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Perspectives on R&D Needs For Gas Turbine Power Generation in a Carbon Constrained World

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imagination at work

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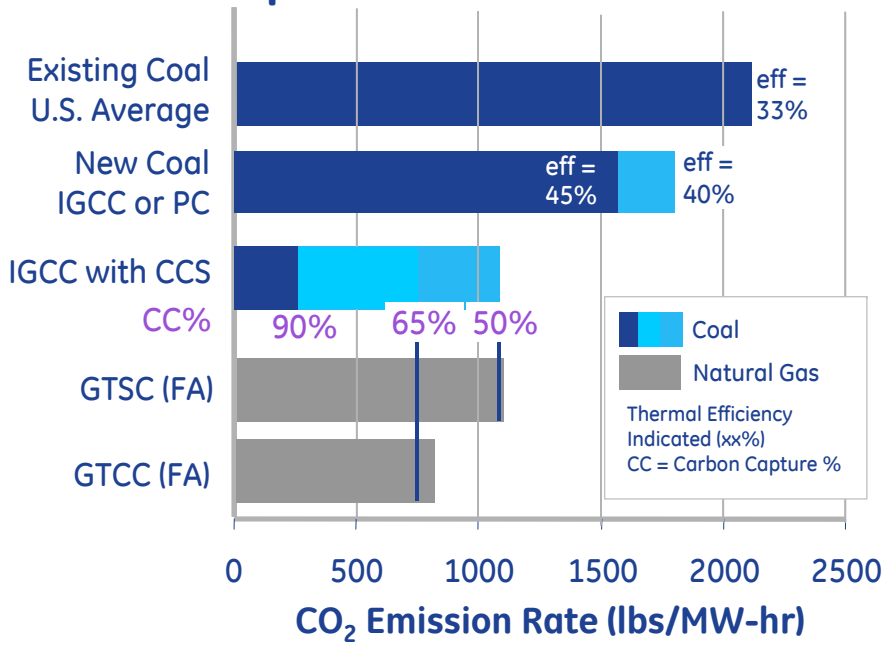
Impact of Carbon Capture

