GE
Energy

GE Perspectives – Advanced IGCC/Hydrogen Gas Turbine Development

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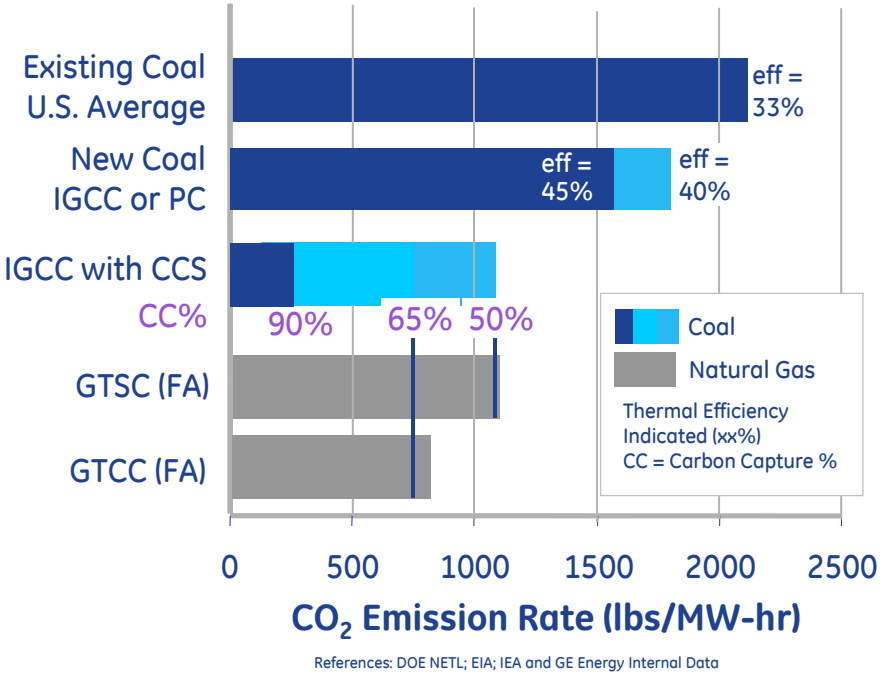
IGCC with CCS – Part of the Solution for the Carbon Constrained World

Impact on Emissions



References: DOE NETL; EIA; IEA and GE Energy Internal Data

Technology Available

2 GE 7F Syngas Units Shipped in 2010 to Duke Edwardsport for Operation in 2012

So What's the Hold Up?

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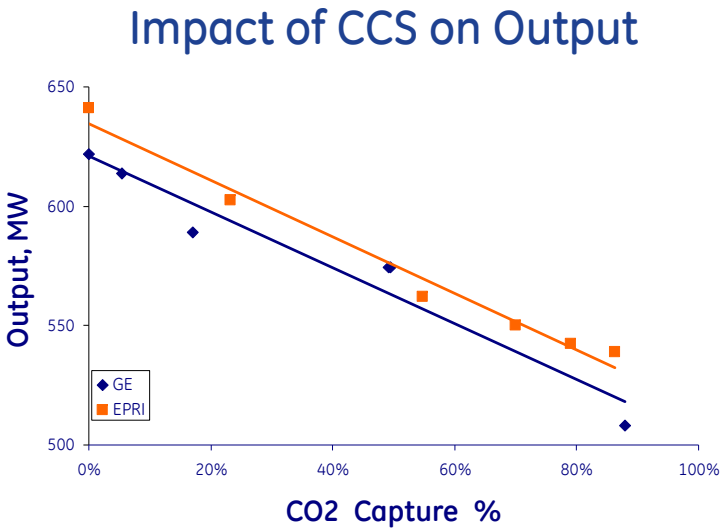
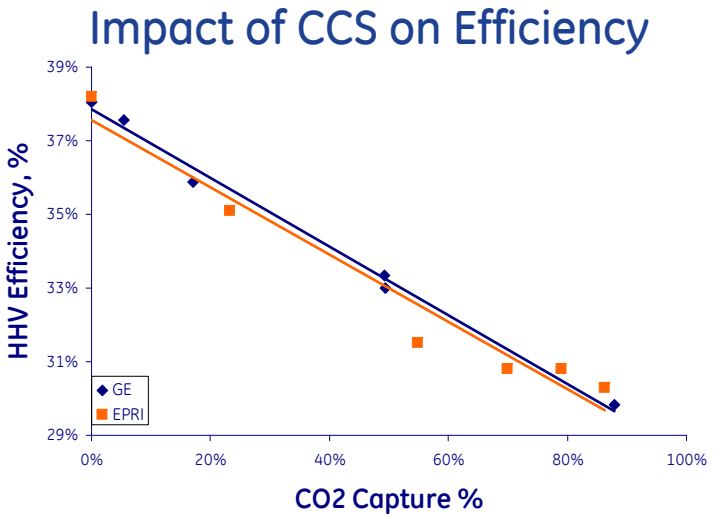
Current Barriers – Cost & Policy

