Clean ENERGY – for the – 21st Century

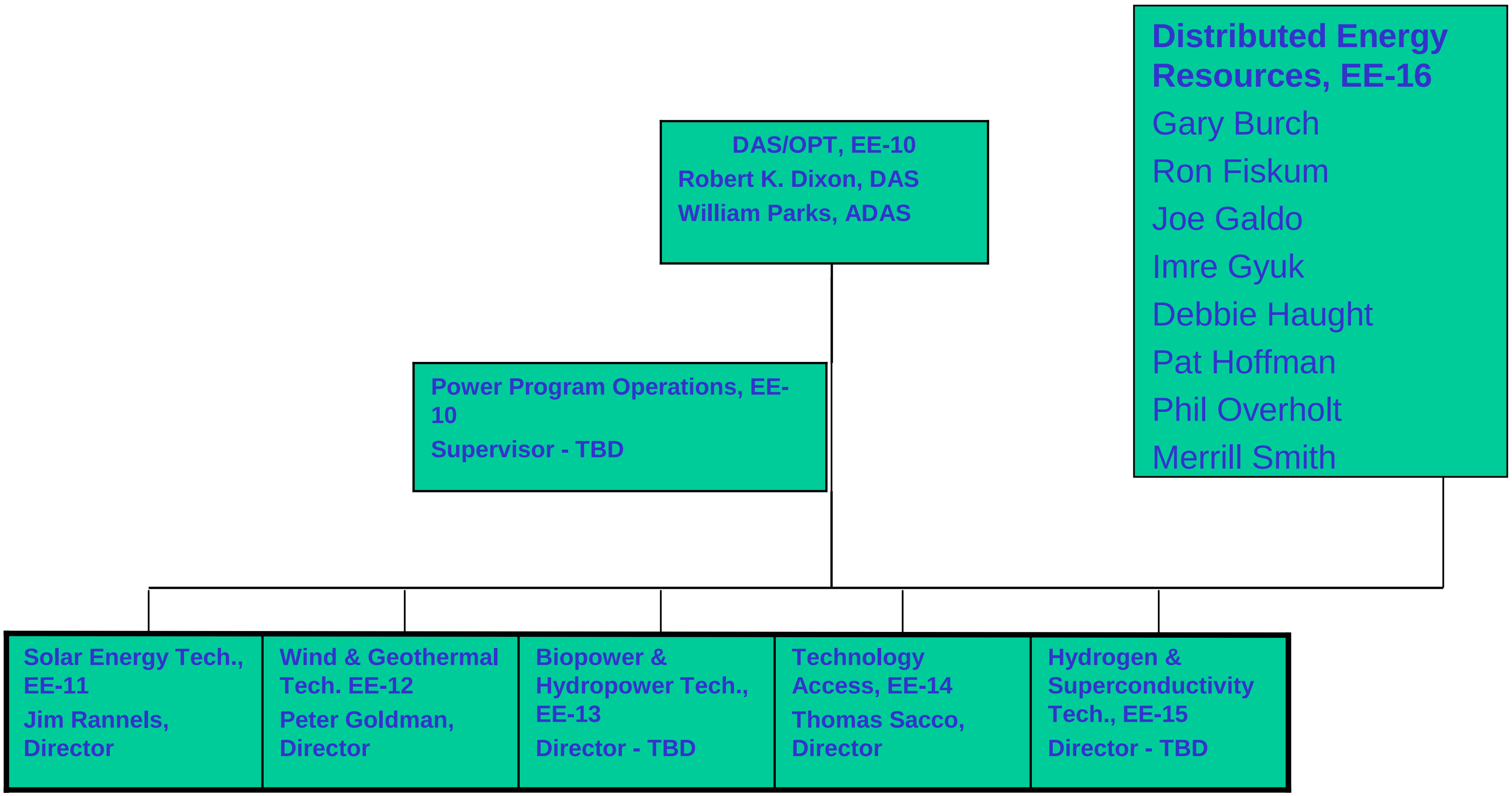
DOE Advanced Microturbine Program Update

Final ATS Annual Program Review Meeting

December 4- 6, 2000
Alexandria, VA

Debbie Haught
Office of Power Technologies
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Office Of Power Technologies Organization (12/00)



DER Program Integration

Before - Distributed Programs

From OPT
- Distributed Power
- Transmission Reliability
- Energy Storage
- Electricity Restructuring

From OIT
- Advanced turbines
- Microturbines
- Reciprocating Engines
- CHP
- Advanced materials

From OBT
- Thermally Activated Techs
- PEM Fuel Cells
- Equipment Integration
- BCHP

After - Consolidation in OPT

Advanced Energy Technologies
- Natural Gas Prime Movers
- Thermally Activated Technologies
- Energy Storage Systems