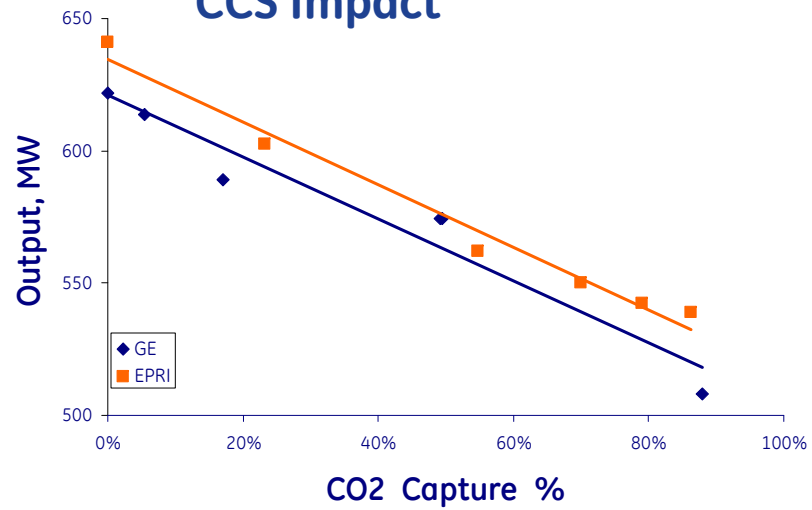
Carbon Footprints



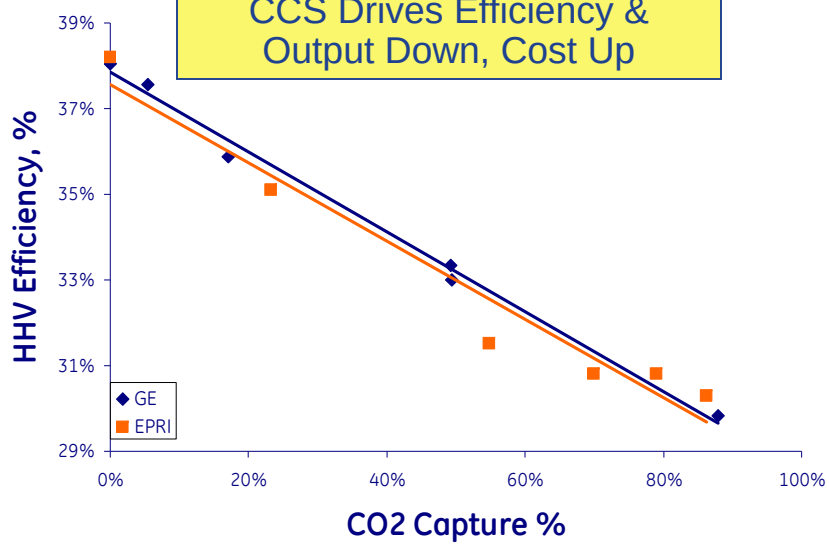
References: DOE NETL; EIA; IEA and GE Energy Internal Data

- IGCC w/ CCS is a solution for the carbon constrained world
- Technology is available today
- Currently key barriers to implementation are cost and CO2 policy/legislation
- Further technology development can improve cost competitiveness

CCS Impact



CCS Drives Efficiency & Output Down, Cost Up



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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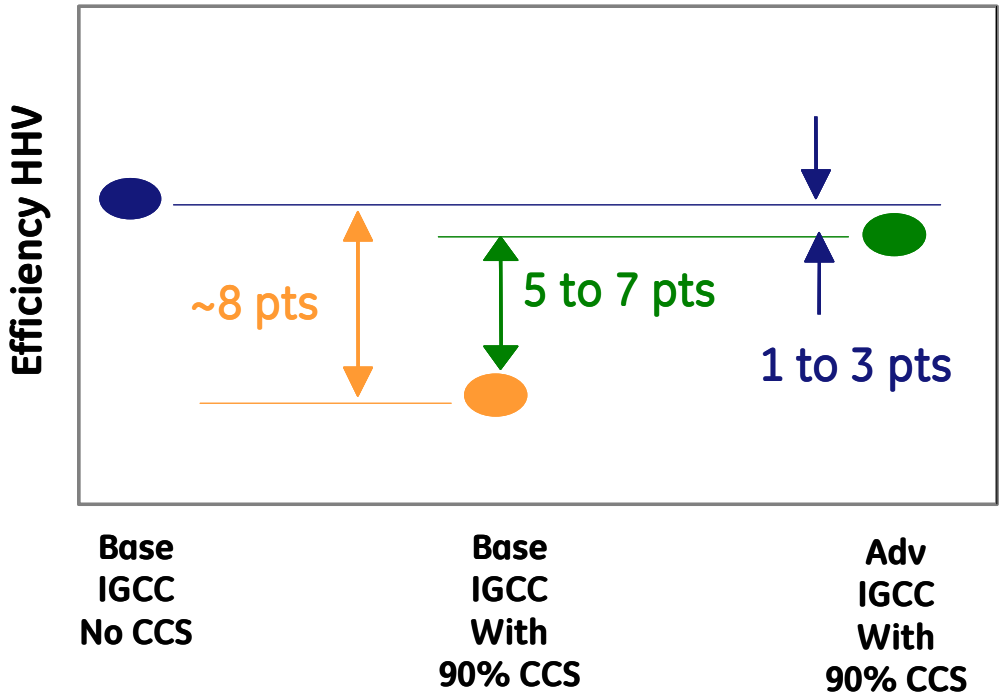
GE/DOE Developing Technology to Offset Much Of CCS Penalty

- Combustion
  - Higher temperature, lower emissions operation with highly reactive fuels
- Turbine
  - Higher component efficiency with higher flow rates
- Materials
  - Higher temperature materials and coatings in an IGCC/H2 environment
- Systems
  - Improved GT Integration with BOP



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Combustion Challenges

NOx

2 ppm goal aggressive at higher Tfire conditions required to meet program goals.

