

# PROJECT facts

## University Turbine Systems Research

### Establishing The Scientific Foundation For Advanced Energy Systems

#### Description

The University Turbine Systems Research (UTSR) Program, developed by the DOE National Energy Technology Laboratory, is coordinated through the South Carolina Institute for Energy Studies (SCIES). The program started in 1992 and supports and facilitates development of advanced energy systems incorporating turbines through a U.S. based university research environment. The UTSR Program uses existing university research capabilities to introduce students to high level turbine related issues and to engage them in research that is consistent with the primary mission of universities; to be institutions of learning of the highest level.

Industry involvement and leadership is used to help set the highest possible standard for execution of university research consistent with two important goals; relevance to advanced energy systems development and the cultivation of student learning. The process of industry involvement includes:

- Recommending the most appropriate topics for university research.
- Evaluating proposals submitted by universities.
- Recommending the best proposals for award.
- Supporting and improving university-industry interfaces and interactions.
- Improving technology transfer processes by supporting the highest educational and training standards.

The DOE Turbine Program focuses on the development of technology to increase turbine power plant fuel flexibility and efficiency as well as reliability, availability, and maintainability, with low emissions and life cycle costs. The UTSR Program is producing the technology base needed to enable the development of turbines and advanced engine modules for 21st century energy plants to operate at high performance levels with syngas and hydrogen fuels.

#### Period of Performance

Start Date	1992
Projected End Date	2008

#### PRIMARY PROJECT PARTNER

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

#### MAIN SITE

**Clemson University**  
Clemson, SC

#### TOTAL ESTIMATED COST

\$50,131,000

#### COST SHARING

DOE	\$ 48,200,000
Non-DOE	\$ 1,931,000



## Goals and Objectives

**Figure 1** shows the goals and objectives of the DOE Turbine Program. The DOE Turbine Program seeks to develop turbines and associated systems that can utilize high hydrogen fuels, facilitate use of hydrogen derived from coal, and can be integrated into systems that eliminate emissions of carbon dioxide.

## Major Project Areas

- Hydrogen Turbines for Future Gen
- Coal-Based Oxy-Fuel System Evaluation and Combustor Development
- Turbines for Oxy-Fuel Rankine Cycle Coal Based Power Systems
- Highly Efficient Zero Emissions Hydrogen Combustion Technology for Mega-Watt Scale Turbines
- Hydrogen Combustion Systems for Fuel Augmentation to Reduce NO<sub>x</sub> in MW-Scale Combustor Turbines
- MW-Scale Turbines for Power and Hydrogen Co-Production in Industrial Applications
- Novel Concepts for the Compression of Large Volumes of Carbon Dioxide
- Advanced Brayton Cycles for Highly Efficient Zero Emissions Systems

2010

- ≈ 45-50% efficient coal turbine plants
- ≈ Capital cost < \$1000/KW
- ≈ 2-3 percentage points greater efficiency than current IGCC Plants

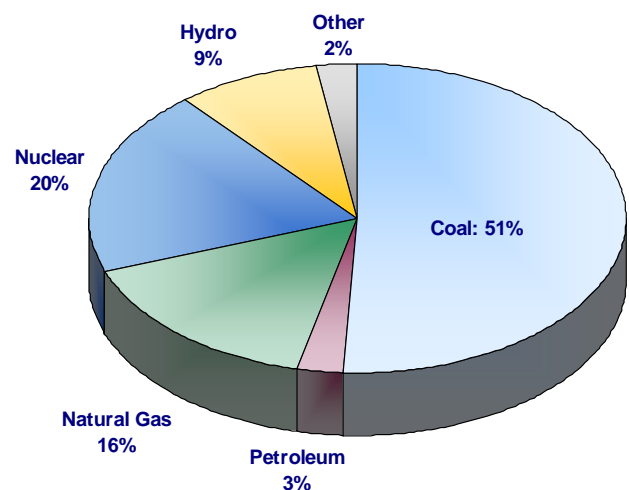


2020

- ≈ Large frame machine designed for hydrogen and coal derived syngas fuels
- ≈ Equivalent efficiency to current turbines operating with natural gas
- ≈ 3-5 percentage points greater efficiency than current IGCC plants

### The Turbine Program Goals

Figure 1



### U.S. Electric Generation By Fuel

Figure 2

## Program Research Accomplishments

Technical accomplishments are summarized in three major research areas: aerodynamics and heat transfer, combustion, 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 have been 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.
- Five 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 Corporation in their compressor design codes. The same data is being used by Stanford University to predict the flow field in an entire engine.

