3.3 Power Generation

CONTENTS

POWER GENERATION

3.3.1 TECHNOLOGY SUMMARY

Activities in the area of Power Generation are focused on developing cleaner, more efficient systems for both utility and industrial electric power generation. Although the target fuel is natural gas, systems are being developed for use of coal, biomass, and other fuels. Two types of systems, fuel cells and advanced turbines, are being addressed in programs conducted within the Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy.

A fuel cell (Exhibit 4) is an electric power generator made with parts similar to the common storage battery. Unlike a battery, it will continue to provide power as long as air and fuel is supplied. The air and fuel are combined electrochemically in the fuel cell to produce electricity without combustion. Individual fuel cells are connected in varying numbers of stacks to match the particular power application. The fuel cell systems produce very high quality DC electricity that can be used directly or efficiently converted to AC power. Fuel cells have been used for many years in space vehicles for on-board electric power, and have recently begun to find applications for commercial power and transportation.

Gas turbines (Exhibit 5) are heat engines that use a high temperature, high pressure gas from a combustor. Part of the heat supplied by the gas is used to rotate a generator and produce AC electricity. Much of the remaining thermal energy can be used to create steam for industrial processes or additional electricity.

Because they are compact, lightweight, and simple to operate, gas turbines have found many applications in aircraft, power generation, and industrial cogeneration. Today's industrial and utility gas turbine systems have benefited from incremental changes in existing designs. Turbine manufacturers and DOE are sharing the cost of high-risk research and development aimed at revolutionary but achievable advances.

Exhibit 4 - A Fuel Cell is Similar to a Battery But It Does Not Have to be Recharged.

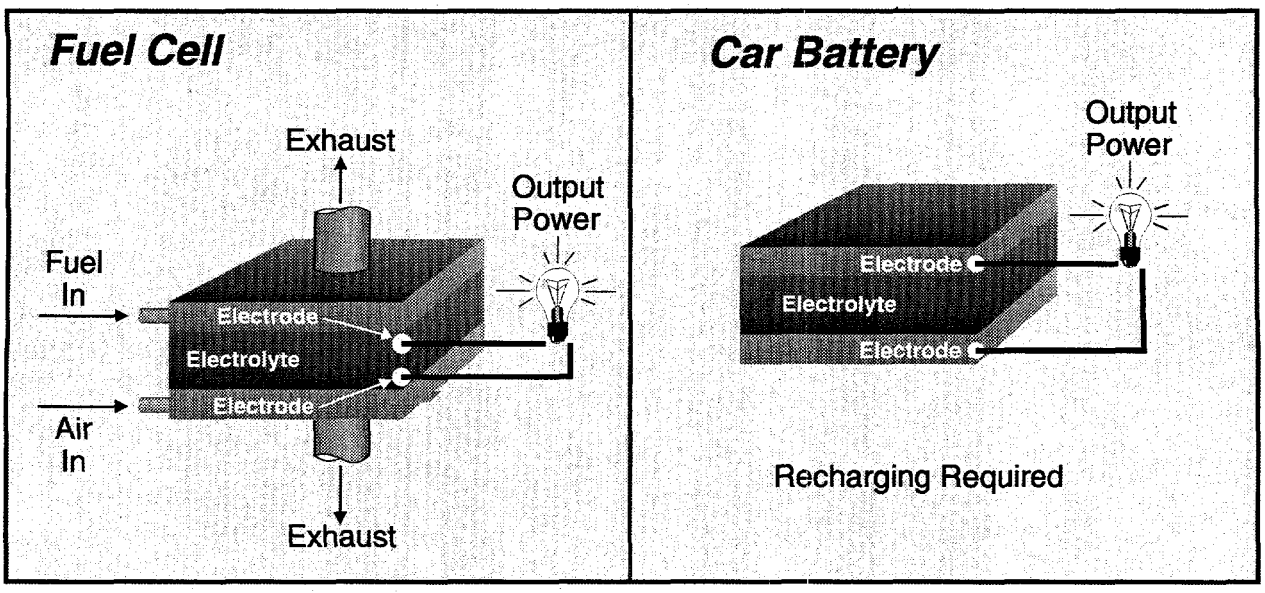
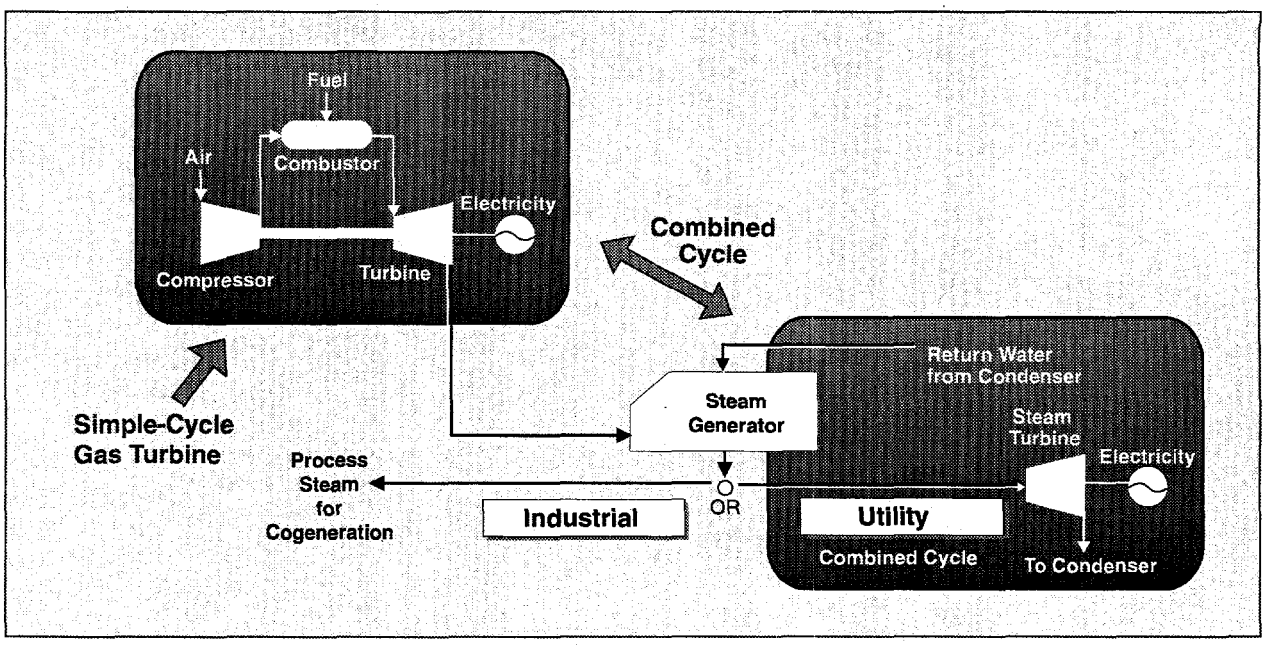


Exhibit 5 - A Gas Turbine Engine Consists of a Compressor, Combustor, and Turbine in Series. A Combined Cycle Power Plant Uses Both a Gas and a Steam Turbine.



