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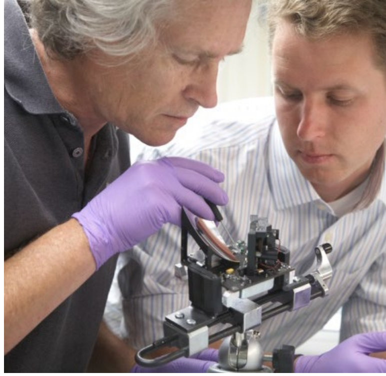

Project Review Meeting
DE-FE0031597
Mixed-Salt Based Transformational Solvent Technology for CO_2 Capture

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Principal Scientist

Integrated Systems and Solutions Division

SRI International

August 16, 2021

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 CO_2 Capture

- Need:
  - Reducing capture costs beyond the current values and develop a pathway to reach DOE 2030 CO_2 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)

K_2CO_3–NH_3–amine-H_2O system
Absorber operation at 20° - 40 °C at 1 atm
Regenerator operation at 90 ° - 120 °C at ~10 atm

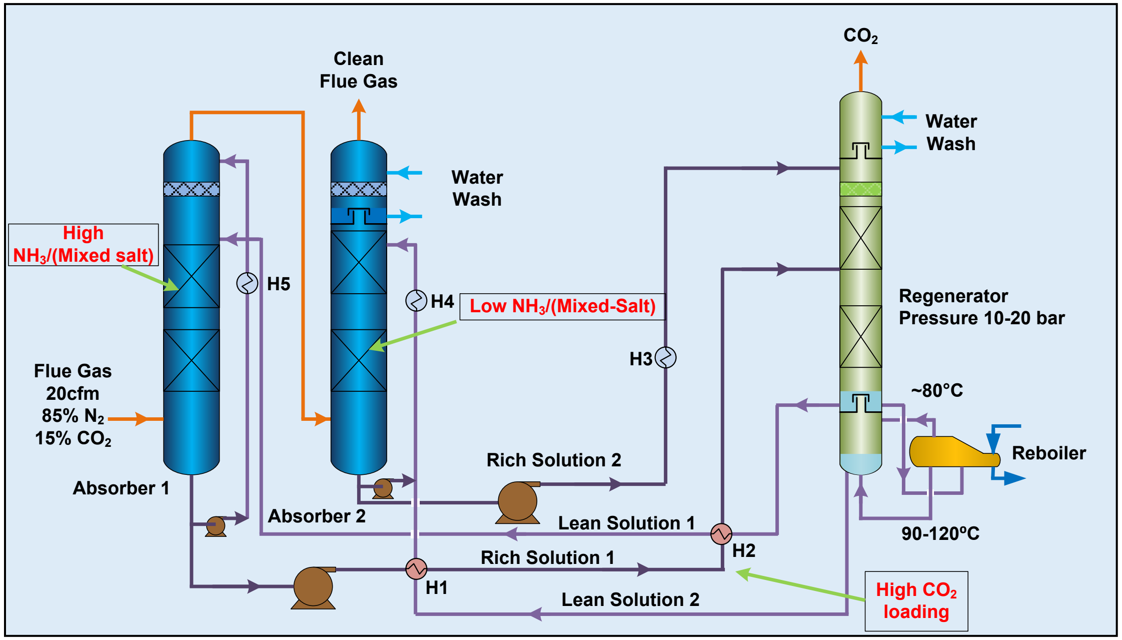
A-MSP will retain MSP advantages:
- Reduced Ammonia Emission
- Reduced Reboiler duty
- Reduced CO_2 Compression Energy

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

Increased CO_2 loading

Reduced parasitic energy load

A significant step change for reaching DOE's reduced CO_2 capture cost targets.



