UPDATE ON DOE ADVANCED IGCC/H₂ GAS TURBINE

Ray Chupp
GE Energy
Greenville, South Carolina

Update on DOE Advanced IGCC/H₂ Gas Turbine
DE-FC26-05NT42643
Ray Chupp
2008 NASA Seal/Secondary Air System Workshop
November 18-19, 2008
Update on DOE Advanced IGCC/H2 Gas Turbine
DE-FC26-05NT42643
Ray Chupp
2008 NASA Seal/Secondary Air System Workshop
November 18-19, 2008

1. This material is based upon work supported by the Department of Energy under Award Number DE-FC26-05NT42643

2. This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
Acknowledgements

GE would like to extend a special thanks to the US Department of Energy National Energy Technology Laboratory and the following individuals for their past and continued support on the DOE/GE “Advanced IGCC/Hydrogen Gas Turbine Development Program”

Rich Dennis
Turbine Technology Manager
Office of Fossil Energy
U.S. Department of Energy
National Energy Technology Laboratory

Ron Harp
Project Manager
Power Systems Division
U.S. Department of Energy
National Energy Technology Laboratory
IGCC - H₂ Gas Turbine Landscape

Objective
Cleaner Energy from Coal via IGCC with Carbon Capture

Approach

**Today**
- GE existing products:
  - 7FB-H2
- Capabilities:
  - High-H₂ GT fleet
  - Successful operation
  - Diffusion flame
  - Diluent for NOx

**Future**
- Technology Advances
  - Reduced NOx (2ppm)
  - Increased Performance (+3-5pts)
- DOE Program
  - Increased Output
  - Reduced Cost

Capability

Combustion
- Turbine
- Materials
- Systems

Program Timeline


- Phase I (CPT) Concept Design
- Phase II (Awarded, In Progress) Detailed Design & Component Validation Test
- Phase III (Not Yet Awarded) Final Design & Field Evaluation

Combustion Technology:

Phase I... focus on fundamentals
- ‘Chemistry’ evaluation – fuels, mixing, residence time, EGR
- Benchmark existing NG designs on high H2 fuels
- Evaluate 1\textsuperscript{st} Gen prototypes (based on traditional designs)
- Evaluate 2\textsuperscript{nd} Gen prototypes (more ‘out-of-the-box’
  – designed specifically for high H2)

Phase I Goal Complete: Select top two concepts for further evaluation in Phase II

Phase II... design optimization
- Optimize designs for resistance to flashback, flameholding, dynamics
- Obtain data to minimize risk
- Validate the technology

Status: Initial full can/larger scale testing of down selected concepts providing promising results, continuing to drive down emissions and extend operability
Materials Technology:

Phase I... characterization and development
  - Characterizing the environment
  - Identification of candidate material/coating systems
  - Development of screening tests for material systems (corrosion, erosion, impact)
  - CMC/EBC development

Phase I Goal Complete: Screened list of candidate material systems for Phase II

Phase II... enabling turbine technology improvements
  - Validation of material systems at component level
  - Field testing of components where applicable

Status: Interim down select completed with significant capability improvements, line of sight to program targets
Turbine Technology:

Phase I... identifying turbine technology improvements

**Phase I Goal Complete:** Technology development plan for Phase II

Phase II effort is an integrated process with other discipline areas to develop turbine technologies to achieve DOE goals

**Phase II Goal:** Validated technologies at the component level

Turbine - Aerodynamics

Advanced Design

- work splits, reaction, and airfoil counts.
- 3-D Aero & Endwall Contouring

Turbine Rig Testing

- Learning, Validation
Turbine - Mechanical

**Turbine Goal:**
- Higher component efficiency with higher flow rates

**Turbine Efforts Launched:**
- Conceptual design studies on different turbine concepts – aerodynamic and mechanical
- Advanced technology development to reduce parasitic leakages
  - Transition Piece/Stage 1 nozzle seal
  - Turbine interstage beneath nozzle
- Advanced technology dev. to address turbine blade durability
  - Damping effect on aeromechanics
  - Fretting and wear

