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

DE-FE0031945

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2022 Carbon Management Project Review Meeting
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Project Overview

DOE PM Dustin Brown

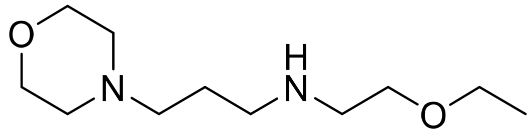
Project period October 2020 to March 2024

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

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Meet the Team

EPRI


Joe Swisher


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Charles Freeman

PMMC, LLC


Paul Mathias

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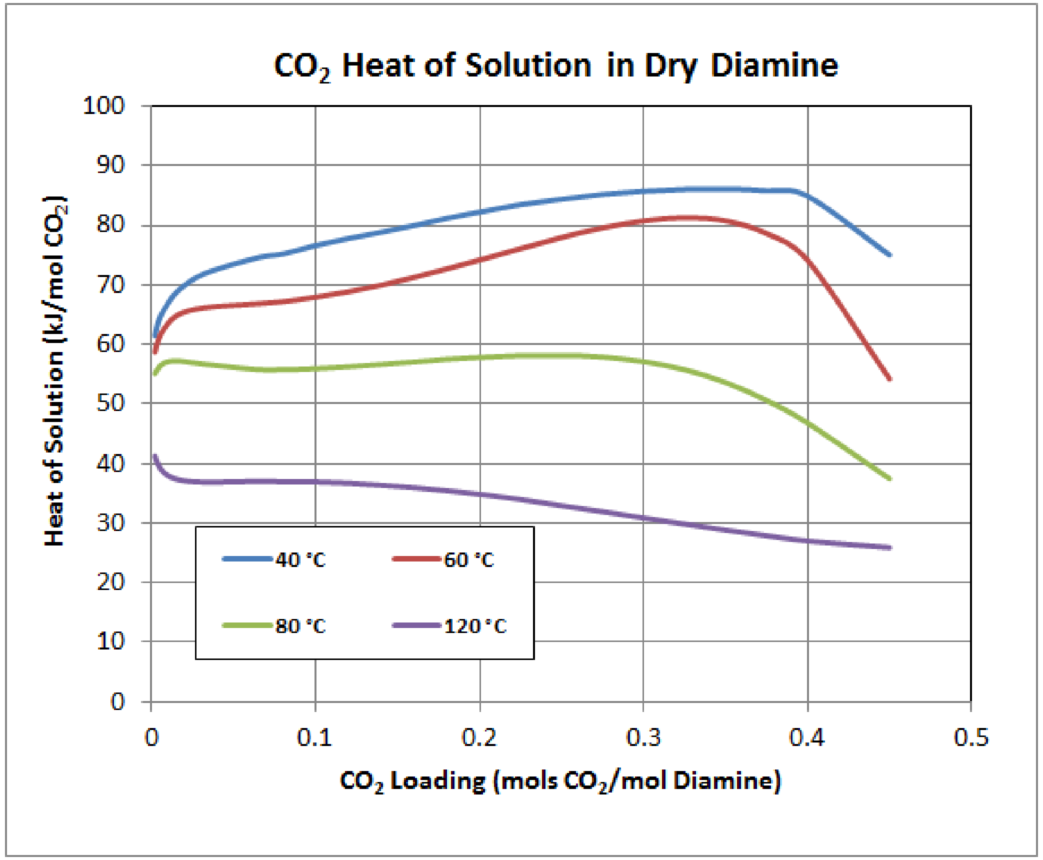
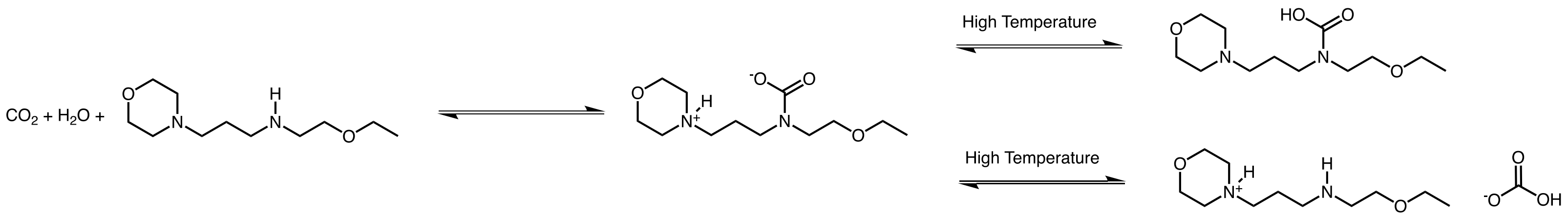
EEMPA can achieve low specific reboiler duties

