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# U.S. Department of Energy Power Generation Programs for Natural Gas

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# 1.5 U.S. Department of Energy Power Generation Programs for Natural Gas

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## ABSTRACT

The U.S. Department of Energy (DOE) is sponsoring two major programs to develop high efficiency, natural gas fueled power generation technologies. These programs are the Advanced Turbine Systems (ATS) Program and the Fuel Cell Program. While natural gas is gaining acceptance in the electric power sector, the improved technology from these programs will make gas an even more attractive fuel, particularly in urban areas where environmental concerns are greatest.

Under the auspices of DOE's Office of Fossil Energy (DOE/FE) and Office of Energy Efficiency and Renewable Energy (DOE/EE), the 8-year ATS Program is developing and will demonstrate advanced gas turbine power systems for both large central power systems and smaller industrial-scale systems. The large-scale systems will have efficiencies significantly greater than 60 percent, while the industrial-scale systems will have efficiencies with at least an equivalent 15 percent increase over the best 1992-vintage technology. The goal is to have the system ready for commercial offering by the year 2000.

DOE/FE and DOE/EE also cooperate in the development of fuel cells. DOE/EE is responsible for transportation applications, while DOE/FE supports fuel cell development for stationary electric power. Fuel cell systems in the 100 kilowatt (kW) to several megawatt (MW) size range are an attractive technology for power generation because of their ultra-high energy conversion efficiency and extremely low environmental emissions. As modular units for distributed power generation, fuel cells are expected to be particularly beneficial where their by-product heat can be effectively used in cogeneration applications. The first generation of fuel cells for power generation is currently entering the commercial market. Advanced fuel cell power systems fueled with natural gas are expected to be commercially available by the turn of the century. The domestic and international market for this advanced technology is expected to be very large.

## INTRODUCTION

The U.S. will not be able to produce and use hydrocarbon fuels to their full potential—efficiently, affordably, and with environmental responsibility—unless new technology is developed and deployed. Failure to build on the substantial technological capabilities we already possess will put the U.S. at a competitive disadvantage to other countries who are pushing hard to dominate an increasingly "high-tech" global energy market.

The economic slowdown in the 1980s reduced the need for new electric power plants. Few large plants are being built today. With the economy growing again, the U.S. will require new electric power generating capacity early in the next century. The next generation of power plants, however, will have to meet new environmental standards, while still producing affordable electricity. Traditional technology cannot meet the more stringent standards and keep energy costs down and the economy growing.

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The pace of technology development is critical. We can keep our domestic economy growing and stay ahead of our international competitors, only if new technology is ready in time to meet critical market "windows." We don't believe that will happen unless the Federal Government and the private and academic sectors join in concerted, forward-looking, risk-shared partnerships.

In today's highly competitive international marketplace, other countries have created their own public-private research and development (R&D) ventures in an effort to gain significant global advantages in developing and marketing energy technologies for the 21st century. In the U.S., our Government can provide the critical catalyst that stimulates the private sector to look beyond immediate financial benefits and invest in higher-risk technologies that can maintain our Nation's competitive edge. Industry participation also assures that the technology in which the Government invests has real market pull.

The DOE/FE Fiscal Year (FY) 1995 appropriation for natural gas R&D is $116 million. This appropriation includes $50 million for the Fuel Cell Program and $38 million for the ATS Program. The FY 1996 budget request for natural gas R&D is $145 million, which includes $55 million and $43 million, respectively, for the Fuel Cell and the utility scale portion of the ATS Programs. The DOE/FE's total funding for the Natural Gas R&D Program is illustrated in Table 1.

Natural gas is a rapidly resurging domestic energy option. The prevailing opinion of the 1970s that gas was a scarce resource, and has been replaced with a much better understanding of the tremendous domestic supply that actually exists. The National Petroleum Council, in the most extensive study to date, has concluded that nearly 1,300 trillion cubic feet of natural gas is technically recoverable in the lower 48 states. Far from being "scarce," this resource base represents a 60-year supply, with the likelihood that even more will be found as technology improves. The challenge is to turn this huge resource base into proven reserves.

While natural gas is gaining acceptance in markets such as the electric power sector, improved technology is needed to make gas an even more attractive fuel, particularly in urban areas where environmental concerns are greatest. Some potential customers, again largely

**Table 1. Budget Authority in Millions**

| Natural Gas Research and Development | FY 1995 Appropriations | FY 1996 Request |
|---|---|---|
| Fuel Cells | $49.60 | $55.50 |
| Advanced Turbine Systems | 37.70 | 44.00 |
| Natural Gas Production | 29.00 | 46.40 |
| **Total Natural Gas R&D** | **$116.30** | **$145.90** |

in markets such as power generation, still lack confidence in the supply and availability of natural gas. By developing improved ways to use natural gas for power generation, such as advanced gas turbines and fuel cells, we can offer new options for meeting future growth in electric power demand.