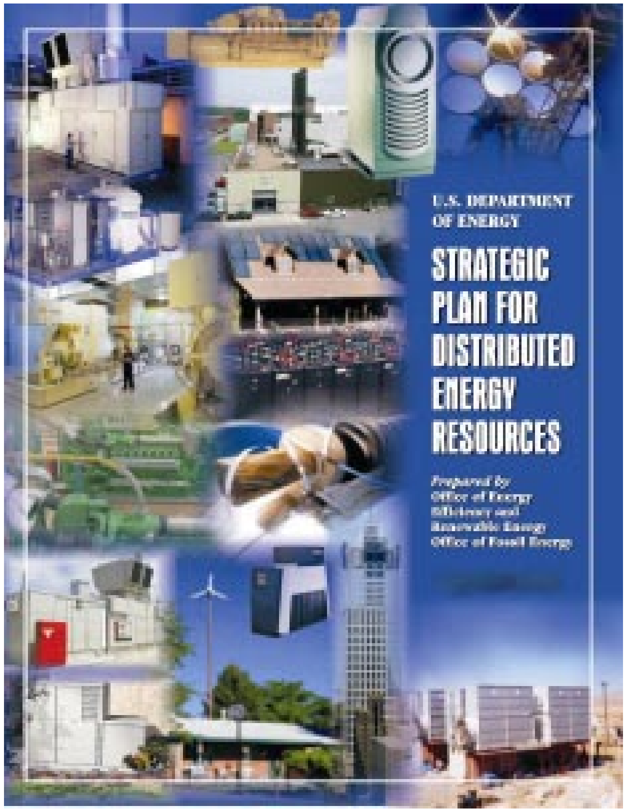
Crosscutting Technologies
- Advanced Control Technologies
  - Grid Control
- Advanced Materials

Systems Integration, Testing, and Demonstrations
- Buildings Applications
- Industrial Process Applications

Market and Outreach
- Transmission Reliability (Market Issues)
- Utility Practices (Interconnection Standards)
- Electricity Restructuring
- DER Implementation (Regulatory Issues)

DER Strategic Plan

- www.eren.doe.gov/der/taskforce.html



- Integrated Energy Efficiency and Renewable Energy/Fossil Energy effort

DOE/OPT Microturbine Activities

- State-of-the-art technology assessments; industrial market studies
- Baseline Microturbine Testing
  - University of California-Irvine & Southern California Edison
  - National Rural Electric Cooperative Association (NRECA)
- Advanced Microturbine Program
  - Competitive solicitation, awards announced 7/00
- Supporting Materials Technology Projects
- Collaborating/joint planning with CEC, NYSERDA, EPRI, CANMET, NRECA

Baseline Microturbine Evaluation Program

- 2.1^+$ Million Program begun by Southern CA Edison (SCE) and University of CA-Irivine (UCI) in 1996
- Funded by: SCE, DOE, CEC, EPRI
- Project Goal:
  - Determine the availability, operability, reliability and performance characteristics of commercially available microturbines
- Project Objectives
  - Compare manufacturer claims to actual experiences from installation, operation and testing of units
  - Assess microturbine performance against SCAQMD emissions rule and IEEE power quality standards

Microturbine Test Site Features

- UCI Combustion Laboratory used as test facility; modifications were necessary to prepare site to provide natural gas, grid connections, and handle thermal load requirements of cogen units
- Installed 400 amp service to test pad, added 100 psig Natural Gas Fuel Header, Installed Blended Gas Mixing Capability for lower BTU fuel content testing
- Site capable of running 4 MTGs simultaneously
- MTGs instrumented with sensors and meters to collect operational data automatically
- Seasoned veteran two-person on-site test crew

Microturbine Program Schedule

1Q97 - 2Q97: Two Capstone Beta Units

2Q97 - 4Q97: Two Capstone Charlie Units

1Q98 - 4Q98: Prepare MTG Testing Site at UCI
Seek & purchase available MTGs

1Q99 - 4Q99: Bowman 35 kW, Bowman 60 kW,
Capstone HP 28 kW

1Q99 - 1Q01: Capstone LP 30 kW, Honeywell 75 kW,
Elliott 80 kW & Bowman 45 kW

Microturbine Installations

MTG	Installation Date	Total Op Hours	Status
Bowman 35 kW	Feb-99	100	Completed
Bowman 60 kW	Jun-99	60	Completed
Capstone HP 28 kW	Apr-99	10700	Operating
Parallon 75 kW	Jun-00	2650	Operating
Capstone LP 30 kW	Aug-00	1300	Operating

Capstone HP 28 kW Description

- Configuration:
  - Model 330 rated output: 28 kW at ISO
  - 480 VAC, 3-phase, 60 Hz
  - Recuperated single stage radial flow compressor and turbine on a single shaft, integrated with generator
  - Equipped with a low NOx combustor
  - Not equipped with a waste heat recovery boiler
  - Fourth generation unit