### Combustion Research

The goal of the combustion research area is to permit higher turbine inlet temperatures to achieve cycle efficiency benefits while lowering NO<sub>x</sub>, CO, and UHC emissions and improving flame stability. There have been combustion projects in four areas: lean premixed/instability experiments, advanced modeling, sensors and active control, and catalytic combustion. Key accomplishments 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<sub>x</sub> emissions reduction.

1994

Brigham Young University  
Clarkson University  
Lehigh University  
Louisiana State University  
Pennsylvania State University  
Purdue University  
Texas A&M University  
University of California-Berkeley  
Vanderbilt University  
Virginia Polytechnic Institute

1995

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

1996

Arizona State University  
Clemson University  
Georgia Institute of Technology  
Pennsylvania State University (2 awards)  
Syracuse University  
Massachusetts Institute of Technology  
University of Central Florida  
University of Connecticut (2 awards)  
Michigan State University

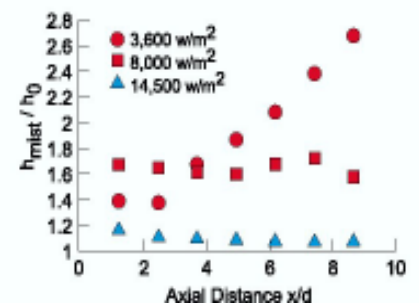
1997

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

1998

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, Santa Barbara  
University of Central Florida  
University of Minnesota/  
Pennsylvania State University  
University of Pittsburgh  
Virginia Polytechnic Institute

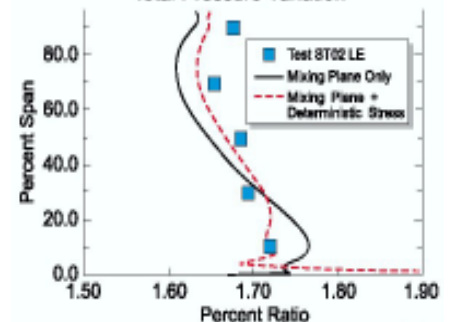
Heat Transfer Enhancement for Mist Flow



Heat Transfer  
Clemson University

General Electric and Siemens Westinghouse

Stator 2 Leading Edge Spanwise Total Pressure Variation

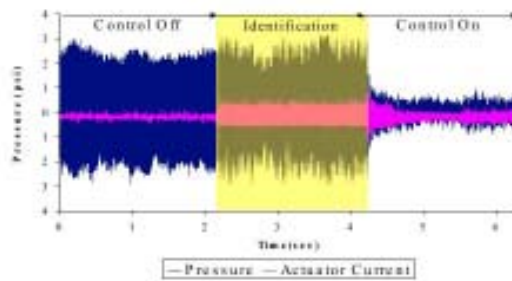


Aerodynamics. Incorporation of Deterministic Stress Modeling Procedure improves the prediction of spanwise distribution of flow parameters.

Penn State University

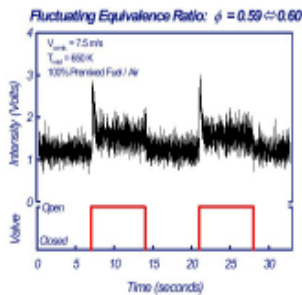
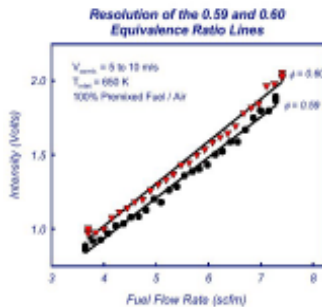
## Combustion Research

