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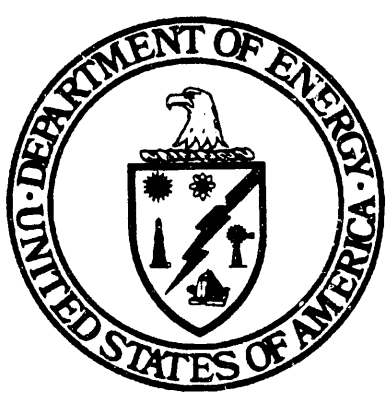
Report to Congress
COMPREHENSIVE PROGRAM PLAN FOR ADVANCED TURBINE SYSTEMS



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SECTION 1 - EXECUTIVE SUMMARY

Consistent with the Department of Energy (DOE) mission, the Advanced Turbine Systems (ATS) Program will develop more efficient gas turbine systems for both utility and industrial electric power generation (including cogeneration). The Program will develop base-load power systems for commercial offering in the year 2000. Although the target fuel is natural gas, the ATS will be adaptable to coal and biomass firing. All ATS will exhibit these characteristics:

- Ultra-high efficiency [utility systems: 60 percent (lower heating value basis); industrial systems: 15 percent improvement over today's best gas turbine systems],

- Environmental superiority [reduced nitrogen oxides (NOx), carbon dioxide (CO_2), carbon monoxide (CO), and unburned hydrocarbons (UHC)], and

- Cost competitiveness [10 percent lower cost of electricity].

This Program Plan was requested in the House, Senate, and Conference Reports on the FY 1993 Interior and Related Agencies Appropriations Act, Public Law 102-381, and is consistent with the Energy Policy Act of 1992, which (in Section 2112) identifies work for improving gas turbines. This plan outlines the 8-year ATS Program and discusses rationale and planning. Total Program costs are estimated to be $700 million, consisting of an approximate $450 million government share and an approximate $250 million cost-share by industrial participants.

DOE's Offices of Fossil Energy (FE) and Energy Efficiency and Renewable Energy (EE) [formerly the Office of Conservation and Renewable Energy (CE)] are jointly responsible for the ATS Program. Management of the Program is coordinated with the Environmental Protection Agency (EPA), the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), gas turbine manufacturers, the Department of Defense (DOD), and others.

Gas turbines in industrial and utility applications can help meet future National and worldwide power generation requirements. Turbine systems burning natural gas offer environmentally sound and economical power generation and cogeneration. Since United States demand alone will require up to 15 gigawatts (GW) per year of new and replacement capacity after the year 2000, the availability of ATS to fill a share of this need will save significant amounts of fuel and benefit the environment. Implementation of the ATS Program will also keep U.S. manufacturers on the cutting edge of turbine technology for power generation applications and enhance the nation's economic competitiveness.

The basic Program strategy is to fund teams led by U.S. turbine manufacturers to develop ATS from concept and component development to full-scale prototype demonstrations. Major contracts will be competitively awarded, with new competitions at the completion of key development stages. These will allow re-evaluation of concepts and competitive reduction of the number of systems being developed. Only one utility-scale system and one industrial-scale system will be demonstrated with Federal Government support.

In parallel with the major contracts, generic research and development (R&D) will address key technical issues, and technology will be transferred between this and other programs.

The ATS Program has four elements:

- Innovative Cycle Development will lead to concept definition for integrated systems meeting ATS goals. EE will develop the industrial-scale systems. FE will develop the utility-scale systems.

- Utility System Development and Demonstration will consist of component design and testing, integrated sub-system testing, and full system demonstration of a utility system. Private sector participants will be selected via competitive procurement.

- Industrial System Development and Demonstration will consist of a 4,000-hour ceramic retrofit engine test program and an advanced cycle industrial-scale system demonstration. Private sector participants will be selected via competitive procurement.

- Technology Base Development will support the overall Program. A university/industry consortium will provide cross-cutting technology support. Other activity includes advanced materials support, METC in-house combustion studies, and technology transfer to coal and biomass applications.

Planning and initial implementation of the ATS Program has progressed significantly:

- Planning activities began with two workshops,[1,2] one of several mechanisms for input to the Program from industry. In these and other forums,[3,4] strong industrial support was voiced for the Program.

- DOE's FE and EE have cooperated in planning the Program. Their Assistant Secretaries have signed a Memorandum of Agreement (included in the Appendix) outlining further cooperation in a joint Program to achieve ATS goals.

- In an existing program which will be included in the ATS Program, EE awarded a contract to Solar Turbines to develop and demonstrate an advanced ceramic retrofit engine for the industrial market.

- The South Carolina Energy Research and Development Center (SCERDC) at Clemson University was awarded a cooperative agreement by FE. This agreement will support an industry/university consortium to conduct technology base R&D for the ATS Program. An industrial advisory board will guide the consortium which has significant support from industry.

- Six U.S. turbine manufacturers have performed preliminary system studies of ATS. In interim letter reports, they confirmed their desire to participate in the Program and supported Program goals. They identified the systems they want to develop and estimated development and demonstration costs. These estimates were used to work up total Program costs.

- FE released a solicitation on August 28, 1992, to start the next phase of Innovative Cycle Development. Four awards are expected in July, 1993, with a total value of about $10 million.

SECTION 2 - INTRODUCTION

Clean, affordable, and reliable natural gas technologies will play a growing role in meeting future power generation needs in the United States. The DOE projects that total consumption of natural gas will rise from 18.8 trillion cubic feet (tcf) in 1990 to as much as 23.5 tcf by the year 2000.[5] Generation of electric power from natural gas is expected to account for much of this increase in demand.

This report presents an exciting program, called the ATS Program, which will assure that advanced power systems burning natural gas will be available to meet the country's needs. The ATS Program will marshal the resources of gas turbine manufacturers, the electric utility industry, and the university community, as well as government and private sector R&D sponsors and laboratories.

The Past....

Since manufacturers introduced gas turbines commercially more than 40 years ago, they have steadily improved turbine efficiency and have reduced emissions. Over the same period, they have improved reliability, availability, and maintainability (RAM). Many of the turbine improvements for the commercial sector resulted from technology developed through military R&D programs. Direct government funding for civilian sector turbine development was minimal.

The Present....

Now, gas turbine manufacturers are developing an improved class of turbines scheduled for commercialization in the next few years. These improvements result from incremental changes in existing designs. The turbine manufacturers themselves are paying for development costs for these near-term improvements.

This near-term class of turbine systems will have higher efficiencies and lower emissions, with efficiencies in the mid-50 percent range for large natural-gas-fired combined-cycle systems. Smaller turbine systems for the industrial market will show more modest efficiency improvements. Both the utility and industrial systems will feature dry, low-NOx combustion systems, with manufacturers guaranteeing NOx levels to 25 ppm or lower with use of natural gas fuel.

The Future.....

Further improvements in gas turbine efficiency are both possible and desirable. To reach the achievable goal of 60 percent efficiency, however, materials science advances and integral thermodynamic cycle changes will be required, and a significant amount of technology base research and system/component development will, therefore, be necessary. Due to technical/economic risks involved, private industry is not expected

to pursue this ultra-high efficiency goal without risk sharing in the form of a government/industry cost-sharing partnership.

The United States faces major changes in the 1990s in the power generation market for both utilities and industry. Power producers must meet new emission requirements, new capacity needs, and increasing pressure to improve energy efficiency and reduce dependence on conventional coal and oil consumption. Demonstration of new natural gas-fueled technologies is the best way to meet all of these needs.

Actions Taken.....

This Program Plan was requested in the House, Senate, and Conference Reports on the Fiscal Year (FY) 1993 Interior and Related Agencies Appropriations Act, Public Law 102-381. Both DOE and Congress have recognized the need for an ATS Program to develop and prove the next generation of utility and industrial power systems featuring natural gas-fired turbines. As discussed in Section 3.3, DOE included the ATS Program in the draft *Natural Gas Strategic Plan and Multi-Year Program Crosscut Plan, FY 1993-1998*[6] and in the *Clean Coal Research, Development, and Demonstration (RD&D) Program Plan*[7] (still in preparation). In FY 1992 appropriations bills, Congress gave DOE/FE $750 thousand to initiate planning for a cooperative advanced turbine program in concert with DOE/EE, turbine manufacturers, GRI, EPRI, and others. The FY 1993 budget appropriation includes $10 million and the FY 1994 budget request is $24 million for DOE/FE activities. For DOE/EE, $2.2 million was appropriated in FY 1992 and $3.0 million in FY 1993 for ceramic retrofit engine development and materials base research. In FY 1994, the DOE/EE budget request is $8.3 million.

SECTION 3 - NATIONAL NEEDS

3.1 National Energy Needs

President Clinton has stated in a recent presentation to Congress[8] that his administration will "...launch initiatives to develop new, clean, renewable energy sources that cost less and preserve the environment. We will also encourage energy efficiency and conservation..." This presentation reinforces the DOE mission as it pertains to the ATS Program. Overall DOE goals include increasing energy efficiency, securing future energy supplies, respecting the environment, and building a technical knowledge base that will enhance U.S. competitiveness in the global market. Implementation of the ATS Program supports these goals; technologies developed under the ATS Program will be advanced ultra-high efficiency, environmentally superior energy producing systems that will have definite cost advantages over systems they replace.

Specifically, development of ATS will offer:

- Improved energy efficiency and fuel flexibility in both the central power and industrial market sectors.
- Significantly improved environmental performance.
- Opportunities for conversion to coal or renewable energy, and technology transfer to coal and renewable energy systems.
- Accommodation of need for increased electrical generation while reducing use of oil.
- Reduction in the costs of electric power.
- Increased competitiveness of U.S. industry (both equipment suppliers and electricity users).

The introduction of ATS by the year 2000 will significantly reduce U.S. fuel consumption. A potential national fuel savings of about one quadrillion Btus (i.e., one quad) annually by 2020, compared to using today's best gas turbine technology, assumes:

- An efficiency increase from 52 to 60 percent [heat rate improvement from 6,560 BTU/kwh to 5,680 BTU/kwh (LHV)].
- An overall market of approximately 15 GW/year.
- An average operating time of 7,000 hours/year.
- That the ATS will achieve 50 percent market share.