- With existing technology, adding CCS to an IGCC plant increases COE beyond what most markets are currently willing to pay.
- Uncertainty with respect to indemnity, etc. on CO2 storage
- Technology Improvements and Legislative Action on CO2 Needed
  - Carbon Pricing
  - Storage Clarity
  - More efficiency & output to lower $/kW

As Engineers & Scientists We Can Be A Key Part of the Solution





Sources: GE Internal Study, 2007 and EPRI IGCC Design Considerations for CO2 Capture: Engineering and Economic Assessment of IGCC Coal Power Plants for near-term Deployment, 2008

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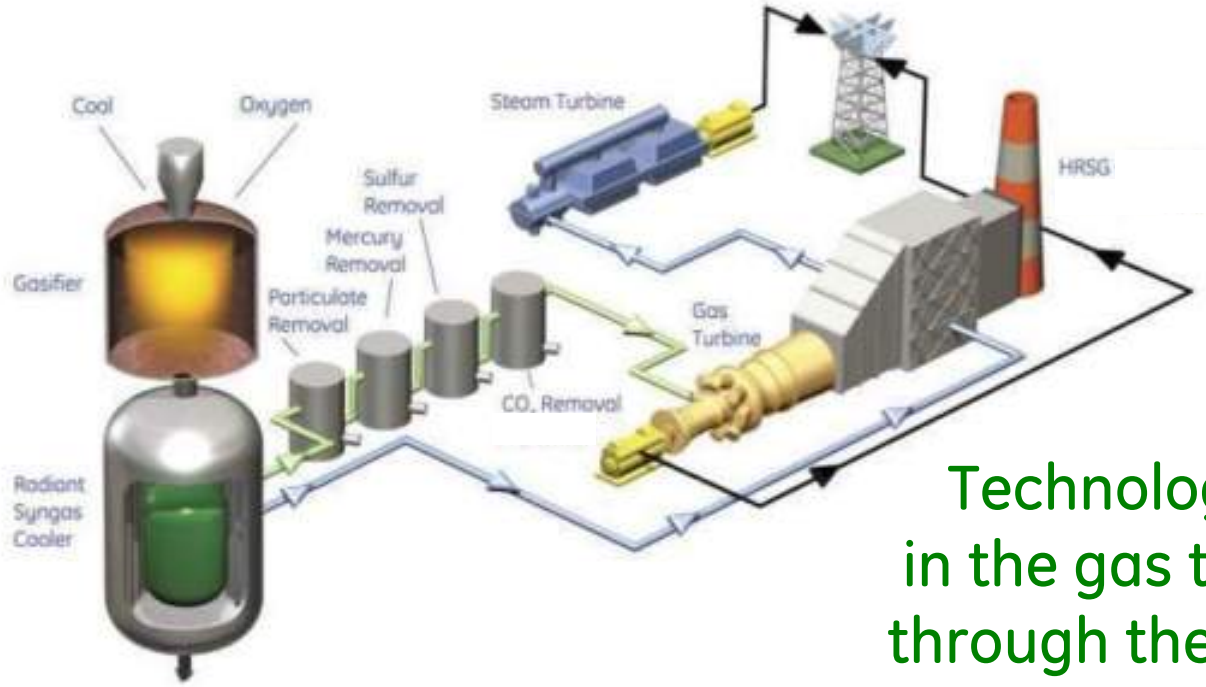
Gas Turbine Technology Advancements – High Leverage, High Impact on IGCC Plant



Technology advancements in the gas turbine propagate through the rest of the plant:

- More efficient GT's use less fuel, require smaller, less costly gasification systems
- Advanced GT's could enable improved ST operation
- Advanced combustion systems requiring less diluent for NOx control enables increased efficiency levels and improved plant integration flexibility

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DOE Advanced H_2/IGCC GT Program

DOE goals

Performance:

- +2 to 3 % pts efficiency by 2010
- +3 to 5 % pts efficiency (total) by 2015

Emissions:

- 2 ppm NOx by 2015
- Fuel flexibility – Syngas & H_2

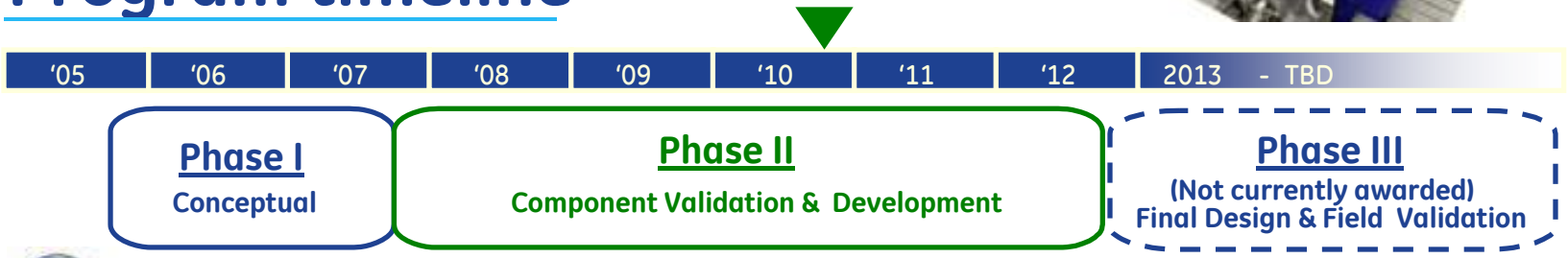
Cost:

