Pushing Forward IGCC Technology at Siemens

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Content

- Introduction
- Fuel flexibility and IGCC experience of Siemens/Siemens Westinghouse gas turbines
- The ELCOGAS IGCC power plant – Status and recent activities
- IGCC development at Siemens/Siemens Westinghouse and ELCOGAS – Current R&D
  - Vx4.3A Syngas Burner for advanced high efficient IGCC applications
  - Ultra low-NO\textsubscript{x} combustion technology
  - Next generation IGCC power plant
  - Concepts for future gasification-based energy plants
- Outlook
IGCC – Environmental Benefit for Power Generation

- **High Potential to save primary energy sources**
  - **high plant efficiency** potential of approx. 52 % (net) aimed to be achieved within this decade
  - **feedstock flexibility** (coal, refinery residues, biomass, waste, ...) ⇒ substitution of valuable high-grade fossil fuels, avoid disposal

- **Low emissions** of pollutants (dust, SO₂, NOₓ, etc.) because of
  - **high efficient pre-combustion gas cleaning** systems (pressurized gas) and **low NOₓ combustion**
  - **option of** (additional) **post-combustion gas cleaning**

- **Option of CO₂ removal** with moderate total plant efficiency reduction (5-7 %-points, gaseous state)
## Siemens Heavy Duty Gas Turbine Technology for Syngas Applications

### Experience from operation at ELCOGAS plant
- Successful tests - combustor extremely stable, NO\textsubscript{x} target (25 ppmv) at base load by steam
- Well proven at Nuon (V94.2) and ISAB (V94.2K) IGCC plant

### Adaptation for syngas application under work
- Experience from operating DOW Chemicals IGCC

### Table: Performance Characteristics

<table>
<thead>
<tr>
<th></th>
<th>50 Hz</th>
<th>60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V94.3A</td>
<td>V94.3</td>
</tr>
<tr>
<td>Gross power output  [MW]</td>
<td>266</td>
<td>222</td>
</tr>
<tr>
<td>Gross efficiency [%]</td>
<td>38.6</td>
<td>36.2</td>
</tr>
<tr>
<td>Gross heat rate     [kJ/kWh]</td>
<td>9323</td>
<td>9945</td>
</tr>
<tr>
<td>[Btu/kWh]</td>
<td>8836</td>
<td>9426</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td>17.0</td>
<td>16.1</td>
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</table>
**Operational Experience of Siemens Gas Turbine Technology on Low-BTU Gases**

<table>
<thead>
<tr>
<th>Turbine Type</th>
<th>Site Details</th>
<th>Capacity</th>
<th>Gas Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>W501D5</td>
<td>DOW Chemicals, Plaquemine/USA</td>
<td>208 MW</td>
<td>DOW coal gasification start-up 1987</td>
</tr>
<tr>
<td>V94.2</td>
<td>Nuon Power Buggenum/NL</td>
<td>253 MW</td>
<td>SHELL coal gasification start-up 1993 NG, 94/95 CG</td>
</tr>
<tr>
<td>V94.3</td>
<td>ELCOGAS, Puertollano/E</td>
<td>300 MW</td>
<td>PRENFLO coal gasification start-up 1996 NG, 97/98 CG</td>
</tr>
<tr>
<td>V94.2K</td>
<td>ISAB Energy, Priolo Gargallo/I</td>
<td>521 MW</td>
<td>TEXACO heavy-oil gasification start-up 1998 FO, 1999 SG</td>
</tr>
<tr>
<td>V94.2K</td>
<td>ELETTRA GLT, Servola/I</td>
<td>180 MW</td>
<td>CC with steel-making recovery gas start-up 2000</td>
</tr>
</tbody>
</table>

- **OH**: operating hours
- **NG**: natural gas
- **CG**: coal gas
- **SG**: syngas
Fuel Flexibility and Integrational Features of Siemens Gas Turbine Applications