If compared to the average efficiency of all industrial and utility plants currently operating in 1992 (around 34 percent) rather than today's best systems, the revised potential fuel savings for this market is about 4 quads/year.

The ATS Program will reduce overall emissions from power plants. Although there will be some reduction in CO and UHC, reduction of NOx (to ninety percent of today's lowest levels) will be the most important achievement. Turbines fired with natural gas produce negligible amounts of sulfur dioxide, and CO_2 emissions will be reduced by the high efficiency of ATS.

3.2 Energy Policy Act of 1992

The Energy Policy Act of 1992 provided comprehensive legislation affecting all aspects of the energy sector of the U.S. economy. Section 2112 of this Act calls for "...a 5-year program...to improve the efficiency of heat engines." Such program shall...

(1) include field demonstrations of sufficient scale and number so as to demonstrate technical and economic feasibility;

(2) incorporate materials that increase engine efficiency and improve equipment performance; and

(3) cover advanced engine designs for electric and industrial power generation for a range of small-, mid-, and large-scale applications...."

The Act also specifies particular technical approaches to improve the performance of gas turbine systems with a goal of "...over 50 percent efficiency in the mid-term."

The ATS Program will satisfy the intent of this legislation. The ATS Program is a 8-year program, rather than five, and the efficiency goals are more ambitious than the 50 percent minimum required. However, during the eight years, intermediate technology will likely be commercialized by both utility and industrial turbine manufacturers. In particular, the ceramics retrofit portion will lead to an early 4,000-hour test, incorporating advanced materials into turbines at an early stage of the Program.

Many, but not all, of the specified technical approaches to improve turbine performance will likely be employed in the Program. Technical approaches, however, will depend on DOE evaluation of offers in response to competitive solicitation.

The Act requires that, within one year of its passage, proposals be solicited for conducting activities. The ATS Program has already met this requirement with the solicitation of concept development proposals, as discussed in later sections.

3.3 Natural Gas Strategic Plan

Consistent with the Energy Policy Act of 1992, the mission statement in the draft *Natural Gas Strategic Plan*[6] calls for reducing oil use in the United States and for diversifying the technology choices to produce electric power. The plan states that the new gas strategy emphasizes utilization and delivery/storage, and calls on both FE and EE to continue their advanced gas turbine technology development. Specific strategies in the Utilization Area of the Plan explicitly include the major elements of the ATS Program:

- Development of ultra-high efficiency, environmentally superior, cost-competitive gas turbine systems for utility and industrial applications.
- Development of dry, low-NOx combustors.
- Basic R&D to improve the performance of gas turbines.
- Development of ceramic technology for high temperature turbines.

The ATS Program and the ceramic retrofit stationary engine program are included in the associated *Multi-Year Program Crosscut Plan*[6] as key elements in the Utilization Area of the Natural Gas Program.

3.4 Clean Coal RD&D Program Plan

The Clean Coal Program supports DOE goals for coal, including maintaining coal's competitiveness while meeting environmental, health, and safety requirements. The *Clean Coal RD&D Program Plan*[7] (still in preparation) includes a key strategic goal to demonstrate advanced coal technologies by 2010 with efficiencies of at least 55 percent. These systems are to have emissions less than one-tenth of today's New Source Performance Standards.

Advanced cycles using gas turbines generally have higher efficiency than those with only steam turbines. Consequently, high efficiency coal systems being developed by DOE (except fuel cell, diesel, and magnetohydrodynamic systems) include gas turbines:

- Integrated Gasification Combined Cycle (IGCC)
- Advanced Pressurized Fluidized Bed Combustion (APFBC)
- Indirectly Fired Cycle (IFC)
- Direct Coal-Fired Gas Turbines (DCFGT).

However, even these systems will not be able to meet the goal efficiency level without advanced turbine technology. Technology (such as high-temperature turbines or advanced materials) must be transferred from the ATS program to the coal programs if full potentials from these systems are to be achieved. The "Coal Applications" subelement of the ATS Program is intended to serve this need.

Through the ATS program, new high efficiency systems with possibilities for coal application will be identified. Although the major systems portion of the Program will not include development or testing of coal applications components, systems studies will address the potential for converting the systems to coal firing.

3.5 Markets

Over 7 GW per year of gas turbine capacity is manufactured today in the United States, an amount which is rapidly growing. This translates into over $1.8 billion for turbines alone, and balance-of-plant costs roughly double this number. Figure 1, taken from the previously proposed Natural Energy Strategy (NES),[9] shows twelve projections for United States demand for electricity through 2030. Combined with capacity projections in the Energy Information Administration's *Annual Energy Outlook 1993*,[5] the increased demand for electricity suggests a market of up to 15 GW per year for new power equipment after the year 2000, for the High Economic Growth Case. Currently, over 50 percent of new capacity installed is gas turbine systems. Predictions for natural gas availability and price are favorable, the emissions benefits of natural gas firing will likely become even more important, and the costs of these systems will remain attractive.

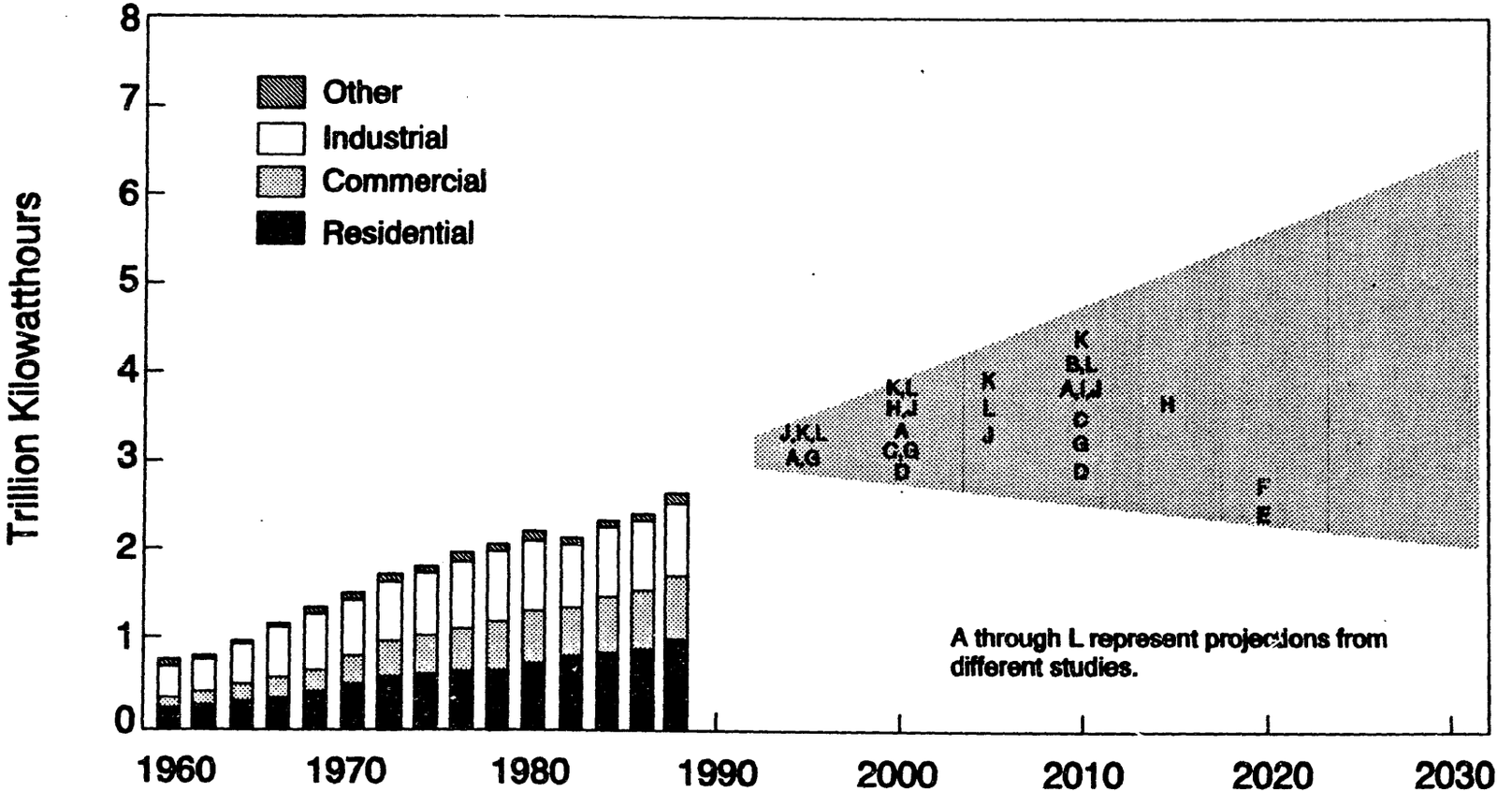
Keeping United States turbine manufacturers on the forefront of power system technology will enable them to increase their already substantial exports to a rapidly growing world market. A recent study by Argonne National Laboratory (ANL) indicated a strong influence of heat engines sales on the total United States GNP, depending on whether the heat engines are manufactured here or abroad.[10]

Gas turbines must do several things to be commercially acceptable:

- Must continue to exhibit RAM at least equal to current machines.
- Must result in lower cost of electricity than competing systems.
- Must meet ever more stringent emission requirements.
- Must meet existing codes and standards.
- Must be as efficient as possible.

The ATS Program addresses these requirements.

Figure 1. Projections of U.S. Demand for Electricity



SECTION 4 - PROGRAM OBJECTIVES

The objective of the ATS Program is to develop ultra-high efficiency, environmentally-superior, and cost-competitive gas turbine systems for base-load application in utility, independent power producer (IPP), and industrial markets. Specific performance targets have been set using natural gas as the primary fuel:

- System efficiency that will exceed 60 percent [lower heating value basis (LHV)] on natural gas for large-scale utility turbine systems, of (for industrial applications) will result in a 15 percent improvement in heat rate compared to currently available gas turbine systems.

- An environmentally superior system that will not require use of post-combustion emissions controls under full-load operating conditions.

- Busbar energy costs that are 10 percent less than current state-of-the-art turbine systems, while meeting the same environmental requirements.

- Fuel-flexible designs that will operate on natural gas but are also capable of being adapted to operate on coal, coal-derived, or biomass fuels.