- Contribute to IGCC capital cost reduction

Key Technologies

	emissions	efficiency	output	cost
• Combustion	✓	✓	✓	✓
• Turbine	✓	✓	✓	✓
• Materials	✓	✓	✓	✓
• Systems	✓	✓	✓	✓

Program timeline



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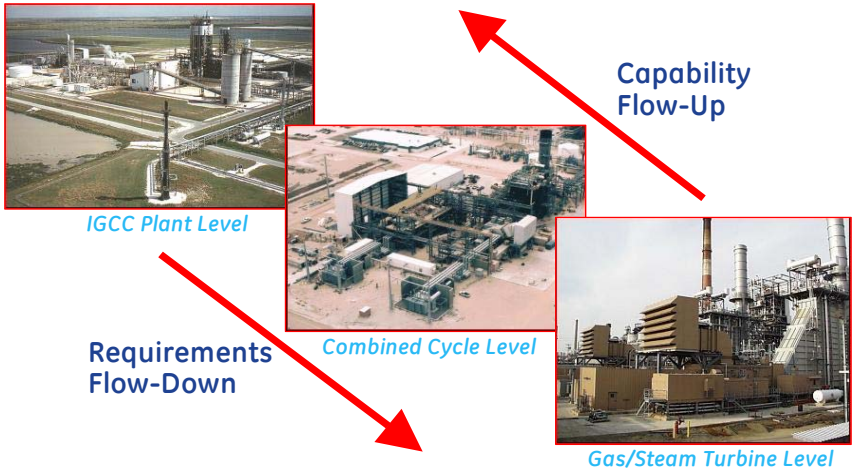
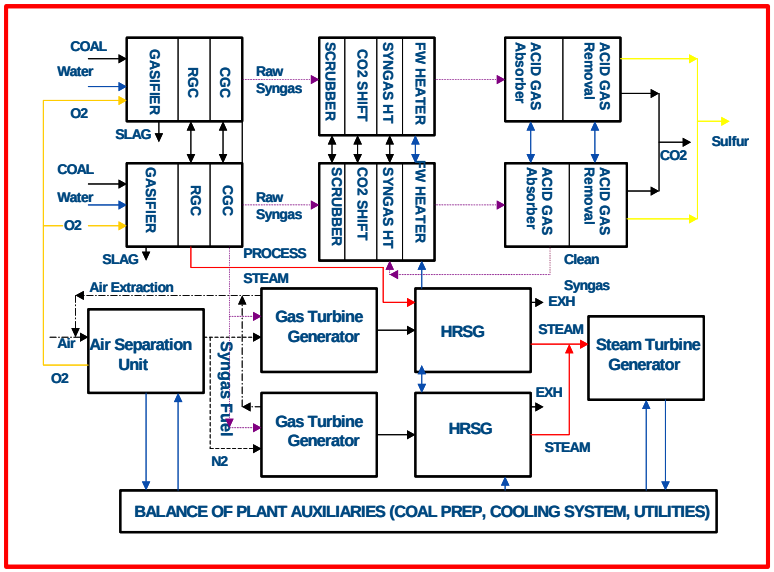
Systems Analysis and Performance Validation

- Translate Goals in to Key Plant Level, CC Level, and GT Level Parameters
- Create Baseline Performance Models & Understand Gaps/Sensitivities
- Quantify Benefits of Turbine Technology Improvements
- Recommend Turbine Technology Design Path
- Re-evaluate and Adjust Plan If Needed As Results of R&D Are Obtained





