The U.S. Department of Energy

OFFICE OF FOSSIL ENERGY
OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY
OFFICE OF INDUSTRIAL TECHNOLOGIES

ADVANCED TURBINE SYSTEMS

THE NEXT GENERATION OF GAS TURBINES

By the year 2000, gas turbine systems will deliver the most efficient, environmentally beneficial, and cost-effective electric power generation and cogeneration options ever. These systems will be made possible through the Department of Energy's Advanced Turbine Systems (ATS) program—a cooperative, cost-effective effort with the U.S. gas turbine industry, universities, natural gas companies, and electric power producers. DOE's Office of Fossil Energy and the Office of Energy Efficiency and Renewable Energy's Office of Industrial Technologies (EE/OIT) share responsibility with their industrial partners for developing these revolutionary systems. Advanced turbine systems will outperform all other power systems—converting greater than 60 percent of input energy to useful electricity.

A New Era of Energy Efficiency Is Within Reach

Enhancing Our Industrial Competitiveness

DOE estimates that advanced technology could provide national fuel savings of about 1 trillion cubic feet of natural gas annually by the year 2020. These fuel savings will lower energy costs to consumers and enhance the global competitiveness of American industry.

The U.S. Department of Energy's Advanced Turbine Systems (ATS) program is helping U.S. manufacturers to remove the technical barriers to achieving significant advances in gas turbine technol-ogy. The program provides the government/industry partnership needed to deliver efficient, cost-effective power generation systems while maintaining U.S. supremacy in the highly competitive international gas turbine market.

Advanced gas turbines are the preferred solution for domestic and international market electricity demand. The increased demand for electricity in the United States is projected to be approximately 80 gigawatts over the next decade. A large portion of this increased demand will be met by advanced gas turbine systems.

Manufacturers' projections suggest that greater than 70 percent of all new power generation equipment installed in the U.S. after 2000 will be derived from the ATS program. This represents a domestic market as large as $5 billion per year after the year 2000.

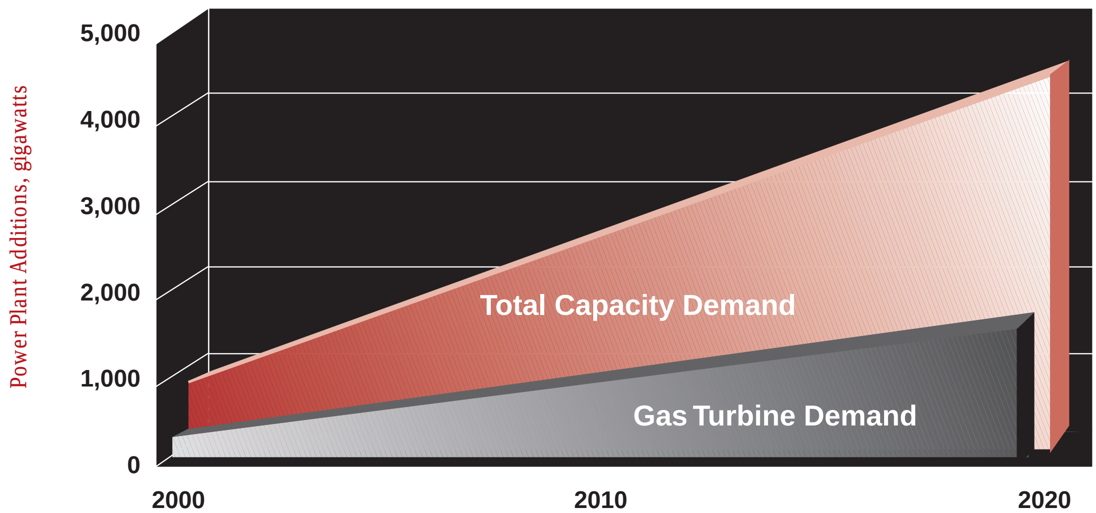
The total world market for electric power generation could exceed 1000 gigawatts between now and 2010. This tremendous growth in electric energy demand is estimated to provide an advanced turbine systems market exceeding $1 trillion.

More Exports Mean More Jobs for Americans

Currently U.S. turbine manufacturers annually export more than $3 billion worth of power generation systems. Maintaining the U.S. technological lead in gas turbines will provide for increased exports and enhance our industrial competitiveness.

