PROJECT facts

University Turbine Systems Research

Establishing The Scientific Foundation For Advanced Energy Systems

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

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

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 NOx 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

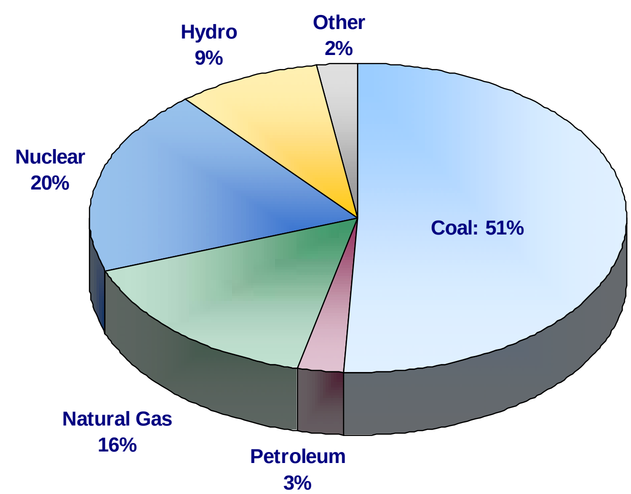
= 45-50% efficient coal turbine plants
= Capital cost < $1000/KW
= 2-3 percentage points greater efficiency than current IGCC Plants

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

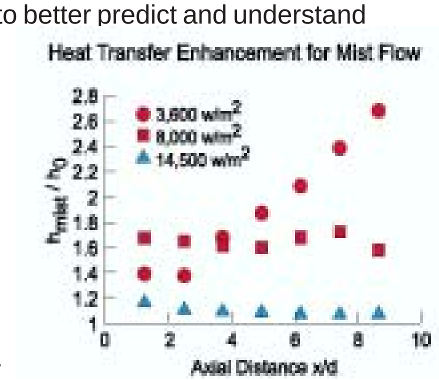
Program Research Accomplishments

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

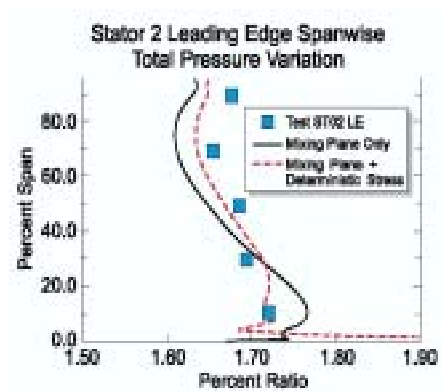
Aerodynamics and Heat Transfer Research

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.



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 area is to permit higher turbine inlet temperatures to achieve cycle efficiency benefits while lowering NOx, 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_x 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

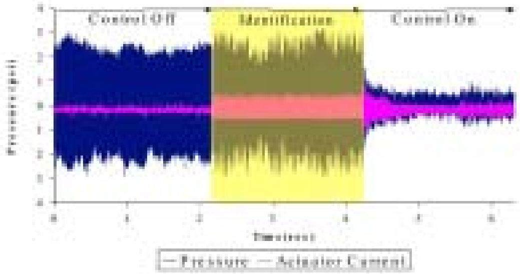
1997
Cornell University
Cleveland State University
Massachusetts Institute of Technology
Northwestern University
Pennsylvania State University
Purdue University
University of California at Davis
University of Pittsburgh/
University of Connecticut
University of Wisconsin-Madison/
University of Texas at 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

Combustion Research

- A short course on Combustion Dynamics has been developed by Cal-Tech in cooperation with Pratt and Whitney.

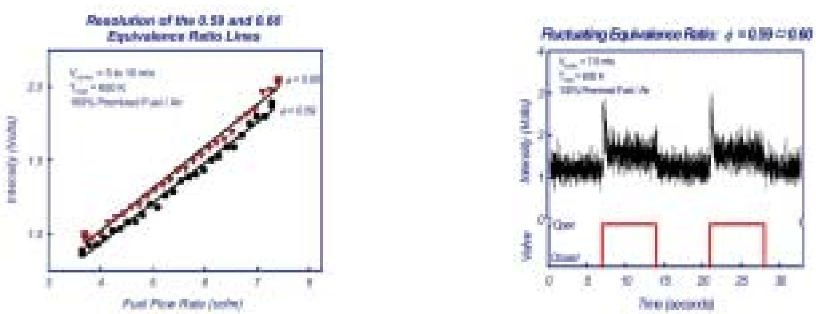
- Georgia Tech and Siemens Westinghouse conducted a series of active combustion control tests on a 3 MW atmospheric combustor that demonstrated how the Active Control System automatically detected combustion instabilities, identified combustor characteristics, and instantaneously" attenuated the unstable 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_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.
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)