- The favorable thermal performance is attributable to
  - the low water content (around 2 wt.% or less) meaning less water to vaporize, and
  - 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[1] have been observed in experiments. Cost-optimal designs for coal indicate 2.34 GJ/tonne is achievable.[2]





1. *Energy. Environ. Sci.* (2020), *13*, 4106-4113
2. *IJGHGC*, (2021), *106*, 103279

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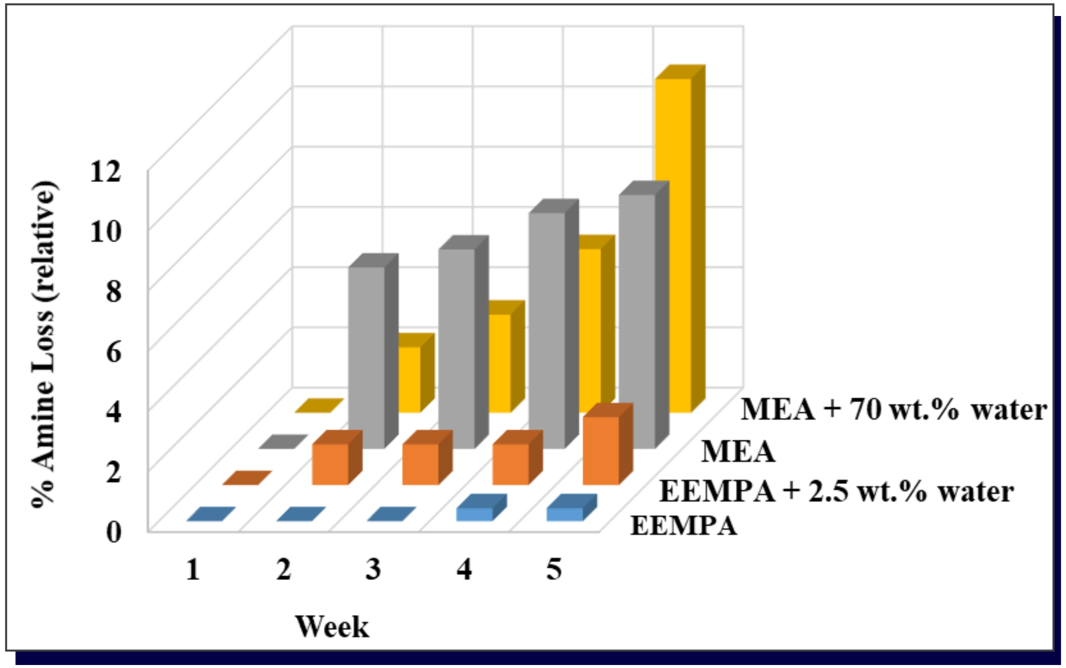
More about EEMPA

- 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

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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

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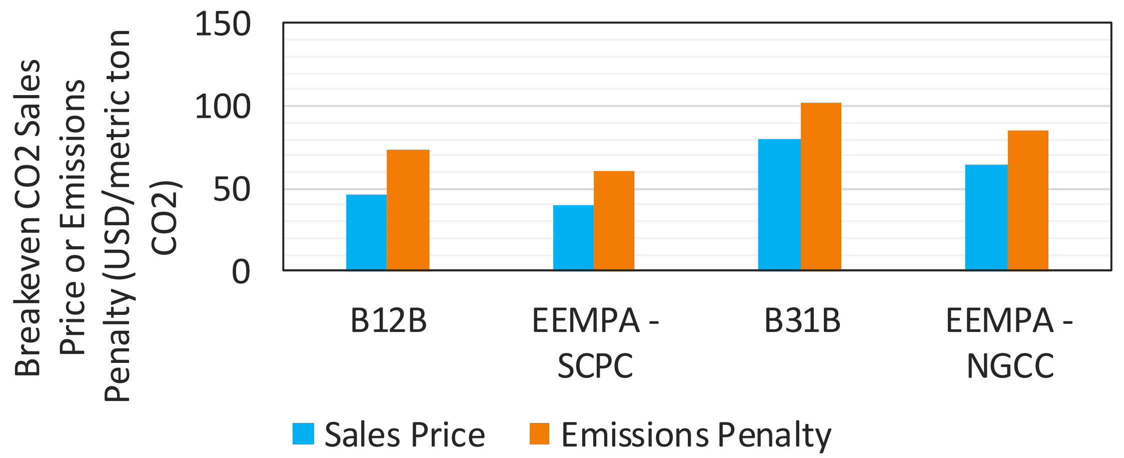
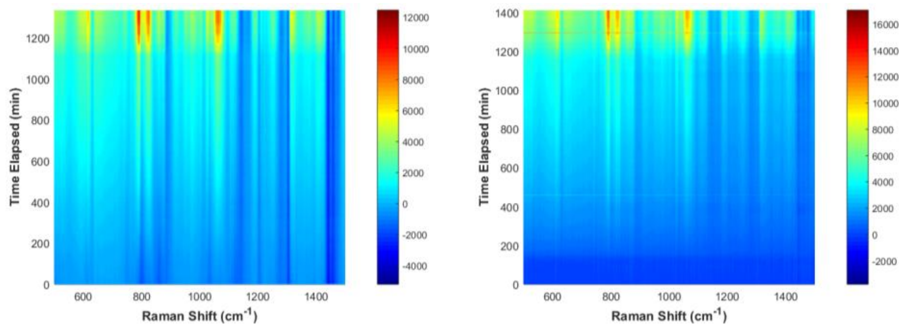
Review of budget period 1 accomplishments

