Project Review Meeting
DE-FE0031597
Mixed-Salt Based Transformational Solvent Technology for CO$_2$ Capture

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Presentation Outline

- Technology Background
- Project Structure
  - Budget, Team, Tasks and Schedule
- Budget Period 1 (Completed)
  - VLE Measurements
  - Kinetic studies
  - Solvent stability
  - Process modeling
- Budget Period 2 (Ongoing)
  - Large Bench Scale Absorber and Regenerator testing
  - Integrated Testing
  - Technoeconomic Analysis
  - Technology Maturation Plan
- Acknowledgements
Mixed-Salt Based Transformational Solvent Technology for CO₂ Capture

• **Need:**
  - Reducing capture costs beyond the current values and develop a pathway to reach DOE 2030 CO₂ capture goals

• **Approach:**
  - New transformational technologies that provide a step reduction of the regeneration energy
    - Low regeneration energy by solvent pairing
    - Water-lean solvents to reduce sensible heat
    - Energy recovery by advanced heat integration

• **Technology:**
  - Advanced Mixed Salt Process
    - Development of a solvent formulation that contain ammonia, potassium carbonate, and a tertiary amine
**Advanced Mixed-Salt Process (A-MSP)**

- **K₂CO₃–NH₃–amine-H₂O system**
  - Absorber operation at 20° - 40 °C at 1 atm
  - Regenerator operation at 90 ° - 120 °C at ~10 atm

**Key advancement in A-MSP over MSP:**
- Increased solvent concentration

- **Increased CO₂ loading**

- **Reduced parasitic energy load**

**A significant step change for reaching DOE’s reduced CO₂ capture cost targets.**

- Improved Absorber Kinetics
- Improved Regenerator Performance

**A-MSP will retain MSP advantages:**
- Reduced Ammonia Emission
- Reduced Reboiler duty
- Reduced CO₂ Compression Energy

**Diagram:**
- Absorber 1
- Absorber 2
- Lean Solution 1
- Lean Solution 2
- Rich Solution 1
- Rich Solution 2
- Reboiler

**CO₂ loading**
- Regenerator Pressure 10-20 bar
- ~80°C
- 90-120°C

**Process Flow:**
- Clean Flue Gas
- Water Wash
- Flue Gas 20cfm
- 85% N₂
- 15% CO₂
- High (NH₃/(Mixed salt))
- Low NH₃/(Mixed-Salt)
- H1
- H2
- H3
- H4
- H5
- CO₂
Project Objectives, Budget and Period of Performance (Contract No: DE-FE0031597)

- **Project Objectives**
  - High CO$_2$ loading capacity
  - Water lean solvent system
  - Potential to reach DOE cost target $30/ton CO$_2$ by 2030

- **Period of Performance**
  - BP1: 6/1/2018 to 12/31/2020
  - BP2: 1/1/2021 to 06/30/2022

- **Project budget**
  - DOE Funding: $3,105,797
  - Partner Share: $951,897
Mixed-Salt Based Transformational Solvent Technology for CO₂ Capture

Project Manager: Krista Hill, NETL
Prime Contractor: SRI International
Project Team: US and International Partners

- DOE
- SINTEF
- GASSNOVA
- Trimeric Corporation
- Denmark Technical University (DTU)
- OLI Systems
- Baker Hughes (BH)
- Cost sharing Partner (BP2)
Work Organization

• SRI International, USA
  - Project management
  - Advanced mixed-salt composition development and testing
  - Heat capacity measurements
  - Absorption and desorption kinetic measurements
  - Integrated system testing

• DTU, Denmark (Cost-share partner)
  - VLE Measurements & Thermodynamic modeling

• OLI Systems, USA
  - Flowsheet Modeling (energy and mass balance)

• Trimeric Corp., USA
  - Process Techno Economic Analysis

• SINTEF, Norway (Cost-share partner - BP1)
  - Degradation studies
  - Alternative Mixed-salt composition development

• Baker Hughes (Cost share partner - BP2)
Project Tasks

- Task 1: Project management and Planning
- Task 2: Vapor-Liquid-Equilibria (VLE) Measurements
- Task 3: Process Kinetic Assessment
- Task 4: Degradation and Emission Assessment
- Task 5: Rate-Based Model Development
- Task 6: Preliminary TEA
- Task 7: Integrated System Testing at SRI Site
- Task 8: Flowsheet Development
- Task 9: Techno-economic Analysis
# BP1 Project Status

