Comparative Assessments of PC, NGCC and IGCC Power Plants
With and Without CO$_2$ Capture and Storage

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Objectives

• Compare the performance and cost of current fossil fuel power systems with and without CO$_2$ capture and storage (CCS)
  - Pulverized coal combustion (PC)
  - Integrated coal gasification combined cycle (IGCC)
  - Natural gas combined cycle (NGCC)
What’s New Here?

• We explore a broader range of conditions that influence comparisons among these technologies

• We highlight the implications of CCS energy penalties on resource requirements, multi-pollutant emissions, and cross-media environmental impacts

• We use the (publicly available) IECM computer model to systematically evaluate all three systems
The IECM is Available At . . .

• CO₂ Version (Beta):
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    mikeb@cmu.edu

• Web Access :
  ▪ www.iecm-online.com

• Technical Support:
  ▪ PED.modeling@netl.doe.gov
Case 1:

Nominal Assumptions
## Nominal Case Study Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NGCC</th>
<th>PC</th>
<th>IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference Plant (~500 MW)</strong></td>
<td>2 x 7FA</td>
<td>Supercritical</td>
<td>Texaco quench</td>
</tr>
<tr>
<td>Fuel Type</td>
<td>Nat. Gas</td>
<td>2%S Bit</td>
<td>2%S Bit</td>
</tr>
<tr>
<td>Net HHV Efficiency (%)</td>
<td>50.3</td>
<td>39.3</td>
<td>37.5</td>
</tr>
<tr>
<td>Capacity Factor (%)</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Fuel Cost, HHV ($/GJ)</td>
<td>3.92</td>
<td>1.27</td>
<td>1.27</td>
</tr>
<tr>
<td><strong>CCS Plant (~500 MW)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ Capture System</td>
<td>Amine</td>
<td>Amine</td>
<td>Shift+Selexol</td>
</tr>
<tr>
<td>CO₂ Removal (%)</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Pipeline Pressure (MPa)</td>
<td>13.8</td>
<td>13.8</td>
<td>13.8</td>
</tr>
<tr>
<td>Geologic Storage Option</td>
<td>Aquifer</td>
<td>Aquifer</td>
<td>Aquifer</td>
</tr>
</tbody>
</table>

Also: fixed charge factor = 0.148; all costs in constant 2002 US$
CO₂ Emission Rates (kg/MWh)

- Ref. Plant
  - PC: 810 kg/MWh
  - IGCC: 818 kg/MWh
  - NGCC: 374 kg/MWh

- with CCS
  - PC: 107 kg/MWh
  - IGCC: 89 kg/MWh
  - NGCC: 44 kg/MWh
Cost of Electricity (COE) (Levelized $/MWh)

Ref. Plant +capture + transport & storage

PC IGCC NGCC PC IGCC NGCC PC IGCC NGCC

46 49 43 80 67 62 66 54 56

EOR Storage
Cost of CO$_2$ Avoided ($/tonne CO$_2$)

- PC: 49
- IGCC: 26
- NGCC: 59
- PC: 28
- IGCC: 8
- NGCC: 41

Capture and transport + storage costs for different technologies.
Case 2:

Effects of Fuel Price and Plant Dispatch
Differences in Total Variable Operating Cost ($/MWh)

(Includes fuel, chemicals, utilities, wastes and byproducts)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Fuel Price</th>
<th>Ref. Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>$1.27/ MBtu</td>
<td>(Base case)</td>
</tr>
<tr>
<td>IGCC</td>
<td>$1.27/ MBtu</td>
<td>~ 0</td>
</tr>
<tr>
<td>NGCC</td>
<td>$2.50/MCF</td>
<td>+ 3</td>
</tr>
<tr>
<td></td>
<td>$4.50</td>
<td>+15</td>
</tr>
<tr>
<td></td>
<td>$6.50</td>
<td>+27</td>
</tr>
</tbody>
</table>

Implication: Decreasing dispatch of NGCC at higher gas prices if coal plants are available
Recent Trends for NGCC Plants

Average Gas Price ($/MBtu) vs Year

- Assumed CF=85%
- Actual = 45%
- 32%

Effect of Variable Capacity Factor on Breakeven NG Price

- PC @ 75% CF
- NGCC @ 85/50/35% CF
- NGCC @ 85% CF

Natural Gas Price ($/MCF)

COE ($/MWh)

- Variable CF
- Constant CF

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Differences in Total Variable Operating Cost w/ CCS ($/MWh)

