Integrated Gasification Combined Cycles with CO$_2$ Capture

Dr. Jeff Phillips
Project Manager
Advanced Generation
Outline

• What is IGCC?
• IGCC with CO$_2$ capture compared to other fossil fuel power generation options
• IGCC commercial status
• Research, Development and Demonstration needs for IGCC with CO$_2$ capture
What is gasification?

- Similar to combustion but with less than half the amount of oxygen needed to fully burn the coal
- Combustion: excess air
- Gasification: excess fuel (by a lot!!)
Combustion & Gasification Products

Diagram showing the mole percentages of various gasification products as a function of oxygen-to-coal feed ratio. Key components include CH₄, H₂S, H₂, H₂O, SO₂, C, CO, and CO₂. The diagram illustrates the gasification zone and complete combustion boundary for a specific type of coal (Illinois).
Coal Boiler
Combustion vs Gasification

- SO$_2$ & SO$_3$ must be scrubbed out of stack gas
- NO$_x$ controlled with low NO$_x$ burners and catalytic conversion (SCR)
- Large volume of flyash & sludge causes disposal issues
- Hg removed by contacting flue gas with activated carbon
- CO$_2$ must be separated from stack gas
- H$_2$S & COS are easily removed and converted to solid sulfur
- NH$_3$ washes out of gas with water, thermal NO$_x$ controlled by diluent injection in CT
- Ash is converted to glassy slag which is inert and usable
- Hg removed by passing high pressure syngas thru activated carbon bed
- CO can be shifted to CO2 & removed from high pressure syngas
Conventional Coal Plant

100 MW

15 MW

85 MW

40 MW

45 MW

100 MW

40 % Efficiency

© 2005 Electric Power Research Institute, Inc. All rights reserved.
Combined Cycle

19 MW + 38 MW = 57 MW
57% Efficiency!
Combined Cycle
Net Coal to Power:
\[30 + 22 - 9 = 43\%\]
Levelized Cost of Electricity
(Assumes $1.50/MMbtu Coal, $5/MMBtu Natural Gas)
IGCC with CO₂ Removal and Optional Hydrogen Co-Production

Coal Prep → Gasification \( C + H_2O = CO + H_2 \) → Gas Cooling → Sulfur and CO₂ Removal

Air Separation Unit

O₂ \( \rightarrow \) N₂

Gasification \( C + H_2O = CO + H_2 \) → Gas Cooling \( \rightarrow \) Shift \( CO + H_2O = CO_2 + H_2 \) → Sulfur and CO₂ Removal

Sulfur \( \rightarrow \) CO₂ to use or sequestration

Hydrogen

Gas Turbine

Air

BFW

HRSG

Steam Turbine

Steam

BFW
## CO₂ Capture Comparison

<table>
<thead>
<tr>
<th></th>
<th>Stream Pressure</th>
<th>CO₂ Volumetric Concentration in Stream</th>
<th>CO₂ Partial Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Combined Cycle</td>
<td>100 kPa</td>
<td>4%</td>
<td>4 kPa</td>
</tr>
<tr>
<td>Supercritical Coal Combustion</td>
<td>100 kPa</td>
<td>13%</td>
<td>13 kPa</td>
</tr>
<tr>
<td>IGCC</td>
<td>5700 kPa</td>
<td>40%</td>
<td>2280 kPa</td>
</tr>
</tbody>
</table>
Costs of Electricity from New Fossil Fuel Power Plants with & without CO2 Capture (based on today’s technology)

- **NGCC 525 MW ($3.50 NG)**
  - COE $/MWh with Capture & Sequestration
- **NGCC 525 MW ($5 NG)**
  - COE $/MWh with CO2 Capture
- **IGCC 520 MW**
  - COE $/MWh w/out Capture
- **USC PC 600 MW**
  - COE $/MWh with Capture & Sequestration
Existing Coal-based IGCCs

Puertollano (Spain)

Wabash (Indiana)

Polk (Florida)

Buggenum (NL)
## Coal Based IGCC Plants

<table>
<thead>
<tr>
<th>Project/Location</th>
<th>Combustion Turbine</th>
<th>Gasification Technology</th>
<th>Net Output MW</th>
<th>Start-Up Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuon Buggenum, Netherlands</td>
<td>Siemens V 94.2</td>
<td>Shell (Offered jointly with Krupp-Uhde)</td>
<td>253</td>
<td>Jan 1994</td>
</tr>
<tr>
<td>Wabash River, IN</td>
<td>GE 7 FA</td>
<td>E Gas (ConocoPhillips)</td>
<td>262</td>
<td>Oct 1995</td>
</tr>
<tr>
<td>Tampa Electric, FL</td>
<td>GE 7 FA</td>
<td>Texaco (GE Energy)</td>
<td>250</td>
<td>Sept 1996</td>
</tr>
<tr>
<td>ELCOGAS Puertollano, Spain</td>
<td>Siemens V 94.3</td>
<td>Prenflo (Offered jointly with Shell)</td>
<td>300</td>
<td>Dec 1997</td>
</tr>
</tbody>
</table>
# Salient Characteristics of Major Gasification Technologies

