TECHNOLOGY DEVELOPMENT FOR IGCC WITH CCS

2nd International Conference on Energy Process Engineering:
Efficient Carbon Capture for Coal Power Plants

Mark J. Prins
Shell Projects and Technology
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• **Reserves**: Our use of the term “reserves” in this presentation means SEC proved oil and gas reserves and SEC proven mining reserves.

• **Resources**: Our use of the term “resources” in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves or SEC proven mining reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

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1. Shell Coal Gasification Process (SCGP)
2. IGCC unit operations
3. Technology Development for IGCC with CO$_2$ capture
   - Water Gas Shift
   - Desulphurization of syngas
   - CO$_2$ removal
4. Future Outlook

**IGCC = Integrated Gasification Combined Cycle**

**USC = Ultra Super Critical**
1.0 SECTION ONE

Shell Coal Gasification Process
SHELL COAL GASIFICATION PROCESS

Slagging condition
Membrane wall gasifier
Dry feed system
Water tube boiler
Solid slag handling
SHELL SCGP PROCESS LINE-UP

Coal/pet coke → Milling/drying → Coal feeding → Gasifier

Quench gas → HP steam → Dry Solids Removal

MP steam → Wet scrubbing

Fly ash recirc. → Gasifier

900°C

1,600°C

Slag → Fly ash to milling and drying (if required)

Fly ash system

Wet scrubbing → Water treatment

Raw syngas

Salts
SCGP – ADVANTAGES

High availability and low maintenance cost owing to the robustness of the membrane wall gasifier and the long life time of coal burners

High throughput through multiple burners

Efficient use of coal (low operating expenditure) and low CO₂ emissions resulting from complete conversion of any coal/coke (carbon conversion >99%)

High cold gas efficiency resulting in the production of more syngas from the same amount of coal/coke owing to the optimised operating temperature

High flexibility to feedstocks (most coal types and petroleum coke)

High operating flexibility with respect to short-term coal quality changes
SCGP – TYPICAL ENERGY BALANCE

- Coal in 100%
- 82% Raw synthesis gas
- 2.0% Steam from reactor wall (reused)
- 12.8% Steam from Syngas cooler (reused)
- 0.5% Unconverted carbon (fly ash/slag)
- 2.7% Low-level heat (cooling of slag)
- 18.0% Total
SCGP IS A PROVEN TECHNOLOGY ON AN EVER-INCREASING SCALE

- 6 t/d (1976) Pilot unit Amsterdam, Netherlands
- 150 t/d (1978) Demonstration unit Harburg, Germany
- 250 t/d (1987) SCGP-1 Houston, USA
- 2,000 t/d (1993) NUON IGCC Buggenum, Netherlands
- 7,500 t/d licensed, a further 7,500 t/d considered (2006) Largest Chinese licence

Coal intake (total)
SCGP IS A PROVEN TECHNOLOGY ON AN EVER-INCREASING SCALE

In operation (2008)
- 976,000 (7)
  - 50,000-100,000 Nm3 syngas/hr
  - 100,000-150,000 Nm3 syngas/hr
  - 150,000-250,000 Nm3 syngas/hr

In operation (2011)
- 1,800,000 (13)
  - 50,000-100,000 Nm3 syngas/hr
  - 100,000-150,000 Nm3 syngas/hr
  - 150,000-250,000 Nm3 syngas/hr

Commissioning
- 970,000 (5)
  - 50,000-100,000 Nm3 syngas/hr
  - 100,000-150,000 Nm3 syngas/hr
  - 150,000-250,000 Nm3 syngas/hr

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SECTION TWO

IGCC
IGCC UNIT OPERATIONS

Coal treatment and supply → Coal gasification → Gas cooling and purification → Gas turbine → Generator → Steam turbine

Stack

Steam

Waste heat boiler

Oxygen

Nitrogen

Air separation

Sulphur production

Sulphur

Water purification

Air

Slag

Sulphur

Salts

Electricity

Gasification/gas treating

Air separation

Combined cycle

Waste water treating
Integrated coal gasification combined-cycle power plant
Commissioned in 1994 as a demonstration plant
Commercial operation since 1998
2,000 tonne/day coal producing $4.0 \times 10^6$ Nm$^3$ syngas

Energy balance:
- Coal intake: 585 MWe
- Gas turbine output: 156 MWe
- Steam turbine output: 128 MWe
- Total output: 284 MWe
- Own consumption: 31 MWe

Net output: 253 MWe

Net efficiency (LHV): 43%
INDUSTRIAL GAS TURBINES

Long-term development target for 1700°C class

Available for syngas (F-class) Available for natural gas (G/H-class)

1993 (E-class)

Turbine Inlet Temperature

Efficiency on NG (% LHV)

Pressure ratio

Turbine Inlet Temperature

Efficiency on NG (% LHV)

Copyright of PT-Upstream
Basis: El Cerrejon coal with Cold Gas Efficiency ~82%. Site is sea shore in the Netherlands, typical ISO ambient conditions (15°C air, 12°C sea water, temperature range sea water = 8°C), 0 m elevation.
3.0

SECTION THREE

Technology Development for IGCC with Carbon Capture
IGCC WITH CO₂ CAPTURE – ADDITIONAL UNITS

