IGCC power plants with and without CCS – developments to meet market needs

Juergen Karg

Siemens AG
Energy Sector
Agenda

1. Market requirements and CCS options
2. Available experience with IGCC
3. Key components and integration
4. Challenges for IGCC commercialization, improvement potential
5. Summary, conclusions
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1. Market requirements and CCS options
   - Market environment
   - CCS options
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Energy supply in the future will place major challenges on the infrastructure

Three global megatrends in the energy sector

Demographic dynamics
- Population growth: 7.5 bn in 2020 (+1.1 bn)
- Power consumption: +5.2% p.a. in emerging regions and 1.4% in developed world
- Megacities (>10 million inhabitants): 27 megacities in 2025

Resource scarcity
- Geopolitics: 70% of world oil and gas supplies only in a few countries
- Fuel diversity: 100% increase in oil prices over last 2 years accelerates shift to broader fuel mix

Environmental focus
- Global emissions: 40% increase in air pollution over past 20 years
- Climate change: Global warming limited to an average increase of 2 degrees Celsius

Quellen: UN, IEA, Stern
Renewables are gaining in importance – but fossil fuels will continue to be the mainstay

Power Generation (in 1000 TWh¹)

- **2008**: 21,000 TWh
  - **Renewables (excl. hydro)**: 600 TWh (3% of total)
  - **Fossil fuels**: 20,400 TWh
    - **Coal**: 42%, **Oil**: 5%, **Gas**: 15%
  - **Water**: 13%
  - **Nuclear**: 13%
  - **Biomass**: 28%
  - **Geothermal**: 13%
  - **Solar**: 2%
  - **Wind**: 28%

- **2030**: 37,000 TWh
  - **Renewables (excl. hydro)**: 5,200 TWh (14% of total)
  - **Fossil fuels**: 32,800 TWh
    - **Coal**: 36%, **Oil**: 3%, **Gas**: 21%
  - **Water**: 13%
  - **Nuclear**: 13%
  - **Biomass**: 19%
  - **Geothermal**: 49%
  - **Solar**: 28%
  - **Wind**: 4%
  - **Others**: 1%

Source: Siemens Energy MOP3 – scenario "Base" Case 2008

¹ Terawatt-hours
From primary energy to power distribution: CO₂ reduction efforts needed in the whole process chain

Examples for contributions from Power Generation:
- Highly efficient gas turbines for CCPP and IGCC
- Supercritical steam technology
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   ▪ CCS options
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Process options for CO₂ capture

**CO₂ capture before combustion (Pre-combustion)**
IGCC process (coal) or IRCC process (natural gas)

Fuel → Gasification → Syngas cleaning → CO₂ capture → Combined Cycle with H₂ turbine

**Integrated CO₂ capture (Oxyfuel)**

Coal → Steam Generator → Flue gas cleaning → Condensation → CO₂

**CO₂ capture after combustion (Post-combustion)**
Conventional PP with CO₂ wash

Coal → Conventional SPP → Flue Gas cleaning → CO₂ capture → CO₂

*) typical for 700 MW class

CO₂ is easier to capture in an IGCC power plant

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Pre-combustion capture (IGCC)
- Gasification technology: multi-fuel capability
- Alternative route for chemical / fuel production, hydrogen economy
- Technology ready for implementation
- Siemens option for new coal fired power plants and coal gas ready CCPP

Post-combustion capture
- Scalable market introduction, demonstration plants with slipstreams
- Enhancement potential for scrubbing process, solvents and plant integration
- Siemens option for retrofit and new coal-fired power plants

Siemens pursues both: pre- and post combustion capture.
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Gasification capacity and product split

<table>
<thead>
<tr>
<th>Global Syngas Capacity by Feedstock</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>55 %</td>
</tr>
<tr>
<td>Petroleum</td>
<td>32 %</td>
</tr>
<tr>
<td>Gas</td>
<td>8 %</td>
</tr>
<tr>
<td>Petroleum Coke</td>
<td>3 %</td>
</tr>
<tr>
<td>Biomass/Waste</td>
<td>2 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product Distribution of 2007 World Gasification Capacity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals</td>
<td>45 %</td>
</tr>
<tr>
<td>Liquid Fuels</td>
<td>30 %</td>
</tr>
<tr>
<td>Power</td>
<td>19 %</td>
</tr>
<tr>
<td>Gaseous Fuels</td>
<td>6 %</td>
</tr>
</tbody>
</table>

More than 80 percent of global industrial gasification capacity is already capturing CO₂ as part of the manufacturing process.