Improved Absorber Kinetics
Improved Regenerator Performance

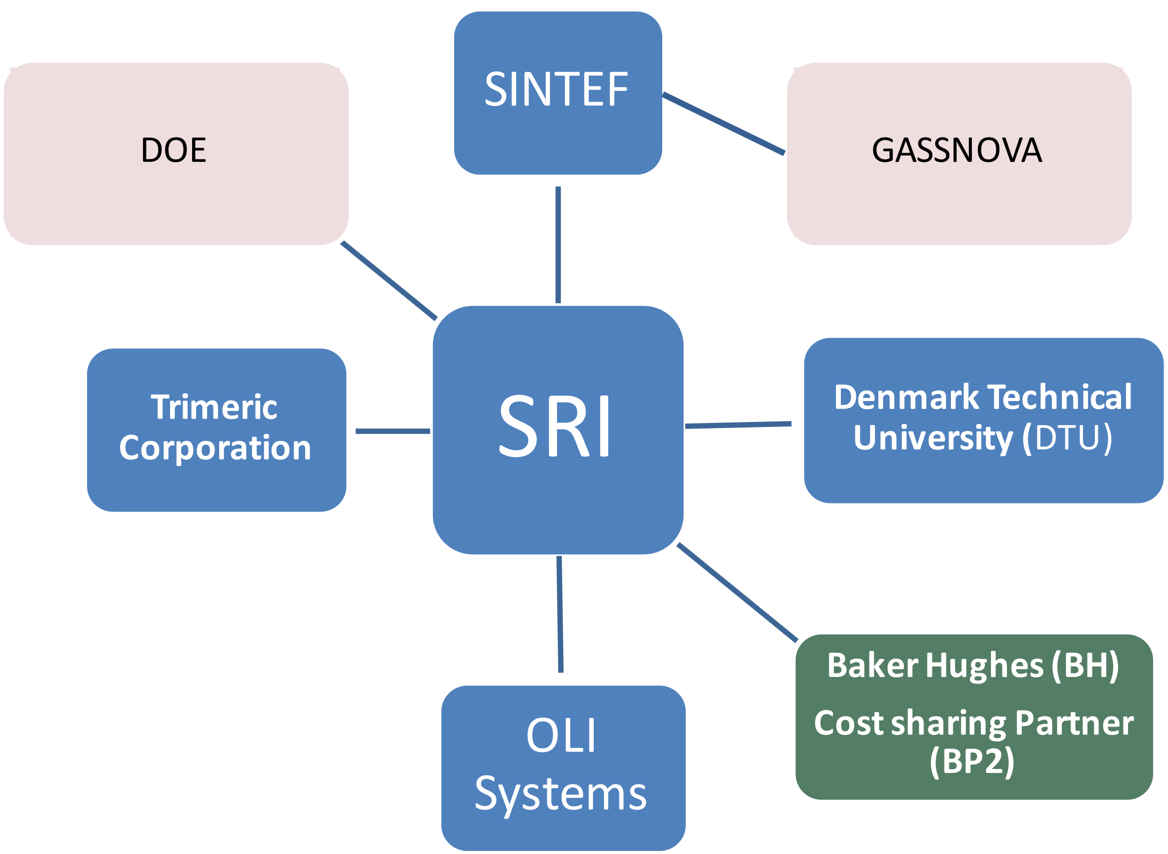
Project Objectives, Budget and Period of Performance (Contract No: DE-FE0031597)

- 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

Project Team

Mixed-Salt Based Transformational Solvent Technology for CO_2 Capture

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



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 — BP1 & BP2
- 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

BP1

- Task 7. Integrated System Testing at SRI Site
- Task 8. Flowsheet Development
- Task 9. Techno-economic Analysis

BP2

BP1 Project Status

Success Criteria and Decision Points

Decision Point	Basis for Decision/Success Criteria
A. Completion of Budget Period 1	**Successful completion of all work proposed in Budget Period 1** ✓
	Submission of a Technology Maturation Plan ✓
	Submission of Preliminary Techno-Economic Analysis topical report ✓
	Experimentally validate at least 10 bar pressure in the regenerator ~120°C ✓
	Partnering agreement finalized ✓
	Successful completion of the VLE model development and demonstrating the lower regeneration (less than 120°C) potential of the A-MSP solution ✓
	Completion of the spread-sheet model by OLI to demonstrate the regeneration energy to be less than 2.3 GJ/tonne CO_2 ✓