- RAM that is equivalent to the current advanced turbine systems.

- Water consumption minimized to levels consistent with cost and efficiency goals.

- Commercial systems that will enter the market in the year 2000.

4.1 Ultra-High Efficiency

For large utility-scale power generation applications, ATS efficiencies will be higher than 60 percent (LHV) on natural gas. Industrial-scale power generation systems will improve by at least 15 percent in heat rate (from 29 to at least 34 percent, simple cycle efficiency) over currently available gas turbine systems.

To achieve ultra-high efficiency, significant changes in turbine design are required, particularly in the following two areas:

- Cycle Modifications. Innovative cycles will be needed to achieve efficiency goals, possibly including intercooling, chemical recuperation, massive moisture injection (15 to 50 percent of the turbine air flow), and reheat combustors.

- Higher Firing Temperatures. ATS will need to operate at sustained turbine firing temperatures of more than 250°F above the highest levels used today, possibly at high pressure ratios. Gas turbines are now reaching the practical limits of the

traditional approach for hot gas path cooling (i.e., air extraction). State-of-the-art utility gas turbines presently use firing temperatures of up to 2,350° F, while industrial machines are typically below 2,100° F. This increase in firing temperature is a significant design change because it will require development of new hot gas path hardware.

Section 5.1 discusses approaches to achieving ATS performance goals.

4.2 Environmen al Superiority

- ATS systems will produce 10 percent less NOx [measured as pounds per kilowatt-hour (lb/kW-hr)] than the best current gas turbine systems, when measured at full-load operating conditions without use of selective catalytic reduction (SCR) or other post-combustion emission control processes. [As a reference point, one turbine manufacturer currently offers a 48 percent (LHV) efficient, combined-cycle system that produces 9 parts per million volume (ppm) NOx at 15 percent oxygen.]

- CO and UHC emissions will each be less than 20 ppm. Emissions are measured in lb/kW-hr, using current system efficiencies [approximately 50 percent (LHV)] as reference.

Achieving environmental superiority will also require changes in turbine design, since higher turbine firing temperatures tend to increase NOx. Component development will be needed in a number of areas. One area in particular, combustor design, may require improvements such as hot wall ceramics, catalytic combustion, or staged combustion.

4.3 Reduction in Cost of Power

Gas turbine manufacturers will continue to reduce the costs of systems and of power during the 1990s to remain competitive. Gas turbine prices in constant dollars have continued to decline during the 1980s as improvements were added from DOD developments, although this should diminish as DOD programs are reduced. The ATS Program targets a 10 percent reduction in cost-of-electricity compared to conventional systems meeting the same environmental requirements. This reduction can be achieved through increased power output compared to current designs for the same turbine package, or through elimination of the downstream clean-up equipment.

4.4 Relationship to Coal Applications

While markets will ultimately determine the most economic mix of electric supply resources, coal will continue to play a major role in electric power generation for the foreseeable future. Coal costs less (from an energy content viewpoint) than other fossil fuels, and the United States has an abundant supply — a coal reserve of more than 250

years at current consumption rates. Thus, developing advanced systems that can use coal or a coal-based fuel ensures that the United States will have cost-effective and environmentally sound options for supplying future power generation needs.

Many of the advanced, coal-fueled power generation technologies currently being developed or demonstrated incorporate gas turbines, including IGCC, APFBC, DCFGT, and IFC. Systems where injected moisture can boost both power and efficiency include the Integrated Gasification Humid Air Turbine (IGHAT) and the Water-Augmented Externally-Fired Combined Cycle (EFCC).

The ATS Program will serve the need for attractive coal systems in several ways. Although the major systems portion of the Program targets the demonstration of systems for natural gas firing, studies will address issues related to adaptation of these systems to coal and biomass firing. Also, the technology base and ceramic component portions of the Program will yield technical results that can benefit systems fired with fuels other than natural gas. Last, the "Coal Applications" portion of the Program specifically addresses the transfer of technology developed in the ATS Program to advanced coal-fueled systems.

In the same way that ATS technology can improve coal systems, technology improvements in coal-fired systems can be incorporated into natural gas-fired ATS. Specific turbine improvements currently being developed in the Coal R&D Program include rich-quench-lean combustors to reduce NOx formation, hot gas scrolling between the combustor and the turbine expander, combustors to accept gas with a range of compositions and heating values, and techniques to extract air from the compressor discharge with minimum pressure loss.

4.5 Relationship to Biomass Systems

The DOE mission dictates increased work to develop alternative energy options, including biomass systems. Liquid fuels developed from biomass for power generation represent a viable future option in the energy mix. Like coal systems, biomass systems can incorporate gas turbines in gasification or externally-fired cycles. It is expected that, also like coal, there will be a significant flow of technology between the ATS Program and programs to develop these systems.

4.6 Reliability, Availability, and Maintainability

Gas turbine manufacturers have continuously worked on RAM improvements since first offering power system products. Current systems have very good performance records, often with over 95 percent availability. Any new systems would have to match this service record in commercial practice.

4.7 Water Consumption

Quality and quantity of water is critical to siting and operating power systems. Several potential advanced cycles may use steam or water injection, such as the Humid Air Turbine (HAT) cycle. To remain competitive, one ATS goal is to maintain water consumption levels similar to current systems.

4.8 Commercialization

Successful commercialization of the ATS will require manufacturers to constantly reexamine cost and performance goals throughout development to remain competitive. During the Program, commercialization strategies will be affected by changes in environmental policies, new material processing costs, and other parameters. The ATS goal is to demonstrate the technical performance of turbine-based systems which the market will select as preferred technology.

SECTION 5 - TECHNICAL ISSUES FOR ADVANCED GAS TURBINE SYSTEMS

The most important technical issues for developers of ATS are performance (efficiency and output), emissions abatement, and reliability, availability, and maintainability (RAM). While one of these issues may be more important in a particular application or situation, manufacturers must adequately address all three technical issues successfully to produce a viable ATS.

Operating conditions and equipment specification can be different for turbines in utility and industrial applications. However, the important technical issues are the same for turbines in either application. Therefore, this discussion does not differentiate between industrial and utility applications, except in the use of ceramic blading.

5.1 Performance

- Goal

  The goal for ATS efficiency is 60 percent (LHV basis) for utility systems and a 15 percent improvement for industrial systems.

- Background and Current Status

  Gas turbine manufacturers have recently developed and sold an improved class of turbines. These utility-sized models have high output (over 150 MW) and high efficiency (better than 35 percent) in the simple-cycle mode. These machines work well in combined-cycle operation because of the high exhaust temperature and flow. In combined-cycle utility applications, the systems have shown LHV efficiencies of 53 percent with outputs over 200 MW. Manufacturers have also improved the performance of aeroderivative turbines and now offer systems with over 40 percent (LHV) efficiency and 40 MW output in simple-cycle operation. Combined-cycle operation can push the efficiency of these systems to almost the level achieved with non-aeroderivative turbines. Performance of combined-cycle industrial systems varies with system size, but efficiency has now been improved, for example, to over 40 percent in the 10 to 15 MW range.

  Advanced turbines on the market continue the transfer of aircraft engine technologies to heavy-duty turbines, including advances in compressor aerodynamics, airfoil cooling, production techniques, and materials and coatings. Features, such as an impingement cooled transition piece, blading with internal serpentine cooling passages, and directionally solidified cast materials in the hot gas path, allow base-load operation at firing temperatures over 2,300° F.

At present, gas turbine manufacturers plan to sell a further improved class of turbines in the next few years. Improvements will be incremental changes to existing turbine designs. This near-term class of turbine systems will have efficiencies in the mid-50 percent range for large utility systems. Smaller turbine systems for the industrial market will also show modest efficiency improvements.

- Technology Improvements to Achieve ATS Goals

Manufacturers will not achieve ATS efficiency goals through incremental changes. Only significant changes in turbine design will allow the industry to achieve ATS goals. Each manufacturer will have its own approach; however, changes will involve higher firing temperatures and innovative cycles.

To achieve the efficiency goals, ATS will need to operate at sustained turbine firing temperatures of more than 2,600°F (compared with the current 2,350°F firing temperatures) and at high pressure ratios. Today, manufacturers use air extracted from the turbine compressor to cool hot-gas-path blading. For the near future, as gas turbine technology continues to evolve along its present path of development, use of air extraction cooling will continue, but this traditional approach is now reaching its practical limit. ATS firing temperatures will demand changes to the hot-gas-path blading.

There are several approaches to living with ultra-high firing temperatures. Using water or steam for blade cooling gives a higher cooling effectiveness, materials can be exposed to hotter gases, but will remain at safe temperatures. A hybrid system could use steam for stationary parts and advanced air cooling for rotating parts. Manufacturers can also perfect existing methods of achieving high cooling effectiveness, such as serpentine internals for blading and transpiration cooling schemes.

Materials with improved high-temperature corrosion resistance and strength allow operation at high gas temperatures. An option is multi-material blading, in which a corrosion-resistant skin (for example, Inconel) protects a substrate of high thermal conductivity (for example, copper).

Using thermal barrier coatings on airfoils reduces coolant requirements and permits operation at high firing temperatures. Advanced overlay coatings, applied by vacuum plasma spray, will increase resistance to corrosion and oxidation at high gas temperatures.

For industrial turbines, advanced ceramics are one option for moving to higher firing temperatures. Use of ceramics for hot gas path parts, such as blading and shroud shields, will allow operation at higher turbine firing temperature.

Operating at ultra-high firing temperature alone will not achieve ATS efficiency goals. Manufacturers must also develop innovative cycles. Potential cycle changes include using compressor precooling, intercooling and aftercooling, chemical recuperation, thermal recuperation, massive moisture injection (15 to 50 percent of the turbine air flow), and turbine reheat.

Using these cycles will require manufacturers to consider:

- Changes to compressors to accommodate inter-cooling and spray evaporation for cooling.
- Expanders capable of handling the increased mass flow from moisture injected cycles.
- More cost-effective heat exchangers, including heat exchangers to condense water from the flue gas to balance water consumption in moisture injected cycles.
- Combustor changes to accommodate higher temperatures of combustor inlet air.
- Tradeoff of cost and performance benefit versus possible adverse effects on RAM.

