LCA of Carbon Capture Retrofit Using the “Petra Nova Style” Model

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Attribution

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• Partnership between JX Nippon Oil and Gas Exploration and NRG Energy
  • US DOE grant
• Amine based capture unit operational December 29, 2016
• Captures 90% of CO₂ emissions from a flue gas slipstream
  • W.A. Parish Unit 8 (240 MW)
  • 5,000 metric tons captured daily
• Capture unit powered by 75 MW cogeneration natural gas generator
  • No generation from coal-fired Unit 8 used for capture unit

Source: EIA, 2017. “Petra Nova is one of two carbon capture and sequestration power plants in the world.”

Petra Nova Plant
Outside of Houston, Texas
Eliminating The Derate Of Carbon Capture Retrofits, in review
Vincent Chou, Norma Kuehn, Eric Lewis, Marc Turner, and Mark Woods

- Modeling NETL Subcritical Pulverized Coal (SubPC) plants in the “Petra Nova Style”
- Provides performance and GHG results for Shell Cansolv capture system implemented with auxiliary plant arrangement
- Compares same capture technology on same retrofit plant, one using a parasitic load, and two using natural gas cogeneration power

<table>
<thead>
<tr>
<th>Objective</th>
<th>Case</th>
<th>Existing ST Extraction</th>
<th>Duct Firing</th>
<th>CO₂ Capture Criteria¹</th>
<th>Auxiliary Plant Arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrofit Baseline</td>
<td>0</td>
<td>As Required</td>
<td>None</td>
<td>90% from PC flue gas</td>
<td>N/A</td>
</tr>
<tr>
<td>Retrofit with NGSC CHP Repowering</td>
<td>1</td>
<td>None</td>
<td>None</td>
<td>90% from PC flue gas</td>
<td>Natural Gas Simple Cycle (NGSC) Auxiliary Plant with a hypothetically sized CT, no carbon capture</td>
</tr>
<tr>
<td>Retrofit with NGCC CHP Repowering</td>
<td>2</td>
<td>None</td>
<td>None</td>
<td>90% from PC flue gas</td>
<td>Natural Gas Combined Cycle (NGCC) Auxiliary Plant with (2x) GE 7FA CTs, no carbon capture</td>
</tr>
</tbody>
</table>
Boundaries

• **Base power plant technology:**
  • Subcritical Pulverized Coal (SubPC)
  • Illinois 6 Bituminous coal feed
  • Located in Midwest

• **Cogeneration technology:** differs by scenario (none, NGSC or NGCC)

• **Capture technology:** Amine-based (Shell Cansolv)

• **CO₂ pathway:** Sequestration (EOR is run in sensitivity analysis)

• **Boundary:** Cradle-to-grave

• **Functional Unit:** 1 MWh electricity delivered to end user

• **Impact categories included:** TRACI 2.1
  • Global Warming (modified to use AR5 instead of AR4); Eutrophication; Acidification; Smog; Ozone Depletion; and Particulate Matter, Air
## Scenario Design

<table>
<thead>
<tr>
<th></th>
<th>Uncaptured</th>
<th>Captured</th>
<th>Captured + Simple Cycle (SC)</th>
<th>Captured + Combined Cycle (CC)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Power Plant Type</strong></td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
</tr>
<tr>
<td><strong>Cogeneration Technology</strong></td>
<td>None</td>
<td>None</td>
<td>NGSC CHP</td>
<td>NGCC CHP</td>
</tr>
<tr>
<td><strong>Net Power Output (MWe)</strong></td>
<td>550</td>
<td>425</td>
<td>730</td>
<td>1060</td>
</tr>
<tr>
<td><strong>Capture Technology</strong></td>
<td>None</td>
<td>Shell Cansolv</td>
<td>Shell Cansolv</td>
<td>Shell Cansolv</td>
</tr>
<tr>
<td><strong>Capture efficiency</strong></td>
<td>None</td>
<td>90%</td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Overall CO₂ Capture</strong></td>
<td>n/a</td>
<td>90%</td>
<td>71%</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Coal Flow Rate (kg/hr)</strong></td>
<td>187,000</td>
<td>187,000</td>
<td>187,000</td>
<td>187,000</td>
</tr>
<tr>
<td><strong>Coal Input (kg/MWh)</strong></td>
<td>340</td>
<td>439</td>
<td>256</td>
<td>176</td>
</tr>
<tr>
<td><strong>Natural Gas Flow Rate (kg/hr)</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>20,800</td>
<td>38,200</td>
</tr>
<tr>
<td><strong>Natural Gas Input (kg/MWh)</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>62.8</td>
<td>79.3</td>
</tr>
</tbody>
</table>
How to Compare Like to Like?