The focus of the ATS and Fuel Cell Programs has been on commercialization from the outset. Most work is performed by industrial teams which will ultimately commercialize the technologies, and they are generally directly responsible for any work which supports initial demonstration and commercialization. Some generic R&D is performed by universities, national laboratories, and others. This work is generally targeted for a somewhat longer timeframe than initial demonstration and will provide the foundation for later system improvements.

## ADVANCED TURBINE SYSTEMS PROGRAM

The ATS Program began in 1992 with the appropriation of funding for the planning of a comprehensive 10-year program. Support has been strong, and the Program has since been accelerated by 2 years so that demonstrations of full-scale systems will be completed by the year 2000. Budget projections show the total DOE cost of the program will be $470 million to be cost-shared with an additional $230 million of industrial funding.

Planning for the ATS Program has included the solicitation of views from interested groups. An important step was the conducting of two workshops in Greenville, South Carolina[1,2]. Sponsored by DOE and hosted by Clemson University, each workshop brought together more than 75 representatives from the gas turbine R&D and user communities. Gas turbine manufacturers, the electric utility industry, and the university community were represented, along with Government and private sector R&D sponsors. Input for program planning was provided at the workshops, including the identification of R&D needs and the assessment of program goals. A draft plan for the ATS program[3] was presented at the second workshop and the plan revised based on guidance received from workshop participants.

Further public input was obtained as the Program Plan evolved. The plan was presented in numerous other forums (e.g., Reference 4), and a Program Plan[4] required by Congress was jointly prepared by DOE/FE and DOE/EE. A public meeting was held in Pittsburgh, Pennsylvania, on June 4, 1993, for the purpose of soliciting public comment.

Forty-five (45) organizations offered their views on the Program, and their comments were forwarded to Congress along with the plan. The comments showed broad and enthusiastic support for the planned program, although many specific comments were offered for modification.

The objectives and structure of the Program Plan emerging from this process, and sent to Congress via a formal report[5], is described in the next two sections.

## PROGRAM OBJECTIVE

The objective of the ATS Program is to develop ATS for base load application in the utility, independent power producer, and industrial electric power markets. The systems should be ready to enter the commercial market by 2000 and have the following characteristics:

- Efficiency. More than 60 percent (lower heating value [LHV] basis) on natural gas for large-scale utility turbine systems. For industrial power generation systems, greater than 15 percent improvement in heat rate compared to 1992-vintage gas turbine systems.

- Environment. Environmental superiority under full-load operating conditions without the use of post-combustion controls. Nitrogen oxide ($NO_X$) emissions should be less than 8 parts-per-million (ppm). Carbon monoxide and hydrocarbon emissions should each be less than 20 ppm. Because of changing environmental requirements, these targets will undergo periodic review.

- Fuel Flexibility. Natural gas-fired ATS designs are to be adaptable to coal or biomass firing.

- Cost of Power. Busbar energy costs 10 percent less than current state-of-the-art turbine systems meeting the same environmental requirements.

- Reliability and Maintainability. Equivalent to state-of-the-art turbine systems.

## PROGRAM STRUCTURE

The ATS Program is jointly funded and managed by DOE/FE and DOE/EE. A Steering Committee is composed of representatives of DOE/FE, DOE/EE, the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), and the U.S. Environmental Protection Agency. This committee assures that work under the ATS Program is complementary with other work supported by these funding organizations. It is also responsible for coordination of ATS Program work with that supported by other Federal, State, and private funding organizations and for liaison with industry groups.

Much of the major development activity in the ATS Program is conducted by teams led by U.S. turbine manufacturers. This work is performed under a series of competitively awarded agreements with DOE. At first, there are multiple projects for both industrial and utility applications, but these will eventually be reduced to one full-scale prototype demonstration in each area. For the major projects, cost-sharing began at about 10 percent at the outset of the Program and will rise to greater than 50 percent for demonstrations of prototype systems.

As illustrated in Figures 1 and 2, the ATS Program consists of four elements:

### Element I—Innovative Cycle Development

This element targets the initial development of concepts which will meet ATS Program goals. In the first phase of this element, six U.S. turbine manufacturers conducted studies to define systems which they would like to commercialize. In the second phase, teams led by turbine manufacturers have been competitively selected to advance ATS systems through concept development. Technical, economic, and environmental performance of the ATS are being evaluated for both coal and natural gas firing. The teams are completing conceptual designs, market studies, and designs of critical components. They are also initiating small-scale testing for natural gas-fired systems.

### Element II—Utility System Development and Demonstration

In this element, DOE/FE will support the development and demonstration of ATS for utility application. R&D will be completed for multiple systems, including development all the way through full-scale component and integrated subsystem testing. Only one full-scale prototype demonstration is planned.