Capstone 28 kW Results

- Several overspeed trips were resulting from flame control algorithm; Capstone remotely downloaded revised control system software; no overspeed trips since software revised
- Reliable operation following resolution of overspeed
- Comparing manufacturer’s efficiency and heat rate claims with test results converted to a common basis, resulted in testing results consistent with claims as shown below
  @ 70°F, about sea level, and LHV:

	(tested)	(claimed)
Efficiency	23.7% ± 0.45%	24.5% ± 0.5%
Heat rate	14,415 BTU/kWh	13,931 BTU/kWh

Advanced Microturbine Program

- Six year program (FY 2000 - 2006), $60+ million Govt investment
- Program to include:
  - Competitive solicitation(s) for engine conceptual design, development, and demonstration; component, sub-sub-system development
  - Competitive solicitation(s) for Technology base in areas such as materials, combustion, sensors and controls, etc
  - Technology Evaluations and Demonstrations
- End-use applications open to include stationary power applications in industrial, commercial, and institutional sectors

DOE Advanced Microturbine Program

Next Generation Microturbine System (< 1,000 kW) by 2006 :

- **High Efficiency** - Fuel-to-electricity conversion efficiency of at least 40%
- **Environmental Superiority** - NOx < 7 ppm (natural gas)
- **Durable** - 11,000 hours of reliable operations between major overhauls and a service life of at least 45,000 hours
- **Economical** - System costs < $500/kw, costs of electricity that are competitive with the alternatives (including grid) for market applications
- **Fuel Flexible** - Options for using multiple fuels including diesel, ethanol, landfill gas, bio-fuels

Honeywell

United Technologies Research Center

Pratt & Whitney Canada
Une societe de United Technologies/A United Technologies Company

Capstone

IR Energy Systems

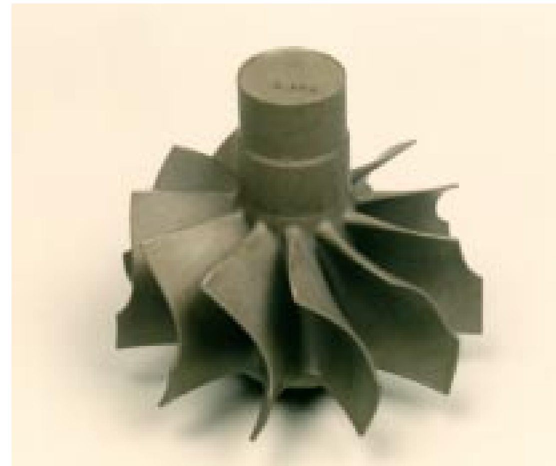
Solar Turbines
A Caterpillar Company

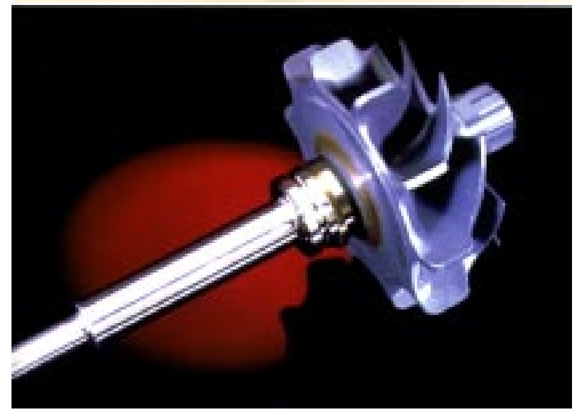
Ingersoll-Rand's-
Advanced Microturbine Program

- DOE Funding: $1.4 M over 4 years
- Partners: Kyocera, Honeywell Ceramic Components, ORNL, NASA
- Approach: Apply today's Si_3N_4 turbine technology to PowerWorks™ platform:
  - Power Gen (100 – 250 kW with an electrical efficiency of 40% LHV
  - High efficiency direct-drive air compressor
  - Advanced high efficiency chiller and refrigeration packages

Ingersoll-Rand's- Advanced Microturbine Program

- Applying today's Si_3N_4 technology to microturbines will achieve near-term product success:
  - PowerWorks™ air compressors use turbine rotors comparable in size (<3 in dia.) and geometry to Si3N4 turbochargers that have been produced in high-volume.





  - These small turbocharger rotors are low in cost, and operate at temperatures above that of uncooled metallic candidates.