<table>
<thead>
<tr>
<th>Technology Name/Design Feature</th>
<th>GE Energy (formerely Texaco)</th>
<th>E-Gas (ConocoPhillips)</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed System</td>
<td>Coal in Water Slurry</td>
<td>Coal in Water Slurry</td>
<td>Dry Coal. Lock Hopper &amp; Pneumatic Conveying</td>
</tr>
<tr>
<td>Gasifier Configuration</td>
<td>Single Stage Downflow</td>
<td>Two Stage Upflow</td>
<td>Single Stage Upflow</td>
</tr>
<tr>
<td>Gasifier Wall</td>
<td>Refractory</td>
<td>Refractory</td>
<td>Membrane Wall</td>
</tr>
<tr>
<td>Pressure (psig)</td>
<td>500-1000</td>
<td>Up to 600</td>
<td>Up to 600</td>
</tr>
<tr>
<td>Notes</td>
<td>Offered as Quench or with Heat Recovery</td>
<td>Currently only offered with Heat Recovery</td>
<td>Currently only offered with Heat Recovery</td>
</tr>
</tbody>
</table>
Polk Power Station

Gasifier, Syngas Cooler, and Scrubber Arrangement

Oxygen
Coal/Water Slurry

Gasifier

Scrubbed Raw Syngas To COS Hydrolysis and Low Temperature Cooling

Syngas Scrubber

Formerly to Hot Gas Cleanup
Convective Syngas Cooler

HP Steam

Radiant Syngas Cooler

Convective Syngas Cooler

Syngas Scrubber

HP Steam
E-Gas Gasifier—As used at Wabash IGCC (Technology now owned by ConocoPhillips)
Shell Gasifier Cutaway

Syngas

Quench Gas

Coal & O2

Slag
Worldwide IGCC Experience

• Four coal based IGCC plants Tampa, Wabash, Buggenum and Puertollano.

• Eight operating IGCC plants based on Petroleum Residuals. Three more in construction. These plants represent considerable additional commercial operating experience for the many components that are common with coal based IGCC plants (ASUs, Gas clean up, Sulfur recovery, Combined Cycles, SCR etc).

• Cumulative Combustion Turbine experience on a wide variety of syngas compositions and heating values (range 100-350 Btu/SCF) is well over a million hours.
Great Plains Synfuels Plant

Source: Dakota Gasification

95 MMSCFD
IGCC CO2 Recovery R&D Needs

• All the technology necessary for an IGCC with 90% CO2 capture has been demonstrated at commercial scale except:
  – An advanced (F class or better) combustion turbine fired on near 100% H2
    • Current OEM restrictions on H2 content limit CO2 capture to about 85%
  • Need to develop a CT which can accept the syngas produced by 90% CO2 capture
IGCC Demonstration Needs

- Even though all the different pieces of an IGCC with CO$_2$ capture have been demonstrated, they have never been demonstrated together in one plant
  - Water-Gas Shift of syngas and CO$_2$ capture and compression has been demonstrated at Great Plains Gasification
  - Integration of gasification and combined cycles has been demonstrated at 4 large facilities
  - Still need to demonstrate IGCC plus water-gas shift and CO$_2$ capture and compression in an integrated plant to identify any operations and controls issues
IGCC Improvement Opportunities

• Reduce ASU power consumption
  – New ASU – perhaps Ion Transfer Membrane (ITM)?
  – An ASU at 200-300°C would be nice.

• Gas separation membranes and processes that can operate at warmer temperatures and that can also reduce the auxiliary power requirements for separation and compression.

• Gas turbine redesign to recover the derated performance (efficiency) with hydrogen firing.

• Longer term possibilities such as the Clean Power Systems concept and Solid Oxide Fuel Cell with Oxygen Transfer Membrane on Anode gas would eliminate the need for shift and CO₂ removal from the syngas since the flue gas is essentially CO₂ and water.
IGCC Availability History
(excludes operation on back-up fuel)
### Coal IGCC- Historical Causes of Outage

<table>
<thead>
<tr>
<th>Project/Cause</th>
<th>Wabash</th>
<th>Tampa</th>
<th>Nuon</th>
<th>ELCOGAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Feeding</td>
<td>No</td>
<td>Minor</td>
<td>Minor</td>
<td>Yes</td>
</tr>
<tr>
<td>Injector Tip Life</td>
<td>90 days</td>
<td>60-90 Days</td>
<td>&gt; 1 year</td>
<td>&gt; 1 year</td>
</tr>
<tr>
<td>Refractory Wear</td>
<td>~ 2 years</td>
<td>~ 2 years</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>Slag Tap Blockage</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Circ. Slag Water</td>
<td>Minor</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Erosion/Corrosion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syngas Cooler Fouling</td>
<td>Yes – but can clean in situ</td>
<td>Radiant – No Convective - Yes</td>
<td>Minor – Rappers work well</td>
<td>Yes – but has not been major outage cause</td>
</tr>
<tr>
<td>Candle Filter Failure</td>
<td>Yes – but improved</td>
<td>Not applicable</td>
<td>Yes – but now solved</td>
<td>Yes</td>
</tr>
<tr>
<td>Gas Turbine Vibration</td>
<td>No</td>
<td>No</td>
<td>Yes – but improved</td>
<td>Yes – improved but fuel switch is problematic</td>
</tr>
</tbody>
</table>
IGCC: Ideas to improve RAM

- Develop improved refractory improvement
  - (or improved flux to lower gasifier temperature and extend refractory life)
- Develop gasifier instrumentation to guide operations
  - More reliable thermocouples and gasifier temperature measurement
  - On line slag analysis to prevent plugging
  - On line pH measurement in circulating slag/ash loops
  - On line slurry analysis
  - Demonstrate rapid on-line syngas composition measurement via laser adsorption spectroscopy
- Research methods to prevent syngas cooler plugging/fouling
- IGCC dynamic models & adaptation for operator training
- Improved feed injectors
- Reliability survey of existing gasification plants
- More durable warm gas filter elements
- CFD modeling of gasifiers
The End