Engineering-scale test of a water-lean solvent for post-combustion capture DE-FE0031945

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Project Overview

Organiz

ations

| DOE PM | Dustin Brown | า | Modified dates & budget, pending approval |
|-------------------|--------------------------------|---|--|
| Project period | October 202 | 0 to March 2024 | <i>to June 2025</i> |
| Funding | Federal Cost share Total | \$4,129,607 \$1,032,411 \$5.162.018 | \$5,028,677 \$1,257,169 \$6.285.846 |

Electric Power Research Institute

Pacific Northwest National Lab.

Paul M. Mathias Consulting, LLC

Southern Company Services (NCCC)

RTI International

Gradient

Worley

2025 677 169 \$6,285,846 capture.

Objective – Perform extended test campaigns on coal and natural gas flue gases with the EEMPA solvent operating at the ~0.5 MWe-equivalent scale for both coal and gas to verify its favorable performance characteristics while evaluating the environmental, health and safety (EH&S) risks of the technology and quantifying its potential to lower the cost of CO₂



N-(2-ethoxyethyl)-3-morpholinopropan-1-amine

or



Overview of EEMPA's characteristics

Strengths

- Single-component, miscible in water
- Low viscosity gain upon reaction with CO₂
- Low surface tension
- Compatible with potentially cheaper materials of construction (e.g., plastics)
- Low corrosivity
- Good thermal and chemical stability
- Potential for advanced heat integration and regeneration steps that could save costs (e.g., flash regeneration)

Challenges

- Solvent is presently costly to produce, and largescale production yet to be demonstrated
- Imposes need for careful control of the process water balance

EEMPA has several characteristics that make it a promising post-combustion capture solvent



EEMPA's chemistry helps lead to the potential for low specific reboiler duties



- Spectroscopic and computational evidence point to enthalpically favored formation of EEMPA tetramers.
- Current hypothesis: denaturing of these tetramers leads to observed changes in heat of solution.¹
- SRDs as low as 2.0 GJ/t CO₂ have been observed in lab experiments.² Cost-optimal designs for coal flue gas achieve 2.34 GJ/t CO₂ captured.³



Courtesy of PNNL

This figure shows the heat of solution of CO_2 absorbing into dry EEMPA as a function of loading and temperature. At fixed loading, the heat of solution decreases with increasing temperature.

- 1. Heldebrant et al. (2023), *In review*.
- 2. Zheng et al., Energy. Environ. Sci. (2020), 13, 4106-4113.
- 3. Jiang et al., IJGHGC, (2021), 106, 103279.



EEMPA may capture benefits from the use of plastics

- EEMPA is chemically compatible with a range of polymer materials, including polyolefins like polypropylene
- EEMPA exhibits a low surface tension (see right) an ability to wet many of these materials
- Potential benefits include...
 - Capital cost savings through cheaper absorber packing
 - Lower degradation rates by eliminating a source of metal ions that might catalyze particular degradation pathways
 - Enhancement of mass transfer characteristics through favorable solvent-packing interaction



Courtesy of PNNL

Plot of observed surface tension vs. temperature for EEMPA and other solvents. EEMPA exhibits a significantly lower surface tension than monoethanolamine.

Grubel et al. In preparation.



Scope for an engineering-scale test

- Develop a route to produce larger volumes of EEMPA at lower cost
- Plan a test using the Pilot Solvent Test Unit (PSTU) at the National Carbon Capture Center
- Modify PSTU equipment to accommodate EEMPA
- Manufacture the required quantity of solvent
- Run test campaigns on coal and natural gas flue gases
- Conduct a final TEA and environmental, health, and safety (EH&S) risk assessment



Image courtesy of Southern Company Services

Establishing alternatives for synthesizing EEMPA

Objectives

 Develop alternatives to the single-step established route, which reacts 4morpholinopropyl amine (MPA) with 2bromoethyl ethyl ether (2-BEEE) to yield EEPMA.



- 2-BEEE must be shipped under refrigeration, adding substantially to its procurement cost and logistics.
- Evaluate the most promising alternatives for the potential to achieve a \$10/kg cost target.

Outcomes

- Several promising alternatives were identified using less expensive, widely available feedstocks.
- At present pricing for the scale required for this project (7.5 t), further development is required to translate the best alternatives to larger scales and achieve potential cost reductions.

Highest readiness synthesis routes considered



Setup process for larger-scale synthesis

Objectives

- Test larger batches of most promising routes to confirm yields
- Determine feedstock availability and pricing at toll manufacturing scale
- Identify toll manufacturers and evaluate quotes for manufacturing 7.5 t (about 2,000 gallons) of EEMPA.

Outcomes

- We solicited quotes from multiple toll manufacturers. Due to extra steps and lower level of development, the best alternative was quoted at higher cost than the original route.
- 2-BEEE has become ~3 times more expensive than during the proposal phase.
- The team has selected a manufacturer and quote based on the established route.

Planning for NCCC testing development

- Developed Aspen Plus models for coal and NGCC-like flue gas scenarios for the PSTU with the EEMPA property models
- An initial evaluation of the cooling needs to achieve the desired water balance in PSTU was performed (see right).