**Scaled-Up Comparison**
(both systems net 730 MW)

- **Upstream Processes**
- **Power Plant of Interest**
  - 550 MW
- **Cogen**
  - 180 MW
- **End user**

**System Expansion**
(both systems net 730 MW)

- **Upstream Processes**
- **Power Plant of Interest**
  - 550 MW
- **Cogen**
  - 180 MW
- **End user**

**Comparison Case**

- **Upstream Processes**
- **Similar Power Plant**
  - 730 MW
- **End user**

**Upstream Processes**

- **coal**
- **NG**
- **e-**

**Upstream Processes**

- **coal**
- **NG**
- **e-**

**Upstream Processes**

- **coal**
- **NG**
- **e-**

**Upstream Processes**

- **coal**
- **NG**
- **e-**

**Grid Makeup**

- **coal**
- **e-coal**
- **NG**
- **180 MW**
- **End user**
Size and scale act as shorthand for equivalency – streamlined approach

• Power Plant of Interest compared to a different power plant
  • Does not represent consequential result

• Useful for high-level technology comparison
  • Technology profiles can form the basis of the input to a consequential LCA model

• Can provide benchmarking for attributional analysis among functionally equivalent services
## Scenario Design, Scaled-up Coal Power

<table>
<thead>
<tr>
<th></th>
<th>Cap + SC</th>
<th>Uncap 730</th>
<th>Cap 730</th>
<th>Cap + CC</th>
<th>Uncap 1060</th>
<th>Cap 1060</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Power Plant Type</strong></td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
</tr>
<tr>
<td><strong>Cogeneration Technology</strong></td>
<td>NGSC CHP</td>
<td>None</td>
<td>None</td>
<td>NGCC CHP</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Net Power Output (MWe)</strong></td>
<td>730</td>
<td>730</td>
<td>730</td>
<td>1060</td>
<td>1060</td>
<td>1060</td>
</tr>
<tr>
<td><strong>Capture Technology</strong></td>
<td>Shell Cansolv</td>
<td>None</td>
<td>Shell Cansolv</td>
<td>Shell Cansolv</td>
<td>None</td>
<td>Shell Cansolv</td>
</tr>
<tr>
<td><strong>Capture efficiency</strong></td>
<td>90%</td>
<td>None</td>
<td>90%</td>
<td>90%</td>
<td>None</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Overall CO₂ Capture</strong></td>
<td>71%</td>
<td>n/a</td>
<td>90%</td>
<td>60%</td>
<td>n/a</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Coal Flow Rate (kg/hr)</strong></td>
<td>187,000</td>
<td>248,000</td>
<td>321,000</td>
<td>187,000</td>
<td>360,000</td>
<td>465,000</td>
</tr>
<tr>
<td><strong>Coal Input (kg/MWh)</strong></td>
<td>256</td>
<td>340</td>
<td>439</td>
<td>176</td>
<td>340</td>
<td>439</td>
</tr>
<tr>
<td><strong>Natural Gas Flow Rate (kg/hr)</strong></td>
<td>21,000</td>
<td>0</td>
<td>0</td>
<td>38,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Natural Gas Input (kg/MWh)</strong></td>
<td>62.8</td>
<td>0</td>
<td>0</td>
<td>79.3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The scaled up plants no longer describe the *same* retrofitted power plant. The comparison now represents different base plants with or without retrofit options, providing the same net output electricity.
Maintains the “Power Plant of Interest”
  - Represents a consequential result

Useful for understanding the consequence of a decision – a single plant or other change to the system
  - Should the plant use the “Petra Nova style” of carbon capture over other methods?

Makeup power depends on specific local and temporal conditions

If the makeup power is a similar plant to Plant of Interest, system expansion and non-system expansion would be the same
### Scenario Design, System Expansion

<table>
<thead>
<tr>
<th></th>
<th>Cap + SC</th>
<th>Uncap, SE 730</th>
<th>Cap, SE 730</th>
<th>Cap + CC</th>
<th>Uncap, SE 1060</th>
<th>Cap SE 1060</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Power Plant Type</strong></td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
<td>SubPC</td>
</tr>
<tr>
<td><strong>Cogeneration Technology</strong></td>
<td>NGSC CHP</td>
<td>None</td>
<td>None</td>
<td>NGCC CHP</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>Output from Primary Plant (MW)</strong></td>
<td>730</td>
<td>550 (75%)</td>
<td>425 (58%)</td>
<td>1060</td>
<td>550 (52%)</td>
<td>425 (40%)</td>
</tr>
<tr>
<td><strong>Displaced power</strong></td>
<td>0</td>
<td>180 (25%)</td>
<td>305 (42%)</td>
<td>0</td>
<td>510 (48%)</td>
<td>635 (60%)</td>
</tr>
<tr>
<td><strong>Net Power Output (MW)</strong></td>
<td>730</td>
<td>730</td>
<td>730</td>
<td>1060</td>
<td>1060</td>
<td>1060</td>
</tr>
</tbody>
</table>