The focus of these efforts is shown in Exhibit 6 (utility systems).

Because of their potential for ultra-high efficiencies and extremely low emissions, fuel cell and advanced turbine systems are expected to contribute substantially to future growth in electric power demands. Their inherent siting flexibility permits them to be installed in both conventional settings or to be located much closer to their loads (Exhibit 7). In countries like the United States, where transmission and distribution systems are near capacity limits and stringent emissions standards prevent the siting of conventional power generators, systems consisting of fuel cells, advanced turbines, or combined units could be deployed in a distributed generation mode, close to the load requirements.

The Department-wide power generation programs for natural gas-fired systems are described in detail in the program descriptions for fuel cells and advanced turbines.

FY 1996-1999 Crosscut Budget Summary ($ in Millions)

Projects	FY 1996	FY 1997	FY 1998	FY 1999 Request
Fuel Cells	51.20	48.80	40.20	42.20
Advanced Turbines	57.57	71.20	79.60	76.00
Total	**108.77**	**120.00**	**119.80**	**118.20**

Exhibit 6 - Utility Advanced Turbine Systems.

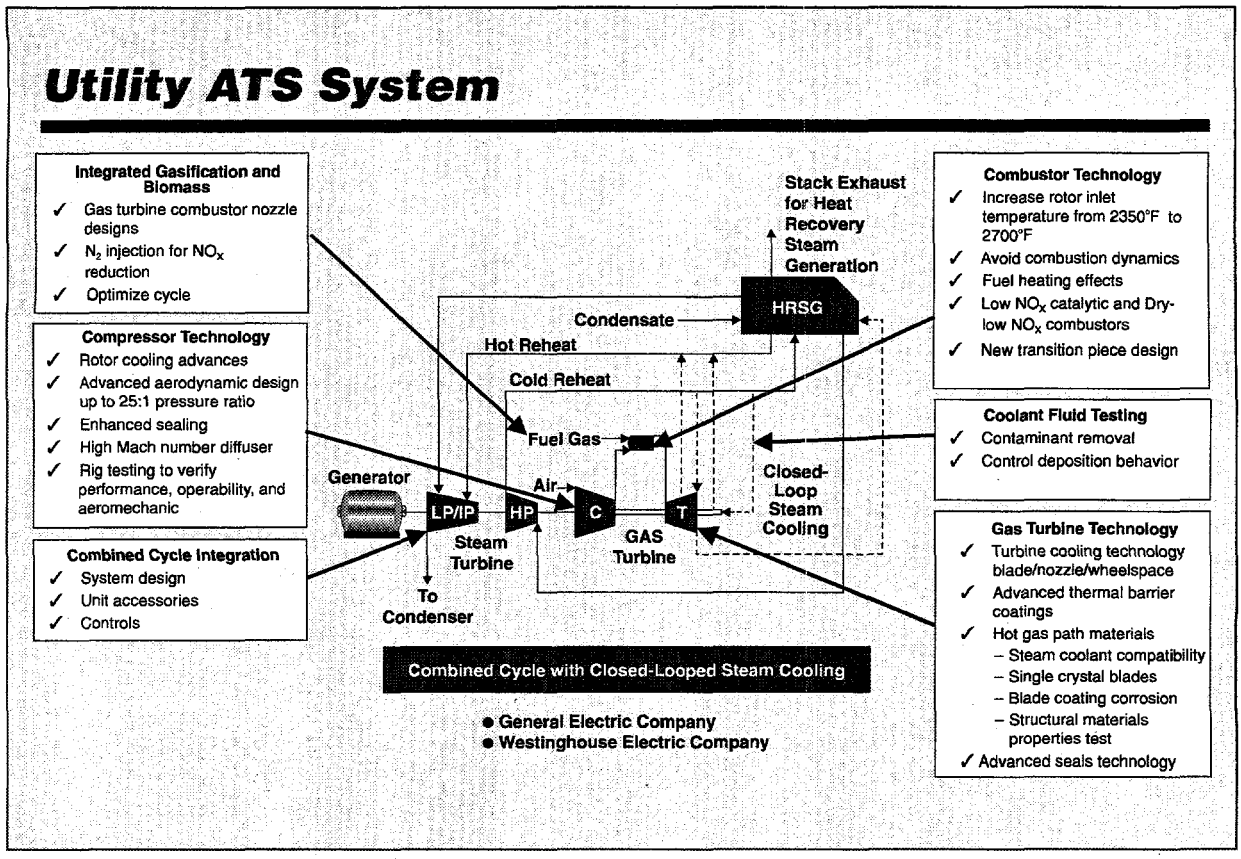
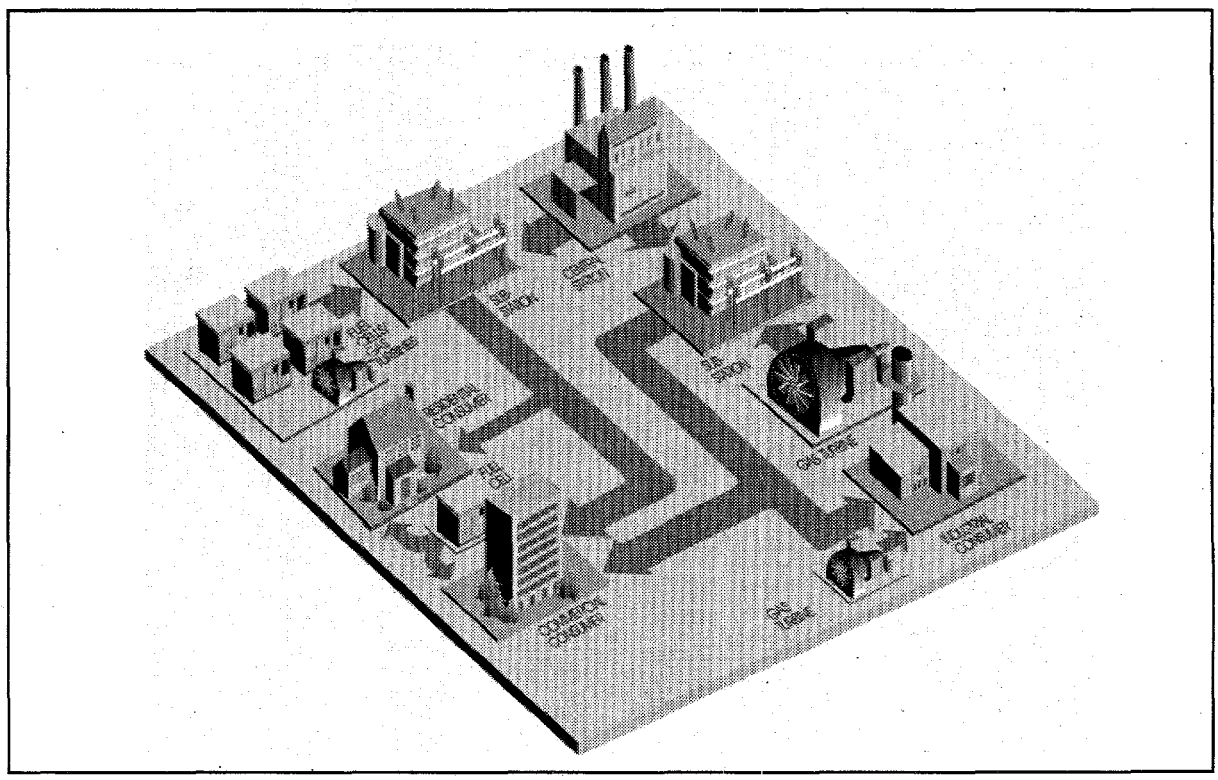