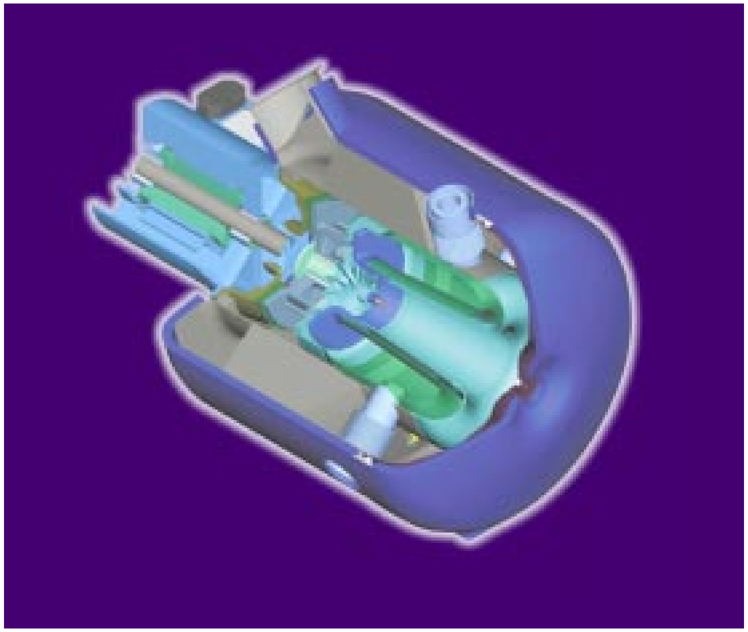
Capstone Turbine – Advanced Microturbine Program

DOE Funding: $10.0 M over 5 years

Partners: Kyocera, Honeywell Ceramic Components, ECI, Solar Turbines, ORNL, UCI, UCLA

Design concept for 100 – 200 kW microturbine with

- Single shaft powerhead / generator
- Air bearings
- Recuperated cycle
- Lean premix combustion
- High efficiency components, including ceramics



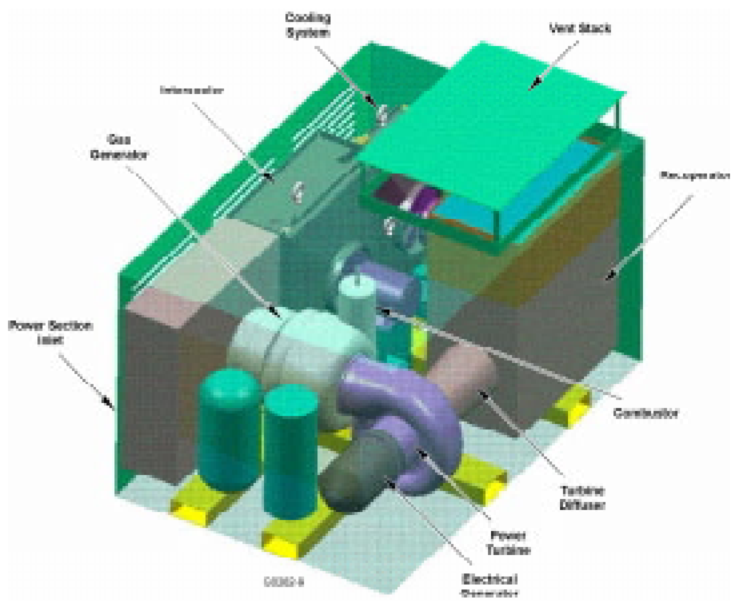
Honeywell – Advanced Microturbine Program

DOE Funding: $10.0 M over 3+ years

Partners: Honeywell Engines and Systems (Torrance, Phoenix, Ceramic Components), Precision Combustion Inc., LBNL, Calnetix

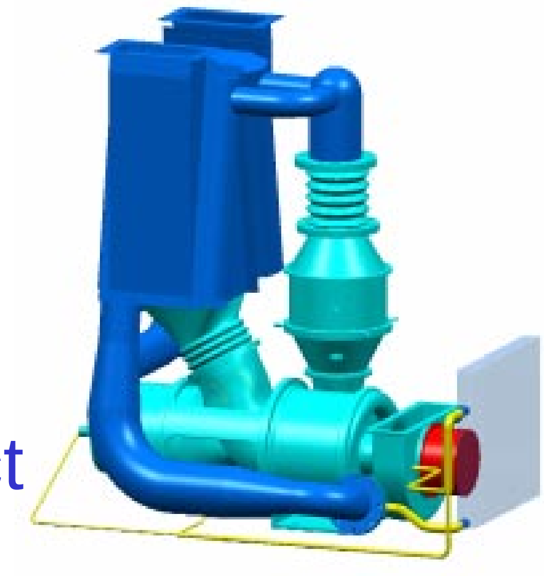
Design concept for 300+ kW microturbine:

- Judicious use of advanced materials to reach efficiency targets
- Low emission combustor
- Builds upon the technology of the Parallon ™75 microturbine for increased efficiency, lower emissions, and improved life costs



UTC - Advanced Microturbine Program

- DOE Funding: $8.6 M over 5 years
- Partners: **UTRC, DTE Energy, P&W Canada, TurboGenset, Hamilton Sundstrand, SatCon, Kyocera, ORNL, Solar Turbines**



- Approach: Demonstrate new product capability of enhanced ENT-4000 microturbine system
  - **400-kW class recuperated microturbine based on PWC ST5 engine, 30% electrical efficiency**
  - **Launched in July 2000 through partnership of DTE Energy Technologies, P&W Canada, and TurboGenset**
  - **Initial product delivery in March 2002**