- A short course on Combustion Dynamics has been developed by Cal-Tech 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<sub>x</sub> 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.  
*Penn State University*

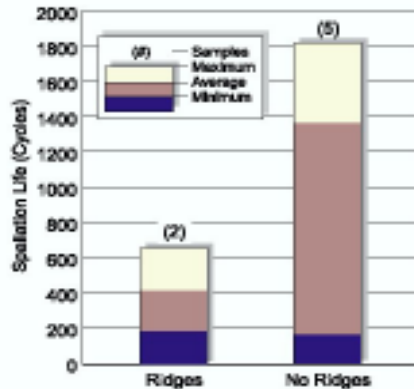
- Purdue University has developed an infrared sensor for accurate combustor temperature measurements. New temperature sensors that can withstand actual combustion conditions are useful to industry in monitoring emissions as opposed to measuring temperatures downstream of the combustor and correlating 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 proposes.
- Nine 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.

## UTSR Awards

- 1999
  - Georgia Institute of Technology
  - Mississippi State/
  - Air Force Institute of Technology
  - Pennsylvania State University
  - Pennsylvania State University/
  - University of Minnesota
  - University of California, Berkeley
  - University of Central Florida/
  - Air Force Research Laboratory
  - University of Connecticut
  - University of Pittsburgh/
  - Carnegie Mellon University
- 2000
  - Purdue University
  - Texas Engineering Experiment Station
  - University of California-Irvine
  - University of Connecticut
  - University of North Dakota
  - University of Washington
  - Virginia Commonwealth University
- 2001
  - Louisiana State University
  - Pennsylvania State University
  - Texas Engineering Experiment Station
  - University of California-Santa Barbara
  - University of Connecticut
  - University of Texas-Austin
- 2002
  - Brigham Young University
  - University of Central Florida
  - University of Connecticut
  - Georgia Institute of Technology (2)
  - Louisiana State University
  - University of Minnesota
  - University of Pittsburgh
  - Virginia Polytechnic Institute (2)
- 2003
  - University of Wisconsin, Madison
  - Texas A&M University
  - Cleveland State University
  - Georgia Institute of Technology
  - University of Connecticut
  - Clemson University
  - Pennsylvania State University
  - Virginia Polytechnic Institute
  - University of California, Irvine
- 2004
  - University of Central Florida
  - University of Pittsburgh (2)
- 2005
  - Pennsylvania State University
  - University of Central Florida
  - University of North Dakota
  - Brigham Young University
  - Massachusetts Institute of Technology
- 2007
  - Georgia Institute of Technology
  - Virginia Polytechnic Institute
  - University of Pittsburgh
  - University of California, Santa Barbara
  - University of Colorado
  - University of Texas, Austin

## Materials Research

The goal of materials research is to improve the performance and durability of thermal barrier coatings (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:



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

- 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.
- 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.
- Five materials workshops have been held.

## UTSR Workshops

The UTSR uses workshops to further facilitate early discussion and release of research progress, promote interaction and teaming among research groups, and to assist in defining industry research needs. Personnel from industry, universities, and government attend these workshops. Numerous workshops and specialty meetings have been conducted by the UTSR in the areas of combustion, aerodynamics/heat transfer, and materials. When appropriate, the UTSR has also led specialty meetings. To date, a total of 26 workshops have been hosted by the South Carolina Institute for Energy Studies.

## Program Outreach

The UTSR Program also includes an outreach mission to increase Turbine Program public benefits. Regional workshops to identify and serve the needs of the US regions; involvement with State Energy Offices; expansion of the Performing Member University network; and expansion of the internships and faculty fellowships will be mechanisms to achieve greater outreach.