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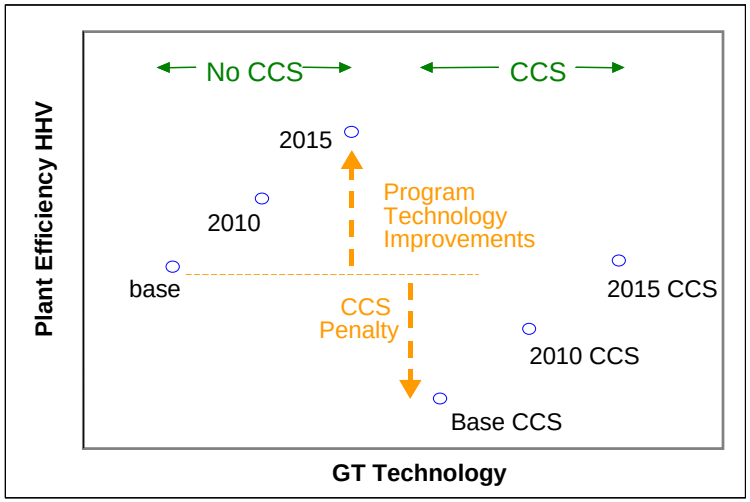
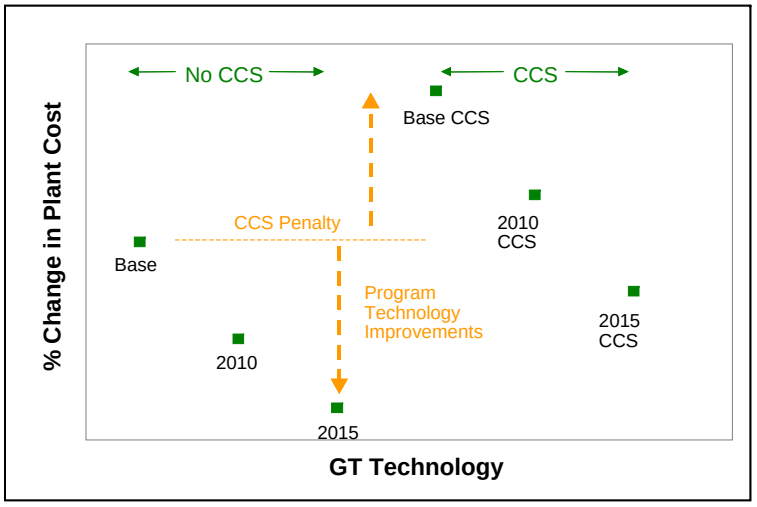
Estimated Project Benefits: Current Status

- Line of Sight to Program Efficiency Goal (+ 3 to 5 pts)
- NOx emissions of 2ppm
- CO_2 emissions reduction consistent with 90% Carbon Capture and Storage (CCS) Level
- CCS Cost Penalty Neutralized ($/kW basis)

Efficiency



Cost



NOTES: Values assume use of Advanced Combustion System and SCR

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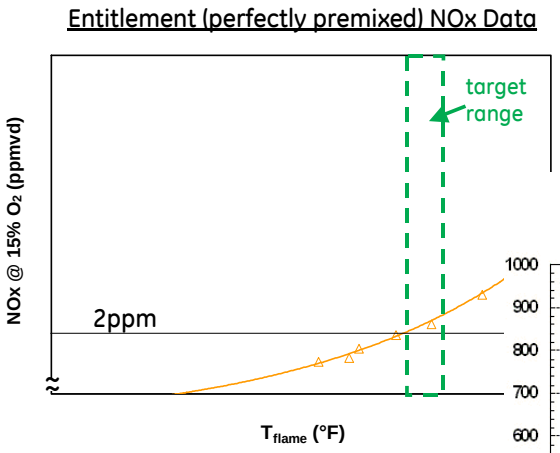
Combustion Challenges