Turbine – Heat Transfer/Sealing Plans

- **Cooling Flow Reduction:**
  - Focus on improving turbine hot gas path part cooling efficiency
  - Applicable to current metallic turbine components and synergistic with advance materials
  - Address challenges of IGCC/hydrogen fuel environment (for example, possible cooling hole plugging)

- **Leakage Flow Reduction:**
  - Focus on decreasing turbine parasitic leakages, i.e. between static-to-static, static-to-rotating, and rotating-to-rotating turbine parts
  - Develop improved seal designs in a variety of important areas

- **Purge Flow Reduction:**
  - Focus on decreasing required flows to keep rotor disk cavities within temperature limits
  - Develop improved sealing at the cavity rims and modified flow geometries to minimize hot gas ingestion and aerodynamic impact
Cooling—Advanced Film Cooling

Diffuser and Chevron shaped film cooling hole geometries*

- Shaped "Baseline"
- Chevron 1 "Fist"
- Chevron 2 "Tent"
- Chevron 3 "Arcuate"

- 0.66 mm diameter
- 20-deg lateral diffuser
- 30-deg to surface tangent
- 10-deg laidback
- 0.46 mm diameter "chevron" edge troughs

Example geometries for shallow trench film cooling*

- Baseline Trench

Results to date show:
- Some hole/trench configurations provide up to 20% higher average film effectiveness than diffuser shaped holes.
- Aerodynamic mixing losses were also measured

Blowing Ratio or Pressure Ratio
Low
Moderate
High

Shaped Holes

Chevron Holes

Full-surface film effectiveness data for diffuser shaped holes and chevron holes.


Laterally averaged film effectiveness curves

Film Effectiveness vs Distance Downstream of Holes / Hole Diameter

Advanced Sealing—Four Focus Locations

**Transition Piece/Stage 1 Nozzle Seal**

- New flow fixture built to test engine size seals.
- Relative axial movement modeled.
- Leakage through various paths measured.
- Current and new seal designs tested to optimize seal design.

![Transition Piece/Stage 1 Nozzle Seal Image]

**Turbine Interstage Seal**

- New seal approaches investigated.
- Initial testing on 5-in flow rig.
- Intermediate size rig being built.

![Turbine Interstage Seal Image]

**High Pressure Packing Seal**

- Passive retractable brush seal design based on successful GE steam turbine retractable seals.
- Testing at full pressure conditions.

![High Pressure Packing Seal Image]

**Angel Wing Seal**

- Identified optimum abradable geometry/material vs. location.
- Flow resistance quantified via. CFD.
- Honeycomb \( \rightarrow \) good flow restriction for engine radial closures.
- Studying aluminizing honeycomb material to increase oxidation resistance.

![Angel Wing Seal Image]
Purge Flow—Transonic Annular Cascade Screening Tests

Regional static pressure distributions, Infrared surface temperature maps, trench and buffer cavity cooling effectiveness.

- Annular sector cascade rig run to gather data on rim seal region pressures, temperatures, and hot gas ingestion for various geometries.
- Data used to validate detailed CFD model analysis.
- Potential improved rim seal configurations being tested.
**Purge Flow—Rotating Wheelspace Rig Development**

**Wheelspace Rig Schematic**

**Test Section Features**

- Scaled baseline geometry with flexibility to model other engine configurations
- Features to allow testing variations.
- Rotating and static instrumentation
- Configurations will be tested to achieve optimum designs.
- Data will be used to validate detailed CFD models with rotation.

*imagination at work*

Summary and Conclusions

1. Strong program – structured to meet DOE goals on efficiency, emissions, and capital cost

2. Phase I completed – all milestones met and significant progress made:
   - Obtained near-entitlement NOx emissions at temperatures of interest for this program
   - Turbine technologies identified to achieve DOE goals – development will expand in Phase II

3. Phase II Underway:
   - **Combustion** focus narrowed to two concepts
   - **Materials** focus on optimization of materials/coating systems for environment
   - Heavier **turbine** effort on mechanical and aero aspects plus:
     - Cooling—initially looking at advanced film cooling
     - Sealing—focusing on four key leakage areas
     - Purge flow—initially using a cascade rig to screen configurations & validate CFD, rotating rig being developed