Engineering Scale Testing of Transformational Non-Aqueous Solvent-Based CO_2 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

EPRI ELECTRIC POWER RESEARCH INSTITUTE

CCSI^2 Carbon Capture Simulation for Industry Impact

Technology Background

New coal-fired power plants with CO_2 capture at a cost of electricity 30% lower than the baseline cost of electricity from a supercritical PC plant with CO_2 capture, or approximately $30 per tonne of CO_2 captured by 2030.

Breakdown of the Thermal Regeneration Energy Load

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

Reboiler Heat Duty | Sensible Heat | Heat of Vaporization | Heat of Absorption

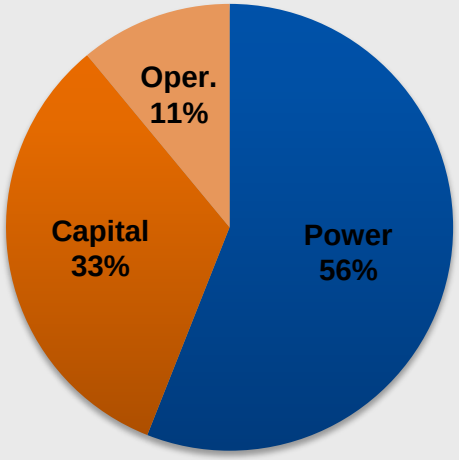
Solvent	C_p [J/g K]	ΔH_{abs} [kJ/mol]	ΔH_{vap} [kJ/mol]	x_{solv} [mol solvent/mol solution]	$\Delta\alpha$ [mol CO_2/ mol solvent]	Reboiler Heat Duty [GJ/t-CO_2]
30 wt% MEA-H_2O	3.8	85	40	0.11	0.34	3.75
RTI's NASs	2.0	85	negl.	0.47	0.45	2.40

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

Path to Reducing ICOE and Cost of CO_2 Avoided

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



[1] Rochelle, G. T. Amine Scrubbing for CO_2 Capture. *Science* **2009,** 325, 1652-1654.

Technology Background

Lab-Scale Development & Evaluation (2010-2013)

Solvent screening and Lab-scale evaluation

~$2.7MM

Large Bench-Scale System (RTI facility, 2014-2016)

Demonstration of key process features (≤ 2,000 kJ/kg CO_2) at bench scale

~$3 MM
6kW

Pilot Testing at Tiller Plant (Norway, 2015-2018)

Demonstration of all process components at pilot scale

~$3MM
60 kW

Pilot Testing at SSTU (NCCC, 2018)

Degradation, emission, and corrosion characterizations under real flue gas

~$0.75MM
50 kW

Emissions control (Tiller, 2018+)

Effective emissions mitigation strategy for WLS at engineering-scale

~$3.5MM

Engineering-Scale Validation (2018+)

Pre-commercial Demonstration at Technology Centre Mongstad, Norway (~12 MWe)

~$18.75 MM
12 MW

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

Decision Point	Date	Success Criteria
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

Task No.	Milestone No.	Milestone Description	Planned Completion Date	Actual Completion Date
1.0	1	Updated Project Management Plan (PMP)	Oct. 31, 2018	Sept. 5, 2018
1.0	2	Project Kickoff Meeting	Oct. 31, 2018	Oct. 2, 2018
1.0	3	Initial TMP	Dec. 31, 2018	Dec. 31, 2018
2.0	4	EH&S report as outlined in Appendix E of the FOA	Jan. 31, 2019	Jan. 31.2019
3.0	5	Solvent qualification test results	July 31, 2019	January 17th, 2020
4.0	6	FEED study and cost estimate	Dec. 31, 2019	February 4th, 2020
5.0	7	Submit requisition for interstage cooler heat exchanger to fabricator	March 31, 2021	February 24, 2021
5.0	8	Submission of purchase order to manufacturer for initial solvent fill	May 31, 2021	June 25, 2021
5.0	9	Receive forced recirculation pump for regenerator for installation at host site	November 15, 2021	
6.0	10	NAS solvent batch (~80 tons) delivered to TCM site	December 31, 2021	
5.0	11	Commissioning of the revamped unit	January 31, 2022	
7.0	12	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	June 30, 2022	
8	13	Confirmation of decommissioning and waste handling	September 30, 2022	
9	14	Final TEA according to DOE guidelines	December 31, 2022	
10	15	EH&S report as outlined in Appendix E of the FOA	December 31, 2022	
10	16	Maturation Plan and Technology Gap Analysis following DOE guidelines in FOA appendices	December 31, 2022	

