Engineering Scale Testing of Transformational Non-Aqueous Solvent-Based CO₂ Capture Process at Technology Centre Mongstad

DE-FE0031590

Marty Lail, RTI International

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management and Natural Gas & Oil Research Project Review Meeting
Virtual Meetings August 2 through August 31, 2021
Project Overview

Description: Testing and evaluation of Non-Aqueous Solvent (NAS)-based CO$_2$ capture technology at engineering scale at TCM

Key Metrics
- Energy requirements
- Solvent losses
- Solvent degradation
- Technoeconomic and EHS evaluation

Specific Challenges
- Minimize rise in absorber temperature
- Operate TCM plant within emission requirements
- Optimize solvent regeneration
- Maximize NAS performance with plant modifications
Project Overview

Funding

- Total $ 17,384,512
- DOE $ 10,013,512
- Cost-share $ 7,371,000

Project Performance Dates

- August 8, 2018 – December 31, 2022

Project Participants

RTI International

TECHNOLOGY CENTRE MONGSTAD

PRESSURA

SINTEF

EPR2I

CCSI²
Technology Background

New coal-fired power plants with CO₂ capture at a cost of electricity 30% lower than the baseline cost of electricity from a supercritical PC plant with CO₂ capture, or approximately $30 per tonne of CO₂ captured by 2030.

Path to Reducing ICOE and Cost of CO₂ Avoided

- Primarily focus on reducing energy consumption – reboiler duty
- Reduce capital expenditure
  - Simplify process arrangement
  - Materials of construction
- Limit operating cost increase

Breakdown of the Thermal Regeneration Energy Load

\[
q_R = \left[ \frac{C_p(T_R - T_F)}{\Delta \alpha} \cdot \frac{M_{sol}}{M_{CO_2}} \cdot \frac{1}{x_{sol}} \right] + \left[ \frac{\Delta H_{V,H_2O}}{P_{H_2O}} \cdot \frac{P_{CO_2}}{M_{CO_2}} \cdot \frac{1}{x_{sol}} \right] + \left[ \frac{\Delta H_{abs, CO_2}}{M_{CO_2}} \right]
\]

<table>
<thead>
<tr>
<th>Solvent</th>
<th>(C_p) [J/g K]</th>
<th>(\Delta H_{abs}) [kJ/mol]</th>
<th>(\Delta H_{vap}) [kJ/mol]</th>
<th>(x_{solv}) [mol solvent/mol solution]</th>
<th>(\Delta \alpha) [mol CO₂/mol solvent]</th>
<th>Reboiler Heat Duty [GJ/t-CO₂]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 wt% MEA-H₂O</td>
<td>3.8</td>
<td>85</td>
<td>40</td>
<td>0.11</td>
<td>0.34</td>
<td>3.75</td>
</tr>
<tr>
<td>RTI's NASs</td>
<td>2.0</td>
<td>85</td>
<td>negl.</td>
<td>0.47</td>
<td>0.45</td>
<td>2.40</td>
</tr>
</tbody>
</table>

For NAS, heat of vaporization of water becomes a negligible term to the heat duty

Process capable of achieving these criteria will have a lower energy penalty than SOTA processes

Technology Background

From lab to large scale (12 MW) demonstration through series of projects.
Technical Approach – Project Objectives

- Confirm the potential to reduce the parasitic energy penalty by 20 to 40% compared with the MEA process
- Demonstrate the long-term process operational reliability
- Perform NAS-specific modifications to the TCM unit to show lower energy penalty
- Demonstrate NAS in the modified TCM unit for at least two months
- Verify solvent degradation rate, emissions, solvent loss, and corrosion characteristics
## Technical Approach - Success Criteria