UTC Advanced Microturbine System: Approach

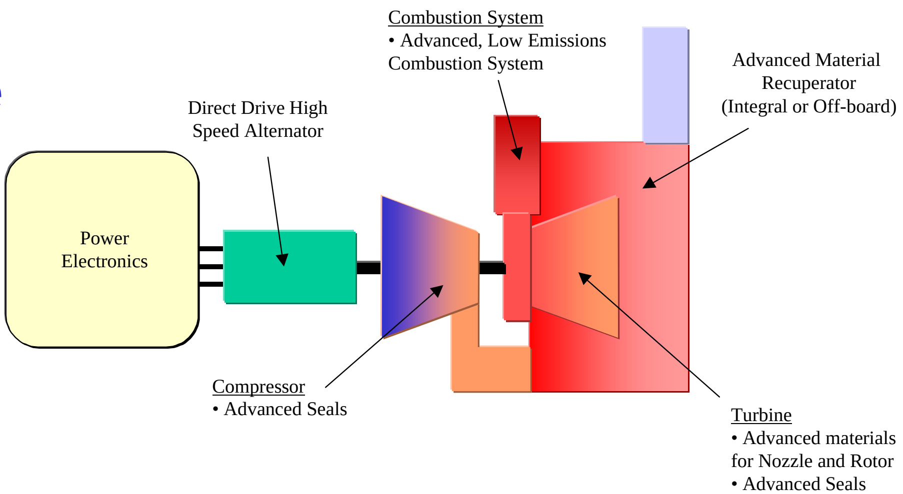
- Approach:
  - Identify & develop technologies to achieve DOE goals for electrical efficiency, NOx, cost, and life
  - Demonstrate performance on test-stand, and durability in microgrid
- 3-Part Strategy for >40% Electrical Efficiency
  - Increase RIT using uncooled, ceramic hot section components
  - Increase power generation/conversion efficiency
  - Convert exhaust energy with Organic Rankine Cycle (ORC)
- Preserve low NOx with affordable, small-scale fuel-air mixers

GE – Advanced Microturbine Program

- DOE Funding: $4.7 M over 4 years
- Partners: GE (Corporate Research, Power Systems, Industrial Systems), Semikron, Kyocera

Design concept for 175- 350 kW microturbine:

- Advanced recuperator design
- Low emission combustion system
- Advanced sealing and material usage
- State-of-the art power electronics and controls
- Compressor and turbine advanced turbomachinery design methodology



Solar Turbines
Advanced Microturbine Program

- DOE Funding: $4.5 M over 3 years
- Partners: Allegheny Ludlum, ORNL, Capstone Turbine, Elliott Power Systems, UTRC
- Approach: Update existing Primary Surface Recuperator (PSR) Capability
  - Increase the turbine exhaust temperature capability from 649º to 732ºC
  - Alloy modification to improve strength, creep strength and oxidation resistance
  - Strong focus on cost containment and reduction
    - Recuperators, one third the cost of a microturbine system
  - Improve key high cost manufacturing processes used in the manufacturer of microturbine recuperators

Microturbine Materials Technology Activities

- Si_3N_4 Ceramics
  - Environmental Stability (Honeywell, Kyocera, ORNL)
  - Mechanical Properties (UDRI, ORNL)
  - Protective Coatings (ORNL)
  - Reliability and Life Prediction (NASA, ORNL)
  - NDE (ANL)
- Recuperator Materials
  - SOA Materials Assessment (ORNL)
  - Advanced and Improved Materials (ORNL)
  - Microturbine Materials Test Facility (ORNL)
- Heat Sinks
  - High Conductivity Carbon Foam (ORNL)