Risk and Mitigation Strategies

Description of Risk/Area		Probability	Impact	Risk Management
Material	Cost and Availability of NAS Components	Low	High	Discussions with Clariant to confirm solvent can be supplied in the required quantities. Very low risk now, production underway.
Process	Solvent Loss	Low	Moderate	Evaluated an activated carbon bed wash system to confirm recovery of solvent at bench-scale
Process	Solvent Loss due to Aerosols, Solvent Emissions	Moderate	Moderate	Confirmed ability to reduce solvent loss via recovery of solvent using activated bed wash system to < 3 ppm at RTI's bench-scale system.
Process	Inability to meet TCM emission limits of < 1 ppm	Moderate	High	Evaluated and confirmed ability to control emissions to < 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.
Process	Extended Solvent Exposure to Coal-derived Flue Gas	Moderate	Moderate	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.
Process	Water Management	Low	High	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.

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

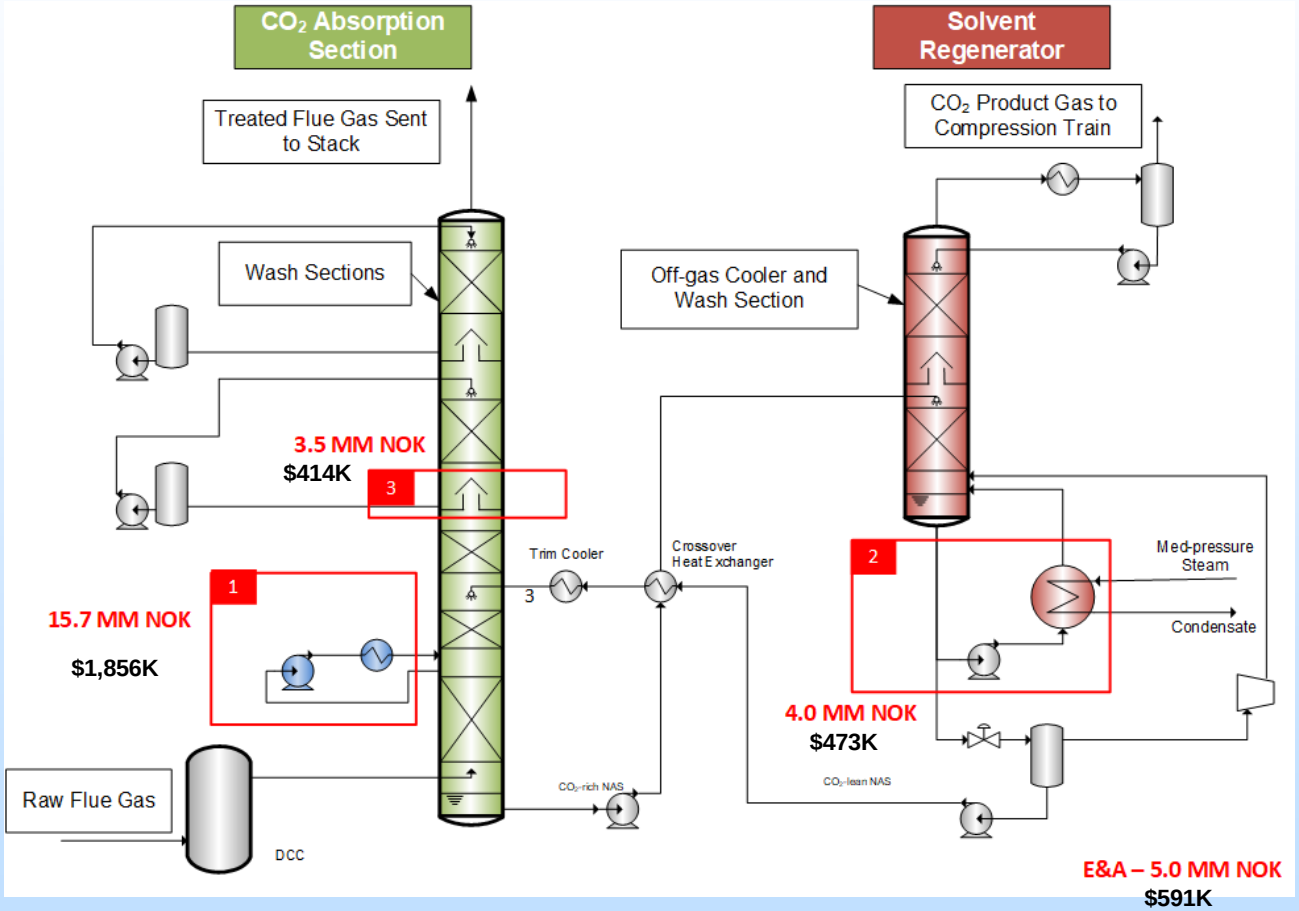
Task 1: Project Management

	Description
1	Completed BP2 Continuation Application process
2	Finalized and signed test agreement with TCM
4	Held frequent meeting with Pressura and TCM in early stages of detailed engineering and procurement of long lead items
3	Holding monthly meetings with PM Andrew Jones and colleagues at NETL, TCM, and Pressura
4	Held bi-weekly meeting with Clariant and TCM February – April to plan solvent logistics
5	Held bi-weekly meeting with TCM advisory services to iron out analytical tests, REACH registrations, initial solvent fill volumes, and refine the process model.