The success of the UTSR Program's outreach efforts has resulted in articles on UTSR research being published for the following:

- ≈ *Gas Turbine World* November-December 2002 Issue
- ≈ *Gas Turbine World* January-February 2003 Issue
- ≈ *Gas Turbine World* June-July 2004 Issue
- ≈ *Gas Turbine World* March-April 2005 Issue
- ≈ *Turbo Machinery International* July-August 2003 Issue
- ≈ *ASME Turbo Expo 2004* Paper GT2004-54323
- ≈ 2005 ASME International Mechanical Engineering Congress & Exposition Paper ASME MECE2005-82534

## UTSR Performing Member Universities

At present, there are 111 performing member universities representing 42 states, and 14 major cost-sharing corporations. (Figure 3 - states with performing member schools appear in blue)

Performing Member Universities receive notification of the Request For Proposal released each year by the UTSR Program. Performing Member universities also receive notification of the Gas Turbine Industrial Fellowship Program. In the past 12 years, 187 students attending Performing Member Universities have participated in the Fellowship Program.

## Industrial Review Board (IRB)

UTSR research is defined by an Industrial Review Board and is conducted by Performing Member Universities. Gas turbine research needs defined by the IRB are used for an annual Request for Proposal (RFP) that is released to Performing Member Universities. Proposals from the universities are reviewed by the IRB and awards made to the highest ranked proposals. Definition of research topics and selection of awards by the IRB keeps the research program relevant. Coordination with industry and review of the university project reports by the IRB companies also accelerates the technology transfer.

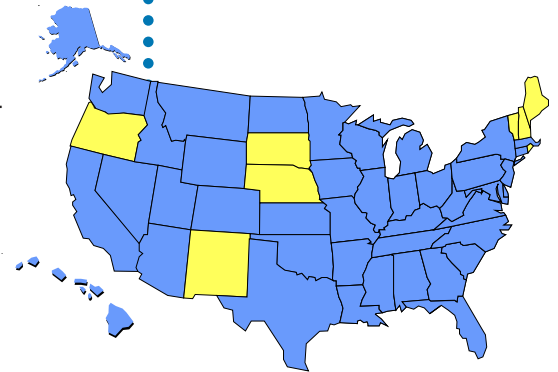
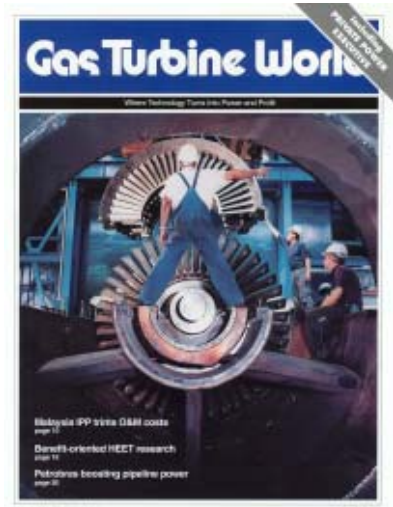


Figure 3

### Industrial Review Board

- BP
- Clean Energy Systems
- Duke Energy
- EPRI
- ExxonMobil
- General Electric Company
- Ingersoll Rand Energy Systems
- Parker Hannifin
- Pratt & Whitney/UTRC
- Precision Combustion, Inc.
- Siemens Power Generation
- Solar Turbines, Inc.
- Southern Company Services
- Woodward FST

There are fourteen turbine related organizations participating in the project. Each company contributes \$25,000 (non-voting \$7,500) per year to the program.



2006 UTSR Academic Advisory Board

## CONTACT POINTS

### Ron Harp

Project Manager  
National Energy Technology  
Laboratory, U.S. DOE  
(304) 285-5436  
(304) 285-4403 fax  
[ronle.harp@netl.doe.gov](mailto:ronle.harp@netl.doe.gov)

### Richard Wenglarz

Manager of Research  
UTSR Program  
South Carolina Institute  
for Energy Studies  
Clemson University  
386-2 College Avenue  
Clemson, SC 29634-5711  
(864) 656-2267  
(864) 656-0142 fax  
[rwnglrz@clemson.edu](mailto:rwnglrz@clemson.edu)

### William H. Day

Outreach Manager  
UTSR Program  
South Carolina Institute  
for Energy Studies  
Clemson University  
25 Longview Drive  
Avon, CT 06001  
860-404-0759  
860-673-5958 fax  
[billday3@comcast.net](mailto:billday3@comcast.net)

### Rob Leitner

Director  
South Carolina Institute  
for Energy Studies  
Clemson University  
386-2 College Avenue  
Clemson, SC 29634-5711  
(864) 656-2267  
(864) 656-0142 fax  
[rlleitne@clemson.edu](mailto:rlleitne@clemson.edu)

## UTSR Academic Advisory Board

During the UTSR Peer Review Workshop II, the Academic Advisory Board (AAB) was formed in an effort to enhance the academic voice in the UTSR Program. Also during the workshop, officers for the AAB were elected (see below). Richard Huntington of ExxonMobil was appointed as the IRB liason for the AAB.