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>DOW Plaquemine (USA)</th>
<th>Nuon Power Buggenum (NL)</th>
<th>Elcogas Puertollano (E)</th>
<th>ISAB Energy Priolo Gargallo (I)</th>
<th>Elettra GLT Servola (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal</td>
<td>Coal/biomass</td>
<td>Coal/petroleum coke</td>
<td>Asphalt</td>
<td>Blast furnace gas Coke oven gas Natural gas</td>
</tr>
<tr>
<td>Gasification</td>
<td>DOW</td>
<td>Shell</td>
<td>Prenflo</td>
<td>Texaco</td>
<td>41.0 (incl. Ar, O₂)</td>
</tr>
<tr>
<td>Fuel gas temperature</td>
<td>149 °C/300 °F</td>
<td>300 °C/ 572 °F</td>
<td>302 °C/ 576 °F</td>
<td>195 °C/ 383 °F</td>
<td>10 % 16.3</td>
</tr>
<tr>
<td>Fuel gas compositions</td>
<td>% vol</td>
<td>% vol</td>
<td>% vol</td>
<td>% vol</td>
<td>% vol</td>
</tr>
<tr>
<td>H₂</td>
<td>41.4</td>
<td>12.3</td>
<td>10.7</td>
<td>31.3</td>
<td>9.0</td>
</tr>
<tr>
<td>CO</td>
<td>38.5</td>
<td>24.8</td>
<td>29.2</td>
<td>28.5</td>
<td>16.3</td>
</tr>
<tr>
<td>CO₂</td>
<td>18.5</td>
<td>8.0</td>
<td>1.9</td>
<td>3.2</td>
<td>13.6</td>
</tr>
<tr>
<td>N₂</td>
<td>1.5</td>
<td>42.0</td>
<td>53.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.1</td>
<td>-</td>
<td>0.01</td>
<td>-</td>
<td>14.6</td>
</tr>
<tr>
<td>Ar</td>
<td>-</td>
<td>0.6</td>
<td>0.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H₂O</td>
<td>-</td>
<td>19.1</td>
<td>4.2</td>
<td>36.9</td>
<td>5.5</td>
</tr>
<tr>
<td>O₂</td>
<td>-</td>
<td>0.4</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H₂/CO ratio (vol)</td>
<td>1.07</td>
<td>0.50</td>
<td>0.36</td>
<td>0.85</td>
<td>0.55</td>
</tr>
<tr>
<td>Lower heating value</td>
<td>239 BTU/SCF</td>
<td>113 BTU/SCF</td>
<td>123 BTU/SCF</td>
<td>174 BTU/SCF</td>
<td>209 BTU/SCF</td>
</tr>
<tr>
<td></td>
<td>10.4 MJ/kg</td>
<td>4.3 MJ/kg</td>
<td>4.3 MJ/kg</td>
<td>9.1 MJ/kg</td>
<td>7.2 MJ/kg</td>
</tr>
<tr>
<td>Secondary fuel</td>
<td>Natural gas</td>
<td>Natural gas</td>
<td>Natural gas</td>
<td>Fuel oil</td>
<td>Natural gas</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>2 x W501D5</td>
<td>1 x V94.2</td>
<td>1 x V94.3</td>
<td>2 x V94.2K</td>
<td>V94.2K</td>
</tr>
<tr>
<td>Air extraction form GT</td>
<td>related to ASU</td>
<td>0 %</td>
<td>100 %</td>
<td>100 %</td>
<td>0 %</td>
</tr>
<tr>
<td></td>
<td>related to compressor</td>
<td>0 %</td>
<td>16 %</td>
<td>18 %</td>
<td>0 %</td>
</tr>
<tr>
<td>Nitrogen integration</td>
<td>0 %</td>
<td>100 %</td>
<td>100 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
<tr>
<td>Net power output</td>
<td>208 MW</td>
<td>253 MW</td>
<td>300 MW</td>
<td>521 MW</td>
<td>180 MW</td>
</tr>
<tr>
<td>Net efficiency (LHV)</td>
<td>Not available</td>
<td>43.2 %</td>
<td>45.0 % *)</td>
<td>&lt; 40.0 %</td>
<td></td>
</tr>
</tbody>
</table>

*) ISO conditons and use of high quality coal
Standardized V94.2K-Based IGCC Power Plant for Refinery Residues (500 MW Class)