<table>
<thead>
<tr>
<th>Decision Point</th>
<th>Date</th>
<th>Success Criteria</th>
</tr>
</thead>
</table>
| Completion of BP2       | 12/31/2022 | 1. Successful completion of all work proposed in Budget Period 2  
2. Completion of the TCM amine plant modifications and commissioning. The success is measured by more than 48 hours of continuous key component - absorber loop, regenerator loop, and water wash loop – operation with achievement of mechanical integrity and operability, electric and control operability, and achieving design duty of the heat exchangers during hot commissioning.  
3. Acceptance of Recipient’s modified TCM amine plant test plans  
4. Completion of dynamic NAS testing using the modified TCM amine plant (600 hours) while adjusting absorber temperature, regenerator temperature, L/G ratio, and inlet flue gas humidity. Identification of optimal operating conditions for long-term testing.  
5. Completion of long-term NAS testing using the modified TCM amine plant (1,000 hours) with results showing process emissions < 1 ppmv, solvent makeup rate of 0.8 kg/hr, and total energy consumption < 2.6 GJ/tonne CO$_2$ that indicate significant progress toward achieving the DOE’s CO$_2$ Capture goals of 95% CO$_2$ purity at a cost of $30/tonne of CO$_2$ captured and 40% improvement over the benchmark MEA solvent.  
6. Submission of (1) updated State-Point Data Table; (2) updated TMP; (3) Techno-Economic Analysis topical report; (4) Technology Gap Analysis topical report; and (4) Environmental Health & Safety Risk Assessment topical report based on the results of engineering scale testing  
7. Submission of a Final Report |
## Project Schedule and Milestones

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Milestone No.</th>
<th>Milestone Description</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1</td>
<td>Updated Project Management Plan (PMP)</td>
<td>Oct. 31, 2018</td>
<td>Sept. 5, 2018</td>
</tr>
<tr>
<td>1.0</td>
<td>2</td>
<td>Project Kickoff Meeting</td>
<td>Oct. 31, 2018</td>
<td>Oct. 2, 2018</td>
</tr>
<tr>
<td>1.0</td>
<td>3</td>
<td>Initial TMP</td>
<td>Dec. 31, 2018</td>
<td>Dec. 31, 2018</td>
</tr>
<tr>
<td>2.0</td>
<td>4</td>
<td>EH&amp;S report as outlined in Appendix E of the FOA</td>
<td>Jan. 31, 2019</td>
<td>Jan. 31, 2019</td>
</tr>
<tr>
<td>3.0</td>
<td>5</td>
<td>Solvent qualification test results</td>
<td>July 31, 2019</td>
<td>January 17th, 2020</td>
</tr>
<tr>
<td>4.0</td>
<td>6</td>
<td>FEED study and cost estimate</td>
<td>Dec. 31, 2019</td>
<td>February 4th, 2020</td>
</tr>
<tr>
<td>5.0</td>
<td>7</td>
<td>Submit requisition for interstage cooler heat exchanger to fabricator</td>
<td>March 31, 2021</td>
<td>February 24, 2021</td>
</tr>
<tr>
<td>5.0</td>
<td>8</td>
<td>Submission of purchase order to manufacturer for initial solvent fill</td>
<td>May 31, 2021</td>
<td>June 25, 2021</td>
</tr>
<tr>
<td>5.0</td>
<td>9</td>
<td>Receive forced recirculation pump for regenerator for installation at host site</td>
<td>November 15, 2021</td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>10</td>
<td>NAS solvent batch (~80 tons) delivered to TQM site</td>
<td>December 31, 2021</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>11</td>
<td>Commissioning of the revamped unit</td>
<td>January 31, 2022</td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>12</td>
<td>Test reports for parametric and long-term testing in revamped capture unit together with an updated State Point Data Table as defined in Appendix A of the FOA</td>
<td>June 30, 2022</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>13</td>
<td>Confirmation of decommissioning and waste handling</td>
<td>September 30, 2022</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>Final TEA according to DOE guidelines</td>
<td>December 31, 2022</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>EH&amp;S report as outlined in Appendix E of the FOA</td>
<td>December 31, 2022</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>Maturation Plan and Technology Gap Analysis following DOE guidelines in FOA appendices</td>
<td>December 31, 2022</td>
<td></td>
</tr>
</tbody>
</table>
### Risk and Mitigation Strategies