Source: Gasification Technologies Council
IGCC power plants built, in operation, under design, construction or commissioning

<table>
<thead>
<tr>
<th>Region</th>
<th>Total Built MW&lt;sub&gt;el&lt;/sub&gt;</th>
<th>Total Operational MW&lt;sub&gt;el&lt;/sub&gt;</th>
<th>Operational Coal/pet coke IGCC</th>
<th>Operational Oil/ heavy residues IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>4,170</td>
<td>2,620</td>
<td>35 %</td>
<td>65 %</td>
</tr>
<tr>
<td>Asia/Australia</td>
<td>1,120</td>
<td>840</td>
<td>38 %</td>
<td>62 %</td>
</tr>
<tr>
<td>Americas USA, Canada</td>
<td>1,390</td>
<td>960</td>
<td>83 %</td>
<td>17 %</td>
</tr>
<tr>
<td>Total</td>
<td>6,680</td>
<td>4,420</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>
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IGCC/IGCC CCS plant solutions need proper integration design for the interfaces between combined cycle plant and gasification/gas island.
Siemens Solutions for IGCC Power Plants

Siemens will provide key components & systems for IGCC power plants
Gasification and IGCC business opportunities: Plant design and Siemens scope

- **Fuel**
  - Coal
  - Lignite
  - Petcoke
  - Refinery residues
  - Biomass

- **Gas Island**
  - Fuel preparation
  - Air Separation Unit
  - Gasifier
  - CO Shift (optional)
  - Sulfur Removal
  - CO₂ Removal (optional)

- **Applications**
  - Combined Cycle
    - Power Island
    - Power
  - FT Synthesis
    - Transportation fuels
  - Methanol Synthesis
    - Methanol
  - Ammonia Production
    - Ammonia / Fertilizer
  - Hydrogen

Possible Siemens scope for IGCC plants

- Siemens Basic Engineering & Design
- Siemens Supply of Key Equipment
- Siemens EPC

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   - Integration
   - Gas Turbine
   - Gasification
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Integration options for IGCC power plants
(ASU = Air Separation Unit)

Increasing efficiencies with increased air integration,
…but also increased plant complexity.

Preferred solutions

Non-integrated (independent) air separation unit

Partially integrated air separation unit

Fully integrated air separation unit
Effect of ASU integration on IGCC net efficiency

Improvement potential: e.g. optimisation of nitrogen integration and syngas saturation

Characteristic for syngas-proven gas turbines with 100% nitrogen integration

Variation resulting from different plant concepts

ASU = Air Separation Unit

Relative net IGCC efficiency in %

ASU air integration (m_{Extraction air} / m_{Air to ASU}) in %
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Siemens heavy duty gas turbine portfolio

- SGT5-8000H: 340 MW
- SGT5-4000F: 292 MW
- SGT6-5000F: 208 MW
- SGT6-4000F: 187 MW
- SGT5-2000E: 168 MW
- SGT6-2000E: 113 MW
Siemens Combined Cycle: Efficiency Evolution

SGT5-2000E
52 %
CC efficiency
CCPP Killinghome

SGT5-4000F
56 %
CC efficiency
CCPP Didcot

SGT5-4000F
58 %
CC efficiency
CCPP Mainz-Wiesbaden

SGT5-8000H
60%
CC efficiency
CCPP Irshching 4, 530 MW

Reduction of CO₂ Emission (scaled to 530MW)

<table>
<thead>
<tr>
<th>Year</th>
<th>Basis</th>
<th>1992</th>
<th>1996</th>
<th>2001</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basis</td>
<td>-113.000 t/a CO₂</td>
<td>-164.000 t/a CO₂</td>
<td>-212.000 t/a CO₂</td>
<td></td>
</tr>
</tbody>
</table>

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Energy Sector
Development of IGCC net plant efficiencies for coal-based IGCC plants without CCS

**Net Plant Efficiency in % (LHV)**

- European demonstration plants with dry-fed coal gasifiers
- US demonstration plants with slurry-fed coal gasifiers
- Japanese demonstration plant with dry-fed coal gasifier

**World’s first IGCC plant**
- Lünen, Germany (V93)

**Clean Coal Power**
- Puertollano, Spain (V94.3)
- Buggenum, Netherlands (V94.2)
- Tampa
- Wabash River
- Cool Water

**Achievable with today’s**
- F class gas turbines without CCS
- E class gas turbines without CCS

**Increasing plant sizes and efficiencies of demonstration plants**

Puertollano plant efficiency for ISO conditions and high quality coal
Relative efficiencies of CCPP, IGCC and IGCC with CCS