- 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

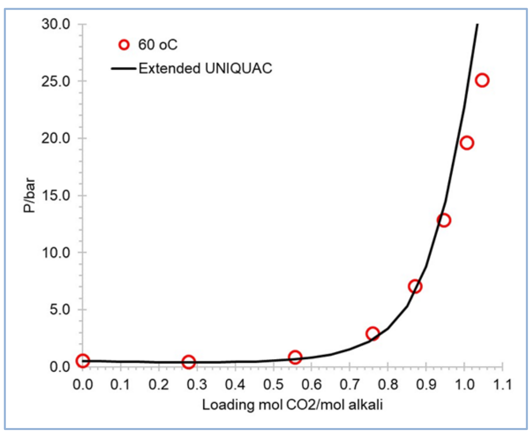
Photograph of the VLE measurement setup

Commonly Available

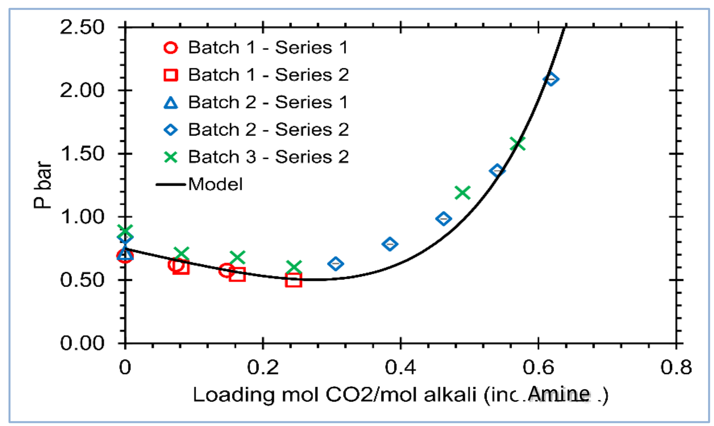
- NH3+ CO2+H2O
- K2CO3 + CO2+ H2O
- Amine + CO2 + H2O

Generated under current program

- NH3+ K2CO3 + CO2 + H2O
- K2CO3 + Amine + CO2 + H2O
- NH3 + Amine + CO2 + H2O
- NH3+ K2CO3 + Amine + CO2 + H2O

