Improving IGCC Flexibility Through Gas Turbine Enhancements

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Presented at
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October 5, 2004
Washington, DC
Agenda

- Who we are
- Solutions for Today’s IGCC Plants
- Siemens IGCC Experience
- Gas Turbine Roadmap
  - Update on IGCC Related Gas Turbine R&D Programs
  - Key Gas Turbine Enabling Technologies
- Conclusions
Siemens Power Generation
Product and Service Scope

**Fossil Power Generation**
- Gas turbines and combined cycle plants
- Steam turbines and power plants
- Electrical generators
- Plant Diagnostics
- Operating Plant Service (~600GW's)

**Industrial Applications**
- Industrial size turbines and power plants
- Turbo compressors and drives
- Oil and Gas Sector
- Service – Over 12,000 Units

**Stationary Fuel Cells**

**Instrumentation & Controls Power Generation**
- Instrumentation and control systems
- IT solutions for power plant management
- New Energy Associates

**Joint Venture**
- Framatome Advanced Nuclear Power (Siemens stake 34%)
- Voith Siemens Hydro (Siemens stake 35%)

**Regional Offices Worldwide**
Siemens Solutions for Today’s IGCC Plants

Gas Turbine Generators

Air / N₂ / O₂ / Syngas Compressor Trains

Steam Turbine Generators

IGCC Plant Instrumentation and Control Systems

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Gas Turbines Available for IGCC Applications

60 Hz Applications

- W501D5A
  - Over 140 Units in Operation
- W501F
  - Over 175 Units in Operation
- W501G
  - 20 Units in Operation

Applications Include:
- Coal, Pet coke, or Residual Oil Based IGCC
- Small Coal or Biomass Based IGCC
- Other Low-BTU or Med-BTU Applications
- Greenfield IGCC or Repowered NGCC

Geared Units

- Typhoon
  - Over 300 Units in Operation

50 Hz Applications

- V94.2 / V94.2K
  - Over 220 Units in Operation
- V64.3A
  - Over 10 Units in Operation
- V64.3
  - Over 40 Units in Operation
- V94.3A
  - Over 65 Units in Operation

Applications Include:
- Coal, Pet coke, or Residual Oil Based IGCC
- Small Coal or Biomass Based IGCC
- Other Low-BTU or Med-BTU Applications
- Greenfield IGCC or Repowered NGCC

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# Siemens Power Generation

## IGCC Experience List

<table>
<thead>
<tr>
<th>Customer / Plant (Location)</th>
<th>Electrical Output (net)</th>
<th>Plant Features</th>
<th>Siemens Technology Gas Turbine</th>
<th>Other Siemens Scope</th>
<th>Start-up Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hörde Steelworks (Dortmund, Germany) Handan Iron &amp; Steel (Handen, P.R. China)</td>
<td>8 MW</td>
<td>Fuel: blast-furnace gas, GT used as compressor drive</td>
<td>VM5</td>
<td></td>
<td>1960, 2000</td>
</tr>
<tr>
<td>U.S. Steel Corp. (Chicago, IL)</td>
<td>20 MW</td>
<td>Fuel: blast-furnace gas</td>
<td>CW201</td>
<td></td>
<td>1960</td>
</tr>
<tr>
<td>STEAG / Kelkermann (Lünen, Germany)</td>
<td>163 MW</td>
<td>1st CC Plant with integrated gasifier Gasifier: LURGI (Air Blown)</td>
<td>V93</td>
<td></td>
<td>1972</td>
</tr>
<tr>
<td>Dow Chemicals/ LTGI (Pilaquemeine, LA)</td>
<td>208 MW</td>
<td>Gasifier: DOW (COP E-Gas) Feedstock: Coal</td>
<td>2 X W501D5</td>
<td>ASU Main Air Compressor</td>
<td>1987</td>
</tr>
<tr>
<td>Nuon Power Buggenum (Buggenum, Netherlands)</td>
<td>253 MW</td>
<td>Gasifier: SCGP Feedstock: Coal and biomass blend</td>
<td>V94.2</td>
<td>ASU Air Compressor (for start-up) N, Compressors O2 Compressor</td>
<td>NG: 1993 Syngas: 1994/95</td>
</tr>
<tr>
<td>Global Energy / Wabash River IGCC (West Terre Haute, IN)</td>
<td>262 MW</td>
<td>Gasifier: COP E-GAS Current Feedstock: Pet coke</td>
<td>----</td>
<td>ASU Main Air Compressor</td>
<td>1995</td>
</tr>
<tr>
<td>Tampa Electric / Polk Co. IGCC (Mulberry, FL)</td>
<td>250 MW</td>
<td>Gasifier: TGP Feedstock: Coal</td>
<td>----</td>
<td>ASU Main Air Compressor N, Compressors O2 Compressor</td>
<td>1996</td>
</tr>
<tr>
<td>HRL (Morwell, Australia)</td>
<td>10 MW</td>
<td>Demonstration Plant Gasifier: IDG (Air Blown) Feedstock: Lignite</td>
<td>Typhoon</td>
<td></td>
<td>1996</td>
</tr>
<tr>
<td>ELETTAGLT (Servola, Italy)</td>
<td>180 MW</td>
<td>Fuel: Steel making recovery gas</td>
<td>V94.2K</td>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>ARBRE Energy (Eggborough, UK)</td>
<td>8 MW</td>
<td>Gasifier: Air Blown Feedstock: Biomass</td>
<td>Typhoon</td>
<td></td>
<td>2002</td>
</tr>
<tr>
<td>NPRC / Negishi IGCC (Negishi, Japan)</td>
<td>348 MW</td>
<td>Gasifier: TGP Feedstock: Asphalt</td>
<td>----</td>
<td>ASU Main Air Compressor N, Air Compressor O2 Compressor</td>
<td>2003</td>
</tr>
<tr>
<td>EniPower (Sannazzaro, Italy)</td>
<td>250 MW</td>
<td>Gasifier: SHELL Feedstock: Heavy oil</td>
<td>V94.2K</td>
<td></td>
<td>2005</td>
</tr>
</tbody>
</table>

