# ESTABLISHING THE SCIENTIFIC FOUNDATION FOR THE 21ST-CENTURY GAS TURBINE

## Description

The U.S. Department of Energy (DOE) and the nation's leading gas turbine manufacturers have embarked upon a program to develop the gas turbine of the 21st century. Developing this ultra-clean, high-efficiency turbine will require substantial leaps forward in:

- high-temperature, corrosion-resistant materials science,
- improved understanding of combustion phenomena,
- fundamentals of innovative thermodynamic cycles, and
- knowledge of pollutant formations when natural gas and other fuels are burned and emissions minimization.

The South Carolina Institute for Energy Studies (SCIES) is coordinating the Advanced Gas Turbine Systems Research (AGTSR) Program, a consortium of more than 98 universities in 37 states to provide these technological advances and establish a fundamental base of knowledge. There are three major project areas in the AGTSR Program: (1) promoting collaborative research and development, (2) organizing industrial workshops and seminars to share important new information, and (3) sponsoring internships and fellowships on the university level to provide a foundation for future breakthroughs in advanced gas turbine technology.

Under DOE supervision, the consortium brings together the engineering departments of the nation's leading universities and industrial turbine developers to ensure that the next generation of natural gas turbines is built on a solid base of knowledge. The consortium's projects will be critical to the U.S.'s continued world leadership in turbine technology for the 21st century.

The AGTSR Program targets R&D topics in combustion, aerodynamics and heat transfer, and materials. Research thrust areas may vary from year to year, depending on the specific needs of the Industry Review Board (IRB), which also evaluates and recommends for support top university proposals submitted in response to Requests for Proposals. The IRB currently consists of ten gas turbine/component manufacturers.

## Duration

Start Date 1992

Projected End Date 2001

### PRIMARY PROJECT PARTNER

**South Carolina Institute for Energy Studies**
Clemson, SC

### MAIN SITE

**Clemson University**
Clemson, SC

### TOTAL ESTIMATED COST

$36,870,799

### COST SHARING

| | |
|---|---|
| DOE | $35,570,799 |
| Non-DOE | $1,300,000 |

NETL

# AGTSR University Project Partners,

## 1994 TO 1996

**1994**

University of California-Irvine
Carnegie Mellon University
University of Central Florida
Clemson University
Cornell University
Georgia Institute of Technology
University of Maryland
Massachusetts Institute of Technology
Michigan State University
University of Minnesota
University of Oklahoma
Purdue University
University of Wyoming

**1995**

Arizona State University
Clemson University
University of Connecticut (2 awards)
Georgia Institute of Technology
Pennsylvania State University (2 awards)
Syracuse University
Vanderbilt University/Cal Tech

**1996**

Cornell University
Cleveland State University
Massachusetts Institute of Technology
Northwestern University
Pennsylvania State University

Purdue University
University of California at Davis
University of Pittsburgh/
University of Connecticut
University of Wisconsin-Madison/
University of Texas at Austin

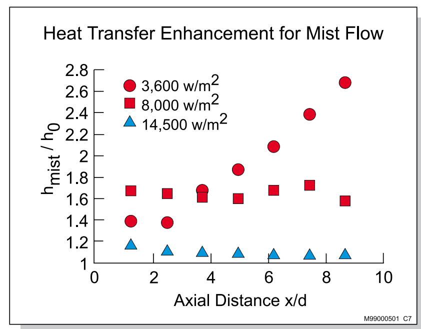
# Key Accomplishments

Technical accomplishments are summarized in three major research areas: combustion, aerodynamics and heat transfer, and materials.

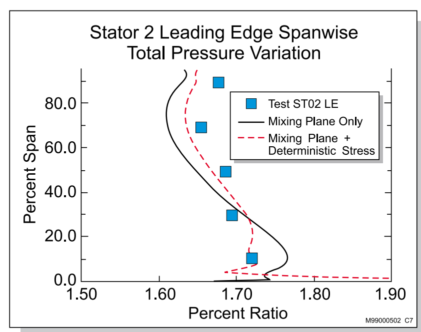
### Aerodynamics and Heat Transfer Research.

The goal of aero-heat transfer research is to enhance the performance and efficiency of advanced, land-based gas turbines while improving durability. This is accomplished by reducing film-cooling air, implementing innovative external and internal cooling strategies, optimizing airfoil designs, and reducing aerodynamic losses. Research projects are in four areas: internal cooling enhancement, external cooling flows, alternative cooling strategies, and aero optimization and new design methods. Key accomplishments are noted below.

- Texas A&M has developed an improved unsteady transition model for turbo machinery computer codes that can be used to better predict and understand turbine heat transfer.
- Syracuse University has implemented an inverse design code to improve compressor rotor performance. New code enables better compressor designs — and thus better loading and efficiency gains.
- Clemson University has demonstrated a 100-percent heat transfer improvement using mist cooling versus steam cooling. Mist cooling may be the next generation of closed-loop cooling to outperform steam-only cooling.
- Clemson University has developed an advanced film cooling computational methodology that can be used to more accurately predict three-dimensional heat transfer on turbine blades.
- Three heat transfer workshops have been held. A 2-day short course on Advanced Film Cooling Flows was held at Clemson University in August 1997.
- Penn State University has developed flow data in a multi-stage compressor environment that has been used by Rolls-Royce Allison in their compressor design codes. The same data is being used by Stanford University to predict the flow field in an entire engine.