<table>
<thead>
<tr>
<th></th>
<th>Relative net plant efficiency in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCPP (natural gas)</td>
<td>100</td>
</tr>
<tr>
<td>IGCC without CCS (coal)</td>
<td>80</td>
</tr>
<tr>
<td>IGCC with CCS (coal)</td>
<td>60</td>
</tr>
</tbody>
</table>

Losses with additional process steps

Variation depending on fuel and process

Improvement potential process and integration
Global experience with Syngas/IGCC and steel making recovery gas applications

<table>
<thead>
<tr>
<th>Customer/Plant (Location)</th>
<th>Electrical Output (net)</th>
<th>Gas Turbine</th>
<th>Main Features</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hörde Steelworks (Dortmund, Germany)</td>
<td>8 MW</td>
<td>1 x VM5</td>
<td>Blast-furnace-gas-fired, gas turbine as compressor drive</td>
<td>1960/2000</td>
</tr>
<tr>
<td>Handan Iron &amp; Steel (Handan, P.R. China)</td>
<td>8 MW</td>
<td>1 x VM5</td>
<td>Blast-furnace-gas-fired gas turbine</td>
<td>1960</td>
</tr>
<tr>
<td>U. S. Steel Corp. (Chicago, USA)</td>
<td>20 MW</td>
<td>1 x CW201</td>
<td>First CC plant in the world with integrated LURGI coal gasification (hard coal)</td>
<td>1960</td>
</tr>
<tr>
<td>STEAG/Kellermann (Lünen, Germany)</td>
<td>163 MW</td>
<td>V93</td>
<td>CC plant with integrated DOW coal gasification</td>
<td>1972</td>
</tr>
<tr>
<td>DOW Chemicals (Plaquemine, USA)</td>
<td>208 MW 1)</td>
<td>2 x W501D5</td>
<td>CC plant with integrated SHELL coal gasification (hard coal and biomass blend)</td>
<td>1993</td>
</tr>
<tr>
<td>Nuon Power Buggenum (Buggenum, Netherlands)</td>
<td>253 MW</td>
<td>1 x V94.2</td>
<td>CC plant with integrated PRENFO coal gasification (coal and petroleum coke blend)</td>
<td>1996/97</td>
</tr>
<tr>
<td>HRL (Morwell, Australia)</td>
<td>10 MW</td>
<td>1 x Typhoon</td>
<td>CC plant with integrated drying gasification process (lignite)</td>
<td>1996</td>
</tr>
<tr>
<td>Sydkraft (Värnamo, Sweden)</td>
<td>6 MW</td>
<td>1 x Typhoon</td>
<td>First CC plant in the world with integrated biomass gasification</td>
<td>1996</td>
</tr>
<tr>
<td>ELCOGAS (Puertollano, Spain)</td>
<td>300 MW</td>
<td>1 x V94.3</td>
<td>CC plant with integrated DEW coal gasification (asphalt)</td>
<td>1999</td>
</tr>
<tr>
<td>ISAB Energy (Priolo Gargallo, Italy)</td>
<td>521 MW</td>
<td>2 x V94.2K</td>
<td>CC plant with integrated TEXACO heavy-oil gasification (asphalt)</td>
<td>1998</td>
</tr>
<tr>
<td>ELETTRA GLT (Servola, Italy)</td>
<td>180 MW</td>
<td>1 x V94.2K</td>
<td>CC plant with steel-making recovery gas</td>
<td>2000</td>
</tr>
<tr>
<td>ARBRE (Eggborough, UK)</td>
<td>8 MW</td>
<td>1 x Typhoon</td>
<td>CC plant with integrated biomass gasification</td>
<td>2002</td>
</tr>
<tr>
<td>EniPower (Sannazzaro, Italy)</td>
<td>250 MW</td>
<td>1 x V94.2K</td>
<td>CC plant fuelled with syngas from SHELL heavy-oil gasification</td>
<td>2006</td>
</tr>
<tr>
<td>Huaneng Tianjin IGCC Green Coal Power (Tianjing, China)</td>
<td>250 MW</td>
<td>1 x SGT5-2000E(LC)</td>
<td>CC plant with integrated TPRI gasification (coal)</td>
<td>2010</td>
</tr>
</tbody>
</table>