5.2 Emissions

- Goals

The successful ATS will emit 10 percent less NOx than the best available gas turbine systems, without post combustion abatement. CO and UHC emissions must each be less than 20 ppm.

- Background and Current Status

For turbines burning natural gas, NOx, UHC, and CO are the only potentially significant emissions. CO or UHC emissions can only be a problem when the turbine is operating at partial load or when NOx abatement is by steam or water injection. However, NOx formation tends to increase with firing temperature. The critical emissions issue for the ATS is, therefore, NOx abatement at high firing temperature without a consequent increase in the other emissions.[11]

By using dry low-NOx technology, the best systems now can produce single-digit (9 ppmvd at 15 percent oxygen) NOx emission levels without water or steam injection.[12] However, these low NOx levels are for turbines with firing tempera-

tures in the 2,000° F to 2,100° F range. For the advanced gas turbines with firing temperatures 2,300° F and over, manufacturers can achieve 25 ppmvd at 15 percent oxygen without water or steam injection. Near-term improvements (1995 time-frame) will result in the advanced gas turbines producing 9 ppmvd at 15 percent oxygen without water or steam injection.

Several manufacturers of small gas turbines have been active in developing dry low-NOx systems for industrial applications. However, single-digit NOx levels may not be possible in these machines.

- Technology Improvements to Achieve ATS Goals

For manufacturers to achieve ATS levels, they must pursue development in one or more of the following areas:

- Change combustor designs to use ceramics for the hot wall. Ceramics allow the combustor to operate with more premixing, which in turn reduces NOx and formation of CO and UHC.[13] Ceramics also allow higher combustor inlet temperatures such as those in a recuperative cycle.

- Use chemical recuperation of natural gas. The hydrogen content in the reformed fuel will increase the ability to stabilize the combustor flame and lead to lower NOx emissions. A low-temperature reforming catalyst may be required.

- Develop lean-premixed combustion systems. This is not only important for NOx abatement, but also for turbine performance. Elimination of water injection for NOx abatement can improve combined-cycle efficiency several percent. Ending the need for selective catalytic reduction (SCR) after the turbine significantly reduces system capital and operating costs.

- Use a catalytic metal or ceramic matrix reactor in the combustor to reduce emissions. Catalysts stabilize combustion at low peak temperatures, thereby reducing formation of NOx.

5.3 Reliability, Availability, and Maintainability

- Goal

The ATS must meet, or exceed, the RAM performance of today's advanced machines.

- Background and Current Status

  In the early 1970s, when the demand for gas turbines surged, domestic manufacturers shipped newly-developed turbines with unacceptable RAM levels.[14] After 10 years of progressively isolating and correcting RAM-related problems in the field (assisted by EPRI's focus on this issue in the early 1980s), manufacturers realized they needed to design reliability into their product.

  By eliminating parts and configurations which tend to compromise RAM, manufacturers can now produce reliable gas-turbine-based power generation systems. With the methods available, manufacturers should be able to exceed 3,000 hours mean time between failures. Today's gas turbines meet the EPRI reliability goal of 96.7 percent (based on forced outages) and the availability goal of 95 percent (based on planned plus forced outages).

- Technology Improvements to Achieve ATS Goals

  Buyers specifications have long required manufacturers to guarantee output, heat rate, and emissions of the turbine-generator power plant. Today, buyers often require reliability guarantees as well. Therefore, the developers of ATS must be careful not to compromise RAM. This will certainly be a challenge to turbine developers, because in order to meet ATS efficiency and emissions goals, developers will likely add complexity and new parts, which tends to compromise reliability. For example, adding even a well-understood change like compressor intercooling could compromise reliability because a heat exchanger, extra piping, and controls are now part of the power plant.

  To achieve ATS goals, manufacturers will need to address both flange-to-flange issues and power plant issues. Flange-to-flange equipment, such as hot-gas-path blading and combustion hardware, are important because inspection and repair of these parts affect RAM values. Power plant equipment, such as generators, microprocessor controls, and accessories are important because failure of these parts, or their instrumentation, can cause forced outages. Control and accessory systems are the major causes of unreliability in gas turbine units. One study found that control and accessory systems caused one-third of forced outage time and two-thirds of forced outages.[15]

  One approach to achieving RAM goals is to use concurrent engineering, a systematic approach to the integrated design of products and their related processes, including engineering and support. The goal of concurrent engineering, sometimes called 'Integrated Product Development', is to develop a quality product while avoiding costly and disruptive iterations. A manufacturer's ATS will only have high RAM if engineers address the reliability of parts and configurations during the design process. This requires reliability goals to be set for both the

power plant and the gas turbine-generator unit. Reliability analysis tools, such as Reliability Block Diagram Analysis, Fault Tree Analysis, and Failure Modes and Effects Analysis, can compare estimated RAM to RAM goals, but meeting goals may require simplifying a system or adding redundant sensors.

5.4 Need for Government Funding To Resolve Technical Issues

Since gas turbines were introduced commercially more than 40 years ago, manufacturers have steadily improved performance, emissions abatement, and RAM. Many turbine improvements for the civilian sector resulted from military-sponsored R&D programs. Government funding for civilian sector turbine development has been minimal.

In recent years, the pattern of commercial turbine performance improvement has been one of incremental upgrades to basic simple- and combined-cycle systems. Gas turbine cycle efficiency is highly dependent on turbine inlet temperature — the greater the inlet temperature, the better the net system efficiency. Efficiency improvements over the years have resulted from the higher turbine inlet temperatures that advanced materials and air cooling of hot gas path metals have allowed. It might seem that further improvements in system efficiency could result from increased use of air cooling for even higher turbine inlet temperatures. However, the diversion of greater and greater amounts of air from the compressor side of the turbine for air cooling eventually becomes unfeasible due to thermodynamic limitations.

Continued incremental improvements are expected to improve gas turbine systems efficiencies to the mid-50 percent (LHV) range during the 1990s. To achieve the ATS Program goal of at least 60 percent (LHV) efficiency, however, not only higher firing temperatures but also integral cycle changes will be required. At a minimum, these cycle changes will include advanced cooling (such as steam cooling to conserve compressed air), but may also include such advances as intercooling, recuperation, or moisture injection.

The goal of the ATS Program is to achieve a step improvement in turbine systems performance, significantly higher than would have otherwise been achieved by industry alone. Therefore, government funding is necessary in order to share risk in the development of the new systems. Involvement of U.S. turbine manufacturers in the ATS Program will keep this segment of American industry at the cutting edge of technology, maintaining or improving its competitive position.

SECTION 6 - PROGRAM STRATEGY

6.1 Program Coordination

The ATS Program is the joint responsibility of DOE's FE and EE Offices. As will be discussed in more detail in Sections 7 and 8, FE has primary responsibility for the development and demonstration of utility systems, while EE has the same role for industrial systems. In the technology base portion of the Program, EE has responsibility for materials studies, while FE is responsible for managing an industry-driven consortium in which universities will conduct generic R&D supporting ATS development. FE will be responsible for the application of ATS technology to coal systems, while EE will assure that ATS technology is available for biomass systems. FE's Morgantown Energy Technology Center will conduct in-house R&D in support of the Program.

FE and EE will each have primary responsibility for the procurement of work to be performed with its funds. However, both organizations will be represented on the evaluation teams for major procurements.

As shown in Figure 2, a Steering Committee, including senior executives from both FE and EE, will guide the Program. The Environmental Protection Agency will be represented, and members from the Electric Power Research Institute and the Gas Research Institute will represent the interests and viewpoints of system users. The Steering Committee will be the primary link with external organizations and programs. A Working Party of program and technical representatives of FE and EE will assure the coordination of work performed under the various elements of the Program and will be an additional interface with outside programs and organizations.

Technology transfer between Program elements and with other programs will be carried out in a number of ways: program reviews, workshops, and systematic publication and exchange of reports.

A significant element in the development of the ATS Program was the conduct of two workshops to define gas turbine R&D needs.[1,2] At these workshops, over 150 representatives of gas turbine manufacturers, funding organizations, universities, and utilities not only identified R&D needs, but also commented on the planned Program. This Program Plan includes input received at those forums.

National laboratories are currently participating in this program through the EE-sponsored elements — particularly in the materials and manufacturing technology area. The laboratories have a technology transfer mission which is served by providing expertise to the principal industrial participants through cooperative agreements or direct subcontracting. Once such arrangements are made, funding to the laboratories would be provided through usual Work Authorization and funds transfer mechanisms. Na-

tional laboratories can also submit proposals directly to DOE in response to identified needs, and will have access to program results and identified technical issues through participation in the workshops planned during the course of the program.

6.2 Phasing of Major Systems Development

The bulk of Program funding will be used for the development and demonstration of ATS by teams led by U.S. turbine manufacturers. These teams will include users, thus enhancing the ability to define and develop ATS with real commercial viability. The work will be done under competitively awarded contracts, and the requirement for significant cost share (Section 11) will ensure that the contractors are seriously interested in marketing the systems being developed.

The major systems portion of the Program (Elements I, II, and III in Figure 3) proceeds in a sequence of phases which allows re-competition and re-evaluation of concepts at reasonable intervals. Contracts will be of limited duration so that reduction to fewer systems being developed can be competitively achieved at interfaces between old and new contracts.

Initial implementation of this work has proceeded along two parallel paths. In a pre-existing program now part of the ATS Program, EE has competitively awarded a $28 million contract which will lead to a 4,000-hour test of an industrial turbine retrofitted with ceramic components. Meanwhile, FE has initiated projects to define other advanced systems for both central power and industrial markets. Approximately $100,000 each was awarded to the six U.S. turbine vendors who manufacture turbines of a suitable size for the Program. These projects led to the definition of ATS that would meet Program goals, and which the manufacturers would like to develop and market, if Program support is available. The next step for FE is the competitive award of cost-shared contracts to continue four projects through concept development. Total value of these contracts will be about $10 million, including a contractor cost-share of approximately 25 percent. Contract duration will be 18 months.

At the completion of these contracts, the FE and EE work together will have defined the range of realistic opportunity for ATS. New competitive solicitations (by FE for utility and by EE for industrial applications) will select projects to continue into the component development phase of the Program. These competitions will allow a re-assessment of concepts based on progress to date, and a re-determination that the candidate systems will meet all ATS Program goals. The integration of all industrial development under EE will allow comparison of the relative merits of alternate technical approaches. In the utilities, it is expected that not all component development will be done in one phase, but that there will be a second, intermediate competition. Only one utility and one industrial concept will proceed into the demonstration phase, with those concepts selected in additional competitive solicitations.