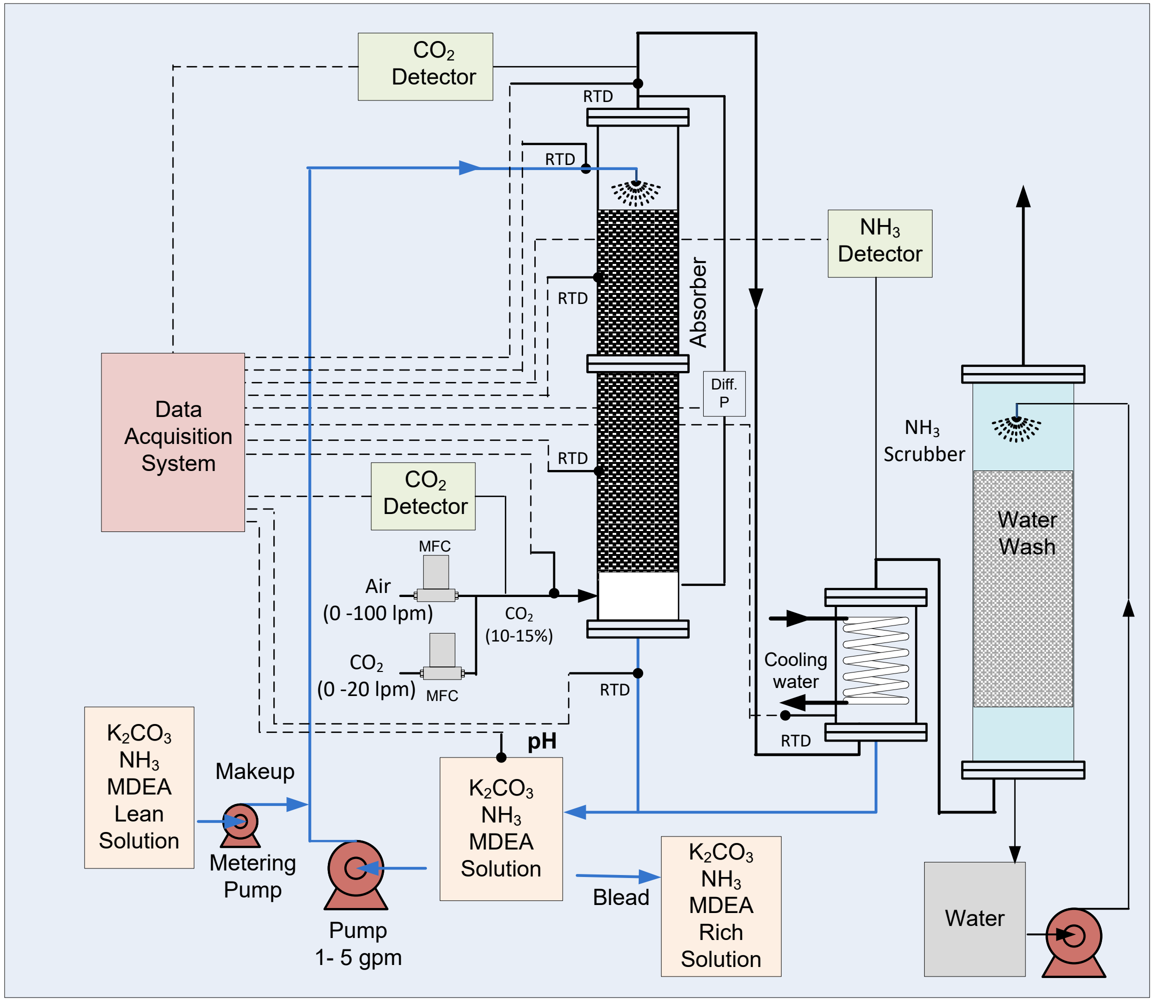


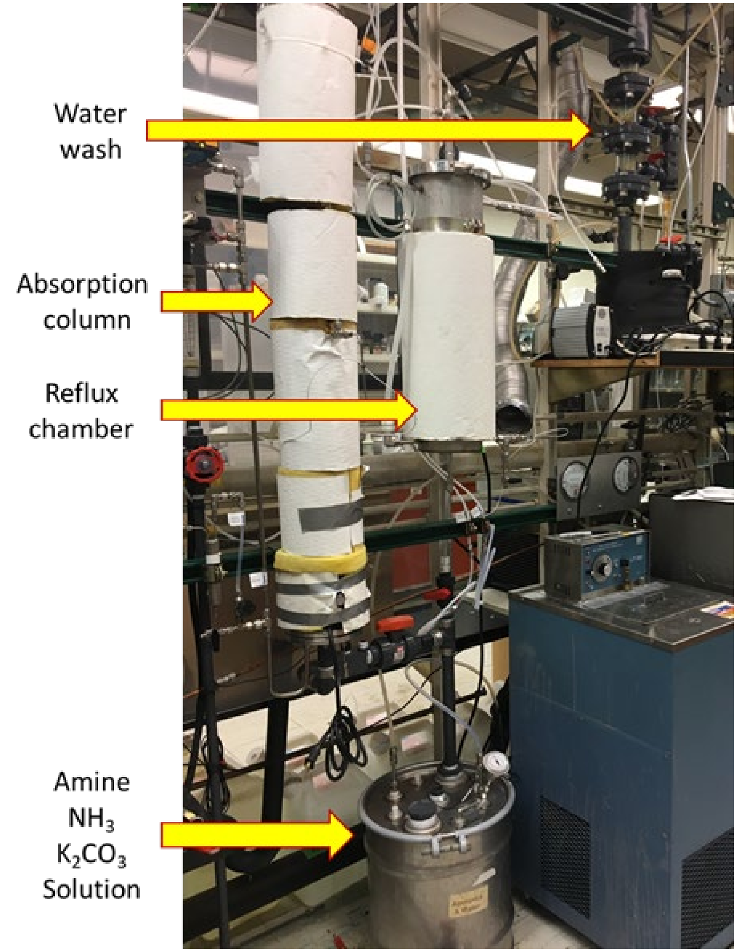
VLE measurements for NH_3-CO_2-H_2O mixtures at 60°C compared to the predictions of the Extended UNIQUAC model