1) 160 MW from syngas and 48 MW from natural gas; 2) Natural gas firing; 3) Oil firing;
SGT5-2000E = V94.2 (old naming); SGT5-2000E(LC) = V94.2K (old naming) => engine with modified compressor

Total experience of more than 650,000 operating hours.
Influence of ASU Integration Concept on Gas Turbine/Compressor Mass Flow Ratio

**Natural Gas Operation**
- Natural Gas
  - LHV = 50056 kJ/kg
  - 102 %
  - 2 %

**Syngas Operation**
- Syngas
  - LHV = 5000 - 10000 kJ/kg ("diluted")
  - 10-20%
  - 100 %

**Compressor modification required**

**Non-integrated (independent) air separation unit**

**Fully integrated air separation unit**

**Air to ASU**
- 15 - 20 %

**Syngas Operation**
- Syngas
  - LHV = 4000 - 5000 kJ/kg ("diluted")
  - 17 - 24 %
  - 102 - 104 %

- 100 %
Criteria / challenges for H₂ combustion in gas turbines

- Clearly higher stoichiometric combustion temperature
- Smaller volumetric calorific values
- High flame speed

- Large increase in volumetric fuel flow rates
- Increased overheating potential

- Fast homogeneous mixing of fuel and air within shortest possible time
- Elimination of any flow separation
- High gas flow velocity to compensate increased flame speed

**Dilution with inerts to avoid:**
- high NOₓ emission due to high/peak flame temperature
- high flame speed and lower flashback potential

<table>
<thead>
<tr>
<th>Fuel Properties</th>
<th>CH₄</th>
<th>H₂</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV [MJ/kg]</td>
<td>50.3</td>
<td>119.9</td>
<td>10.1</td>
</tr>
<tr>
<td>[MJ/m³]</td>
<td>33.9</td>
<td>10.2</td>
<td>12.6</td>
</tr>
<tr>
<td>Flame speed in air [cm/s]</td>
<td>43</td>
<td>350</td>
<td>20</td>
</tr>
<tr>
<td>Stoich. comb. temp. [K]</td>
<td>2227</td>
<td>2370</td>
<td>2374</td>
</tr>
<tr>
<td>Density [kg/m³_STP]</td>
<td>0.72</td>
<td>0.09</td>
<td>1.25</td>
</tr>
<tr>
<td>Specific heat [kJ/kgK]</td>
<td>2.18</td>
<td>14.24</td>
<td>1.05</td>
</tr>
<tr>
<td>Flammability limits [vol %]</td>
<td>5 - 15</td>
<td>4 - 75</td>
<td>12.5 - 74</td>
</tr>
</tbody>
</table>
Syngas Experience with 50-Hz Gas Turbines

Risk of Overheating

Risk of Lean Blow-off

Standard Syngas Combustion System

Buggenum
Puertollano
Prioro Gargallo
Servola

hydrogen content in diluted syngas [vol%]

Higher hydrogen-content fuels tested in test rig

Engine References
Combustion system development combustion testing

**Combustion Test Rig**
- High pressure
- High temperature
- Engine conditions are simulated
- Fuel flexible: SG / H₂ / NG

**Combustion Test Gases**
- H₂O, N₂ Diluents available
- H₂, CO, CO₂, NG available for testing
50 Hz gas turbine modifications for IGCC applications

Syngas-specific features of “LC” (Low Calorific Gas) gas turbines

- Additional compressor stage to meet the requirements of no or only partial air integration
- New syngas burners and piping systems for syngas supply to individual burners
- Openings for optional air extraction and piping systems for extracted air
- Modular syngas fuel conditioning and air extraction system
- New / additional controls

**E Class:** References available
Gross GT output: 173 MW *)

**F Class:** Development underway
Gross GT output: > 300 MW *)

*) Assumption: Syngas operation in a non air-integrated IGCC plant concept

Gas turbine basic design remains unchanged
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SFGT Product Designs for Different Feedstocks

Gasification conditions and reactor type depend on feedstock characteristics:

**Ash content & Physical characteristics**
- Carbon, hydrogen content, heating value, moisture level
- Ash composition determines ash melting temperature
- Gasification temperature
  AMT: 1,300 - 1,800 °C (2,370 - 3,270 F)

**Ash content: > 2 %**
- Reactor wall with cooling screen
- Slag layer for thermal protection
- Feedstock: Solid
  - Pneumatic dense flow feeding system
  - Dust fuel burner