The funding estimates given in Section 11 assume that two industrial and two utility projects will proceed through component development before the competitive selection of only one each to proceed to demonstration.

6.3 Implementation of Technology Base Development

The Technology Base Development portion of the Program contains sub-elements which address generic technology issues for the ATS. One sub-element is the materials/manufacturing technology program to be directed by the Oak Ridge National Laboratory (ORNL), with work performed at national laboratory and private industry sites. This sub-element includes materials issues, such as long-term mechanical property testing and materials exposure testing, which are important for all turbine manufacturers but not specific to any one individual manufacturer's project. Projects in this sub-element will be aimed toward hastening the incorporation of new materials and components into gas turbines.

FE's Morgantown Energy Technology Center (Office of Technology Base Development) will carry out R&D relevant to critical ATS issues, including use of a recently completed Advanced Turbine Combustion Facility to conduct combustion studies. It is expected that some of this work will be done in coordination with other Program efforts. The facility is of a proper size to perform screening studies for turbine manufacturers and scaleup studies for universities and others.

A cooperative agreement has been signed with the South Carolina Energy R&D Center for an industry/university consortium to conduct R&D in support of the Program. To date, five turbine manufacturers have agreed to co-sponsor the consortium (Allison Gas Turbines Division of General Motors, General Electric Power Generation, Solar Turbines Inc., United Technologies' Turbo Power and Marine Systems Inc., and Westinghouse Electric Corporation's Power Generation Business Unit), along with an engineering and construction company (Fluor Daniel, Inc.). To date, fifty-six universities, located in thirty states, have expressed a desire to be performing members in the consortium.

The industrial co-sponsors constitute an Industrial Review Board, which identifies ATS issues suitable for university research. The SCERDC issues competitive solicitations reflecting this guidance to obtain proposals from the university participants. The proposals are evaluated by the Industrial Review Board, which recommends any projects to FE that should be supported with the year's funding. Approval of the suite of projects is provided by the METC Office of Product Technology Management, which is organizationally separate from the Office of Technology Base Development and conducts no in-house R&D. The industrial co-sponsors commit $25,000 per year to the consortium as well as significant time in program guidance and proposal review.

Work by the university participants will be performed in existing facilities, so program funding will be spent on R&D. University membership remains open, and does not require a fee. The work will generally be non-proprietary, with intellectual rights retained by the performing universities.

Sub-elements of the Technology Base Development address the application of technology developed in the ATS Program to coal- and biomass-fired systems being developed in other DOE programs. This work may be performed as additions to either the ATS major systems projects or to the DOE projects to develop coal and biomass systems. These awards will be sole-source, because they will narrowly target systems already under development, but the contracts to which the funds will be added will have been competitively awarded.

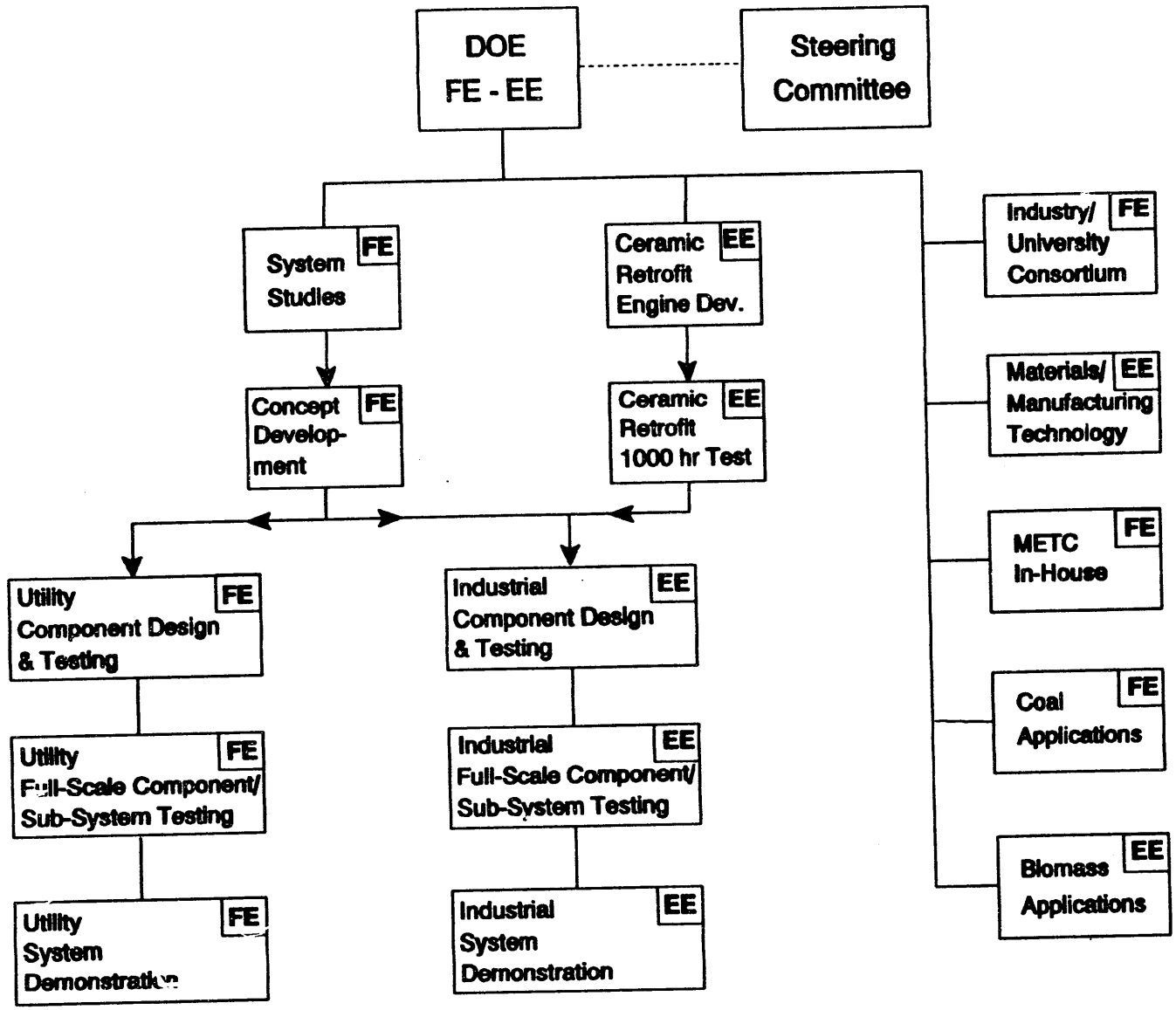


Figure 2. Advanced Turbine Systems Program Structure

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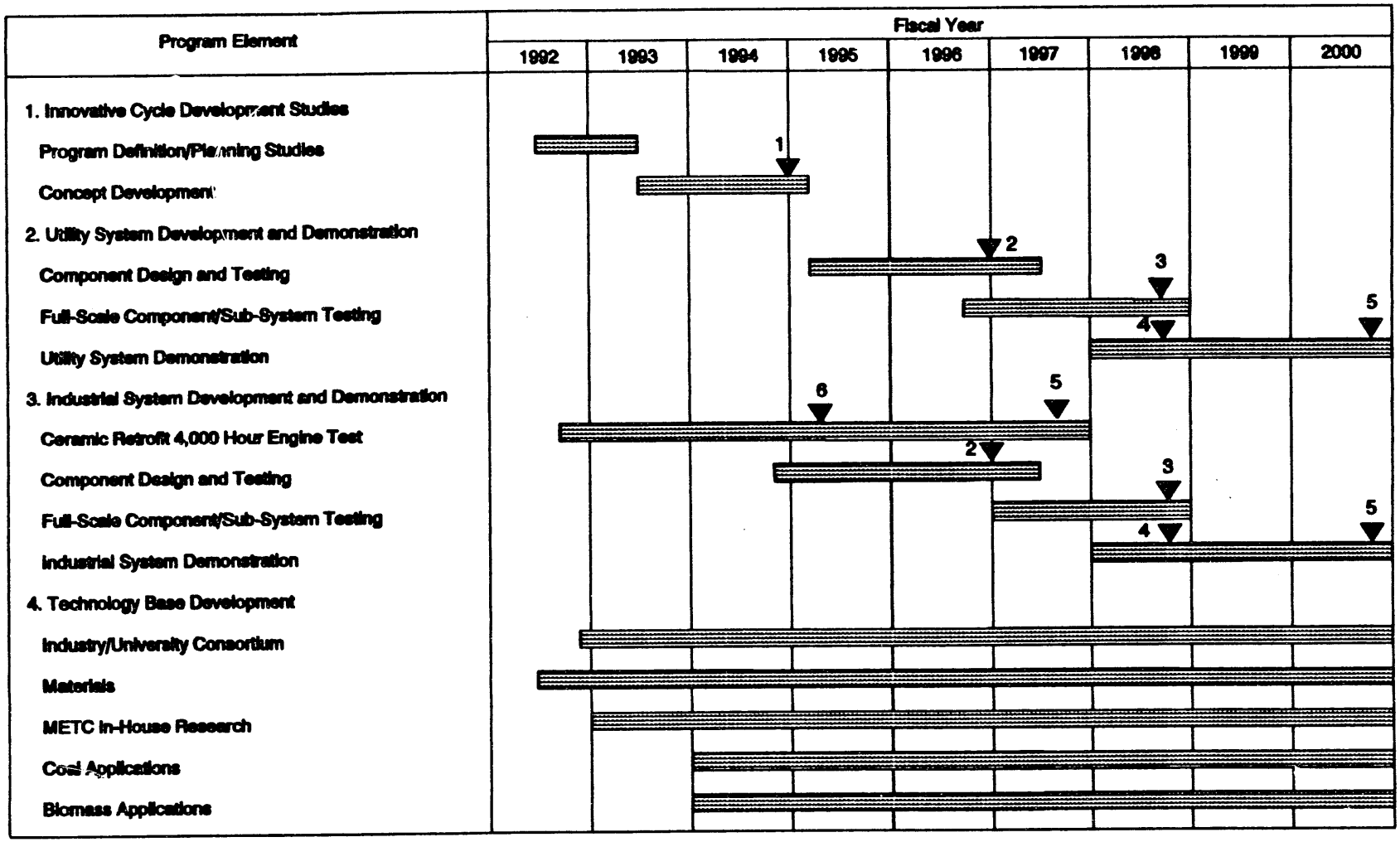
Figure 3. Proposed Schedule for Advanced Turbine Systems Program



1. Complete Concept Development
2. Complete Subscale Testing
3. Complete Full-Scale Component Tests
4. Complete Prototype Design
5. Complete Prototype Testing
6. Complete Component Development

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SECTION 7 - PROGRAM STRUCTURE

The aim of this Program is to conduct system design and development activities that will directly lead to cost-shared field demonstration of two ATS by the year 2000. One of the demonstrations will be for an industrial gas turbine system; the other will be for a utility-scale turbine system. The demonstrations will be full-scale prototype turbines operating on natural gas. RD&D activities in this Program will be conducted primarily by teams led by United States turbine manufacturers.

