Engineering-Scale Test of a Water-Lean Solvent for Post-Combustion Capture

DE-FE0031945

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Virtual Meetings August 2 through August 31, 2021

Project Overview

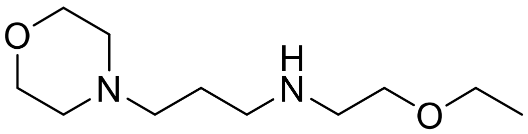
Project period October 2020 to March 2024

Funding

Federal	$4,129,607
Cost share	$1,032,411
Total	$5,162,018

Organizations
Electric Power Research Institute
Pacific Northwest National Lab.
RTI International
Paul M. Mathias Consulting, LLC
Gradient
Worley
Southern Company Services (NCCC)

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 CO_2 capture.



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

or

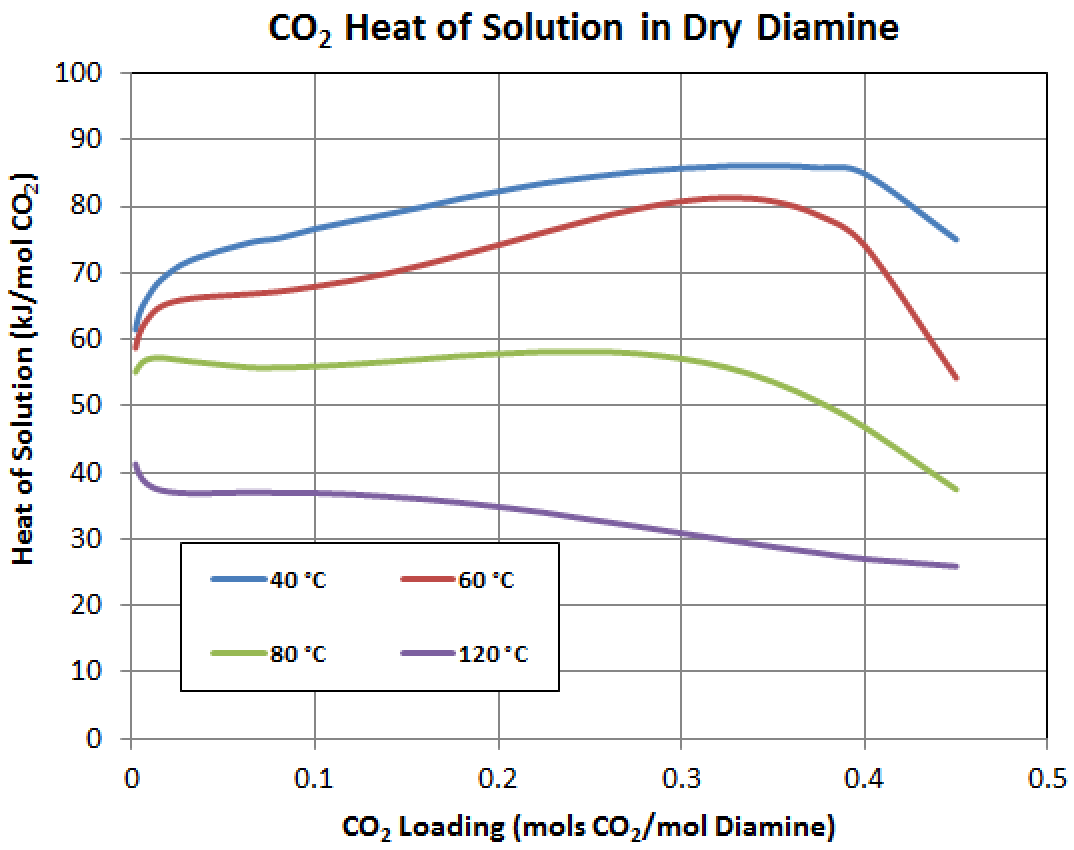
EEMPA

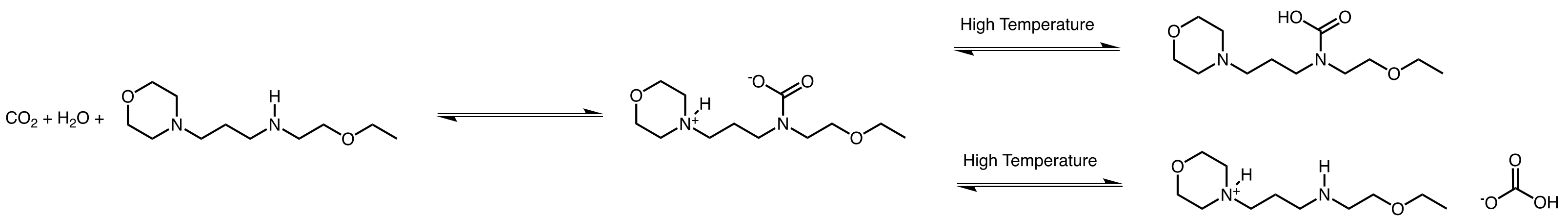
EEMPA can achieve low specific reboiler duties

The favorable thermal performance is attributable to

- The low water content (around 2 wt.% or less) meaning less water to vaporize
- A shift in the ionic character of the solvent with higher temperature, disfavoring the CO_2-bound ionic species