Exhibit 7 - Distributed Generation Provides Options to Improve Electric Distribution.



3.3.2 Project Descriptions

3.3.2.1 Fuel Cells for Power Systems

Background

Fuel cell power systems are emerging power generation technologies for efficient, economical and environmentally acceptable production of electricity. In some applications the heat by-product can also be efficiently used in cogeneration. Fuel cells produce electricity through electrochemical oxidation of a fuel. They can be operated on a variety of fuels, including natural gas, coal gas, land fill gas, and renewable fuels. First market entry units are fueled by natural gas. Fuel cells offer opportunity for a major new domestic manufacturing industry to be strongly competitive in the international market. A description of fuel cell technology is contained in *Fuel Cells - A Handbook*, Revision 3, U.S. Department of Energy, Office of Fossil Energy, January 1994.

The Department of Energy, Office of Fossil Energy is a leading sponsor of U.S. fuel cell technology for stationary applications. The Office of Fossil Energy is also an active member in the coordinated National Fuel Cell Program, a domestic program whose membership has interests in many fuel cell technologies. Other U.S. organizations providing major support for this program are the Department of Energy, Office of Energy Efficiency and Renewable Energy, the Department of Defense, National Aeronautics and Space Administration, Electric Power Research Institute, Gas Research Institute, and gas and electric utilities as well as the companies developing the fuel cell technologies and other private, State, and local interests.

The sponsoring organizations meet periodically to coordinate the program, ensuring that any technology gaps are bridged and that duplication of projects does not occur. The sponsoring organizations also orchestrate the bi-annual Fuel Cell Seminar, attended by participants from all over the world. For more information on the 1998 Fuel Cell Seminar, contact Courtesy Associates, Inc., Washington, D.C., (202) 973-8671.

There is world-wide interest in fuel cell technology and in its development which is indicated by broad international participation in fuel cell seminars and other similar technical meetings, by fuel cell technical literature, and by visits to international developers. Japan has a strong, well-organized fuel cell program sponsored by the Japanese Ministry of International Trade and Industry and by the Japanese private sector. A number of significant efforts are being focused on a variety of fuel cells within the European Commission and within individual countries in Europe. The Canadian government is also providing significant support for development of fuel cells. Russia and South Korea have begun active fuel cell programs as well.

Major Goals

The goal of the fuel cell program is to develop fuel cell power plant technology for use in electric utility, on-site cogeneration, distributed generation, industrial, and commercial sectors, producing high efficiencies and economic and environmental benefits. The focus of the development is to strengthen technology to a mature, cost-effective level where the developers can furnish viable commercial fuel cell power systems and the new domestic industry can strongly compete in the international fuel cell market.

Program Objectives

The objectives of the fuel cell program are:

- By 2002, have market-ready advanced fuel cell systems with efficiencies higher than 60 percent for use on natural gas for multi-kilowatt on-site cogeneration, low megawatt distributed power, and multi-megawatt central station markets.

- By 2005, adapt advanced fuel cell systems for use with coal-derived fuel gas to enhance coal-based system efficiencies in the 50 percent range.
- By 2010, develop and validate coal-fueled advanced fuel cell systems with near-zero emission of pollutants.
- By 2010, develop and validate advanced hybrid-cycle systems combining fuel cells and advanced gas turbines with efficiencies in excess of 70 percent on natural gas and with near-zero emission of pollutants.