- **Initial TEA** – Estimated costs to capture CO_2 around $39.4/t and $64.1/t for coal and NGCC cases, respectively.
- **Initial EH&S assessment** – used a look-across analysis of structurally similar compounds to provide an initial identification of potential toxicity hazards.
- **Model development** – developed an Aspen Plus model of the PSTU and verified the physical properties model with the most recent experimental data.
- **Raman** – investigated the potential to use Raman as a real-time technique for tracking the loading of the solvent.



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



Dry EEMPA

2 wt% water in EEMPA

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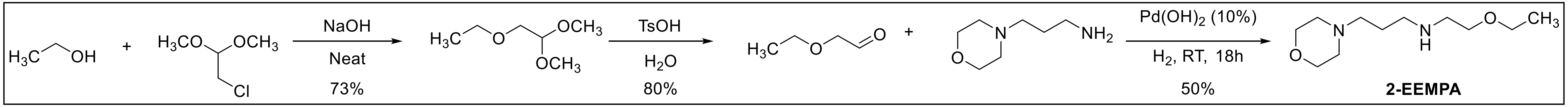
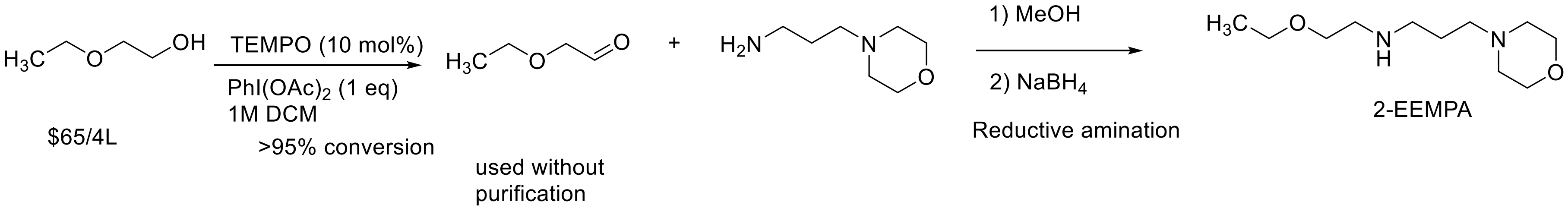
Multi-Step Cost-Effective Synthesis of 2-EEMPA

Route 1



- Three step synthesis of 2-EEMPA starting with cheap, readily available chemicals
- Optimization of the first two steps complete
- Reductive amination step optimization in progress
- Estimated cost of production of using this route at current yields is **$6.42/kg** compared to **$13/kg** for established synthesis

Route 2



- Oxidation of 2-ethoxyethanol using TEMPO/Iodobenzamide diacetate ($PhI(OAc)_2$) works with >95% conversion
- Conservative cost estimate for a catalytic use of reagents, based on 50% yield for all steps is about $6/kg (targeting $4-5/kg)
- Optimization of this two-step, one-pot reaction is ongoing

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Modifying the PSTU for EEMPA

As a water-lean solvent, EEMPA needs two key changes to the PSTU:

1. Cooling the flue gas with low temperature water to lower the dew point of the gas contacting the solvent
2. A different reboiler design to handle the lower thermal conductivity and vapor production compared to an aqueous solvent

