Engineering Scale Testing of Transformational Non-Aqueous Solvent-Based CO_2 Capture Process at Technology Centre Mongstad

DE-FE0031590

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Capture

2020 Integrated Review Webinar

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Program 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
- Maximize NAS performance with plant modifications

Program Overview

Funding

- Total $ 18,738,512**
- DOE $ 10,013,512
- Cost-share $ 8,725,000

Project Performance Dates

- August 8, 2018 – December 31, 2022

Project Participants

RTI INTERNATIONAL

TECHNOLOGY CENTRE MONGSTAD

PRESSURA

SINTEF

EPRI ELECTRIC POWER RESEARCH INSTITUTE

CCSI² Carbon Capture Simulation for Industry Impact

**Pending approval

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

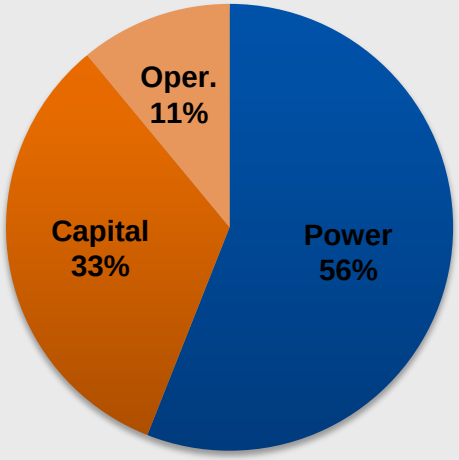
Solvent	C_p [J/g K]	ΔH_{abs} [kJ/mol]	ΔH_{vap} [kJ/mol]	x_{solv} [mol solvent/mol solution]	$\Delta\alpha$ [mol CO_2/ mol solvent]	Reboiler Heat Duty [GJ/t-CO_2]
30 wt% MEA-H_2O	3.8	85	40	0.11	0.34	3.75
RTI's NASs	2.0	85	negl.	0.47	0.45	2.40

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

Decision Point	Date	Success Criteria
Completion of BP1	09/31/2020	1. Successful completion of all work proposed in Budget Period 1 2. Submission of a Preliminary Technology Maturation Plan (TMP) 3. Completion of large batch NAS qualification testing at SINTEF's Tiller facility (100 hours) with results showing L/G ratio of 2.5 to 4 with 90% CO_2 capture from coal flue gas composition and a specific reboiler duty < 2.3 GJt/tonne CO_2. 4. Acceptance of RTI's detailed design and final cost estimate for TCM amine plant modifications to accommodate NAS testing at engineering scale 5. Submission of TCM Test Agreement and TCM Signed Cover Letter

Gantt Chart – Milestone Log

Milestone	Task No.	Milestone Description	Planned Completion Date	Verification Method
A	1	Updated Project Management Plan (PMP)	Oct 31, 2018	PMP file
B	1	Project Kickoff Meeting	Oct 31, 2018	Presentation file
C	1	Initial TMP	Dec 31, 2018	TMP file
D	2	EH&S report as outlined in Appendix E of FOA	Jan 31, 2019	Topic report
E	3	Solvent qualification test results	Jul 31, 2019	Quarterly report
F	4	FEED study cost estimate	Dec 31, 2019	Quarterly report
G	5	Commissioning of the revamped unit	Jan 30, 2022	Quarterly report
H	6	NAS solvent batch (~50 tons) delivered to TCM site	Dec 31, 2021	Quarterly report
I	7	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	Jun 30, 2022	Quarterly report
J	8	Confirmation of decommissioning and waste handling	Sep 31, 2022	Quarterly report
K	9	Final TEA according to DOE guidelines	Dec 31, 2022	Topical report
L	10	EH&S report as outlined in Appendix E of the FOA	Dec 31, 2022	Topical report
M	10	Maturation Plan and Technology Gap Analysis following DOE guidelines in FOA appendices	Dec 31, 2022	TMP file & Gap Analysis report

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.
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 CO2 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

Task 1: Project Management and Planning
Task 2: TCM EH&S Risk Evaluation and Permitting
Task 3: Solvent Qualification
Task 4: FEED Study of NAS-Specific TCM Amine Plant Modifications