Flashback

Very high flame speeds require novel approaches to premixed technology

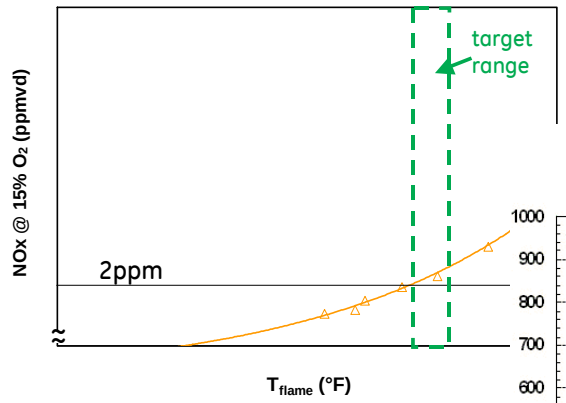
Dynamics

Premixed H_2 flame shapes far different than methane; new dynamics modeling and mitigation strategies required.

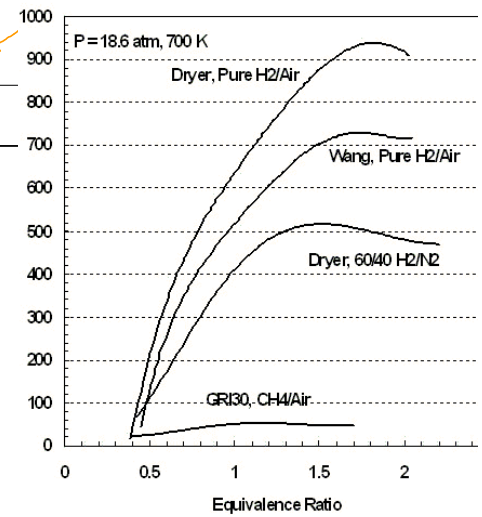
Fuel Flexibility

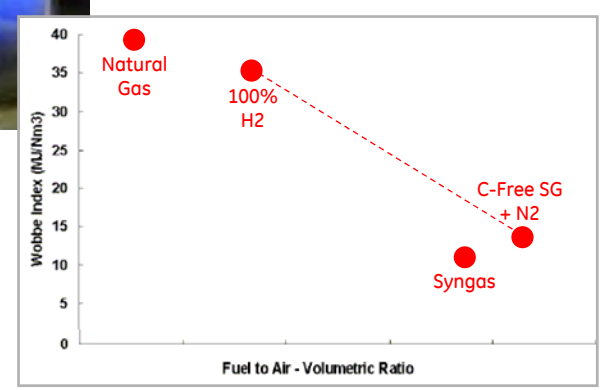
Designing for a wide fuel range (syngas, C-free syngas, natural gas) increases the challenge

Entitlement (perfectly premixed) NOx Data



Flame Speed





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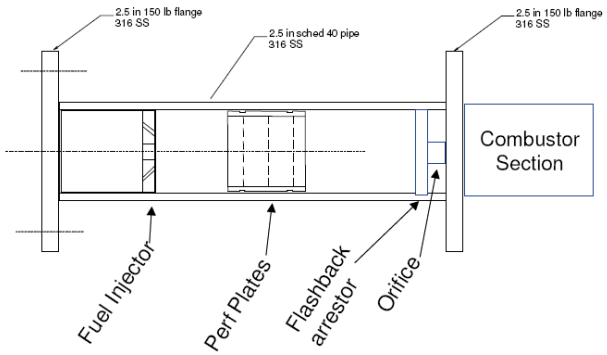
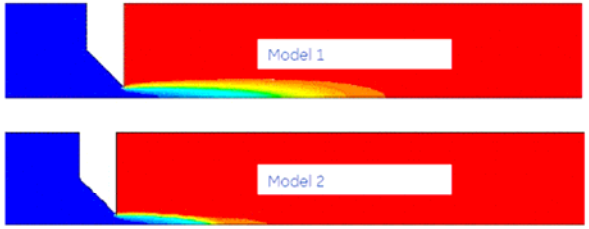
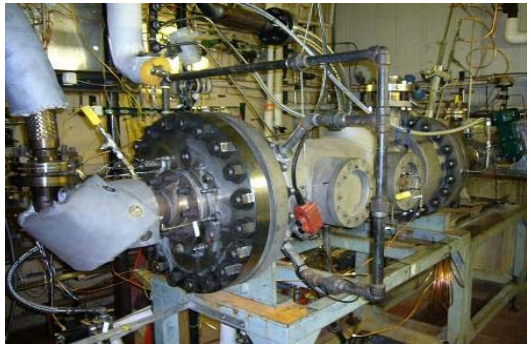
Combustion Progress



