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Siemens Advanced Hydrogen Turbine Development Program

UTSR 2012

John Marra, Siemens Energy, Inc.

October 2nd, 2012

Agenda

1. Siemens and IGCC Market
2. Program Challenges, Solutions and Major Accomplishments
3. Siemens/DOE UTSR Partnership
4. Conclusions

Agenda

1. **Siemens and the IGCC Market**
2. **Program Challenges, Solutions and Major Accomplishments**
3. **Siemens/DOE UTSR Partnership**
4. **Conclusions**

IGCC Market Challenges

- IGCC plant capital and O&M costs
- Improved IGCC plant performance and plant availability
- Minimizing impact of CO_2 capture on plant efficiency
- Legislative and regulatory uncertainty related to CO_2
- Ready availability of low-cost natural gas

Develop plant IGCC design expertise
Development of efficient Technologies

Efficient GT
Overall Cycle Efficiency

CO2 Sequestration/EOR, Plant Efficiency

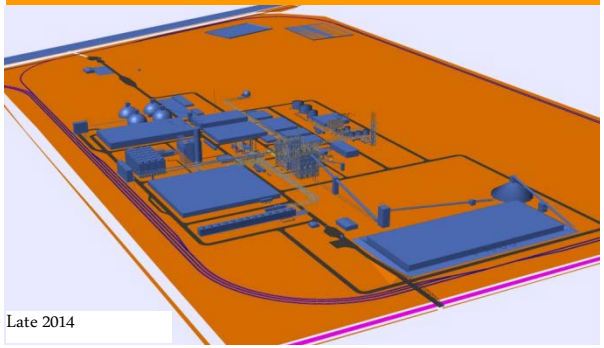
Development of Poly-Gen capabilities to ensure multiple revenue streams

IGCC technology is a viable coal based power generation option.

However, it brings significant R&D challenges.

Siemens Current IGCC Projects

Summit Power
Texas Clean Energy Project



Late 2014

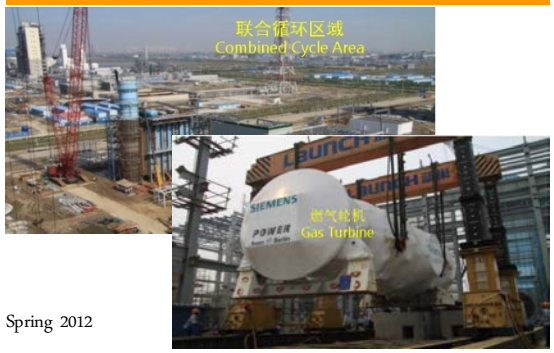
- 400 Mw_{egross}, UREA, CO_2
- 90% carbon capture (2.7M tons of CO_2/year)
- Siemens scope includes
  - SFG-500 gasifiers
  - SGCC6-5000F 1x1 power block operating on high H_2 syngas
  - Plant Operation and Maintenance services
- Located directly atop Permian Basin and CO_2/EOR opportunities
- Poly-gen Urea production as well

Mississippi Power
Plant Ratcliffe IGCC Project

Spring 2013

- 582 MW_{enet}
- ~65% carbon capture (~3 M tons of CO_2/year)
- Siemens scope includes two SGT6-5000F Gas Turbines
  - Will Operate on high H_2 syngas as the primary fuel and natural gas as the backup/startup fuel
  - Will include capability to extract air for integration with the air-blown gasifier
- Located in Kemper Co., Mississippi

Huaneng Greengen Co. Ltd.
Tianjin IGCC Project



Spring 2012

- 265 MW_{egross}
- CCS to be included in later phase
- Siemens scope includes one SGT5-2000E gas turbine and auxiliaries
  - Main fuel: Coal-based syngas diluted with N_2
  - Secondary fuel: Fuel oil
- Located in Tanggu District, Tianjin, China

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DOE - Siemens
Advanced Hydrogen Turbine Program Strategic Goal