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

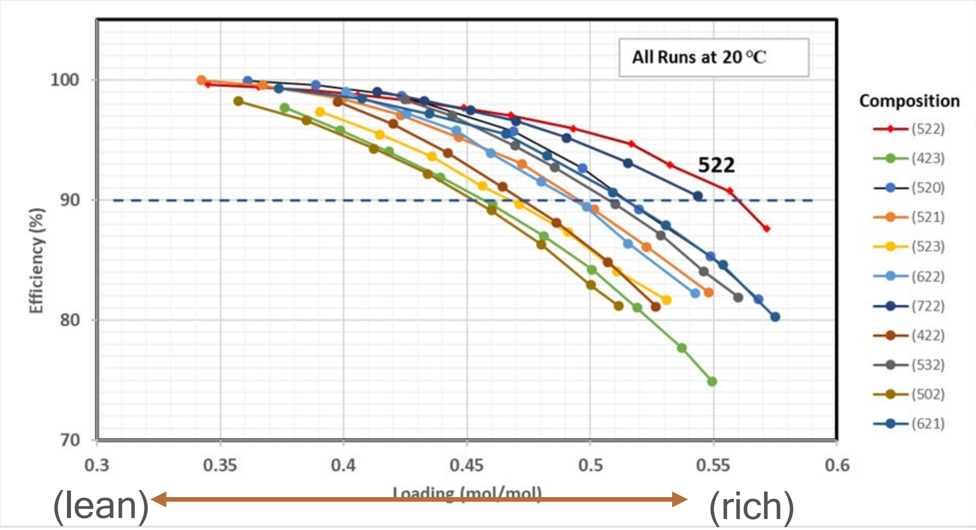
Gas flow rate:10-40 slpm, solution composition: 20-55 wt.%, solution temperature: 20- 40°C

Representative Data - Process Kinetic Assessment

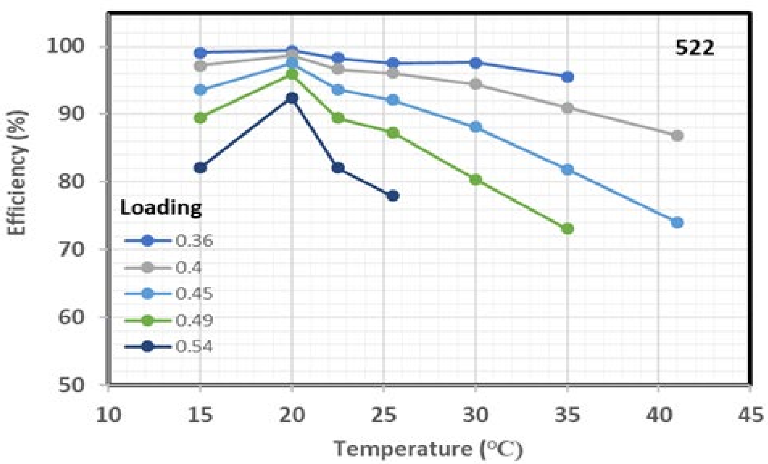
Rapid Design of Experiment for the Kinetic Study

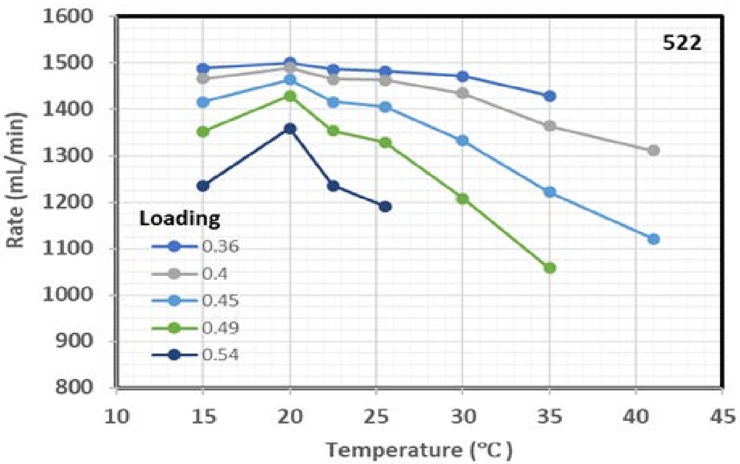
Sample parametric test performed at 20°C

Composition Label	Absorber Temperature	loading (initial)	loading (final)
522	20°C	0.35	0.65
521	20°C	0.37	0.57
423	20°C	0.38	0.56
520	20°C	0.36	0.59
521	20°C	0.34	0.57
523	20°C	0.39	0.54
622	20°C	0.40	0.55
722	20°C	0.41	0.56
422	20°C	0.40	0.54
532	20°C	0.42	0.56
502	20°C	0.36	0.51