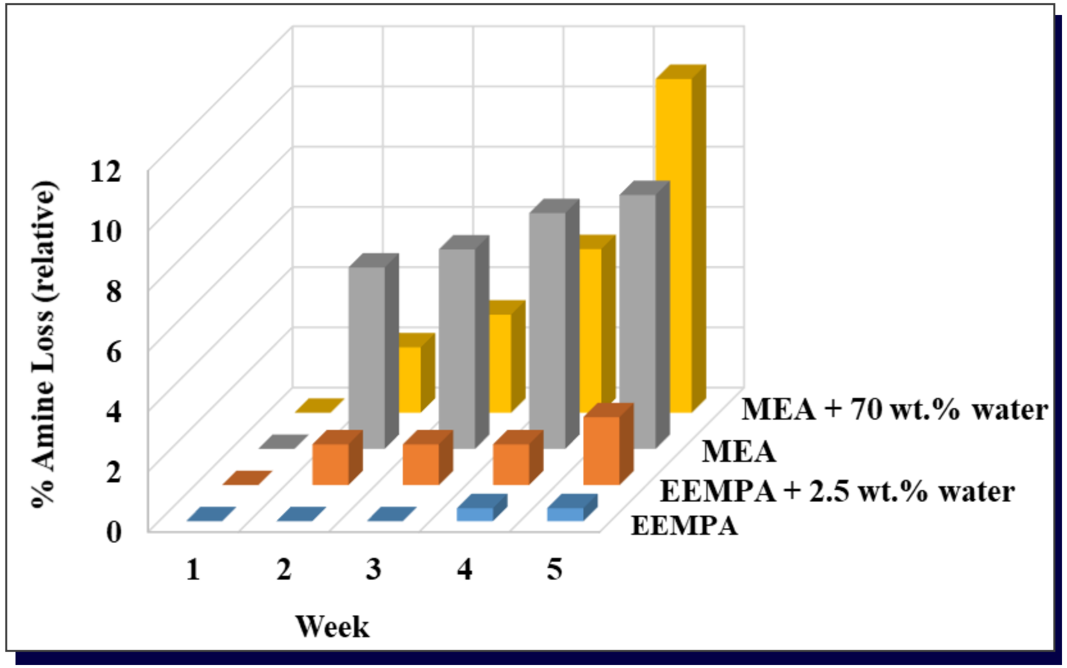
- SRDs down to 2.0 GJ/tonne have been observed in experiments. Cost-optimal designs for coal indicate 2.34 GJ/tonne is achievable.





More about EEMPA

- Strengths
  - Single-component, miscible in water
  - Low viscosity gain upon reaction with CO_2
  - 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
  - Potentially costly, and large-scale production yet to be demonstrated
  - Imposes need for careful control of the process water balance