The displaced power included in the expanded system depends on local conditions and time period, and likely changes frequently. Therefore, the displaced power is modeled several different ways: as the average grid mix (2013), a similar SubPC power plant without capture, and hydropower.
## Method Comparison

<table>
<thead>
<tr>
<th></th>
<th>System Expansion</th>
<th>Scaling Up</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LCA type?</strong></td>
<td>Consequential</td>
<td>Attributional</td>
</tr>
<tr>
<td><strong>Time frame?</strong></td>
<td>Compare before-and-after</td>
<td>Compare within same time-frame</td>
</tr>
<tr>
<td><strong>Specificity?</strong></td>
<td>Requires a defined geographical and temporal boundary and economics</td>
<td>Standard technology representation</td>
</tr>
<tr>
<td><strong>Benchmarking?</strong></td>
<td>Requires multiple consequential scenarios</td>
<td>Benchmark-ready</td>
</tr>
</tbody>
</table>
“What are the attributional footprints?”

No Adjustments to Plant Size or Displaced Power
Capture + SC Summary
Normalized to Capture + SC scenario, set as 100% for all categories

Electricity Makeup Power

Scaled Up Comparison Plants

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Acidification

Eutrophication

Global Warming

Particulate Matter, Air

Ozone Depletion

Smog

---

Cap + SC | Uncap | Cap
---|---|---

---

Cap + SC | Uncap 730 | Cap 730
Normalized to Capture + CC scenario, set as 100% for all categories

**Displaced US Average Electricity**

- **Smog**: 100% (Cap + CC), 96% (Uncap), 106% (Cap)
- **Ozone Depletion**: 100% (Cap + CC), 100% (Uncap), 100% (Cap)
- **Particulate Matter, Air**: 100% (Cap + CC), 150% (Uncap), 163% (Cap)
- **Global Warming**: 100% (Cap + CC), 134% (Uncap), 205% (Cap)
- **Eutrophication**: 100% (Cap + CC), 90% (Uncap), 101% (Cap)
- **Acidification**: 100% (Cap + CC), 163% (Uncap), 165% (Cap)

**Scaled Up Comparison Plants**

- **Smog**: 100% (Cap + SC), 121% (Uncap 730), 193% (Cap 730)
- **Ozone Depletion**: 100% (Cap + SC), 192% (Uncap 730), 248% (Cap 730)
- **Particulate Matter, Air**: 100% (Cap + SC), 192% (Uncap 730), 248% (Cap 730)
- **Global Warming**: 90% (Cap + SC), 100% (Uncap 730), 246% (Cap 730)
- **Eutrophication**: 96% (Cap + SC), 96% (Uncap 730), 124% (Cap 730)
- **Acidification**: 100% (Cap + SC), 167% (Uncap 730), 167% (Cap 730)
Conclusions

• The exact question asked can change the answer

• Carbon capture inherently involves tradeoffs between global warming potential and other impact categories

• Retrofits using Petra-Nova-style cogeneration can have environmental benefits, depending on the exact question being asked, and the local conditions

• Further study into LCA modeling using dispatch curves would greatly reduce the scenario uncertainty
Contact Information

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Backup – Cap + SC with Makeup Power

Global Warming, Grid Mix Makeup Power

- kg CO₂ eq/MWh electricity delivered
- Cap + SC: 451
- Uncap: 979
- Cap: 510

Eutrophication, Grid Mix Makeup Power

- kg N eq/MWh electricity delivered
- Cap + SC
- Uncap
- Cap

Acidification, Grid Mix Makeup Power

- kg SO₂ eq/MWh electricity delivered

Particulate Matter, Air, Makeup Displaced Power

- kg PM2.5 eq/MWh electricity delivered
- Cap + SC: 3.09
- Uncap: 3.63
- Cap: 4.02

Ozone Depletion, Grid Mix Makeup Power

- kg CFC 11 eq/MWh electricity delivered
- Cap + SC: 1.31E-05
- Uncap: 1.31E-05
- Cap: 1.31E-05