6	Navigated increase in volumetric requirements and pricing updates and generated PO for solvent purchase
7	Identified make-up amine providers and selected source which could be delivered within budget
8	Helped researchers work on campus during the coronavirus pandemic to perform essential experiments

Scientific Stature

1) Gupta, V.; Mobley, P.; Tanthana, J.; Cody, L.; Barbee, D.; Lee, J.; Pope, R.; Chartier, R.; Thornburg, J.; Lail, M., Aerosol emissions from water-lean solvents for post-combustion CO_2 capture. *International Journal of Greenhouse Gas Control* **2021,** *106*, 103284.
2) Lail, M.; Mobley, P.; Rayer, A. V.; Gupta, V.; Soukri, M.; Faramarzi, L.; Hantveit, K.; Benquet, C.; Nesse, S. O.; Jones, A.; Davison, M.; Figueroa, J.; Brickett, L.; Litynski, J. In *Engineering Scale Testing of Transformational Non-Aqueous Solvent-Based CO_2 Capture Process at Technology Centre Mongstad*, 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting, Pittsburgh, PA, August 28, 2019; Pittsburgh, PA, **2019**
3) Paul Mobley; Aravind V. Rayer; Jak Tanthana; Vijay Gupta; Mustapha Soukri; S. James Zhou. In *Corrosion Analysis of RTI's Non-Aqueous Solvent for Carbon Capture*, 2019 AIChE Annual Meeting, Orlando, FL, November 11th, 2019; Orlando, FL, **2019**
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 (CH_4, C_2H_6) and acid gases (CO_2 and H_2S) at 298-353K. *Journal of Chemical and Engineering Data* **2019,** *64* (2), 545-556.
5) Rayer, A. V.; Mobley, P. D.; Soukri, M.; Gohndrone, T. R.; Tanthana, J.; Zhou, J.; Lail, M., Absorption rates of carbon dioxide in hydrophilic and hydrophobic solvents. *Chemical Engineering Journal* **2018,** *348*, 514-525.