The U.S. Department of Commerce estimates that every $1 billion of exports equates directly to 20,000 jobs. More than 60,000 jobs can be accredited to U.S. turbine manufacturers through the export of power generation systems.

Global Market Potential for Gas Turbine Power Generation



Cumulative Capacity Additions of Power Plants since 1992

A New Era of Power Generation Is Within Reach

There is a growing national need for increased electricity and reduced emissions from electric power generating plants. The ATS program's objective is to develop ultra-high-efficiency gas turbine systems for utilities, independent power producers, and industrial markets.

What Is a Gas Turbine?

A gas turbine is a heat engine that uses a high-temperature, high-pressure gas as the working fluid. Part of the heat supplied by the gas is converted directly into the mechanical work of rotation. In most cases, the hot gases for operating a gas turbine are obtained by the combustion of a fuel in air, which is why gas turbines are often referred to as "combustion" turbines.

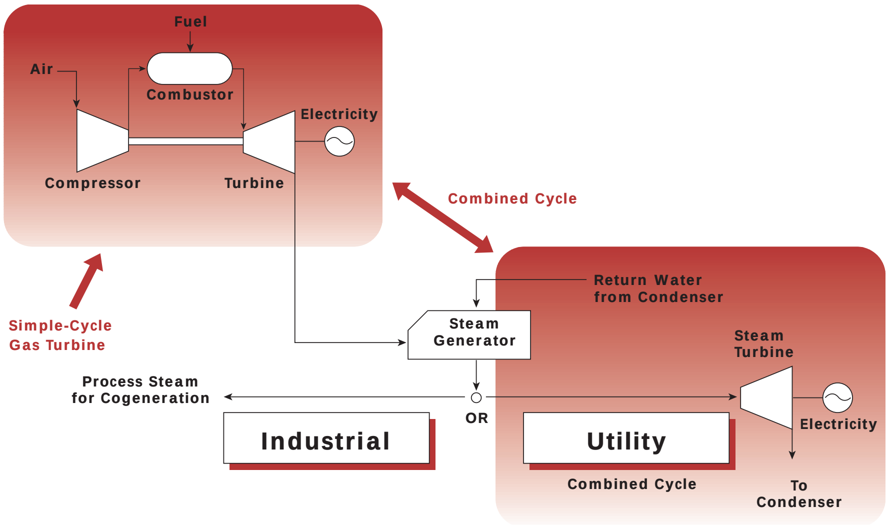
Because they are compact, lightweight, and simple to operate, gas turbines have found many applications, notably in jet aircraft and in electricity generation. Gas turbines are used in industrial and utility settings to produce electricity and steam. (Many industrial processes require steam in addition to electricity.) In such cases, "simple cycle" gas turbines convert a portion of input energy to electricity and use the remaining energy to produce steam in a steam generator. For utility applications, which require maximum electric power, a "combined cycle" steam turbine is added to convert steam to electricity.

Poised for a Major Breakthrough

Manufacturers have achieved dramatic advances in gas turbine efficiency since introducing the systems more than 40 years ago. The historical incremental improvements in turbine technology are reaching the limits of current materials, however. The reason? The thermal efficiency of a gas turbine depends on the temperature of the gas entering the turbine blading. In theory, this temperature should be as high
as possible, but in practice it is limited by potential heat damage to the turbine blades. To achieve the very high gas temperatures needed for optimal thermal efficiency, researchers will have to come up with new materials or cost-effective ways to cool the blades.

By pursuing materials science advances, integral thermodynamic changes, base technology research, and system development, the ATS program is poised to address these limitations and make unprecedented breakthroughs in gas turbine efficiency.

Advanced Turbine System



Breaking Efficiency

Tomorrow's industrial turbine systems for distributed power generation will be 15 percent more efficient.

Today's industrial and utility gas turbine systems have benefited from incremental changes in existing designs—near-term improvements the turbine manufacturers are paying for themselves. By sharing the cost of high-risk research and development with DOE, the ATS program is striving for revolutionary, yet achievable, advances:

- Industrial turbine systems for distributed power generation will show a 15 percent improvement over today's best gas turbine systems. (Distributed power generation involves siting the turbine system close to where the power is needed.)
- Utility systems, the large central power plants that provide electricity to cities, will actually break the 60 percent barrier in net thermal efficiency—long regarded as the "four-minute mile" of the power generation industry.