	Task No.	Milestone No.	Milestone Description	Planned Completion Date	Actual Completion Date	Verification Method	
BP1	1	1	Updated Project Management Plan (PMP)	Oct 31, 2018	Sep 05, 2018	PMP file	☑
	1	2	Project Kickoff Meeting	Oct 31, 2018	Oct 02, 2018	Presentation file	☑
	1	3	Initial TMP	Dec 31, 2018	Dec 31, 2018	TMP file	☑
	2	4	EH&S report as outlined in Appendix E of FOA	Jan 31, 2019	Jan 31, 2019	Topic report	☑
	3	5	Solvent qualification test results	Jul 31, 2019	Jan 24, 2020[a]	Quarterly report	☑
	4	6	FEED study cost estimate	Dec 31, 2019	Feb 04, 2020	Quarterly report	☑
BP2	5	7	Commissioning of the revamped unit	Jan 30, 2022		Quarterly report	
	6	8	NAS solvent batch (~50 tons) delivered to TCM site	Dec 31, 2021		Quarterly report	
	7	9	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	Jun 30, 2022		Quarterly report	
	8	10	Confirmation of decommissioning and waste handling	Sep 31, 2022		Quarterly report	
	9	11	Final TEA according to DOE guidelines	Dec 31, 2022		Topical report	
	10	12	EH&S report as outlined in Appendix E of the FOA	Dec 31, 2022		Topical report	
	10	13	Maturation Plan and Technology Gap Analysis following DOE guidelines in FOA appendices	Dec 31, 2022		TMP file & Gap Analysis report	

[a] Completion of second attempt at qualification

Task 1: Project Management

Description	
1	Successfully managing a re-budget of the project in September 2019
2	Working out the details of the pre-FEED and FEED study engineering support sub-contract with TCM, Pressura, and DOE
3	Arranging a second solvent qualification test with SINTEF to replace the first unsuccessful attempt
4	Arranging for the purchase, production, budgeting, and delivery of a second batch of solvent for qualification testing with Clariant
5	Arranging a workshop at SINTEF with lead engineers from TCM during testing of NAS at the CO_2 Lab at Tiller
6	Navigating a change in planned regenerator modification in the FEED study resulting from TCM-Pressura haz-op analysis and coming up with an acceptable design for regenerator modification
7	Arranging NDAs for collaboration with CCSI[2]
8	Obtaining permission for limited researchers to work on campus during the coronavirus pandemic to perform essential experiments

Scientific Stature

1) 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 CO2 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

2) 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**

3) 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.

4) 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 2: TCM Process for Technology Assessment

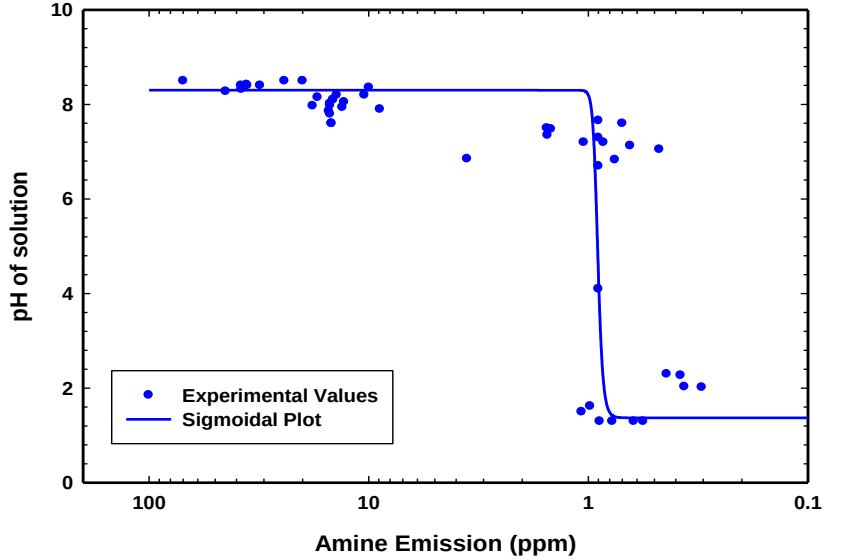
- HSE assessment
  - MSDS review
  - Emissions (permit requirements) – environmental impact
  - Rate of solvent degradation
  - Waste production & solvent make-up
- Laboratory procedures
  - Solvent components & degradation products
  - CO_2 loading
- Online Instruments/Analyzers
  - Requirements for technology specific components
- Verification of TRL (Technology Readiness Level)
- Technical Integrity
  - Demonstrate solvent compatibility with TCM amine plant