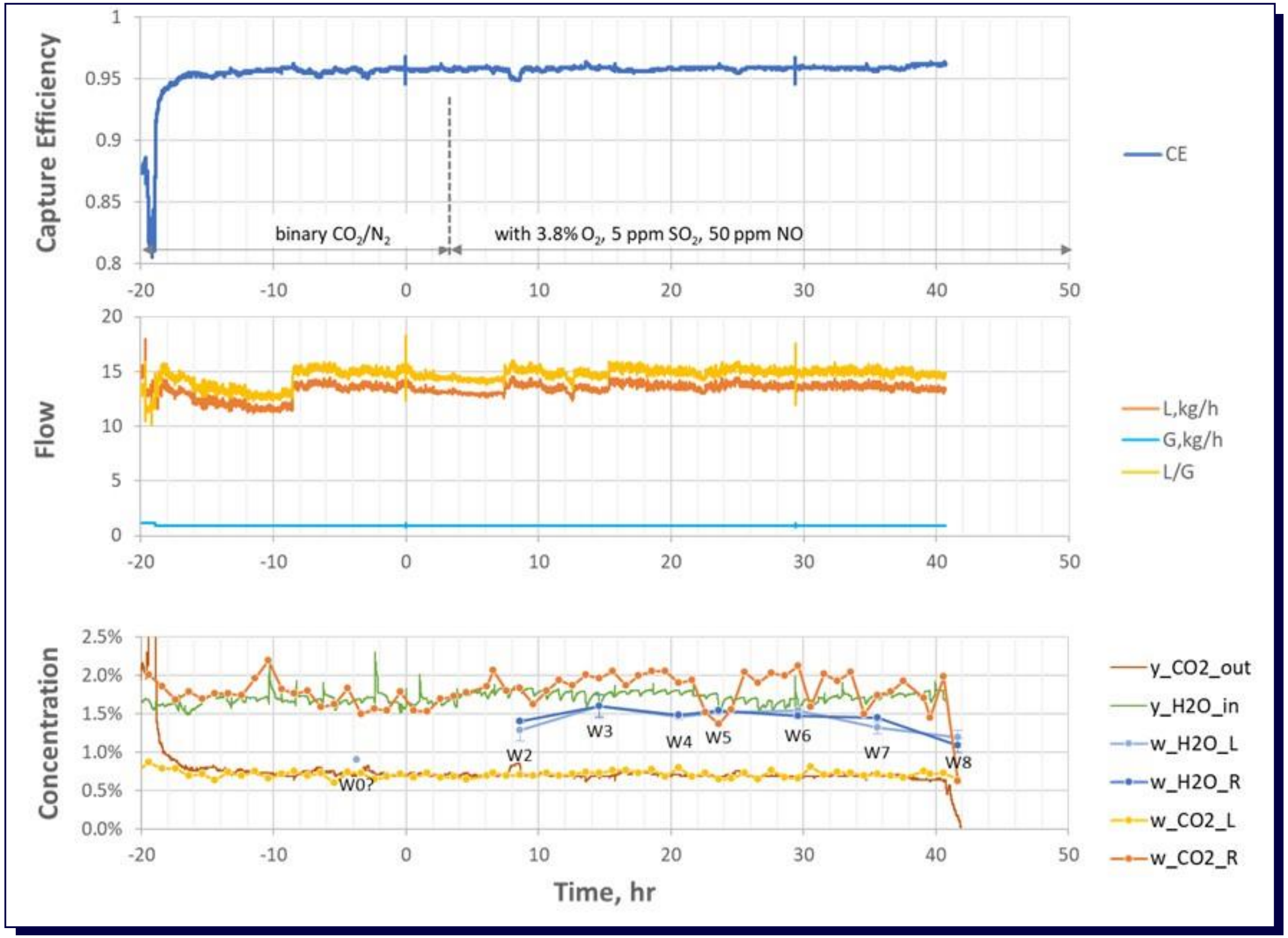


Comparison of thermal degradation of EEMPA with MEA under similar experimental conditions. EEMPA achieved 90% slower degradation than MEA under comparable experimental conditions

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

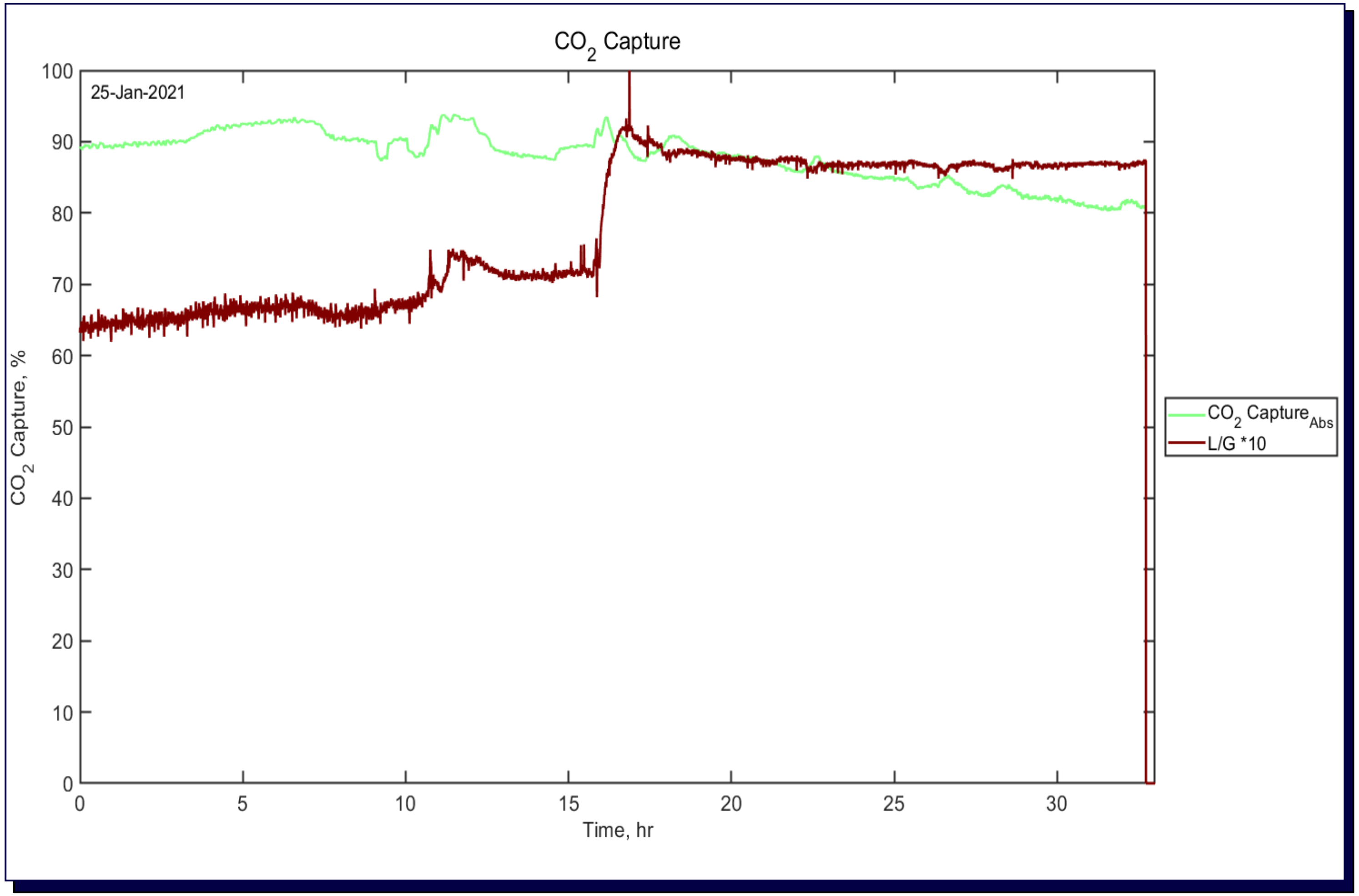
First testing milestone: lab-scale testing (FWP-70924)