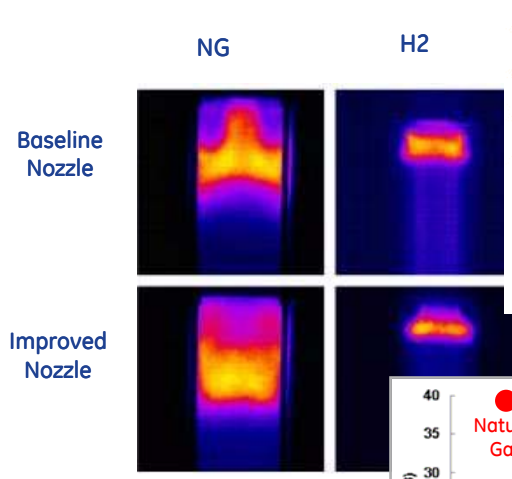
NOx

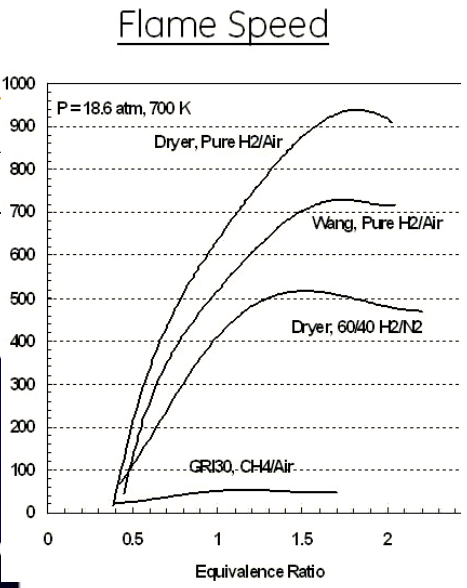
Flashback

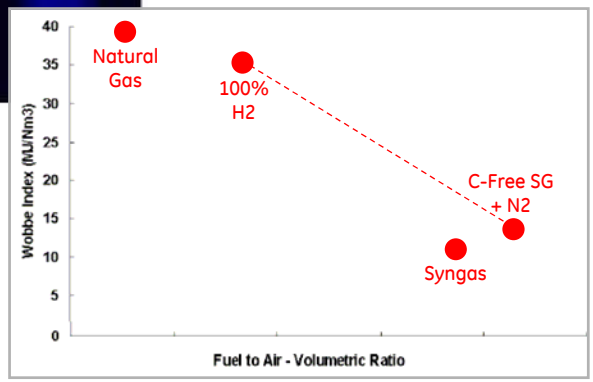
Dynamics

Fuel Flexibility









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Combustion Development

Technology Basics

- Modeling & Design
- Entitlement Data
- Concept Characteristics

- Fundamental Research

Nozzle Scale

- NG / Syngas / High H_2
- Emissions, Dynamics, Lean Blow Out

2010 Focus

Full Can Scale

- NG / Syngas / High H_2
- Combustor Performance

Gas Turbine

- Simple & Combined Cycle
- Part load to Full Load

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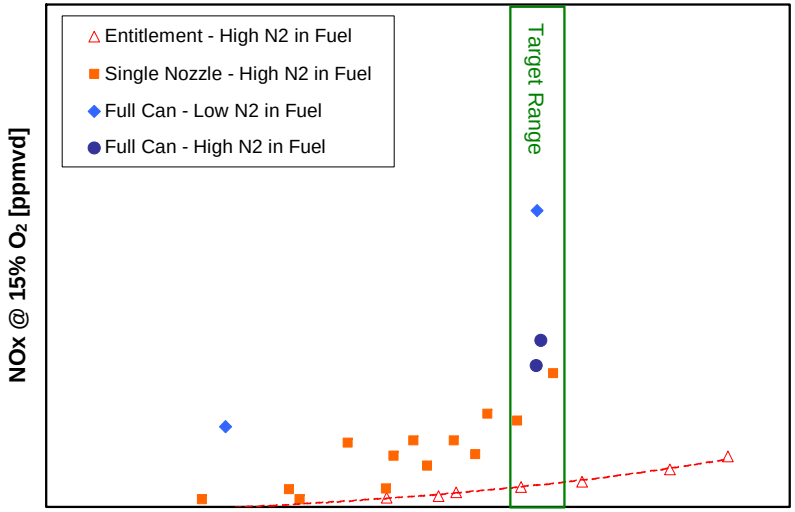
Combustion Development Status

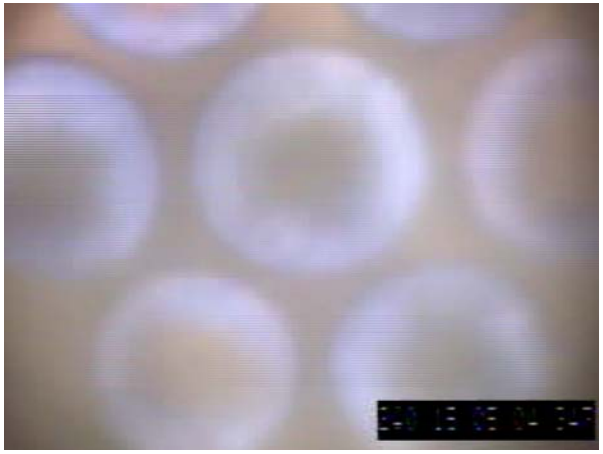
- Extensive Modeling & Testing at Component Scale

- Best Concepts Carried Forward for Full Can Multi Nozzle Testing
  - Single digit NOx emissions at F-Class + temperatures and pressures
  - Promising operability and dynamics on hydrogen, natural gas, and syngas
  - 60+ hours operation, multiple 6-hour blocks at full load

- Next Steps
  - Further optimize, scale up, and address manufacturability, reliability, durability, etc.



NOx Emissions vs. Temperature


Full Can Testing

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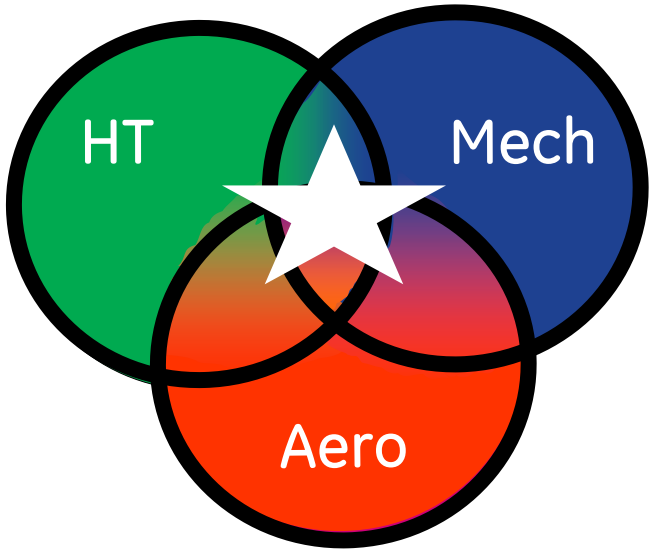
Turbine System Goals



- Increasing firing temp and output
  - Enable advanced materials & coating in IGCC/H2 environment
  - Increased mass flow