Advanced Microturbine Hot Section Materials Program Objectives

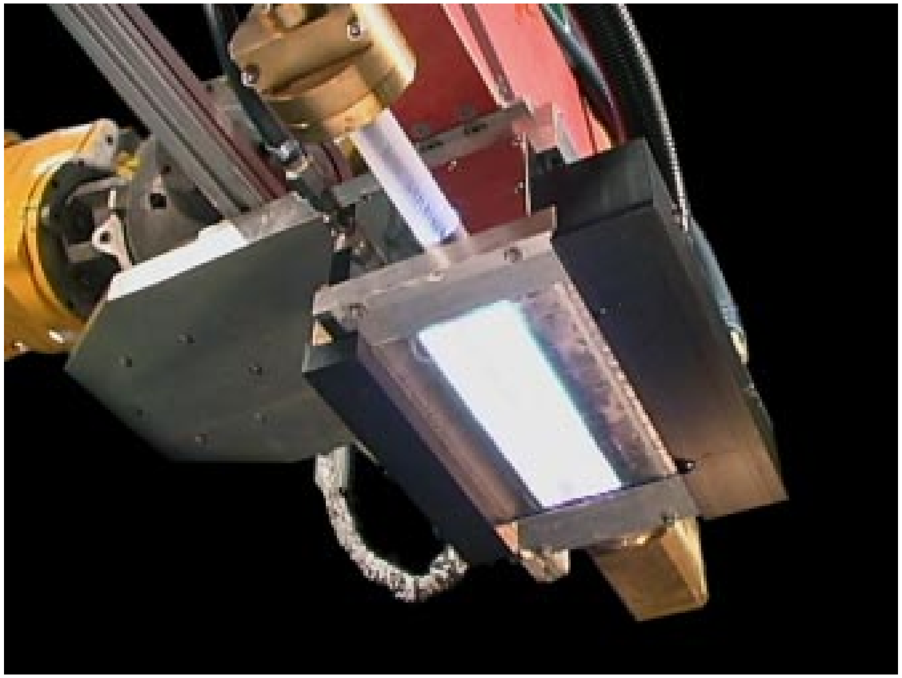
- Develop a design envelope of anticipated operating conditions for a Si_3N_4 rotor for an advanced microturbine
- Evaluate the effects of temperature, pressure, water vapor, and other gas species typical of advanced microturbines on the environmental resistance and mechanical stability of candidate Si_3N_4 ceramics
- Complete an assessment and initial evaluation of methods to improve or enhance the environmental stability of candidate Si_3N_4's (coatings)
- Enhance current structural ceramic reliability and life prediction capabilities to incorporate environmental and coating issues
- Develop advanced ceramic manufacturing approaches capable of reducing the development cost and time for the prototype-to-production transition (optional)

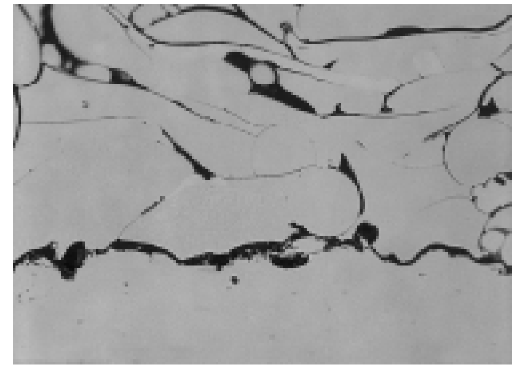
Program Participants

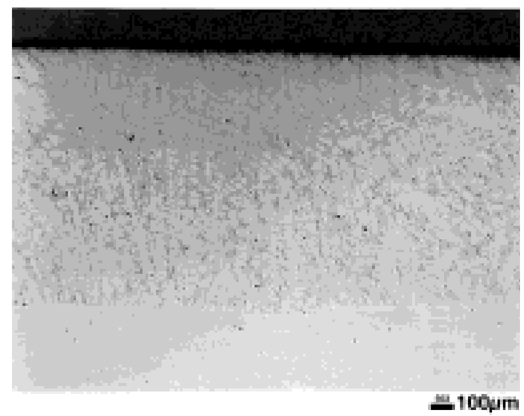
- **Honeywell Ceramic Components**
  - Phase I
    - Task 1: Advanced Microturbine Scoping Studies and Research Plan
  - Phase II
    - Task 1: Environmental Effects Evaluation (Uncoated)
    - Task 2: Technology Assessment for Environmental Protection
    - Task 3: Rapid Prototyping
- **Kyocera Industrial Ceramics Corporation**
  - Phase I: Develop Database of Application Requirements
  - Phase II: Provide Data on Performance of Materials in Microturbines
    - Evaluate Baseline (Uncoated), Coated, and Alternate Materials