<table>
<thead>
<tr>
<th>Description of Risk/Area</th>
<th>Probability</th>
<th>Impact</th>
<th>Risk Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Low</td>
<td>High</td>
<td>Discussions with Clariant to confirm solvent can be supplied in the required quantities. Very low risk now, production underway.</td>
</tr>
<tr>
<td>Process</td>
<td>Low</td>
<td>Moderate</td>
<td>Evaluated an activated carbon bed wash system to confirm recovery of solvent at bench-scale</td>
</tr>
<tr>
<td>Process</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Confirmed ability to reduce solvent loss via recovery of solvent using activated bed wash system to &lt; 3 ppm at RTI’s bench-scale system.</td>
</tr>
<tr>
<td>Process</td>
<td>Moderate</td>
<td>High</td>
<td>Evaluated and confirmed ability to control emissions to &lt; 1 ppm using an acid wash system at Tiller. Confirmed ability of acid wash system at TCM to perform at higher efficiency than at Tiller.</td>
</tr>
<tr>
<td>Process</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Extended exposure of NAS to coal-derived flue gas (or similar flue gas) could cause degradation of the solvent different from what has been observed in the lab. Long-term testing under coal-derived flue gas conditions is needed to address this risk.</td>
</tr>
<tr>
<td>Process</td>
<td>Low</td>
<td>High</td>
<td>Failure to maintain a water balance in the NAS CO$_2$ capture process leads to water accumulation within the process and can result in major operational and potentially environmental issues. We have demonstrated successfully at the small pilot scale (40 kW at SINTEF) that the water balance can be controlled using appropriate process parameters. Review of TCM operations has been conducted and modifications planned to ensure adequate leak rate in the chimney of the water wash section.</td>
</tr>
</tbody>
</table>
Progress and Current Status BP2

Task 1: Project Management and Planning
Task 5: TCM Amine Plant Equipment Procurement, Modification, and Commissioning
Task 6: Solvent Production
Task 7: NAS Modified Amine Plant Test Plan Development, Testing, and Data Analysis
Task 8: Decommissioning and Waste Handling
Task 9: Final Techno-Economic Analysis and EH&S Risk Assessment
Task 10: Technology Gap Analysis
Task 1: Project Management

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

Scientific Stature


4) Rabindran, A. V. R.; Tanthana, J.; Gupta, V.; Mobley, P. D.; Soukri, M.; Zhou, S. J.; Lail, M., Experimental study of a hydrophobic solvent for natural gas sweetening based on the solubility and selectivity for light hydrocarbons (CH₄, C₂H₆) and acid gases (CO₂ and H₂S) at 298-353K. *Journal of Chemical and Engineering Data* 2019, 64 (2), 545-556.

Task 5: Revamp Implementation

Absorber Modifications
- All PO’s for long lead items placed
- Satisfactory delivery estimates obtained for all items
- Equipment under FEED budget by ~$100K
- Fabrication and installation budget scenarios
  - Best will be under FEED budget by ~$277K
  - Worst will exceed FEED budget by ~$89K

Regenerator Mods
- All PO’s for long lead items placed
- Satisfactory delivery estimates obtained for all items
- Equipment under FEED budget by ~$67K
- Fabrication and installation budget has two scenarios
  - Best will exceed FEED budget by ~$61K
  - Worst will exceed FEED budget by ~$310K
Task 6: Solvent Production

Solvent and Diluent
- 80 MT of solvent inventory (adjusted increase over 65 ton budgeted amount due to modifications)
- REACH registration for solvent led by Clariant
- Pricing increased due to increase in cost of reagents
- Schedule is adequate for delivery before test campaign
- Received green light from TCM to order solvent
- Received green light from TCM to order makeup diluent
- Cost of solvent is over budget due to combined factors of higher volume and higher price

Make-up Amine
- Sourced three suppliers for make-up amine
- Targeting ~$6/kg, received $5.43/kg
- Received COA on product
- Received green light from TCM for HSE
- Supplier can easily supply requisite volume to meet schedule
- PO submitted to supplier for make-up amine
Task 7: NAS Modified Amine Plant Test Plan Development, Testing, and Data Analysis

- Working with TCM Advisory Services on NAS process model refinement.
- Working with CCSI² on quantifying uncertainty in model predictions.