Absorption efficiency as a Function of CO_2 loading

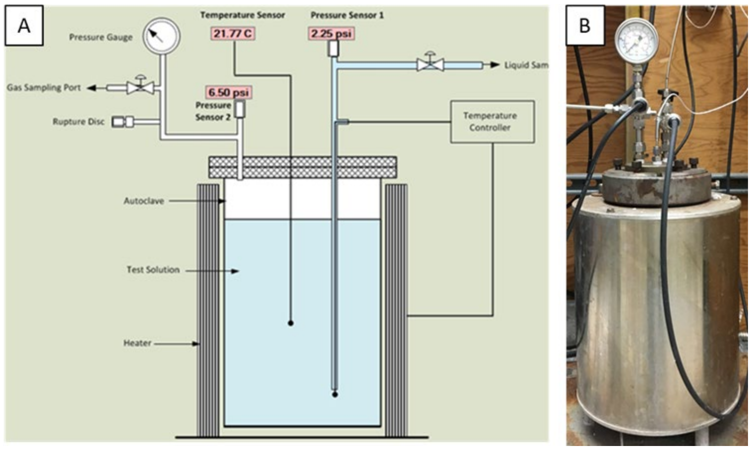




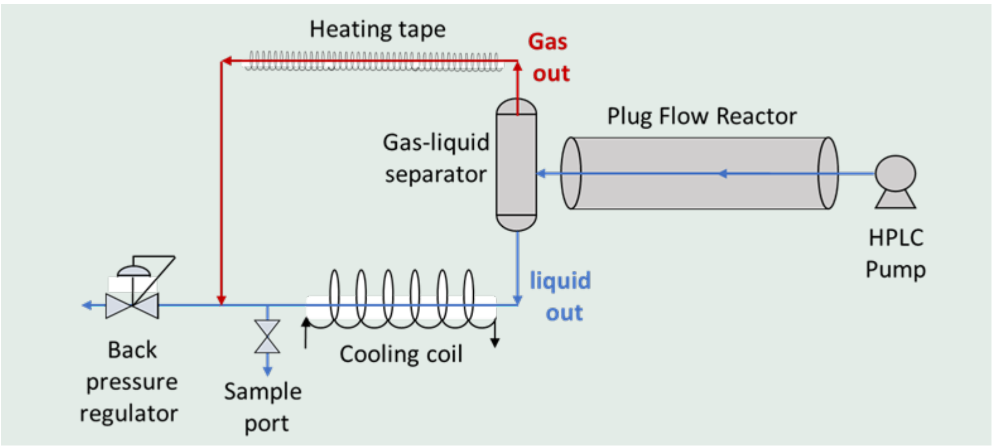
Effects of temperature on efficiency (left) and absorption rate (right) for a given loading.

Representative Data - Desorption Measurements

Static and Dynamic Regenerator Measurements



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

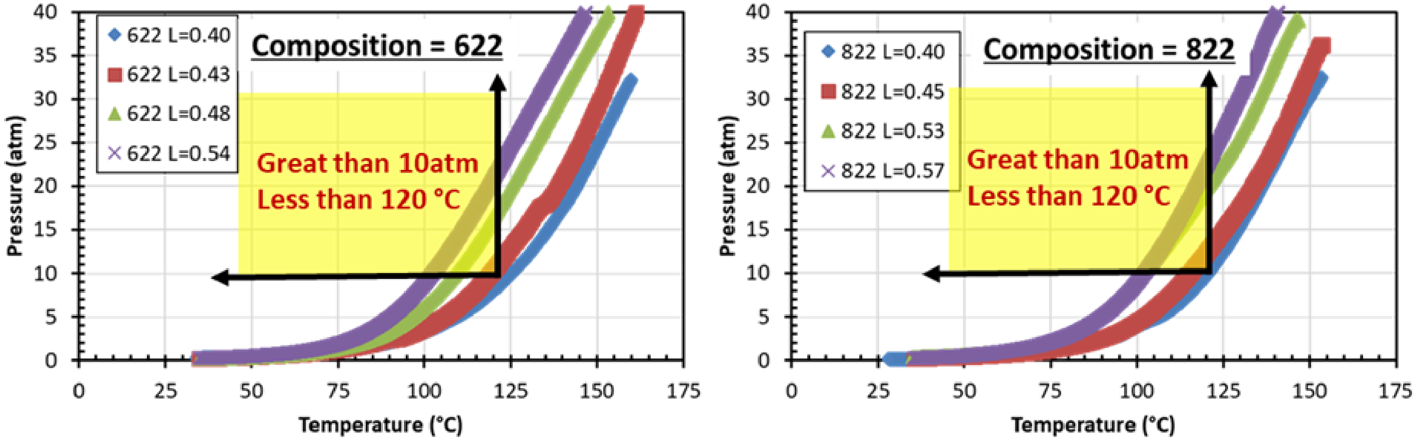


Continuous Flow, Plug Flow Reactor System
(Operability Limit: up to 400°C and 4000 psi)