Expected Benefits

- *Environmental*: Widespread use of fuel cell power plants offer significant environmental benefits. The prospects are substantial of reducing criteria pollutants well below current New Source Performance Standard levels, reducing noncriteria pollutants such as CO_2 and acid rain precursors, and reducing thermal emissions to the environment. These reductions are achieved through the ultra-high efficiency and the inherently low emissions of fuel cell systems. Furthermore, fuel cell systems are expected to exhibit extremely quiet operation.
- *Efficiency*: Fuel cells are unique in that they offer high efficiency even at part-load and in small sizes. Advanced fuel cell generation systems can be designed with electric efficiencies in the 50 to 60 percent range and would extend to over 70 percent in a combined cycle with gas turbines. Use of available by-product heat from a fuel cell power system could augment total energy utilization to about 85 percent.
- *Economic*: A new fuel cell industry could be expected to produce high quality jobs and product exports. Modular fuel cell systems would allow ideal generator/load matching, thereby significantly reducing generation capital costs. Fuel cell systems are ideal for the distributed generation mode, obviating the need to expand transmission lines and eliminating long transmission line losses.
- *System Reliability*: Currently operating market entry phosphoric acid fuel cell units are exhibiting about 95 percent availability. Advanced fuel cells are expected to equal or better this mark.
- *Power Quality*: Fuel cells provide high quality power with no spikes, surges, or electrical noise; hence, they are ideal for sensitive equipment.

Planned Products

Each of three advanced fuel cell developers is planning to develop a fuel cell system that is suitable for entry into the fuel cell power market. Unique systems, representative of each developer's market entry unit, will be built and verified by operation at field sites by utilities. In the molten carbonate fuel cell (MCFC) program, one manufacturer is developing a system for on-site cogeneration applications, and another company is developing a system for multi-megawatt distributed generation applications. The solid oxide fuel cell (SOFC) developer is focusing on a fuel cell with gas turbine combined cycle system for central power. Near-term planned products are listed below:

- Field test of 250 kW to 1 MW MCFC power plants fueled by natural gas (2000)
- Field test of a 1-2 MW SOFC-with-gas-turbine power plant fueled by natural gas (2000)
- Initial commercial production of two natural gas-fueled MCFC power plants (2002)
- Initial commercial production of a natural gas-fueled SOFC power plant (2002)

Strategy (FY 98 Funding: $40.2 Million)

The fuel cells program is included as part of DOE's overall Gas Research Program. Gas-fueled fuel cells will be developed before coal-fueled fuel cells, and gas-fueled fuel cells will most likely be placed into use years before a coal-fueled fuel cell system could be fully developed. Research conducted by the Fossil Energy fuel cells program is applicable to both coal and gas-fueled fuel cells; the fuel cell program is currently developing gas-fueled applications. Although advanced fuel cell systems achieved high efficiencies and ultra low emissions in development field testing with gaseous fuels, the systems must be further scaled up to commercial size power plants and demonstrated to have acceptable capital cost and long operating life.

The strategy of this program is to support development, integration, scaleup, and commercial scale demonstration of molten carbonate and solid oxide fuel cell power plants with private sector cost sharing. Cost-sharing in major activities ranged from 30 percent to slightly over 50 percent in recent years, depending on the nature of the activity. Product improvement and cost reduction activities in molten carbonate and solid oxide systems are under way and are expected to result in commercially ready power systems. New systems will be explored to take advantage of synergistic effects between major components in combined cycle systems.

Work is under way to characterize fuel cell and gas turbine combinations to realize major increases in system electric efficiencies. In addition, outreach to the private sector is facilitated by stimulating interactions among manufacturers, suppliers, and potential users. Activities will be continued for basic and applied research on materials, processes, and components applicable to fuel cell systems to achieve steady progress in improving these technologies. This effort provides supporting technology as well as evaluation of improvements.

The advanced research activity supports program objectives by studying critical enabling science and technology topics related to research on fuel cells, to better understand the basis of the underlying processes involved, and to explore novel concepts. Results of the investigations are used by those who develop, design, manufacture, and operate fuel cell systems including the MCFC and SOFC systems discussed above. Advanced research of superclean fuel cell power systems seeks to capitalize on their intrinsic high efficiency and environmentally benign characteristics, emphasizing research on electrochemistry, catalysis, interconnections, and materials interactions for molten carbonate, solid oxide, and advanced devices.

The DOE Fossil Energy program is coordinated with GRI and EPRI fuel cells programs through periodic meetings and informal communication. The GRI and EPRI programs emphasize application to gas and electric utility industries and provide synergistic support of the DOE program, which emphasizes development of critical technologies.

Recent Accomplishments

Phosphoric acid fuel cell systems have reached commercial status and market entry units are being manufactured for various applications. Production of more than one-hundred fifty 200-kW units has been accomplished. Reliable operation is under way at sites around the world.

Advanced molten carbonate and solid oxide integrated systems have been successfully operated at the 25-kW to 2-MW scale. A field test of a 250-kW molten carbonate system was conducted in San Diego, California (see Exhibit 8) and a 2-MW molten carbonate system has completed field testing in Santa Clara, California (see Exhibit 9). Twenty-five kilowatt solid oxide systems have been successfully tested (see Exhibit 10) and field testing of a 100-kW solid oxide fuel cell system is underway. Accomplishments expected in FY 1998 include:

MCFC – On-Site cogeneration Design:

- Test a 75-kW MCFC stack at San Diego Facility using commercial design repeat parts.
- Install modifications at the San Diego Facility to enable it to function as a Power Plant Verification Facility.
- Manufacture 250-kW MCFC stack using commercial design repeat and non-repeat parts for testing at the San Diego facility.

MCFC – Distributed Generation Design:

- Complete MCFC market entry design subscale stack test series.
- Execute the first MCFC market entry tall stack test.
- Determine MCFC market entry product size.
- Finalize market entry plant design.

SOFC – Fuel Cell/Gas Turbine Combined Cycle Design:

- Start site testing of 100-kW SOFC field unit.
- Start pressurized test of SOFC cell bundle.
- Complete manufacture of SOFC cells for 250-kW combined cycle unit.
- Qualify SOFC sintered fuel electrode process for low cost cell production.

For information on each major fuel cell project, see the fuel cell web site, at *www.fe.doe.gov/program.html*.

Program Funding

Program implementation is through the Federal Energy Technology Center (Morgantown, WV). Most of the activities are through cost-shared contracts with private industry interested in commercializing these power plants. Some supporting research is also performed by the National Laboratories and by universities. The table below shows appropriated and requested funding. DOE requested slightly lower funding for FY 98 in response to having to balance fiscal restraints with program needs.