**Heat Transfer**
*Clemson University*
*General Electric and Siemens Westinghouse*



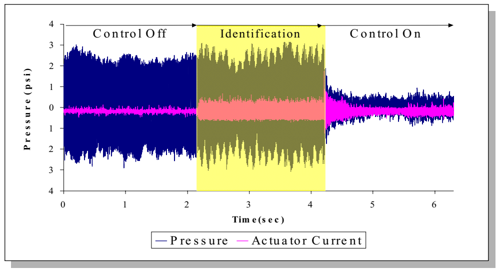

**Aerodynamics.** Incorporation of Deterministic Stress Modeling Procedure improves the prediction of spanwise distribution of flow parameters.
*Penn State University*

### Combustion Research.

The goal of the combustion research is to permit higher turbine inlet temperatures to achieve cycle efficiency benefits while lowering nitrogen oxides, carbon monoxide, and unburned hydrocarbons emissions and improving flame stability. Combustion projects are in four areas: lean premixed/instability experiments, advanced modeling, sensors and active control, and catalytic combustion. Key accomplish-ments are noted below.

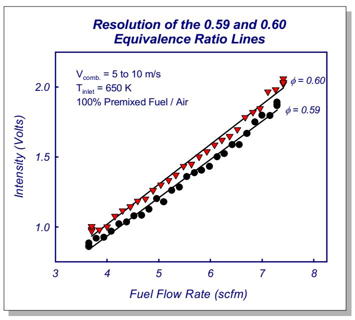
- The University of California at Berkeley has developed a fiber-optic probe for measuring fuel-air mixedness. The probe is used to determine the level of premixing which relates to $NO_x$ emissions reduction.

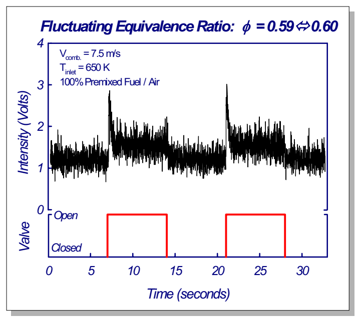
- A short course on Combustion Dynamics has been developed by CalTech in cooperation with Pratt and Whitney.
- Georgia Tech and Siemens Westinghouse conducted a series of active combustion control tests on a 3 MW atmospheric combustor that demonstrated how the Active Control System automatically detected combustion instabilities, identified combustor characteristics, and "instantaneously" attenuated the unstable mode.




**Combustion Research.** Identification and control using the Lean-Premixed Combustor. *Georgia Institute of Technology*

- The Georgia Institute of Technology has demonstrated active control of instabilities in a laboratory-scale combustor. These instabilities must be controlled either passively or actively in lean-premixed combustors to achieve ultra-low $NO_x$ capability.
- Pennsylvania State University has tested a new sensor for measuring the equivalence ratio. New sensors are in demand by industry to see how well the fuel and air are mixed, and to correlate this mixing with emissions produced.




**Combustion Research.** Using the Flame Chemiluminescence Sensor, an equivalence ratio resolution of 0.01 is achieved, and the sensor has fast response time. *Pennsylvania State University*

- Purdue University has developed an infrared sensor for accurate combustor temperature measurements. New temperature sensors that can withstand actual combustion conditions are useful to industry in monitoring emissions as opposed to measuring temperatures downstream of the combustor and correlating emissions.
- Cornell University has pioneered an advanced combustion chemistry algorithm for use by industry. Traditional combustor codes are too time-intensive to capture and predict multiple chemical species efficiently. Cornell has proposed an efficient chemistry algorithm that speeds up the calculations to the point that they become realistic for industry to potentially use for combustion design processes.
- Six combustion workshops have been held. The workshops serve to define areas of technology where directed fundamental research offers promise, to permit informal researcher-to-researcher interaction and collaboration, and to provide relevance through industry direction.

## Materials Research.

The goal of materials research is to improve the performance and durability of thermal barrier coating (TBC) substrate materials as applied to turbine blades that are used in advanced land-based gas turbines. The focus of TBCs applied by air plasma spray (APS) and/or chemical-physical vapor deposition methods. Research projects are in three areas: TBC modeling and durability experiments, new coating techniques, and life prediction and non-destructive evaluation (NDE). Key accomplishments are noted below.

- The University of Connecticut has shown that the failure of TBCs consisting of platinum-modified NiAl bond coats and physical-vapor-deposited 7YSZ coatings are related to preferential oxidation and cracking at the ridges associated with the grain boundaries. Removal of the ridges improved TBC lifetime by a factor of 3.

