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 2007

TOTAL ESTIMATED COST
$44,740,299

COST SHARING

DOE $42,920,799
Non-DOE $1,819,500
Goals and Objectives

Figure 1 shows the goals and objectives of the DOE Turbine Program. The Turbine Program will also provide the research and development support for the utilization of high hydrogen fuels in advanced coal based power plants that have competitive costs, high efficiency, near zero emissions and a significant percentage of carbon dioxide capture. The UTSR Program is advancing critical technologies needed for the Turbine Program in the areas of combustion, materials, aero-heat transfer, and instrumentation and sensors and life.

Major Project Areas

- **High Efficiency Power Modules**
  - Development of hybrids and advanced industrial systems

- **Durable Materials - Near Zero Emissions/Fuel Flexibility**
  - Coatings and advanced alloys
  - Catalytic Combustion
  - Trapped Vortex Combustion
  - Advanced after treatment

- **Improved Electricity Reliability**
  - Condition Monitoring
  - Sensors/Controls
  - Information Technology

Public Benefits

- **Potential U.S. Market (year 2005-2015) - 106 GW**

  Figure 2 - Electric Generation By Fuel

- Clean, reliable power in load congested regions

- By year 2020, cumulative savings:
  - Advanced Coal Plants
    - Savings in the cost of electricity: $350 Million/yr
    - Carbon emissions reduction: 15 Million tons/yr

- Maintain U.S. industry competitive position in growing international power markets

- National solutions for power and defense--Collaboration between agencies
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 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 NOx emissions reduction.
- 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 a t m o s p h e r i c combustor that demonstrated how the Active Control System automatically detected combustion instabilities, identified combustor characteristics, and instantaneously attenuated the unstable mode.

- 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.

- 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.
Materials Research

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.

Three 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 24 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
- Turbo Machinery International July-August 2003 Issue

UTSR Performing Member Universities

At present, there are 107 performing member universities representing 40 states, and 15 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 10 years, 140 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.
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UTSR Academic Advisory Board

During the recent 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 liaison 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
Instrumentation, Sensors and Life: 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.

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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developed forms for rapid technology transition and entry into the gas turbine industry

established a recognized centralized location for gas turbine technology inquiries

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Programmatic Impact of UTSR

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