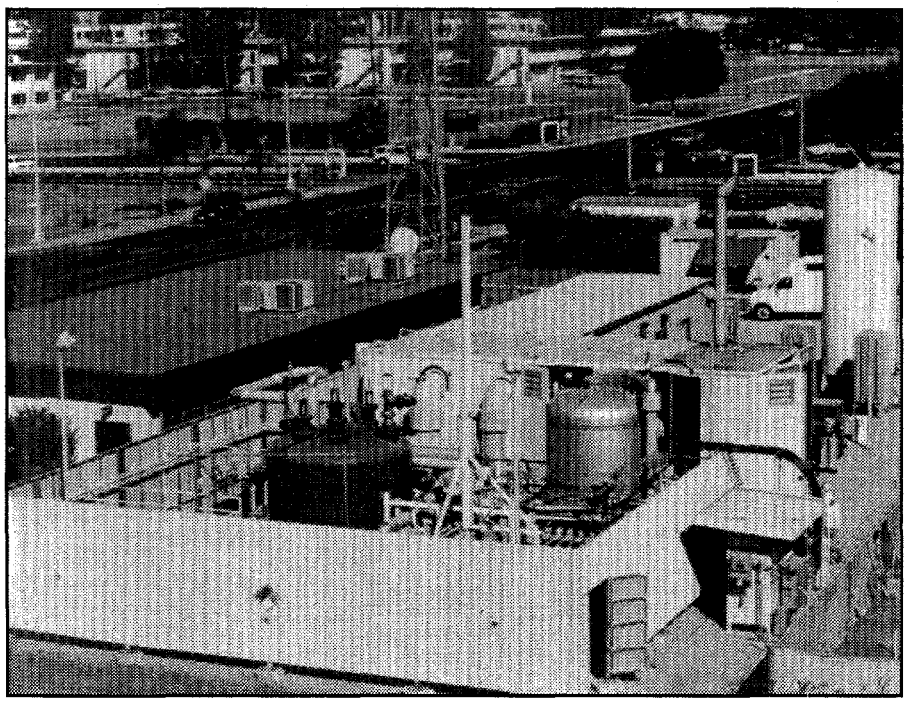


Exhibit 8 - Two Hundred Fifty Kilowatt MCFC Field Test at San Diego, California.

Exhibit 9 - Two Megawatt MCFC Field Test at Santa Clara, California

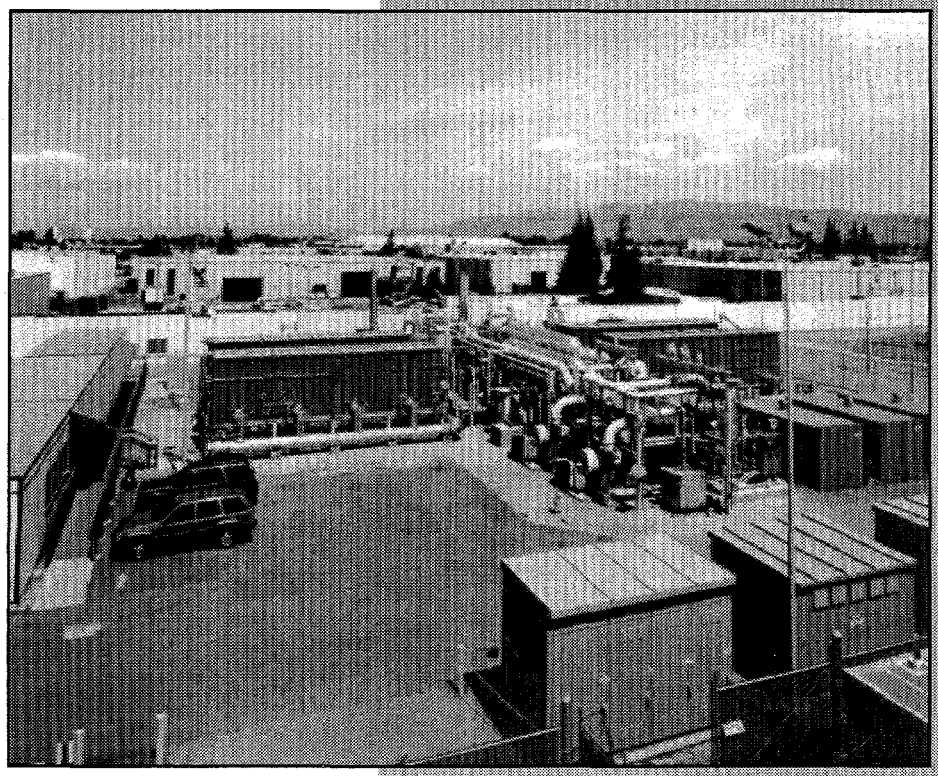
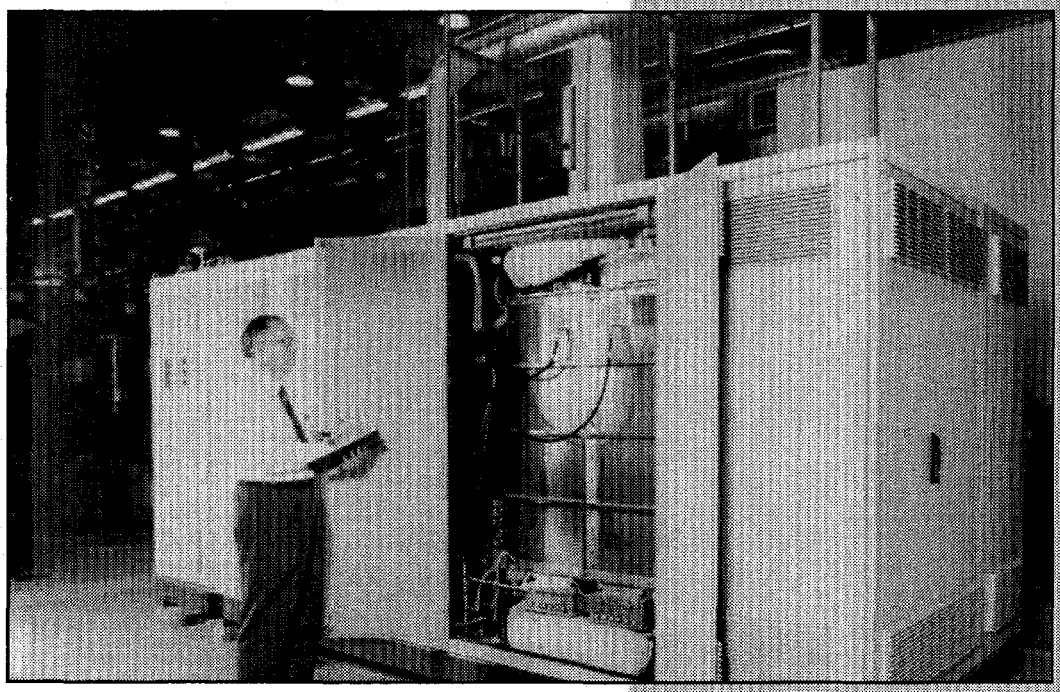


Exhibit 10 - Twenty-Five Kilowatt SOFC System.



