activities include engineering analysis, modeling, and small-scale testing by two industry teams that were selected by competitive solicitation. A preliminary commercial plant design will be created by the end of 1994, and a research, development, and test plan generated to develop the technical information base needed to prepare a final comprehensive design. The two industry teams that were awarded contracts for this phase are both developing power systems that are based on a HITAF, use an indirectly fired gas turbine combined cycle, and include advanced environmental control technology. However, they offer significantly different approaches to the design of the HITAF, which is the only major subsystem that requires substantial development.

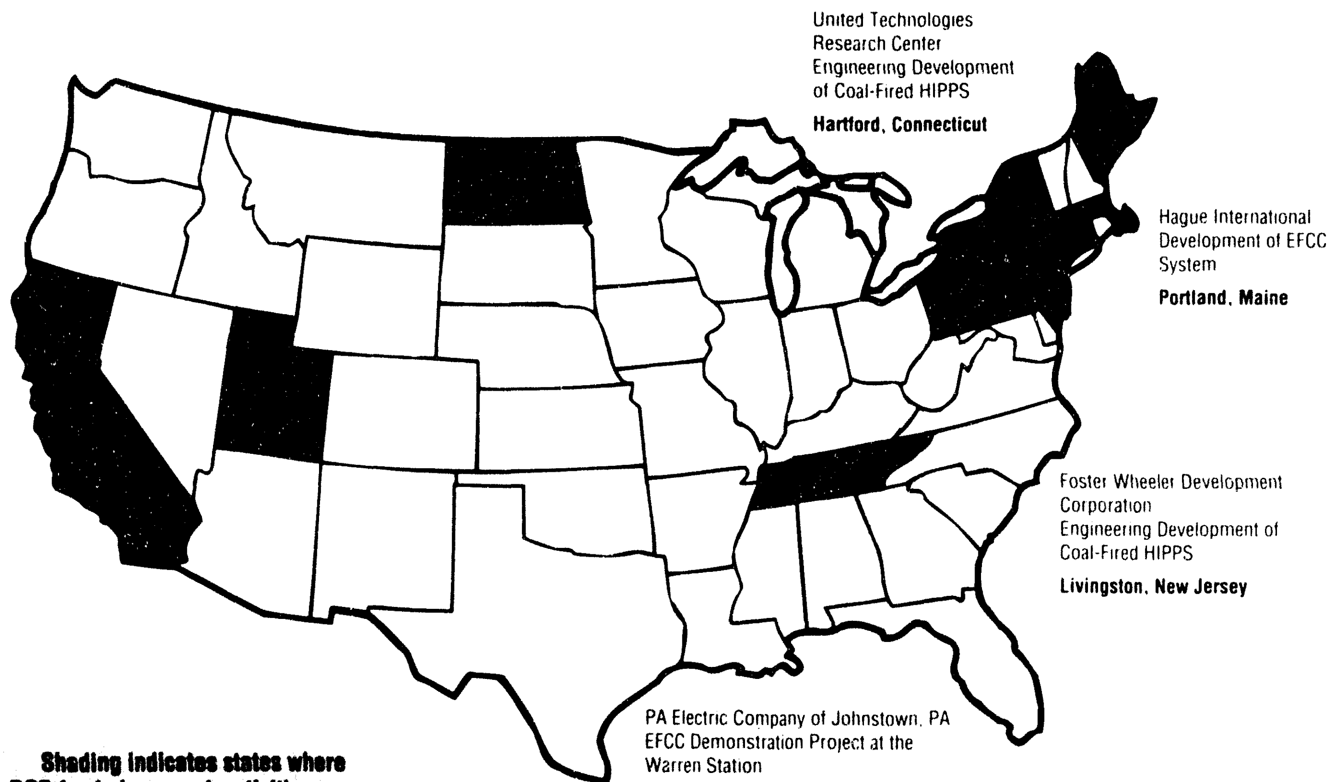
Phase 2. Engineering Development and Testing

The most promising systems will be selected in mid-FY 1994, following a second competitive bid, and will continue with engineering development, testing, and design of a prototype commercial plant. Development and testing activities needed to generate information critical to prototype plant design will include development of components such as burners, and of individual subsystems, such as the high-temperature advanced furnace and the flue gas cleanup subsystem. The major effort will be focused on the design, construction, and evaluation of a high-temperature furnace at moderate scale. The commercial prototype plant designs will then be evaluated to determine which project will proceed into the third phase.

Phase 3. Commercial Prototype IFC Plant

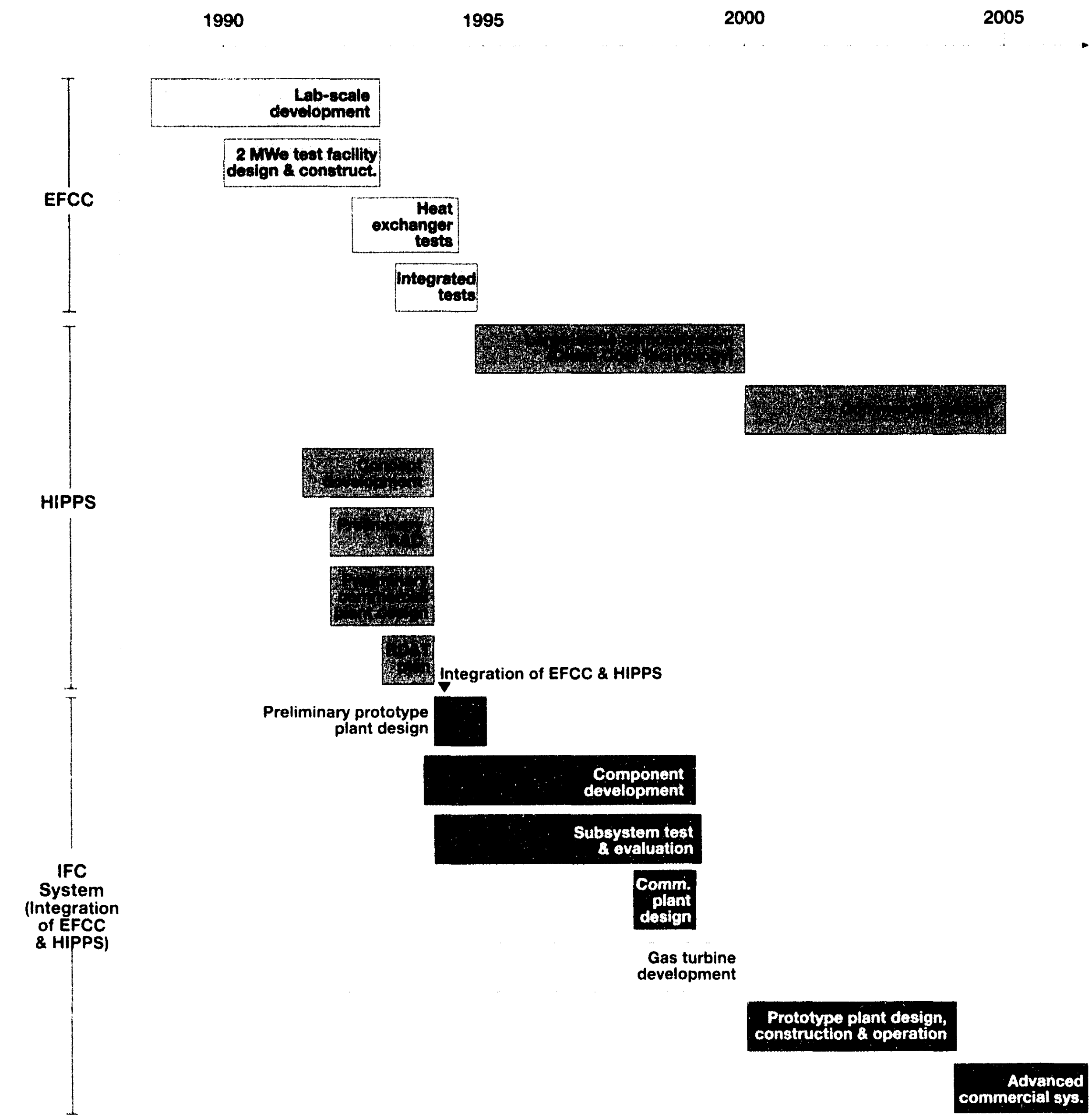
A commercial prototype plant will be designed in 1999, and will start up in full operation in 2001 as a 40 MWe to 80 MWe demonstration. An integrated IFC system with high efficiency and ultra-low emissions, it will prove the commercial readiness of HIPPS technology. Substantial support for this and the prior phase will come from industry cost-sharing. The first actual commercial plant will follow the prototype closely.

Major Demonstrations and Activities



Shading indicates states where DOE-funded research activities occur.

Major Activities and Milestones



▲ Integration of the HIPPS program with the EFCC program in 1994 will provide a commercially viable, cost-effective IFC system. Several important EFCC development activities precede integration with the HIPPS program. Development of EFCC components and systems, first in the lab and then on an industrial scale, concludes with the design and construction of a 2 MWe test facility. Phase 1 of HIPPS development occurs concurrently: concept development, preliminary research, initial commercial plant design, and the creation of a full RD&T plan. Design, construction, and operation of a prototype plant follow further component and subsystem development. In addition to features of the EFCC and HIPPS development programs, prototype and commercial IFC plant designs may also include advanced turbine technology, which is being developed separately with funding from the DOE Natural Gas program.

Direct Coal-Fired Heat Engines Systems

Direct Coal-Fired Heat Engines (DCFHE) systems incorporate two distinct but related power generation systems: Direct Coal-Fired Gas Turbines (DCFGT) and Direct Coal-Fired Diesels (DCFD). DCFHE power systems are characterized by net system efficiencies of 40 percent or higher, and by the ability to meet existing environmental regulations for acid rain emissions.

For the past decade, DOE has sponsored a program of coal-fired engine development in conjunction with major U.S. manufacturers. This has now reached the proof-of-concept (POC) stage. Potential applications range from transportation to industrial cogeneration and utility systems.

DCFHE RD&D Program Description

The overall objective of the Direct Coal-Fired Heat Engine (DCFHE) program is commercialization of direct coal-fired heat engines by the private sector. There are two different types of coal-fired engines in the program:

- Direct coal-fired gas turbines (DCFGTs).
- Direct coal-fired diesels (DCFDs).

Direct Coal-Fired Gas Turbines

The current work on gas turbines addresses the use of both coal-water slurry and dry pulverized coal. A conventional gas turbine is extremely sensitive to certain fuel impurities, so either the working fluid resulting from the combustion of coal must have acceptably low amounts of corrosive and erosive impurities, or the turbine must be designed to be more tolerant to these impurities. The DCFGT program is pursuing both approaches.

Specific objectives of the DCFGT program are:

- To complete integrated system tests by the end of FY 1994.
- To determine technical feasibility by the end of FY 1994.
- To achieve an overall system efficiency of approximately 40 percent.
- To achieve SO_2 and NOx emission rates significantly better than applicable New Source Performance Standards (NSPS) limits for gas turbines.

Direct Coal-Fired Diesels

The diesel engines under development are designed to burn coal-water slurry. Parts of the engine, including the cylinder walls, piston head, and fuel injector, directly contact the burning fuel, and this contact can lead to component wear. The potential erosion and corrosion problems caused by the fuel's incombustible mineral matter and other fuel contaminants can significantly lower the operating lifetime of a diesel engine. Enhancing the quality of the coal-based fuel, and designing engine components which can withstand corrosion, are the approaches the DCFD program uses to combat these problems.

Specific objectives of the DCFD program are:

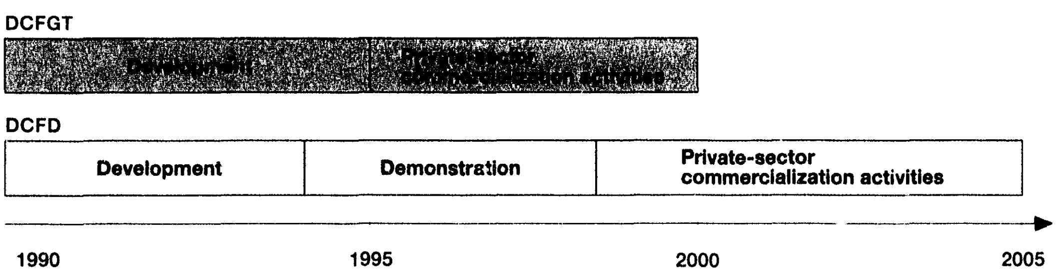
- To develop an R&D base for a commercial-scale technology demonstration.
- To determine technical feasibility and economic viability by the end of FY 1993.
- To achieve a net system efficiency of approximately 45 percent.
- To achieve SO_2 and NOx emissions at least equivalent to NSPS limits for small boilers.

Environmental Goals

The environmental objective of the program is to develop coal-fueled diesels and gas turbines that not only meet all existing regulations, but also are capable of meeting possible future standards. The prospects of achieving this goal are good, although for some applications addressed by the program, there are no emissions regulations yet. Advanced cleanup devices will be used for both coal-fired gas turbines and coal-fired diesels.