The ATS Program is divided into four major elements spanning the period 1992-2000. Figure 2 shows the areas of development and structure of the Program, while Figure 3 shows the schedule.

7.1 Program Element I - Innovative Cycle Development

This element includes two phases led by FE:

- Program Definition/Planning Studies

  In this phase, six gas turbine manufacturers perform scoping studies to identify incentives and define technical issues and resource requirements for developing natural gas-fired ATS, with the contractor selecting the specific system configuration (e.g., HAT, intercooled/steam-injected, advanced combined cycle) and size to be analyzed. The performance of the ATS will be defined in these studies as well as the performance of the ATS adapted for coal-firing. Costs for the overall development effort will also be estimated in this Phase.

- Concept Development

  Contracts with up to four gas turbine manufactures will be awarded to develop conceptual designs of gas-fired ATS that can be adapted for operation on coal and biomass fuels. The technical, economic, and environmental performance for ATS operating on natural gas and in a coal-fueled mode will be assessed. Detailed designs of critical components for natural gas-fired ATS will be completed. A market study will be conducted.

7.2 Program Element II - Utility System Development and Demonstration

FE is responsible for the three phases of this element:

- Component Design and Testing

  Critical components for the utility-scale system will be tested. Subscale assemblies will be evaluated, including hot rig testing. A final design of the major gas turbine components will be generated.

- Utility Full-Scale Component and Integrated Subsystem Testing

  FE will contract testing of full-scale components and integrated subsystems for the natural gas-fired ATS. The contractors will make all changes required to meet the full ATS goals.

- Utility System Demonstration

  This phase will demonstrate a full-scale utility system operating on natural gas.

7.3 Program Element III - Industrial System Development and Demonstration

EE is responsible for the four phases of this element:

- Ceramic Retrofit Engine Demonstration

  The aim of this phase is to evaluate the effects of substituting ceramic components for metallics in current engine designs, with projected benefits of increased power output, reduced emissions, and higher efficiency. The benefits result in part from higher turbine inlet temperatures, improved internal aerodynamic flow, and reduced cooling losses.

  Ceramic combustors, blades, and nozzles will be produced and evaluated in test rigs. A current engine design (3.5 MW) will be modified to accept the ceramic components, culminating in a 4,000-hour engine test. Ceramic components will be produced and tested in both the industrial and utility turbines systems as warranted.

- Component Design and Testing

  Critical components for the industrial scale engine will be tested. Sub-scale assemblies will be evaluated, including hot rig testing. A final design of the major gas turbine components will be generated.

- Industrial Full-Scale Component Development and Integrated Sub-Scale Testing

  EE will contract the testing of full-scale components and integrated subsystems for an industrial system.

- Industrial System Demonstration

  An industrial-scale system will be constructed and tested for 8,000 hours operating on natural gas.

7.4 Program Element IV - Technology Base Development

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

- Industry/University Consortium

  Much of the R&D called for in this Program element will be performed by an industry/university consortium established by a cooperative agreement between FE and the SCERDC. Industrial co-sponsors will identify critical technology needs and evaluate proposals prepared by the university participants. Five turbine manufacturers, an engineering and construction company, and fifty-six university participants have joined the consortium.

- Materials/Manufacturing Technology

  A separate sub-element will address critical materials and manufacturing technology issues for the whole Program. EE will access the expertise of the Oak Ridge Field Office for the management of this part of the Program.

- METC In-house Studies

  The FE METC in-house R&D organization will also participate in the Technology Base Development. Much of their work will likely be cooperative with other organizations performing R&D in this Program element and in Program Element II. In particular, a new turbine combustion facility is being completed at METC with multiple test cells and capabilities relevant to ATS studies.

- Coal Applications

  This FE-directed program sub-element will consider adapting improvements for natural gas-fueled ATS to coal-fueled systems. It is expected that technology developed in the other elements of the Program will also improve advanced coal-based systems.

- Biomass Applications

  The last program sub-element will, under EE lead, address the application of ATS technology to biomass systems.

SECTION 8 - PROGRAM MANAGEMENT

The ATS Program will marshal the resources of gas turbine manufacturers, the electric utility industry, and the university community, as well as government and private-sector R&D sponsors. There are a number of special management considerations because diverse types of organizations will participate.

FE and EE will jointly manage the ATS Program as shown in Figure 4. Each of these organizations has long-standing program management structures and procedures to conduct government-funded programs. This section discusses only the relationships among participating organizations and non-routine management considerations.

8.1 Steering Committee

DOE will establish a Steering Committee for the ATS Program, with representatives from DOE/FE, DOE/EE, EPRI, GRI, and the EPA, whose function is to:

- Define Program goals and responsibilities,
- Agree on lead roles for FE and EE,
- Ensure that work under the ATS Program will complement other work conducted by federal, state, and commercial organizations,
- Maintain a dialogue with private-sector organizations, and
- Periodically review Program direction and market prospects for ATS systems.

8.2 Responsibility Within DOE

DOE FE and EE share management responsibility for the ATS Program, as outlined in a Memorandum of Agreement between their Assistant Secretaries (see Appendix). Each organization will use existing support structures to manage its portion of the Program.

Within EE, the Office of Industrial Technologies will manage EE's portion of the ATS Program. The DOE Chicago Field Office will be responsible for procurement, day-to-day project management, and technical support for EE's industrial contracts. DOE's Oak Ridge National Laboratory will direct the materials portion of EE's program.

Program responsibility for FE's portion of the ATS Program will lie with the Office of the Deputy Assistant Secretary for Coal Technology. The METC Office of Product Technology Management will be responsible for managing this portion of the Program.

In addition, researchers at METC will be directly involved in the technology base element of the Program, working on barrier issues in METC's on-site laboratories.

METC will also be responsible for managing a cooperative agreement with SCERDC, which has set up an industry-led consortium of universities to perform generic R&D support.

EE and FE members of the Steering Committee will define and periodically review lead roles for FE and EE. Initial scope splits will likely be as follows.

EE will be responsible for:

- Development of ceramic components for the existing stationary gas turbines program (also known as the retrofit engine or 4,000-hour engine). Improvement of the components of the retrofit engine to be suitable for a full-service engine.
- A demonstration in industry of the full-service industrial engine cogeneration system, using an improved performance steam system.
- Development of advanced ceramic components.
- Development of generic materials technology applicable to the full range of ATS.
- Development of sub-systems and peripherals (e.g., heat exchangers and recuperators) for industrial engine systems.
- Support of technology base development.
- Integration with biomass-derived fuels.

FE will be responsible for:

- Systems studies by major engine manufacturers.
- Development of the components for utility systems.
- Utility demonstration of innovative systems.
- Utility demonstration of high-temperature capability.
- Technology base development.
- Combustion development related to ATS.

- Integration with coal-derived fuels.

8.3 Procurement

Generally FE and EE will be responsible for procurement and management for the funds in their budgets. In some cases, however, it may be advantageous to pursue joint procurement, or for one organization to handle some procurements for the other. DOE will use various procurement vehicles to secure the work necessary for the ATS Program. All procurement will comply with the requirements of the Federal Acquisition Regulations, the National Environmental Protection Act, and all other federal, state, and local laws and regulations.

8.4 Intellectual Rights

Manufacturers of gas turbines will conduct much of the major development in the ATS Program under cost-shared contracts with DOE. This approach increases technology transfer to and cost-sharing by the final commercializers of advanced turbines. Since industry will share a large portion (See Section 9) of Program costs for the major projects, DOE expects to grant advance patent waivers for this part of the work. A large part of the generic technology base work will not be highly cost shared, but laws pertaining to work by universities and small businesses may apply.

8.5 Technology Transfer

An active interchange of information between various elements of the ATS Program is needed to maximize overall Program progress. Contractor reports and program reviews, which are standard features of both FE and EE program management, will enhance intra-program communication; reports will be widely disseminated, and review meetings will be open to all Program participants. When possible, review meetings will be held jointly, with performers of different elements of the Program participating. Special meetings will address specific topics, and may be structured along the lines of the two Clemson workshops.