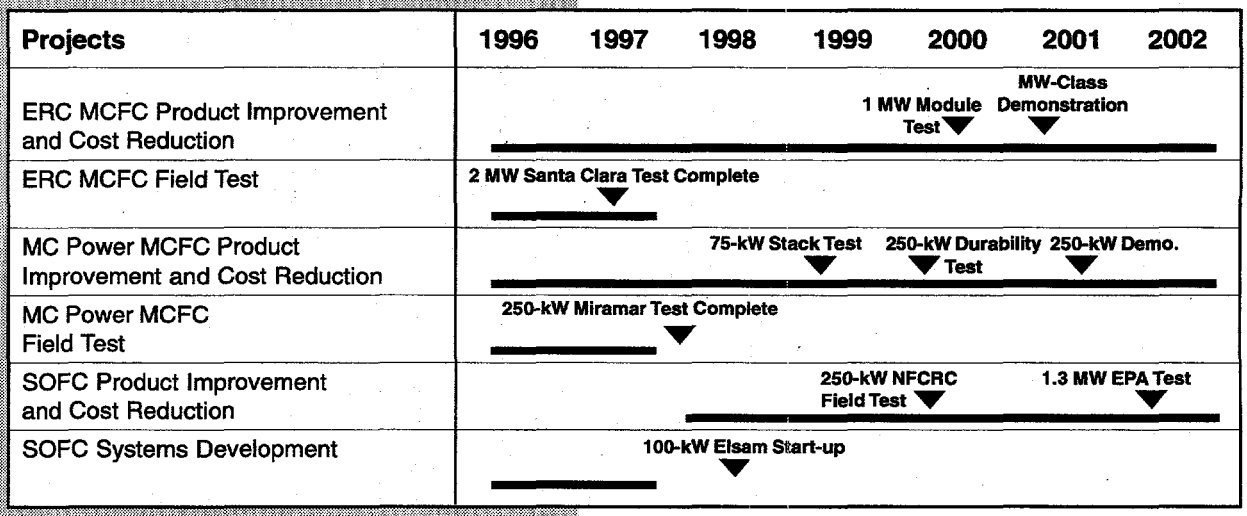
DOE Historical Spending ($ in millions)

Projects	FY 1996	FY 1997	FY 1998
Fuel Cell Systems Development	49.9	47.6	39.0
Advanced Research	1.3	1.2	1.2
Total	**51.2**	**48.8**	**40.2**

Cost Sharing (percent of project cost)

Projects	FY 1996	FY 1997	FY 1998 Estimate
Solid Oxide Fuel Cell	50	50	50
Molten Carbonate Fuel Cell	33	33	33

Schedule



3.3.2.2 Advanced Turbine Systems

Background

The Advanced Turbine System (ATS) Program was initiated in April 1993 to develop more efficient gas turbine systems for both utility and industrial electric power generation (including central station, distributed generation, and cogeneration). The program will provide base-load power systems for commercial at the offering at the beginning of the 2000s. Although the target fuel is natural gas, advanced turbine systems will be adaptable to coal and biomass firing. The ATS Program is marshalling resources of the Nation's gas turbine manufacturers, the electricity utility industry, and the university community, as well as government and private sector R&D sponsors and laboratories.

The ATS Program is the joint responsibility of the Department of Energy's Fossil Energy (FE) and Energy Efficiency and Renewable Energy (EE) offices. The Fossil Energy office has primary responsibility for the development and demonstration of utility systems, while EE has the lead role for industrial systems. There is also a very significant technology base element of the program. EE has the responsibility for material studies in the technology base area, and FE is responsible for managing an industry-driven consortium in which universities conduct generic research and development supporting the advanced turbine system development. The FE program will develop advanced turbine system technology for coal-based systems, while EE will assure that ATS technology is available for biomass systems.

This program consists of four elements:

Program Element I is Innovative Cycle Development. This element included two parts:

- Program Definition Planning Studies: In this phase (completed 1993) gas turbine manufacturers performed scoping studies to identify incentives and defined technical issues and resource requirements for developing natural gas-fired turbine systems.
- Contracts were awarded to gas turbine manufacturers to develop conceptual design of gas- fired advanced turbine systems that can be adopted for coal firing. This was completed in 1994.

Program Element II is Utility System Development. The three phases of this element are:

- Phase II - Component Design and Testing (completed in 1997).
- Phase III - Utility Full-Scale Component and Integrated Subsystem Testing (completed in 1998).
- Phase IIIR - Utility System Demonstration (to be completed in 2002).

Program Element III is Industrial System Development.

- The Office of Energy Efficiency and Renewable Energy is responsible for this element.

Program Element IV is Technology Base Development (to be completed in 2001)

- The aim of this element is to support advanced turbine systems development by conducting research and development on gas turbine issues, including materials evaluation, materials development, coating development, manufacturing process development, heat transfer model testing, component testing, computer code development, combustion testing, combustion testing, and field test data reduction. Research and development on specific proprietary hardware development (for example, high flow expanders) is not considered appropriate for the Technology Base

program element. Sub-elements of the Technology Base Development include, Industry/University Consortium, Materials/Manufacturing Technology, Federal Energy Technology Center In-house Studies and Coal Applications.