Smog, Grid Mix Makeup Power

- kg O₃ eq/MWh electricity delivered
- Cap + SC: 23.7
- Uncap: 20.2
- Cap: 24.2
Backup – Cap + CC with Makeup Power

**Global Warming, Grid Mix Makeup Power**

<table>
<thead>
<tr>
<th></th>
<th>Cap + CC</th>
<th>Uncap</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg CO2 eq/MWh</td>
<td>4.18</td>
<td>8.17</td>
<td>5.68</td>
</tr>
</tbody>
</table>

**Eutrophication, Grid Mix Makeup Power**

<table>
<thead>
<tr>
<th></th>
<th>Cap + CC</th>
<th>Uncap</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg N eq/MWh</td>
<td>0.056</td>
<td>0.051</td>
<td>0.057</td>
</tr>
</tbody>
</table>

**Acidification, Grid Mix Makeup Power**

<table>
<thead>
<tr>
<th></th>
<th>Cap + CC</th>
<th>Uncap</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg SO2 eq/MWh</td>
<td>21.1</td>
<td>20.2</td>
<td>22.3</td>
</tr>
</tbody>
</table>

**Particulate Matter, Air, Grid Mix Makeup Power**

<table>
<thead>
<tr>
<th></th>
<th>Cap + CC</th>
<th>Uncap</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg PM2.5 eq/MWh</td>
<td>2.13</td>
<td>3.20</td>
<td>3.47</td>
</tr>
</tbody>
</table>

**Ozone Depletion, Grid Mix Makeup Power**

<table>
<thead>
<tr>
<th></th>
<th>Cap + CC</th>
<th>Uncap</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg CFC 11 eq/MWh</td>
<td>9.03339E-06</td>
<td>9.05E-06</td>
<td>9.05E-06</td>
</tr>
</tbody>
</table>

**Smog, Grid Mix Makeup Power**

<table>
<thead>
<tr>
<th></th>
<th>Cap + CC</th>
<th>Uncap</th>
<th>Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg O3 eq/MWh</td>
<td>2.13E+01</td>
<td>20.2</td>
<td>22.3</td>
</tr>
</tbody>
</table>
Backup – Upper and Lower Makeup Power

**Case 1, Uncap SubPC Coal Makeup Power**

- **Smog**: 100% (Cap), 85% (Uncap), 102% (Cap + SC), 132% (Cap + CC)
- **Ozone Depletion**: 100% (Cap), 133% (Uncap), 155% (Cap + SC), 215% (Cap + CC)
- **Particulate Matter, Air**: 100% (Cap), 132% (Uncap), 155% (Cap + SC), 216% (Cap + CC)
- **Global Warming**: 100% (Cap), 152% (Uncap), 236% (Cap + SC), 243% (Cap + CC)
- **Eutrophication**: 100% (Cap), 83% (Uncap), 99% (Cap + SC), 49% (Cap + CC)
- **Acidification**: 100% (Cap), 133% (Uncap), 133% (Cap + SC), 78% (Cap + CC)

**Case 1, Hydropower Makeup**

- **Smog**: 100% (Cap), 64% (Uncap), 63% (Cap + SC), 93% (Cap + CC)
- **Ozone Depletion**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Particulate Matter, Air**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Global Warming**: 100% (Cap), 54% (Uncap), 179% (Cap + SC), 182% (Cap + CC)
- **Eutrophication**: 100% (Cap), 62% (Uncap), 64% (Cap + SC), 49% (Cap + CC)
- **Acidification**: 100% (Cap), 99% (Uncap), 78% (Cap + SC), 49% (Cap + CC)

**Case 2, Uncap SubPC Coal Makeup Power**

- **Smog**: 100% (Cap), 96% (Uncap), 100% (Cap + SC), 193% (Cap + CC)
- **Ozone Depletion**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Particulate Matter, Air**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Global Warming**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Eutrophication**: 100% (Cap), 94% (Uncap), 106% (Cap + SC), 106% (Cap + CC)
- **Acidification**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)

**Case 2, Hydropower Makeup**

- **Smog**: 100% (Cap), 50% (Uncap), 49% (Cap + SC), 100% (Cap + CC)
- **Ozone Depletion**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Particulate Matter, Air**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Global Warming**: 100% (Cap), 100% (Uncap), 100% (Cap + SC), 100% (Cap + CC)
- **Eutrophication**: 100% (Cap), 49% (Uncap), 50% (Cap + SC), 100% (Cap + CC)
- **Acidification**: 100% (Cap), 85% (Uncap), 67% (Cap + SC), 100% (Cap + CC)