**Ash content: < 2 %**
- Reactor wall with refractory lining
- Feedstock: Liquid
  - Feed pumping
  - Liquid spray burner

Feedstock: Solid

Cooling Screen Gasifier

Refractory Lined Gasifier
Influence of gasifier syngas heat recovery concept on IGCC net efficiency

<table>
<thead>
<tr>
<th>IGCC Net Efficiency Difference in Percentage Points</th>
<th>IGCC without CCS (no CO₂ capture)</th>
<th>IGCC with CCS (90% CO₂ capture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Syngas Cooler&quot; (Reference)</td>
<td>&quot;Quench&quot;</td>
<td>&quot;Syngas Cooler&quot; (Reference)</td>
</tr>
<tr>
<td>&quot;Quench&quot;</td>
<td></td>
<td>&quot;Quench&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IGCC Net Efficiency Difference in Percentage Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>-1</td>
</tr>
<tr>
<td>-2</td>
</tr>
<tr>
<td>-3</td>
</tr>
<tr>
<td>-4</td>
</tr>
<tr>
<td>-5</td>
</tr>
</tbody>
</table>

**Note**: Comparable overall plant integration concept assumed for concepts with “Syngas Cooler” and “Quench”
## Siemens gasification experience and current projects

<table>
<thead>
<tr>
<th>Plant Name/Owner</th>
<th>Country</th>
<th>Start up / Project Status</th>
<th>Feedstock</th>
<th>Units and Size</th>
<th>Final Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVZ Schwarze Pumpe</td>
<td>Germany</td>
<td>COD 1984 (shut-down 2006)</td>
<td>Lignite, natural gas, tar oils, liquid waste</td>
<td>200 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Methanol and power</td>
</tr>
<tr>
<td>Sokolovská uhelná a.s.</td>
<td>Czech Republic</td>
<td>COD 2008</td>
<td>Generator tar and other fixed-bed gasifier by-products</td>
<td>175 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Power (IGCC)</td>
</tr>
<tr>
<td>Shenhua Ningxia Coal Industry Group Co., Ltd.</td>
<td>China</td>
<td>PDP engineering completed, 5 SFG-500 gasifier shipped and erected COD in 2010</td>
<td>Bituminous coal</td>
<td>5 x 500 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>Shanxi Lanhua Coal Chemical Comp., Jincheng</td>
<td>China</td>
<td>PDP engineering completed, 2 SFG-500 gasifier manufactured COD in 2012</td>
<td>Anthracite</td>
<td>2 x 500 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Ammonia/ fertilizers</td>
</tr>
<tr>
<td>Secure Energy, Inc. Decature, Illinois</td>
<td>USA</td>
<td>BEDP engineering completed, 2 SFG-500 gasifiers shipped, COD in 2011</td>
<td>IL bituminous coal</td>
<td>2 x 500 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>SNG</td>
</tr>
<tr>
<td>Summit Power, Inc.</td>
<td>USA</td>
<td>SFGT Technology selected COD in 2014</td>
<td>Lignite</td>
<td>3 x 500 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Power (IGCC)</td>
</tr>
<tr>
<td>Epcor Power Inc. Genesee</td>
<td>CAN</td>
<td>License, Engineering and Hardware Agreements signed, Basic Eng. in progr. COD in 2015</td>
<td>Sub-bituminous coal</td>
<td>1 x 500 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Power (IGCC)</td>
</tr>
<tr>
<td>AEC Australian Energy Company</td>
<td>Australia</td>
<td>SFG technology selected, FEED to start mid 2009 COD in 2013</td>
<td>Lignite</td>
<td>2 x 500 MW&lt;sub&gt;th&lt;/sub&gt;</td>
<td>Ammonia/ urea</td>
</tr>
</tbody>
</table>
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Actions needed for technology commercialization

Source: World Coal Institute, “Coal Meeting the Climate Challenge”, September 2007

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Summary

- IGCC attractive for coal if CO\textsubscript{2} capture is required
- Siemens main scope for IGCC: Gasifier and Power island
- Commercial standard-size gasifier with robust design available
- Considerable track record in Syngas Gas Turbines
- New order: advanced E-class gas turbine for IGCC in China
- Modern F-class engine for syngas under development
- Phased IGCC approach may offer an attractive no-regret strategy

IGCC with CCS is a promising technology to satisfy the market needs but needs a robust regulatory framework and clear investment incentives.
Many thanks for your kind attention!