Design and costing of ION’s CO₂ capture plant retrofitted to a 700 MW coal-fired power plant

2021 NETL CO₂ Capture Technology Project Review Meeting
August 3, 2021

Project: Commercial Carbon Capture Design and Costing: Part 2 (C3DC2) - DE-FE0031840
Andy Awtry, Ph.D. – VP Engineering
ION Clean Energy, Boulder, CO, USA
ION’s CO₂ Capture Technology Development

Accelerated development path leveraging existing research facilities
ION Technology Overview

• Proprietary Solvent-based Technology
  – Liquid absorbent-based capture
  – Low aqueous
  – Worldwide Patents

• Established Engineering Process
  – Learnings from Boundary Dam
  – Learnings from Petra Nova

• Basis of Performance
  – Fast kinetics (on par or faster than MEA)
  – Working capacity (higher than MEA)
  – Low heat capacity (much lower than MEA)
  – < 1,090 Btu/lb CO₂ (2.5 MJ/kg CO₂)
ION Technology Overview

Value Added

• High Capture Efficiency
  – Up to 96% CO₂ Capture

• Design System for CAPEX/OPEX savings
  – Smaller absorber column(s) vs higher carrying capacity
  – Pumps/HEXs are smaller due to lower liquid flow rates

• Low regeneration energy requirement
  – Low parasitic load
  – Low steam demand – reduction in plant de-rate if integrated into the steam cycle

• Demonstrated lower corrosion rates than MEA

• Demonstrated lower total emission rates than MEA
Nebraska Public Power District

Host Site – Gerald Gentleman Station

- Located in Sutherland, Nebraska
- Largest generating station in Nebraska
- Two units with total capacity of 1,365 MW
  - Unit 1 – 1979 – 665 MW
  - Unit 2 – 1982 – 700 MW
- Burns Powder River Basin Coal
Objective: Retrofit a Carbon Capture System at a power station

- Nebraska Public Power District’s (NPPD) Gerald Gentleman Station (GGS)
- 300 MWe Slipstream for carbon capture
- Ownership model: NPPD owns and operates the capture island
- Design Basis: CO₂ product for enhanced oil recovery (not regulatory driven)

Class 3 (AACE) Cost Estimate

- Cost Estimate is -20% to +30%
- Completed about 20% of Engineering Effort

Completed 18mo Project in Q4 of 2019
## Commercial Carbon Capture Design & Costing Study

<table>
<thead>
<tr>
<th>Value</th>
<th>Units</th>
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<tbody>
<tr>
<td>Slipstream</td>
<td>300 MWe</td>
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<tr>
<td>EPC Capital Cost</td>
<td>$438,000,000</td>
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<tr>
<td>Loan Term</td>
<td>20 years</td>
</tr>
<tr>
<td>Interest Rate</td>
<td>4.5%</td>
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<tr>
<td>Total OPEX</td>
<td>$28,200,000</td>
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<tr>
<td>Total Annual Cost</td>
<td>$61,800,000</td>
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<tr>
<td>Total Annual CO₂ Production CF</td>
<td>1,900,000 tonne/yr</td>
</tr>
<tr>
<td>Cost of CO₂ Capture</td>
<td>$32.50</td>
</tr>
</tbody>
</table>

**Total Annual CO₂ Production CF:** 1,900,000 tonne/yr

**Cost of CO₂ Capture:** $32.50/tonne
COMMERCIAL CARBON CAPTURE DESIGN & COSTING STUDY: PART 2

DE-FE0031840
Commercial Carbon Capture Design & Costing Study: Part 2
(C3DC2) DE-FE0031840

• Retrofit a Carbon Capture System at an existing power station
  – Nebraska Public Power District’s (NPPD) Gerald Gentleman Station (GGS)
  – 700 MWe carbon capture system (2x 350 MWe trains)
  – Ownership model: Capture System is 3rd Party Owned and Operated
  – Design Basis: CO₂ product for EOR (not regulatory driven)

• Class 2 (AACE) Capital Cost Estimate
  – Estimate Accuracy Range: -15% to +20%
  – Complete about 50-60% of Engineering Effort

• 18-month project; to be completed in Q1 of 2021

• $5.8M project budget
  – $4.6M DOE-NETL
  – $1.2M ION & Partners
C3DC2 Study
Project Team and Roles

ION Clean Energy
- Technology Developer
- Process Design and Project Management

Nebraska Public Power District
- Host Site (GGS)
- Power Generation Engineering, Operational and Financial Expertise