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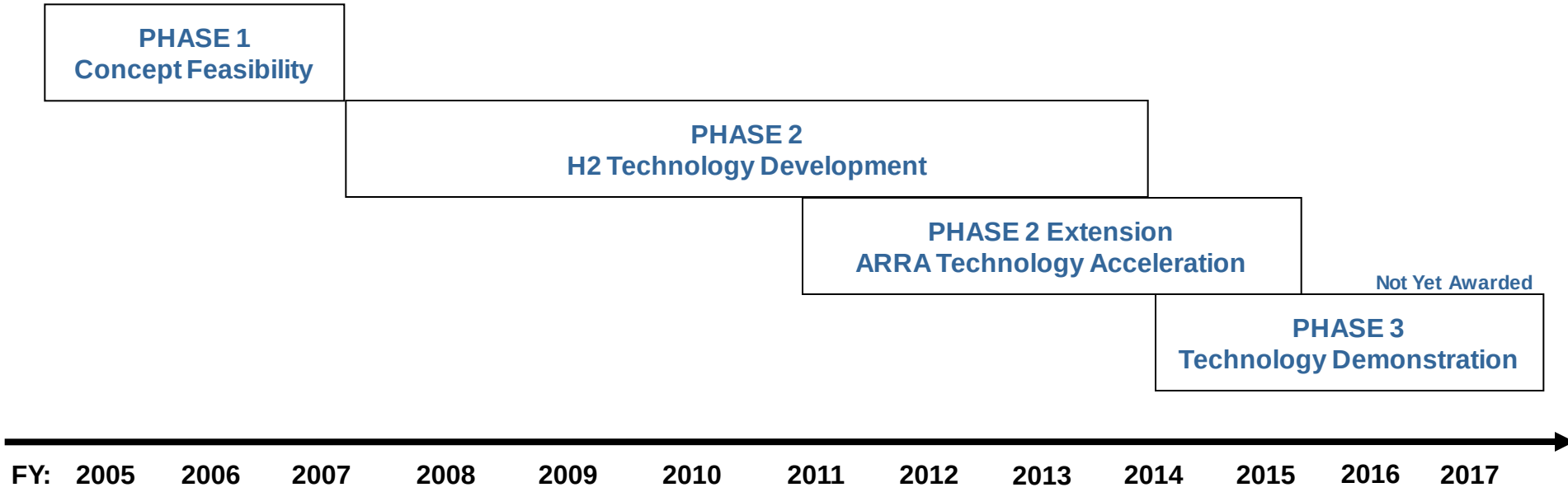
Siemens was contracted for PHASE 1 and PHASE 2 of a multi-year program to develop an advanced GT for Hydrogen / Syngas applications.



- **3-5% pt. improvement in CC efficiency over baseline**
- **H_2 Turbine with 2 ppm NOx**
- **20 – 30% ($/kW) Cost Reduction in Power Plant**

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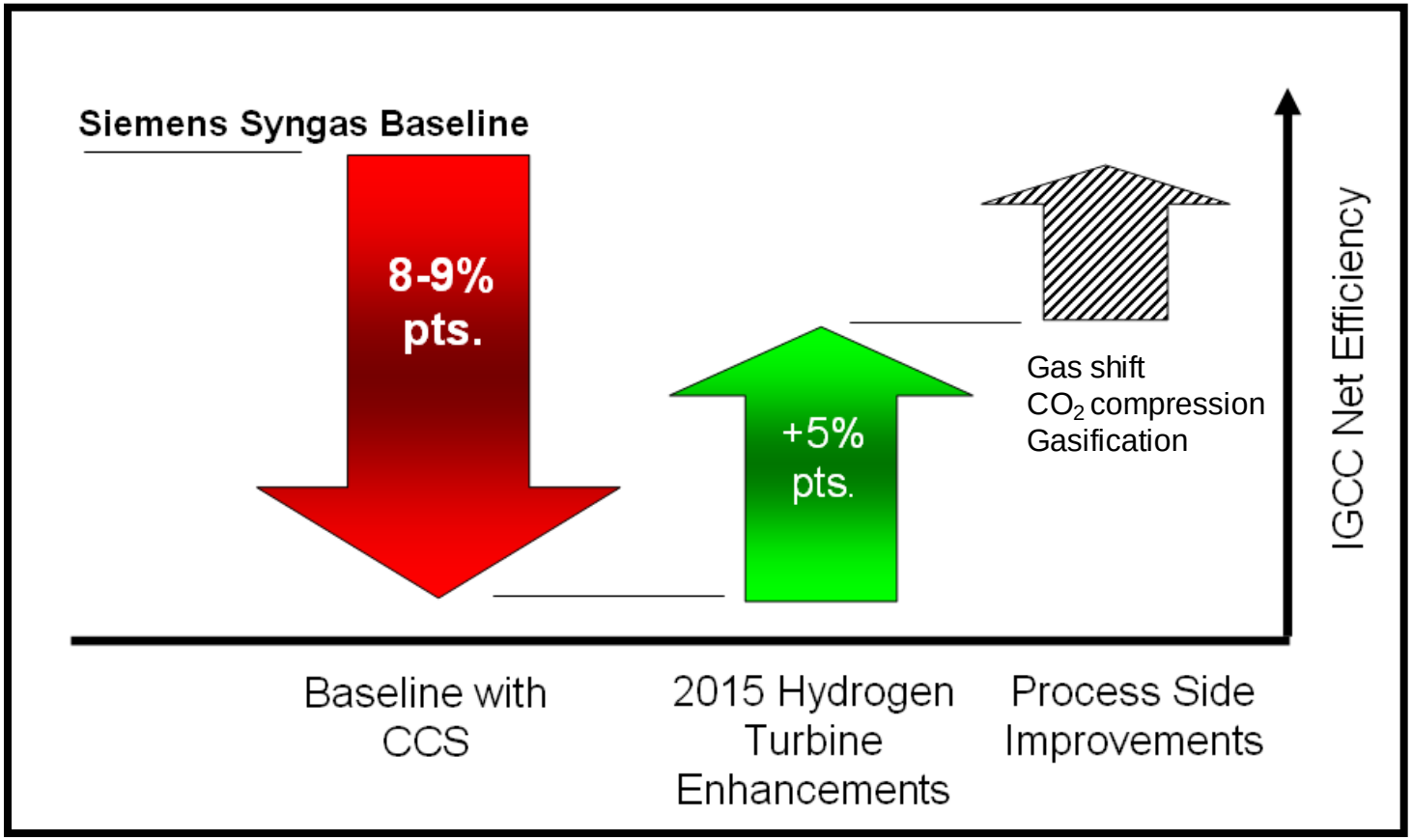
Carbon Capture and Sequestration Impacts Plant Cycle