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

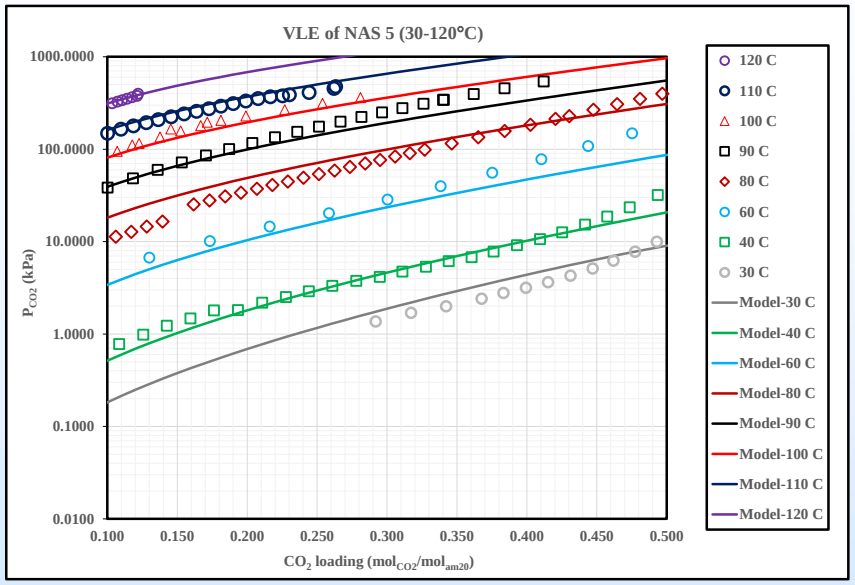
Solvent and Diluent

- 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

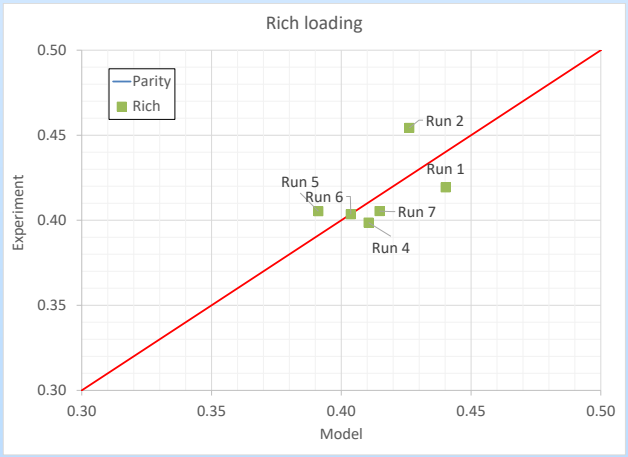
- Sourced three suppliers for make-up amine
- Targeting ~$6/kg, received $5.43/kg
- Received COA on product
- Received green light from TCM for HSE
- Supplier can easily supply requisite volume to meet schedule
- PO submitted to supplier for make-up amine

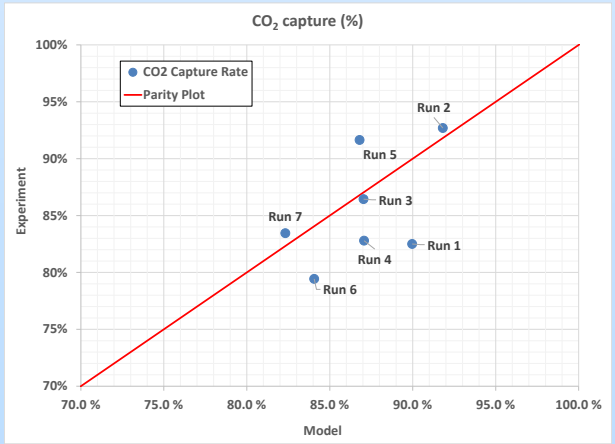
Task 7: NAS Modified Amine Plant Test Plan Development, Testing, and Data Analysis