Based on

- Refinery residues (secondary fuel oil)
- Shell Gasification Process
- 2 x V94.2K
- 50 % air-side integration

⇒ Turnkey concept of a standardized IGCC power plant

Net power output 484.9 MW, net efficiency 42.8%
(ISO conditions, condenser 0.055bar)

IGCC plants are competitive if the fuel price difference (natural gas versus residues) is higher than 2.0 to 2.5 US$/GJ
ELCOGAS IGCC Power Plant, Puertollano - Status

On average more than 5,100 syngas and 7,000 total OH/year in 2001/2002

Demonstrates IGCC competitiveness in the Spanish liberalized electricity market
Design of the burner outlet is characterized for

- **Low NO\textsubscript{x} formation**
  - Segments for excellent fuel gas/air mixture

- **Robust design**
  - Elongated cone to move flame shape away from axial swirler

\[ \text{NO}_x \text{ emissions are in the same range than burner with segments, due to the particular treatment and preparation of syngas before it is fed to the burners (water saturation and nitrogen dilution)} \]
ELCOGAS IGCC Power Plant, Puertollano - Modified Master Control Concept

Natural Gas Admixing

Gasifier

Gas Cleaning

Saturator

Gas Turbine

Plant Load Setpoint

Natural Gas Admixing

Oxygen

Waste Nitrogen

Extracted Air

Gasifier

Gas Cleaning

Saturator

Gas Turbine

Plant Load Setpoint

Natural Gas Admixing

Oxygen

Waste Nitrogen

Extracted Air

Gasifier

Gas Cleaning

Saturator

Gas Turbine

Plant Load Setpoint

Natural Gas Admixing

Oxygen

Waste Nitrogen

Extracted Air

Gasifier

Gas Cleaning

Saturator

Gas Turbine

Plant Load Setpoint

Natural Gas Admixing

Oxygen

Waste Nitrogen

Extracted Air
IGCC Technology Improvement

- **Target**
  - Commercial design w/o learning curve
  - IGCC efficiency > 52% (LHV)
  - Capital cost < $1000/kW
  - Lowest emission (e.g. NO\textsubscript{x}, CO\textsubscript{2}, Hg)

- **Further development of IGCC technology**
  - National governments (U.S. DOE, German BMWA, ...)
  - European Commission (FP5, FP6, CARNOT, ...)

- **Support**

- **Main focus of Siemens / ELCOGAS R&D**
  - Syngas burner systems for high efficient Gas Turbine application
  - Ultra low-NO\textsubscript{x} combustion technology
  - Next generation IGCC concept
  - Concepts for future gasification-based energy plants (power & H\textsubscript{2})
  - Pre-combustion \textsubscript{CO}_{2} removal
  - IGCC with ITM for oxygen production
Advanced Syngas Combustion - Project Outline

EC project NNE5/644/2001 (HEGSA)

**High Efficient Gas Turbine with Syngas Application**

**Targets**
- Increasing theoretical and technological knowledge of syngas combustion
- Improving the flexibility of current gas turbine syngas combustion systems
- Developing an advanced combustion system for annular burner technology operating at higher pressure and temperature using low-BTU syngases

**Scope**
Specification of requirements - adjusted CFD simulations including generic burner experiments - thermo-acoustic investigations - design studies - prototype design - atmospheric and pressure combustion tests

**Partners**
- Siemens AG PG (Coordinator, D) 01/2003 – 12/2005
- ANSALDO ENERGIA Spa (I)
- Universiteit Twente (NL)
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (D)
- Enel Produzione SpA (I)
- NV NUON Energy Trade & Wholesale (NL)
Advanced Syngas Combustion - Burner Design Criteria

- Minimum syngas pressure drop
  - Burner capacity and minimum gas turbine load
- Stable burning conditions
  - Adjustment of syngas swirl angle
- Minimum NO\textsubscript{x} values/ robust design
  - Good syngas mixing
  - Nozzle design based on lessons learned
- High fuel and operational flexibility
  - Two passage concept for high flame stability and minimal pressure drop

Advanced syngas combustor available for high efficient gas turbine with syngas application in 2006
Ultra Low-NO$_x$ Combustion Technology

