Coal IGCC for Hydrogen Production, CO$_2$ Recovery and Electricity

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Argonne, Illinois
IGCC full-energy cycle analysis

FIGURE S.2 Energy System Components for CO₂ Recovery
Both the Shell and Texaco entrained gasifier systems are under consideration.

Shift will need to be integrated into the process design which will be modified to produce H₂, recover CO₂, and produce electricity.

A full-energy cycle analysis will be developed based on an Aspen7 simulation of plant with a special focus shift, sulfur, CO₂ recovery, PSA for hydrogen, and power generation.

Feed will be Illinois #6 coal.

High purity H₂ sent 100 km by pipeline.

Supercritical-CO₂ sent 500 km by pipeline.
IGCC - Study Basis

- Linkage to SAIC for LC Advantage – Victor Gorokhov and Masood Ramezan
Power use in deep-mining

Illinois #6 coal

Graph - Mining Electricity (kWh/1,000kg coal)
## Coal Methane Emission Importance


<table>
<thead>
<tr>
<th></th>
<th>Concentration ppm in 1994</th>
<th>Warming %</th>
<th>Life years</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>356.000</td>
<td>1</td>
<td>63.8</td>
</tr>
<tr>
<td>CH₄</td>
<td>1.725</td>
<td>56</td>
<td>19.2</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.311</td>
<td>280</td>
<td>5.7</td>
</tr>
</tbody>
</table>
### Diesel-rail fuel efficiency changes with grades and curves

Stodolsky, F., et al., 3rd Total Life-cycle Conf., Graz, Austria (Dec. 1998)

<table>
<thead>
<tr>
<th>Setting</th>
<th>Duration (h)</th>
<th>Distance Traveled, km (mi)</th>
<th>Fuel Consumed, with Grade Assump., L (gal)</th>
<th>Fuel Efficiency, T-km/L (t-mi/gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic brake at 19 km/h (12 mph) (down grade)</td>
<td>0.125</td>
<td>2.4 (1.5)</td>
<td>11 (3)</td>
<td>791 (2050)</td>
</tr>
<tr>
<td>Idle</td>
<td>0.38</td>
<td>0 (0)</td>
<td>8 (2)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Notch 1</td>
<td>0.065</td>
<td>0.97 (0.6)</td>
<td>8 (2)</td>
<td>475 (1230)</td>
</tr>
<tr>
<td>Notch 2</td>
<td>0.065</td>
<td>1.6 (1.0)</td>
<td>15 (4)</td>
<td>395 (1025)</td>
</tr>
<tr>
<td>Notch 3</td>
<td>0.052</td>
<td>2.4 (1.5)</td>
<td>26 (7)</td>
<td>341 (879)</td>
</tr>
<tr>
<td>Notch 4</td>
<td>0.044</td>
<td>2.6 (1.6)</td>
<td>34 (9)</td>
<td>261 (729)</td>
</tr>
<tr>
<td>Notch 5</td>
<td>0.038</td>
<td>2.6 (1.6)</td>
<td>42 (11)</td>
<td>98 (254)</td>
</tr>
<tr>
<td>Notch 6</td>
<td>0.039</td>
<td>3.2 (2.0)</td>
<td>57 (15)</td>
<td>211 (547)</td>
</tr>
<tr>
<td>Notch 7</td>
<td>0.03</td>
<td>2.7 (1.7)</td>
<td>53 (14)</td>
<td>192 (498)</td>
</tr>
<tr>
<td>Notch 8 at 35 km/h (22 mph) (up grade)</td>
<td>0.068</td>
<td>2.4 (1.5)</td>
<td>72 (19)</td>
<td>125 (324)</td>
</tr>
<tr>
<td>Notch 8 at 101 km/h (63 mph)</td>
<td>0.094</td>
<td>9.5 (5.9)</td>
<td>276 (73)</td>
<td>128 (331)</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>30.4 (18.9)</td>
<td>602 (159)</td>
<td>188 (487)</td>
</tr>
<tr>
<td>Accessory loads</td>
<td></td>
<td></td>
<td>13 (3.5)</td>
<td></td>
</tr>
</tbody>
</table>
Greenhouse gas emissions before Gasification plant

MINING

COAL PREPARATION 2x4" round trip

TRANSPORT - #2 diesel: 161 km round trip

N2O gm/h
CH4 kg/h
CO2 kg/h
Conclusions: Mining & transport

- Coal bed methane is an important uncontrolled emission
- Diesel rail transport emissions of $N_2O$ are less than 10% of typical values for Illinois
- Regulations for diesel fuel are reducing sulfur - hence $N_2O$ from diesel should be lower in the future
IGCC with CO$_2$ and H$_2$ recovery
Major material flows for Gasification plant

- Coal
- O2
- Solid waste
- Sulfur
- SO2
- CO2 (143 bar)
- H2 (31 bar)

-16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6

- $10^4$ kg/h
- $10^6$ nm$^3$/d

- Graph showing the material flows and their respective units.
Shift precedes $H_2S$ removal to yeild a high-$H_2$ synthesis gas.
Glycol recovery of $H_2S$ to Claus-SCOT tail gas for sulfur
Glycol CO\textsubscript{2} recovery to supercritical compression 143bar
Pressure-swing adsorption (PSA) for $H_2$ purification to 99.999%
Power balance for Gasification plant excluding $H_2$
Hydrogen and electricity from Gasification plant