- Working with TCM Advisory Services on NAS process model refinement.
- Working with CCSI^2 on quantifying uncertainty in model predictions

Model Predictions for NAS VLE





Preliminary results for prediction of Tiller qualification runs

Progress Since Last Year

Description	Status / BP2 Achievement
Successful completion of Continuation Application Process	Continuation into BP2 **approved** by DOE and started in November 2020.
Detailed engineering of equipment for modifications	**Completed** detailed engineering of heat exchanger, piping, pumps, instrumentation, valves, and civil supports for modifications to amine unit.
Procurement of identified long-lead equipment items for delivery during the construction phase.	**Completed** in June. All estimated deliveries are within the scheduled 90-day construction and installation period. Met the project milestone for PO submissions.
Procurement of solvent volume required for testing.	**PO submitted** to Clariant to produce 75 tons anhydrous solvent. Met the project milestone for PO submission.
TCM approval for storage of make-up amine on site during test campaign	Solvent storage **approved** after flash-point measurement and identification of suitable safe storage conditions.
Identification of supplier for make-up amine	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.

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.

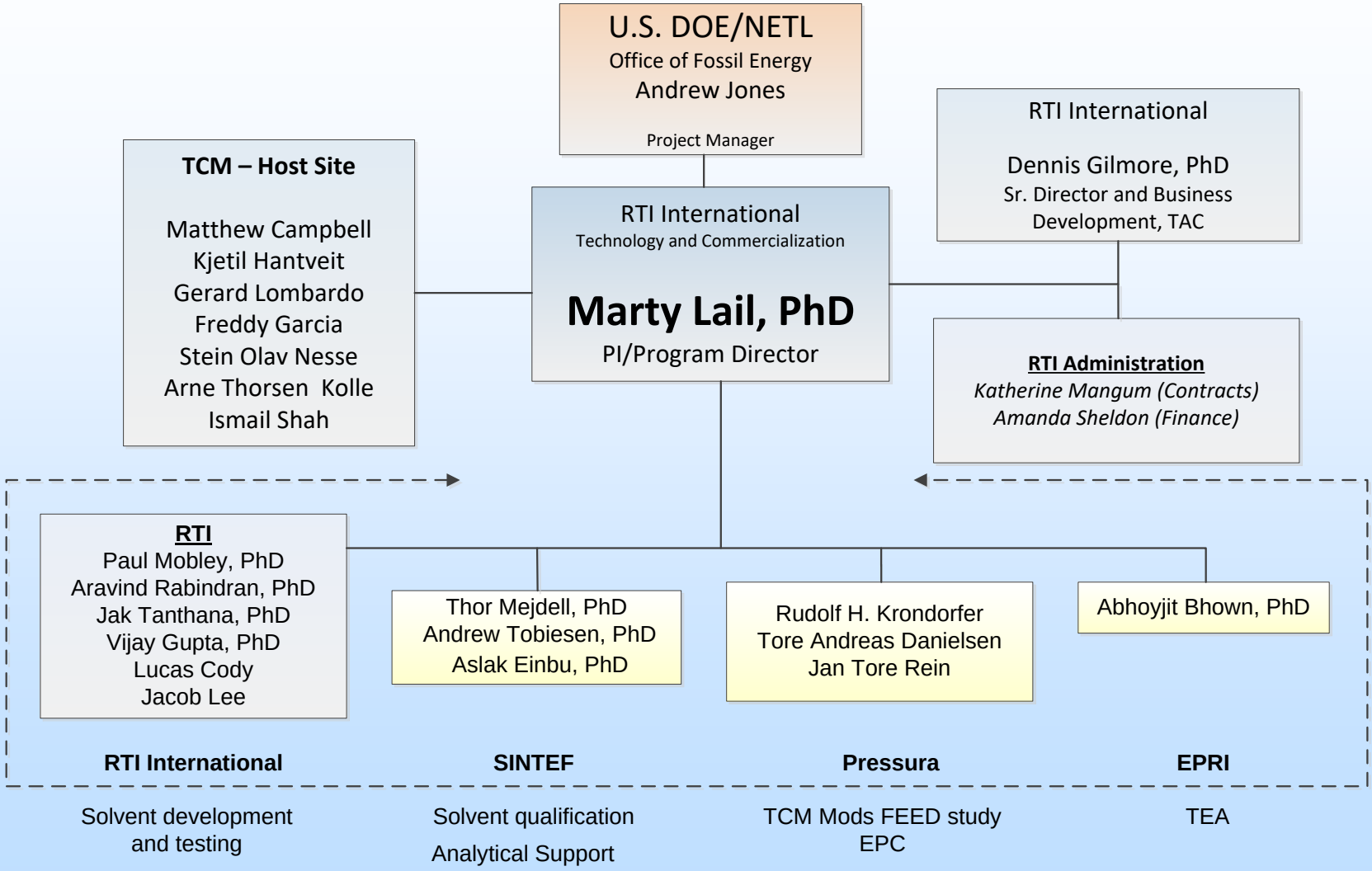
Summary

- 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.

