Guidance for NETL’s Carbon Capture R&D Program

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Objectives

• Devise a methodology to estimate power plant performance and cost using specific developer-provided characteristics of advanced CO₂ capture technology
  – Ensure results on a consistent basis
  – Include diverse capture technologies: solvents, sorbents, adsorbents, membranes, phase change, cryogenic concepts
  – Reduce time and cost to assess advanced technology development status and guide development

• Develop ‘COE’ and ‘cost of CO₂’ metrics for an advanced capture technology that relate to the NETL advanced power plant R&D goals

Example
PC plant with 2nd gen post-comb. capture

COE contributions from
• Capture technology
• Steam conditions
• Compression technology

Plant COE Goal: 20% reduction in SOA IGCC with capture ($106/MWh)
Approach

NETL Baseline Study Reference Plants (PC post-combustion, PC oxy-combustion, IGCC pre-combustion) with Representation of Today’s Capture Technology

Remove ‘Conventional’ CO₂ Capture Process; Insert Advanced Capture Technology

- Developer given plant design basis and boundary conditions
- Developer provides specific set of performance and cost estimate parameters for their process

Methodology Utilizes Adv. Technology Inputs to Project Integrated Plant Performance and Cost
Methodology for Power Plant Performance and Cost Scaling

BASE POWER PLANT WITH CONVENTIONAL CARBON CAPTURE

Coal →
Balance of Power Plant →
Conv. CO₂ Separation System →
Conv. CO₂ Purification & Compression System →
CO₂ Product

Known Base plant characteristics:
- Capacity (kW) $P_b$
- Cost of Electricity ($/MWh) $COE_b$

Direct Substitution

MODIFIED POWER PLANT WITH ADVANCED CARBON CAPTURE

Fixed Coal Rate →
Balance of Power Plant →
Advanced CO₂ Separation System →
Advanced CO₂ Purification & Compression System →
CO₂ Product

Modified plant characteristics:
- Capacity (kW) $P$
- Cost of Electricity ($/MWh) $COE$
PC Post-Combustion

Stein Condenser

Steam Plant

Cooling Water System

CO₂ Capture Process

CO₂ product vent condensate

Stack Gas

CO₂ P&C System

Steam condensate extraction heating steam

Consumables

Boiler

Coal Prep

Air

Coal

Secondary air primary air

ID Fan

FGD & Polisher

Flue Gas

CO₂ Separation System

Process Cooling

SH-steam BFW primary air & coal

FD Fan

Air

P&C System

Vent

Cooling Water System

Source: NETL
PC Oxy-Combustion

Steam Power Cycle

Coal

Primary Oxidant Fan

Air

Vent

steam cond

Oxidant

ASU

Secondary Oxidant Fan

PC Boiler

Baghouse

ID Fan

FGD

Warm Recycle Option

Heater

BFW

recycle CO₂

BFW

LP-steam

CW

Vent

CO₂ Purification & Compression System

CO₂ Product

CO₂ capture process components

Interacting components

Source: NETL
IGCC Pre-Combustion Conventional Gas Cleaning

Coal → Conventional ASU, Gasification, Sour Shift, Gas Cleaning → Shifted Syngas → CO₂ Separation System → Raw CO₂ → CO₂ Purification & Compression System → CO₂ Product

- N₂ Compressor
- N₂
- Expander
- Recovered Fuel
- Fuel Gas
- Gas Turbine System
- Steam Turbine System
- Exhaust Gas
- Air
- Net Process Heating Steam
- Process Cooling Water
- Cooling Water System

Source: NETL
IGCC Pre-Combustion
Advanced Humid Gas Cleaning

Source: NETL
Power Factor (PF) Associated with Advanced Capture Technology

• Represents the sum of the impacts of the advanced CO₂ capture process on the power plant generating capacity

• Form of the Power Factor (kW per tonne/hr CO₂) is:

\[
PF = A_{CO₂} + A_{P&C} + (P_{bST} - P_{ST}) + \Sigma (A_i - A_{bi})
\]

– \( A_{CO₂} \): Advanced CO₂ separation system auxiliary power, kW/tonne/hr CO₂
– \( A_{P&C} \): Purification & compression system auxiliary power, kW/tonne/hr CO₂
– Interaction terms:
  • \((P_{bST} - P_{ST})\): Difference between steam cycle power in advanced and base plant
  • \((A_i - A_{bi})\): Difference between system “i” auxiliary power in advanced and base plant
COE Factor (COEF)

- Represents all contributions of the advanced CO$_2$ Capture Process components to the power plant COE
- The form of the COE Factor ($ per tonne/hr CO$_2$) is:

\[
\text{COEF} = C_{\text{CO2}} + C_{\text{P&C}} + (C_{\text{ST}} - C_{\text{bST}}) + \Sigma (C_i - C_{bi}) + K_c \cdot OC_{\text{VarCO2}}
\]

- $C_{\text{CO2}}$: Capital cost of the CO$_2$ separation system, $/\text{tonne/hr CO}_2$
- $C_{\text{P&C}}$: Capital cost of the CO$_2$ purification and compression system, $/\text{tonne/hr CO}_2$
- $OC_{\text{VarCO2}}$: Variable operating cost of the CO$_2$ separation and CPU systems, $/\text{yr per tonne/hr CO}_2$
- $K_c$ is a constant based on financial assumptions
- Interaction terms:
  - $C_{\text{ST}} - C_{\text{bST}}$: Change in capital cost of the steam turbine system, $/\text{tonne/hr CO}_2$
  - $C_i - C_{bi}$: Change in capital cost of the “I” system, $/\text{tonne/hr CO}_2$
Methodology for Power Plant Performance and Cost Scaling