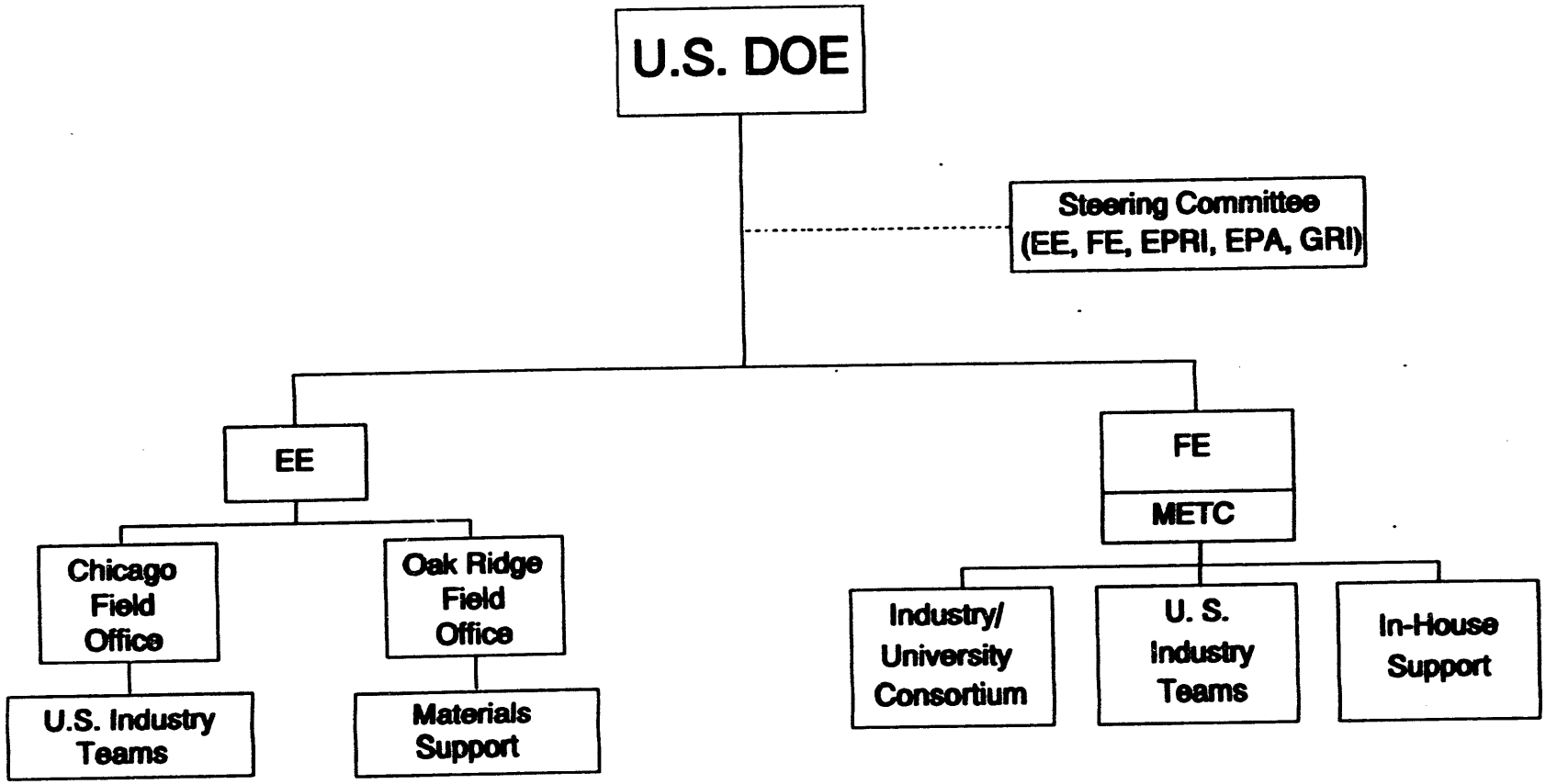

Figure 4. Management Structure for the ATS Project

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SECTION 9 - ACTIVITIES TO DATE

The past year has seen the completion of major elements of program planning and the initial stages of implementation:

9.1 Clemson Workshops

Two workshops were sponsored by DOE and Clemson University.[1,2] Each workshop brought together over 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. These workshops were one (but not the only) mechanism for defining Program goals and assessing Program value. A draft plan for the ATS Program was presented at the second workshop and revised based on comments of workshop participants. The plan has since been presented in several other forums, receiving broad support from turbine manufacturers and users.

9.2 FE/EE Cooperative Planning

FE and EE have cooperated closely in planning an integrated Program that takes advantage of the strengths of each organization. A Memorandum of Agreement between FE and EE has been signed by their Assistant Secretaries. It is included in the Appendix.

9.3 GRI, EPRI Cooperative Planning

Participation in the Clemson workshops and meetings with METC management have been the primary vehicles for GRI and EPRI input into ATS Program planning. GRI and EPRI will be members of the Steering Committee, along with representatives of FE, EE, and EPA. The Steering Committee will have liaison responsibility for other organizations, such as the American Gas Turbine Manufacturers Association and the Pacific Gas and Electric Company.

9.4 Systems Studies

Systems studies were initiated by six turbine manufacturers: Allison Gas Turbines, Asea Brown Boveri, GE, Solar Turbines, Turbo Power and Marine, and Westinghouse. The manufacturers were selected on the basis that they manufacture, in the U.S., turbines large enough to apply into the Program. The studies are sources of information essential for Program planning. They define systems that will meet Program goals and assess cost and performance. The six manufacturers have submitted preliminary letter reports identifying the systems they would like to develop, and estimating costs for development.

9.5 Ceramic Components Award

Included in the overall ATS Program is the existing EE program to develop and demonstrate ceramic retrofit components for an industrial turbine. Solar Turbines, Inc., was awarded $28 million to develop this technology over the next five years, including a 4,000-hour demonstration of integrated system operation.

9.6 Industry/University Consortium

A cooperative agreement has been awarded to South Carolina Energy R&D Center to fund an industry/university consortium to meet many of the needs of the technology base portion of the Program. Initial funding for the generic technology work to be performed by the consortium is $2 million in the first year. To date, five turbine manufacturers and an engineering and construction company have committed to join the consortium as industrial sponsors. Fifty-three universities have requested a copy of the initial solicitation.

The consortium will be industry-driven: the industrial sponsors will define areas of turbine technology needing advancement, and the university participants will prepare proposals for evaluation by the industrial sponsors.

9.7 Solicitation Released

A Request for Proposals[16] has been issued to establish four projects for the concept development portion of the Program. Total cost of the four projects will approach $10 million. The projects will include in-depth system definition and conceptual design, as well as performance, cost and market analysis. Each will develop an integrated program plan, which will define the requirements to continue system development through demonstration and commercialization. The contract values also include work on the design and testing of critical components. FE is responsible for this procurement, but a EE representative is on the evaluation team. Award of contracts is scheduled for July 1993.

SECTION 10 - RELATIONSHIP TO OTHER PROGRAMS

10.1 DOE/EE Programs

Several major EE projects or programs will indirectly support for the ATS Program:

- Cogeneration Program - This program develops advanced cogeneration equipment, including the high-performance steam turbine project. This program potentially offers one improved steam turbine option for the ATS combined-cycle systems.

- Continuous Fiber Reinforced Composites - This 10-year, $100 million program will develop new ceramic composite materials for industrial applications, including gas turbine components.

- Advanced Turbine Technology Applications Program (ATTAP) - This 5-year program advances the use of turbines for automotive applications.

- Ceramics for Advanced Turbine Engines - This project provides ceramic materials support for the ATTAP program.

10.2 DOE/FE Programs

The following FE programs offer technical support or targets for integration with coal-derived fuel:

- Coal-Fueled Turbines - Direct-coal-fired gas turbines are being developed for electric power generation. Technology developed in this coal program has already been commercialized for natural gas applications, and it is expected that advances will contribute to the ATS Program.

- Integrated Gasification Combined Cycle (IGCC) - Systems are being developed in which gasified coal fuels combined-cycle systems integrated with the gasifier. Combustion technology developed in this program could contribute to the ATS Program, and high-performance ATS turbines will improve IGCC system performance.

- Advanced Pressurized Fluidized Bed Combustion - 'Second-generation' pressurized fluidized bed combustion (PFBC) systems use coal pyrolysis products to increase turbine inlet temperature. This technology is following first-generation PFBC into the demonstration phase.

- Indirectly Fired Cycle (IFC) - These gas turbine systems must address technology issues that also need to be investigated for some ATS systems, including high temperature combustion while limiting NOx emissions.

- Clean Coal Technology Program - In this program advanced coal technologies are demonstrated at full scale in projects that are more than 50 percent cost-shared by industrial participants. Advanced systems and components with application to natural gas as well as coal will complete development in this program.

- Advanced Research and Technology Development Program - This program includes ongoing research and development on combustion, materials, and other related fields.

10.3 Other Federal Agencies

A number of Federal programs outside DOE are developing technology which may benefit (and may benefit from) the ATS Program. In addition to existing programs to transfer information, technology will be exchanged with these programs through interactions by all levels of Program participants. The United States turbine manufacturers who will take the lead in major development projects also typically participate in these programs, establishing a more effective direct communication.

Significant programs in this category include:

- Integrated High Performance Turbine Engine Technology - Combined services project for advanced military turbine development.

- National AeroSpace Plane - Experimental component development.

- Strategic Defense Initiative - Work on advanced turbine materials and systems.

- Advanced High Temperature Engine Materials Technology Program (HITEMP) - NASA Civilian aircraft engine component development.

- Advanced Research Projects Agency (ARPA) - Advanced ceramics and turbine development programs.

- Naval Surface Warfare Center - Program covering steam injection and water injection for gas turbines, as well as intercooled recuperated gas turbines for marine application.

- Materials Development programs in the Navy, Air Force, and Army.

10.4 Non-Federal Programs

A number of related major programs are being conducted by organizations other than the Federal government:

- GRI - The Gas Research Institute conducts a comprehensive program dealing with natural gas issues. Major efforts address natural gas utilization in all sectors, including electric power generation. Their programs include work complementary to that to be performed under the ATS Program. GRI is represented on the ATS Program Steering Committee to incorporate GRI/industry participation and expertise, and to ensure that activities are cooperative with no duplication of effort.

- EPRI - The Electric Power Research Institute conducts a diverse program addressing issues of interest to member electric utilities, including substantial effort on gas turbine systems. Like GRI, it enjoys effective industry participation in its program development and planning, and EPRI's expertise covers a wide range of utility issues and technologies. EPRI is also a member of the ATS Program Steering Committee, ensuring effective coordination with their programs.

- Other Public and Private Organizations - Significant programs are conducted by such organizations as the California Energy Commission and the Pacific Gas and Electric Company. The Steering Committee will assign responsibility for coordination with these organizations.

SECTION 11 - RESOURCE REQUIREMENTS

Table 1 gives funding requirements for the ATS Program over its planned eight-year duration. The costs are organized according to the five work elements shown in Figure 2 and Figure 3.

Initial cost estimates for the work elements were based on FE and EE experience with similar types of work. The greatest uncertainty in these early estimates was in the cost of the major systems portion of the Program. Revised estimates were based on the letter reports from the six turbine manufacturers selected for systems studies. The letter reports identified the systems of interest to the manufacturers and estimated Program costs, differentiating between component development and demonstration costs. Averages of these estimates were used to develop the "Utility Application" and "Industrial Application" estimates shown in the table.