Both teams include microturbine manufacturers

Novel Infrared Processing May Produce Cost Effective Coatings



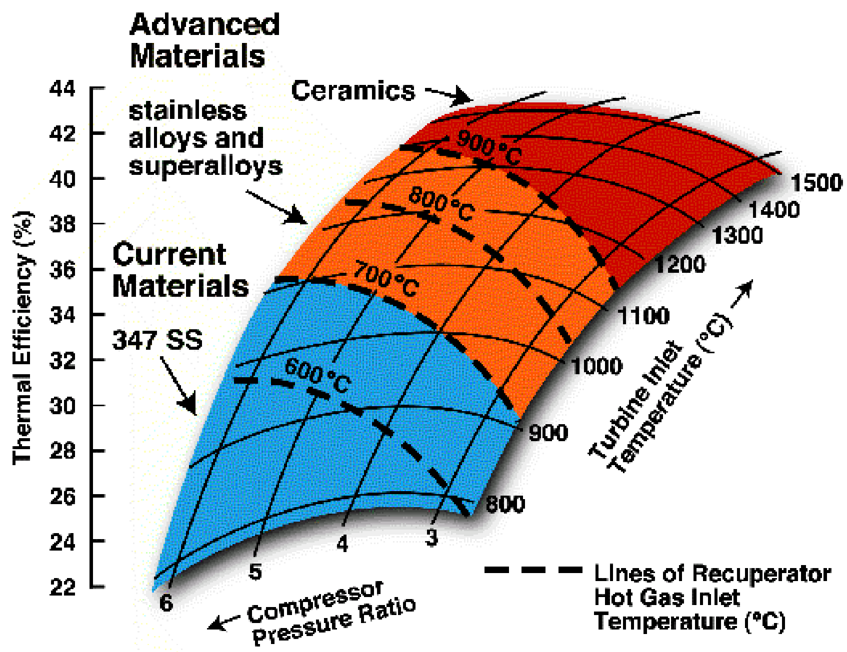




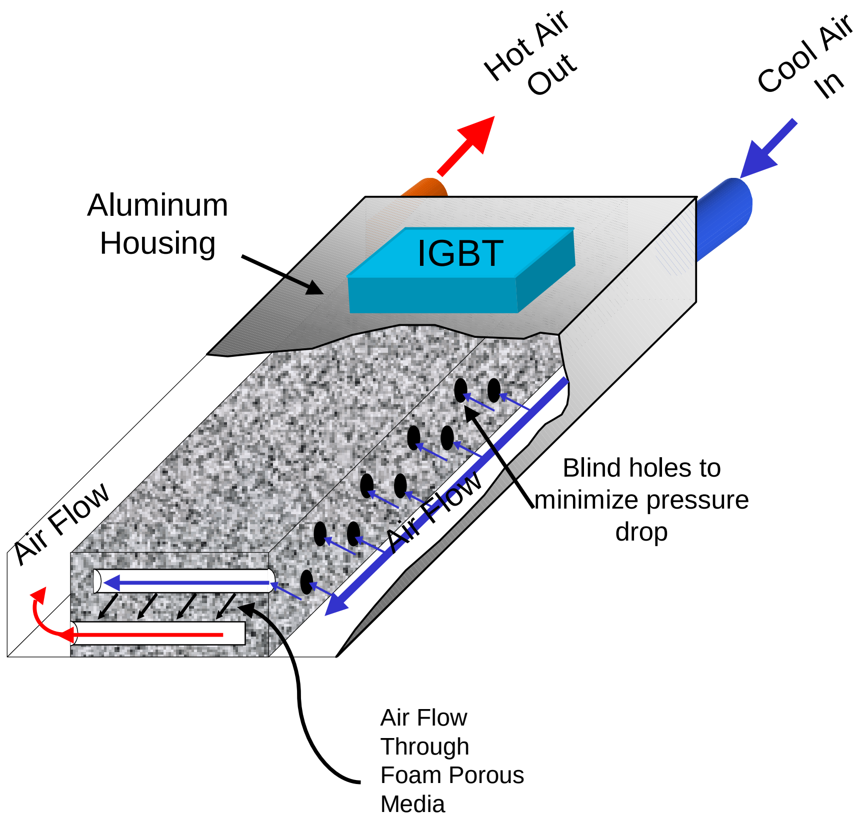
Slurry-based and plasma sprayed coatings are being densified or fused using the infrared lamp to improved their corrosion resistance

Advanced Recuperator Materials

- Advanced Microturbines Will Operate at Higher Temperatures and Demand Improved Recuperator Materials
- Current Activities Focused on:
  – Creep-resistant Materials (600-750°C) (ORNL)
  – Oxidation-resistant Materials (750-900°C) (ORNL)
  – Microturbine Materials Test Facility (ORNL)



Carbon Foam Heat Exchangers are being Optimized for Heat Transfer and Pressure Drop



Second Generation Carbon Foam Heat Sink for Power Electronics

	Heat Transfer Coefficient h, (W/m²·K)	ΔP/L (psi/in)
Solid Foam	2600	2
Finned	1000	<0.05
Pin-Fin	1500	0.05
Blind-holes (pin fin negative)	3500	1
Blind-holes (parallel to air flow)	3100	1
Current Radiators	20-40	<0.05

Microturbine Program Contacts

- DOE Office of Power Technologies
  Debbie Haught 202.586.2211
  debbie.haught@ee.doe.gov
- DOE Chicago Operations Office
  Steve Waslo 630.252.2143
  stephen.waslo@ch.doe.gov
- Oak Ridge National Laboratory
  Mike Karnitz 423.574.5150
  karnitzma@ornl.gov
- Dave Stinton 423.574.4556
  stintondp@ornl.gov

Update on Follow-on Industrial Gas Turbine Work

Further Advancement of Industrial Gas Turbines Sought

- Improve performance of industrial gas turbines through use of advanced materials
- Low Emissions Technology – target < 5 ppm NOx
  - Consideration for transition to back-up fuels
  - Durable for at least 8000 hours
  - No more than 10% cost add-on
  - No negative impacts on gas turbine performance

Advanced Materials Solicitation Winners

- GE Corporate Research & Development
- Teledyne Continental Motors
- Siemens Westinghouse
- Solar Turbines

DOE Funding is $7.0 Million over 3 years

GE Advanced Materials Project

- **Melt Infiltrated Ceramic Matrix Composites for Shrouds and Combustor Liners of Advanced Industrial Gas Turbines** - General Electric Corporate Research and Development, ($2.7 million)
- Partners: G.E. Power Systems; Honeywell Advanced Composites ; B.F. Goodrich Aerospace; and Oak Ridge National Laboratory
- GE will focus on application of MI composites to first stage shrouds of industrial gas turbines,building upon efforts under the Continuous Fiber Ceramic Composite (CFCC) program. The technology will be subsequently be applied to other hot stage components, including the combustor transition piece, turbine nozzles, and ultimately turbine buckets.