➤ **Both the Direct Coal-Fired Gas Turbine and Direct Coal-Fired Diesel programs are well into their planned development activities. DCFGT begins commercialization activities in the private sector at the end of 1994, and DCFD enters its commercial phase even earlier, having determined technical feasibility and economic viability by the end of 1993.**

Development Cycle



RD&D Program Goals

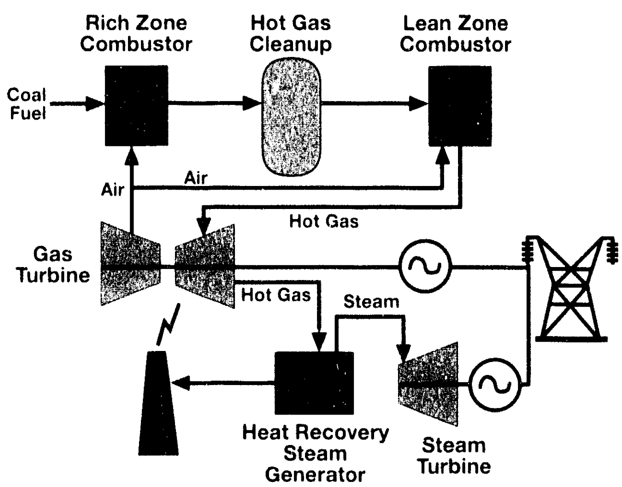
DCFHE Power Systems	DCFGT	DCFD
Net electric system efficiency	40%	45%
SO_2 emissions relative to current NSPS	to meet	to meet
NO_x emissions relative to current NSPS	to meet	to meet
Air toxics emissions relative to 1990 CAAA	to meet	to meet
Capital cost, $ per kW	$1,400	$1,300

NSPS=New Source Performance Standards

CAAA=Clean Air Act Amendments

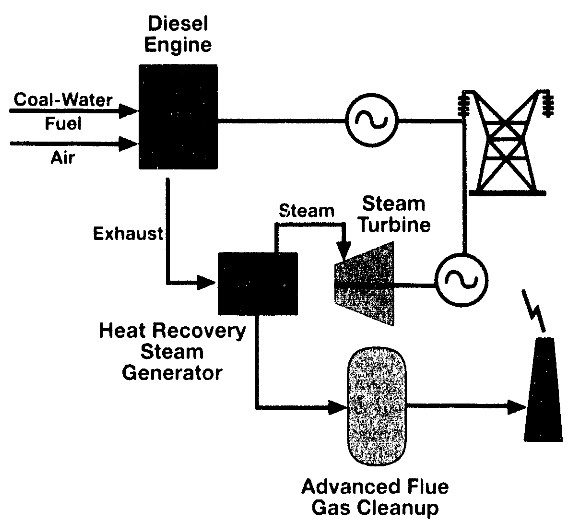
System Components

Direct Coal-Fired Gas Turbine



▲ The gas turbine is a simple power-generating unit. It consists of a compressor, in which ambient air is compressed to pressures of 8 to 16 atmospheres; a combustor, in which the compressed air is heated to temperatures of 870 to 1,290 degrees Celsius (1,600 to 2,350 degrees Fahrenheit); and a turbine, in which the hot gases expand to atmospheric pressure. The power generated is sufficient to drive a mechanical device or generator, in addition to driving the compressor. The gas turbine can operate on low-cost coal-based fuels instead of on premium fuels.

Direct Coal-Fired Diesel



▲ The operating principle of a diesel engine is very simple. A piston compresses air in a cylinder to a pressure at which the generated heat will ignite the fuel injected into the cylinder at the top of the stroke. The expanding hot gas then drives the piston downward, producing power. Fresh air is admitted to the cylinder and the process is repeated. The diesel engine can be fueled successfully by coal, instead of by premium fuels.

DCFHE Program Activities

The program includes POC and support projects for both gas turbine and diesel development. The POC projects include operation of systems at full commercial scale for short periods of time. The support projects address specific technology issues. Gas turbine and diesel contractors working in conjunction with the DOE have already made significant progress toward demonstrating the technical feasibility of the systems.

Direct Coal-Fired Gas Turbines

Activities include:

- Research conducted at the Morgantown Energy Technology Center (METC) facility exploring the methods of overcoming technology barrier issues in DCFGT systems. These and contractor activities investigate concepts which offer potential cuts in capital costs with increases in system efficiency.
- Major development projects with Allison Gas Turbines Division of General Motors (AGT/GM), Solar Turbines, and Westinghouse. All projects are scheduled for completion by the end of 1994.
- Short-term integrated tests of a 4 MWe or 5 MWe DCFGT system at Allison Gas Turbines Division of General Motors (AGT/GM). These tests have already been conducted using coal-water slurry, and are planned using dry coal.

Direct Coal-Fired Diesels

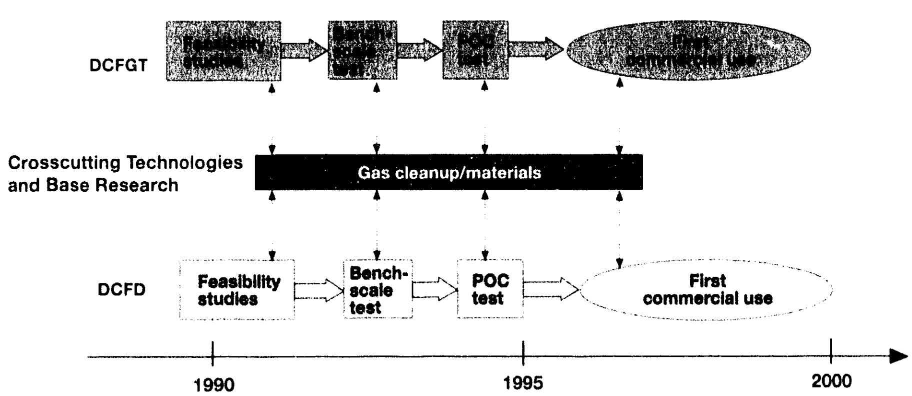
Activities are scheduled for completion by 1994, and include:

- Research and feasibility studies conducted at METC, exploring methods of overcoming DCFD technology barrier issues.
- Small-scale tests of a fuel processor at Caterpillar facilities, and tests of a coal-fired, high-speed diesel at Detroit Diesel facilities.
- A short-term 1.8 MWe stationary diesel POC demonstration test. This will take place at Arthur D. Little/Cooper-Bessemer facilities. An additional POC test of a coal-fired locomotive will take place at General Electric.

Crosscutting Technologies and Base Research

In addition to these program elements, each of the DCFHE power systems is also supported by gas cleanup crosscutting development activities, and by materials science base research activities.

Program Elements Interaction



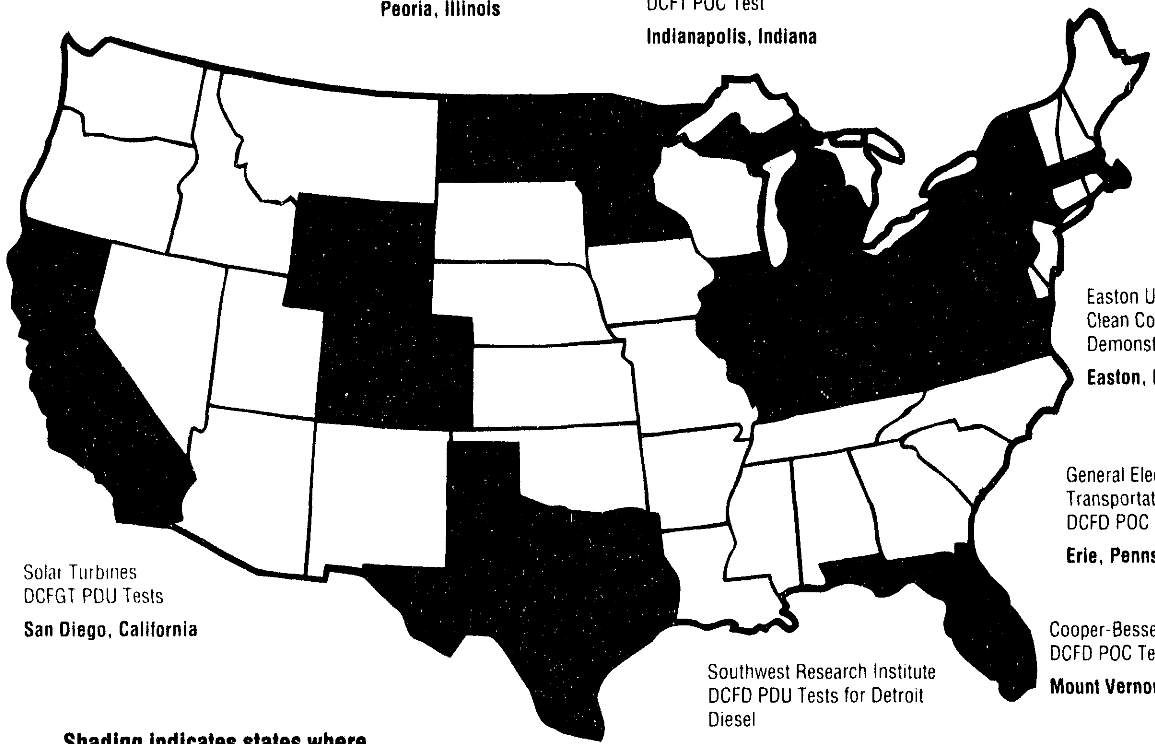
◄ Feasibility studies for the DCFGT system began in 1986, and those for the DCFD system in 1987. The bench-scale tests and POC tests that follow system development are closely tied to a materials base research program. Development of hot gas cleanup methods is essential to the achievement of DCFGT goals, while hardened materials are essential for DCFD success.

Major Demonstrations and Activities

Caterpillar, Inc.
DCFT POC Test
DCFD PDU Tests
Peoria, Illinois

General Motors
Allison Gas Turbine Division
DCFT POC Test
Indianapolis, Indiana

Textron Defense Systems
DCFT PDU Tests for Westinghouse
Haverhill, Massachusetts



Easton Utilities/A.D. Little
Clean Coal Diesel Tech. Demonstration
Easton, Maryland

General Electric
Transportation Systems
DCFD POC Test
Erie, Pennsylvania

Cooper-Bessemer
DCFD POC Test for A.D. Little
Mount Vernon, Ohio

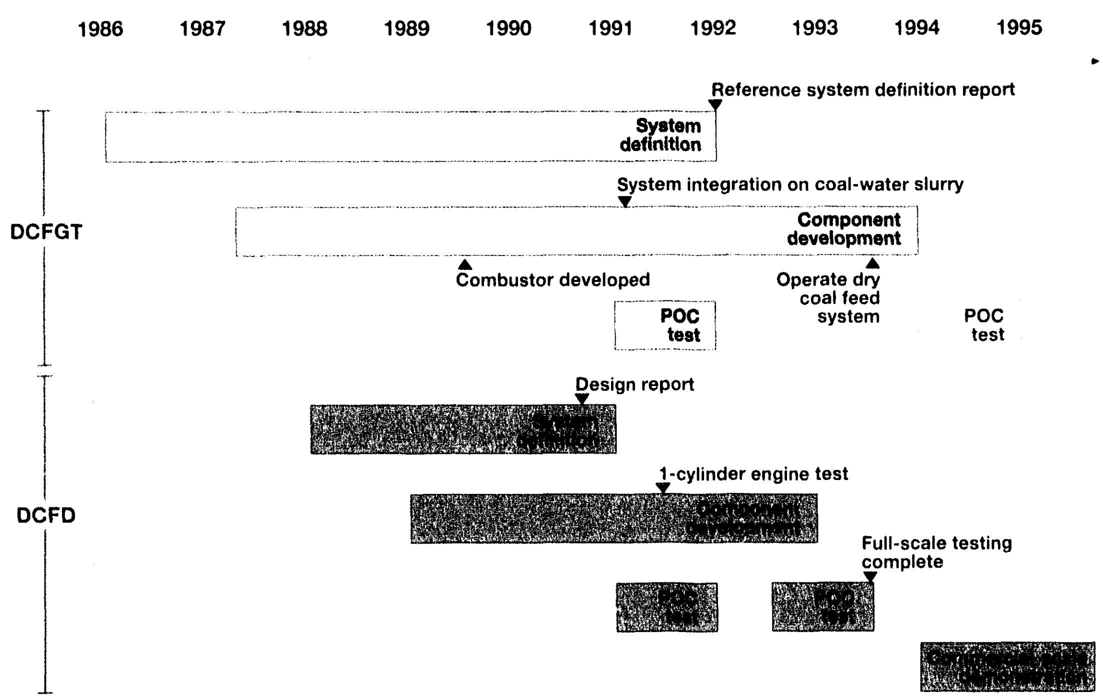
Southwest Research Institute
DCFD PDU Tests for Detroit Diesel
San Antonio, Texas

Solar Turbines
DCFGT PDU Tests
San Diego, California

Shading indicates states where DOE-funded research activities occur.

Major Activities and Milestones

➤ A number of milestones have been developed to mark the progress of the DCFGT and DCFD systems toward the programs' ultimate goal of commercial use. These include POC tests and support projects addressing specific technology issues. Contractors also investigate concepts that offer potential cuts in capital costs and increases in system efficiency. Major POC projects for DCFGT include Allison Gas Turbines Division of General Motors (AGT/GM), Solar Turbines, and Westinghouse. A short-term 1.8 MWe stationary diesel POC demonstration test will be completed by Arthur D. Little/Cooper-Bessemer by 1994. Full-scale testing will then be complete.



