Techno-economic Evaluation of State-of-the-Art and Advanced Post-Combustion Capture Plants

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Office of Program Performance and Benefits
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• **Outline**
  – Bituminous Baseline Study Revision 3
  – Clean Coal Research Program Goal Review
  – NETL Advanced Capture Technology Assessments

• **Acknowledgements**
  – DOE:
    • Tim Fout
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BITUMINOUS BASELINE STUDY

REVISION 3
Update to the Bituminous Baseline Study

Overview

Full Title: Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 3, Fall/Winter 2014

Purpose: to provide a basis for evaluation of advanced technologies on a consistent set of technical and economic assumptions

• Major change summary
  • Updated basis for performance and cost for CO₂ capture system, CO₂ compression, steam turbines, natural gas turbines
  • Update of all cases to 2011$
  • Updated environmental control train to address EPA regulations
  • Updated tables to include additional data
  • New case numbering system (conforms with Low Rank study)
  • Minimal changes to IGCC cases (further updates coming soon!!)
Flowsheet Changes

B11A and B12A – No CO₂ Capture

Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.
Flowsheet Changes

B11B and B12B – with CO₂ Capture

**New**

**Updated**

Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.
Amine-based capture system

Features:
Absorber – acid brick lined concrete structure
90% CO₂ Capture
Pre-scrubber used in coal cases only
Baseline Greenfield Capture and Compression Technology Update

### PC Plants Quote Vintage

<table>
<thead>
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</tr>
</tbody>
</table>

**PC:** ~25% reduction in regeneration energy penalty

**NGCC:** ~20% reduction in regeneration energy penalty

### 2012 Update

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Electrical Derate</th>
<th>Steam Turbine Derate</th>
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<tbody>
<tr>
<td>PC-F</td>
<td>69%</td>
<td>69%</td>
</tr>
<tr>
<td>NGCC-F</td>
<td>70%</td>
<td>70%</td>
</tr>
<tr>
<td>PC-CS</td>
<td>63%</td>
<td>63%</td>
</tr>
<tr>
<td>NGCC-CS</td>
<td>61%</td>
<td>61%</td>
</tr>
</tbody>
</table>
Bituminous Baseline Revision Comparisons

**Net Plant Efficiency (% HHV)**

- **Rev 2**
  - B11A, Sub PC: 37
  - B11B, Sub PC w/ Cap: 31
  - B12A, Super PC: 33
  - B12B, Super PC w/ Cap: 28
  - B31A, NGCC: 50
  - B31B, NGCC w/ Cap: 46

- **Rev 3**
  - B11A, Sub PC: 39
  - B11B, Sub PC w/ Cap: 41
  - B12A, Super PC: 39
  - B12B, Super PC w/ Cap: 41
  - B31A, NGCC: 52
  - B31B, NGCC w/ Cap: 43

**Total Plant Cost (2011$/kW)**

- **Rev 2**
  - B11A, Sub PC: $3,000
  - B11B, Sub PC w/ Cap: $3,500
  - B12A, Super PC: $2,500
  - B12B, Super PC w/ Cap: $3,000
  - N31A, NGCC: $1,500
  - N31B, NGCC w/ Cap: $1,000

- **Rev 3**
  - B11A, Sub PC: $3,500
  - B11B, Sub PC w/ Cap: $4,000
  - B12A, Super PC: $4,000
  - B12B, Super PC w/ Cap: $4,500
  - N31A, NGCC: $500
  - N31B, NGCC w/ Cap: $0
Bituminous Baseline Revision Comparisons (con’t)

Total COE w/o T&S (2011$/MWh)

<table>
<thead>
<tr>
<th>Plan</th>
<th>Rev 2</th>
<th>Rev 3</th>
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</thead>
<tbody>
<tr>
<td>B11A, Sub PC</td>
<td>82</td>
<td>83</td>
</tr>
<tr>
<td>B11B, Sub PC w/ Cap</td>
<td>142</td>
<td>135</td>
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<tr>
<td>B12A, Super PC</td>
<td>81</td>
<td>83</td>
</tr>
<tr>
<td>B12B, Super PC w/ Cap</td>
<td>137</td>
<td>135</td>
</tr>
<tr>
<td>B31A, NGCC</td>
<td>60</td>
<td>58</td>
</tr>
<tr>
<td>B31B, NGCC w/ Cap</td>
<td>87</td>
<td>83</td>
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</tbody>
</table>