These systems will also operate at costs 10 percent lower than those of conventional power systems, and reduce nitrogen oxides, carbon dioxide, carbon monoxide, and unburned hydrocarbons.

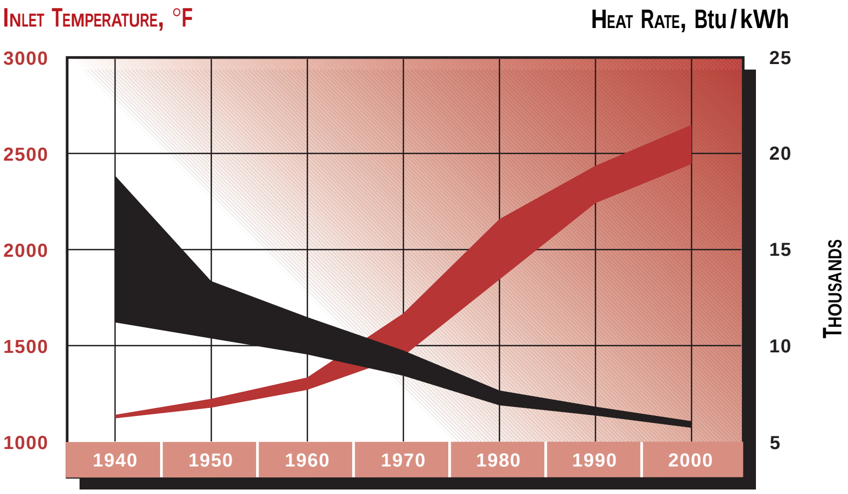
Although the ATS program will demonstrate performance with natural gas fuel, advanced turbine system designs will make use of fuels other than natural gas, such as abundant coal and renewable biomass. Designing advanced turbine systems for fuel flexibility will not only expand market opportunities, but also minimize the economic impact if natural gas prices increase.

Higher Efficiency Means a Cleaner Environment

Advanced turbine systems deliver superior environmental performance. Because of their high efficiency, ATS systems will emit less CO_2 than other competing fossil-fueled technologies, thus providing an alternative for meeting future electrical energy demands while minimizing their contribution to global warming. The high efficiency of ATS will provide fuel savings of more than 1 trillion cubic feet of natural gas annually by the year 2020.

Increases in Gas Turbine Firing Temperatures and Efficiency

Since 1940, manufacturers have dramatically improved gas turbine efficiency by achieving ever-higher firing temperatures.