Pressurized Fluidized-Bed Combustion (PFBC) systems have several inherent advantages over conventional pulverized coal power production systems. High system efficiency results from the combined-cycle configuration, which includes a conventional steam cycle and a gas turbine. Removal of sulfur oxides in the combustion gas by using limestone or dolomite mixed with coal in the fluidized-bed eliminates the need for post-combustion flue gas desulfurization. A lower combustion temperature reduces the amount of nitrogen oxide emissions, and fluidized-bed combustion systems also produce a dry ash that is a usable by-product.

First-generation PFBC power systems are capable of net system efficiencies approaching 42 percent, while second-generation PFBC systems will have system efficiencies approaching 45 percent. These systems are now at the commercial demonstration stage of development. Advanced, super-clean PFBC systems, capable of system efficiencies of at least 50 percent, are expected to see large-scale demonstration in the middle of the next decade.

PFBC RD&D Program Description

The PFBC program consists of three different development generations.

- First-generation PFBC power systems.
- Second-generation PFBC power systems.
- Super-clean, super-efficient PFBC power systems.

Program Goals

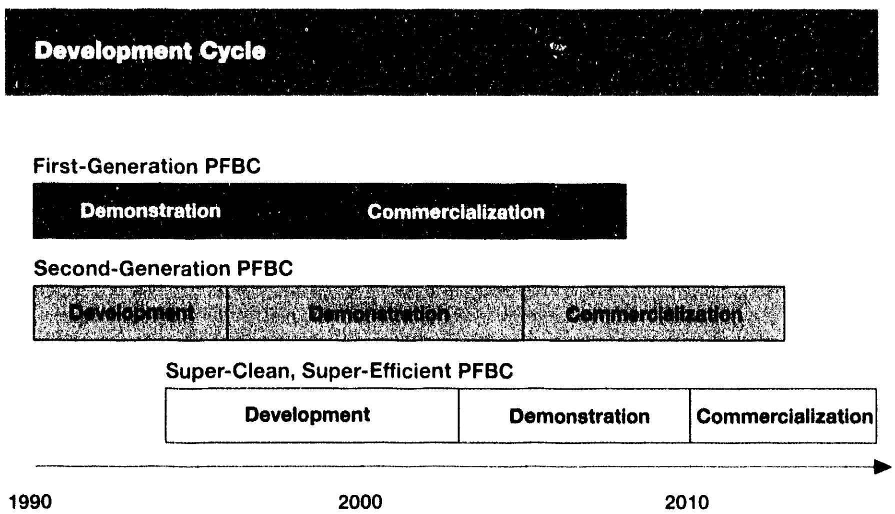
The R&D program has three primary objectives:

- To demonstrate the viability of first-generation PFBC technology in U.S. utility applications.
- To develop and demonstrate second-generation PFBCs with efficiencies approaching 45 percent.
- To increase the efficiency of PFBC systems to 50 percent, and to improve PFBC environmental performance.

The present DOE PFBC program is focused on developing and demonstrating second-generation and advanced PFBC components, concepts, and subsystems at up to proof-of-concept (POC) scale, with eventual commercial-scale demonstration of complete integrated power production systems.

The major PFBC program elements include:

- PFBC Fundamental Advanced Research.
- PFBC component development.
- PFBC systems development, integration, and testing.
- Environmental and economic performance studies.
- Commercial-scale demonstrations.



➤ **First-generation PFBC systems are currently being demonstrated at the 70-80 MWe size, which are units large enough for use by small utilities or independent power producers. Scaling up to the size large utilities need (greater than 300 MWe) will take place in the latter part of this decade. More efficient and cost-effective second-generation PFBCs are entering the demonstration phase. These should be fully commercial systems by the end of the decade. Further improvements to second-generation PFBCs will produce very clean systems, with electrical efficiencies approaching 50 percent.**

RD&D Program Goals

PFBC Power Systems	First-Generation	Second-Generation	Improved Second-Generation
[illegible]	40%	45%	≥ 50%
[illegible]	1/4	1/5	1/10
[illegible]	1/3	1/5	1/10
[illegible]	to meet	to meet	to meet
[illegible]	$1,300	$1,100	$1,000
[illegible]	90%	80%	75%

NSPS=New Source Performance Standards

CAAA=Clean Air Act Amendments

PFBC Program Activities

PFBC program activities are aimed at full commercialization of the PFBC systems in the next two decades.

Advanced Research

Moderate levels of advanced research are planned to provide continuing refinement and improvement of PFBC power systems. Activities in this program element include coal and ash chemistry base research (including combustion and devolatization mechanisms), process control methodologies advanced research, materials base research, and development of advanced instrumentation.

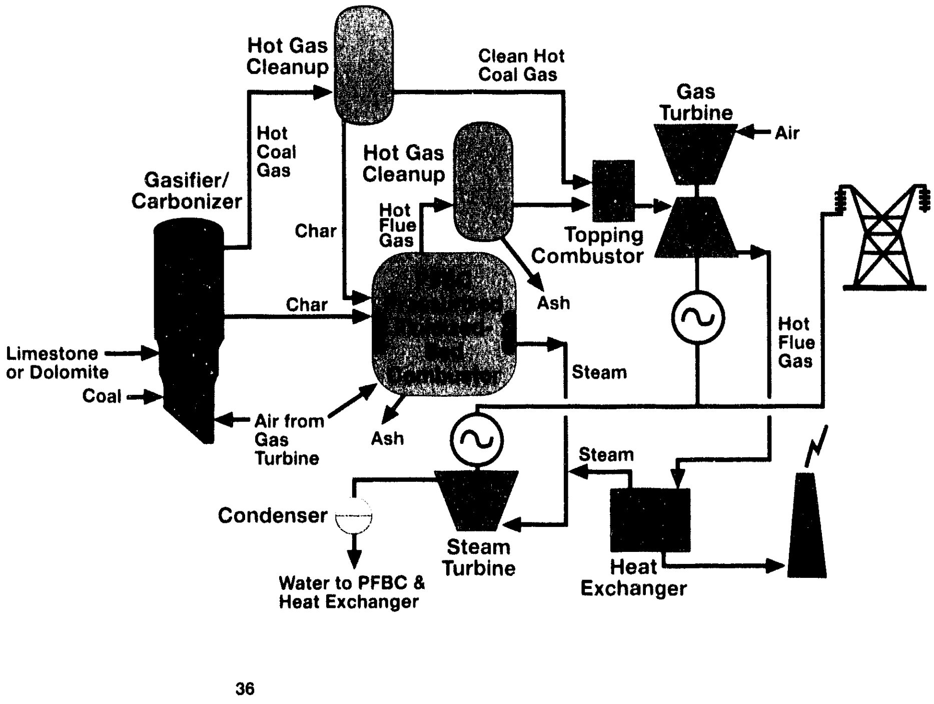
Component Development

Component development will allow significant improvements in the economic viability of PFBC systems. Further development of ceramic barrier filters is urgently needed. A crucial project in the development of ceramic filter components is the demonstration of at least two ceramic filter hot gas cleanup devices in utility-scale tests at Ohio Power's Tidd PFBC demonstration project. This research and development will

➤ In a second-generation PFBC power plant, coal mixed with limestone or dolomite sorbent is initially pyrolized in a carbonizer to produce a combustible fuel gas and a solid char. The char/sorbent mixture is then combusted at high pressure in the fluidized-bed combustion vessel. In both the carbonizer and fluidized-bed combustion vessel, the sorbent acts to remove sulfur impurities from the coal. After particulates are removed from the fuel gas and fluidized-bed combustion gas, these gas streams are combined and combusted in a topping combustor. The hot topping combustor exhaust gas enters a high-efficiency gas turbine to generate electrical power. Hot, low-pressure exhaust gas from the gas turbine, and heat from the combustion of the char, are utilized to produce steam and generate additional power via a steam turbine.

Advanced, second-generation PFBC systems feature evolutionary improvements to turbines and other components to raise system efficiencies further. First-generation PFBC systems do not feature a carbonizer or a combustion turbine, and are less efficient, due to the resulting lower temperature of the gas being sent to the gas turbine.

System Components



be conducted in conjunction with equipment suppliers. Small businesses will be specifically targeted for work in this area.

Cost-sharing contracts with U.S. equipment manufacturers will address the capability of U.S. industry to produce PFBC components that compete successfully in the domestic and international markets. In addition to ceramic filters, important components that could be produced competitively in the U.S. are hot gas piping, solids transfer valves, coal-water paste pumps, and gas turbines optimized for PFBC systems.

Advanced Turbines Systems

A separate Advanced Turbines Systems crosscutting development program is being funded by the DOE Natural Gas Program. This will develop and demonstrate next-generation gas turbine technology for use with natural gas and coal-derived gas.

Systems Development, Integration, and Testing

The testing activities for PFBC systems consist mainly of assessing the operating performance of a partially integrated second-generation PFBC at the Foster Wheeler Development Corporation's pilot plant facility. This testing will verify the economic and environmental performance and efficiency of this PFBC system. Major components and high-temperature solids transfer issues are also under study.

A fully integrated second-generation PFBC will be operated and analyzed at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama. This PFBC testing will evaluate the integration of all of the components in the PFBC system with primary emphasis on the marriage of hot gas cleanup ceramic filters to gas turbines.

Environmental and Economic Performance Studies

Environmental and economic performance studies will address the ongoing need to develop and commercialize more efficient, environmentally superior power systems. The activities in this area of the PFBC program will explore the full potential of PFBC systems to produce extremely low pollutant emissions levels, while also attaining correspondingly high ratings for energy efficiency. The engineering issues associated with integrating advanced steam turbines and advanced gas turbines into super-clean, super-efficient PFBC systems will be investigated.

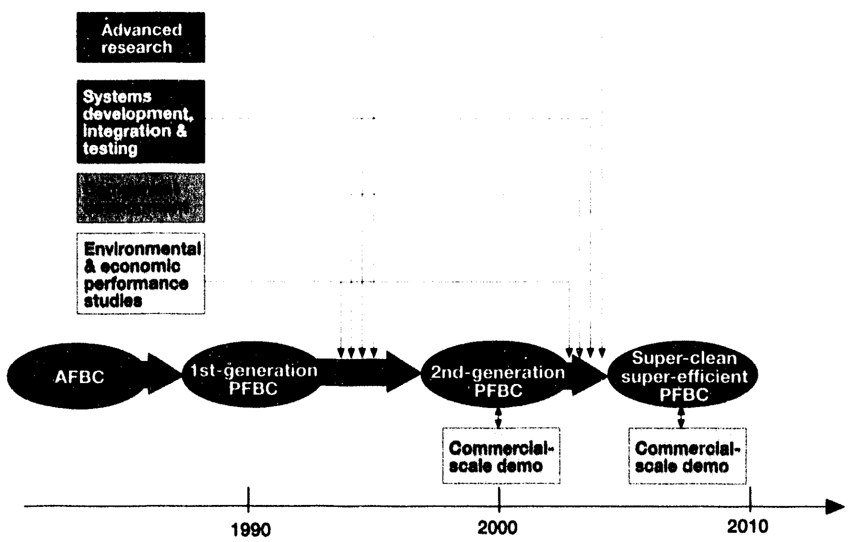
Activities will include research studies using cost-shared, competitive contracts resulting from proposals submitted in response to a Program Research Development Announcement. Feasibility studies and POC evaluations will be conducted at PFBC pilot plants, utility facilities, and boiler manufacturing facilities. Crosscutting research conducted by the Waste Management program on ash utilization is also a part of this program element.

Commercial-Scale Demonstration

The results of the component development, environmental studies, and efficiency development activities in the PFBC program will lay the technological foundation for commercial-scale demonstrations on a 50/50 cost-sharing basis.