One of the first activities of the AAB, was the preparation and participation in the Short Course entitled, "Impact of Coal Derived and Hydrogen Fuels Relevant to Gas Turbines" at the West Virginia University National Research Center for Coal and Energy (NRCCE) in August 2004. The AAB is currently offering a series of short courses to industry.

**Chair** - Tim Lieuwen, Georgia Institute of Technology  
**Co-Chair** - Jeffrey Bons, Brigham Young University  
**Past Chair** - Karen Thole, Pennsylvania State University  
**Secretary** - Vince McDonell, University of California, Irvine  
**Education** - Bob Santoro, Pennsylvania State University  
**Combustion** - Dom Santavicca, Pennsylvania State University  
**Materials** - Eric Jordan, University of Connecticut  
**Aero/Heat Transfer** - Sumanta Acharya, Louisiana State University  
**Instrumentation, Sensors and Life** - Michael Renfro, University of Connecticut

## Gas Turbine Industrial Fellowship Program

The program offers students valuable work experience and the opportunity to practice the "art" of engineering in an industrial setting. Discipline areas, as applied to land-based gas turbine power generation systems, include mechanical design and manufacturing, heat transfer, aerodynamics, combustion, thermodynamic analyses, materials and coatings, and testing and evaluation.

Emphasis is placed on gas turbine component design and manufacturing techniques, using state-of-the-art experimental and computational facilities. UTSR professors and industry engineering staff serve as mentors and advisors for the fellows. Students are exposed to gas turbine design techniques, analysis and system optimization methods, design limitations and practical problems encountered in the industry.

Program eligibility requires students to be in good standing in an appropriate graduate degree program at an accredited U.S. college or university that is a UTSR Performing Member. The program targets B.S., M.S. and Ph.D. students. Applicants must be U.S. citizens or permanent resident aliens. The applicant's selection is based on academic record, aptitude and gas turbine engineering interest, as well as the recommendation of the applicant's advisor and engineering instructors.



Fellowship Poster Presentation at the UTSR Peer Review Workshop, October 2003



**2005 UTSR Peer Review Workshop III  
Gas Turbine Industrial Fellows who presented posters at workshop.**

Brett Bathel	University of Iowa	General Electric
David Beerer	University of California, Irvine	Pratt & Whitney
Bradford Borchert	Brigham Young University	Clean Energy Systems
Keith Fackler	University of Washington	Solar Turbines
William Humber	Pennsylvania State University	Pratt & Whitney
Mouna Lamnaouer	University of Central Florida	Siemens Power Generation
Scott Lewis	Brigham Young University	Precision Combustion
Fabian Mueller	University of California, Irvine	General Electric
Travis Patterson	University of Central Florida	Siemens Power Generation
Stephen Peluso	Pennsylvania State University	Solar Turbines
Misty Pender	University of Central Florida	EPRI
Naoufal Souitat	University of New Hampshire	Ingersoll Rand Energy Systems
Daniel Sweeney	Colorado State University	Woodward FST

#### 2007 UTSR Industrial Fellowship Awards

### Programmatic Impact of UTSR

- established a successful dialogue between industry, universities, and government that can continue beyond
- marshaled/focused U.S. university research on gas turbine industry research needs - the only focused group in the nation
- produced a cross cutting network of new technology usable by the gas turbine industry
- developed collaborations between government, industry and universities that accelerated research
- developed forms for rapid technology transition and entry into the gas turbine industry
- established a recognized centralized location for gas turbine technology inquiries
- developed university student interest in and provided mechanism for preparations for work in the gas turbine industry.