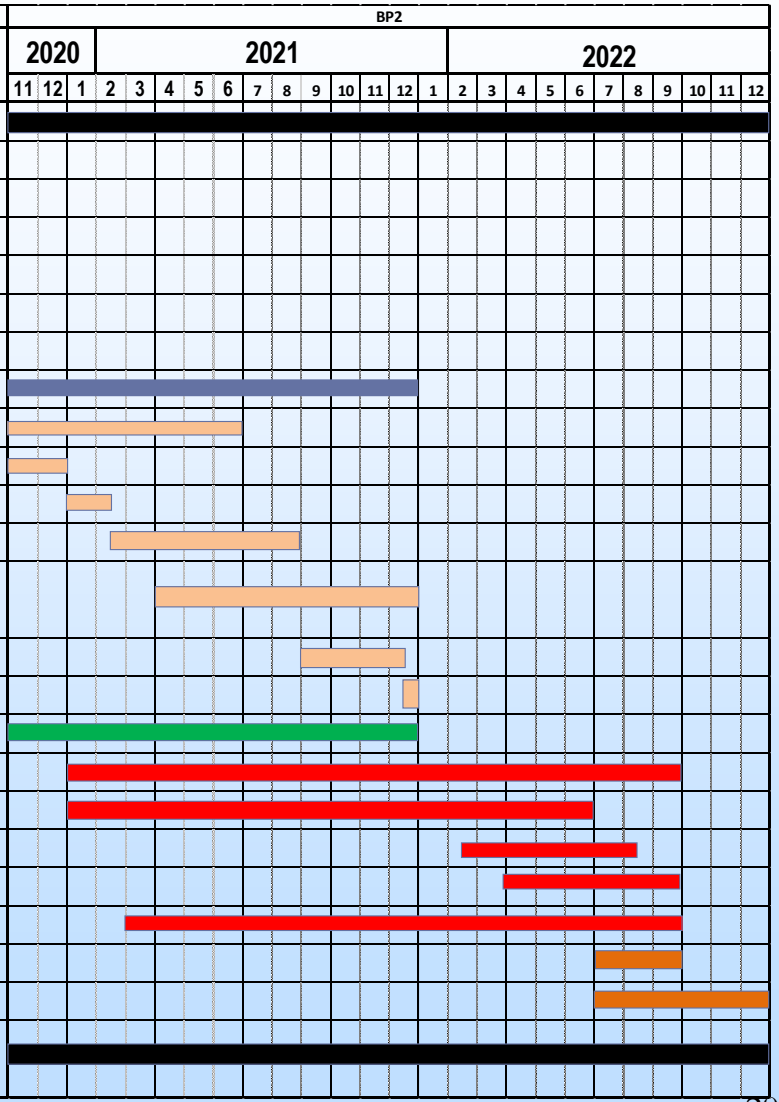
Organization Chart



Development Team

Gantt Chart

#	Task title	Start date	End date
1.0	Project Management and Planning	08/08/18	12/31/22
	1.1 Test Agreement with TCM	08/08/18	09/30/20
2.0	EH&S and Risk Evaluation and Permitting	08/08/18	02/28/19
3.0	Solvent Qualification	03/01/19	01/31/20
4.0	Preliminary Design of a NAS Optimized System	08/01/19	07/31/20
	4.1 Pre-FEED	08/01/19	09/30/19
	4.2 FEED study	10/01/19	02/28/20
5.0	Revamp Implementation	10/01/20	12/31/21
	5.1 Detailed Engineering and Procurement	10/01/20	06/30/21
	5.11 Design Freeze	11/01/20	12/31/20
	5.12 Long Lead Items Ordered	01/01/21	02/12/21
	5.13 Long Lead Items Received	02/12/21	09/01/21
	5.2 Interstage Cooler and Recirculation Pump Install	04/01/21	12/31/21
	5.21 Installation and Commisisoning	09/01/21	12/15/21
	5.22 Mod Project Closeout	12/15/21	12/31/21
6.0	Solvent Production	10/01/20	12/03/21
7.0	Test Plan Development, Testing, Data Analysis	01/01/21	06/30/22
	7.1 Modified Amine Plant Test Plan Development		
	7.2 NAS Modified Amine Plant Testing		
	7.3 NAS Modified Amine Plant Data Analysis		
	7.4 EPRI Third Party Verification		
8.0	Decommissioning and Waste Handling	07/01/22	09/30/22
9.0	Final TEA (550 MW Net)	07/01/22	12/31/22
10.0	Cost Benefit Analysis and Technology Mat Planning	10/01/20	12/31/22



Milestone Log

Task No.	Milestone No.	Milestone Description	Planned Completion Date	Actual Completion Date	Verification Method