- Advanced turbine technology
  - Reduced cooling flows
  - Reduced leakage/purge flows
  - Advanced aerodynamics for improved turbine efficiency

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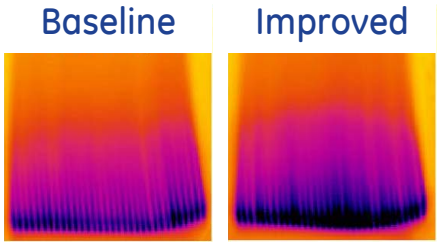
Turbine Aero & Heat Transfer Development

Cooling Flow Reduction:

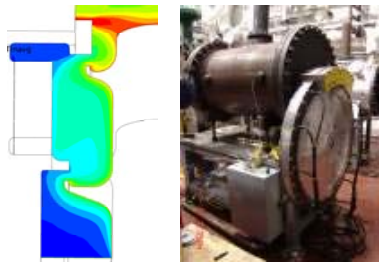
- Develop & validate advanced cooling schemes



Advanced Film Cooling Hole Shapes

Leakage & Purge Flow Reduction:

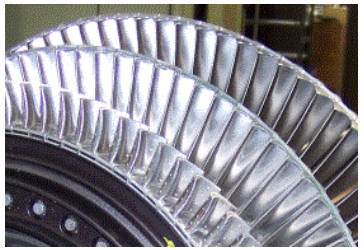
- Develop & validate improved seal designs
- Optimize flow geometries to minimize hot gas ingestion



Hybrid Rotating Cascade Rig & CFD

Aerodynamics:

- Improve CFD accuracy & validate turbine aero efficiency improvements provided by new technology



Aero Rig Test Parts

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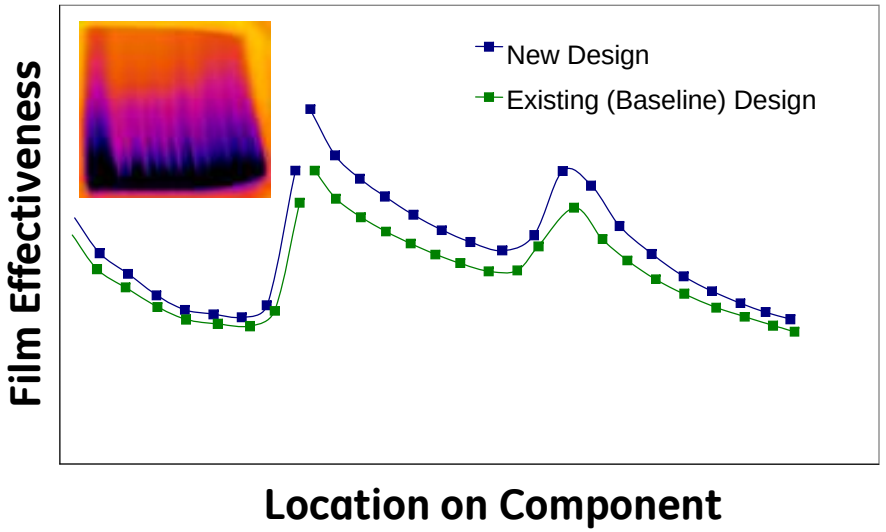
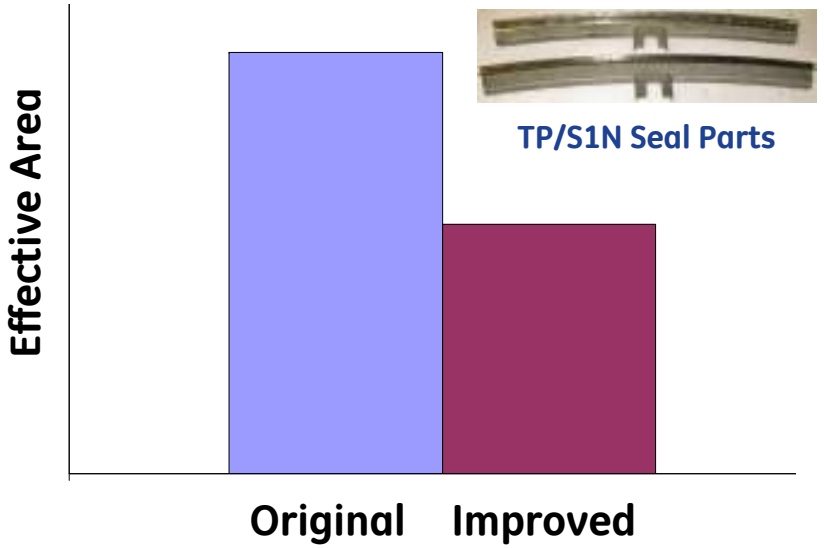
Heat Transfer Development Status

Advanced Film Cooling



TP/S1N Seal



Achieved target flow reductions for Round 1 Technologies

- Airfoil film cooling
- Transition Piece to Stage 1 Nozzle
- High Pressure Packing
- Angel Wing