Modeled cooling duties required to achieve target dew points for natural gas and coal conditions

| | | NGCC conditions | Coal conditions |
|--------------------------------------|-----------------------|-----------------|------------------------|
| Starting temperature range | °F | 110-130 | 110-180 |
| Target absorber inlet temperature | °F | 68.0 | 60.5 |
| Total duty | Btu/hr | 148,800-158,400 | 339,600-373,200 |
| | tons of refrigeration | 12.4-13.2 | 28.3-31.1 |

Equipment engineering and cost

- Further evaluation helped determine two key areas for modification of the PSTU to achieve target performance:
 - Enhancing cooling of the flue gas using both the pre-scrubber and cooler/condenser column
 - Using a larger reboiler to supply sufficient heat transfer area for the needed duty.
- Cooling the flue gas
 - New exchanger will be added to cool the prescrubber
 - Chilled water will be provided to both this exchanger and the existing cooler/condenser exchanger.

- Reboiler enhancement
 - A new steam heater will be installed along with a forced circulation pump to provide the required heating duty.
 - A larger exchanger is required compared to the existing reboiler due to lower thermal conductivity of the solvent compared to aqueous solvents.

EPC



Courtesy of Southern Company Services







Courtesy of Southern Company Services









Courtesy of Southern Company Services



Design of engineering-scale test

Plastic packing

- Different packing manufacturers were interviewed to determine different options.
- A polypropylene packing comparable to the existing PSTU was selected.
- The current plan is to conduct testing with both the current packing and plastic to help provide a comparison.

Safety

- A Safety Data Sheet for EEMPA has been compiled using the expected composition based on the chosen synthesis route. A look-across analysis was performed
- HAZOP/DHR exercise was performed 6/29. One safety related issue was identified and a preliminary mitigation proposed.

EPC

18

Next project phases

Budget Period 2

- Manufacture ≈2,000 gallons of EEMPA
- Make modifications to the PSTU to support EEMPA's testing
 - Chiller loop installation
 - Regenerator enhancements
- Develop a comprehensive test plan
 - Working with CCSI2 to develop a structured test plan using sequential design of experiments to help achieve

Budget Period 3

- Commissioning and parametric testing
- Testing with metal packing
- Testing with plastic packing
- Testing flue gas campaigns for both natural gas and coal flue gas
- Project final techno-economic analysis
- Project final environmental health and safety analysis

Key Points

Solvent synthesis

Found multiple potential synthesis routes, but moving forward with the existing route to protect the project schedule to the greatest extent possible.

Test engineering

Developed a plan to modify the PSTU. Moving forward on implementing that plan.

Next steps

Moving toward a start of testing in early 2024.

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Project organization chart with key personnel





Gantt chart

| _ | Task Name | Start Hinish | Quer 1, 2021 Quer 2, 2021 Quer 3, 2021 Quer 4, 2021 Quer 1, 2022 Quer 2, 2022 Quer 4, 2022 Quer 4, 2022 Quer 4, 2023 Quer 4, 2023 Quer 4, 2023 Quer 4, 2024 Quer 2, 2024 Quer 3, 2024 Quer 4, 2024 Quer 4, 2024 Quer 4, 2025 Quer 3, 2025 Quer 4, 2024 |
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| 2 | Project management and planning Project Management Plan under er | Fri 1/29/21 Man 6/30/ | |
| 3 | Revised PMP provided to DOE/NEIL | Sun 2/28/2 Sun 2/28/2 | MI . |
| 4 | Technology Maturation Plan | Man 2/1/2 Fri 4/30/21 | |
| 5 | Initial Techno-economic analysis and | Man Fri 4/30/21 | |
| £ | BH&S review Then initial TTA and initial TTAC | 2/1/21 | |
| 0 | assessment delivered to DOF/NETL | məy30y21 məy30y21 | |
| 7 | Scale-up of solvent production | Mon 2/1/2 Sun 4/30/2 | |
| 8 | Determine best synthesis route for larg | ar Mon Tue | |
| 9 | Synthesis route developed that can me | st Wed Wed | M3 • |
| | \$10/kg cost target with expected reag | nt 2/15/23 2/15/23 | |
| 10 | and manufacturing costs. Setun micross for larger-scale synthesis | Thu 7/1/21 Sun 4/30/2 | |
| 11 | Toll manufacturer identified. Cost and | Fri 3/31/23 Fri 3/31/23 | M4 + |
| | availability of reagents verified to mee | | |
| 12 | Design of Engineering Scale Test Funione | nt Thu 4/1/21 Fri 3/81/23 | |
| 13 | Adapt models to evaluate test design | Thu 4/1/21 Fri 3/31/23 | |
| 14 | Design and specify equipment | Thu 7/1/21 Fri 3/31/23 | |
| 15 | Develop construction cost and plan | Wed 9/1/21Fri 3/31/23 | |
| 16 | Models developed to assist in the engineering of the test eminancet | Tue Tue 2/28/23 ว./วค./ว.ว | NC + |
| | Engineering on the desired equipment selection | 420/23 2/20/23 | |
| | completed. Plan for procurement and | | |
| | project budget. | | |
| 17 | Host site planning | The 4/1/21 The 18/31/ | |
| 18 | Conduct design hazard review | Thu 4/1/21 Fri 6/30/23 | |
| 19 | Design Hazard Review completed. | Fri 6/30/23 Fri 6/30/23 | |
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