- Conducted at PNNL on the **L**aboratory **C**ontinuous **F**low **S**ystem
- Accumulated 40 hours on simulated flue gas
- Achieved a 96% capture rate
- Observed a reboiler duty as low as 2.0 GJ/tonne CO_2

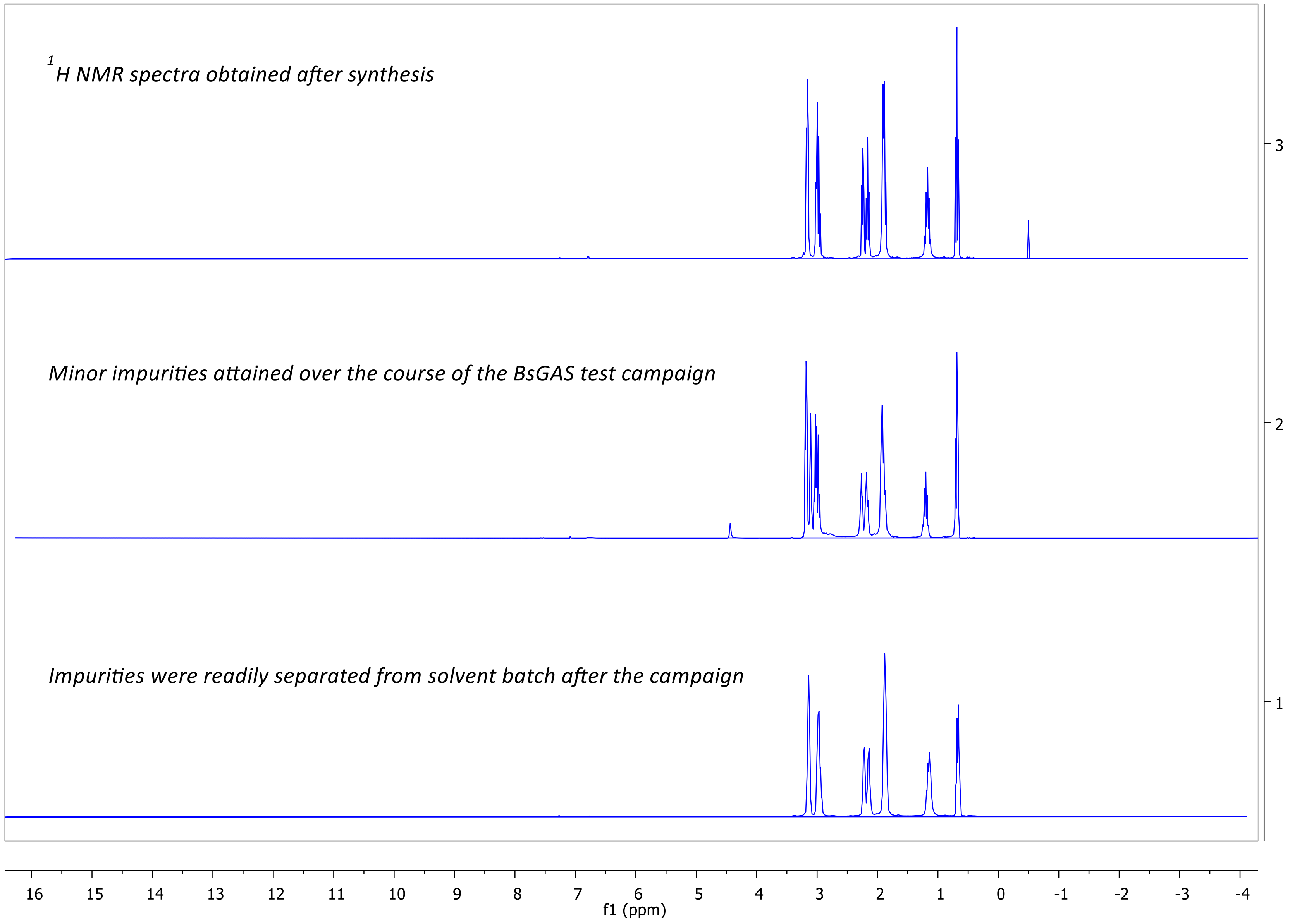


Next stage: bench-scale testing (FWP-70924; FWP-76949)

- Conducted using RTI's **B**ench-**s**cale **G**as **A**bsorption **S**ystem
- Accumulated 137 hours of testing
- Achieved ~90% capture for over 40 hours of the testing
- Tested three regeneration methods
  - Reboiler
  - interstage heaters
  - 2-stage flash



EEMPA exhibited good stability during bench-scale test



The current project: engineering scale testing

Scope

- Develop a route to produce larger volumes of EEMPA
- Plan a test using the Pilot Solvent Test Unit (PSTU) at the National Carbon Capture Center
- Modify PSTU equipment
- 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