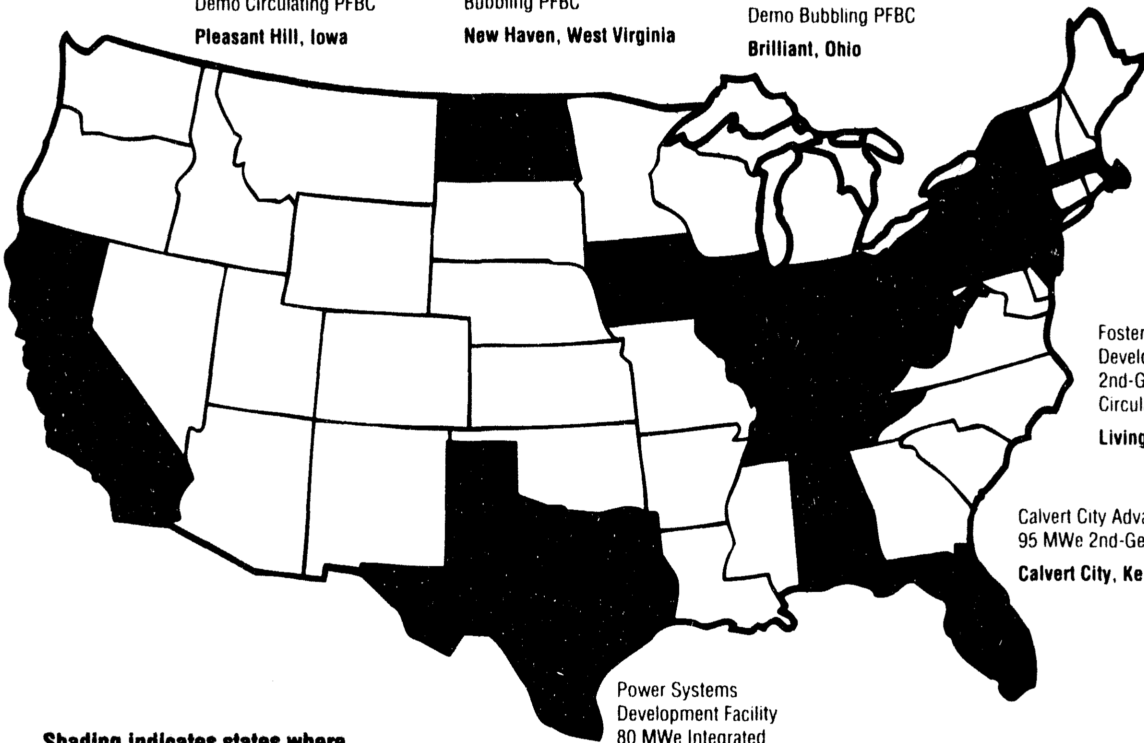
The demonstration program element focuses on the design, construction, start-up, and operation of an advanced, super-efficient PFBC commercial-scale power plant. This large-scale demonstration plant would be selected by competitive procurement, and would have at least a 50 percent cost-share from an industrial partner or consortium.

Program Elements Interaction



◄ **First-generation PFBC Systems have evolved from Atmospheric Fluidized-Bed Combustion (AFBC) technology. With the incorporation of hot gas filters, PFBC developers will be able to use U.S.-supplied gas turbines. The addition of a fuel gas producer, or carbonizer, is necessary to evolve PFBC technology into second-generation PFBC systems. Additional advances in the development of the carbonizer, hot gas cleanup systems, gas turbines, and steam cycles will result in super-clean, super-efficient PFBCs.**

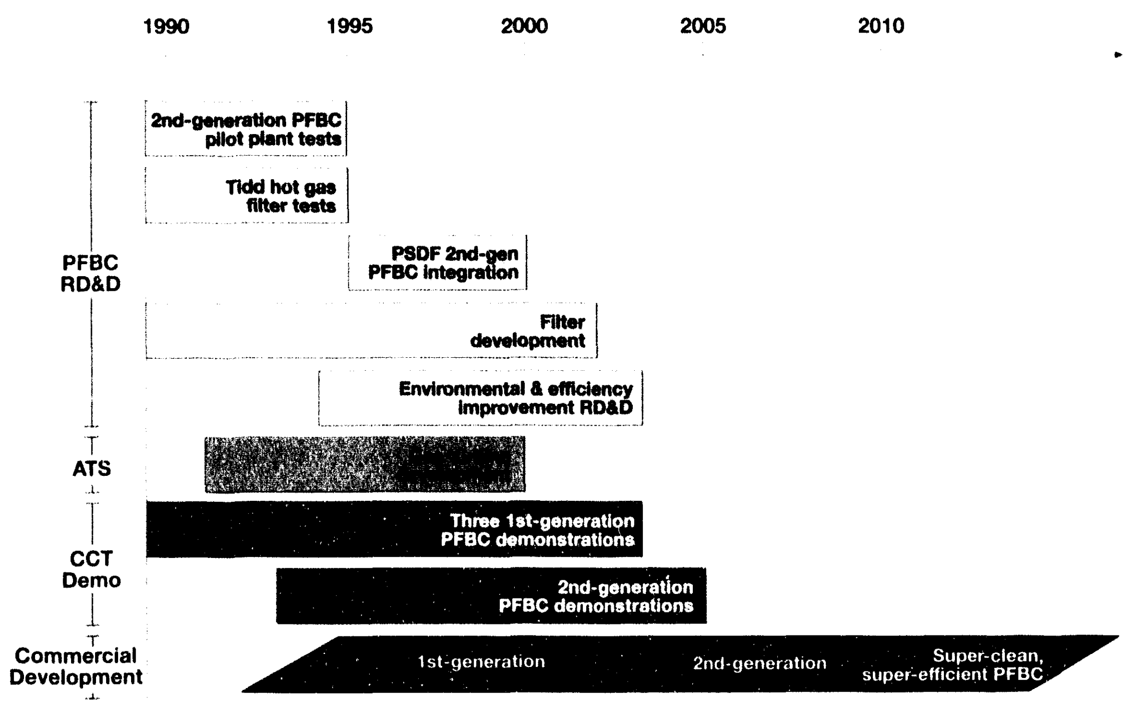
Major Demonstrations and Activities



Shading indicates states where DOE-funded research activities occur.

Major Activities and Milestones

➤ PFBC research and development activities include subsystems and component testing, component development, environmental and economic performance studies, and second-generation PFBC pilot tests. Advanced turbines systems are being developed separately with funding from the DOE Natural Gas program. Three first-generation PFBC demonstrations will be followed by second-generation commercial-scale demonstrations on a 50/50 cost-sharing basis. Fully commercial PFBC systems will be available by the end of the decade.



Magnetohydrodynamics (MHD) systems differ from other advanced coal-fired systems in that they use a channel in a magnetic field connected to the combustor for production of electric power. As the ionized combustion gases pass through the channel's magnetic field at close to the speed of sound, electricity is created. A conventional steam cycle utilizes remaining heat to produce additional power.

Thermal efficiency of a full-scale, commercial, combined-cycle MHD plant is projected to be over 60 percent, while conventional coal-fired power systems offer only 32 to 35 percent efficiency. In addition, MHD technology provides strict controls of SO_2 and NOx emissions, removing more than 99 percent of the impurities from coal.

With efficiencies almost double those of current plants, and emission levels near zero, MHD will be important in the energy production market of the future.

MHD RD&D Program Description

The major goal of the MHD program is to develop and demonstrate a dramatically different advanced power plant with a net efficiency of over 60 percent. Key components developed and demonstrated are:

- An integrated topping cycle, which includes a combustor, an MHD generator, a magnet, and a diffuser.
- An integrated bottoming cycle, which includes a radiant boiler and particulate collection devices.
- An MHD seed regeneration system.

Additional goals include the achievement of extremely low SO_2, NOx, and air toxics emissions, and high economic efficiency (including an electricity cost more than 20 percent lower than that of current generation pulverized coal power plants).

This technology is already in the proof-of-concept (POC) phase, and is expected to be in demonstration, and ready for commercial development, in the year 2005.

Program Elements

The MHD program consists of:

- POC demonstration, during which an integrated system is tested to show the performance and durability of key components.
- Field demonstration of a coal-fired steam power plant with an MHD topping cycle. Cost-sharing with private industry is expected at this stage.
- Design and demonstration of a first-generation MHD plant.
- Advanced engineering component and system development.
- Demonstration of commercial readiness.

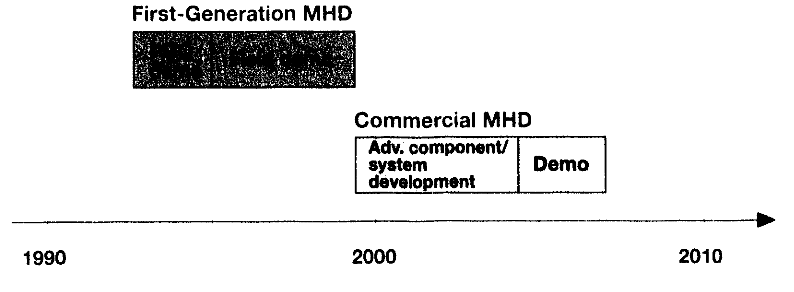
Crosscutting Technologies

Continued R&D in various technology areas is crucial to the development of MHD power systems. Advanced combustion, flue gas cleanup, and waste management activities give critical support to the emission goals of the program. Coal preparation and base research activities are key in the development of high-temperature air heaters, and the Base Research Program also supports work on long-duration generators. Progress in these areas will feed into the MHD development program, and be incorporated into the first commercial MHD systems.

Industry Cost-Sharing

The schedule of events is to some extent dependent upon industry sponsorship of MHD commercialization. As commercial interest builds following demonstration of a retrofit or stand-alone MHD plant, it is expected that industry sponsorship will speed up the advanced generator design and high-temperature air heater development. These elements are essential to the attainment of MHD's maximum commercial potential.

Development Cycle



➤Already in the POC phase, first-generation MHD will next be demonstrated in the field, when an MHD topping cycle will be added to the existing steam cycle. Subsequent development of components and systems will lead to a demonstration of second-generation commercial MHD before the year 2005.

RD&D Program Goals

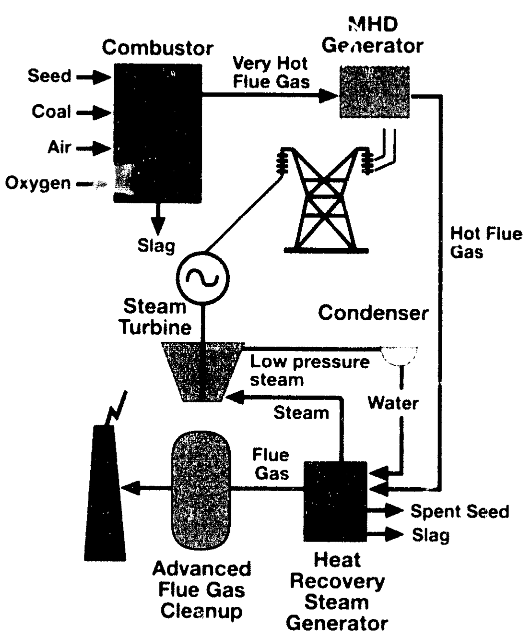
MHD Power Systems

[illegible]	**> 60%**
[illegible]	**1/10**
[illegible]	**1/6**
[illegible]	**65%**
[illegible]	**to meet**
[illegible]	**$1,200**

NSPS=New Source Performance Standards

CAAA=Clean Air Act Amendments

System Components



◄ MHD technology creates a coal-fired, MHD steam-power, combined-cycle plant that incorporates three separate systems:

- The MHD topping cycle, the most innovative component of which is an MHD channel, where electric power is produced. Oxygen-enriched or preheated-air coal combustion takes place in a combustor connected to the MHD channel. The ionized combustion gases pass through this channel surrounded by a superconducting magnet, and produce electricity as they pass through the magnetic field. A diffuser links the topping cycle to the bottoming cycle. The topping cycle also includes power conditioning and coal-feed subsystems.
- The steam bottoming cycle, which recovers heat from the combustion gases exiting the diffuser, and removes and collects coal slag, ash, and spent seed. This cycle is responsible for controlling gas-phase and particulate emissions.
- The seed regeneration system, which converts spent seed, usually potassium sulfate, to a reusable sulfur-free potassium compound. This compound is then reinjected into the combustor. The seed material fulfills two purposes: it makes the high-temperature gases electrically conductive, while also removing sulfur from the gas stream.

MHD Program Activities

There are five major phases to the current program, each integral to the long-term objectives of the MHD program.

Phase 1. POC Demonstration

Development and demonstration of integrated MHD topping cycle, bottoming cycle, and seed regeneration systems are aimed at providing an engineering database from which decisions on MHD retrofit and stand-alone plants can be made by both the public and private sectors. Significant progress toward completion of the POC demonstration is expected during 1993, with the following milestones:

- Long duration topping cycle tests at the Component Development Integration Facility in Butte, Montana.
- Bottoming cycle tests on both eastern bituminous and western subbituminous coals at the Coal-Fired Flow Facility in Tullahoma, Tennessee.
- Seed recovery and regeneration program tests.
- Updated conceptual designs for site-specific retrofit.

The POC phase will prove the MHD concept. It will demonstrate large-scale heat recovery and particulate removal systems, using a variety of coals. It will show that elimination of sulfur oxide emissions through effective seed collection, regeneration, and reinjection is a primary system benefit inherent in the MHD process.

Phase 2. MHD Field Demonstration

A private-sector group in the U.S. has proposed an MHD field demonstration, and would provide at least 50 percent of the cost of such an effort. The engineering database developed in the POC demonstration will be the basis for this design. The MHD facility will consist of an MHD topping cycle with a steam bottoming cycle.

Phase 3. Design and Demonstration of a First-Generation MHD Plant

Development of an advanced generator will produce an optimized MHD power plant design in the year 2000. This may be called first-generation MHD technology. This dedicated MHD plant will use preheated, oxygen-enriched air for combustion, and include state-of-the-art subsystems and components.

