Transformational Sorbent-Based Process for a Substantial Reduction in the Cost of CO$_2$ Capture (DE-FE0031722)

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U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 - 19, 2022
Executive Summary

• CO₂ Capture with physical sorbents with low heats of sorption (~0.8 GJ/MT)
  — High purity CO₂ (>98%) at high recovery (>90-95%),
    • Up to 99% recovery possible with some process modifications
  — The absolute energy requirement (excluding compression) of 1.6-1.8 GJ/MT of CO₂, needed at about 110°C
    • Absolute energy requirement is 40% lower than Shell Cansolv and 57% lower than MEA
    • The relative energy requirement, based on lost work analysis, is 66% lower than Shell Cansolv and 73% lower than MEA assuming 160°C steam extraction temperature for amines
  • Significantly lower capital (>45% reduction), and parasitic power (>45% reduction) leading to >45% lower capture cost
    — <$30/MT capture cost for pipeline quality CO₂
  • Lab scale testing, process simulation, and a preliminary TEA during BP1; bench scale testing at TCM and a final TEA during BP2
The DOE Project (FE0031722)

- Objectives: >90% CO$_2$ recovery, >95% purity with a potential pathway for <$30/MT capture cost by 2030
- The total project budget is U.S. $4 million ($3.13 MM DOE, $0.87 MM match including significant match from TCM)
- In the first budget period (May 2019 to March 2021) we
  - Optimized the sorbent and the regeneration process through lab testing, Monte Carlo simulations, and process simulation
  - Did a detailed design and costing of the bench unit, a preliminary TEA, and a HAZOP addressing TCM integration issues
- In the second budget period (April 2021 to Dec 2022) we are
  - Constructing a field test unit (500 Nm$^3$/hr scale)
  - Will carry out testing at TCM, a detailed engineering design, and a Rev 4 techno-economic evaluation for a commercial scale unit (550 MW power plant)
Project Participants

DOE/NETL
• Project oversight, feedback, funding (Project Manager: Mariah Richardson)

InnoSepra
• Technology development at lab and bench scale, coordinate with partners, project management and reporting

Main Line Engineering
• Engineering design of the full scale plant, TEA, cost share

TCM
• Field testing, commercial feedback and cost share

Adroitech
• Monte Carlo Simulation, fabrication of structured sorbents

Adsorptech / Fabrication Partners
• Bench unit design and fabrication, cost share
Flue gas pretreatment for NO\(_2\) and SO\(_X\) removal to sub-ppm levels, removal of substantial amounts of aerosols, and moisture removal to ppm levels

- NO\(_2\), SO\(_X\) and aerosol removal demonstrated at pilot scale; applicable to solvent capture

Physical sorbents with a very high surface area (>10 million m\(^2\)/m\(^3\)), low heats of adsorption (0.8 GJ/MT of CO\(_2\))

- Adsorption at 25-40\(^\circ\)C, regeneration at 90-110\(^\circ\)C, high net CO\(_2\) capacity (>8-wt%)
- Pipeline quality CO\(_2\) (>98% purity, <1 ppm H\(_2\)O and SO\(_X\), <10-ppm O\(_2\)), >90% recovery

Key innovation is **the novel combination** of process, sorbent regeneration and materials leading to >45% reduction in parasitic power

- Performance similar to or better than amines, much lower regeneration energy requirement
Field Demonstration of First Generation CO₂ Capture Process

- NRG’s Indian River, DE coal fired power plant, more than 8 weeks of testing
- 80-100 scfm flue gas, 22-32°C feed, 50-ppm SO₂, 10-12% CO₂
- 8-10.5 wt% net CO₂ capacity in the field
- >94% CO₂ recovery, 98.5-99.5% CO₂ purities, pipeline / EOR quality gas (<10 ppm oxygen and moisture)
- Flue gas purification demonstrated at the Abbott power plant (800 scfm)
Second Generation InnoSepra Process

• A breakthrough regeneration method has allowed reduction in the absolute energy requirement to 1.6-1.8 GJ/MT (based on lab testing and process simulation) at about 110°C
  — The process is also simpler, significant capital savings over the first generation process
• Effective parasitic load of 0.96 GJ/MT based on a steam extraction temperature of 160°C (74 psia) for MEA and Cansolv
  — About 67% lower than Cansolv, and about 73% lower than MEA
  — Less than 16% of plant’s output for CO₂ capture and compression
• The technology is to be demonstrated at the bench scale at TCM (Technology Centre Mongstad) in 2022
Technical Approach

Experimental Design and Work Plan

• The Work Plan for BP1 involved
  • Identification of suitable materials based on lab testing and Monte Carlo simulations
  • Testing the materials in a lab scale unit for purity and recovery
  • Process simulation to estimate the energy requirements and equipment sizing
  • A techno-economic analysis to estimate the capital cost and the CO$_2$ capture cost