H2 Equivalent
Gross Power
In-Plant use

MW
**CO₂ supercritical pipelines are currently operated for EOR**

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Company</th>
<th>Approx. Start of Operation</th>
<th>Approx. Throughput (MMscf/day)</th>
<th>Pipe Diameter</th>
<th>Line Length (miles)</th>
<th>Operating Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>McElmo Dome, near Cortez, CO</td>
<td>Shell Pipeline Corp.</td>
<td>1984</td>
<td>700&quot;</td>
<td>30&quot;</td>
<td>500</td>
<td>2600</td>
</tr>
<tr>
<td>Sheep Mountain, southern CO</td>
<td>ARCO Oil &amp; Gas Co.</td>
<td>1983</td>
<td>500</td>
<td>20 - 24&quot;</td>
<td>405</td>
<td>1200-2780</td>
</tr>
<tr>
<td>Bravo Dome, eastern New Mexico</td>
<td>Amoco Corp.</td>
<td>1985</td>
<td>400-700</td>
<td>20&quot;</td>
<td>210</td>
<td>--</td>
</tr>
</tbody>
</table>
$CO_2$ for Enhanced Oil Recovery

- **Purity:** Not critical, dry, $H_2S$ benefits EOR but should be limited
- **Production** still to be set
- **Shipment:** 500 km; 330 mm pipe at 143 bar
- **Capacity factor:** 95%
- **Capital recovery:** 12%
- **Transmission** linked to $CO_2$ infrastructure
$H_2$ pipelines use lower pressures & shorter runs than natural gas

<table>
<thead>
<tr>
<th>Location</th>
<th>Company</th>
<th>Approx. Start of Operation</th>
<th>Pipe Material</th>
<th>Pipe Diameter</th>
<th>Network or Line Length (miles)</th>
<th>Operating Pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA – Gulf Coast, TX</td>
<td>Air Products &amp; Chemicals, Inc.</td>
<td>1970</td>
<td>var., including Sch. 40 steel</td>
<td>4” – 12”</td>
<td>140</td>
<td>50-800</td>
</tr>
<tr>
<td></td>
<td>Praxair</td>
<td>1970’s</td>
<td>--</td>
<td>8”</td>
<td>125</td>
<td>--</td>
</tr>
<tr>
<td>USA – Miss. River Corridor, LA</td>
<td>Air Products &amp; Chemicals, Inc.</td>
<td>late 1980’s</td>
<td>ASTM 106 steel</td>
<td>4” – 12”</td>
<td>60</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Praxair</td>
<td>1990’s</td>
<td>--</td>
<td>--</td>
<td>34</td>
<td>--</td>
</tr>
<tr>
<td>Germany – Ruhr Valley</td>
<td>Chemische Werk Huls, AG</td>
<td>1938</td>
<td>seamless, SAE 1016 equiv.</td>
<td>6” – 12”</td>
<td>130</td>
<td>up to 360</td>
</tr>
<tr>
<td>France – NE</td>
<td>L’Air Liquide</td>
<td>1966</td>
<td>seamless, carbon steel</td>
<td>var., 4” typical</td>
<td>180</td>
<td>950 – 1450</td>
</tr>
</tbody>
</table>
Hydrogen product

- Purity: $\text{H}_2$ at 99.999%, 119.9 KJ/g (LHV)
- Production go for high purity product and send blowdown to turbines
- Shipment: 100 km; 343 mm pipe at 30 bar
- Capacity factor: 95%
- Capital recovery: 12%
- Transmission: 0.171 $/10^3$ scf; 0.564 $$/GJ
Advanced $H_2$ Turbine Cycle

High-efficiency $H_2$ turbine goals

$O_2$ from pressure vacuum swing absorption  


**Fig. 1.** Development of electricity consumption for the production of gaseous oxygen.
Electricity: $O_2$-blown KRW IGCC

All values for full-energy cycle

- **No CO$_2$ recovery:**
  - 396-MW full-cycle at 0.83 kgCO$_2$/kWh

- **With CO$_2$ recovery:**
  - 366-MW full-cycle at 0.20 kgCO$_2$/kWh

- **With CO$_2$ and H$_2$ recovery to fuel cells:**
  - 344-MW full-cycle at 0.22 kgCO$_2$/kWh
    - 52-MW busbar and 298-MW solid-oxide FC
  - 377-MW full-cycle at 0.20 kgCO$_2$/kWh
    - 52-MW busbar and 332-MW alkaline FC
Equivalent CO$_2$ greenhouse emissions 396 MW net-cycle
Conclusions: IGCC plant

- CO₂ as a supercritical product (143 bar) can be recovered from coal gasification. Where there is an Enhanced Oil Recovery market, this is economical. The need for high pipeline-utilization is critical.

- Hydrogen can be recovered at high purity (99.999%) for sale from coal gasification, the need for high pipeline-utilization is critical. Pressures of 35 bar are optimal.
Status – June 2000

- ASPEN 10.1 upgrade on IGCC programs is now operational
- Linkage with SAIC has been established
- Linkage with Equation of State modeling community for ASPEN has been established
- Process economics will be treated in a more detailed manner
- Optimization of Shift integration has begun
Conclusions: $H_2$ use

- Conversion efficiencies need to approach 77% to match the Base Case output:
  - Solid-oxide fuel cell efficiencies are 53-58%
  - Alkaline fuel cell efficiencies near 70%
- Hydrogen can be delivered as a commodity