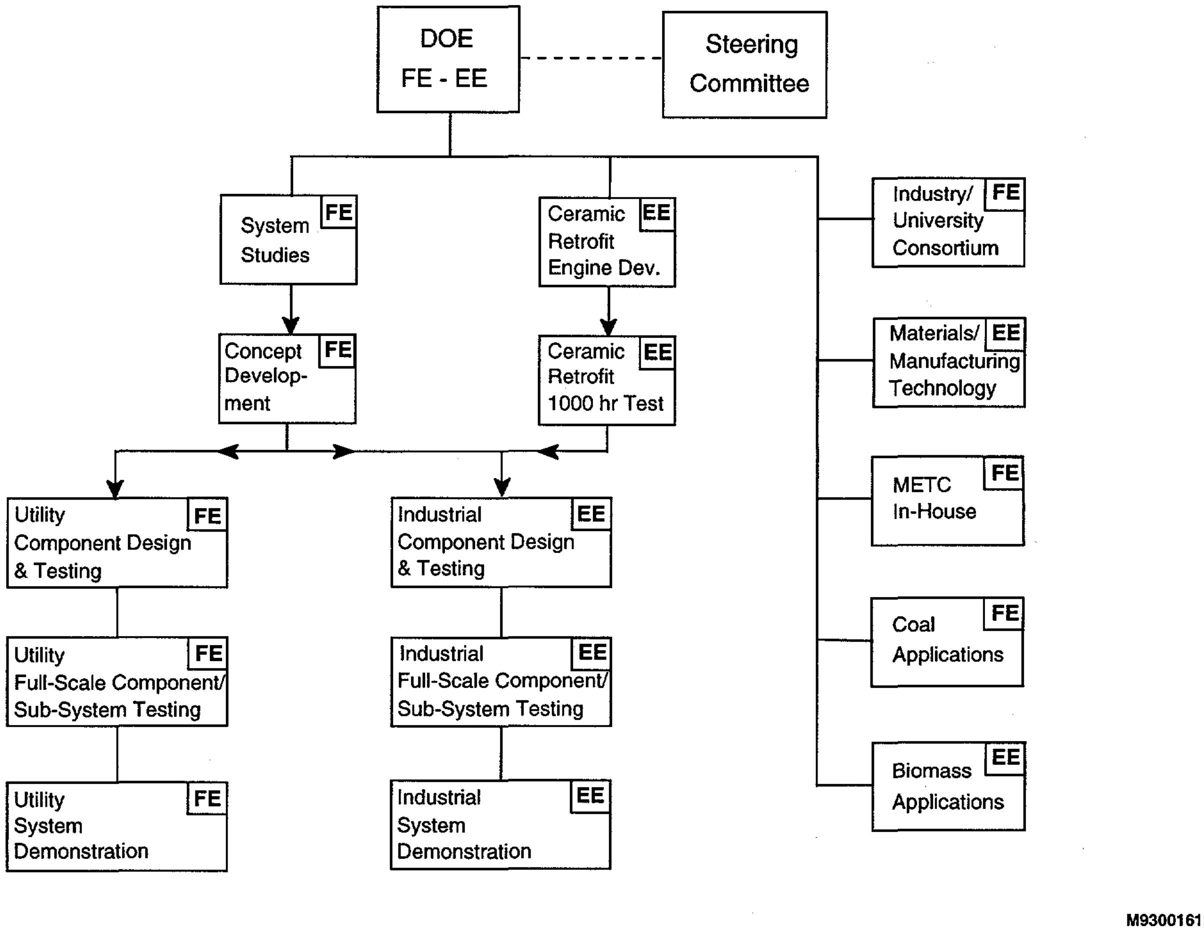


**Figure 1. Advanced Turbine Systems Program Structure**

## Element III—Industrial System Development and Demonstration

The first phase of this element was initiated by DOE/EE in parallel with Element I. Work is underway by Solar Turbines, Inc., to evaluate the benefits of upgrading existing industrial turbine designs by retrofitting with ceramic components. The study will culminate in the 4000-hour test of a 3.5-MW engine.

The second phase of this element will parallel Element II, and support the development of industrial ATS, leading to the demonstration of one full-scale prototype system.

## Element IV—Technology Base Development

R&D on generic technology issues supports the ATS development effort. Much of the Technology Base Development is performed by an industry/university consortium established by a cooperative agreement between DOE/FE and the South Carolina Energy Research and Development Center. Industrial co-sponsors identify critical technology needs and evaluate proposals prepared by the university participants.