## Success Criteria and Decision Points

<table>
<thead>
<tr>
<th>Decision Point</th>
<th>Basis for Decision/Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Completion of Budget Period 1</strong></td>
<td></td>
</tr>
<tr>
<td>Successful completion of all work proposed in Budget Period 1</td>
<td>✓</td>
</tr>
<tr>
<td>Submission of a Technology Maturation Plan</td>
<td>✓</td>
</tr>
<tr>
<td>Submission of Preliminary Techno-Economic Analysis topical report</td>
<td>✓</td>
</tr>
<tr>
<td>Experimentally validate at least 10 bar pressure in the regenerator ~120°C</td>
<td>✓</td>
</tr>
<tr>
<td>Partnering agreement finalized</td>
<td>✓</td>
</tr>
<tr>
<td>Successful completion of the VLE model development and demonstrating the lower regeneration (less than 120°C) potential of the A-MSP solution</td>
<td>✓</td>
</tr>
<tr>
<td>Completion of the spread-sheet model by OLI to demonstrate the regeneration energy to be less than 2.3 GJ/tonne CO₂</td>
<td>✓</td>
</tr>
</tbody>
</table>

- The team completed the BP1 scope of work and achieved the associated milestones and success criteria on schedule (December 31, 2020) and within budget.
- The project team is continuing the project in BP2 (1/1/21-06/30/22) with no change in scope, period of performance (18-months) or budget.
Representative Data - VLE Measurements

**Comparison of measured values with model predictions**

- VLE measurements for NH₃-CO₂-H₂O mixtures at 60°C compared to the predictions of the Extended UNIQUAC model.

**Commonly Available**
- NH₃ + CO₂ + H₂O
- K₂CO₃ + CO₂ + H₂O
- Amine + CO₂ + H₂O

**Generated under current program**
- NH₃ + K₂CO₃ + CO₂ + H₂O
- K₂CO₃ + Amine + CO₂ + H₂O
- NH₃ + Amine + CO₂ + H₂O
- NH₃ + K₂CO₃ + Amine + CO₂ + H₂O

Photograph of the VLE measurement setup

VLE measurements for NH₃-CO₂-H₂O mixtures at 60°C compared to the predictions of the Extended UNIQUAC model.

VLE measurements (approx. 60°C) compared to the preliminary parametrization of the Extended UNIQUAC model.
Representative Data - Process Kinetic Assessment

Small bench scale absorber system for AMSP testing
Gas flow rate: 10-40 slpm, solution composition: 20-55 wt.% , solution temperature: 20-40°C
Representative Data - Process Kinetic Assessment

Rapid Design of Experiment for the Kinetic Study

Sample parametric test performed at 20°C

<table>
<thead>
<tr>
<th>Composition Label</th>
<th>Absorber Temperature</th>
<th>loading (initial)</th>
<th>loading (final)</th>
</tr>
</thead>
<tbody>
<tr>
<td>522</td>
<td>20°C</td>
<td>0.35</td>
<td>0.65</td>
</tr>
<tr>
<td>521</td>
<td>20°C</td>
<td>0.37</td>
<td>0.57</td>
</tr>
<tr>
<td>423</td>
<td>20°C</td>
<td>0.38</td>
<td>0.56</td>
</tr>
<tr>
<td>520</td>
<td>20°C</td>
<td>0.36</td>
<td>0.59</td>
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<tr>
<td>521</td>
<td>20°C</td>
<td>0.34</td>
<td>0.57</td>
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<tr>
<td>523</td>
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<td>0.39</td>
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</tr>
<tr>
<td>622</td>
<td>20°C</td>
<td>0.40</td>
<td>0.55</td>
</tr>
<tr>
<td>722</td>
<td>20°C</td>
<td>0.41</td>
<td>0.56</td>
</tr>
<tr>
<td>422</td>
<td>20°C</td>
<td>0.40</td>
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<tr>
<td>532</td>
<td>20°C</td>
<td>0.42</td>
<td>0.56</td>
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<tr>
<td>502</td>
<td>20°C</td>
<td>0.36</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Absorption efficiency as a Function of CO₂ loading

Effects of temperature on efficiency (left) and absorption rate (right) for a given loading.
**Representative Data - Desorption Measurements**

**Static and Dynamic Regenerator Measurements**

**Static Autoclave System**  
(Operability Limit: up to 250°C and 300 psi)

**Continuous Flow, Plug Flow Reactor System**  
(Operability Limit: up to 400°C and 4000 psi)

### Static System
- Slow Heating  
- Long retention time  
- VLE Curve

### Continuous Flow System
- Rapid Heating  
- Short retention time  
- Rate Profile
Representative Data - Desorption Measurements