Phase 4. Advanced Engineering Component and System Development

In order to develop the second-generation technology necessary to allow MHD to achieve long-term efficiency, and environmental and cost goals, a series of advanced engineering projects will be undertaken prior to the optimum commercial operation of MHD facilities. These include:

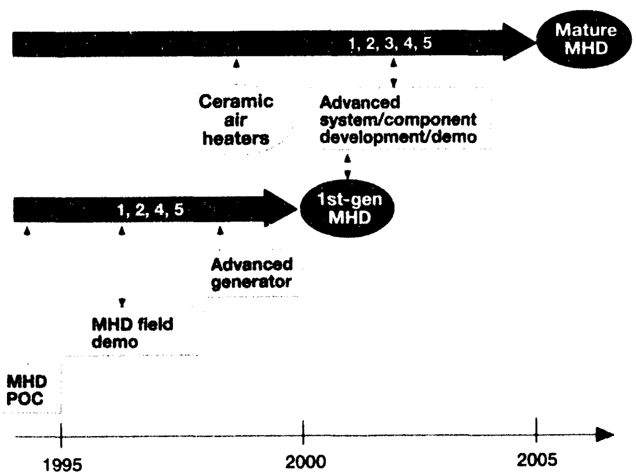
- Development of an MHD high-temperature regenerative or recuperative air preheater.
- Evaluation of the use of cleaned coal in an MHD process.
- Design, fabrication, and testing of an advanced MHD channel.
- Design of an improved superconducting magnet and materials.
- Development of advanced power conditioning and controls for an MHD facility.
- Development of improved techniques for solid materials feeding and handling.
- Advanced MHD system conceptual design studies.

These developments are slated for completion in 2004.

Phase 5. Commercial Readiness of MHD Technology

Second-generation MHD technology is expected to be in demonstration and available for commercial use by the year 2005.

Program Elements Interaction

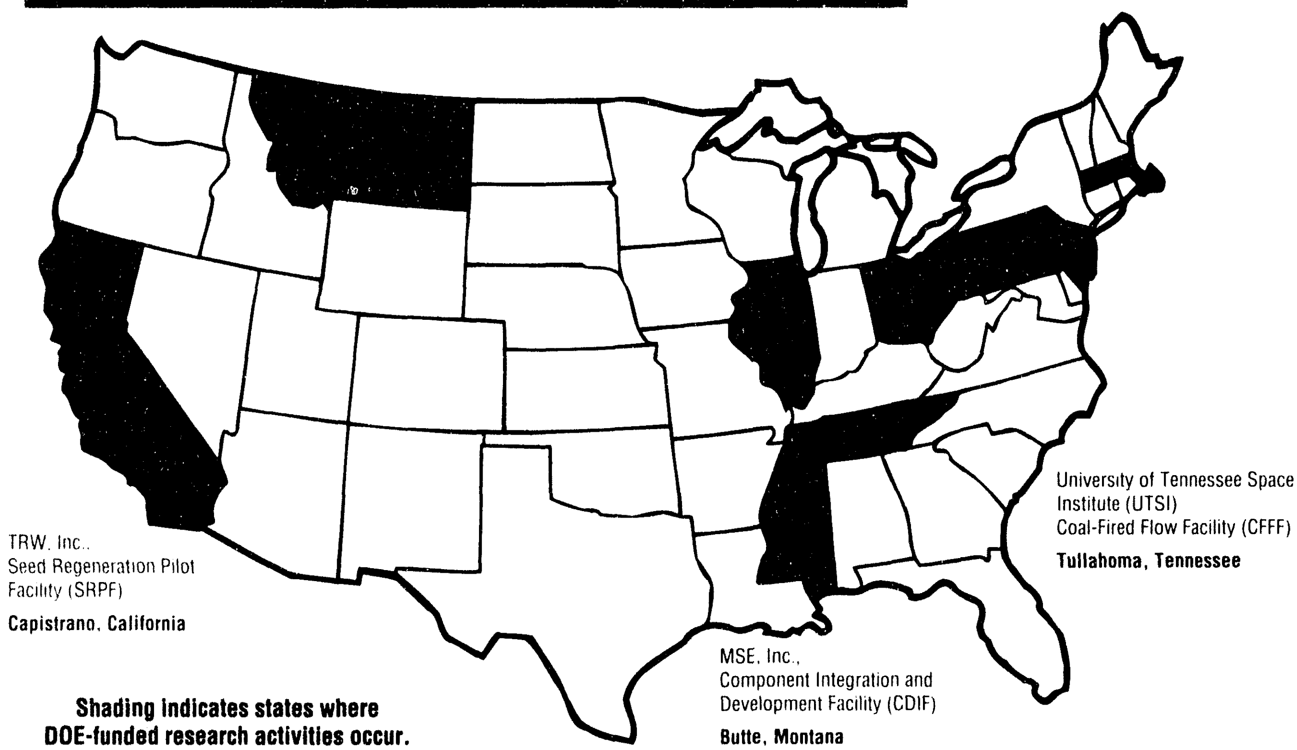


◄ Crosscutting technology development is crucial to the commercialization of MHD power systems. Advanced combustion, flue gas cleanup, and waste management activities speed achievement of emission goals; coal preparation and base research activities underlie the development of the high-temperature air heater which is integral to second-generation mature MHD.

Key to Crosscutting Technologies

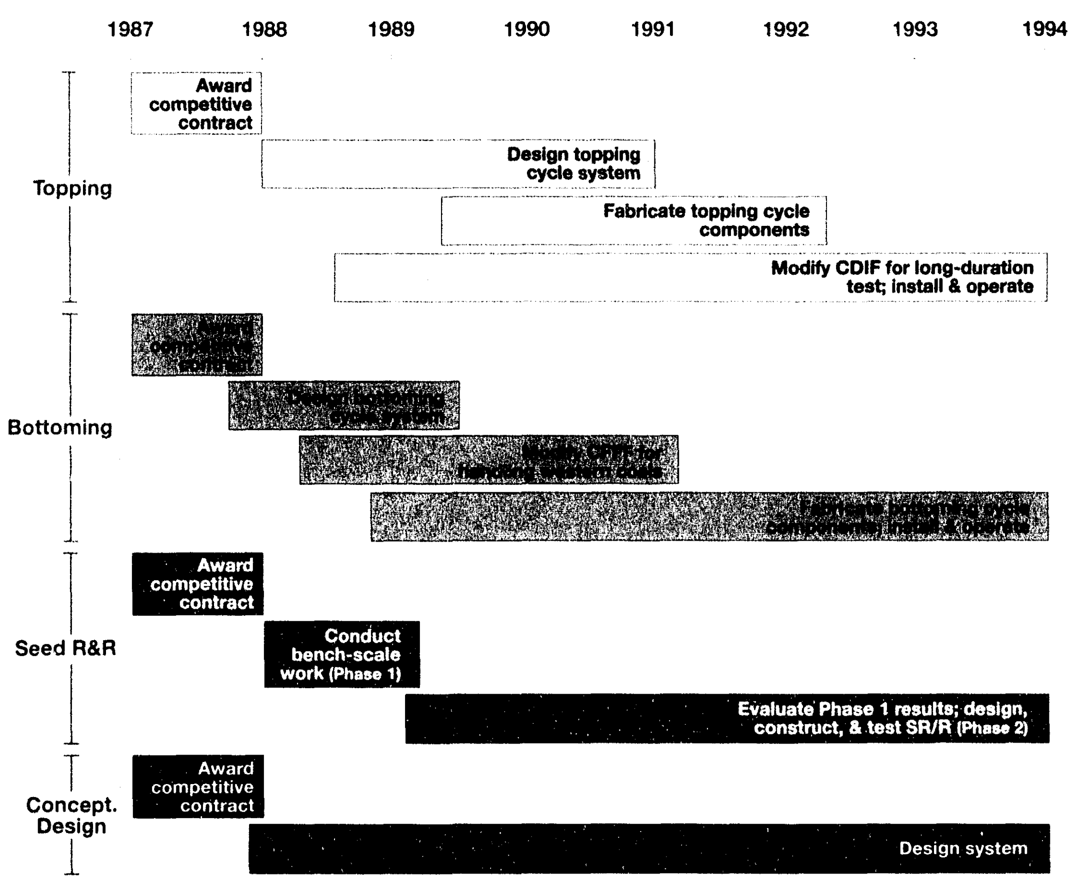
1. Advanced Combustion
2. Base Research
3. Coal Preparation
4. Flue Gas Cleanup
5. Waste Management

Major Demonstrations and Activities



Shading indicates states where DOE-funded research activities occur.

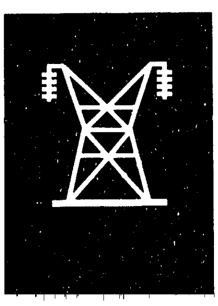
Major Activities and Milestones



➤ Milestones have been developed for the progress of the MHD program towards proposed commercialization by 2005. The MHD system will remove more than 98 percent of the impurities from coal, and efficiencies exceeding 60 percent are attainable with the integration of building-block technologies such as advanced power train, heat exchangers, and air pollution control technology. The input from these technologies is carefully timed to correlate with the development of the MHD topping cycle, bottoming cycle, and seed recovery/regeneration sectors of the project.

Integrated Gasification Combined Cycle (IGCC) systems replace the traditional coal combustor with a gasifier and gas turbine. The primary advantages of gasification-based power systems are the high system efficiencies obtained by their combined-cycle configuration, and the ultra-low acid rain emissions. Over 99 percent of the coal's sulfur is removed before the gas is burned in the gas turbine.

First-generation IGCC power systems are capable of net system efficiencies up to 42 percent, with SO_2 and NOx emissions less than one-tenth of that allowed by NSPS limits. These systems are at the commercial demonstration stage of development. Advanced IGCC systems of up to 45 percent efficiency are expected to see large-scale demonstration by the end of this decade. Next-generation Integrated Gasification Advanced Cycle (IGAC) systems, featuring advances in gas turbine technology, will demonstrate net system efficiencies of at least 50 percent by next decade's end.



IGCC RD&D Program Description

The IGCC program consists of four different gasification-based, power-generating technologies:

First-Generation IGCC Power Systems

These systems use oxygen-blown gasification and "cold," or solution-based, fuel gas desulfurization. Power is generated by using a Brayton gas turbine cycle and a Rankine steam cycle. These systems are presently at the commercialization stage, and are being demonstrated with design improvements in the Clean Coal Technology program.

Second-Generation IGCC Power Systems

These systems are different from first-generation systems, in that they use "hot," or metal oxide sorbent-based, gas desulfurization, and may also use air-blown gasification. Second-generation IGCC systems improve on the efficiency and capital costs of first-generation IGCC power systems.

Integrated Gasification Advanced Cycle (IGAC) Power Systems

These systems use a single, advanced, moisturized gas turbine cycle or other turbine system improvements resulting from the Advanced Turbines Systems program. IGAC systems will feature higher efficiencies and lower capital costs than IGCC power systems.

Integrated Gasification Fuel Cell (IGFC) Power Systems

These systems incorporate advanced fuel cells for power generation and may eliminate gas turbine cycles entirely. IGFC power systems are described in detail in a separate section of this Program Plan.

Program Goals

The IGCC program currently has two primary objectives:

- To develop an advanced second-generation IGCC system having a net system efficiency of at least 45 percent by the year 2000.
- To develop an IGAC system with a net system efficiency of at least 50 percent by the year 2010.

The present DOE IGCC program is focused on developing and demonstrating second-generation IGCC components, concepts, and subsystems at up to proof-of-concept (POC) scale, or as a major slipstream on an existing or planned IGCC commercial-scale system.

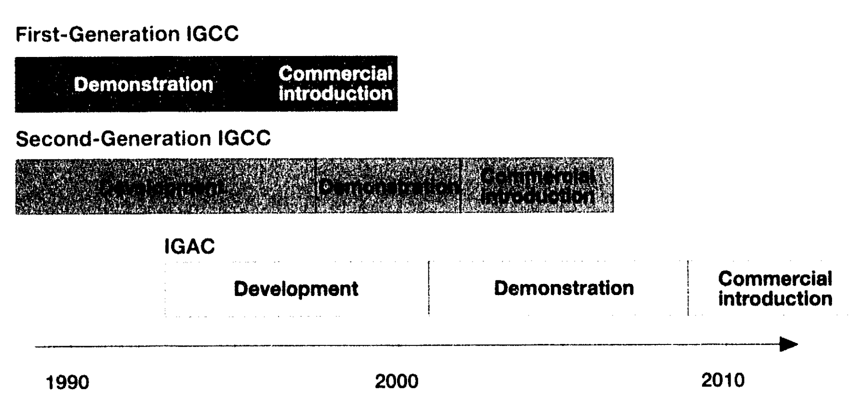
The major IGCC program elements include:

- Development and/or small-scale demonstration of advanced gasifiers and second-generation IGCC systems.
- Development of advanced hot gas cleanup and trace contaminant control technologies.
- Development of IGAC concepts incorporating advanced turbine technology.
- Commercial-scale demonstrations of IGAC and second-generation IGCC power systems.

Each of these program elements represents a critical, integrated step toward achieving the IGCC program goals. Development of advanced gasifiers and turbines will increase system efficiency. Commercialization of hot gas cleanup will help to lower capital costs, since hot gas cleanup systems are less complex and costly than cold gas desulfurization subsystems. And finally, large-scale demonstrations of new gasification-based power systems are vital for successful commercialization of the technology.