Perfectly Premixed Testing

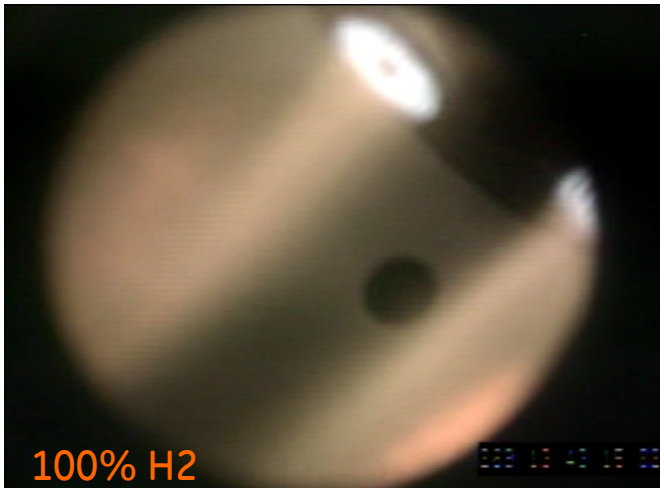


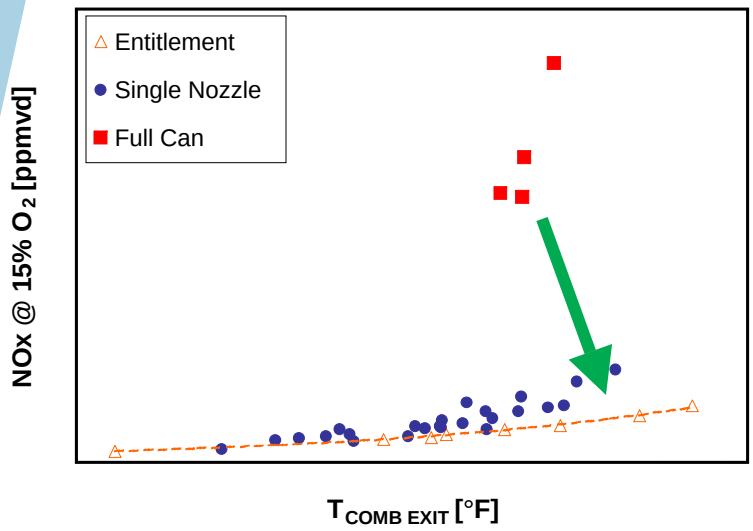
Physics-based predictive models



Single-Element Rig Testing

- Established baseline
- Understood fundamentals
- Aggressive Design/Test of New Concepts
- Selected best performers for scale up
- Demonstrated operation at conditions of interest
- More work remains: reduce emissions, expand operability, and increase reliability





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University Research – Combustion

- **Measure turbulent burning velocities** of syngas fuels at high pressure (with and without diluents)
- Develop and validate a **kinetics mechanism** including NOx chemistry for syngas and carbon-free syngas fuels with and without diluent.
- Develop analytical and/or computational predictive models to study **jet-in-crossflow flame stabilization** for syngas and hydrogen fuels
- Evaluate **combustion dynamics** for syngas fuels