ATS Program

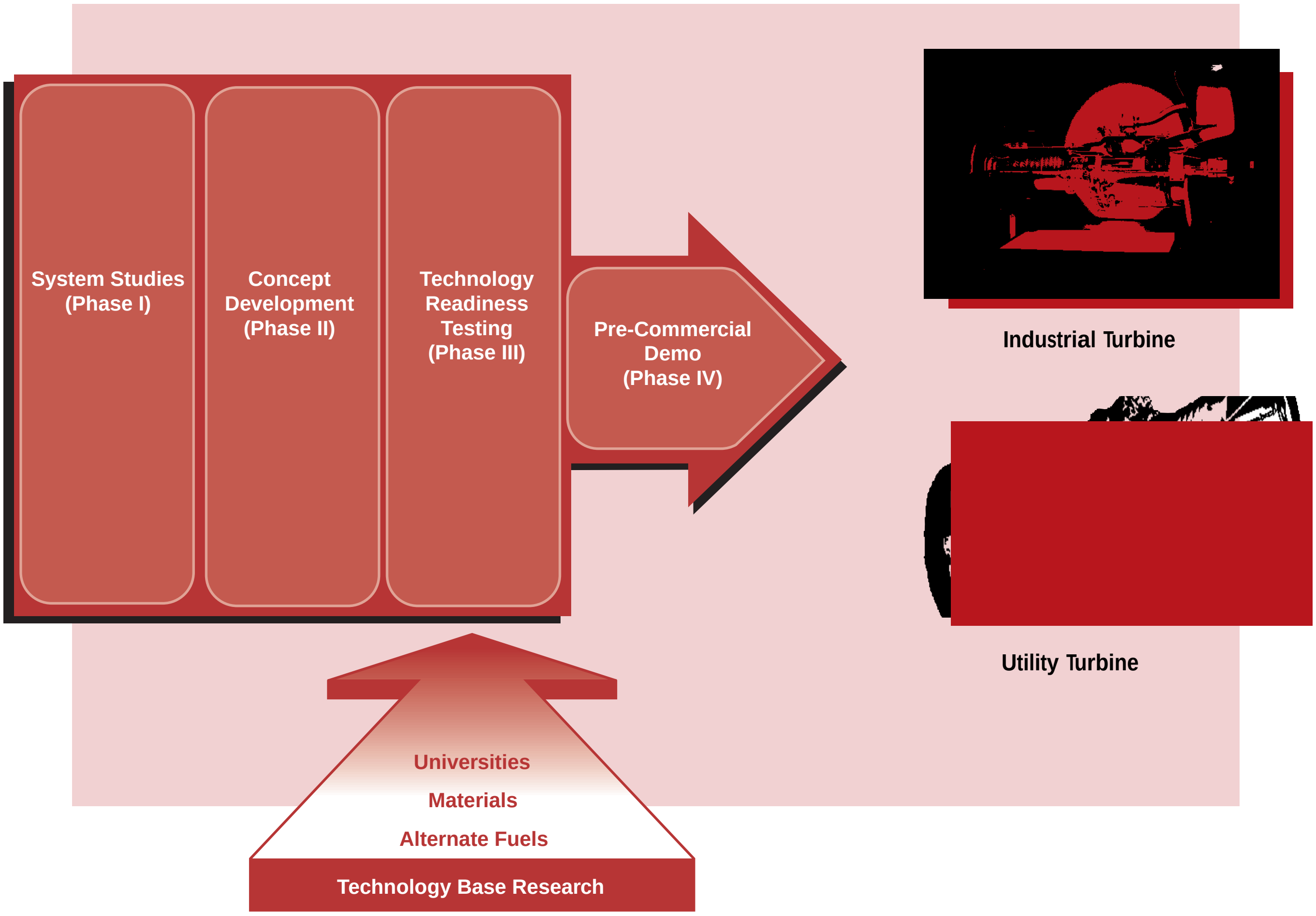
System Studies for Program Definition (Phase I):
During this phase, six gas turbine manufacturers (General Electric, Westinghouse, Asea Brown Boveri, United Technologies, Solar Turbines, and Allison Engine Company) performed studies to identify incentives and define technical issues and resource requirements for developing natural-gas-fired advanced turbine systems.

Concept Development (Phase II):
Five gas turbine manufacturers (General Electric, Westinghouse, Asea Brown Boveri, Solar Turbines, and Allison Engine Company) were selected to design and test critical concepts and components for their proposed ATS systems.

Technology Readiness Testing (Phase III):
Four gas turbine manufacturers (General Electric, Westinghouse, Solar Turbines, and Allison Engine Company) have been selected to bring their ATS concepts to the point of pre-commercial testing. Detailed designs and turbine engine specifications for component manufacturing and assembly will be developed.

Pre-Commercial Demonstration (Phase IV):
A pre-commercial demonstration of a full-scale utility and industrial ATS system will be conducted.

The Four Phases of the ATS Program



Advanced Gas Turbine Sys- tems for the Utility Market

Both General Electric and

Westinghouse, the two utility developers participating in the ATS program, have selected a closed-loop steam cooling system for their advanced combined cycle. This innovative combined cycle will achieve program goals of high efficiency, single-digit nitrogen oxide (NOx) levels, and a 10
percent reduction in the cost of electricity. The integration of an advanced gas turbine with a steam cooling system increases
net thermal performance to the 60 percent level. With the closed-loop steam cooling system, although the operating temperature of the gas turbine is increased, single-digit NOx levels are maintained.