➤ **First-generation IGCC systems are at the commercial demonstration stage of development. Research is presently ongoing for development of advanced gasifiers, hot gas desulfurization, advanced turbines, and other system components that will be used in second-generation IGCC and IGAC systems. These more advanced systems, which will feature higher system efficiencies and lower costs, are expected to see large-scale demonstration by the end of this decade.**

Development Cycle



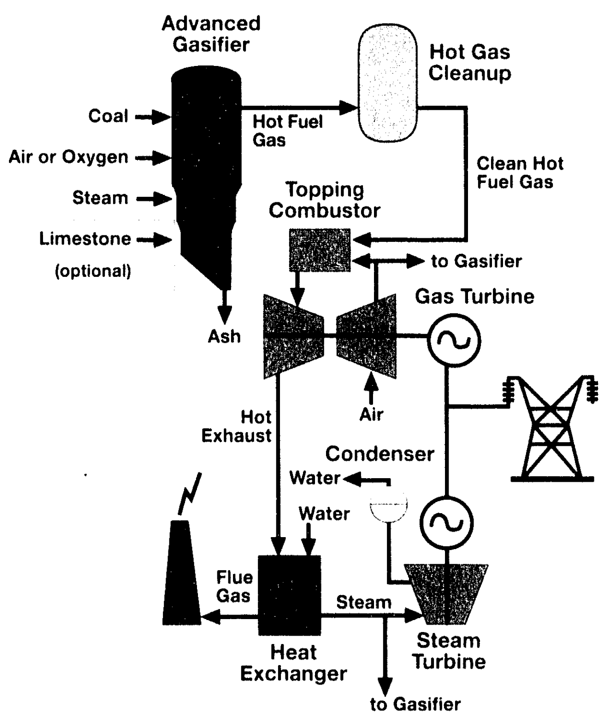
RD&D Program Goals

Gasification Power System	Second-Generation IGCC	IGAC
[illegible]	45% (by 2000)	≥ 50% (by 2010)
[illegible] to NSPS	1/10	1/10
[illegible] emissions relative [illegible]	1/10	1/10
[illegible] emissions relative [illegible] CAAA	to meet	to meet
Capital cost, $ per kW	$1,200	$1,050
Cost of electricity relative to conventional PC power plant	80%	75%

NSPS=New Source Performance Standards

CAAA=Clean Air Act Amendments

System Components



➤ This diagram shows a typical second-generation IGCC system. In an IGCC power plant, fuel gas which consists primarily of hydrogen and carbon oxides is generated in a gasifier by reaction of coal with steam and oxygen (or air) in a fixed-bed, fluidized-bed, or entrained-flow gasifier. At high pressure, the fuel gas is cleaned of impurities and fed to a high-efficiency gas turbine to generate electrical power. Hot, low-pressure exhaust gas from the gas turbine is utilized to produce steam and generate additional power via a steam turbine.

A second-generation IGCC power plant features hot gas desulfurization using a regenerable metal oxide at elevated temperatures, and (optionally) air-blown gasifiers.

IGCC Program Activities

The IGCC program has a number of specific activities under way that will advance each of the major program elements.

Advanced Research

Moderate levels of advanced research are planned to provide continuing refinement and improvement of IGCC power systems. Activities in this program element include coal and ash base research (including gasification mechanisms), gas separations advanced research, process control methodologies advanced research, materials base research, and development of advanced instrumentation.

Second-Generation IGCC RD&D

Five IGCC demonstration projects with an estimated cost of $1.4 billion over the next eight years are being cost-shared under the Clean Coal Demonstration program. Many hot gas advancements are incorporated in these projects.

This program element concentrates on research and pilot-scale development of gasifier and gas stream cleanup advances that can speed commercialization of second-generation IGCC systems.

- The Gasifier Product Improvement Facility (GPIF) features an advanced, five-foot, 150-ton-per-day composite gasifier sited next to an operating power plant.
- An integrated pilot-scale gasifier/moving-bed hot gas desulfurizer, operational since 1988, is providing process knowledge on hot gas subsystems, components, and sulfur removal sorbents.
- Additional activities include feasibility studies and small-scale testing of in-situ desulfurization during coal gasification, optimization studies of new system configurations, and system integration analyses and testing.

Hot Gas Cleanup and Trace Contaminant Control Technologies

This program element focuses on developing and commercializing gas cleanup subsystems that will be used in IGAC and second-generation IGCC power plants.

- The primary activity is the construction of a multi-use test facility in Wilsonville, Alabama. The Power Systems Development Facility (PSDF), scheduled for start-up in 1995, will provide long-term performance testing of up to three different hot gas particulate removal devices simultaneously, at a 38-ton-per-day scale.
- A Process Development Unit (PDU), fueled by a syngas generator, will test an advanced 18-inch diameter fluidized-bed hot gas desulfurization process.
- Additional activities include the development and testing of advanced concepts for removing particulates from hot fuel gas, development of new processes and sorbents for hot gas desulfurization, and measurement/control of air toxic species.

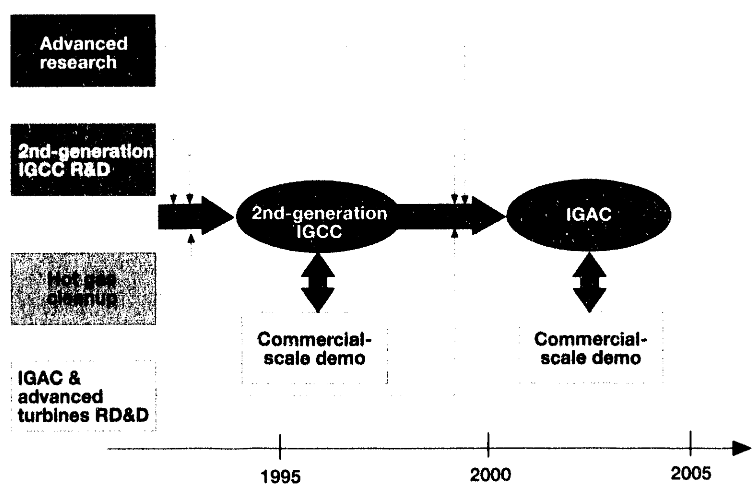
IGAC and Advanced Turbine Technology

IGAC development will concentrate on integrating advanced turbines and thermodynamic cycles into gasification-based power systems. Major activities include advanced turbines system studies and integration tests. A separate Advanced Turbines Systems development program is being funded under the Natural Gas program that will develop and demonstrate next-generation gas turbines systems for use with natural gas and applicable to coal-derived fuel gas.

Commercial-Scale Demonstrations

This program element focuses on the design, construction, start-up, and operation of highly optimized IGAC and second-generation IGCC commercial-scale power plants. These demonstration plants would be selected by competitive procurement, and would have at least a 50 percent cost-share from an industrial partner or consortium.

Program Elements Interaction



◄ Research is presently ongoing in the development of advanced gasifiers, hot gas desulfurization, and hot gas particulate removal subsystems, which are being integrated into highly efficient second-generation IGCC systems. A parallel initiative in the development of advanced gas turbines systems, when integrated into IGAC technology, will provide even higher system efficiency at lower capital cost.

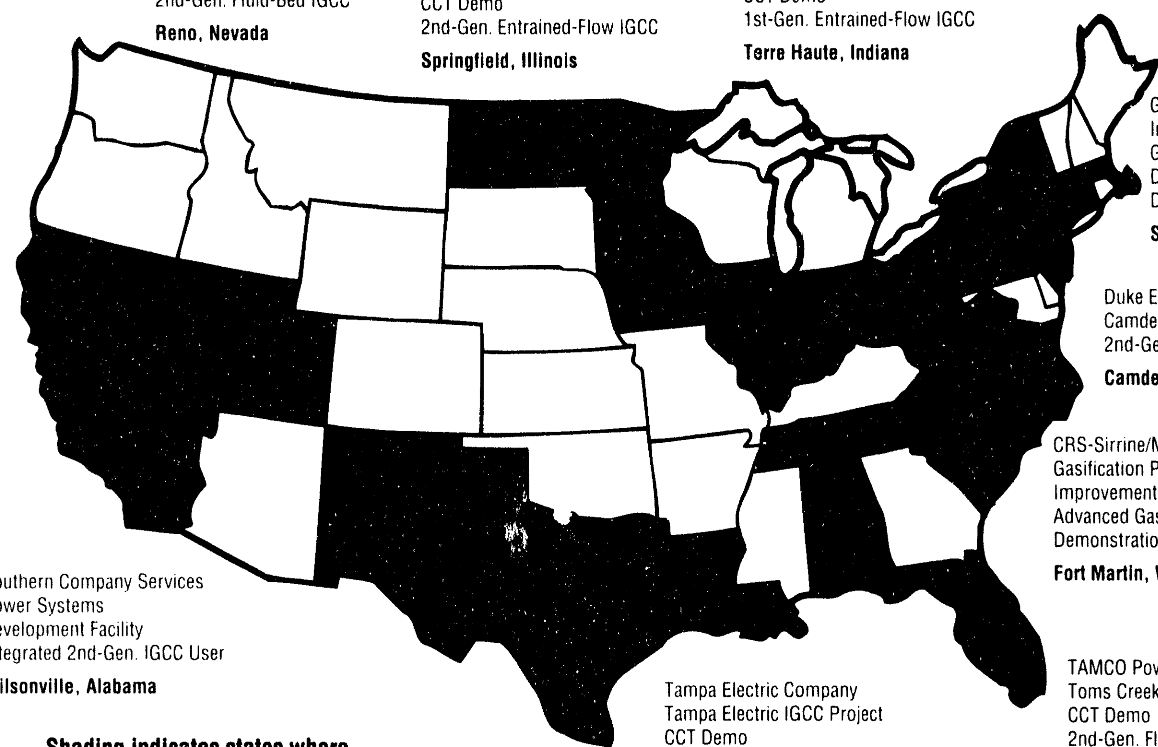
Major Demonstrations and Activities

Centerior Energy
Corex/Clean Power Project
CCT Demo
Corex Process Steel Production/IGCC
Cleveland, Ohio

Sierra-Pacific Power Company
Piñon Pine Power Project
CCT Demo
2nd-Gen. Fluid-Bed IGCC
Reno, Nevada

ABB Combustion Engineering
Lakeside Station Repowering Project
CCT Demo
2nd-Gen. Entrained-Flow IGCC
Springfield, Illinois

PSI Energy/Destec Energy
Wabash River Repowering Project
CCT Demo
1st-Gen. Entrained-Flow IGCC
Terre Haute, Indiana



General Electric
Integrated Fixed-Bed
Gasification/Hot Gas
Desulfurization Process
Development Unit
Schenectady, New York

Duke Energy
Camden Clean Energy CCT Demo
2nd-Generation Fixed-Bed IGCC
Camden, New Jersey

CRS-Sirrine/Monongahela Power
Gasification Product
Improvement Facility
Advanced Gasifier Pilot-Scale
Demonstration
Fort Martin, West Virginia

Southern Company Services
Power Systems
Development Facility
Integrated 2nd-Gen. IGCC User
Wilsonville, Alabama

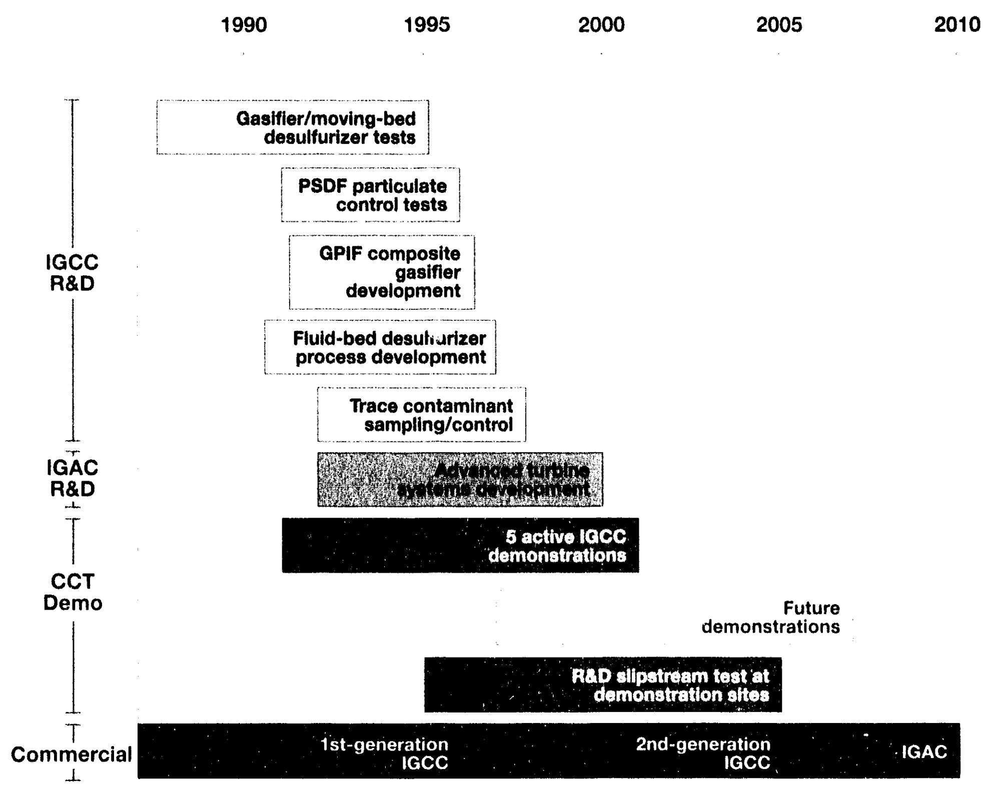
TAMCO Power Partners
Toms Creek IGCC Project
CCT Demo
2nd-Gen. Fluid-Bed IGCC
Coeburn, Virginia

Tampa Electric Company
Tampa Electric IGCC Project
CCT Demo
1st-Gen. Entrained-Flow IGCC
Lakeland, Florida

Shading indicates states where DOE-funded research activities occur.