Preliminary results for prediction of Tiller qualification runs.
## Progress Since Last Year

<table>
<thead>
<tr>
<th>Description</th>
<th>Status / BP2 Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful completion of Continuation Application Process</td>
<td>Continuation into BP2 approved by DOE and started in November 2020.</td>
</tr>
<tr>
<td>Detailed engineering of equipment for modifications</td>
<td>Completed detailed engineering of heat exchanger, piping, pumps, instrumentation, valves, and civil supports for modifications to amine unit.</td>
</tr>
<tr>
<td>Procurement of identified long-lead equipment items for delivery during the construction phase.</td>
<td>Completed in June. All estimated deliveries are within the scheduled 90-day construction and installation period. Met the project milestone for PO submissions.</td>
</tr>
<tr>
<td>Procurement of solvent volume required for testing.</td>
<td>PO submitted to Clariant to produce 75 tons anhydrous solvent. Met the project milestone for PO submission.</td>
</tr>
<tr>
<td>TCM approval for storage of make-up amine on site during test campaign</td>
<td>Solvent storage approved after flash-point measurement and identification of suitable safe storage conditions.</td>
</tr>
<tr>
<td>Identification of supplier for make-up amine</td>
<td>Identified and engaged a supplier for 12-18 tons of make-up amine to be used during the test campaign. Supplier had 15 tons in stock with next production run scheduled for October 2021. PO submitted to supplier.</td>
</tr>
</tbody>
</table>
Future Plans

- Engineering scale testing of NAS at TCM expected in Feb-Aug 2022 during BP2.
- Actively pursuing opportunities for large pilot-scale testing at an industrial site under DOE/commercial funding.
- Find an engineering firm to commercialize the RTI-NAS technology or a company with its own internal expertise to work with a license.
Summary

- Detailed engineering of modifications completed with long-lead items being requisitioned early enough to ensure delivery in time for the construction phase beginning in October 2021.
- Fabrication and installation work orders and purchase orders submitted for modifications and expected to be fulfilled during the construction phase.
- Solvent manufacture sourced and ordered with delivery of 75 tons anhydrous expected ahead of the beginning of the test campaign.
- Make-up amine sourced and ordered with delivery expected ahead of test campaign.
- Projected to be on budget or below in BP2 (met the BP1 budget)
Appendix

- These slides will not be discussed during the presentation, but are mandatory.
<table>
<thead>
<tr>
<th>#</th>
<th>Task title</th>
<th>Start date</th>
<th>End date</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>1.0</td>
<td>Project Management and Planning</td>
<td>08/08/18</td>
<td>12/31/22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.1 Test Agreement with TCM</td>
<td>08/08/18</td>
<td>09/30/20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>EH&amp;S and Risk Evaluation and Permitting</td>
<td>08/08/18</td>
<td>02/28/19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Solvent Qualification</td>
<td>03/01/19</td>
<td>01/31/20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>Preliminary Design of a NAS Optimized System</td>
<td>08/01/19</td>
<td>07/31/20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.1 Pre-FEED</td>
<td>08/01/19</td>
<td>09/30/19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.2 FEED study</td>
<td>10/01/19</td>
<td>02/28/20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>Revamp Implementation</td>
<td>10/01/20</td>
<td>12/31/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.1 Detailed Engineering and Procurement</td>
<td>10/01/20</td>
<td>06/30/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.11 Design Freeze</td>
<td>11/01/20</td>
<td>12/31/20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.12 Long Lead Items Ordered</td>
<td>01/01/21</td>
<td>02/12/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.13 Long Lead Items Received</td>
<td>02/12/21</td>
<td>09/01/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.2 Interstage Cooler and Recirculation Pump Install</td>
<td>04/01/21</td>
<td>12/31/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.21 Installation and Commissioning</td>
<td>09/01/21</td>
<td>12/15/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.22 Mod Project Closeout</td>
<td>12/15/21</td>
<td>12/31/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td>Solvent Production</td>
<td>10/01/20</td>
<td>12/03/21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>Test Plan Development, Testing, Data Analysis</td>
<td>01/01/21</td>
<td>06/30/22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.1 Modified Amine Plant Test Plan Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.2 NAS Modified Amine Plant Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.3 NAS Modified Amine Plant Data Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.4 EPRI Third Party Verification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>Decommissioning and Waste Handling</td>
<td>07/01/22</td>
<td>09/30/22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td>Final TEA (550 MW Net)</td>
<td>07/01/22</td>
<td>12/31/22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0</td>
<td>Cost Benefit Analysis and Technology Mat Planning</td>
<td>10/01/20</td>
<td>12/31/22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Milestone Log