System studies show >50% recovery in the performance lost due to CCS when Advanced Hydrogen Turbine Program technologies are applied to the GT

Gas Turbine Performance Trends

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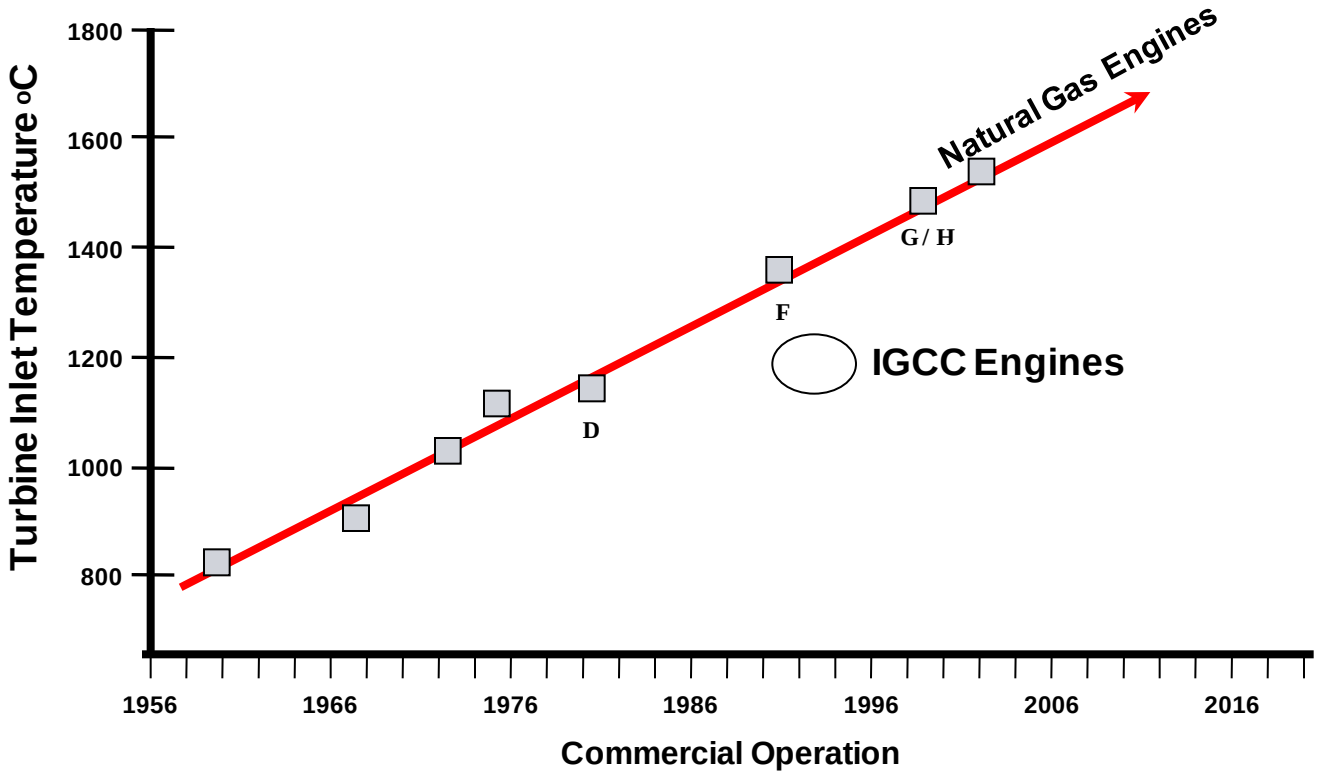

A key to meeting higher efficiency is increasing turbine inlet temperature
Target is same as advanced natural gas engines

Path to Meeting 2ppm Goal

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Advanced High Temperature Combustor

+

Poly-functional Emissions Reduction System

+

Advanced Emissions Sensors

=

2ppm NOx Emissions

- ✓ High Plant Efficiency
- ✓ Low CO_2 emissions
- ✓ Low Plant NOx Emissions
- ✓ Robust to fuel and ambient variation.
- ✓ Best fit with advanced high temperature engine.