A separate component of this element addresses critical materials and manufacturing technology issues for the whole Program. DOE/EE calls on the expertise of the Oak

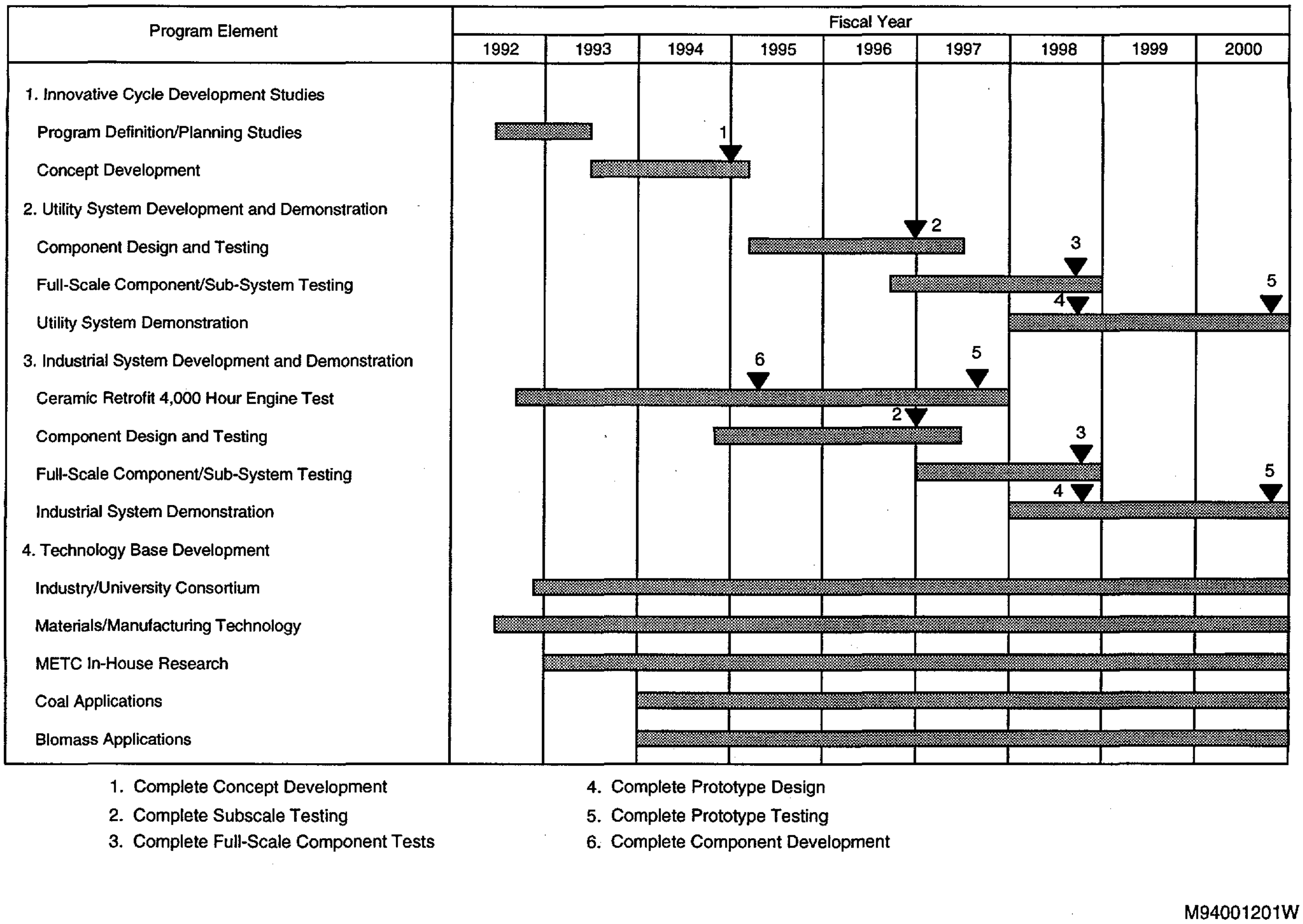


**Figure 2. Schedule for Advanced Turbine Systems Program**

Ridge Field Office for the management of this part of the Program. Projects are currently in place with PCC Airfoils, Inc., and Howmet Corporation to develop advanced turbine components.

The Morgantown Energy Technology Center (METC) in-house R&D organization also participates in this part of the Program. Much of METC's work is to be performed cooperatively with other organizations performing R&D in this program element and in program Elements I and II.

The Technology Base Development element also includes activities to address the application of ATS technology to the coal and biomass systems being developed in other DOE programs.

## PROGRAM STATUS

The initial systems studies of Element I have been completed, and Reference 6 includes papers describing the results obtained by Allison Engine Company, Asea Brown Boveri, General Electric, Solar Turbines, and Westinghouse. In general, each of the manufacturers explored a range of system possibilities and variations on the basic concepts. Advanced cycles were considered, along with significant improvements on basic combined cycle technology. All of the manufacturers saw a need to increase turbine inlet temperature and planed to achieve this through improved cooling and materials technology. Combustor development will be needed to meet emission goals at the higher turbine inlet temperatures. The studies addressed both utility- and industrial-scale systems and included systems based on both heavy duty and aero-derivative technology.

Contracts have been awarded in the second phase of the Program, and the contractors are moving ahead with concept development. In parallel with the latter part of this work, DOE has issued solicitations for Phases 3 and 4. Awards under this round will cover the balance of the development through completion of demonstration. The target award date is late summer 1995. Although multiple awards are expected in both the industrial- and utility-scale categories, it is planned to down-select after component development and only have one demonstration project in each group.