Major Goals

The goals of the ATS Program are:

- Ultra-high efficiency power generation systems firing natural gas. Industrial systems (those with a compressor inlet airflow less than 25 pounds per second) are expected to show a 15 percent increase in efficiency, compared to 1991 vintage systems. Utility systems (compressor inlet airflow 25 pounds per second and higher) are required to feature system efficiencies over 60 percent, on a lower heating value basis.
- Emissions of nitrogen oxides (NO_x) less than 10 parts per million at 15 percent oxygen.
- Busbar energy cost 10 percent less than today's advanced gas turbine systems.
- Adaptability to coal or biomass fuels
- Reliability equivalent to today's advanced systems.
- Availability for market in the year 2002.

Project Objectives

The Federal Energy Technology Center (Morgantown) implements the ATS Program through contracts and financial assistance to turbine manufacturers, universities, national labs, and utilities. The most important projects are listed below:

Westinghouse Electric and General Electric are designing the utility-scale system and Asea Brown Boveri is focused on continued turbine concept development activities. All three developers are also continuing tests to prove the required technology.

Ninety two universities, under the direction of the South Carolina Energy and Research Development Center (SCERDC), have been actively involved in applied research in ATS-related technology areas.

Oak Ridge National Laboratories (ORNL) directs subcontractors to develop and demonstrate ATS related manufacturing technologies. The Office of Fossil Energy is supporting the Materials and Manufacturing element of the ORNL activity and the Office of Energy Efficiency and Renewable Energy is supporting the Thermal Barrier Coating element.

The Federal Energy Technology Center (Morgantown) is conducting applied and fundamental research relative to gas turbine technology, as well as providing support cycle studies and proposal evaluations by modeling innovative power cycles.

Expected Benefits

Advanced gas turbines will provide the capability of generating electric power at efficiencies of over 60 percent and with NOx emissions of well below 9 ppm, allowing them to be sited even in environmentally restricted areas such as California. These public benefits would be derived with actually a reduction in the cost of electricity. Under the deregulated electric power market, the efficiency advantage of the ATS presents opportunities for the merchant plant to be a low cost electricity producer and therefore operate at a high dispatch factor. The fuel cost savings of an ATS compared to the next best technology can be over $2 Million per year. Power generation produces over 1/3 of all greenhouse gas emissions in the United States. Replacing old inefficient power plants with gas-fired ATS combined cycle plants can reduce greenhouse gas emissions by 60 percent. The successful development of ATS can provide the economic benefits of lower cost of electricity and improved return on investment of owners while benefiting our environment with reduced air emissions.

Successful development of these very advanced turbines will assure continuing U.S. leadership in this highly competitive global industry and assure the U.S. of maintaining a large fraction of the international turbine sales with commensurate support of U.S. jobs and a very favorable impact on U.S. balance of payments. The program also benefits hundreds of small companies and universities as subcontractors across the country. The major utility gas turbine developers rely upon and employ numerous small businesses to develop and test the ATS. For example, General Electric, one of the major manufacturers, has its primary facility for the manufacture and assembly of gas turbines in Greenville S.C. and Charlotte N.C., while a number of vendor facilities across the U.S. are utilized to fabricate advanced design components. Both GE and Westinghouse employ up to 35,000 total U.S. employees related to power generation technologies. The program generates U.S. jobs to maintain U.S. leadership in the world turbine industry. In addition to direct GE employment, indirect employment by suppliers of heavy industry parts to GE's turbine systems is estimated at between 3,000 to 3,700. More than 90 percent of the manufacturing value of GE gas turbines and generators are of U.S. origin. Westinghouse employes a comparable level of U.S. suppliers for their ATS system.

Under the technology base program, a profound impact has been made on the U.S. university engineering capabilities. Currently there are 92 universities participating in this program, each proposing and performing research which is of high quality and directly relevant to the ATS technology. The SCERDC program will not only develop improved university capability, but will support the maintenance of that capability for years to come as well as providing for sustained education in science and technology. FETC and National Laboratory scientists are partnering with industries and universities to overcome the critical technical barriers to achieve the ATS program goals. To achieve the aggressive objectives of the ATS program, technology advancements are needed in materials, cooling technology, aerodynamic performance and sealing, heat transfer, and combustion. All these technology advancements are being addressed in the technology base program. Technology already developed under the program is being incorporated into existing turbine products to reduce air emissions and fuel consumption in operating power plants.

Planned Products

FE's ATS Program will develop ultra-high efficiency, environmentally-superior, and cost-competitive gas turbine systems for base-load application in utility and independent power producer markets. These gas turbines will operate at higher turbine inlet temperatures than utility turbines of today. Pictures of the Westinghouse Electric Corporation and the General Electric Company Turbines are shown in Exhibits 11 and 12.

Strategy (FY 98 Funding: $79.6 Million)

The ATS Program is being completed under an extension of Phase III(R). This is based on the need to increase chances of market entry success, while balancing risk management with funding availability. Phase IIIR will develop and complete full-scale testing of two ATS products with EE and Westinghouse. These firms will arrange industry-funded pre-commercial demonstrations. This will enable DOE to retain an affordable turbine technology based program for application to Vision 21 coal-based systems, and permit the newly developed gas-based researchers to compete in near-term global markets.

Recent Accomplishments

- Granted awards to 9 universities on the fourth round of awards by South Carolina Energy Research and Development Center on ATS research topics including combustion, heat transfer, and thermal barrier coatings.

Exhibit 11 - General Electric Company Advanced Gas Turbine.