Siemens multidisciplinary approach at the systems level results in highly efficient combustion and plant technology designs

Maximizing Output & Efficiency
Use of Increased Exhaust Energy

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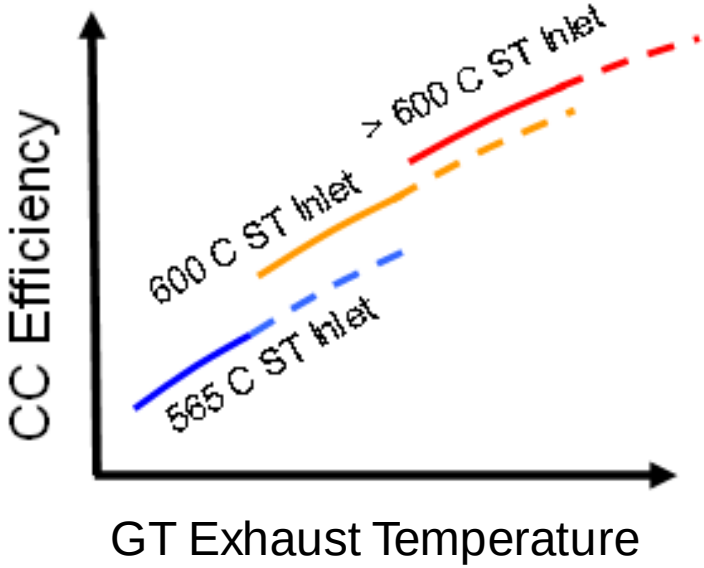
- Plant output and efficiency can also be improved with better utilization of GT Exhaust energy.
  - i.e. Higher bottoming steam temperature and pressure.
- Higher steam cycle conditions are being investigated through multiple system studies



Based on system studies the most economical bottoming cycle possible has been chosen

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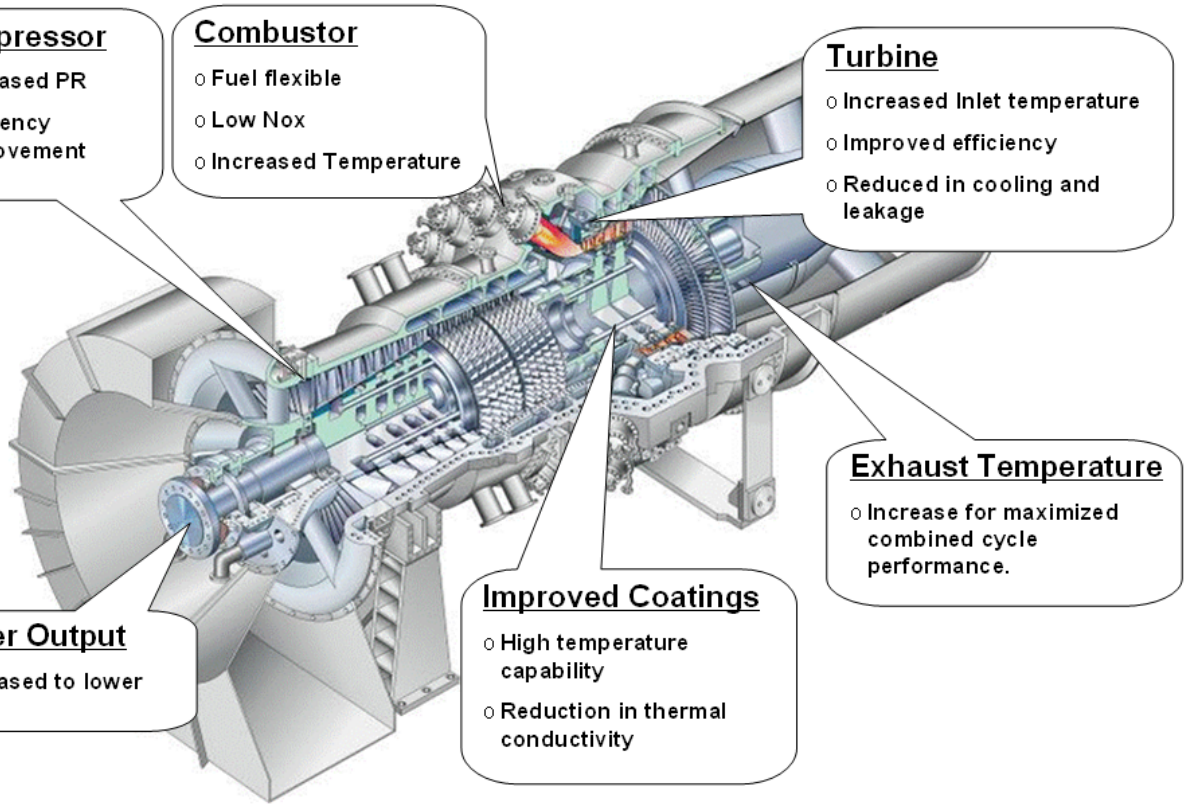
Hydrogen Turbine Program Development Activities

- Improved Efficiency
- Fuel Flexibility
  NG,Syngas,H_2
- Low Emissions
- Reduction in Plant Cost $/KW
- CO_2 Sequestration Ready

Targeted Areas of R&D



The Advanced Hydrogen Program Development and major activities are driven by plant level goals

Component Development
Combustion

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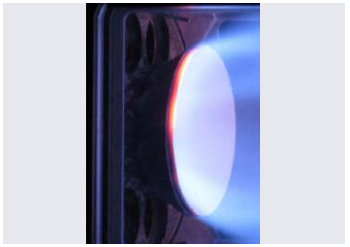
COMBUSTION CHALLENGES