CO₂ Capture Cost w/o T&S (2011$/tonne)

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<thead>
<tr>
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<th>Rev 2</th>
<th>Rev 3</th>
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<tbody>
<tr>
<td>B11B, Sub w/ Cap</td>
<td>55</td>
<td>58</td>
</tr>
<tr>
<td>B12B, Super w/ Cap</td>
<td>56</td>
<td>60</td>
</tr>
<tr>
<td>B31B, NGCC w/ Cap</td>
<td>70</td>
<td>70</td>
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</table>

Capture cost calculated with SC baseline for Coal and NGCC for NG.
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CLEAN COAL RESEARCH PROGRAM (CCRP) GOAL REVIEW
Clean Coal Research Program Goals
Driving Down the COE and Cost of CO₂ Capture of Coal Power with CCS

Cost of Electricity Reduction Targets

<table>
<thead>
<tr>
<th>COE Relative to Today's Coal with Capture, %</th>
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<tbody>
<tr>
<td>110</td>
</tr>
<tr>
<td>100</td>
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<tr>
<td>90</td>
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<tr>
<td>80</td>
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<td>70</td>
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<td>60</td>
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<td>50</td>
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<td>40</td>
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<td>30</td>
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<tr>
<td>20</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>0</td>
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- IGCC or Supercritical PC
- 2nd-Generation Technology
- Transformational Technology

Cost ofCapture, 2011$/tonne CO₂

<table>
<thead>
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<tbody>
<tr>
<td>70</td>
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<td>10</td>
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SOA

2025

2035

Goals shown are for greenfield plants. Costs are nth-of-a-kind, are for the first year of plant operation, and include compression to 2215 psia but exclude CO₂ transport and storage costs. Today's capture costs are relative to Today's SCPC without CO₂ capture. 2025 and 2035 capture costs are relative to an A-USC PC without CO₂ capture.
R&D Driving Down the Cost of CO₂ Capture

Greenfield Post-Combustion Capture Plants

Today's Supercritical PC with Capture ~$60/tonne

Crosscutting Research

2nd-Generation Post-Combustion Capture (Solvents, Sorbents or Membranes) and Adv. Compression

A-USC Steam Cycle

Large-Scale Testing

2nd-Generation Target $40/tonne

Transformational R&D:
- Transformational Post-Combustion Capture (Solvents, Sorbents, Membranes, or Thermal Separation and Multi-contaminant Removal)
- Advanced Power Cycles (i.e. Supercritical CO₂ Cycles)
- Advanced Concepts and Materials

Transformational R&D to Target Cost of Capture <<$40/tonne

Beyond 2025 - Transformational
R&D Driving Down the Cost of CO₂ Capture

**IGCC with Pre-Combustion Capture**

- **Advanced Sorbent, Solvent, Membrane**
- **WGCU, ITM, Dry, High Pressure Feed**
- **Advanced Hydrogen Turbine (2650°F)**

*Today's IGCC with Capture ~$60/tonne*

*2nd-Generation Target $40/tonne*

**Transformational R&D:**
- Transformational Hydrogen Turbine (3100°F, Pressure Gain Combustion)
- ITM/Turbine Integration
- Transformational Hydrogen Production
- Transformational Pre-Combustion Capture

Beyond 2025 - Transformational R&D to Target Cost of Capture <<$40/tonne
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ADVANCED CAPTURE TECHNOLOGY ASSESSMENTS
NETL/OPPB Advanced Capture Ongoing Analyses

• “Current and Future Technologies for Post-Combustion Capture” i.e. PCC Pathway Study
  – Coal – Update to 2011 dollars; preliminary consideration of CO₂ purification
  – NGCC – In progress

• Screening studies (pre- and post-combustion capture)
  – Solvents
  – Sorbents
  – Membranes
  – Internal and external

• R&D Guidance for Post-Combustion Capture Techno-Economic Evaluations
PCC Pathway Study

Objectives & Scope

• Objectives:
  – Develop technology pathways that feature post-combustion CCS-enabled PC plants that achieve DOE goals
  – Utilize the pathway studies to inform technology development through identification of performance and cost targets