## AGTSR University Project Partners,

### 1997 TO 1999

**1997**

California Institute of Technology
Carnegie Mellon University/
University of Minnesota/
Michigan State University
Georgia Institute of Technology
Purdue University (2 awards)
University of California Irvine
University of California at Santa Barbara
University of Central Florida
University of Minnesota/
Pennsylvania State University
Virginia Polytechnic Institute and State University

**1998**

University of Connecticut/
University of California Santa Barbara
University of California Berkeley
Georgia Institute of Technology
Mississippi State/Air Force Institute of Technology
University of Pittsburgh/Carnegie Mellon University
Pennsylvania State University (2)/ Minnesota
University of Central Florida/ Air Force Research Laboratory

**1999**

Texas Engineering Experiment Station
University of Connecticut
Virginia Commonwealth University
University of California-Irvine
Purdue University
University of North Dakota
University of Washington

## CONTACT POINTS


**Abbie W. Layne**
Advanced Turbine and Engines Systems Program Product Manager
National Energy Technology Laboratory
(304) 285-4603
(304) 285-4469 fax
abbie.layne@netl.doe.gov

**Norman T. Holcombe**
Project Manager
National Energy Technology Laboratory
(412) 386-4557
(412) 386-5917 fax
norman.holcombe@netl.doe.gov

**Richard Wenglarz**
AGTSR Manager
South Carolina Institute for Energy Studies
(864) 656-2267
(864) 656-0142 fax
rwnglrz@clemson.edu

**Lawrence P. Golan**
Director
South Carolina Institute for Energy Studies
(864) 656-2267
(864) 656-0142 fax
glawren@clemson.edu

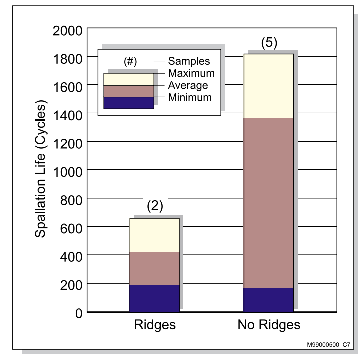

## AGTSR INDUSTRIAL PROJECT PARTNERS

There are ten industrial turbine developers participating in the project. Each company contributes $25,000 (non-voting $7,500) a year to the program.

EPRI (NON-VOTING)
GENERAL ELECTRIC POWER
HONEYWELL ENGINE SYSTEMS
PARKER HANNIFIN (NON-VOTING)
PRATT & WHITNEY
ROLLS-ROYCE ALLISON
SOLAR TURBINES
SOUTHERN COMPANY SERVICES (NON-VOTING)
SIEMENS WESTINGHOUSE
WOODWARD FST (NON-VOTING)

# ESTABLISHING THE SCIENTIFIC FOUNDATION FOR THE 21ST-CENTURY GAS TURBINE

- The University of Connecticut, in collaboration with the University of California at Santa Barbara, has developed the first NDE technique for TBCs using laser fluorescence, which may be used to determine coating quality and life-remaining assessments.
- The Georgia Institute of Technology has patented a novel coating technique that uses the combustion chemical-vapor-deposition (CVD) process — an open-air, cost-effective process that may substantially improve coating life.
- Northwestern University has demonstrated a small-particle plasma spray (SPPS) process to produce novel TBCs. SPPS may be used to produce controlled coatings with improved thermal conductivity properties and oxidation resistant behavior.
- Three materials workshops have been held.




**Materials Research.** Improvements in Thermal Barrier Coating Life
*University of Connecticut*

## Goal

The major goals of the AGTSR Program are to promote industry-university collaborative research and development, nurture multi-disciplinary engineering education, stimulate interest in and further the pursuit of excellence in university research on gas turbines in the United States, and foster the transition of fundamental research from the university laboratory to industrial applications.

## Benefits

Natural-gas turbine systems are rapidly becoming one of the prime technolo-gies for generating electricity. Within the next 20 years, natural-gas turbines could produce at least half of the new power-generating capacity in the U.S. Natural-gas turbine power plants are also attractive in other parts of the world because they can be quickly fabricated and installed with relatively low capital costs.

To ensure that the U.S. remains the world turbine leader, DOE is working with U.S. turbine manufacturers to develop an advanced, ultra-high-efficiency, environmentally superior turbine system that will be less expensive than today's systems.

Development of advanced turbine systems will lead to:

- Energy efficiencies exceeding 60 percent for utility-scale turbines, and a 15-percent improvement for smaller, industrial-scale turbines.
- Fuel flexibility — the ability to use natural gas today, and clean gas from coal or biomass in the future.
- Significantly improved environmental performance, with nitrogen oxide emissions well under half of today's utility-turbine averages.
- Reduction in the costs of electric power, resulting in savings to consumers.
- Increased competitiveness of the U.S. turbine industry, which already leads the world in turbine technology but faces increasing competition abroad.
- Increased competitiveness of U.S. manufacturers, particularly those whose product costs are significantly influenced by the cost of buying electricity.

High-efficiency turbine systems will also reduce U.S. fuel consumption by helping us become more energy-efficient. Introducing advanced turbine systems into the power market by the year 2000 could result in a savings of the energy equivalent of more than 100 million barrels of oil a year by 2020.