• Net power (P) and first-year COE (w/o T&S) Scaling Relationships:

\[
P = B_1 - B_2 \cdot \text{Power Factor}
\]
\[
\text{COE} = \left[ B_3 + B_4 \cdot \text{COE Factor} \right] / P
\]

• The “B” terms are constants derived from the base plant performance and cost
• Power Factor and COE Factor are based on characteristics of the advanced CO₂ capture process

Fixed Coal Feed Rate for Reference Plant and Advanced Capture Plant
### PC Post-Combustion Example
**Inputs for Membrane-Based CO₂ Capture Process**

<table>
<thead>
<tr>
<th>Required CO₂ Capture Process Input Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ process steam heating duty (MMBtu/hr)</td>
<td>0</td>
</tr>
<tr>
<td>Extracted steam heating temperature (F)</td>
<td>N/A</td>
</tr>
<tr>
<td>CO₂ process cooling duty (MMBtu/hr)</td>
<td>0</td>
</tr>
<tr>
<td>CO₂ separator pressure drop (psi)</td>
<td>2</td>
</tr>
<tr>
<td>FD fan boost pressure (psi)</td>
<td>1.5</td>
</tr>
<tr>
<td>CO₂ separation process auxiliary power (kW)</td>
<td>34,897</td>
</tr>
<tr>
<td>CO₂ purification &amp; compression power (kW)</td>
<td>57,404</td>
</tr>
<tr>
<td>CO₂ separation process cost ($1000)</td>
<td>307,311</td>
</tr>
<tr>
<td>CO₂ purification &amp; compression cost ($1000)</td>
<td>67,184</td>
</tr>
<tr>
<td>CO₂ capture process annual variable operating cost ($1000)</td>
<td>5,215</td>
</tr>
</tbody>
</table>

*Includes design concept, permeances (e.g. CO₂, H₂O, SO₂, N₂, O₂), operating temperature, operating pressures, membrane surface area, pressure drop, membrane life, membrane cost, and module cost.*

These input data are based on a hypothetical membrane system concept with design, operating and performance parameters selected to meet the DOE goal.
Example Results for PC Post-Combustion Membrane-Based CO₂ Capture Process

<table>
<thead>
<tr>
<th>PC Power Plant Results</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Factor (kW per tonne/hr flue gas CO₂)</td>
<td>210.06</td>
</tr>
<tr>
<td>Plant net efficiency (% , HHV)</td>
<td>32.81</td>
</tr>
<tr>
<td>COE Factor ($ per tonne/hr flue gas CO₂)</td>
<td>721,849</td>
</tr>
<tr>
<td>COE ($/MWh)</td>
<td>113.3</td>
</tr>
<tr>
<td>COE Reduction (%)</td>
<td>17.5</td>
</tr>
</tbody>
</table>

These input data are based on a hypothetical membrane system concept with design, operating and performance parameters* selected to meet the DOE goal.

* Includes design concept, permeances (e.g. CO₂, H₂O, SO₂, N₂, O₂), operating temperature, operating pressures, membrane surface area, pressure drop, membrane life, membrane cost, and module cost
This plot represents the COE reduction contribution for a plant with:

- Adv. capture tech.
- SC steam
- Conv. compression
- High-risk financial

**Source:** NETL
Methodology for Power Plant Cost Metrics and Goals

• The PC Plant with the advanced CO₂ capture process is related to the NETL advanced power generation R&D goal of 20% reduction in the COE ($106/MWh)

The methodology for an IGCC plant with advanced capture would include options for an advanced gas turbine, ASU, gas cleaning, gasification.
COEF and PF to Meet NETL Advanced Power Generation R&D Goal

Source: NETL
Relationship of Capture Technology Metrics to NETL R&D Program Goal for COE

![Graph showing the relationship between COE Factor and Power Factor with different COE goal reductions. The graph includes lines for different COE goal reductions: 5%, 10%, 15%, 20%, 25%, and 30%. The base plant point is labeled BBR Case 12. The graph also indicates the Minimum Work Limit at COE Factor ($1000 per tonne/hr CO₂) of 0.

- Fixed Coal Feed Rate COE Reductions:
  - 5%
  - 10%
  - 15%
  - 20%
  - 25%
  - 30%

- COE Factor ($1000 per tonne/hr CO₂):
  - 0
  - 50
  - 100
  - 150
  - 200
  - 250
  - 300
  - 350
  - 400
  - 450
  - 500

- Power Factor (kW per tonne/hour CO₂):
  - 0
  - 50
  - 100
  - 150
  - 200
  - 250
  - 300
  - 350
  - 400
  - 450
  - 500

The graph illustrates the impact of different COE goal reductions on the power factor and COE factor, showing how these metrics are related to the NETL R&D program goal for COE.
Methodology Tool Application

• A technology developer or evaluator can apply the methodology relationships to assess the feasibility, sensitivity, development requirements, and development progress of CO$_2$ separation technologies.

• If the technology developer can estimate the PF for the CO$_2$ Capture Process, the COEF required to meet any given COE goal can be determined and assessed.

• If the technology developer can estimate the PF and COEF for the CO$_2$ capture process, the COE for the resulting plant can be determined and assessed.