Schedule and key milestones

Budget period 1 (Oct 2020 – Dec 2021)	• Develop route for synthesis meeting $10/kg cost target • Execute host site agreement
Budget period 2 (Jan 2022 – Dec 2022)	• Manufacture required solvent volume • Made equipment modifications • Develop test plan
Budget period 3 (Jan 2023 – Mar 2024)	• Min. 2 month coal campaign • Min. 2 month natural gas campaign

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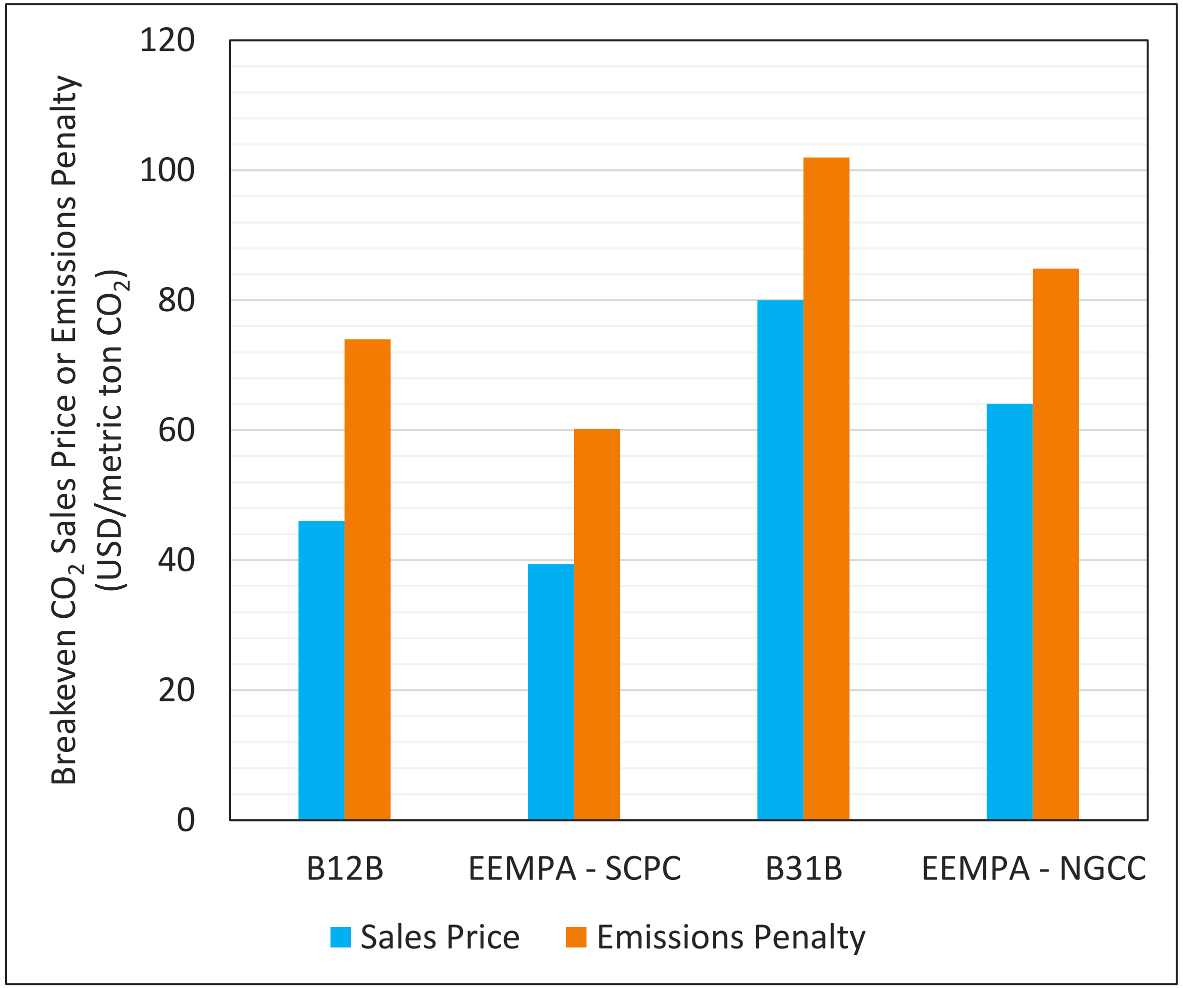
EPRI

Recent progress

Initial techno-economic analysis

- Conducted on Revision 4 basis (NETL-PUB-22638, December 2018 costs)
- Considered 90% capture from both a supercritical coal (SCPC) and natural gas combined cycle (NGCC) plants using a simple stripping configuration
- EEMPA-based capture estimated to achieve 64% and 60% increase in the levelized cost of electricity compared to plants without capture



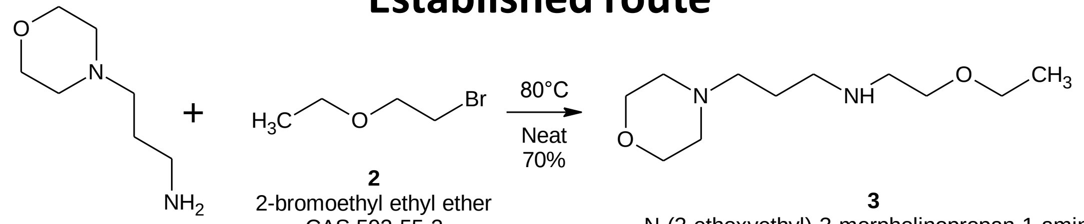
Sales price = cost of CO_2 captured
Emissions penalty = cost of CO_2 avoided