Jugular experiments completed for Round 2 Cooling Technologies

- Entitlement supports targeted improvement levels

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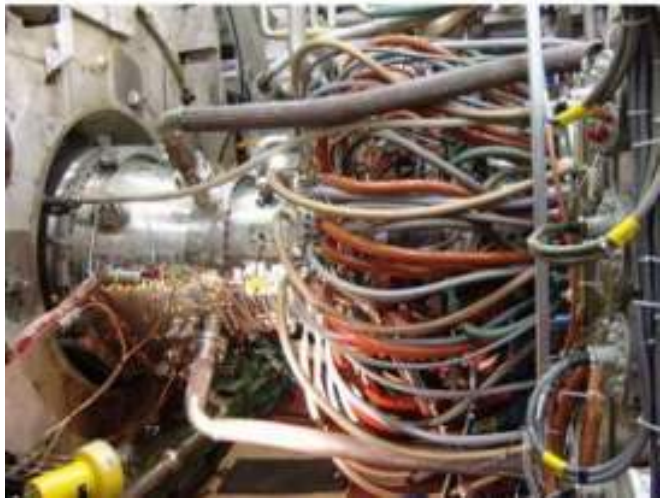
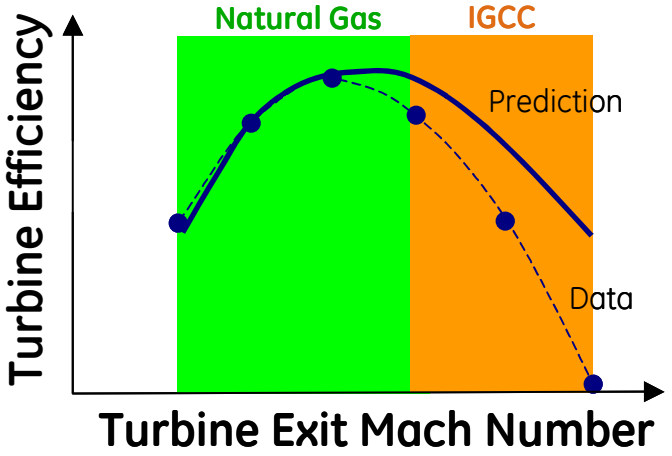
Aerodynamic Development Status

- First round rig testing completed
- Turbine aerodynamics
- Diffuser aerodynamics
- Stable, repeatable performance, consistent with engine experience
- Results to date support projected performance improvement – preparing for next round of testing



Turbine Aero Validation Rig
Test Setup & Results



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Advanced Materials (Coatings)

Goals

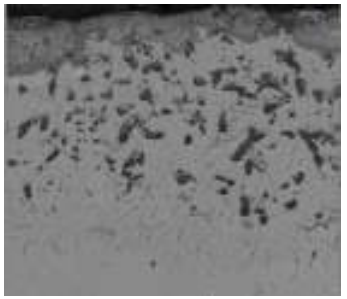
- Enable higher temperature operation for increased efficiency and output
- Address unique conditions associated with IGCC environment, validate durability

Overall Approach

- Characterize the environment and devise representative laboratory tests
- Benchmark degradation of baseline TBC's and Bond Coats
- Develop new coatings
- Downselect to best performers
- Evaluate best performing TBC's and BC's