Teledyne Advanced Materials Project

- **Advanced Materials in Advanced Industrial Gas Turbines** - Teledyne Continental Motors ($300,000)
- Partners: Titanium Products; 3 – ONE – 2; and Consolidated Technologies
- Apply advanced material systems to microturbine components to enable a 450° F cycle temperature increase from first generation design to obtain improvement in the thermal efficiency performance by over a factor of 120%.
  - Low cost process for pressure consolidation of powder nickel super-alloys.
  - Flexible pattern mold process to be used for powder consolidation for net shape processing.
  - Titanium silicon carbide (Ti_3SiC_2) for stationary turbine stage components,

Siemens Westinghouse Advanced Materials Project

- **Cooperative Research and Development for Advanced Materials in Advanced Industrial Gas Turbines**, Siemens Westinghouse Power Corporation ($750,000)
- Partners: Chromalloy Turbine Technologies; Howmet; Engineering Ceramics Inc.; Westinghouse Plasma Corporation; Transtech; Praxair Therma Systems; Oak Ridge National Laboratory; Applied Thin Films, Inc.; LoTec Inc.; and Dow Chemical
- Siemens Westinghouse will advance the development of thermal barrier coatings and demonstrate in a field test at Dow Chemical site.

Solar Turbines Advanced Materials Project

- **Advanced Materials for Mercury 50 Gas Turbine Combustion System**, Solar Turbines ($3.1 million)
- Honeywell Advanced Composites; Schwarzkoph Technologies Corporation; The Welding Institute; Praxair Surface Technologies; Univ. of Connecticut; Oak Ridge National Laboratory; Pratt Whitney – United Technologies Research Center; Argonne National Laboratory; Honeywell Ceramic Components; and Clemson Univ.
- Demonstrate a fully integrated Mercury 50-combustion system, modified with advanced materials technologies, at a host site for 4,000 hours.
- Continued field testing of Ceramic components at Bakersfield and Malden Mills

Low Emission Solicitation Winners

- Precision Combustion Inc (PCI)
- Catalytica Combustion Systems Inc
- Alzeta
- Solar Turbines
- Honeywell Engines

DOE Funding is $6.0 Million over 3 years

PCI Low Emissions Project

- **Catalytic Combustor for Ultra-Low NOX Advanced Industrial Gas Turbines**, Precision Combustion, Inc. ($1.4 million)
- Partners: Haynes International; Honeywell Engines & Systems; Siemens Westinghouse; Solar Turbines; and University of Connecticut
- Precision combustion will continue the development of an advanced catalytic combustion technology that promises many advantages over existing systems.

Catalytica Low Emissions Project

- **Component Development to Accelerate Commercial Implementation of Ultra-Low Emissions Catalytic Combustion**, Catalytica Combustion Systems, Inc., ($1.6 million)
- Partners: Rolls Royce Allison and Solar Turbines
- The project partners will research extending longevity of the catalyst for use with other turbines and lowering the cost of emissions prevention.

Alzeta Low Emissions Project

- **Demonstration of the Surface Stabilized Combustor for Advanced Industrial Gas Turbines**, Alzeta Corporation ($1.2 million)
- Partners: California Energy Commission; Chevron; Honeywell Power Systems, Manufacturing Resources Inc.; National Energy Technology Laboratory; Siemens Westinghouse; and Solar Turbines
- The team will develop and test a novel stabilized combustion technology for industrial gas turbines.

Solar Turbines Low Emissions Project

- **Near Zero NOx Combustion Technology for Advanced Mercury 50 Gas Turbine," Solar Turbines** ($200,000)
- Partners: Catalytica Combustion Systems, Inc.; Precision Combustion Inc.; and University of California-Irvine
- Solar Turbines will design a fully integrated catalytic combustion system for the new Mercury 50 Gas Turbine Combustion System.

Honeywell Engines Low Emissions Project

- **Fuel-Flexible Ultra Low-Emissions Combustion System for Industrial Gas Turbines**,Honeywell Engines & Systems, ($660,000)
- Partners: Precision Combustion Inc.; Texas A&M; and Vericor Power Systems.
- Honeywell will develop an innovative, fuel flexible, air-staged, catalytic gas turbine combustion system with closed-loop control.