**Static Regenerator Measurements**

Regeneration pressure as a function of temperature and CO\(_2\) loading

Model and measured data comparison.
Representative Data - Solvent Degradation Assessment

Oxidative and Thermal Decomposition Study of Amine at SINTEF

- Test conditions
  - Oxidative decomposition performed at 55°C to get accelerated results
  - Thermal decomposition studies performed at 120, 135 and 150°C
  - Testing duration is about 6 weeks
  - Solutions were analyzed by LC-MS, TOC, and ICP-MS

- Results
  - SINTEF reported the oxidative degradation results that showed the selected amine in A-MSP solution is far more stable than MEA and other widely used amines in CO₂ capture.
  - The results for the amine thermal degradation showed it was stable at 120°C.
  - Based on the weight loss, some amine degradation at higher temperatures (>150°C) is predicted.
Model Development Progress

- Thermodynamic model to calculate vapor/liquid compositions - DTU, SRI
- Rate based model to refine the performance under dynamic conditions - OLI Systems
- Flowsheet model to predict the performance of the process and calculate heat and mass balances of process streams for TEA - OLI Systems
- Preliminary Technoeconomic analysis - Trimeric Corporation
Preliminary Technoeconomic Analysis

- Generation of stream tables with heat and mass balance data for TEA
  - Physical properties
    - Temperature, Pressure, pH, Moles (mol/hr), Mass (kg/hr), Volume (L/hr)
  - Phase Flows
    - Liquid moles (mol/hr), Vapor moles (mol/hr), Solid moles (mol/hr)
  - Phase Fraction
    - Liquid mole fraction, Vapor mole fraction, Solid mole fraction
  - Thermodynamic Properties
    - Enthalpy, Ionic strength, Density, Osmotic pressure, Viscosity
- Demonstrated regeneration energy performance consistent with the development pathway outlined for BP1.
  - Regeneration energy 2.2 GJ/tonne CO₂
- Electricity requirements for the A-MSP are ~18% lower than Case B12B.
BP2 Project Tasks (ongoing)

- **Task 1**: Project management and Planning
- **Task 4. Process Emission Assessment**
  - Subtask 4.1: Emission Assessment of the Selected AMSP formulation
- **Task 7. Integrated System Testing at SRI Site**
  - Subtask 7.1: Development of the Test Plan
  - Subtask 7.2: Integrated Testing with A-MSP Compositions
  - Subtask 7.3: Regenerator Steam Use Measurements
  - Subtask 7.4: Test Data Analysis
- **Task 8. Flowsheet Development**
  - Subtask 8.1: Development of Process Flowsheet Model
  - Subtask 8.2: Evaluation of Process Heat and Mass Balances
- **Task 9. Techno-economic Analysis**
  - Subtask 9.1: Techno-economic Analysis
  - Subtask 9.2: Update State-Point Data Table
  - Subtask 9.3: Technology Gap Analysis
  - Subtask 9.4: Environmental Health and Safety Assessment
  - Subtask 9.5: Technology Maturation Plan
Integrated Testing in SRI Large Bench Scale System

Absorbers (0.25 t-CO₂/day capacity)

Continuous operation of the integrated system is ongoing
Flowsheet Optimization and TEA

- Model validation with integrated bench scale data
- Stream tables with heat and mass balances
- Sensitivity analysis to identify critical operating parameters
- Power plant integration
- Itemized costs of installed components
Technology Gap Analysis

- Integration of column functions, particularly for the atmospheric pressure columns.
- Detail evaluation of column designs such as flooding, packing type, mass transfer performance.
- Low-cost, alternative materials for absorption column construction.
- Regenerator design consideration-Alternative reboiler designs.
- Regenerator and heat exchanger optimization to further reduce regeneration energy.
Technology Maturation Plan

- **TRL 2 to TRL 4**
  - Proof of concept, kinetic studies, and small bench testing (1 to 40 slpm)
    - 2018-2020
    - Budget Period 1
  - Large bench-scale testing 200 to 400 slpm
    - 2021-2022
    - Budget Period 2

**Future Projects**

- **V-L-E Study**
- **Lab-Scale Kinetic Study**
- **Slipstream Testing**

**Integrated testing at SRI and SINTEF**

**Opportunities for reducing CO₂ from small and large-scale applications**
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• Baker Hughes –Cost sharing partner
Thank You

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