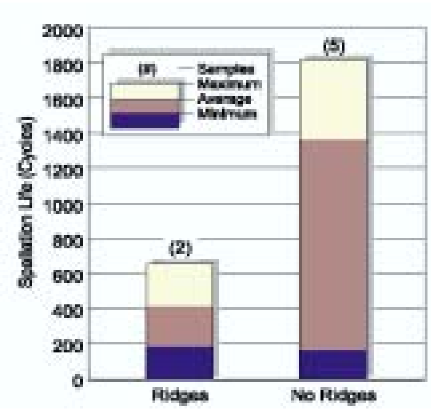
2003
University of Wisconsin, Madison
Texas A&M University
Cleveland State University
Georgia Institute of Technology
University of Connecticut
Clemson University
Pennsylvania State University
Virginia Polytechnic Institute
University of California, Irvine

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

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 oxiadtion resistant behavior.

- Five materials workshops have been held.

UTSR Workshops

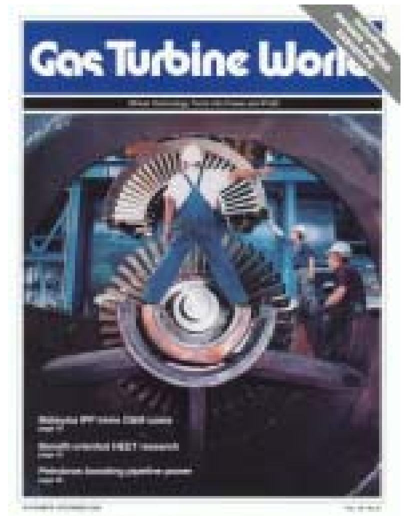
The UTSR uses workshops to further facilitate early discussion and release of research progress, promote interaction and teaming among research groups, and to assist in defining industry research needs. Personnel from industry, universities, and government attend these workshops. Numerous workshops and 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 17 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 11 years, 174 students attending Performing Member Universities have participated in the Fellowship Program.

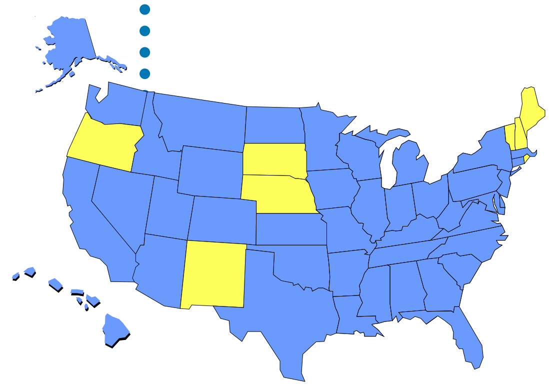


Figure 3

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.

Industrial Review Board

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

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

2004 UTSR Academic Advisory Board

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 will also be proposing research activities to the IRB.

Chair: Karen Thole, Virginia Polytechnic Institute
Co-Chair: Tim Liewen, Georgia Institute of Technology
Secretary: Vince McDonell, University of California, Irvine
Education: Yongho Sohn, University of Central Florida
Combustion: Dom Santavicca, Pennsylvania State University
Materials: Eric Jordan, University of Connecticut
Aero/Heat Transfer: Jeffrey Bons, Brigham Young University
Diagnostics: Scott Sanders, University of Wisconsin

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, aero-dynamics, 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.

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

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.

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

Fellow	University	Company Placement
Brett Bathel	University of Iowa	Woodward FST
Matthew Bloxham	Brigham Young University	Ingersoll Rand Energy Systems
Trey Bolchoz	Clemson University	Solar Turbines, Inc.
David Thiepxuan Cao	Michigan State University	Precision Combustion, Inc.
Marty Chang	Case Western Reserve University	Parker Hannifin Corporation
Clayton DeLosier	University of Nevada, Las Vegas	Clean Energy Systems
Alexander Hreiz	Georgia Institute of Technology	Siemens Power Generation
Jonathan McGlumphy	Virginia Tech	Rolls Royce Corporation
Curtis Memory	Brigham Young University	Ramgen
Emmanuel Oluyede	University of Pittsburgh	EPRI
Travis Patterson	University of Central Florida	Siemens Power Generation
Emmanuel Perez	University of Central Florida	General Electric Company
Daniel Reimann	Brigham Young University	Capstone Turbine Corporation
Jimmy Robertson III	University of Oklahoma	Pratt & Whitney/UTRC

2006 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.