- Flame Speed
- Flashback
- Combustion Dynamics / Acoustics
- Fuel Flexibility (Always need back-up fuel)
- Low Emissions at Increased Temperature



Premixed Combustor Firing

COMBUSTION SOLUTIONS

- Advanced combustion system paired with a multi-fuel capable premixed head end allowing for:
  - High firing temperature
  - Low dilution requirements
  - Low emission levels
- Flashback/dynamics reduction

Premixed Combustor

Component Development Status
Combustion

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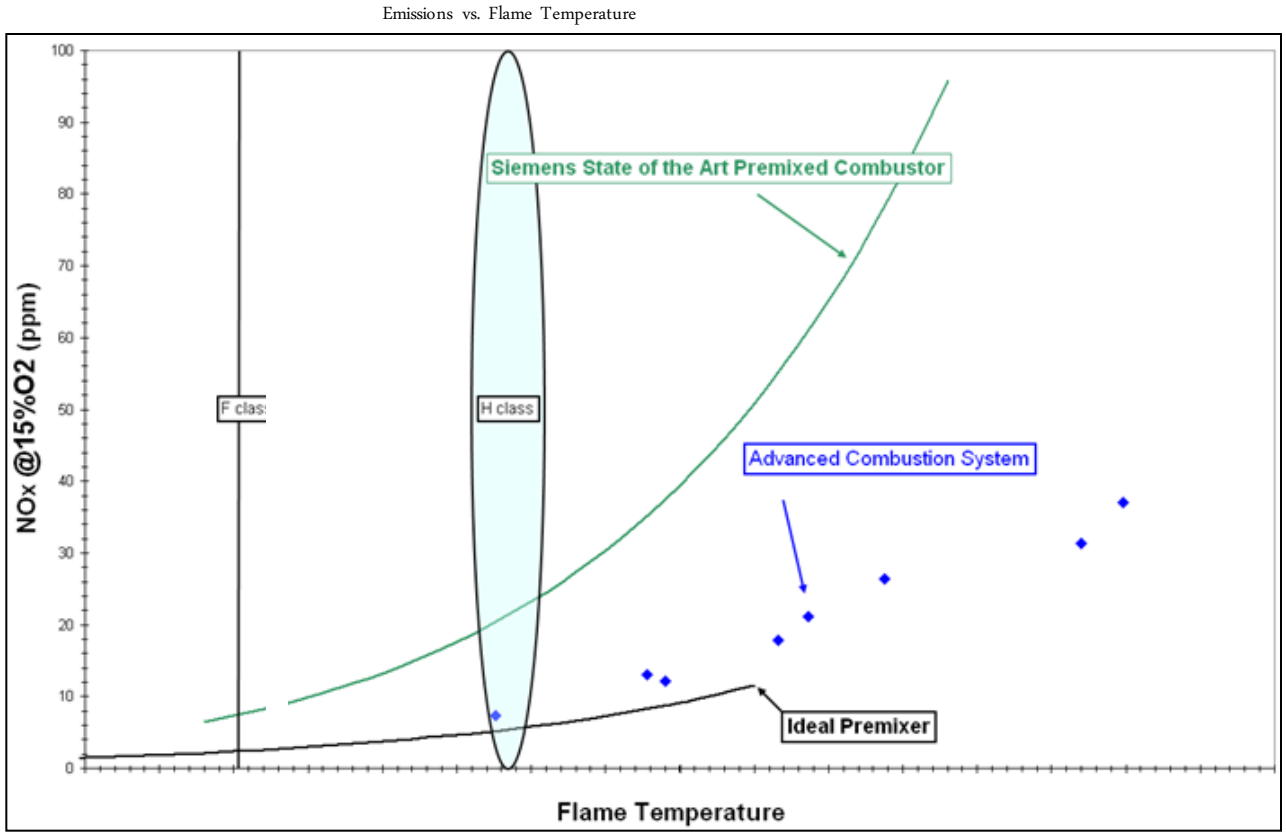
Major Accomplishments



- Stable operation on 100% syngas, all stages, above baseline temps
- Stable operation on 70% H_2; low dynamics, no flashback
- Improved Kinetic mechanism for syngas and high hydrogen fuels
- High pressure hydrogen fuel testing

Component Development
Materials

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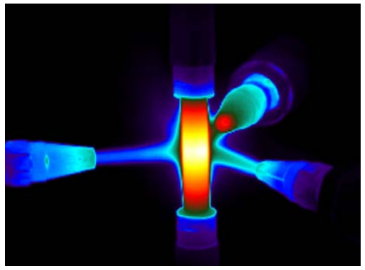
MATERIAL CHALLENGES

- Non-failing, high temperature, low thermal conductivity Thermal Barrier Coating (TBC)
- Increased Capabilities of Bond Coats
- Environmental Issues with Syngas & High Hydrogen Fuels
- Corrosion & Oxidation Capability of Syngas & High Hydrogen Fuels