The other elements of the Program are also well underway. Significant progress has been made in the ceramic retrofit project established with Solar Turbines, and results are being obtained. The Oak Ridge field office has established the Materials/Manufacturing Technology Program, and responses to initial solicitations are being processed. The industry/university consortium is off to a solid start, with more than 70 university members and 23 projects established in the first two annual solicitations. METC has completed shakedown of its Advanced Turbine Combustion Facility, and testing has begun.

## FUEL CELLS PROGRAM

Fuel cell systems offer the potential for ultra-high efficiency energy conversion and the enhancement of the quality of our environment. Because of this, DOE/FE is sponsoring the development of fuel cells for stationary power generation. The Department works closely with the private sector in the development and demonstration of this advanced energy conversion technology.

Concerns for the global environment are driving future power generation systems toward technologies that produce extremely low environmental emissions. Because of their high efficiencies, fuel cell power plants will help in reducing carbon dioxide emissions. Since combustion is not utilized in the process, fuel cells generate very low amounts of $NO_X$, and they emit very little sulfur oxides. Fuel cells have been exempt from air permitting requirements in southern California. Relying on electrochemistry instead of combustion, the fuel cell is attractive for both heavily polluted urban areas and remote applications. Not only will it emit none of the smog-causing pollutants associated with conventional power plants, it is ideal as a distributed power source; that is, it can be sited close to the electricity user—for example, at electrical substations, at shopping centers or apartment complexes, or in remote villages—minimizing long-distance transmission lines.

The Fuel Cell Program is a market-driven program which has more than 40 percent cost-sharing. The fuel cell developers enjoy the support of user groups with more than 75 utility and other end-user members. In addition, DOE cooperates with GRI and EPRI to fully and efficiently leverage funding for the U.S. Fuel Cell Program.

## FUEL CELL TECHNOLOGY

Fuel cells generate electricity and heat using an electrochemical process similar to a battery. A fuel cell will continuously produce power, as long as a fuel, such as natural gas; and an oxidant, air are supplied to the system. Because it is an electrochemical device, the electrical generation efficiency from the use of the fuel can be much more than that of conventional power plants. Present early market systems are achieving over 45 percent (LHV) cycle efficiency. The next generation systems are expected to achieve 55 percent and eventually 70 percent (LHV) cycle efficiencies.

As shown in Table 2, several different types of fuel cells are being developed for stationary power applications. The electrolyte controls the operating temperature of the cells, which in turn determines the materials of construction. Phosphoric acid fuel cells (PAFC's) are now being commercialized, while molten carbonate fuel cells (MCFC's) and solid oxide fuel cells (SOFC's) promise even higher efficiencies for the future[7].

A basic fuel cell (Figure 3) consists of two electrodes, with the anode and cathode separated by an electrolyte. Fuel cell types are characterized by their electrolyte. For example, PAFC's utilize a phosphoric acid electrolyte in a matrix between anode and cathode electrodes. To produce a useable quantity of electric power, individual cells are assembled into a vertical "stack" of repeating components which are electrically interconnected. A fuel cell power plant (Figure 4) consists of the stack or power section integrated with a fuel processor and a power conditioner to convert the power from direct current to alternating current.

The fuel cell is inherently modular. Constructed as an assembly of individual cells, stacks ranging from 100 to 250 kW form a modular building block. Depending on the generating capacity required, 10 to 20 stacks can be grouped with a fuel processor and a power conditioner to create a 1- to 2-MW power plant. Larger plants will use a larger number of stacks. In high growth areas or remote sites, modular power plants located near the demand can offset the cost of right-of-way access and transmission lines.

Another attractive feature of fuel cell power plants is their use at sites where cogeneration is possible. High-grade heat or steam is available for industrial and commercial applications. Industrial drying, prisons, hotels, hospitals, and central heating and air conditioning are examples.

## PROGRAM STATUS

Because of cost-sharing by DOE and its predecessor agencies over the past 20 years, first-generation fuel cells are now in the initial states of commercialization. In the last 5 years, focus has shifted to advanced fuel cells, including molten carbonate and SOFC's. These systems offer higher efficiencies, the potential for lower capital cost, and because of higher operating temperatures, are more suitable for cogeneration.

**Table 2. Types of Fuel Cells**

| Characteristic | PAFC | MCFC | SOFC |
|---|---|---|---|
| Electrolyte | Phosphoric Acid | Lithium Carbonate/ Potassium Carbonate | Stabilized Zirconia |
| Operating Temperature | 400°F | 1200°F | 1800°F |
| Electrical Conversion Efficiency (LHV) | 45-50% | 50-65% | 50-60% |
| Materials | Carbon Platinum | Nickel Stainless Steel | Ceramic |

