Background
Motivation

Coal-derived liquids refers to transportation fuels like gasoline and diesel—typically called synthetic fuels

- Why the interest?
  - Increasing crude oil prices / depleting reserves
  - Reduce dependence on imported oil

- Why synthetic fuels from coal?
  - Extensive coal reserves in U.S.
  - Well-proven conversion technology
  - Potential for co-production of liquid fuels + electricity

- What are the key drawbacks?
  - High capital cost
  - High CO₂ emissions

Previous Work …

- Preliminary analysis of CO₂ reduction potential from CTL options employing a generic slurry-fed gasifier (~1000°C, 43 bar), with data from 2006 design studies

This Study …

- Examines effects of different gasifier types based on more recent studies by USDOE
- Focus on options and costs of CCS for two CTL process configurations
Coal-to-liquids (CTL) process

$\text{CO}_2 + \text{sulfur and other byproducts or wastes}$

Coal → Gasification → Cleanup & Upgrade → Liquefaction → Liquid products

$\text{CO}_2 + \text{sulfur and other byproducts or wastes}$

Two process configurations

**Liquids-only**

- Coal → Gasification → Cleanup & Upgrade → FT synthesis → Liquid fuel
- Unconverted syngas → Purge

**Co-production**

- Coal → Gasification → Cleanup & Upgrade → FT synthesis → Liquid fuel
- Unconverted syngas
- Power block → Electricity
Different gasification technologies*

<table>
<thead>
<tr>
<th>GE (radiant)</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slurry-feed (35% H₂O)</td>
<td>Dry-feed (5% H₂O)</td>
</tr>
<tr>
<td>1,316 °C</td>
<td>1,427 °C</td>
</tr>
<tr>
<td>5.6 MPa</td>
<td>4.3 MPa</td>
</tr>
<tr>
<td>Easier to handle ash/slag</td>
<td>More thermally efficient</td>
</tr>
</tbody>
</table>

*Updated cost models from NETL power plant baseline study (2007)
Techno-economic models

These models can incorporate CCS and co-production options and can also perform probabilistic uncertainty analysis

Base case assumptions

- Primary product = 50,000 bbl/day of liquids output (avg HHV = 5600 MJ/bbl)
- Illinois # 6 coal (bituminous, HHV = 27 MJ/kg)
- Low-temp FT reactor with Fe catalyst
- Capacity factor = 85%
- Capital recovery factor = 0.15
- CO₂ vented, not sequestered
- All prices in constant 2007 $
**Syngas composition at gasifier exit**  
(vol %)

<table>
<thead>
<tr>
<th>Component</th>
<th>GE</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>34.5</td>
<td>57.1</td>
</tr>
<tr>
<td>H₂</td>
<td>33.5</td>
<td>30.0</td>
</tr>
<tr>
<td>CO₂</td>
<td>15.1</td>
<td>2.2</td>
</tr>
<tr>
<td>H₂O</td>
<td>14.2</td>
<td>2.7</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>CO + H₂</strong></td>
<td><strong>68.0 %</strong></td>
<td><strong>87.1 %</strong></td>
</tr>
</tbody>
</table>

- High temperature, dry-fed gasifier (Shell) produces more “FT-useful” syngas than slurry-fed (GE) gasifier

**Analysis of the liquids-only plant**
### Performance and cost results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GE</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant efficiency (% HHV)</td>
<td>56.1</td>
<td>59.4</td>
</tr>
<tr>
<td>Coal consumption ($10^3$ tonnes/day)</td>
<td>19.0</td>
<td>18.0</td>
</tr>
<tr>
<td>$CO_2$ emissions ($10^3$ tonnes/day)</td>
<td>24.7</td>
<td>22.8</td>
</tr>
<tr>
<td>Specific capital cost ($10^3$ $/barrel/day)</td>
<td>91.9</td>
<td>84.8</td>
</tr>
<tr>
<td>Product cost ($/barrel)</td>
<td>76.1</td>
<td>71.0</td>
</tr>
</tbody>
</table>

- Capital cost component dominates the cost of liquid product
- Syngas generation accounts for more than 60% of capital cost
- Cost of liquid product is comparable to recent crude oil prices

### Additional costs of implementing CCS

- Nearly all (~99%) plant level $CO_2$ can be sequestered
- Capital cost increases marginally (1.5%)
- Cost of liquid product increases by 10%
CCS can be cheaper than paying a price for CO₂ emitted

Analysis of the co-production plant
Performance and cost results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GE</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power output (MWe)</td>
<td>1,045</td>
<td>1,196</td>
</tr>
<tr>
<td>Plant efficiency (% HHV)</td>
<td>55.2</td>
<td>58.8</td>
</tr>
<tr>
<td>Coal consumption (10^3 tonnes/day)</td>
<td>23.6</td>
<td>23.0</td>
</tr>
<tr>
<td>CO₂ emissions (10^3 tonnes/day)</td>
<td>35.4</td>
<td>35.0</td>
</tr>
<tr>
<td>Specific capital cost (10^3 $/barrel/day)</td>
<td>117.2</td>
<td>111.5</td>
</tr>
<tr>
<td>Product cost ($/bbl @ $80/MWh)</td>
<td>54.1</td>
<td>44.6</td>
</tr>
</tbody>
</table>

- Co-production plant is cheaper than liquids-only plant if electricity sells for >$35/MWh (no CO₂ price), or >$70/MWh (with a CO₂ price)

Addition of CCS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GE</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions (10^3 tonnes/day)</td>
<td>0.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Net power output (MWe)</td>
<td>887</td>
<td>1,030</td>
</tr>
<tr>
<td>Specific capital cost (10^3 $/barrel/day)</td>
<td>129.4</td>
<td>127.6</td>
</tr>
</tbody>
</table>
Effect of a carbon price (Shell case)

- No CCS, $0/tonne CO2
- No CCS, $25/tonne CO2
- With CCS, $0/tonne CO2
- With CCS, $25/tonne CO2

CO₂ price must be > $35/tonne to make CCS cost-effective over the choice.

Liquids-only vs. co-production (dry-feed)

- No CCS, $0/tonne CO2
- No CCS, $25/tonne CO2
- With CCS, $0/tonne CO2
- With CCS, $25/tonne CO2

Co-production becomes cheaper than liquids-only if electricity price ranges between $35 – 70/MWh.
Co-production vs. separate production of liquids and electricity

**Question:** Which has lower CO$_2$ emissions and coal consumption?

- Co-production plant producing 50,000 bbl/day liquid fuels *and* 1,000 MW$_e$ (with or w/o CCS) or
- 50,000 bbl/day in a liquids-only CTL plant *and* 1,000 MWe in a PC power plant (USC)?

Mantripragada & Rubin, Carnegie Mellon
**Answer** (see analysis for details):

With or without CCS, co-production plants …

- Consume at least 15% less coal, and
- Emit at least 25% less CO₂

…than separate production of liquid fuels and electricity, with or without CCS

Conceptually, by displacing PC plants, co-production with CCS can achieve a net CO₂ reduction, while meeting the liquid-fuel demand

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**Conclusions**

- Performance and cost vary with choice of gasifier technology and plant configuration
  - Dry-feed has the better performance and cost characteristics
- Liquids from co-production plants cheaper than from liquids-only plants for market prices of electricity
- Minimum CO₂ price required to make CCS cost-effective is $12/tonne for liquids-only and $35/tonne for co-production (for the case study plants)
- Co-production is more efficient than separate generation of liquids and electricity
- **Co-production with CCS can achieve a net CO₂ reduction compared to separate liquid fuels and electricity production from coal**
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Thank You

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