The required cost shares were presented at the second Clemson workshop, with the general consensus that they were reasonable. Although not requested, some of the letter reports also volunteered that the cost-share requirements would be met. The willingness of the turbine manufacturers to participate in such highly cost-shared work is evidence of the value of the Program to U.S. industry.

The cost shares used to estimate Program cost were divided according to type of work:

Generic Research and Development	2 to 10 %
Coal Crosscut	25 %
Conceptual Design and Laboratory-Scale Testing	25 %
Component Development	35 %
Demonstration	50 %

Table 1. ADVANCED TURBINE SYSTEMS (ATS) PROGRAM RESOURCE REQUIREMENTS

DOE $ (MILLIONS)

Element/Work	Contractor	DOE	FISCAL YEAR 92	93	94	95	96	97	98	99	00	DOE Total	DOE C/S	Total Cost	Percent C/S
I Innovative Cycle Development															
Concept Development	TBD	FE	0.3	5.8	14.0							20.1	6.7	26.8	25.0%
II Utility System Development and Demonstration															
Component Development	TBD	FE				35.0	40.0	40.0	12.2			127.2	68.5	195.7	35.0%
Demonstration	TBD	FE							30.0	22.4	17.1	69.5	69.5	139.0	50.0%
III Industrial System Development and Demonstration															
Ceram. Retrofit 4000hr Test	Solar	EE	2.2	2.5	4.1	11.4	8.1					28.3	12.3	40.6	30.3%
Component Development	TBD	EE			2.7	12.2	15.7	19.8	14.1			64.5	34.7	99.2	35.0%
Demonstration	TBD	EE							5.5	15.0	13.8	34.3	34.3	68.6	50.0%
IV Technology Base Development															
Industry/Univ. Consortium	SCERDC	FE	0.4	2.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	36.4	1.0	37.4	2.7%
Materials	ORNL	EE		0.5	0.5	4.0	5.0	5.5	5.5	5.0	5.0	31.0	3.4	34.4	10.0%
Manufact. Technologies	ORNL	FE			2.0	2.0	2.0	2.0	2.0	2.0	2.0	14.0	0.0	14.0	0.0%
METC (In-House Research)	METC	FE		1.0	2.4	2.7	3.0	3.0	3.0	3.0	3.0	21.1	0.0	21.1	0.0%
Combustion	TBD	FE		1.0	0.3	0.5	0.5	0.5	0.5	0.5	0.5	4.3	0.5	4.8	10.0%
Coal Application	TBD	FE			1.0	2.0	2.0	2.0	2.0	2.0	2.0	13.0	4.3	17.3	25.0%
Biomass Applications	TBD	EE			1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.0	0.8	7.8	10.0 %
		TOTAL	2.9	12.8	32.0	75.8	82.3	78.8	80.8	55.9	49.4	470.8	236.1	706.6	33.4%

	92	93	94	95	96	97	98	99	00	Total DOE	Total C/S	Total Cost	Percent C/S
FE	0.7	9.8	23.7	47.2	52.5	52.5	54.7	34.9	29.6	305.7	150.5	456.2	33.0%
EE	2.2	3.0	8.3	28.6	29.8	26.3	26.1	21.0	19.8	165.1	85.6	250.7	34.1%
										470.8	236.1	706.6	33.4%

NOTE: Dollar amounts shown for FY 1992-3 are appropriated budget amounts. The FY 1994 column is the Presidential Request budget. Dollar amounts shown for FY 1995 and beyond are for planning purposes (they are not part of the President's budget) and are subject to change.

SECTION 12 - CONCLUSIONS

FE and EE have planned a Program for the development of ATS for base-load power generation in utility and industrial applications. These environmentally benign systems will be highly efficient, substantially reducing national fuel use and supporting the DOE call for increased efficiency in all energy sectors. The systems will initially be fired with natural gas but will be adaptable to coal and biomass fuels, supporting the call for fuel flexibility. The Program will help keep the U.S. gas turbine industry at the forefront of power generation technology and benefit the U.S. economy.

There is broad support for the Program. Turbine manufacturers have voiced their desire to participate (even with high cost share planned) and have endorsed the Program goals and timing. EPRI and GRI also joined in the planning process, as have representatives of the user community and others who would participate in the Program. Both the Executive Branch and the Congress have supported the ATS Program in their budgeting and appropriations processes.

DOE recommends that the planned Program be implemented.

SECTION 13 - REFERENCES

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APPENDIX

AGREEMENT
Assistant Secretary for Fossil Energy
and
Assistant Secretary for Conservation and Renewable Energy
on
THE ADVANCED TURBINE SYSTEMS (ATS) PROGRAM

I. Introduction

A. Background

The United States has a leadership position in the design and manufacture of gas turbines for both airborne and stationary service. Contributions to this leadership position have come from both the aeronautical and the power industry efforts. This leadership role has been, and is continuing to be, challenged by foreign manufacturers. This situation has been recognized by industry. Congress has requested the development of an industry-supported plan to address the problem.

B. Purpose and Scope

The purpose of this Agreement is to structure a relationship between Fossil Energy (FE) and Conservation and Renewable Energy (CE) which will assist in the organization, planning and execution of an Advanced Turbine Systems (ATS) program. This program is to provide advances in fuel efficiency, to reduce environmental impacts, and to improve cost competitiveness of U.S. gas turbine systems. The ATS program will involve both technology development and systems demonstration.

The scope of the program includes stationary gas turbines, associated heat exchangers, and materials and systems for utility and industrial service that are fired by natural gas. Utility systems shall have the potential for later adaption to coal-derived fuel. Improvements in the performance of the systems are expected to be achieved by inherent prime mover and system changes, not by "add-on" equipment.

C. Authority

Senate Report 102-122 to accompany the Department of Interior and Related Agencies Appropriations Bill for Fiscal Year 1992 which stated "$750,000 is for

advanced turbine development in concert with the Energy Conservation Research Programs." In response to this request, the Morgantown Energy Technology Center (METC) of FE is preparing a program plan in concert with The Office of Industrial Technologies of CE.

D. Policy

As designated by Congress, the Assistant Secretary for Fossil Energy is responsible for the overall program in cooperation with the Assistant Secretary of Conservation and Renewable Energy. Disputes that can not be resolved will be forwarded in writing to the Secretary of Energy for binding resolution.

II. Management and Program Guidelines

A. Organization

CE

The CE portion of the ATS program will be managed by the Industrial Energy Efficiency Division of the Office of Industrial Technologies.

FE

The FE portion of the ATS program will be managed by the Office of Product Technology Management of the Morgantown Energy Technology Center.

B. Management and Review

A Steering Committee will be established to coordinate the work performed under the ATS program with that being supported by other funding organizations.

The membership and the duties of the Steering Committee will be defined in detail in the coordinated program plan.

FE and CE will, in accordance with the provisions of the Memorandum-Of-Understanding, each provide members for the Steering Committee.

The CE and FE members of the Steering Committee will define program goals and responsibilities, and agree on lead roles for CE and FE. They will periodically evaluate program technical progress and plans, and review the economics of the systems being developed. Based on these evaluations, they will define appropriate CE and FE budget requirements for the program to proceed.

The parties to this Agreement will designate Program Managers and organize teams; establish milestones & schedules; develop, justify and defend budgets to support mutually agreed upon program plans; and initiate & administer necessary contractual actions for their respective designated efforts.

The parties will appoint a Working Party to develop a program plan and oversee the execution of that plan. The expectation is that the Working Party will consist of members of the Industrial Energy Efficiency Division of the Office of Industrial Technologies, CE and the Office of Product Technology Management of the Morgantown Energy Technology Center, FE. The chairmanship of the Working Party will rotate on an annual basis with the first chairman designated by FE.

FE and CE will conduct program reviews of components of the ATS program. Whenever feasible these reviews will be held together. They will maintain liaison and exchange information on developments that are related to but not part of the ATS program.

C. Guidelines

Lead roles for FE and CE will be defined by the CE and FE members of the Steering Committee and periodically reviewed. It is expected that initial roles will include:

CE will be responsible for:

- The development of ceramic components for existing stationary gas turbines program (also known as the retrofit engine or 1000 hour engine). Improvement of the components of the retrofit engine to be suitable for a full service engine.

- A demonstration in industry of the full service industrial engine cogeneration system, utilizing an improved performance steam system.

- Development of advanced ceramic components.

- Generic materials technology development applicable to the full range of ATS.

- Development of industrial engine sub-systems and peripherals (e.g. heat exchangers/recuperators).

- Support of the technology base development.

- Integration with biomass-derived fuels.

FE will be responsible for:

- Systems studies to be conducted by major engine manufacturers.
- The development of the components for the utility machine in the ATS program.
- The conduct of the improved systems utility machine demonstration.
- The conduct of the high temperature capability demonstration of the utility machine.
- Technology base development.
- Combustion development related to the ATS program.
- Integration with coal-derived fuels.

Both FE and CE will include a requirement for monthly reports of progress in any contracts issued in support of this program. These reports will be submitted to the Office responsible for the work, with copies to the Working Group members as appropriate.

D. Program Funding

Both CE and FE will be responsible for preparing and defending the budgets for their portion of the ATS program for presentation to the Congress as part of their annual request. Each party agrees to diligently pursue sufficient funding to carry out the mutually agreed upon program plan.

III. Administration

A. Patents and Technical Data

Rights in patents and technical data will be managed in accordance with appropriate DOE orders and regulations.

B. Public Information Coordination

FE and CE agree that public information releases concerning the ATS program will be coordinated with each other prior to release.

C. Amendment and Termination

This Agreement may be amended at the mutual agreement of the parties and may be terminated by either party.

This Agreement shall be reviewed every three years to determine its continuing applicability.

D. Effective Date

The effective period for this Agreement is from 1 January 1992 to 1 January 2002 unless terminated at a sooner date.

APPROVED

Original signed by:

J. Michael Davis, P.E.
Assistant Secretary
Conservation and Renewable Energy

Original signed by:

James G. Randolph
Assistant Secretary
Fossil Energy

END

DATE
FILMED
9/24/93