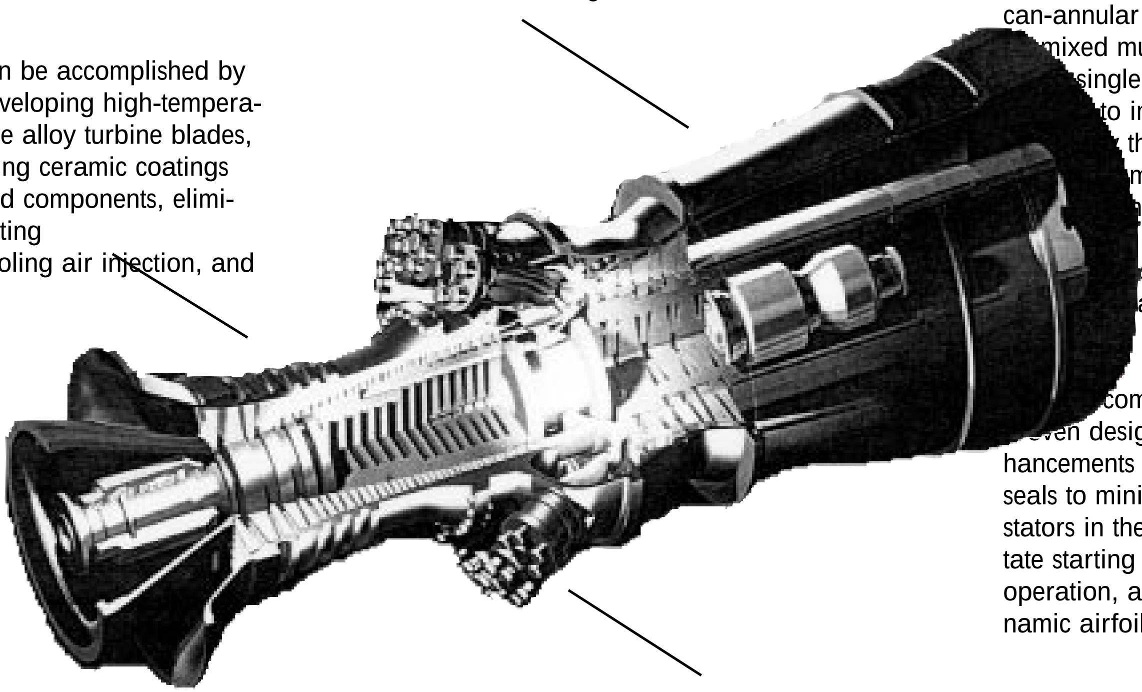
The emerging General Electric and Westinghouse utility ATS designs share the following features:

Combustion System

The dry combustion system has can-annular combustors of lean ...mixed multi-stage design, result- ...single-digit NOx generation. ...to improve performance ... this new design include ...mbustion to reduce ...ating cooling air injec- ... turbine path, and ...steam cooling of the ...and transitions.

...compressor is based on ...en design, with addi-tional enhancements such as advanced seals to minimize leakage, variable stators in the front stages to facilitate starting and part-load operation, and advanced aerodynamic airfoil design.

THE-UTILITY-ADVANCED-TURBINE-SYSTEM



can be accomplished by developing high-temperature alloy turbine blades, using ceramic coatings and components, eliminating
cooling air injection, and

Gas Turbine

To achieve the desired ATS performance objectives, the turbine must be capable of handling inlet temperatures 2600°F or higher. This