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*Siemens Gas Turbines Have Achieved Over 300,000 Operating Hours on Syngas from Modern IGCC Plants*
Gas Turbine Experience Update
Nuon Power Buggenum IGCC Project
ISAB Energy

- **Buggenum IGCC Project**
  - > 71,000 OH in total
  - > 43,000 OH on SG
  - Longest continuous SG run of 2,900 OH

- **ISAB Energy**
  - > 75,500 OH in total
  - > 72,500 OH on SG

- **Buggenum** Continues to Operate As Expected with Single Digit NOx Emissions (< 9 ppm) with No Reduction in Firing Temperature

- **ISAB** Gas Turbines’ Burners Continue to Show No Signs of Overheating Caused by Ni-carbonyl

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Gas Turbine Experience Update
ELCOGAS, Puertollano IGCC Project

- Cumulative Operating Hours
  - > 45,300 OH in total
  - >> 23,400 OH on SG

- Gas Turbine Improvements Implemented in 2003-2004
  - Improved Conical Nozzle
    - Elongated cone moves flame shape away from axial swirlers (e.g., greater deposit resistance)
  - Gas Turbine Compressor End Pressure Control
    - Reduced operational air-side interactions between ASU and gas turbine and minimizing combustor temperature fluctuation

- Recent Inspection Has Confirmed Improved Burner Installed in 2003 has Allowed Normal Gas Turbine Inspection Intervals
- However, Corrosion and Deposit Formations from Trace Contaminates in Fuel are Still Visible in Gas Turbine
Pathways to the Future
Many Views of the Future

Technology Roadmap – Future Energy Plants

Government / Industry Roadmap

Siemens Internal View of the Future

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### Pathway to the Future
### IGCC Gas Turbine Roadmap

#### IGCC Plant Market Drivers

<table>
<thead>
<tr>
<th></th>
<th>Today</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced Capital Cost ($/kW)</td>
<td>1300-1400</td>
<td>1000</td>
<td>900</td>
</tr>
<tr>
<td>Lower Emissions (NOx, lb/10^7 Btu)</td>
<td>0.15</td>
<td>0.05</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Improved Availability (%)</td>
<td>&gt;80</td>
<td>&gt;85</td>
<td>≥90</td>
</tr>
<tr>
<td>Improved IGCC Plant Efficiency (% HHV)</td>
<td>40</td>
<td>45-50</td>
<td>50-60</td>
</tr>
</tbody>
</table>

#### Gas Turbines

- **Conventional IGCC Cycles**
  - Commercial C-Class Gas Turbines
  - Advanced Gas Turbines

- **ITM / CTM IGCC Cycles**
  - Advanced Gas Turbines

- **CO₂ Free IGCC Cycles**
  - H₂ Fueled Advanced Turbines
  - Oxy-Fueled Advanced Turbines

#### Gas Turbine Enabling Technologies

- **Combustion Systems**
  - Technologies for Better Performing Commercial Systems
  - Syngas Combustion Systems for Advanced Gas Turbines
  - ITM / CTM Ready Systems
  - H₂ Combustion Systems
  - Oxy-Fueled Combustion Systems

- **Materials and Coating Systems**
  - Corrosion Resistant Materials and Coatings
  - Coatings and Materials for Improved Efficiency
  - H₂ Tolerant Materials and Coatings

- **Controls and Sensors**
  - Adaptation of IGCC Sensors for IGCC
  - Better Turbine Control and Health Monitoring Sensors

#### Notes:

- In most cases, standard gas turbines can be adapted.
- Today, some areas are being addressed in R&D programs in the U.S. and Europe.
- However, the more advanced cycles require larger and longer gas turbine R&D programs to overcome technical barriers.