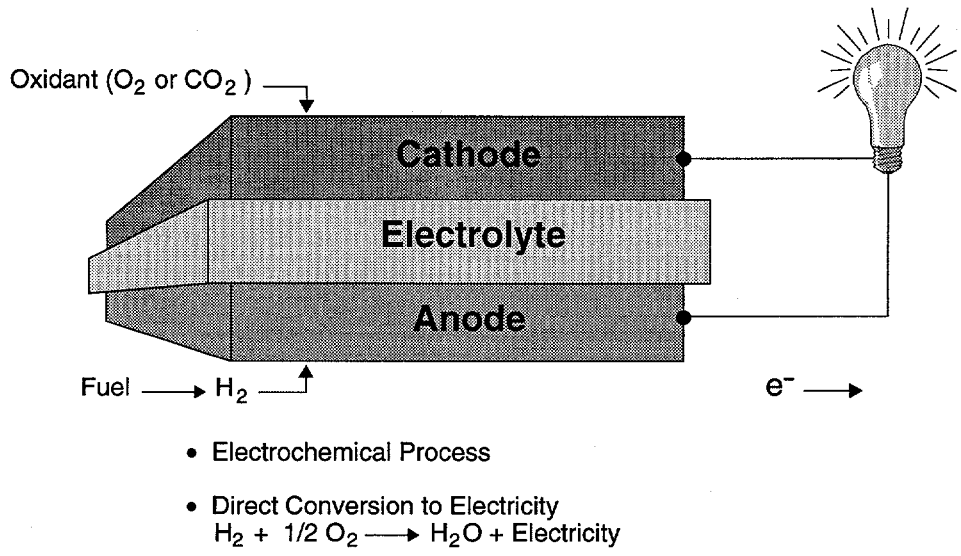


**Figure 3. Basic Fuel Cell**

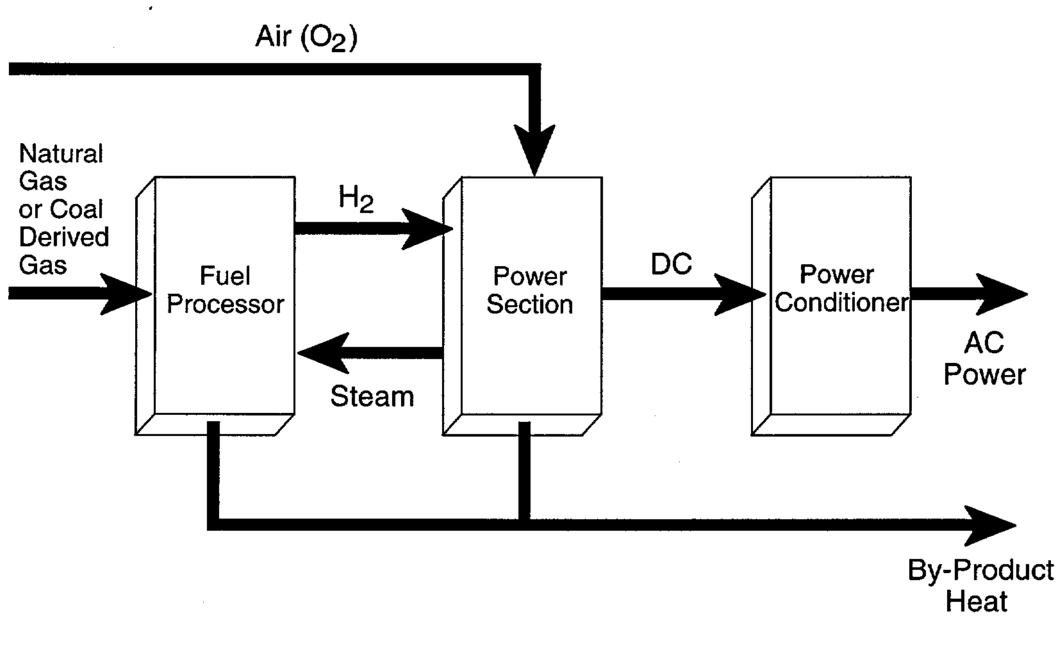


**Figure 4. Fundamentals of a Power Plant**

The Fuel Cell Program objectives are to develop and demonstrate cost effective fuel cell power generation, which can initially be commercialized using natural gas fuel by the year 2000. Figure 5[8] shows the major program activities. The DOE-sponsored PAFC development work was completed in 1992. ONSI Corporation located in South Windsor, Connecticut, has been actively involved in the development and marketing of on-site PAFC systems and has a 40-MW/year manufacturing facility. In their PAFC commercialization, the ONSI Corporation, a subsidiary of International Fuel Cells (IFC), is offering a complete packaged phosphoric acid power plant for $3000/kW. Named PC25, more than 50, 200-kW units are in operation in the U.S. and around the world. Operating experience has been excellent with availabilities of more than 90 percent. IFC is currently developing 1-MW class units based on a five-stack design and developing the PC25C which is lower in size and cost.

DOE is now cooperating with the Department of Defense in supporting the demonstration of the PAFC at customer sites. This activity is attempting to stimulate PC25 sales until the new PAFC fuel cell industry is self-sustaining.