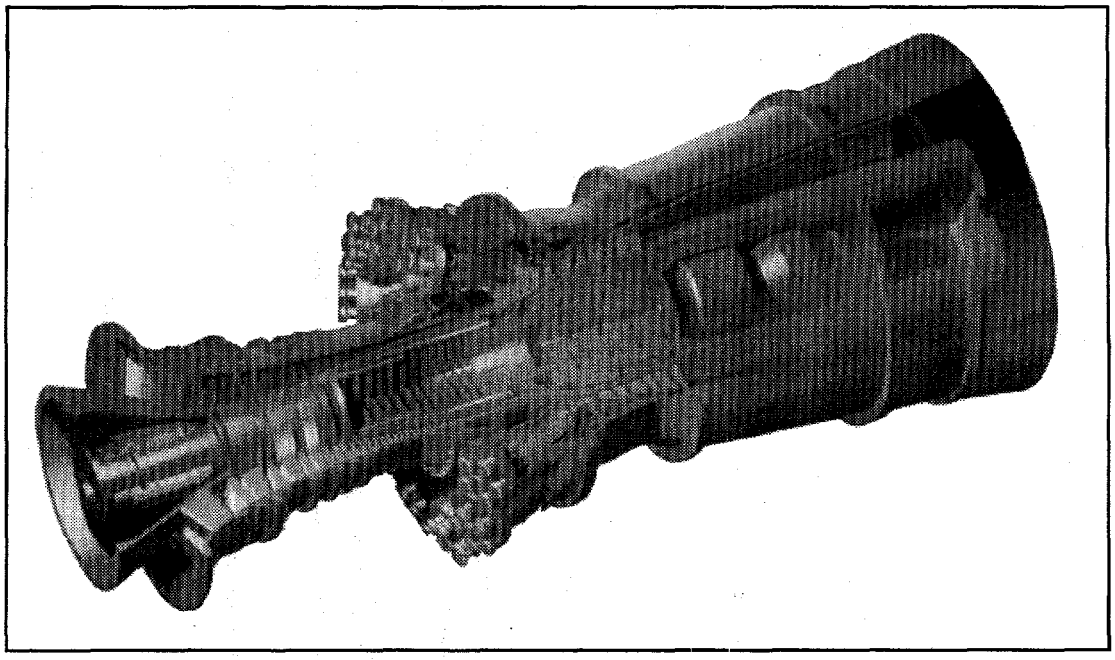
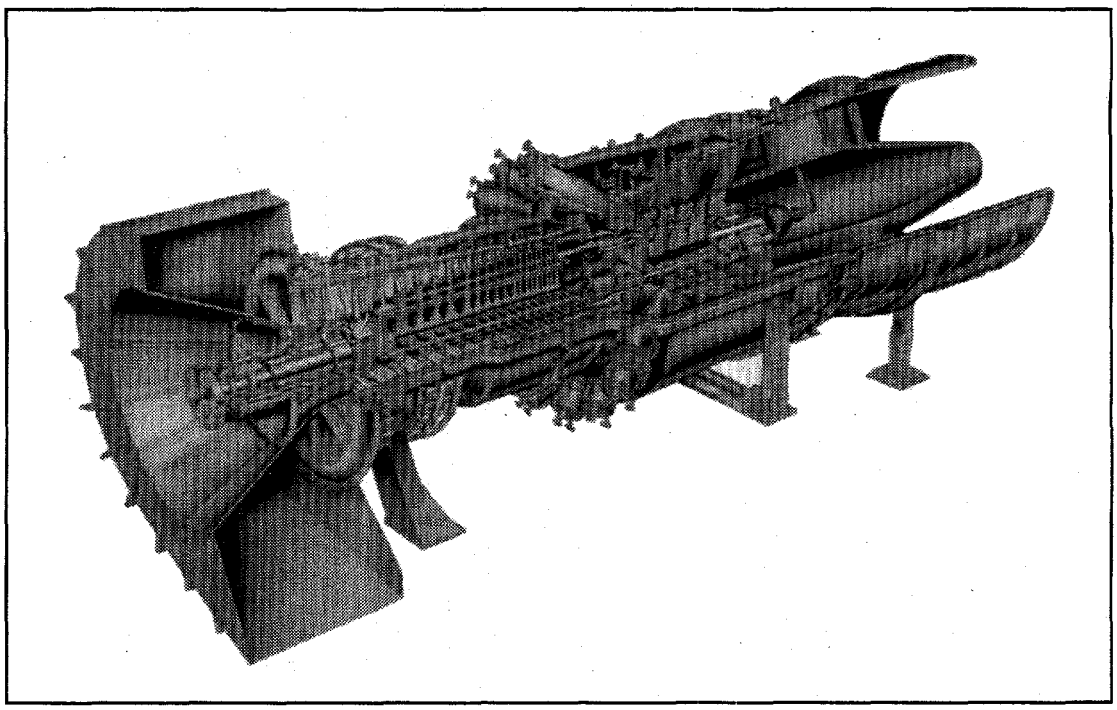


Exhibit 12 - Westinghouse Electric Corporation Advanced Gas Turbine.



- The Federal Energy Technology Center's (Morgantown) Process Engineering Division completed modeling of the cycles selected by the ATS contractors.
- Westinghouse Electric Corporation and General Electric Company completed component design and subscale testing.
- Westinghouse Electric Corporation and General Electric Company initiated cooperative agreement to conduct critical ATS full-scale component and subsystem testing.
- The General Electric Company tested a full-scale Rich-Quench Lean Combustor for coal applications at temperatures up to 2,300 °F. This combustor is designed to permit relatively low NO_x emissions with coal fuels.
- Westinghouse Electric Corporation completed testing of a catalytic combustor designed to produce ultra low NO_x emissions.

Cost Sharing

To ensure maximum efforts, the program will be accomplished by leveraging the funding and resources of all interested parties. Participants will be selected competitively. Overall program cost-sharing is approximately 34 percent.

Program Funding

DOE Historical Spending ($ in Millions)

The FY 99 budget request is based on budget constraints imposed upon all of the Fossil Energy programs.

Program	FY 1996	FY 1997	FY 1998	FY 1999 Request
Fossil Energy	35.97	46.60	45.00	43.00
Energy Efficiency and Renewable Energy	21.60	24.60	34.60	33.00
Total	**57.57**	**71.20**	**79.60**	**76.00**

Schedule

Projects	1996	1997	1998	1999	2000	2001	2002
General Electric Utility ATS (31176)				Complete FSNL Designs; Begin FSNL Testing		Complete FSNL Testing Final Report	
Westinghouse Utility ATS (32267)					Complete FSNL Designs; Complete FSNL Testing		Complete FSNL Testing
FETC In-House R&D			Begin high pressure/fuel flexibility studies and complete flashblock, instability, and humid air combustion studies			Transition into Vision 21	
Manufacturing and Materials (ORNL)			Complete Phase I Materials Development/Initiate Phase 2		Complete Phase 2	Transition into Vision 21 Materials	
University/Industry Consortium (SCERDC)				New Awards	New Awards	Transition into Vision 21	