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Milestone No.</th>
<th>Milestone Description</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1</td>
<td>Updated Project Management Plan (PMP)</td>
<td>Oct. 31, 2018</td>
<td>Sept. 5, 2018</td>
<td>PMP file</td>
</tr>
<tr>
<td>1.0</td>
<td>2</td>
<td>Project Kickoff Meeting</td>
<td>Oct. 31, 2018</td>
<td>Oct. 2, 2018</td>
<td>Presentation file</td>
</tr>
<tr>
<td>1.0</td>
<td>3</td>
<td>Initial TMP</td>
<td>Dec. 31, 2018</td>
<td>Dec. 31, 2018</td>
<td>TMP file</td>
</tr>
<tr>
<td>3.0</td>
<td>5</td>
<td>Solvent qualification test results</td>
<td>July 31, 2019</td>
<td>January 17th, 2020</td>
<td>Quarterly report</td>
</tr>
<tr>
<td>4.0</td>
<td>6</td>
<td>FEED study and cost estimate</td>
<td>Dec. 31, 2019</td>
<td>February 4th, 2020</td>
<td>Quarterly report</td>
</tr>
<tr>
<td>5.0</td>
<td>7</td>
<td>Submit requisition for interstage cooler heat exchanger to fabricator</td>
<td>March 31, 2021</td>
<td>February 24th, 2021</td>
<td>Quarterly report</td>
</tr>
<tr>
<td>5.0</td>
<td>8</td>
<td>Submission of purchase order to manufacturer for initial solvent fill</td>
<td>May 31, 2021</td>
<td>July 16th, 2021</td>
<td>Quarterly report</td>
</tr>
<tr>
<td>5.0</td>
<td>9</td>
<td>Receive forced recirculation pump for regenerator for installation at host site</td>
<td>September 30, 2021</td>
<td></td>
<td>Quarterly report</td>
</tr>
<tr>
<td>6.0</td>
<td>10</td>
<td>NAS solvent batch (~50 tons) delivered to TCM site</td>
<td>December 31, 2021</td>
<td></td>
<td>Quarterly report</td>
</tr>
<tr>
<td>5.0</td>
<td>11</td>
<td>Commissioning of the revamped unit</td>
<td>January 31, 2022</td>
<td></td>
<td>Quarterly report</td>
</tr>
<tr>
<td>7.0</td>
<td>12</td>
<td>Test reports for parametric and long-term testing in revamped capture unit together with an updated State Point Data Table as defined in Appendix A of the FOA</td>
<td>June 30, 2022</td>
<td></td>
<td>Quarterly report</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
<td>Confirmation of decommissioning and waste handling</td>
<td>September 30, 2022</td>
<td></td>
<td>Quarterly report</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>Final TEA according to DOE guidelines</td>
<td>December 31, 2022</td>
<td></td>
<td>Topical report</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>EH&amp;S report as outlined in Appendix E of the FOA</td>
<td>December 31, 2022</td>
<td></td>
<td>Topical report</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>Maturation Plan and Technology Gap Analysis following DOE guidelines in FOA appendices</td>
<td>December 31, 2022</td>
<td></td>
<td>TMP file and Gap Analysis report</td>
</tr>
</tbody>
</table>