• The Work Plan for BP2 involves
  • Bench unit fabrication, HAZOP, shipping and installation
  • Testing at TCM with simulated SCPC flue gas as a function of flow rate, feed temperature, and regeneration temperature
  • Process simulation to update the energy requirements and equipment sizing
  • A final techno-economic analysis to estimate the capital cost and the CO$_2$ capture cost
Technical Approach

Key Milestones

• Identification of suitable materials with at least 6-wt% capacity for >95% purity
• Process model completion and initial techno-economic analysis
• Detailed bench unit design, costing and HAZOP
• Bench unit fabrication, shipping & installation, and testing
• Detailed engineering design for a 550 MW SCPC plant
• Final TEA with Rev 4 guidelines to determine potential capture cost

Project Success Plan

• Thermal requirements below 1.8 GJ/MT and a capture cost below $40/MT based on lab testing & simulation
• Thermal requirements below 1.8 GJ/MT and a capture cost below $40/MT based on field testing & detailed engineering design

Project Risks and Mitigation Strategies

• The key risks include resource availability, and sorbent regeneration. Back up resources and regeneration approaches have been identified.
Key Activities for BP1

- Monte Carlo simulations to identify the suitable sorbents
  - Sorbent structure variation can provide absolute CO₂ capacities (15% CO₂ at 25°C) between 18-wt% (CO₂-N₂ separation factors of 15-20), and 12-wt% (CO₂-N₂ separation factor over 200)
  - Confirmed through microbalance and breakthrough testing
- The regeneration process was optimized through cyclic testing
  - No loss in performance after multiple cycles, >8-wt% net CO₂ capacity
- Process simulation, integration with the host site, preliminary TEA
  - A detailed process simulation confirmed a power penalty of <16% of plant’s output
  - A new CO₂ compression cycle for up to 20% reduction in energy needed for CO₂ compression
  - A detailed HAZOP and test site integration with TCM
  - A preliminary TEA indicating the potential for a capture cost of about $30/MT
Identification of Suitable Materials

• A number of materials were identified based on Monte Carlo simulations and tested in the adsorption microbalance for CO$_2$ and N$_2$ capacities, and CO$_2$-N$_2$ separation

• A typical CO$_2$ isotherm (30$^\circ$C, Micromeritics ASAP 2020) is shown below

![Graph showing CO$_2$ isotherm](image)

• Depending on the material structure CO$_2$ capacities between 12-wt% and 18-wt%, separation factors between 15 and 650 can be obtained
  • High separation factors are associated with low CO$_2$ capacities
Process Simulation Summary (Retrofit)

- Simulation of the CO$_2$ capture plant integrated with the coal-fired power plant with Aveva’s ProII software
- The feed and product conditions (for a 550 MW SCPC plant) are:
  - Flue gas: 74,092 kmol/hr, 57$^\circ$C, 100 kPa, 68.1% N$_2$, 13.5% CO$_2$, 15.2% water
  - Product CO$_2$: 9,517 kmol/hr, 99% CO$_2$, 15,270 kPa
- Energy required for CO$_2$ capture and compression
  - Pumps, blowers and compressors: 54.8 MW
  - Lost electrical output in LP turbine: 24.2 MW
  - Total loss in electrical output: 79 MW
  - Electrical output loss as a percent of total output: 14.4%
- Very significant operational flexibility
  - Five capture modules for a 10,000 MTD plant
  - Continuous operation between 10 and 100% of design is possible
### Techno-Economic Evaluation Summary (Retrofit)

550 MW SCPC Power Plant, 2.86 MM MT/year of CO₂ Captured*

<table>
<thead>
<tr>
<th></th>
<th>Shell Cansolv</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Generation InnoSepra Process</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Generation InnoSepra Process</th>
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<td>Indicative TOC, U.S.$MM</td>
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<td>561</td>
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<td>Power Loss Due to Steam Extraction, MW</td>
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<td>Electrical Power (compression, auxiliaries), MW</td>
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<td>Total Power Loss, MW</td>
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<td>Power Loss as % of Base Output</td>
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<td>18</td>
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<td>CO₂ Capture Cost at the plant gate, $/tonne</td>
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<td>41</td>
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<tr>
<td>CO₂ Capture Cost including TS&amp;M, $/tonne</td>
<td>67</td>
<td>46</td>
<td>39</td>
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</table>

- 10% capital recovery factor + 2.5% maintenance charge (7% CRF in 2019 Baseline Report), $64/MWh replacement power, 85% on stream factor
- A capture cost of $29/MT for the 2<sup>nd</sup> generation InnoSepra Process with a CRF of 7%
- Higher capture rate, ~95%, for the InnoSepra Process not accounted for in the calcs
Key Activities for BP2