Major Activities and Milestones

➤ **Commercialization of advanced IGCC systems is the goal of this DOE program, and will follow operation of demonstration plants funded at least 50 percent by an industrial partner. Specific milestones have been created to focus research and development on this goal. Higher system efficiencies and lower costs will result from the development of advanced gasifiers and advanced turbines, and less complex hot gas desulfurization will lower capital costs. Large-scale R&D projects and five CCT demonstration plants in Illinois, Indiana, Florida, Nevada, and Virginia that use energy-saving hot gas cleanup systems for the removal of sulfur from the hot coal-derived fuel gas will then be followed by entry into the commercial market.**



Fuel Cells/Integrated Gasification Fuel Cell Systems

Fuel cells generate electricity directly from the electrochemical reaction of hydrogen and oxygen. Most of the fuel cell systems currently approaching commercialization are fueled with natural gas, which must be reformed to produce the hydrogen needed to operate the fuel cell.

Coal gasifiers automatically produce a fuel gas containing hydrogen during normal operation, which makes the integration of fuel cell and gasification technologies a promising new approach to power generation. Integrated Gasification Fuel Cell (IGFC) systems are highly efficient power systems with extremely low environmental emissions. With electrical generation efficiencies approaching 60 percent and negligible emission levels, IGFC systems are expected to play an important role in meeting future power generation needs.

IGFC RD&D Program Description

The Fuel Cell/IGFC program has as its primary thrust the further development of fuel cell technology, and the integration of advanced fuel cell technology with other system components, including gasification technology for electric power and cogeneration applications.

Three Fuel Cell Technologies

There are three types of fuel cell technology under development, differentiated by the composition of the electrolyte of the cell. DOE-sponsored development and testing of Phosphoric Acid Fuel Cells (PAFCs) was concluded in 1992, and PAFCs are now in the initial stages of commercialization.

Molten Carbonate Fuel Cells (MCFCs) and Solid Oxide Fuel Cells (SOFCs) are advanced, higher temperature fuel cells currently under development. MCFCs and SOFCs offer higher efficiencies and lower capital costs, and are suitable for integration with coal gasifiers. The objective for MCFC and SOFC development efforts is to have these technologies ready for commercialization by 2005 using natural gas, and by 2010 using coal-derived fuel gas.

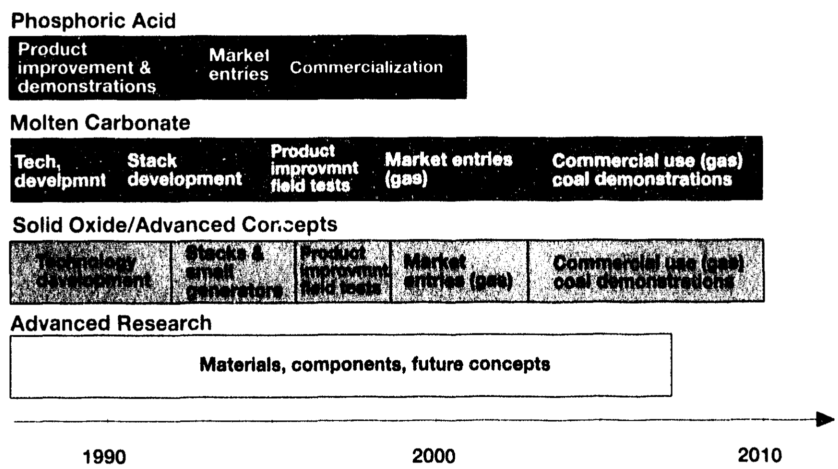
Program Goals

The objective for IGFC development efforts is to have an advanced fourth-generation gasification-based power system with a net system efficiency of at least 60 percent by 2010.

To meet this objective, IGFC activities are focused on developing gasifier technology and associated cleanup systems that are compatible with MCFCs and SOFCs.

The RD&D program for Fuel Cells/IGFC systems includes program elements for each of the major fuel cells currently under development — MCFCs and SOFCs — as well as elements for Fuel Cell Advanced Research and Technology Development, and Gasification and Gas Stream Cleanup technologies.

Development Cycle



➤Three types of fuel cell technology are under development: phosphoric acid, molten carbonate, and solid oxide. DOE-sponsored development and testing of Phosphoric Acid Fuel Cells (PAFCs) was concluded in 1992, at which time commercial units became available. Molten Carbonate Fuel Cells (MCFCs) and Solid Oxide Fuel Cells (SOFCs) are currently under development. These technologies should be ready for commercialization by 2005 or 2010, depending on whether natural gas or coal-derived fuel gas is used. Ongoing advanced research into fuel cell development is also supported by this program.

IGFC Program Activities

PAFC Systems

PAFC product development activities with Westinghouse Electric Corporation and International Fuel Cells were completed in 1992. Current Department of Energy/Fossil Energy activities in this area are focused on aiding the private sector's introduction of a commercial PAFC product through coordination with demonstration programs in DOE's Office of Energy Efficiency and Renewable Energy involving transportation uses, and programs in the Department of Defense involving military base power supplies.

MCFC Systems

Planned activities in this program element focus on continued improvement and testing of MCFC technology. Overall objectives include lowering costs and improving performance to the required level for market entry.

MCFC product development activities with M-C Power Corporation and Energy Research Corporation are currently under way. These activities will include testing of full size 100- and 250-kilowatt MCFC stacks, starting in 1993.

MCFC technology will then be refined through subsequent cost-shared cooperative agreements. Refined MCFC products will be built and tested for performance and endurance. In 1994, the first field tests of natural-gas-fired MCFC power plants (250-kilowatt and 2 MWe) will begin. The first market entry units fueled with natural gas are scheduled to be available beginning in 1997; those with integrated coal gasification, before 2010.

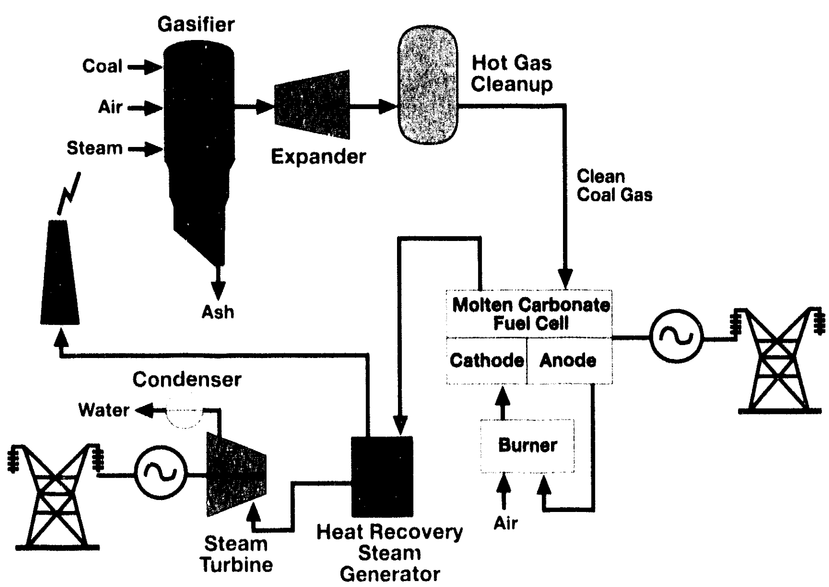
RD&D Program Goals

IGFC Systems (by 2010)	
[illegible]	≥ 60%
[illegible]	1/10
[illegible]	1/10
[illegible]	to meet
[illegible]	$1,100
[illegible]	80%

NSPS=New Source Performance Standards

CAAA=Clean Air Act Amendments

System Components



▲ MCFCs operate at about 650 degrees Celsius (1200 degrees Fahrenheit) and utilize an electrolyte composed of molten alkali metal carbonates. In the IGFC system configuration shown here, the relatively high operating temperature of the MCFC allows the use of a secondary steam Rankine cycle for additional power production, contributing to an overall efficiency approaching 60 percent.

SOFCs under development utilize a yttria-stabilized zirconia electrolyte, requiring them to operate at about 1000 degrees Celsius (1800 degrees Fahrenheit). As with the MCFC system, the high operating temperature allows the use of a secondary steam Rankine cycle for additional power, and projected efficiencies approach 60 percent.

SOFC Systems

SOFC development activities focus on goals similiar to those of the MCFC activities, but are directed toward broader market penetration. The major focus is on continued improvement and testing of the technology, in order to lower product costs and improve product performance to the levels necessary for penetration of a larger market.

Specific activities include the development of tubular SOFC technology through a cooperative agreement with Westinghouse Electric Corporation. Upon completion of this cooperative agreement in 1995, a new activity will be initiated to improve tubular SOFC products, and to build and test them for performance and endurance. In 1996, 100- to 200-kilowatt demonstration tests will be completed; 1 MWe to 2 MWe field unit tests will be conducted in 1997.

SOFC activities also include developing monolithic or planar SOFC technology. These configurations have the potential for higher power density and lower costs than tubular SOFCs, which could make them important additional options for new market sectors. Laboratory tests on 100-watt externally manifolded monolithic SOFC stacks will be completed in 1993.

Fuel Cell Advanced Research

This program element focuses on providing the data, technical information, exploratory studies, and testing needed to develop improved fuel cells. Exploratory studies examine the feasibility of novel fuel cell concepts. Applied research is directed toward eliminating specific technological barriers that are impeding fuel cell development.

Activities include research to improve fuel cells through the study of electrochemistry and electrolytes, electrodes, separators, seals, and interconnects. Other activities aim to enhance fuel cell performance by improving fuel cell materials, components, fabrication methods, and contaminant control techniques. Improved design and manufacturing methods will reduce costs while increasing product reliability and durability.

Specific activities include research on MCFC electrodes and cell resistance reduction, SOFC materials, seals, and interface reactions.

Gasification and Gas Stream Cleanup

Activities in this program element are focused on the development of advanced gasifier technology for integration with fuel cells, and the actual integration of the fuel cell and gasifier technologies into an IGFC system.

Additional activities involve the development of hot gas cleanup systems that are compatible with SOFC and MCFC fuel gas purity requirements.

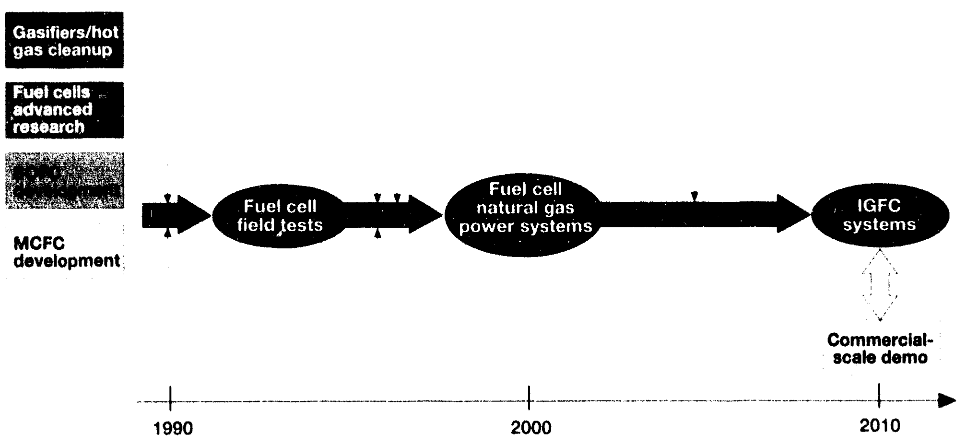
The Power Systems Development Facility (PSDF) at Wilsonville, Alabama, will also host fuel cell performance testing, in addition to previously described PFBC and IGCC program activities. Fuel cells testing will be done on a slipstream from the gasifier module, and will evaluate the performance of advanced fuel cells with coal-based fuel gas and hot gas cleanup technology.

Specific activities include studies to define MCFC and SOFC contaminant tolerances; these studies will be completed in 1994. By 1998, pilot-scale gasification and cleanup activities will be completed.