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

- **Schedule**
  - Started 10/2003
  - 3 Year Program

![Combustor Technologies Diagram](image)
Pre-Engineering Studies for a New IGCC Plant Based on Puertollano ELCOGAS Plant Experience

**Targets**
- Definition of a Second Generation IGCC plant concept
- Assessment of optional pre-combustion CO₂ removal
- Dissemination of IGCC technology capability for clean and efficient power generation

**Scope**
Analysis of relevant plant operation data - definition of improvement potential - evaluation of technical, environmental and other general boundary conditions - definition of main process units - assessment of CO₂ capture and H₂ co-production - market potential emphasizing Russia - dissemination

**Partners**
- ELCOGAS S.A. (Coordinator, E)
- UHDE GmbH (D)
- Siemens AG PG (D)

**Duration**
08/2003 – 01/2005
Next Generation IGCC Power Plant – Main Concept Features

- 400 MW class
- High efficiency
- Cost-effectiveness
- Improved operational behaviour
- Reliability, availability
- Emissions reductions

Improvements in gas island (e.g. fuel flexibility, co-production of H₂)

Partial air-side integration, optimized O₂ purity

Fuel gas saturation (clean gas + waste nitrogen)

Based on gas turbine V94.3A(4)

Optional CO₂ capture

Single train arrangement
Development of IGCC concepts for Refinery Environment – Project Outline

EC project NNE5-2001-670 (MIGREYD)

**Modular IGCC Concepts for In-Refinery Energy and Hydrogen Supply**

**Targets**
- Developing the concept of a "green refinery": Reduction of CO₂ emissions when considering more stringent product and environmental requirements by integrating IGCC power plants into refinery structures
- Optimized modular plant structures aiming at standardisation and cost reduction
- Sustainable pollution control and substitution of high-grade fossil fuels

**Scope**
Market research of refinery residues & H₂ - definition of project data basis - generation of a modular plant structure including process routes for H₂ production and power generation - thermodynamic optimization - evaluation of environmental benefits - co-gasification of biomass - integration of fuel cell topping cycle - economical evaluation - dissemination

**Partners**
- University of Essen (Coordinator, D)
- Siemens AG PG (D)
- Continental Engineers (NL)
- Energy Research Centre of the Netherlands (NL)
- ELCOGAS S.A. (E)
- Instituto Superior Técnico (P)

**Duration**
07/2003 – 06/2006
Modular IGCC Concept and Additional Co-Production Options

- Preparation (Preheating, Grinding, Drying)
  - Slurry (Water, Oil) Dry
- Feeding
- Gasification
  - O₂/Air
  - Raw Gas
  - Slag, Ash
  - Quench
    - Water Quench
    - Gas Quench
  - Syngas Cooling
    - Steam Generation
    - Raw/Clean Gas Heatex
- Soot Removal Dedusting
  - Cyclone
  - Venturi Wash (wet)
  - Candle Filter (dry)
  - Water Treatment
- Waste Water
- Air Separation Unit
  - Cryogenic ITM ¹
- Hydrogen Separation
  - Cryogenic Separation
  - PSA ⁴
  - Membrane
- CO₂ Removal
  - Absorption
  - Membrane
- Syntheses
- Power Generation
- Additional Co-Production Options
- ¹ Ion Transport Membrane
- ² Boiler Feed Water
- ³ Heat Recovery Steam Generator
- ⁴ Pressure Swing Adsorption
- ⁵ Enhanced Oil Recovery
- ⁶ Enhanced Coal Bed Methane

Power Generation
CTET/ G251 18
Outlook – Further R&D

Climate change – challenge for worldwide R&D

IGCC is predestinated for fossil fuel based power generation with CO₂ capture, because it promises

- high efficiency potential
- efficient technology for CO₂ removal

R&D Focus:
Optimised plant integration including CO₂ capture
Application of Ion Transported Membranes (e.g. ITM)
Advanced gas turbine technology based on low NOₓ H₂ combustion

Programs
DOE Vision 21, Future Gen
EC FP6 project "Enhanced capture of CO₂", ENCAP