Recent progress

Progress on synthesis

- Present one-step synthesis has a high yield, but relies on reagents that may be hard to source at lower prices
- Current reagents are available at the needed volumes
- Producers have been identified with sufficient resources for manufacturing
- Multiple routes to EEMPA are currently being investigated that would allow use of less expensive raw materials

Established route



1
4-morpholinepropanamine
CAS 123-00-2

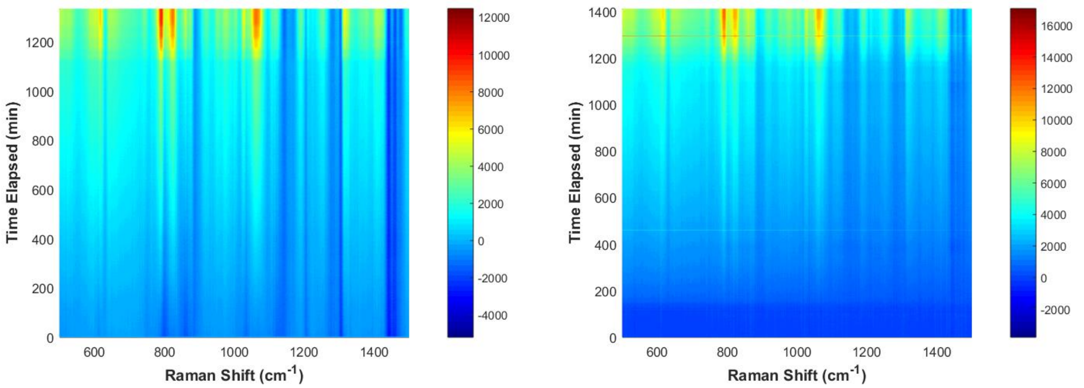
2
2-bromoethyl ethyl ether
CAS 592-55-2

3
N-(2-ethoxyethyl)-3-morpholinopropan-1-amine
Formula Weight: 216.32046

Test planning

- Developing plan for monitoring viscosity, water content, and CO_2 loading to aid process control.
- Raman could be used to track CO_2 loading directly and in real time.

Raman spectra taken over time with exposure to increasing concentration of CO_2.