Commercial-Scale IGFC Demonstration

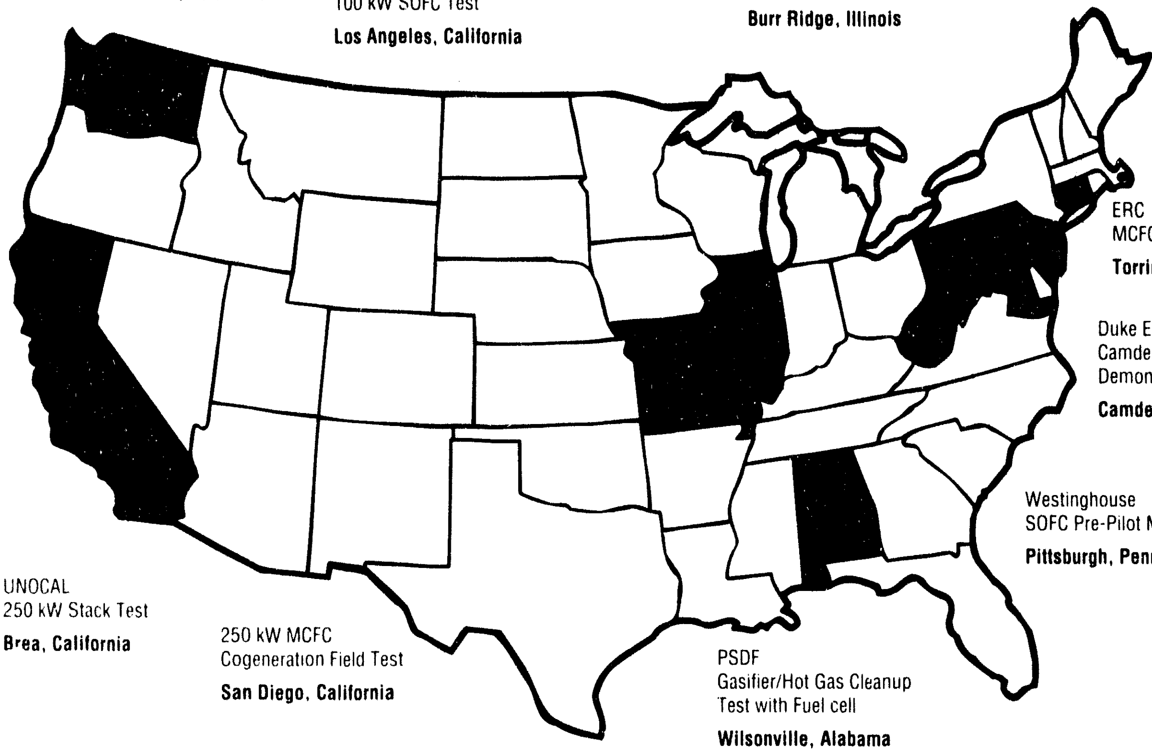
This program element focuses on the design, construction, start-up, and operation of a highly optimized IGFC commercial-scale power plant. The demonstration plant would be selected by competitive procurement, and would have at least a 50 percent cost share from an industrial partner or consortium.

Program Elements Interaction



◄ Development efforts are under way that will lead to the commercialization of SOFC and MCFC natural-gas-based power systems. Integration of fuel cells with advanced gasifiers and gas stream cleanup will result in coal-based power systems that feature very high system efficiencies at low capital cost.

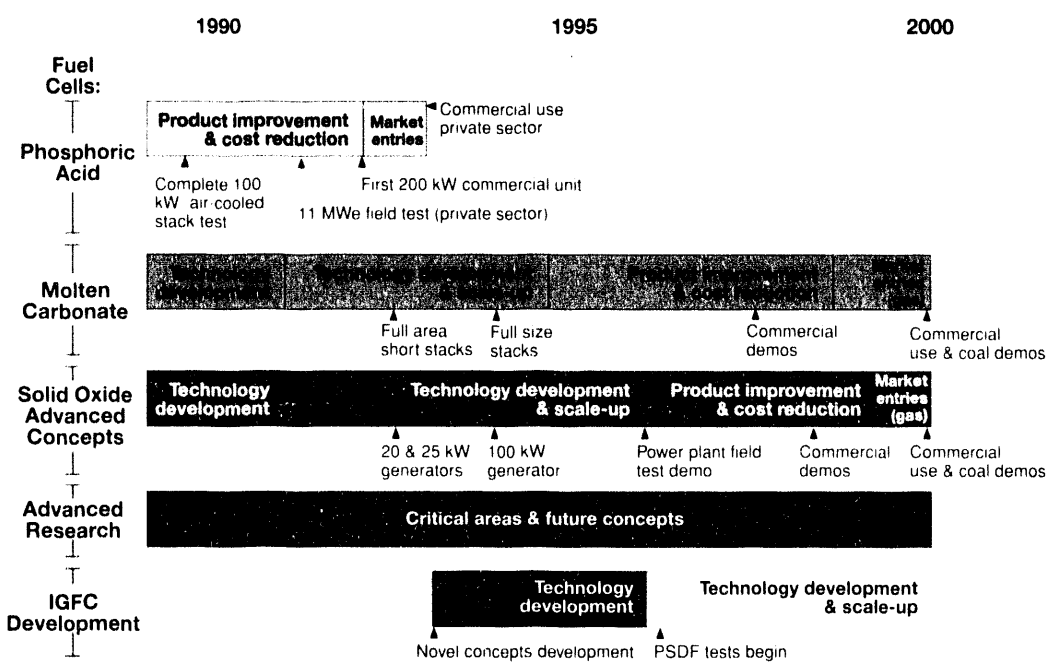
Major Demonstrations and Activities



Shading indicates states where DOE-funded research activities occur.

Major Activities and Milestones

➤ 1992 saw the delivery of the first commercial Phosphoric Acid Fuel Cells, and completion of DOE-sponsored PAFC development activities. Continued improvement and testing of Molten Carbonate Fuel Cells will lead to the testing of two MCFC power plants slated for completion in 1993 and 1994. Field demonstrations are planned from 1995 to 1998. Improved tubular Solid Oxide Fuel Cells technology demonstration tests will be conducted between 1996 and 1998, and monolithic SOFC technology will also be tested. Additional milestones have been developed for ongoing advanced research, providing the data, technical information, and conceptual designs required to conduct successful commercialization of fuel cells. IGFC development activities to determine and test optimum systems for incorporating fuel cells into gasification-based power systems may commence by 1994.



Base Research for Advanced Power Systems: A Crosscutting Program

A program of applied research crosscuts the many technologies described in this Program Plan. The benefits of this Base Research program are felt by more than one given system, and its efforts are as essential to the achievement of systems objectives as those of the systems themselves. Base research focuses on the development of enabling science and technology critical to the development of systems capability.

The Base Research program advances the scientific and technical knowledge required to understand the physical, chemical, biological, and thermodynamic mechanisms that control the behavior of coal-fueled systems, and develops the means to overcome technological barriers that impede the realization of system goals. The Base Research for Advanced Power Systems program develops solutions to the critical science and technology barriers that inhibit the adoption of very high-efficiency, low-emission, coal-based heat and power generation systems.

APS Base Research RD&D Program Description

Base Research for Advanced Power Systems (APS) is an integral part of the coal-fired power generation R&D program. Its activities support all power systems under development, focusing on problems both critical and generic.

The program includes:

- Research into coal combustion science and related technology.
- Development of ways to control deleterious by-products of combustion such as ash and mineral matter, acid rain precursors, toxic emissions, and greenhouse gases.
- Development of high-temperature sensor and diagnostic systems and techniques.
- Development of innovative components and subsystems.

Synergistic contributions are also made to the program by research being conducted in the Advanced Materials, University Coal Research, Coal Bioprocessing, and Small Business Innovation Research programs, which perform research that crosscuts all coal-based fuel and power systems.

Base Research Benefits

The science and technology base required for the design, manufacture, and operation of advanced coal-fired power generation systems depends upon the progress achieved in base research. Benefits will include:

- Identification of new and enhanced subsystems and processes that overcome key barriers and restraints.
- Acquisition of useful scientific and engineering data.
- Development of design techniques and computer-based design aids.
- Development of productive scale-up techniques from laboratory and bench-scale testing.

Recent accomplishments within the APS Base Research program demonstrate the critical nature of such research. They include:

- Acquisition of essential coal devolatization and char combustion data required for advanced combustor design and operation.
- Acquisition of data resulting in a PC-based engineering model enabling manufacturers and operators to evaluate and control boiler slagging and fouling.
- Creation of NOx control techniques through development of combustion air- and fuel-staging techniques.

APS Base Research Program Activities

There are three categories of activity in the APS Base Research program:

- Coal utilization base research.
- Instrumentation and diagnostics base research.
- Components research.

Coal Utilization Base Research

These activities have as their objective the collection of data, engineering designs, and technical information required to develop, design, manufacture, and operate advanced power systems. Important ongoing work includes the development of high-temperature components supporting the Combustion 2000 advanced coal-fired power systems program, and the development of durable and reliable high-temperature ceramic filters to enable the control of particulate emissions required in some APS. This work will continue through 1994.

There are three major areas of activity:

Systems Efficiency

This activity includes research on the combustion mechanisms of fuel injection, coal devolatization and pyrolysis, volatiles formation and combustion, and char oxidation. Research is also conducted on heat and mass transfer, and other systems characteristics, such as component corrosion and erosion, which affect the efficiency of APS. Activities further include the study of the processes involved in high-temperature systems environments as well as in advanced fluidized-bed combustion systems.

Ash Deposition, Erosion, and Corrosion

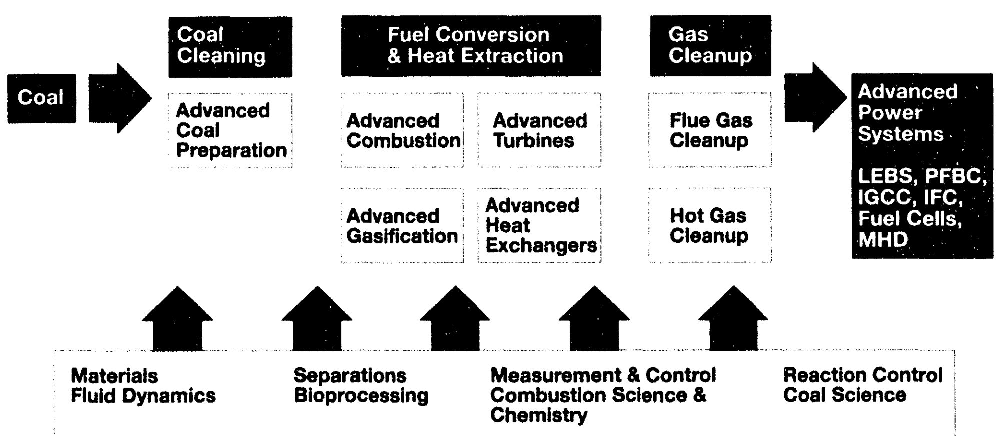
This activity includes research into the formation, transformation, and deposition of coal mineral matter and ash, which both limit the performance and reduce the efficiency of power systems. A means is being sought to mitigate the effects of boiler slagging and fouling. Research is also being conducted into heat exchanger operation and durability, and advanced gas turbine and diesel engine systems.

Reduction of Deleterious Compounds

The fuel, combustion products, and waste streams of all APS contain numerous compounds in addition to the hydrocarbons required for combustion. These degrade efficiency, reliability, cost of operation, and life expectancy, and many are also the subject of significant environmental concern upon release from the system. Solutions are being explored for use in several or all of the APS under

Program Science and Technology

Science and Technology Base Needs
Common to All Advanced Power Systems



Critical Enabling Science and Technologies

◄ Base Research activities promote technological understanding of advanced power systems throughout the various stages of RD&D to produce fundamental product improvements. In contrast to crosscutting research that deals with complete subsystems, base research provides fundamental knowledge of individual elements essential to the development of clean, efficient, and economical coal use methods.

The objective of the Base Research program for Advanced Power Systems is to develop scientific understanding of processes such as ash deposition and pollutant formation, to support the development of advanced power generation and emissions-control concepts.

development. There are two directions taken here. The first is to prevent the formation of compounds detrimental to coal system operation, while a second is to remove them once formed. The specific approaches under consideration begin with precombustion processes such as advanced physical and chemical separation. Processes which can be employed during combustion are also under study, and post-combustion processes such as downstream cleanup are being researched with some urgency, due to their environmental impact.

Instrumentation and Diagnostics Base Research

These activities have as their objective the adaptation and application of state-of-the-art instrumentation and diagnostics to the specialized requirements of all APS. Instrumentation and diagnostic techniques are used by APS for process monitoring and control, as well as for research, development, and manufacture, and so are critical to operations as well as to initial system development.

Activities fall into three categories: chemical species determinations, process control, and information dissemination.

Chemical Species Determination

This research examines advanced spectroscopic and imaging methods for chemical quantitative analysis. It considers particle size, concentration, and velocity determinations, and investigates advanced temperature and pressure instrumentation, including fiber optics techniques. Current activities include development of advanced species characterization instruments and techniques, enabling operational assessment and control in the harsh-condition, high-temperature process streams of APS.

Process Control

Advanced monitoring and control instrumentation and their methodologies are being developed for use with combustors, gasifiers, and gas cleanup subsystems, and for use in solid or liquid effluent handing. Some APS instrumentation needs that are being addressed are: monitoring and control of the combustor; monitoring and control of downstream multiphase flow to fuel-cells, gas turbines, and heat exchangers; monitoring and control of removal devices; monitoring and control of techniques such as heat exchanger soot blowing; monitoring and control of stack emissions; and monitoring and control of solid and liquid waste effluents.

Information Dissemination

The objective is to collect all information regarding instrumentation and diagnostic applications, and then spread it across the entire coal RD&D program, to ensure that the various instrumentation efforts enhance and complement each other.

Components Research

There are two categories of activity:

Novel Components

Components such as high-temperature valves and filter-cleaning devices are under study, and are expected to play a large part in improving the efficiency and environmental controls of many of the advanced power systems under development.

Solids Transport

The underlying fundamental principles governing multiphase solids flow are being explored. Such a knowledge base is required for the design and operation of reliable and economic advanced coal utilization and conversion systems. This includes activities in multiphase flows such as in solids-gas, solids-liquid, and three-phase systems. This sector also supports topical research focused on near-term design problems.