Materials Test Rig

MATERIAL SOLUTIONS

- High temp, Low Thermal Conductivity TBC
  - Optimize material properties through D.o.E
  - Predict performance through modeling & high heat flux testing
  - Develop manufacturing processes
- High Temp Bond Coat
  - Determine oxidation rates, Bond Coat spallation resistance and mechanical properties
- Modular Airfoil Development
- Advanced Manufacturing Capabilities
- High Performance Multi-Fuel Applications

Advanced Core Technology

Component Development Status
Materials

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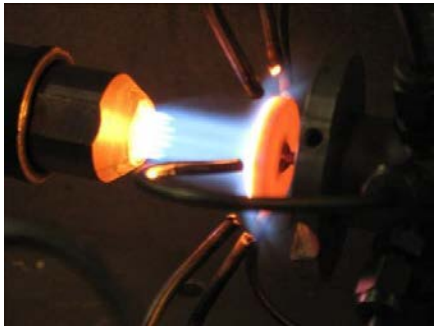
Major Accomplishments



TBC

- Greater than 5x increase in spallation-resistance for extended TBC life

Bond Coat

- Bond coat compositions are being evaluated and have shown:
  - Increased life
  - Lower cost
  - High oxidation resistance

Modular airfoils

- Prototype vanes have been manufactured and undergone full scale engine testing

Manufacturing

- Novel manufacturing techniques are allowing for previously impossible designs

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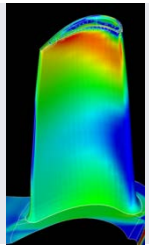
TURBINE CHALLENGES

- High firing temperatures exceed material limits
- Increased mass flow
- Multi-fuel capability requirement
- Increased last row blade height



CFD Analysis

TURBINE SOLUTIONS

- Aerodynamics
  - Advanced 2D & 3D CFD Modeling
  - High Turning, Highly Loaded Airfoils
  - End Wall Contouring development
  - Exhaust diffuser development
  - Sealing Technology
- Heat Transfer
  - Advanced cooling row 1 blade, novel cooling of row 4 blade, advanced film cooling patterns
- Component Design
  - Manufacturing of novel component concepts
  - Blade root design optimization through software tool development

Advanced Vane

Component Development Status
Turbine

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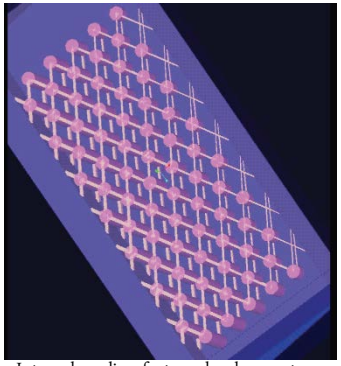
Major Accomplishments

Aerodynamics

- Multiple test campaigns complete
- Highly loaded, high turning airfoils at high mach numbers



Internal cooling feature development

Heat Transfer

- Completed studies:
  - Internal features to promote turbulence
  - effects of bends on heat transfer
  - Evaluation of various trailing edge flows
- Blade 1 advanced cooling designs test at full scale

High turning airfoils cascade testing

Component Design

- Turbine blades 1-4 initial aerodynamic design complete
- Root optimization to allow for increased blade height

Component Development
Compressor

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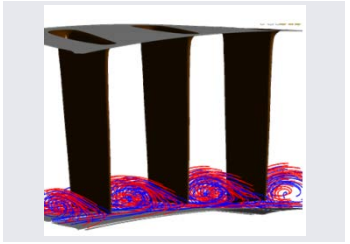
COMPRESSOR CHALLENGES

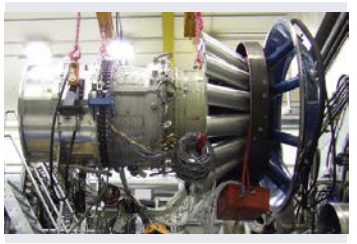
- Increased mass flow
- Increased efficiency requirements
- Increased pressure ratio
- Cost



Compressor CFD Results

COMPRESSOR SOLUTIONS

- New Compressor design, decreased stages
- Lower production cost
- 3-D blading for improved efficiency
- Highly loaded airfoils