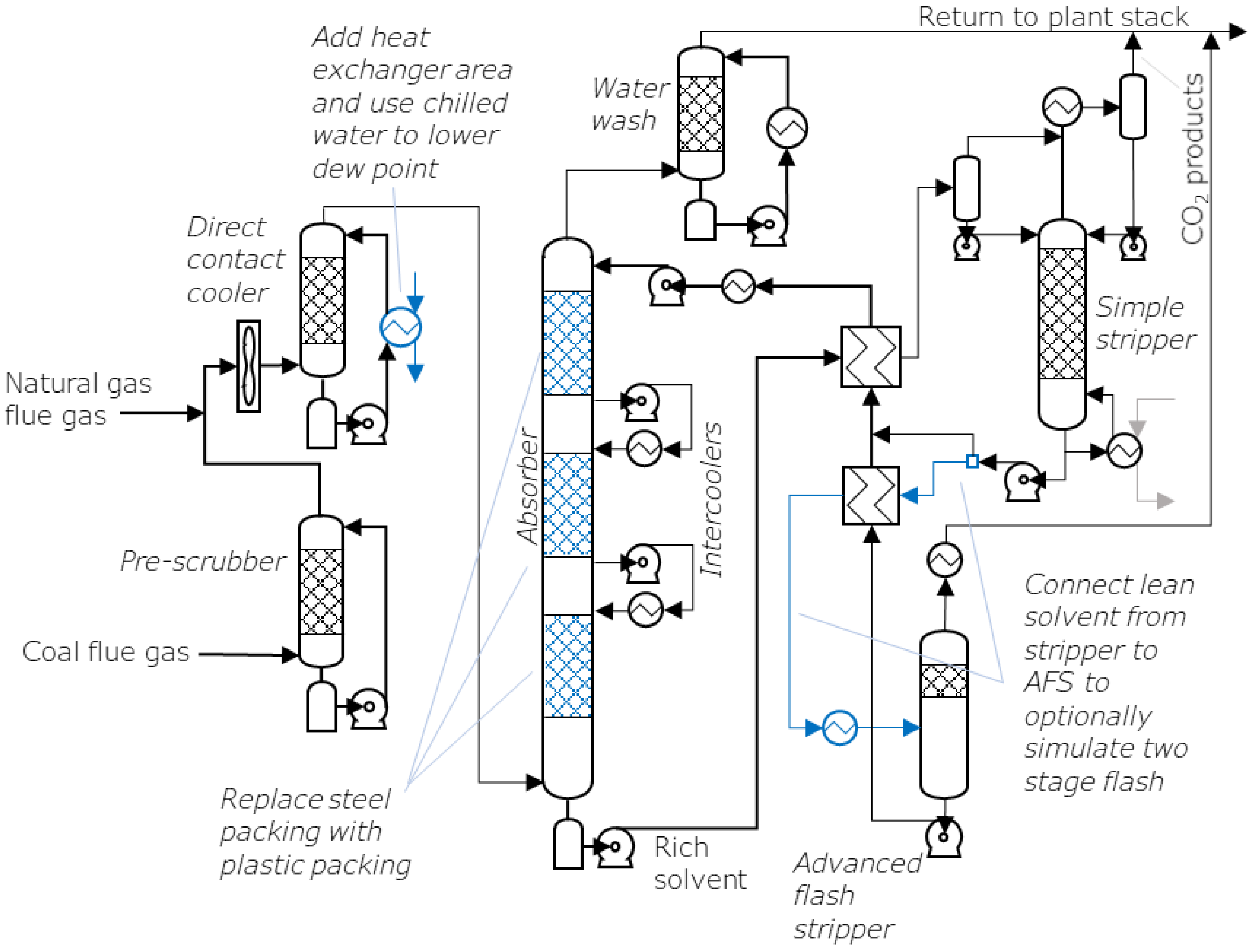
Dry EEMPA

2 wt% water in EEMPA

Recent progress

Test planning

- Aspen Plus models are being developed and verified to predict performance in PSTU equipment.
- Developing plans and equipment specifications for
  - Heat exchanger and chiller for the cooler-condenser
  - Plastic packing for the absorber
  - Flash regeneration using the existing Advanced Flash Stripper equipment



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Future work

Budget period 2 (Jan 2022 – Dec 2022)

- Installation and modification of equipment
- Manufacture of solvent
- Detailed test planning

Budget period 3 (Jan 2023 – Jun 2024)

- Commissioning and parametric testing
- Coal flue gas campaign
- Natural gas flue gas campaign
- Final TEA
- Final EH&S risk assessment

Summary

- EEMPA is promising in several respects
  - It has been demonstrated at the lab & bench scale
  - Low reboiler duty confirmed at both scales
  - Reagents for manufacture of needed quantities can be procured
  - Host site has flexibility to work with optimal configuration
- Progress is being made on developing a larger-scale synthesis method
- Working to develop process modifications to help maintain the water balance of a water-lean solvent

Acknowledgment

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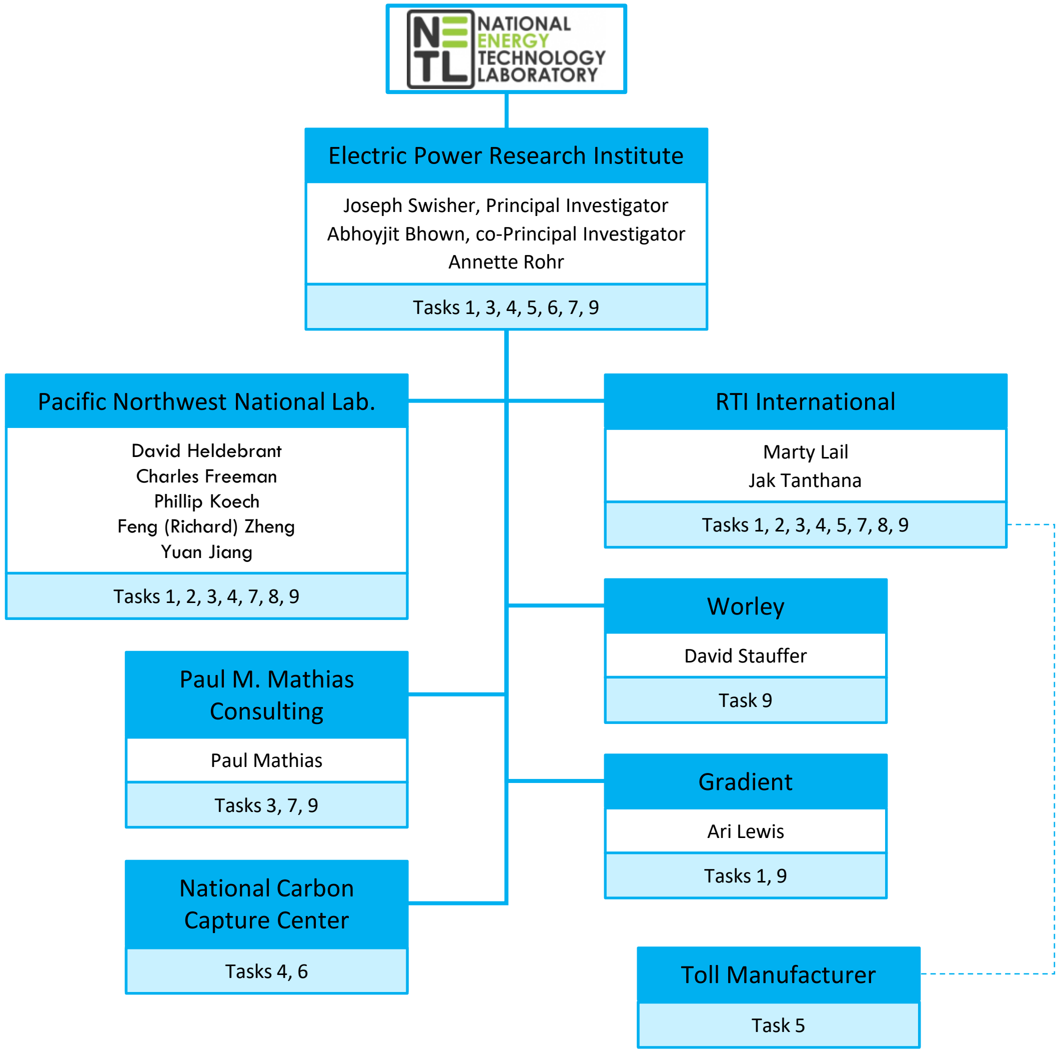
Appendix