Sargent and Lundy
- Balance of Plant (BOP) Engineering
- Overall Cost Estimate Development
- Constructability Review
- Construction Cost Estimating

Koch Modular Process System
- Carbon Capture pilot experience and expertise
- Capture Process Oversight, Design and Costing

Siemens
- Compressor Vendor
ProTreat® Process Model

ION CO₂ Capture Process

Key features of ION process compared to ‘common’ MEA-designed plant

- Cold-Rich By-pass
- Optimized lean rich cross exchanger (LRXO) design
- Caustic addition to DCC to act as SOₓ Polishing Scrubber
- Compressor Selection

ProTreat output provides stream tables, key performance indices, and steam, cooling and electrical duties
System Design
700MWe CO₂ Capture Plant

• Capture System Design
  – 2x 50% trains for the Capture Island
  – 2x 50% on major pieces of equipment to assist in turndown and provide some risk mitigation
  – Designed for operation at full load, and track plant load to maximum turndown
  – Designed for 90% capture of CO₂; resulting in >95% capture at turndown

• BOP Design
  – Steam sourcing from GGS2 steam cycle
  – Cooling water from a hybrid system
Bioenergy w/ Carbon Capture & Sequestration (BECCS)
700MWe (4.3M TPA) CO₂ Capture Plant

• Overall cost evaluation for potential net zero and net negative emissions

• Engineering Design
  – Biofuel Sourcing
    • Corn Stover vs Eastern Red Cedar
    • Pellets vs Bales
  – Gasifier Design
    • Design for 10-15% coal offset
    • Evaluate boiler performance
  – Balance of Plant Design
  – Evaluation of capture performance on the existing CO₂ capture process design
Bioenergy w/ Carbon Capture & Sequestration (BECCS)

BECCS General Arrangement Drawing

- Corn Stover Pellets delivered by truck
- Gasifier converts pellets to syngas
- Boiler mods and resulting flue gas by B&W
**Bioenergy w/ Carbon Capture & Sequestration (BECCS)**

*Flue Gas Comparison and CCS Performance*

- Max Design is the Base Design Case, assuming full load of the power plant
- BECCS case replaces 10% of the coal with the syngas from the gasifier
  - 5.5% reduction in CO$_2$ flow to the capture island
  - Increase in capture efficiency to 93.3% (holding steam consumption constant)
  - 1.6% reduction in CO$_2$ product flow
  - Reduced CO$_2$ by 98% relative to coal emissions
  - CO$_2$ reduction >100% with 10% increase in packing and 23% more plates in LRXC

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Max Design Value</th>
<th>BECCS (Corn Stover)</th>
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<tbody>
<tr>
<td><strong>DCC Inlet Conditions (1x50% train)</strong></td>
<td></td>
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<tr>
<td>Temperature</td>
<td>°F</td>
<td>145</td>
<td>144</td>
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<tr>
<td>Pressure</td>
<td>psia</td>
<td>13.75</td>
<td>13.75</td>
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<tr>
<td>O$_2$ Concentration</td>
<td>vol %</td>
<td>4.34</td>
<td>5.43</td>
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<tr>
<td>CO$_2$ Rate</td>
<td>vol %</td>
<td>11.5</td>
<td>10.78</td>
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<tr>
<td>Flue Gas Flowrate</td>
<td>acfm</td>
<td>1,107,000</td>
<td>1,114,000</td>
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<tr>
<td></td>
<td>lb/hr</td>
<td>3,973,000</td>
<td>4,003,000</td>
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<tr>
<td><strong>CO$_2$ Capture Performance (1x50% train)</strong></td>
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<tr>
<td>Capture Efficiency</td>
<td>%</td>
<td>90</td>
<td>93</td>
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<tr>
<td>CO$_2$ Captured</td>
<td>lb/hr</td>
<td>638,000</td>
<td>628,000</td>
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<tr>
<td>L/G</td>
<td>lb/lb</td>
<td>1.93</td>
<td>1.81</td>
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<td>Electrical Duty</td>
<td>kW</td>
<td>31,900</td>
<td>31,700</td>
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<td>SRD</td>
<td>MJ/kg CO$_2$</td>
<td>2.51</td>
<td>2.55</td>
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<tr>
<td>Steam Consumption</td>
<td>lb/hr</td>
<td>765,100</td>
<td>765,100</td>
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Cost of CO₂ Capture