Coal Milling & Drying → Coal Milling & Drying

ASU (max 50% air int.) → GT air, Air, Oxygen, VHP/HP/LP N₂

Dry Coal → Shell Coal Gasifier

Slag, Flyash, Waste Water, HP (sat) Steam, IP (sh) Steam

Shell Coal Gasifier → Shift

VHP/HP N₂, BFW, LP/IP Steam (sh)

IP (sh) Steam → Claus + SCOT

H₂S → Compression

Compression → CO₂

Power Generation → Power

Sulphur → Sulphur

GT air → GT air

Air → ASU (max 50% air int.)
## TECHNOLOGY DEVELOPMENT OF IGCC COMPONENTS

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
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<tbody>
<tr>
<td>SCGP gasifier</td>
<td>Capacity and operating pressure matches with latest gas turbines</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>Major efficiency improvements due to higher compression ratios and Turbine Inlet Temperatures</td>
</tr>
<tr>
<td>(1) Water Gas Shift</td>
<td>Proven low steam:CO Water Gas Shift process saves steam import; less unconverted steam</td>
</tr>
<tr>
<td>(2) Gas Treatment; H₂S removal</td>
<td>Shell’s Sulfinol process and UOP’s Selexol process are benchmark technologies</td>
</tr>
<tr>
<td>(3) Gas treatment; CO₂ removal</td>
<td>THIOPAQ™ biological desulphurization proven for natural gas; under development for syngas</td>
</tr>
<tr>
<td></td>
<td>Many novel solvents being developed, e.g. ADIP-X</td>
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</tbody>
</table>
(1) WATER GAS SHIFT

CO + H₂O = CO₂ + H₂

Syngas to 1st reactor: CO (60%), H₂ (30%), N₂ (8%), CO₂ (2%)

Novel low steam WGS

Conventional HTS/LTS

Bed temperature

WGS conversion (%)

Steam : CO ratio (mol:mol)
**SOUR WGS PROCESS WITH LOW STEAM:CO RATIO**

- Low steam:CO sour Water Gas Shift process:
  - + lower import of MP steam, utility-efficient
  - + less unconverted steam in the product gas
  - + capital investment is comparable with conventional HTS/LTS


- A retrofit system has recently been installed at the coal gasification plant in Yueyang, Hunan Province, China. The facility is a 50:50 Joint Venture between Sinopec and Shell Coal Gasification Company Limited.
(2) THIOPAQ™ PRINCIPLES

\[ H_2S + CO_3^{2-} \rightarrow HS^- + HCO_3^- \]

\[ HS^- + \frac{1}{2}O_2 + HCO_3^- \rightarrow S^O + CO_3^{2-} + H_2O \]
ADIP-X is a mixture of the tertiary amine N-methyl di-ethanol amine (MDEA), the secondary diethylene di-ethanol amine (piperazine) and water.

Combines benefits of physical solvent (low amount of heat for regeneration) & chemical solvent (high purity of captured CO₂)

Staged flash regeneration is applied with pre-heating of the fat solvent at relatively low temperature (<100°C).

- allows low value heat sources to be utilized (e.g. from the hot syngas ex WGS and the CO₂ compressor intercoolers)
- maximises the amount of CO₂ flashed-off at around 5 bar, minimising required compression power
SECTION FOUR

Future Outlook
4.5-5% LHV efficiency improvement potential for Future IGCC + CO₂ capture
this widens the efficiency gap with post combustion CCS solutions

**IGCC power plant with/without CCS; based on 2 gasification strings + G-class gas turbines**

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<tr>
<th></th>
<th>IGCC</th>
<th>IGCC + 90% CCS</th>
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<tbody>
<tr>
<td>Total plant fuel input (MWth, LHV)</td>
<td>2166.3</td>
<td>2610.0</td>
</tr>
<tr>
<td>Gas Turbines power output (MW)</td>
<td>720.6</td>
<td>816.6</td>
</tr>
<tr>
<td>Steam Turbines power output (MW)</td>
<td>475.2</td>
<td>525.6</td>
</tr>
<tr>
<td>Plant power output, gross (MW)</td>
<td>1195.8</td>
<td>1342.2</td>
</tr>
<tr>
<td>Auxiliary Power (MW)</td>
<td>145.1</td>
<td>259.9</td>
</tr>
<tr>
<td>Plant power output, net (MW)</td>
<td>1050.7</td>
<td>1082.3</td>
</tr>
<tr>
<td>Gross Efficiency (%)</td>
<td>55.20</td>
<td>51.42</td>
</tr>
<tr>
<td>Net Efficiency (%)</td>
<td>48.50</td>
<td>41.47</td>
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CONCLUSIONS

Shell Coal Gasification Process offers high thermal efficiency, large-scale and feedstock flexibility, ideal for IGCC.

SCGP is fully proven technology (~25 licenses worldwide)

Technology development pathway for IGCC with CO\(_2\) capture outlined. In medium-term, advanced technology pushes coal-to-power efficiency:

- above 48% for IGCC
- above 41% for IGCC with CO\(_2\) capture

Other IGCC advantages: ultra-low emissions of NO\(_x\) and SO\(_x\), low cooling water demand, part-load operation with rapid turndown

Financial incentives needed to invest in IGCC + CO\(_2\) capture at current low CO\(_2\) emission prices
Q & A