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
Pre-scrubber	Btu/hr	74,440-79,200	192,000-225,600
Cooler/condenser	Btu/hr	74,400-79,200	147,600
Total duty	Btu/hr	148,800-158,400	339,600-373,200
	tons of refrigeration	12.4-13.2	28.3-31.1

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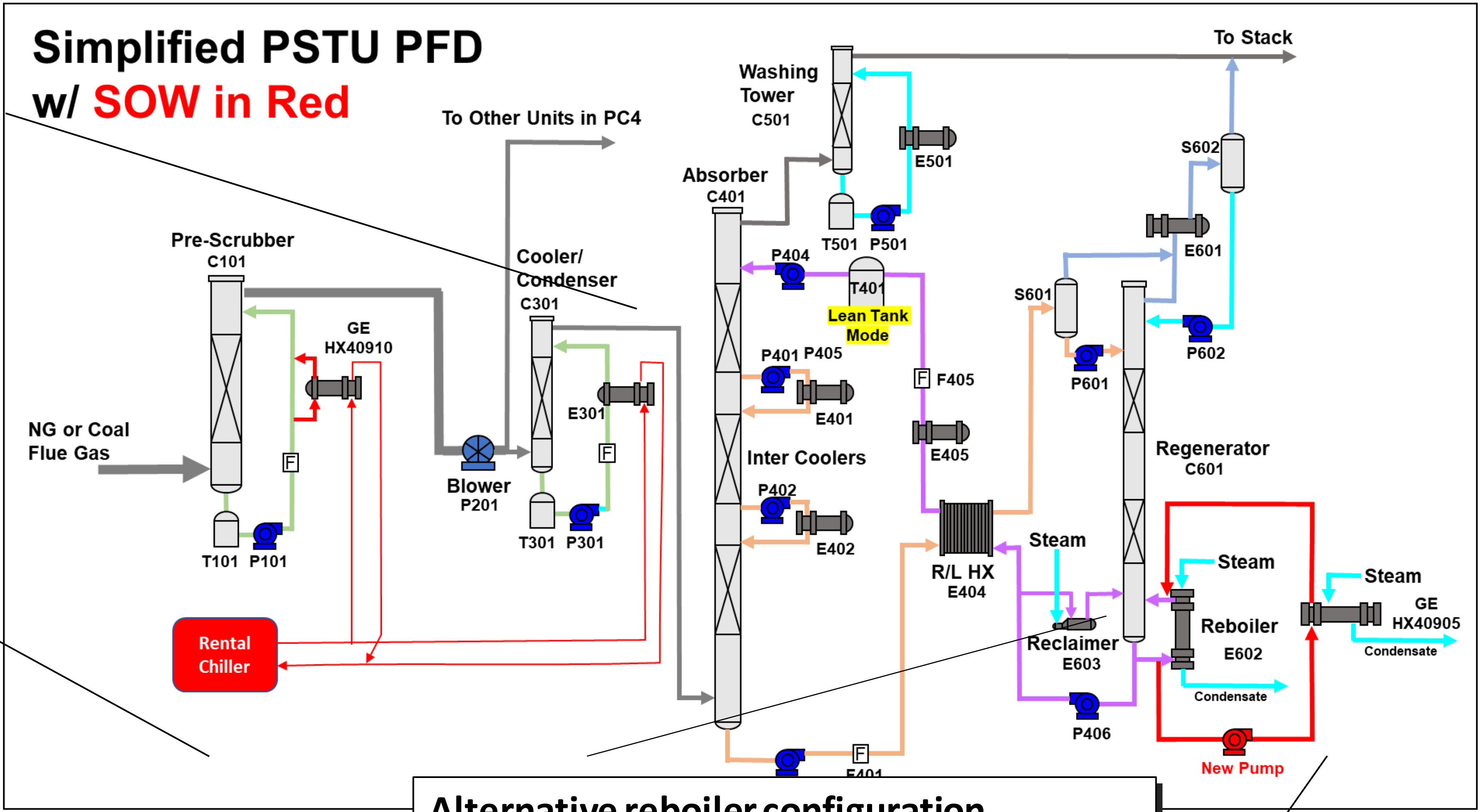
Modifying the PSTU for EEMPA

Cooling the flue gas

Chilled water from an air-cooled chiller would be supplied in a loop to a new exchanger for the pre-scrubber column and the existing exchanger for the cooler/condenser column.