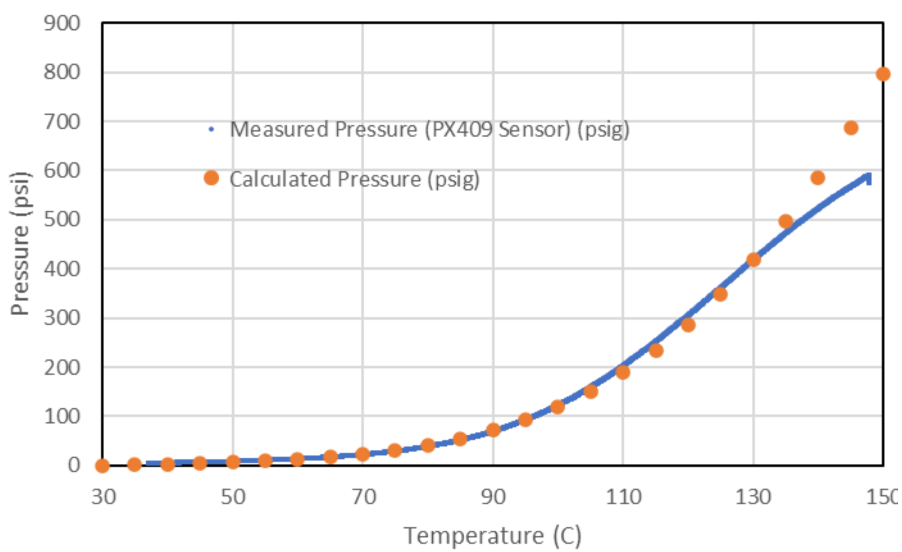
Static System	Continuous Flow System
Slow Heating Long retention time VLE Curve	Rapid Heating Short retention time Rate Profile

Representative Data - Desorption Measurements

Static Regenerator Measurements



Regeneration pressure as a function of temperature and CO_2 loading



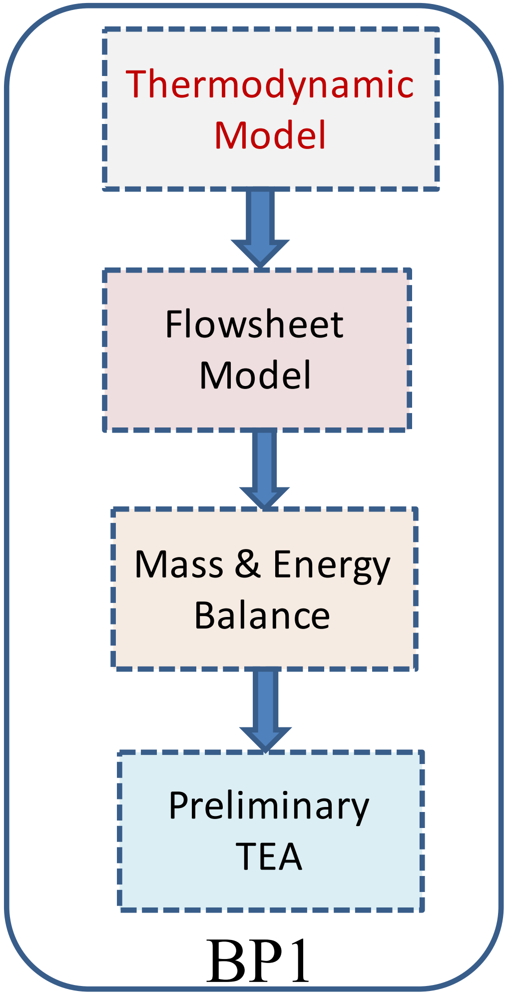
Model and measured data comparison.

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 CO_2 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 CO_2
- Electricity requirements for the A-MSP are ~18% lower than Case B12B.