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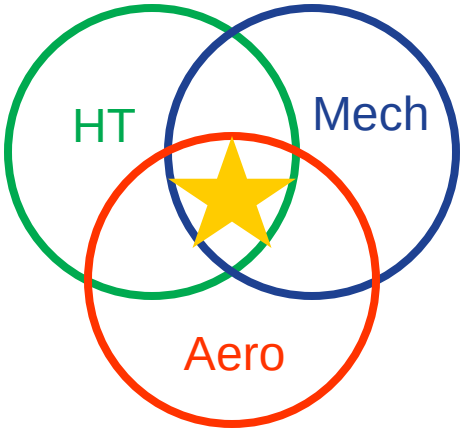
Turbine



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

- Advanced turbine technology
  - Reduced cooling
  - Reduced leakage/purge
  - Advanced aerodynamics
  - Blade durability with increased mass flows

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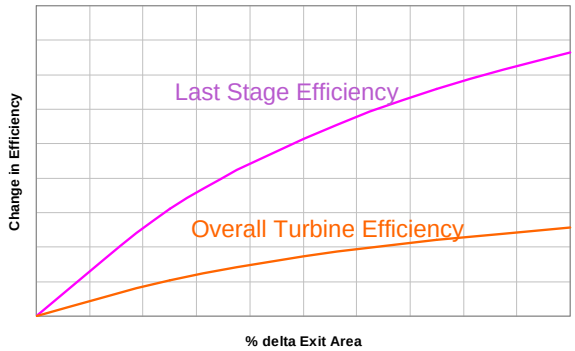
Turbine Aero Status