Industrial Advanced Turbine Systems for Efficient Cogeneration

ATS cogeneration applications will obtain efficiencies of over 80 percent—

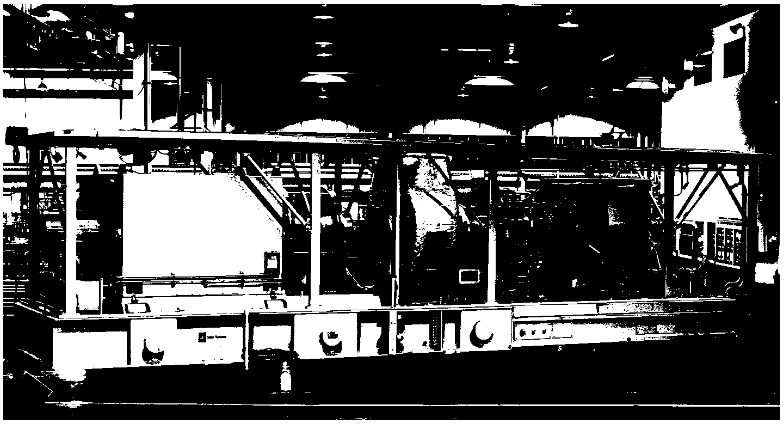
Cogeneration is the concurrent production of two forms of energy from the same source. Gas turbines in the 1- to 20-MW range have promising applications in the industrial sector for cost-effective, environmentally beneficial cogeneration. The seven process industries targeted under OIT's Industries of the Future program (aluminum, chemicals, forest products, glass, metalcasting, petroleum refining, and steel) purchase approximately $16 billion of electricity annually, and the chemicals, forest products, and refining industries in particular show significant potential for cogeneration.

Typically cogeneration uses a gas turbine to first produce electricity, and then uses the heat in the exhaust gas to produce steam. The exhaust gas can also be used for drying or curing. ATS cogeneration applications will obtain efficiencies over 80 percent—the highest efficiency technology available. In addition, they will have the lowest environmental signatures in the world. Because the fuel is burned only once, the emission of NOx and greenhouse gases is greatly reduced. Projected emissions reduction represents five percent of the total emissions from all electric generation sources in the U.S.

Industrial gas turbines are also used in base-load power generation, peak shaving, and distributed power generation. In the latter application, utilities can use small turbines to serve remote customers, avoid costly power grid upgrades, improve power quality, and defer the need for central power plants. An estimated 2000 MW per year of new generation will be in the form of distributed generation.

Industrial gas turbines are also applied to mechanical drive uses in the 1000 to 25,000 horsepower (hp) range. One of the largest applications of turbine mechanical drive is in natural gas compressor stations. This market is projected to grow by 500 million hp between 2000-2010 as the Nation's gas pipeline capacity expands.

Typical Industrial Gas Turbine Installation



Technology Base Research

The ATS program includes technology base activities to support the development effort. Research on barrier issues facing the turbine manufacturers is conducted by a host of organizations, providing a foundation of applied research beneficial to these manufacturers.

Advanced Gas Turbine Systems Research

Critical basic research and development needed to support the ATS program is performed by an industry-university consortium established by DOE's Office of Fossil Energy and the South Carolina Energy Research and Development Center.

Industrial cosponsors identify critical technology needs and evaluate proposals prepared by the university participants. Six turbine manufacturers and 83 universities have joined the consortium. Thirty-two university research projects selected by the industrial members are under way, each focusing on obstacles applicable to the entire industry, and for which university research is most appropriate.

Topic Areas Include:

- Advanced combustion systems to minimize pollution
- Heat transfer and aerodynamics to improve turbine blade life and performance
- Materials to permit higher operating temperatures for more efficient systems

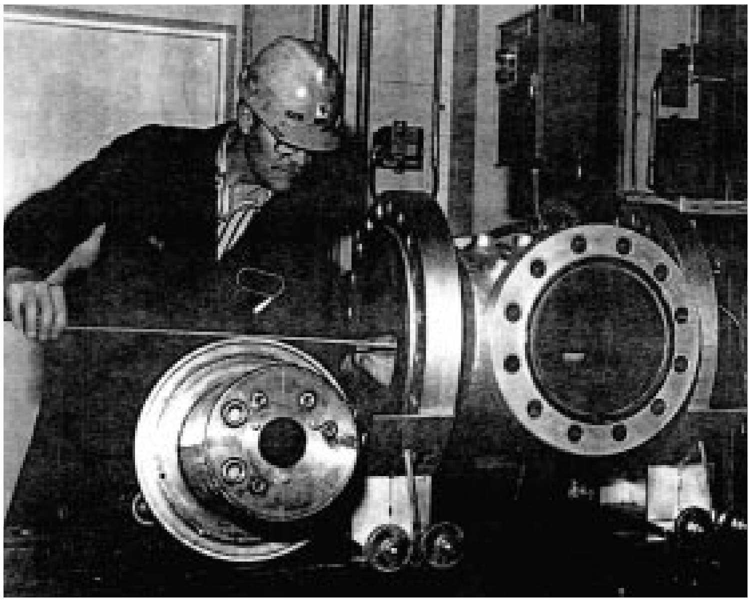
Federal Energy Technology Center (FETC)

FETC, a part of DOE's Office of Fossil Energy, has offices in Morgantown, WV and Pittsburgh, PA. FETC's scientists and engineers are participating directly in the research activities of the ATS program. For example, some university experiments have been brought to FETC for testing at larger scales and higher pressures than can be achieved in most university laboratories. Also, FETC is working directly with industrial partners to help solve practical problems and test new technologies.