Compressor Rear Stage Test Rig

Component Development Status
Compressor

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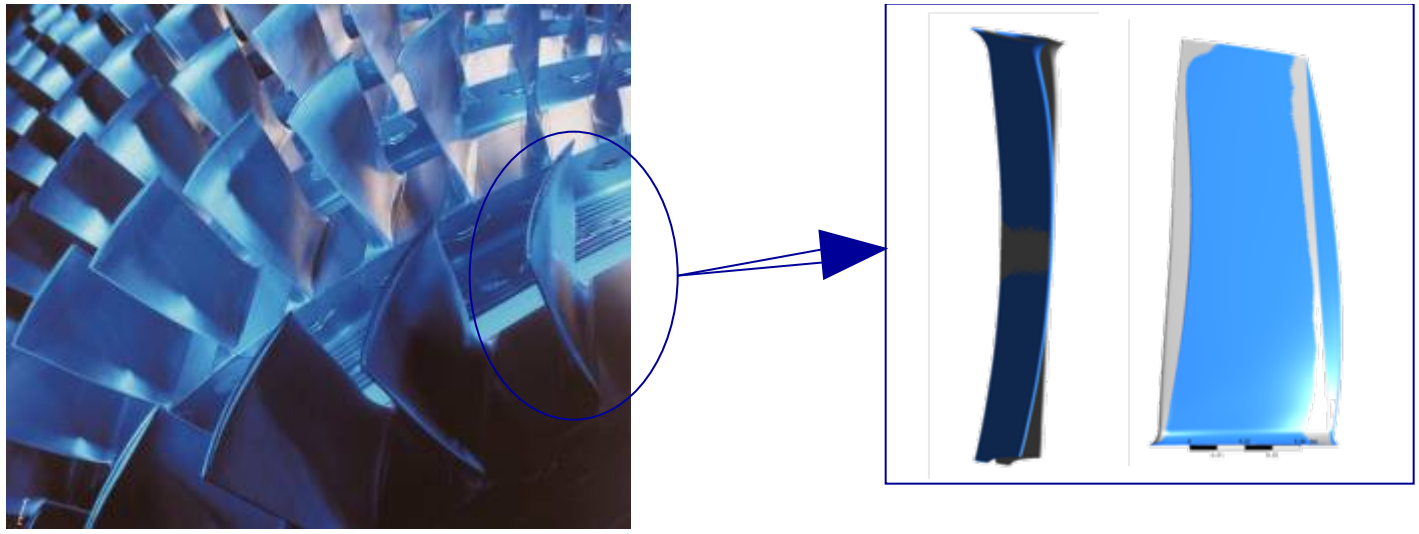
Major Accomplishments

- Rear stage rig has been commissioned and testing is underway
- Significant 3D airfoil design completed and gains in efficiency have been made



Component Development
SCR (Selective Catalytic Reduction)

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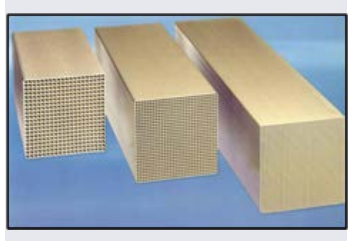
SCR CHALLENGES

- Required >90% efficiency
- Corrosive IGCC environment
- Cost

Corroded tube w/ ammonia bisulfates on it

SCR SOLUTIONS

- > 95% efficient emissions removal process
- Able to minimize ammonia salt formation in the presence of high concentrations of water and sulfur
- More efficient catalytic system than conventional SCR with regards to NH_3 sulfates / bisulfates formation



Commercial scale SCR blocks

Component Development Status
SCR

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Major Accomplishments

- Latest results have demonstrated greater than 95% NOx reduction in the exhaust with 1-20ppm sulfur and up to 25% water content
- Testing of the catalyst in a GT exhaust is scheduled for this year
- Long term durability testing is ongoing and shows good results

Commercial Scale SCR installation

Advancing DOE Technologies
Siemens Full Scale Engine Test

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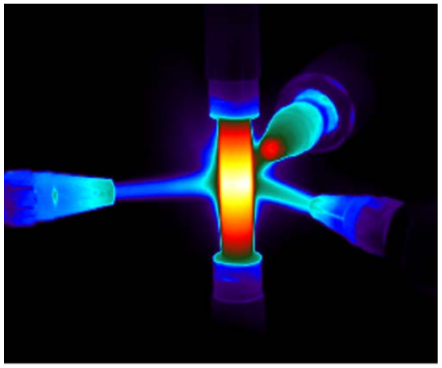
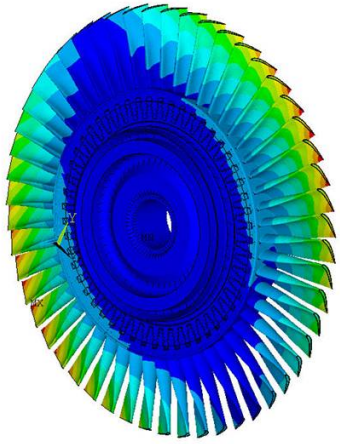
Siemens Berlin Test Facility



Thermal Testing

Advanced Blade Casting

Advanced Coatings



Advanced Tools

Acoustic Sensing

Successful summer test campaign of blades, vanes, sensors, coatings and catalyst

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Technology Collaboration: Leveraging Relationships in World-Wide R&D Network

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Government Funding

Universities

Business Partners

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Energy Policy:

- Global Warming ↓
- Create New Jobs ↑
- Energy Independence ↑

Market Trends:

- Emissions ↓
- Efficiency ↑
- Life Cycle Cost ↓

Siemens is a part of a broad, collaborative R&D, Manufacturing, Validation Network

Common Goal: Accelerate emerging technologies for thermodynamic and environmental performance in Turbo Machinery.