BP2 Project Tasks (ongoing)

- Task1: 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

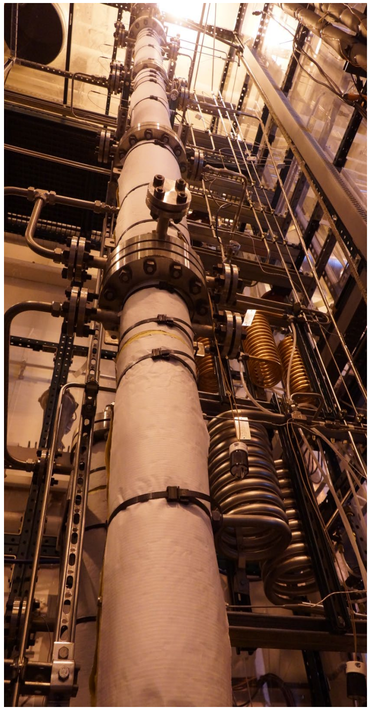
- Task 8. Flowsheet Development
  - Subtask 8.1: Development of Process Flowsheet Model
  - Subtask 8.2: Evaluation of Process Heat and Mass Balances

- 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

Analytical and Control Systems

Absorbers



Regenerator

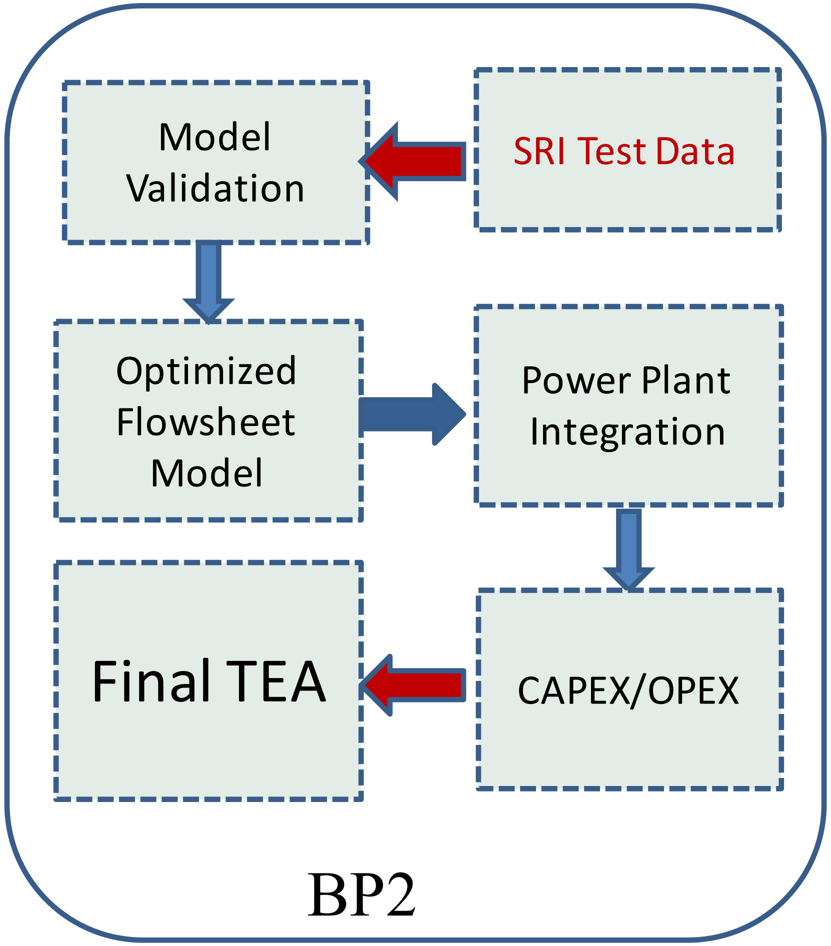
Integrated system after modification in 2020

Absorbers (0.25 t-CO_2/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

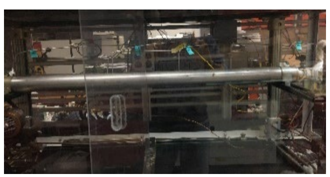
Large bench-scale testing
200 to 400 *slpm*

2021-2022
Budget Period 2

Slipstream Testing

Future Projects

Integrated testing at SRI and SINTEF



Lab-Scale Kinetic Study

V-L-E Study

Opportunities for reducing CO_2 from small and large-scale applications

Acknowledgements

NETL (DOE)

- Krista Hill, Andrew Jones, Jose Figueroa, Lynn Bricket, John Litynski and other NETL staff members

SRI Team

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- DTU (Kaj Thomsen, Philip Loldrup Fosbøl and Lucas Farias Falcchi Corrêa)
- Trimeric Corporation (Andrew Sexton)
- Baker Hughes –Cost sharing partner

Thank You

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