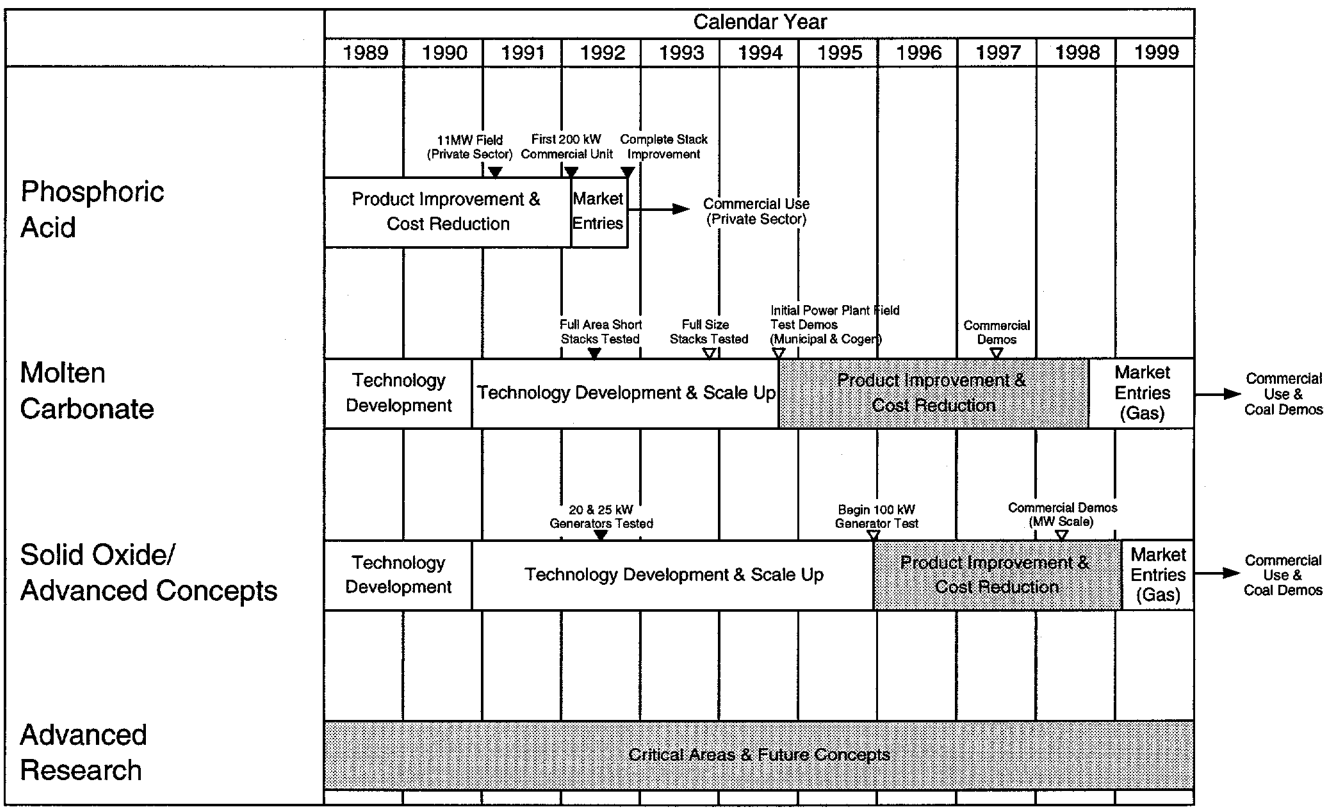


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**Figure 5. Fuel Cell Program Activities**

There are two major U.S. developers of MCFC's. M-C Power (MCP), located in Burr Ridge, Illinois, is developing an internally manifolded design, while Energy Research Corporation (ERC) of Danbury, Connecticut, has developed a stack design based on internal reforming. Both of these developers have Product Design and Improvement cooperative agreements with DOE. The objective of the agreements is MCFC cost reduction, performance improvement, and packaging. MCFC's utilize a molten electrolyte composed of lithium and potassium carbonates. MCP is readying a 250-kW prototype of this next generation of fuel cell technology for testing at the Miramar Naval Air Station in San Diego, California. The heat produced by the fuel cell will be used for on-site heating. This cogeneration approach raises the overall efficiency to nearly 85 percent, meaning that this amount of the available energy in the fuel can effectively be utilized. In addition to this fully integrated test, a test of an 11-square foot, full-size stack is underway at UNOCAL's research center near Los Angeles. ERC will demonstrate an MCFC power plant system at the Santa Clara, California, municipal utility. Scheduled for operation in late 1995, the 2-MW demonstration will be a key milestone in the development of second-generation fuel cell technology. In the ERC fuel cell architecture, the Santa Clara Demonstration will be made up of 125-kW stacks linked together in four-stack modules.

In the 1997 timeframe, MCP and ERC are planning 1-MW and 2-MW demonstrations, respectively. These demonstrations are expected to trigger contingency orders and to finance the construction of larger manufacturing facilities. Commercialization is expected by 2000.