Siemens - DOE - Universities
The Leverage of Mutual Partnership: Estimated by 2015

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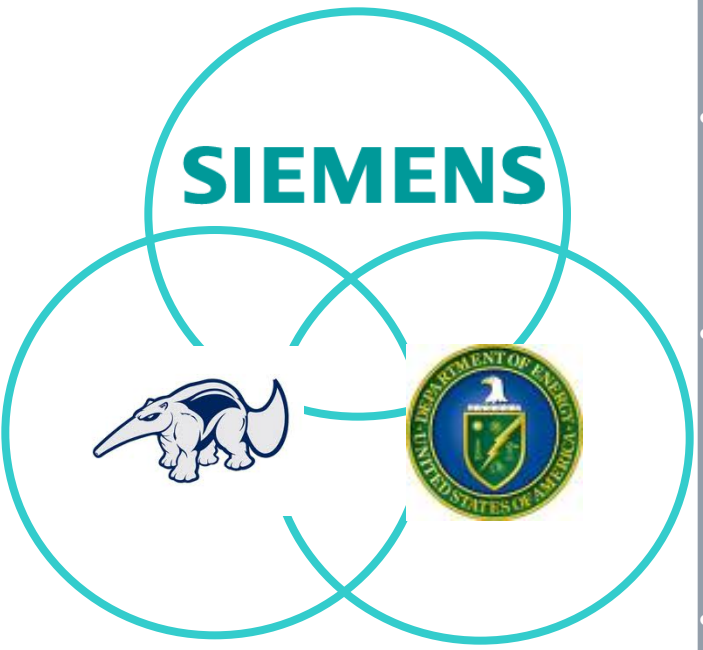

- Innovations in Gas Turbine Technologies for increasing Combined Cycle Power Plant Efficiencies and Performance
- The Next Generation Siemens Gas Turbine has parts designed by UTSR Alumni
- Partnering with 25 top U.S. universities for R&D in the field of Turbo- machinery
  - → over 75 graduate students
- Over 170 Invention Disclosures submitted to USPTO
- Establishing an "engineering talent pipe-line" for our future
- Job creation / economic development of local U.S. economy

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Program Benefits

Approximately 90% of the technologies developed in this program are applicable to any industrial gas turbine, regardless of fuel type, including:

- Thermal Barrier Coatings (TBC)
- Investment casting core manufacturing
- Turbine blade cooling technology
- Selective Catalytic Reduction (SCR)
- Turbine and compressor aerodynamics
- Nickel alloy life prediction
- Leakage reduction technologies
- Advanced design techniques
- High Temperature Combustion technologies

Technologies developed on this program are moving into engine-level testing and will then be ready for download into production

Siemens is Working to Ensure Commercial Viability of the IGCC Hydrogen Turbine

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- Carbon capture and sequestration ready
- Improving gas turbine and combined cycle **efficiency**
- Providing **near term** technology infusion into current engines both IGCC and NGCC
  - Tech partially funded by DOE is successful and ready for download early on
- Lowering **$/kW** cost with increased output and efficiency
- Significantly reducing **CO_2** and **NOx** emissions
- Enabling greater reliance on domestic resources

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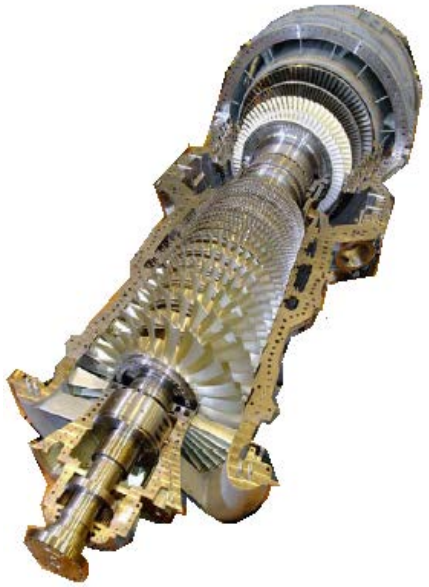

Siemens advanced GT technology aligns with future industry drivers

Conclusions
Technologies Driving Results

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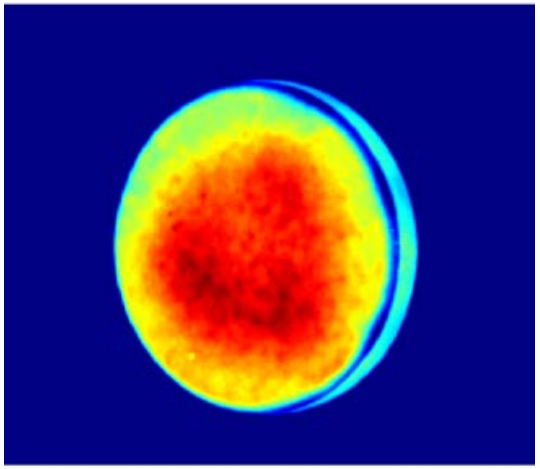

+3-5%

- Improved Efficiency
- Fuel Flexibility NG,Syngas,H_2
- Low Emissions
- Reduction in Plant Cost $/KW
- CO_2 Sequestration Ready

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Acknowledgements

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Answers for Energy.

Thank You.

Questions?