(Includes fuel, chemicals, utilities, wastes and byproducts)

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<tr>
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<tbody>
<tr>
<td>PC</td>
<td>$1.27/ MBtu</td>
<td>(Base case)</td>
</tr>
<tr>
<td>IGCC</td>
<td>$1.27/ MBtu</td>
<td>– 10</td>
</tr>
<tr>
<td>NGCC</td>
<td>$2.50/MCF</td>
<td>– 7</td>
</tr>
<tr>
<td></td>
<td>$4.50</td>
<td>+ 8</td>
</tr>
<tr>
<td></td>
<td>$6.50</td>
<td>+38</td>
</tr>
</tbody>
</table>

**Implication:** Increasing dispatch of IGCC
Cost of Electricity ($/MWh) w/ Differential Capacity Factors

Gas @ $4.50/MCF

PC NGCC IGCC

CF = 75% (all cases)

75% 85% 50%
Case 3:

Effects of IGCC
Financing & Operation
IGCC — Can You Build It?

- Today, IGCC plants are generally more expensive than conventional PC plants, based on expected COE.
- IGCC technology is also perceived as “riskier” by the financial community, and by many utility companies.
- Several efforts underway to develop more attractive financing and ownership arrangements to facilitate deployment of IGCC in the U.S. power market.
Two New Scenarios for IGCC Financing and Operation

• **Unfavorable**
  - Higher fixed charge rate of 17.3% (20% risk premium on rates of return)
  - Lower plant utilization (CF=70%)

• **Favorable**
  - Lower fixed charge rate of 10.4% (e.g., Harvard 3-Party Covenant)
  - Higher plant utilization (CF=80%)
Cost of Electricity ($/MWh) for the Two New Scenarios

Unfavorable

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<thead>
<tr>
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<tbody>
<tr>
<td>49</td>
<td>67</td>
</tr>
<tr>
<td>54</td>
<td>75</td>
</tr>
<tr>
<td>58</td>
<td>80</td>
</tr>
</tbody>
</table>

Favorable

<table>
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<tbody>
<tr>
<td>49</td>
<td>67</td>
</tr>
<tr>
<td>40</td>
<td>56</td>
</tr>
<tr>
<td>38</td>
<td>53</td>
</tr>
</tbody>
</table>
Case 4:

CCS Energy Penalty Impacts on Resource Consumption and Multi-media Emissions
Energy Penalty Defined

- Commonly defined as the reduction in plant output for a constant fuel input (i.e., plant derating) due to CCS
- More general definition is based on change in net plant heat rate or efficiency ($\eta$):

$$EP = 1 - \left(\frac{\eta_{ccs}}{\eta_{ref}}\right)$$

**Case study energy penalties:**

$PC = 24\%$, $IGCC = 14\%$, $NGCC = 15\%$
An Alternative Definition

• An alternative definition of the energy penalty is the increase in plant inputs per unit of output (EP*):

\[ EP^* = \frac{EP}{1 - EP} \]

• This measure reflects increases per unit of product for:
  - Plant fuel consumption
  - Other resource requirements
  - Solid and liquid wastes
  - Air pollutants not captured by CCS
  - Upstream (life cycle) impacts
CCS Energy Penalties

- Case study energy penalties for current technologies based on EP*:
  - PC = 31 %
  - IGCC = 16%
  - NGCC = 18%
Increases in Fuel and Reagent Consumption

Increases in Coal and Natural Gas Consumption

Increase in Ammonia Consumption

Increase in Limestone Consumption

*Based on Illinois #6 coal

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Increases in Solid Wastes & Plant Byproducts

*Based on Illinois #6 coal

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Increases in Air Emission Rates

*Based on Illinois #6 coal
The Critical Importance of Technology Innovation

• New or improved technologies for power generation and CO$_2$ capture can lower the cost of CCS, and significantly reduce adverse secondary impacts by:
  ▪ Improving overall plant efficiency
  ▪ Reducing CCS energy penalties
  ▪ Maximizing co-capture of other pollutants
Work in Progress at CMU

• Incorporate performance and cost models of advanced power systems and CO$_2$ capture options:
  - Oxyfuel combustion
  - ITM oxygen production
  - Advanced IGCC designs
  - Advanced NGCC

• Expand and regionalize transport & storage models

• Comparative analyses of CO$_2$ capture options for new and existing power plants
  - Advanced PC, NGCC and IGCC systems
  - Repowering or rebuild of existing units

• Assessments of R&D Benefits