Project organization chart with key personnel



All BPs	
Task 1	Project management and planning
Budget Period 1	**Solvent scale-up and design of engineering scale test equipment**
Task 2	Scale-up of solvent production
Task 3	Design of Engineering Scale Test Equipment
Task 4	Host site planning
Budget Period 2	**Solvent manufacture and test facility modification**
Task 5	Manufacture of solvent
Task 6	Construction at host site
Task 7	Test plan development
Budget Period 3	**Testing and data analysis**
Task 8	Operation of Engineering Scale Test
Task 9	Data Analysis and Final Reporting

Gantt Chart

Project start date	1/29/2021				Project ordinal month
Project duration	38 months 17 days				Calendar Month
Project end date	3/31/2024				Calendar quarter

	Task/Subtask Title	***Lead organization***	***Start Date***	***End Date***	***Duration (months)***
All Budget Periods	**Engineering Scale Test of a Water-Lean Solvent**		**1/29/2021**	**3/31/2024**	39
Task 1.0	Project management and planning	EPRI	1/29/2021	3/31/2024	39
Subtask 1.1	Project managment Plan updates	EPRI	1/29/2021	3/31/2024	39
Subtask 1.2	Technology Maturation Plan	EPRI	2/1/2021	4/30/2021	3
Subtask 1.3	Initial Techno-economic analysis and EH&S review	EPRI	2/1/2021	4/30/2021	3
Budget Period 1	**Solvent scale-up and design of engineering scale test equipment**		**2/1/2021**	**12/31/2021**	**11**
Task 2.0	Scale-up of solvent production	PNNL	2/1/2021	12/31/2021	11
Subtask 2.1	Determine best synthesis route for larger scale	PNNL, RTI	2/1/2021	9/30/2021	8
Subtask 2.2	Setup process for larger-scale synthesis	PNNL, RTI	7/1/2021	12/31/2021	6
Task 3.0	Design of Engineering Scale Test Equipment	EPRI	4/1/2021	12/31/2021	9
Subtask 3.1	Adapt models to evaluate test design	PNNL, RTI	4/1/2021	8/30/2021	5
Subtask 3.2	Design and specify equipment	PNNL, RTI	7/1/2021	10/31/2021	4
Subtask 3.3	Develop construction cost and plan	PNNL, RTI	9/1/2021	12/31/2021	4
Task 4.0	Host site planning	EPRI	4/1/2021	12/31/2021	9
Subtask 4.1	Conduct design hazard review	PNNL, RTI	4/1/2021	9/30/2021	6
Subtask 4.2	Exectute host site agreement	EPRI, NCCC	6/1/2021	12/31/2021	7
Subtaks 4.3	Permitting	EPRI, NCCC	9/1/2021	12/31/2021	4
Budget Period 2	**Solvent manufacture and test facility modification**		**1/1/2022**	**12/31/2022**	**12**
Task 5.0	Manufacture of solvent	RTI	1/1/2022	12/31/2022	12
Subtask 5.1	Procurement of raw materials	RTI	1/1/2022	4/30/2022	4
Subtask 5.2	Production and delivery to host site	RTI	3/1/2022	12/31/2022	10
Task 6.0	Construction at host site	EPRI	1/1/2022	12/31/2022	12
Subtask 6.1	Permitting	EPRI, NCCC	1/1/2022	6/30/2022	6
Subtask 6.2	Procurement of equipment	EPRI	1/1/2022	9/30/2022	9
Subtask 6.3	Construction activities at the host site	NCCC	3/1/2022	12/31/2022	10
Task 7.0	Test plan development	EPRI	7/1/2022	12/31/2022	6
Budget Period 3	**Testing and data analysis**		**1/1/2023**	**3/31/2024**	**15**
Task 8.0	Operation of Engineering Scale Test	PNNL	1/1/2023	12/31/2023	12
Subtask 8.1	Shakedown and commissioning	PNNL, RTI	1/1/2023	2/28/2023	2
Subtask 8.2	Parametric testing	PNNL, RTI	3/1/2023	4/30/2023	2
Subtask 8.3	Coal flue gas campaign	PNNL, RTI	5/1/2023	7/31/2023	3
Subtask 8.4	Natural gas flue gas campaign	PNNL, RTI	8/1/2023	11/30/2023	4
Subtask 8.5	De-mobilization, removal and/or disposal of solvent	PNNL	12/1/2023	12/31/2023	1
Task 9.0	Data Analysis and Final Reporting	EPRI	7/1/2023	3/31/2024	9
Subtask 9.1	Analysis of test campaign results	PNNL, RTI	7/1/2023	3/31/2024	9
Subtask 9.2	Final TEA	EPRI, PNNL	9/1/2023	3/31/2024	7
Subtask 9.3	Final EH&S Assessment	EPRI	10/1/2023	3/31/2024	6