- Skid design and testing, field test report and updated TEA
- Most of the effort focused on bench unit fabrication including lab tests in support of skid design
  - Capable of processing 500 nm$^3$/hr of flue gas
  - Being designed as three separate skids
  - Skid 1 for feed preparation and drying
  - Skid 2 for CO$_2$ adsorption and regeneration
  - Skid 3 for regeneration
  - Each skid is about 8’ w x 10’ H and 25’ L, about 12,000 lbs each
  - Very significant challenges due to fabrication resources, engineering resources, supply chain constraints leading to project delays

- Bench Unit Status
  - All the major components procured and sent to the fabricators
  - Skid 1 nearing completion
  - Work started on Skid 2 piping and vessels
  - Detailed design for Skid 3 completed
Process Flow Diagram for the Bench Unit

1. Flue Gas Feed
2. T-101 Condensate Separator
3. KV100
4. T-102 Feed Blower
5. C-100 Purification Bed
6. HE-103 DCC
7. HE-104 Regeneration Heater (Electric)
8. HE-304 Regenerant
9. HE-306 Heat Exchanger
10. D-201A Dryer
11. D-201B Dryer
12. D-202A Adsorber
13. D-202B Adsorber
14. VP-303 Vacuum Pump
15. VP Suction KO Drum
16. P-105 To Seawater Return Line
17. To Flue Gas Duct
18. To Vaccum Pump
19. To Seawater Return Line
20. To Duct
Layout of InnoSepra Skid #1

Purification and drying section.
Layout of InnoSepra Skid #2

Adsorption section
Layout of InnoSepra Skid #3
Plan for Future Testing / Commercializations

• Need one intermediate scale up after TCM testing to build commercial scale CO$_2$ capture plants

Steps toward technology commercialization

• FEED study for a 550-650 MW SCPC plant after the completion and analysis of field test results

• Further process demonstration at ~100 tonnes per day scale
  — 25X scale up over the TCM pilot

• Once the process has been demonstrated at 100 tonnes per day scale
  — 1,000-2,500 tonnes per day CO$_2$ capture plants can be built with high degree of confidence
InnoSepra – TCM
interface and utilities

Image of TCM test bay for emerging technologies

- catching our future
The flue gas - RFCC

<table>
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<tr>
<th>Component</th>
<th>Unit</th>
<th>Value</th>
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<td>CO$_2$</td>
<td>mol%</td>
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<tr>
<td>SO$_x$</td>
<td>ppmv</td>
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<tr>
<td>NO$_x$</td>
<td>ppmv</td>
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<tr>
<td>Particles</td>
<td>mg/Sm$^3$</td>
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InnoSepra - Solid Sorbent CO$_2$ Capture

1. Filtered RFCC flue gas enters the InnoSepra unit
2. Pre-treatment
   - NO$_2$ & SO$_x$ removal
3. Capture
   - Drying and capture
4. Depleted flue gas and CO$_2$ product is combined and transported to stack

3D model of temporary linear design at TCM
Summary

• The InnoSepra CO₂ capture technology, based on physical sorbents, has the potential for a significant reduction in the CO₂ capture cost for the power plant and industrial flue gases.

• During BP1 (based on lab testing & process simulation), InnoSepra demonstrated the potential of the technology to obtain 90-95% recovery and >98% purity CO₂ with >45% lower capture cost compared to solvent-based processes.

• During BP2, InnoSepra will demonstrate the technology at the Technology Centre Mongstad and use the test data along with process simulation and a TEA to evaluate the technology’s potential for the reduction in parasitic power and capture cost.

• If the lab results are validated during field testing the InnoSepra technology would represent a viable pathway for decarbonizing power and industrial sectors with a significantly lower green premium compared to solvent-based technologies.
Project Organization Chart

Steering Team
- Mariah Richardson, DOE
- Freddy Garcia, TCM
- Ravi Jain, InnoSepra

DOE Proj Manager
- Mariah Richardson

Principal Investigator
- Dr. Ravi Jain

Technical Project Management
- Mr. Robert Ferrell

Financial & Reporting Management
- InnoSepra

Techno-Economic Analysis
- MLEA

Installation & Testing
- TCM/InnoSepra

Process Design
- Adsorptech/Plant Process

Adsorption Modeling
- InnoSepra

Adsorption Data
- Adroitech/InnoSepra

All Technical & Financial Reports
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<th>Duration</th>
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<td>Project Management &amp; Planning</td>
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<td>4</td>
<td>Milestone 1: Complete Update of Project Management Plan</td>
<td>1 day</td>
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<td>5</td>
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<td>6</td>
<td>BP 1: Materials Selection, Lab Testing, Initial TEA, Bench Unit Design</td>
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<td>Identification of Suitable Materials for Lab Tests</td>
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**Project: Release 9.0**

**Date: Fri 2/11/22**
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