**Costing Basis**

- Designed to produce a reliable CO₂ product stream for EOR/Sequestration; not regulatory driven CO₂ capture
- Used historical data for the unit to model cumulative captured CO₂ based on observed power plant load factor, capture plant uptime, and ambient conditions
- Calculated the cost with and without the additional flue gas pre-conditioning to isolate the cost of CO₂ capture for comparison to sites that may already have this equipment
- BECCS evaluation was performed as a sensitivity study and its incremental capital and operating expenses are separate
- 3rd Party Ownership impact on overall costing being further investigated

<table>
<thead>
<tr>
<th></th>
<th>C3DC1 Results (300 MWe)</th>
<th>C3DC2 Results (700 MWe)</th>
<th>Cooling System Selection Sensitivity</th>
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<tr>
<td>Total CAPEX</td>
<td>$437,500,000</td>
<td>$1,172,900,000</td>
<td>-$140,300,000</td>
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<td>Annualized CAPEX</td>
<td>$33,600,000</td>
<td>$90,200,000</td>
<td>-$10,800,000</td>
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<td>OPEX</td>
<td>$28,200,000</td>
<td>$60,700,000</td>
<td>-$4,100,000</td>
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<td>Annual Cost</td>
<td>$61,800,000</td>
<td>$150,900,000</td>
<td>-$14,900,000</td>
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<td>CO₂ Product</td>
<td>1,900,000</td>
<td>4,310,000</td>
<td>4,310,000</td>
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<tr>
<td>Cost of Capture</td>
<td>$32.53</td>
<td>$35.01</td>
<td>-$3.46</td>
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Acknowledgement and Disclaimer

**Acknowledgement**

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Thanks
C3DC2 Team:
ION, NPPD, S&L, KMPS, Siemens

BECCS TEAM:
Trestle Energy, Frontline BioEnergy, Babcock & Wilcox

Department of Energy:
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<tr>
<th>#</th>
<th>Task</th>
<th>Milestone Title / Description</th>
<th>Completion Date</th>
<th>Verification Method</th>
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<tr>
<td>M1</td>
<td>1.0</td>
<td>DOE Kickoff Meeting</td>
<td>12/5/2019</td>
<td>Meeting Held</td>
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<td>M2</td>
<td>1.0</td>
<td>Updated PMP</td>
<td>11/7/2019</td>
<td>PMP Transmitted to DOE</td>
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<td>M3</td>
<td>2.0</td>
<td>Basis of Design for Project Finalized</td>
<td>1/10/2019</td>
<td>Meeting Held w/ Results Project SharePoint Site; Completion Memo to DOE</td>
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<td>M4</td>
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<td>Preliminary Design Review Complete</td>
<td>3/30/2020</td>
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<td>M5</td>
<td>4.0</td>
<td>Critical Design Review Complete</td>
<td>9/30/2020</td>
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<td>M6</td>
<td>5.4</td>
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<td>M7</td>
<td>6.0</td>
<td>Overall Cost Estimate and Cost of Capture</td>
<td>1/12/2021</td>
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<td>M10</td>
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<td>BioMass Co-firing BOP Design</td>
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<td>M8</td>
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<td>Front-End Engineering Design (FEED) Report</td>
<td>9/1/2021</td>
<td>Report Delivered to DOE/NETL</td>
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<tr>
<td>M9</td>
<td>7.0</td>
<td>Final DOE Report &amp; Presentation</td>
<td>9/30/2021</td>
<td>Report Delivered to DOE/NETL</td>
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# Commercial Carbon Capture Design & Costing Study: Part 2

*(C3DC2) DE-FE0031840*

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<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
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<tr>
<td>1. C3DC2 Project - FEED Study</td>
<td>526 days</td>
<td>Mon 9/2/19</td>
<td>Thu 9/30/21</td>
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<td>2. 1.0 Project Management and Planning</td>
<td>460 days</td>
<td>Mon 9/2/19</td>
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<td>20. 2.0 Overall Project Design Basis</td>
<td>361 days</td>
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<td>51. 3.0 Process Design - CO2 Capture Island Design</td>
<td>290 days</td>
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<td>52. Preliminary Design - CO2 Capture Island</td>
<td>254 days</td>
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<td>103. M4: Preliminary Design Review</td>
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<td>104. Detailed Design - CO2 Capture Island</td>
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<td>137. Detailed Design - Integration and BOP</td>
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<td>384. BECCS - Biomass Co-firing</td>
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<td>430. 5.0 Studies and Investigation</td>
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<td>Fri 7/23/21</td>
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<td>540. 6.0 Cost Estimate</td>
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