Task 2: TCM Process for Technology Assessment

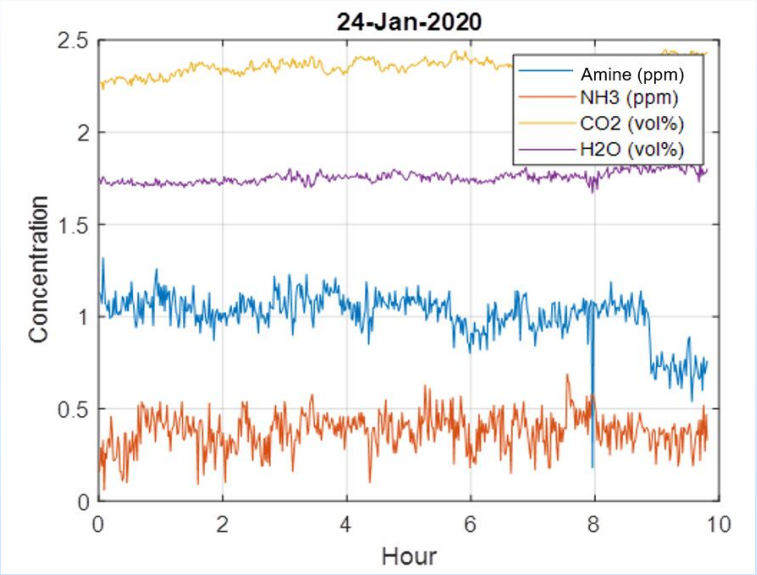
- Process simulation and plant rating
  - Model validation with pilot plant data
  - HMB done with validated model for TCM plant
  - Rating performed to confirm fit
- Risk Evaluation
  - HSE, technical, operational, modifications and financial
- Basis of design for required modifications
  - Hazop
  - Feed study
  - Execution plan
- Techno-economic evaluation
  - Demonstrate benefit of RTI technology versus DOE baselines for MEA