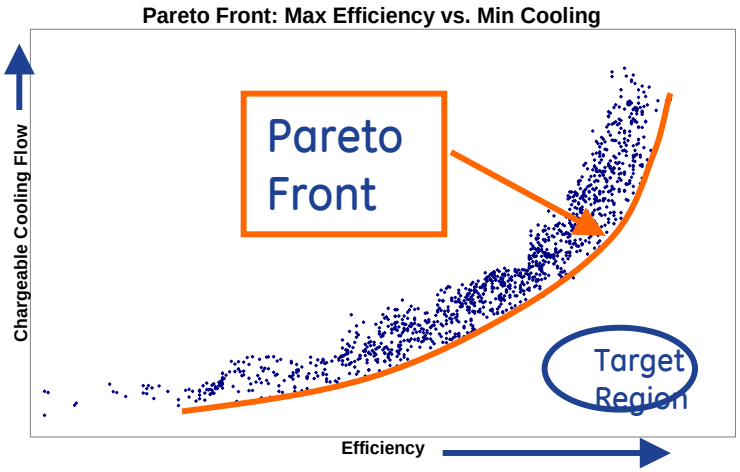
1-D Turbine Aero Analysis

- For fixed mass flow, Exit Area has significant impact on turbine efficiency



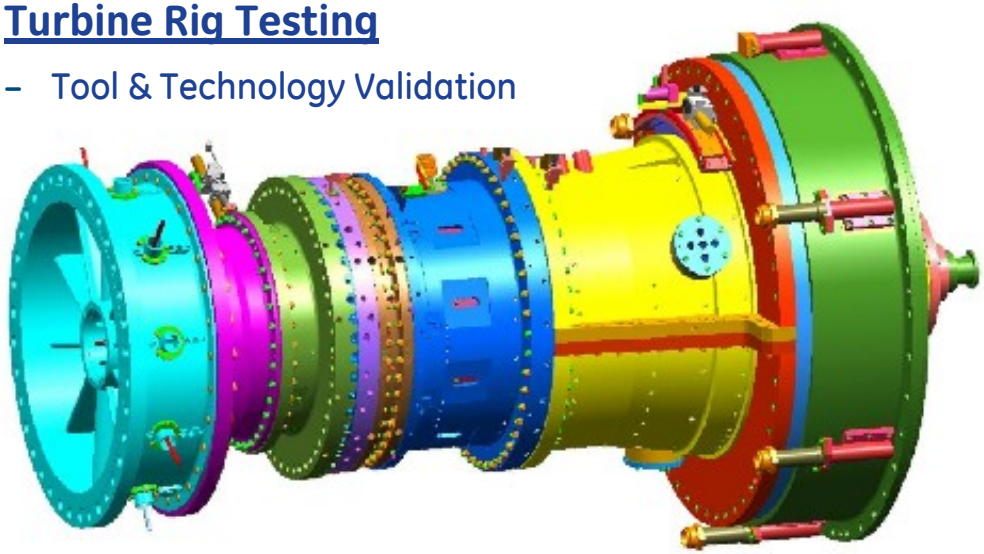
1-D Turbine Aero Optimization

- A 1-D turbine optimizer, which predicts efficiency & cooling flow, explored large design spaces that would otherwise be impossible to process
- Optimization variables include corner point geometry, work splits, reaction, and airfoil counts.



Turbine Rig Testing

- Tool & Technology Validation



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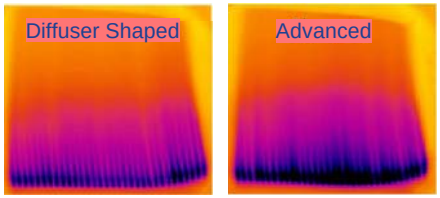
Heat Transfer

Cooling Flow Reduction:

- Develop advanced cooling schemes for current and advanced materials, e.g., advanced film cooling hole shapes
- Address challenges of IGCC/hydrogen fuel environment (e.g., cooling hole plugging)



Advance Film Cooling Hole Shapes

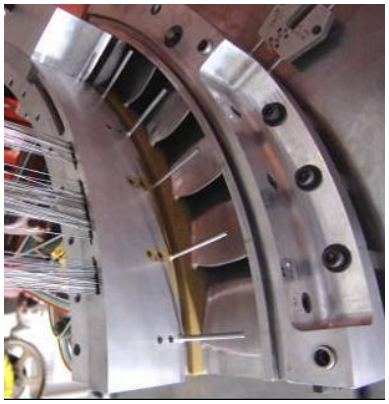
Leakage Flow Reduction:

- Decrease turbine parasitic leakages, i.e. between static-to-static, static-to-rotating, & rotating-to-rotating turbine parts
- Improve seal designs, e.g., high pressure packing, turbine interstage, TP/S1N interface, reduced blade tip clearances

Improved TP/S1N Seal Parts

Purge Flow Reduction:

- Decrease purge flows but keep disk cavities within max. temperatures
- Improve cavity rim sealing
- Optimize flow geometries to minimize hot gas ingestion and aerodynamic impact, e.g., "angel wing" seals



Rotating Cascade Rig

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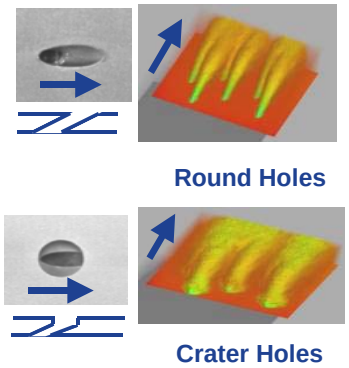
University Research – Turbine Aero/Thermal

Aero:

- **Higher IGCC mass flow produces greater exit Mach Numbers**
  - Better airfoil shapes at high mach numbers
  - Exit conditions more suitable for diffusers
  - Increase diffuser performance when high inlet Mach Number
- **IGCC sometimes produces greater temperature variation.**
  - Determine impact of radial & circumferential temp variation v. turbine performance
  - Determine how to counter effects

Heat Transfer:

- **Improved Cooling**
  - Improve airfoil surface cooling with film cooling or other approaches
  - Determine next generation internal surface cooling
- **Improved Sealing/Reduced Purge Flow**
  - Develop next generation of rotor/stator sealing
  - Optimize rotor rim geometry to maintain/improve aero efficiency and minimizing ingestion