The team is evaluating the re-use of exchangers from the GE-CSTR unit



Alternative reboiler configuration

Switching to forced circulation reboiler with a larger exchanger and a pump would provide sufficient duty for target operations.

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Other considerations for PSTU testing

- **Cooling and water balance**

  In addition to cooling the flue gas, we considered cooling the water wash liquid. However, it was deemed acceptable to rely on addition of water to the wash to maintain water balance rather than the added complexity of cooling the wash water.

- **Plastic packing**

  Evaluating polypropylene structured packings from multiple manufacturers. Initial evaluations suggest they will meet the mass transfer requirements while imposing slightly higher pressure drops than comparable steel packing.

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Next steps

Wrapping up BP1

- Determine which synthesis route is best of the project at this point, meeting both cost and schedule needs
- Finalize and get approval for modifications to the PSTU
- Finalize agreement with NCCC

Major milestones

Budget period 1	• Develop route for synthesis • Execute host site agreement
Budget period 2	• Manufacture required solvent volume • Make equipment modifications • Develop test plan
Budget period 3	• Min. 2-month coal campaign • Min. 2-month natural gas campaign

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Summary

- Potentially competitive alternative syntheses have been developed
- Final engineering is progressing on modifications to the PSTU that would allow good performance of EEMPA
- Work is proceeding to prepare the pieces needed to start testing at the NCCC in 2023

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Appendix

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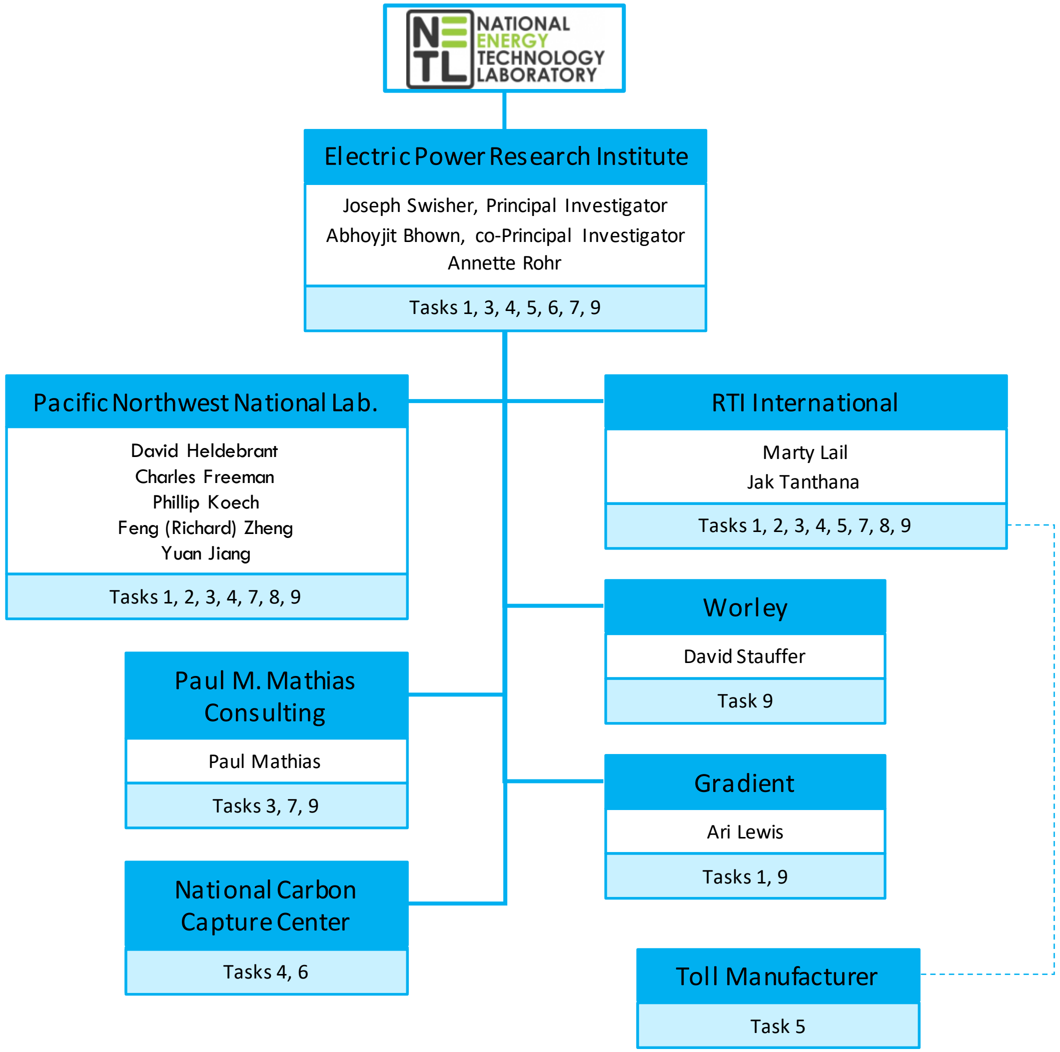
Project organization chart with key personnel