• Technologies included:
  – 2nd-generation post-combustion CO₂ capture
  – Adv. Ultrasupercritical (A-USC steam) conditions (5000psig/1350F/1400F)
  – Advanced CO₂ compression

• Scope:
  – Pathway begins with 1st generation supercritical PC plant with today’s post-combustion capture technology
  – Emerging technologies added based on mature stage of development, thus simulating “n-th-of-a-kind” plant performance and cost
  – 2nd-generation post-combustion CO₂ capture and compression cost and performance adjusted to meet program goals
PC with Adv. Membrane – Example to Meet Goals

Key Membrane Parameter Assumptions

- CO₂ and SO₂ Permeance: 3,500 gpu
- N₂, O₂, Ar Permeance: 100 gpu
- H₂O Permeance: 5,000 gpu
- Pressure drop: 1.0 psi (flue gas and sweep sides)
- Vacuum pump achieves 0.2 bar pressure
- Membrane replacement time 5 years
- Membrane surface area: 1,500,000 m²
- Membrane installed cost $127/m²
- Membrane replacement cost $17/m²

<table>
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<th>Adv. Membrane</th>
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The adv. sorbent process requires considerable extraction steam consumption for flue gas heating and for adsorbent regeneration (> 1x10^6 lb/hr) and large BFW makeup treatment system.

The reaction vessels are very large and mechanical adsorbent circulation is used for the large adsorbent circulation rate required (> 31 x 10^6 lb/hr).

**Key Adsorbent Parameter Assumptions**
- Adsorbent: alkalized alumina; 3/8 inch diameter spheres
- Adsorbent cost: $5/lb
- Sorbent CO₂ loading: 3.0%
- Adsorber and regenerator temperature: 140°C
- Adsorber and regenerator pressure drop: 0.4 psi
- Adsorbent entrains 1.0 wt% of inlet N₂, O₂ and water vapor to the regenerator
- Regenerator off-gas: 50 mole % CO₂
- Adsorber-regenerator type: Moving bed
- Adsorbent transport: Bucket conveyor-elevators

**Capture/Compression Impact**

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PCC Pathway Efficiency and Cost of Capture

NOTES:
• Amine-based cases are consistent with NETL Bituminous Baseline Rev. 2 Report
• All membrane and sorbent-based cases utilize enhanced performance and cost parameters
CO₂ Purification

- Purification of the CO₂ product stream will likely be necessary for most end-uses
- Preliminary evaluation of refining CO₂ purification to PCC Pathway cases
  - CO₂ purity prior to purification: 92-97%
  - Impact using external refrigeration cycles
    - Efficiency reduction ~2% points
    - COE increase 8-10%
- Other potential purification options:
  - Auto-refrigeration cycles
  - Membranes
  - Other capture process optimizations

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<tbody>
<tr>
<td>CO₂</td>
</tr>
<tr>
<td>O₂</td>
</tr>
<tr>
<td>H₂O</td>
</tr>
<tr>
<td>N₂, Ar, CH₄, H₂</td>
</tr>
<tr>
<td>CO</td>
</tr>
<tr>
<td>H₂S</td>
</tr>
<tr>
<td>SO₂</td>
</tr>
<tr>
<td>...etc.</td>
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Current and Future Technologies for Post-Combustion Capture: NGCC

- **Objective:** Evaluate impact of advanced CO$_2$ capture technologies in an NGCC plant
- **Preliminary conclusions:**
  - Sorbents and membranes more sensitive to lower CO$_2$ concentration of NGCC flue gas (~4% vs. ~14% for PC) than solvents
  - Exhaust gas recirculation (EGR) key to increase CO$_2$ concentration in flue gas for sorbents and membranes
Advanced Capture Technology Screening Studies

- **Post-combustion capture solvents:**
  - Model/predict process improvements that are applicable to many capture technologies:
    - L/R exchanger temperature approach
    - CO₂ Stripper regen pressure
    - Advanced heat integration schemes
  - Forecast potential of combining advanced capture technologies with advanced processes

- **Pairing of post-combustion capture technologies**
  - e.g. solvents and membranes

- **Pre-combustion capture sorbents/membranes:**
  - Pairing with advanced gas cleanup systems and CO₂ purification systems

- **NETL may contact you with requests for details about your project (i.e., design and/or performance aspects)**
QUESTIONS?