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**Gasification Technologies 2004**
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Improvements to Commercial Systems
W501F Syngas Combustion Tests

- In 2002, 3 syngas combustion tests were completed. Results from observations indicate that:
  - Combustor is extremely stable during syngas operation over a wide range of loads and gas compositions
  - NO\textsubscript{x} target of 25 ppm was achieved with dilution steam
  - CO emissions were low

- Additional tests to be completed at full pressure in 2005

- Target W501F Emissions: 15 ppm NO\textsubscript{x} on syngas @ 15% O\textsubscript{2}
Improvements to Commercial Systems
Modular IGCC Fuel System For Siemens Gas Turbines

Best of Lessons Learned From Existing Projects

Heating Value Control for Fuel Flexibility

Pre-Heating and Heating Value Control System

IP Steam Flare

Block and Bleed

N\textsubscript{2} from ASU

IP Steam

Natural Gas

Syngas

N\textsubscript{2} Dilution System

Saturation System

From W/S System

to Air Cooler

to W/S System

to ASU

Air Integration System

Kettle Boiler

Vent

Inlet Guide Vane

Gas Turbine (V or W Series)

LP Steam

Vent

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Future Enhancements
Ultra Low-NOₓ IGCC Combustion Technology

DOE / SWPC
Ultra Low NOx Combustion System for Fuel Flexible Gas Turbines

- **Program Objectives**
  - Cost Effective
  - Fuel Flexible
    - Syngas
    - Natural Gas
  - Retrofitable into Existing Gas Turbines
  - < 2-3 ppm NOx
  - Eliminate Need for SCR

- **Schedule**
  - Started 10/2003
  - Finished Phase 1
  - Program Complete in 2007
**Future Enhancements**

**Advanced Syngas Combustion – The European Project HEGSA**

**EC project NNE5/644/2001**

**High Efficient Gas Turbine with Syngas Application**

- **Program Objectives**
  - **Enhanced knowledge** of syngas combustion
    - Chemical kinetics of combustion of typical syngases elaborated for CFD calculation
    - Model of thermo-acoustic behavior
    - Generic diffusion burner for experimental investigations
  - **Development of improved and advanced burners**
    - Develop main design features of improved burners and full-scale test
    - Develop concepts for advanced burner for annular combustion chamber

- **Schedule**
  - Currently mid way through 3-year program

- **Partners**
  - Siemens PG (Coordinator)
  - Ansaldo Energia Spa
  - Universiteit Twente
  - Deutsches Zentrum für Luft- und Raumfahrt e.V.
  - Enel Produzione SpA
  - NV Nuon Energy Trade & Wholesale

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Improvements to Commercial Systems
Evolution of Syngas Burner Technology

Improved Syngas Burner for Silo-type Vx4.2, Vx4.2K

- Use of 2 passages for syngas
- Optimal adaptation of nozzle design to specific application

Advanced Syngas Burner for Vx4.3A

- Derived from well proven Hybrid Burner technology
- Adaptation to annular combustion chamber
- Use of 2 passages for syngas
- Low-NOₓ combustion at elevated firing temperature

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Future Enhancements
Very Low BTU Syngas Combustor

DOE / Southern Co. / SWPC
Wilsonville Power Systems Development Facility

- Piloted Syngas Burner
  - Very Low BTU Syngas
  - Propane

- Started up in October 2003

- 1,750 Hours of Operation Through August 2004

- Operating Flexibility
  Characteristics of Burner Has Been Demonstrated

- Long-Term Durability is the Focus of Future Testing
Future Enhancements
Real Time Engine Health Sensors

DOE / SWPC
On-line TBC Monitor for Real-time Failure Protection and Life Maximization

- **Program Objective**
  - Build and install W501F Blade and Vane TBC Monitor with TBC Lifing Supervisory System

- **Schedule**
  - 4-year program started in 2001
  - *First view of actual operating turbine in Jan. 2004*

- **Partners**
  - Siemens Westinghouse Power Corporation (lead)
  - Indigo Systems
  - Wayne State University

Technology Can Also Be Used in IGCC Gas Turbines

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Future Enhancements
IGCC with Membrane Oxygen Separation

DOE / Air Products / SWPC
IGCC Application of ITM Oxygen Separation

Program Objective
- Optimum IGCC integration of ITM with W501G gas turbine

Scope
- Identify major obstacles and solution paths
- Develop conceptual designs
- Estimate “Nth” unit costs
- Estimate development costs

Schedule
- Started 11/2003
- Planned Completion 9/2005

Partners
- Air Products & Chemicals Inc.
- Siemens Westinghouse Power Corporation