A new gas turbine combustion research facility has recently been built at FETC–Morgantown, with multiple test cells capable of operating at elevated pressures, firing rates up to 3 megawatts thermal (10^7 Btu/hr), and with an air preheater and a variety of advanced combustion diagnostics.

Key areas of research currently include the control of combustion instabilities, testing of novel low-NOx combustor designs, investigation of the chemical kinetics of pollutant formation, and development of advanced diagnostics for measuring heat transfer rates, flow velocities, and pollutant concentrations during turbine component testing. Future research may include investigations of catalytic combustion, low-heating-value gas combustion, combustion effects in advanced turbine cycles, and

FETC supports the industry-university consortium by serving as a bridge between academic-scale research and industrial-scale development.



other topics.

Materials and Manufacturing

A materials/manufacturing plan was developed in 1994 with input from gas turbine manufacturers, materials suppliers, universities, and government laboratories. Major projects are currently under way for coatings and process development, scale-up of single crystal airfoil manufacturing, materials characterization, and technology information exchange.

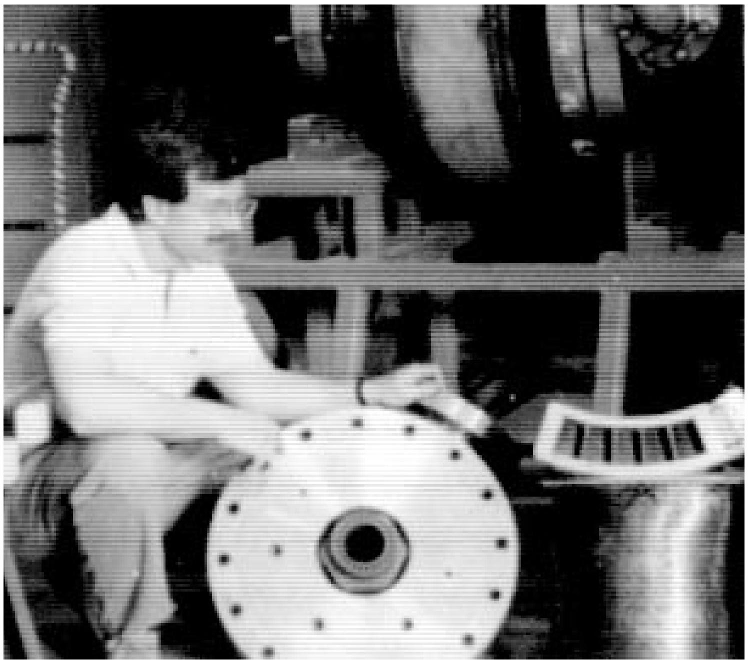
This element of the ATS program is directed by the Department of Energy's Oak Ridge National Laboratory. The work is being conducted through a partnership among industry, universities, and National Laboratories. These projects are accelerating the introduction of new materials and components in land-based gas turbines.

Coal and Biomass Applications

Coal represents 94 percent of proven U.S. fossil fuel reserves, but burning coal to generate energy produces harmful emissions. It is in the Nation's interest to maximize the use of this abundant resource while minimizing its harmful impact on the environment.

Gas turbine improvements being developed for coal and biomass applications include rich-quench-lean combustors that reduce NOx emissions, hot gas scrolling between the combustor and the turbine expander, combustors that accept gas with a range of compositions and heating values, and techniques to extract air from the compressor discharge with minimum pressure loss.

Collaborative projects among industry, universities, and National Laboratories are accelerating the introduction of new materials and components in land-based gas turbines.



Researchers evaluate options for adapting natural-gas-fueled advanced turbine systems to coal- and biomass-fueled systems.

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