The Westinghouse Electric Corporation is the major and world's leading SOFC developer. Westinghouse is developing a tubular SOFC concept, with each tube made up of multiple ceramic layers bonded together. Multiple tubes are linked together to form power modules. The modules are then linked to form small generators or larger power plants. Two 25-kW generators have been tested in Japan. Two additional 25-kW tests are planned in 1995 at the southern California Edison National Fuel Cell Research Center near Riverside, California. These will be followed by 100-kW generators and later MW-size systems. Testing of a 100-kW generator is planned at a utility site in the Netherlands in mid-1996.

Longer range advanced research and technology development is being carried out by DOE's national laboratories and a number of private sector contractors.

Fuel cells operating with natural gas as a fuel, will enter the commercial market over the next few years. The technology is advancing rapidly as developers move from prototype to full commercial-size stacks and packaged integrated systems. Fuel cells are expected to offer long-term cost and environmental advantages. Early units will be limited to a few MWs in size until sufficient operating experience is gained. These first units will be used in dispersed generation and cogeneration applications. The manufacturing of fuel cells will create new industries and add growth to existing industries and services.

## BENEFITS TO THE GAS INDUSTRY

The ATS Program and the Fuel Cell Programs can make a significant contribution to the future strength of the natural gas industry. Each segment of the gas industry will share in the benefits of these programs.

## Potential to Increase Gas Use

The efficiency, economic, and environmental benefits of fuel cell systems and ATS will lead to increased use of natural gas for electric power generation. For the near-term, PAFCs and technological spin-offs from the ATS Program will enter the marketplace. This will result in a modest acceleration of the ramp up in gas use. For the longer term, the efficiency and low-cost of these power generation systems will enlarge the economic "window" in which gas-fired systems are competitive with other types of fossil and renewable energy systems. This will ensure that gas consumption rates remain high, even in the face of rising gas prices in the post-2000 era.

## Reduce User Concerns of "Massive" Gas Price Increases

Increased use of gas by the utility sector (or any other market segment) will tend to increase gas prices. The ATS and Fuel Cell Programs will protect against "massive" gas price increases in two ways. First, ATS designs are adaptable to coal or biomass firing. Thus, large ATS systems at central station utilities will be able to switch to an alternative fuel if gas prices rise beyond a certain level. Second, the higher efficiency of ATS and fuel cell systems will tend to moderate increases in gas use.

## Reduce Seasonal Variations in Natural Gas Consumption and Prices

The ATS and the Fuel Cell Programs will help level seasonal peaks and valleys in natural gas consumption. Natural gas consumption has traditionally been highest in the December through March winter season. Most electric utilities in the U.S. are summer peaking. Gas fired power generation systems will help levelize consumption. This will make all segments of the natural gas industry more profitable.

Producers will have a much greater incentive for maintaining and expanding production capacity. New wells will have a much better payout, and capital investment decisions will be more easily justified. The transmission pipelines will similarly benefit, and it will be easier to justify adding new pipelines.

Local Distribution Companies (LDCs) will also benefit. Industrial-scale ATS and fuel cell systems could have wide-spread application in the dispersed power market and this would increase LDCs sales. While utilities may bypass LDCs in obtaining gas for large turbine systems, traditionally, LDCs have not played a dominant role in this market.

Greater stability in natural gas prices will be an important result of reducing seasonal variations in gas demand. This will increase user confidence in gas availability and reliability. This greater confidence will permeate all transactions with users, whether they are through LDCs, direct with producers, or through pipeline companies. It will also contribute to greater unity among the varied segments of the natural gas industry.

## More Efficient, Lower $NO_X$ Turbines for Pipeline Applications

The goal of the ATS Program is to develop high-efficiency, environmentally benign, cost-effective gas turbine systems. The improved technology developed in this program is applicable to the turbines used in pipeline compressor stations. Additionally, a significant fraction of the gas and oil industry uses gas turbines systems for power generation. Thus, gas and oil industry sites are candidates for demonstration projects in the ATS Program.

**Economic Competitiveness**

The ATS and Fuel Cell Programs will lead to additional U.S. jobs. The domestic market for power generation equipment is estimated to be 8 to 10 gigawatts (GW) per year; the total world market is estimated to be 100 GW per year. Gas turbine based power systems and fuel cell systems are well positioned to capture a significant fraction of this market. Turbines and fuel cells—as high-tech prime movers packaged in a small volume—are ideal candidates for export from the U.S. Thus, the ATS and Fuel Cell Programs will maximize the opportunity for U.S. suppliers to participate in this world market. The U.S. jobs created and maintained by the DOE investment in these programs will result in relatively affluent gas consumers—a benefit to all sectors of the U.S. gas industry.

## SUMMARY

The U.S. DOE is supporting the development of advanced, natural-gas fueled power generation technologies for the next century. These highly efficient and environmentally benign systems will contribute to the future strength of the natural gas industry.

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