Preliminary Results from Study Show that the W501G can be Integrated into the ITM Cycle
Future Enhancements
Syngas Test Rig for Long-Term Testing

DOE / FTT / SWPC / DGC
Advanced Hot Section Materials and Coating Test Rig

➢ Program Objectives
  ➢ Develop materials and coatings test facility capable of simulating near actual gas turbine operating environment for the purpose of obtaining lifing data.
  ➢ Test facility will be able to operate continuously on coal derived syngas and synthetic natural gas

➢ Schedule
  ➢ 3-year program started in 2003
  ➢ Preliminary engineering underway

➢ Partners
  ➢ Florida Turbine Technologies (lead)
  ➢ Siemens Westinghouse Power Corporation
  ➢ Dakota Gasification Co.

Will be the First Syngas Fueled Materials and Coatings Test Rig That Can Address Long-Term Durability
Future Enhancements
Optimized IGCC Integration into Refinery's Structure –
The European Project MIGREYD

EC project NNE5-2001-670
Modular IGCC Concepts for In-Refinery Energy and Hydrogen Supply

➢ Program Objectives
  ➢ Develop "green refinery“ concept that reduces CO₂ emissions while integrating a co-production IGCC power plant into process

➢ Schedule
  ➢ 3-year program started in July 2003

➢ Partners
  ➢ University of Essen (Coordinator)
  ➢ Siemens PG
  ➢ Continental Engineers
  ➢ Energy Research Centre of the Netherlands
  ➢ ELCOGAS S.A.
  ➢ Instituto Superior Tecnico

Conclusions for current market
Liquid residue are currently converted to HFO ⇒ 30-80 USD/ton

Limited market for IGCC today
➢ breakeven price for NG > 3.5 EUR/GJ
➢ H₂ co-production improves competitiveness

Expected future scenario
➢ Stringent S-limits for HFO (1 wt%) in EU/Japan
➢ Increased natural gas price
➢ Increased crude oil demand forecasted

IGCC co-production competitive
➢ Liquid residue value negative
➢ Liquid residue volume increases
➢ Increased H₂ consumption/ export

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CO₂ Free Power Plants
IGCC Concepts for CO₂ Emissions Mitigating

The step of gasification opens IGCC to a variety of CO₂ separation methods.
- **Pre-combustion removal** is the most promising one.

**CO Shift and CO₂ Removal**

1. **Fuel** → **Gasification** → **CO Shift** → **H₂S & CO₂ Removal** → **High-H₂ Gas Turbine** → **CO₂-free Exhaust**

   - **Efficiency reduction:** 5 to 7 %-pts
   - **20 to 40 EUR/ton CO₂ avoided**

   - To be developed in project ENCAP

**H₂/CO Membrane Based Separation**

1. **Fuel** → **Gasification** → **H₂S Removal** → **H₂ /CO Membrane** → **H₂** → **High-H₂ Gas Turbine** → **CO₂-free Exhaust**

   - **Efficiency reduction:** 4 to 5 %-pts
   - **20 to 45 EUR/ton CO₂ avoided**

   - *) Source: Göttlicher

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CO₂ Free Power Plants
CO₂ Removal from Fossil Fuel Fired Power Plants – The European Project ENCAP

6th EU Framework Program, Integrated Project
Enhanced CO₂ Capture

➢ Program Objective
  ➢ Concepts/technology for CO₂ capture from natural gas and coal fired power plants at 50% capture cost reduction & at least 90% capture rate

➢ Partners
  ➢ Vattenfall AB (leader)
  ➢ 32 partners (energy and technology providers, RTD institutes)

➢ Schedule
  ➢ 4.5 years
  ➢ Started March 2004

Siemens main focus
Pre-Combustion Decarbonization Technology
➢ Combustion of H₂-enriched gases in advanced GT:
  ➢ Numerical design tools
  ➢ Burner design incl. tests
  ➢ Effects for gas turbine components
  ➢ Overall plant basic design (concepts, integration aspects, CO-Shift, CO₂ separation)

Oxyfuel Boiler Technology
Chemical Looping Combustion
High-Temperature O₂ Generation for Power Cycles
Novel Pre-Combustion Capture Concepts
Conclusions

Today, Siemens offers a wide range of solutions for IGCC projects

- Gas Turbines
- Control Systems
- Compressor Trains
- Steam Turbines

Customer interest in IGCC has increased significantly over the last 12 months

- Siemens has increased IGCC R&D activities to improve its commercial IGCC products

New gas turbine technology is needed to support the 2010 and 2020 roadmap goals

- Enabling technology requires significant R&D over a number of years
- Lessons learned in Europe and the United States can be leveraged
- Need to get R&D started on key technologies, such as the ones shown here

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