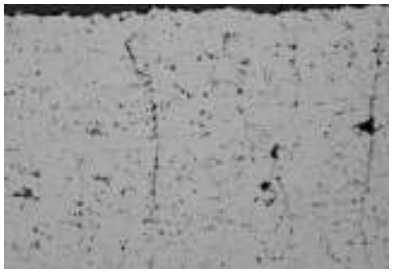
Challenges & Risks

- Target conditions beyond current experience



Field Hardware Inspection

Thermal Shock Test

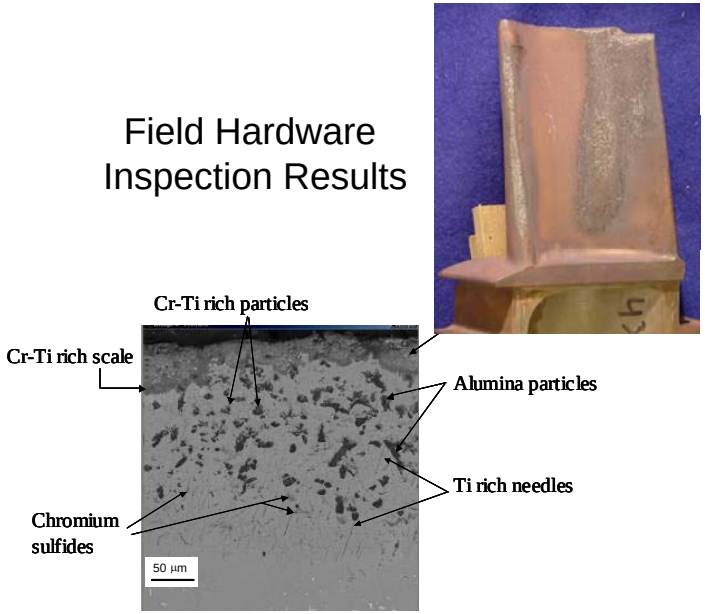


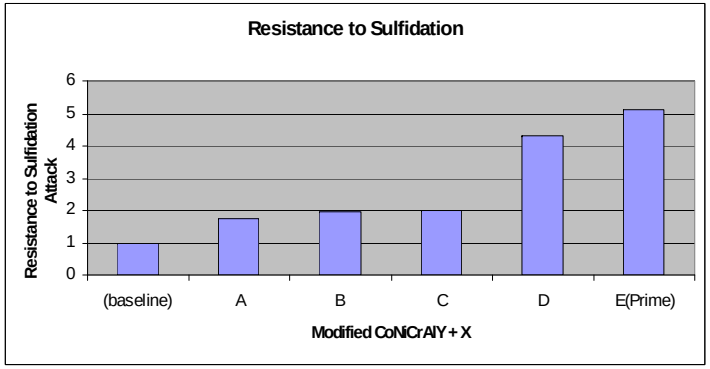
Optimized Coating

Advanced Materials (Coatings) Status

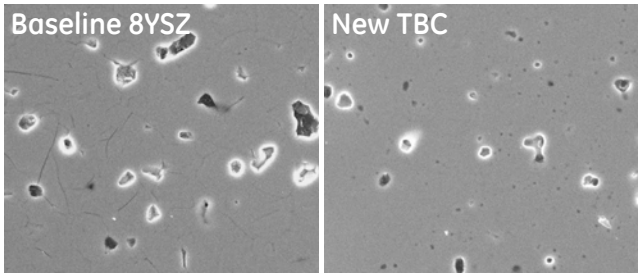
- Reproduced damage modes seen on IGCC field hardware
- Many architectures evaluated over 2+ rounds of optimization
- Performance improvement demonstrated at targeted operating temperatures
- Down selections made to final TBCs and bond coats

Field Hardware Inspection Results





Sulfidation Resistance Test Results



Microstructural Evolution of TBC After Accelerated Isothermal Exposure

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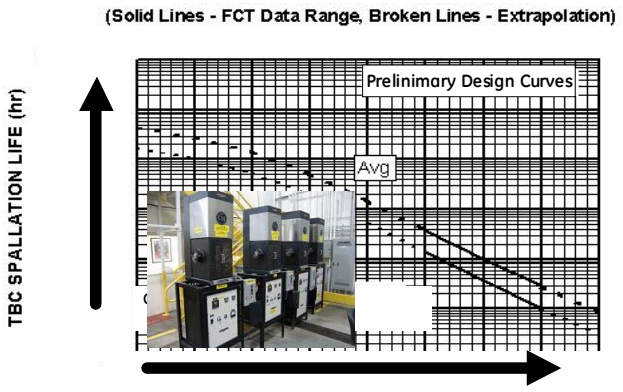
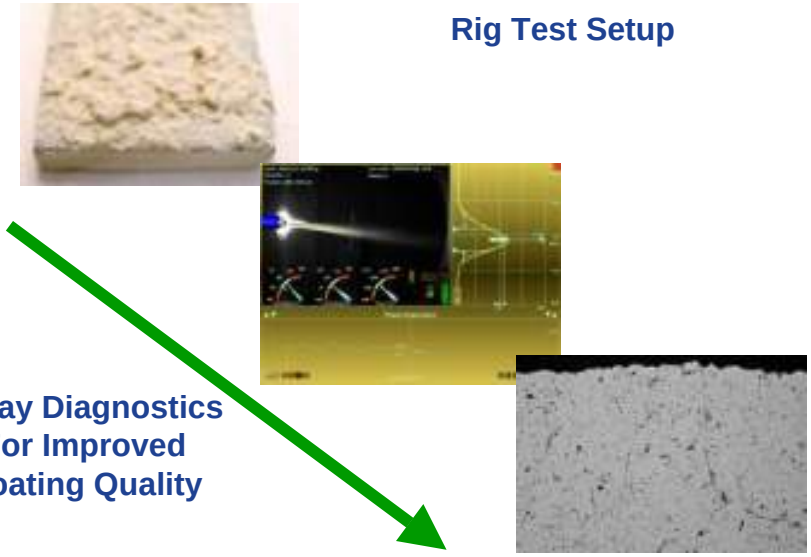
Advanced Materials (Coatings) Next Steps

- Evaluate integrated system rig test data for down selected TBCs/BCs
- Generate design quality data
- Process optimization



FCT Design Curves

Rig Test Setup



Spray Diagnostics For Improved Coating Quality

Summary

- GE building on successful field operational experience for gas turbines in IGCC and high Hydrogen fuel applications
- GE offering IGCC product today, including carbon capture technologies
- GE working with DOE on gas turbine technology advances for future IGCC products with CCS.
    - Higher efficiency, lower cost, lower emissions
- *Technical Challenges Remain for Future Designs*
  Universities play a critical role in the gas turbine technology R&D process

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