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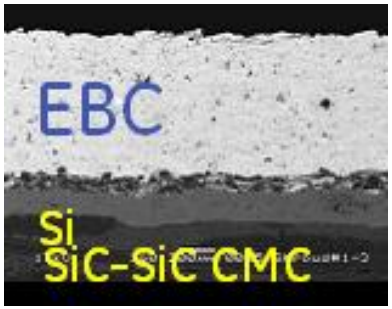
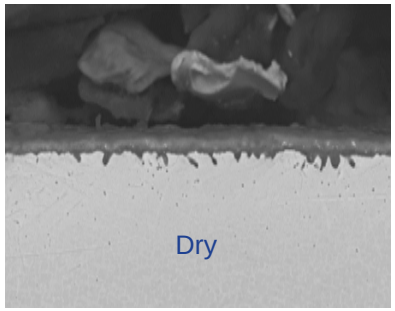
Turbine Materials/Coatings

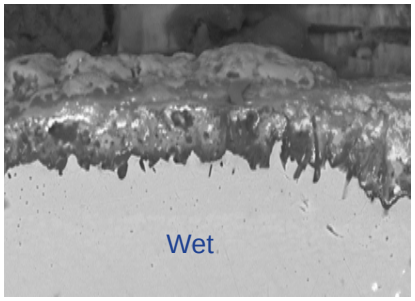
- Increasing Firing Temperature with Reduced Cooling
  - Increase allowable material temperatures, esp. TBC bondcoat
  - Improve stability, durability, and material properties
  - Reduce thermal conductivity of TBC's
  - CMC's/EBC's

- Fuel Flexible Operation
  - Improve and Understand Corrosion Resistance
  - Understand particulate related failure mechanisms
  - Develop validation tests and methods



IGCC Capable Ceramic Systems





Metallic Corrosion

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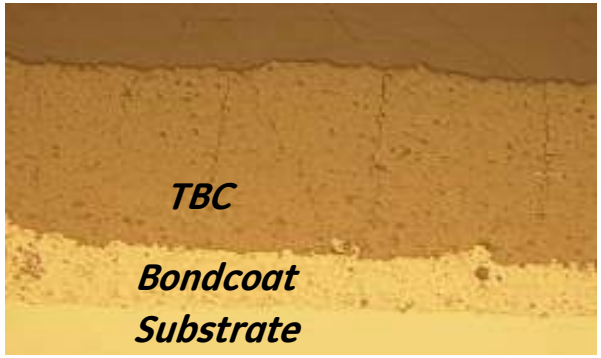
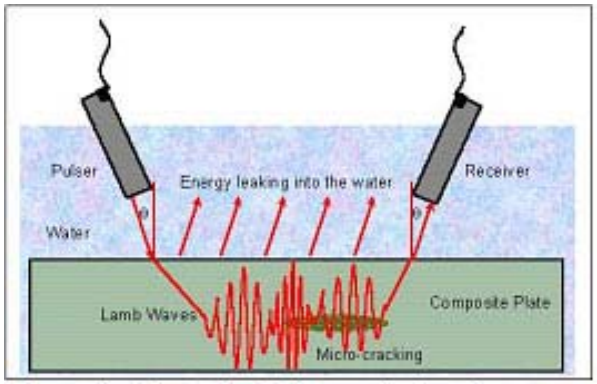
University Research – Materials/Coatings

- **TBC's—Thermal Barrier Coatings**
  - Higher temperature TBC bondcoat with improved rate of TGO for longer TBC life
  - Develop approaches for TBC lifing models by determining what makes a TBC tough
  - Improved corrosion resistance to higher moisture content and deposits such as Na_2SO_4 and $CaSO_4$.
- **EBC's—Environmental Barrier Coatings** for CMC applications with a target performance range above T_{fire} = 2700°F for 24,000 hours
- **NDE**—Identify/verify **Non Destructive Evaluation** inspection techniques

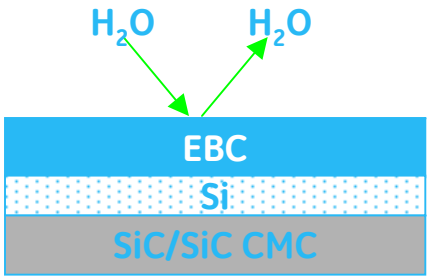


TBC and Bondcoat



Ultrasonic Testing (detects subsurface defects)

CMC with EBC Coating



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