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

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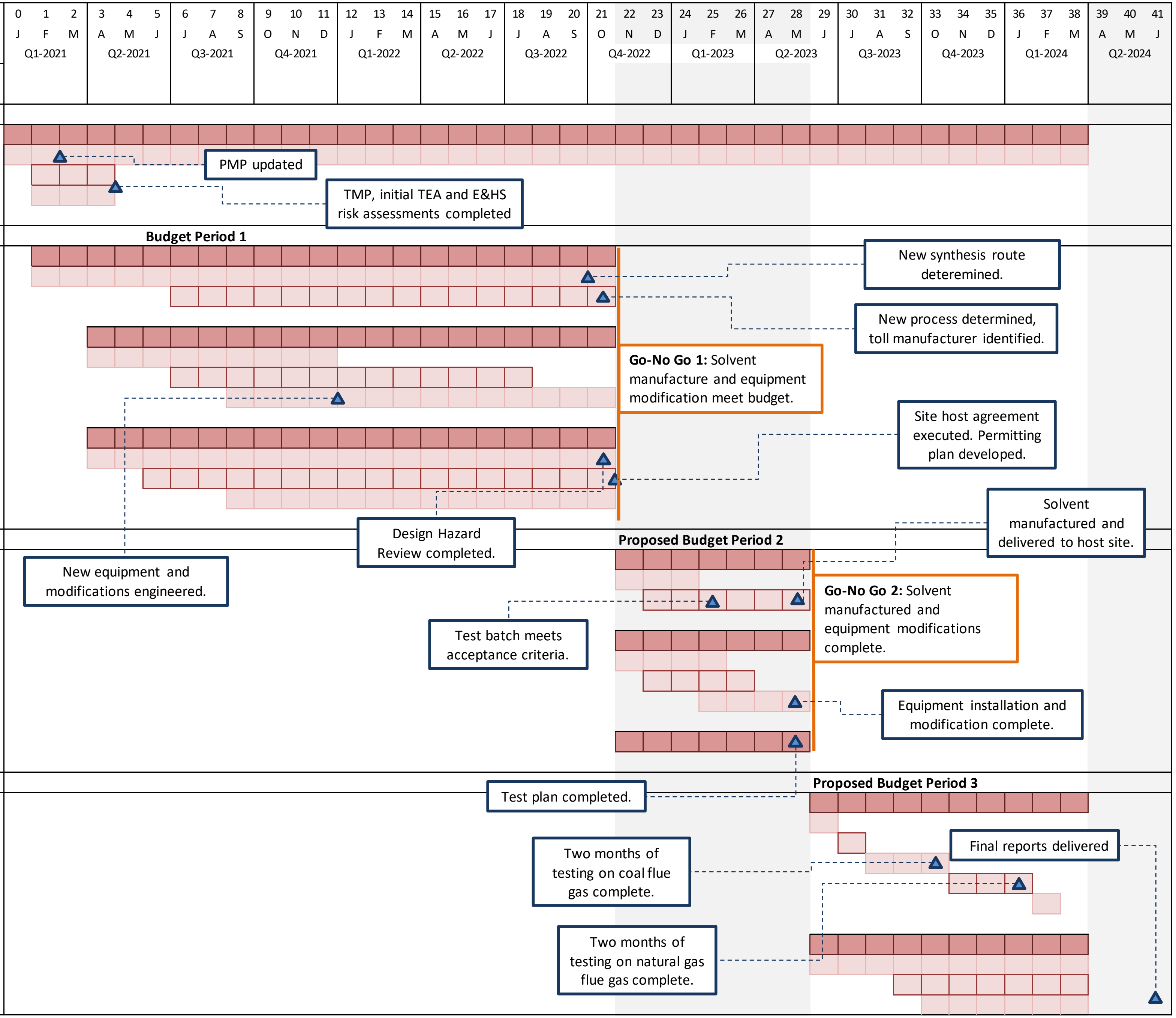
Project start date	1/29/2021
Project duration	38 months 17 days
Project end date	3/31/2024

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



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