1.0	1	Updated Project Management Plan (PMP)	Oct. 31, 2018	Sept. 5, 2018	PMP file
1.0	2	Project Kickoff Meeting	Oct. 31, 2018	Oct. 2, 2018	Presentation file
1.0	3	Initial TMP	Dec. 31, 2018	Dec. 31, 2018	TMP file
2.0	4	EH&S report as outlined in Appendix E of the FOA	Jan. 31, 2019	Jan. 31.2019	Topic report
3.0	5	Solvent qualification test results	July 31, 2019	January 17th, 2020	Quarterly report
4.0	6	FEED study and cost estimate	Dec. 31, 2019	February 4th, 2020	Quarterly report
5.0	7	Submit requisition for interstage cooler heat exchanger to fabricator	March 31, 2021	February 24th, 2021	Quarterly report
5.0	8	Submission of purchase order to manufacturer for initial solvent fill	May 31, 2021	July 16th, 2021	Quarterly report
5.0	9	Receive forced recirculation pump for regenerator for installation at host site	September 30, 2021		Quarterly report
6.0	10	NAS solvent batch (~50 tons) delivered to TCM site	December 31, 2021		Quarterly report
5.0	11	Commissioning of the revamped unit	January 31, 2022		Quarterly report
7.0	12	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	June 30, 2022		Quarterly report
8	13	Confirmation of decommissioning and waste handling	September 30, 2022		Quarterly report
9	14	Final TEA according to DOE guidelines	December 31, 2022		Topical report
10	15	EH&S report as outlined in Appendix E of the FOA	December 31, 2022		Topical report
10	16	Maturation Plan and Technology Gap Analysis following DOE guidelines in FOA appendices	December 31, 2022		TMP file and Gap Analysis report