Task 2: TCM EH&S Risk Evaluation and Permitting

RTI BsGAS



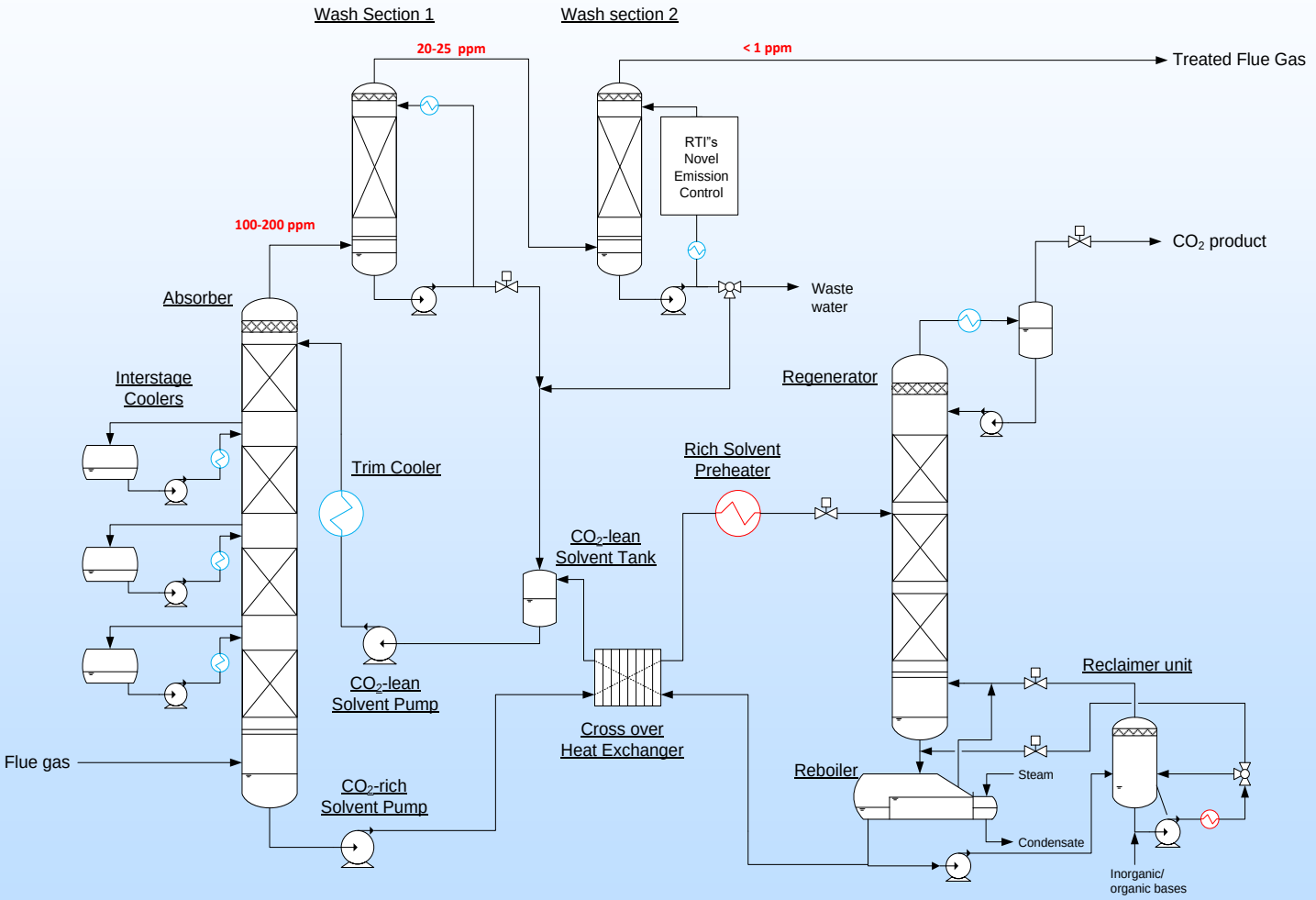
Tiller Plant



Main focus was to demonstrate that amine emissions could be kept at or below 1 ppm during testing at TCM using a water wash and an acid wash

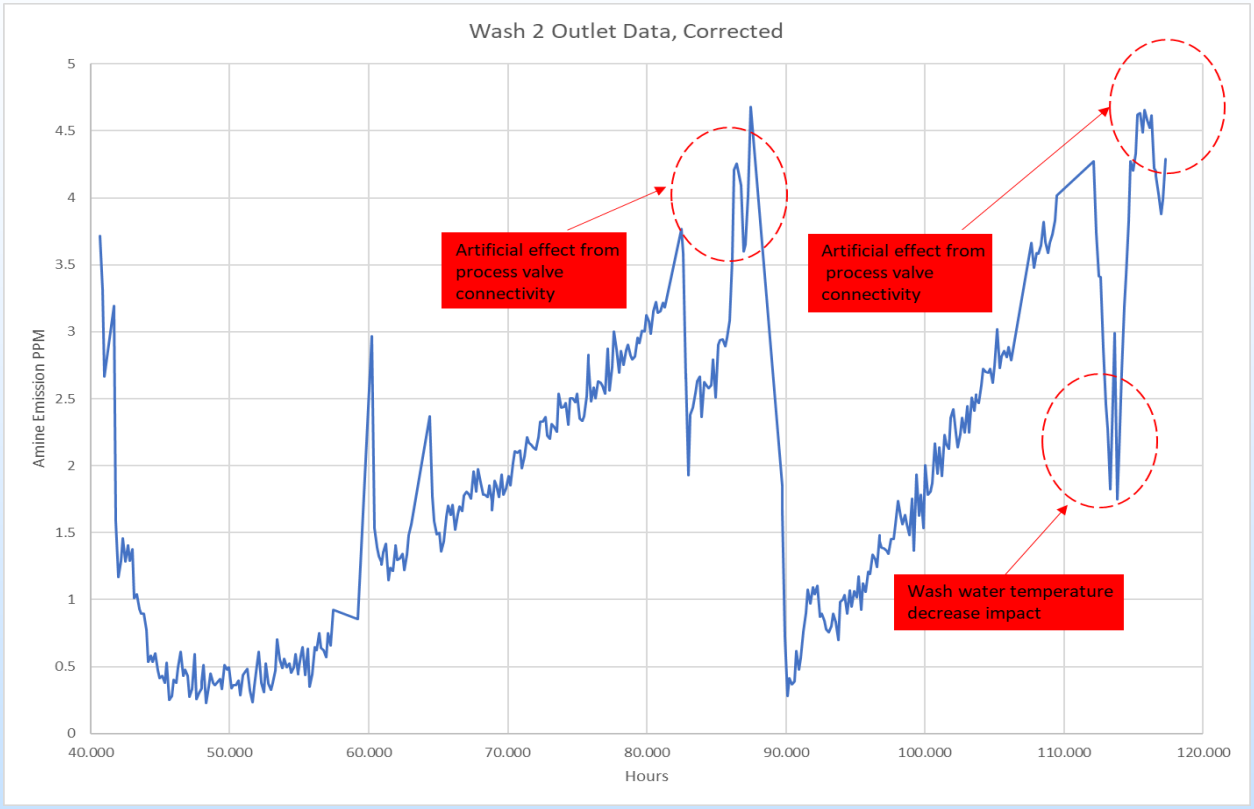
- Demonstrated in early 2019 at RTI BsGAS
- Demonstrated in January 2020 at Tiller plant
- Additional development of commercially viable approach

Task 2: TCM EH&S Risk Evaluation and Permitting



Developed two-stage water wash section at BsGAS

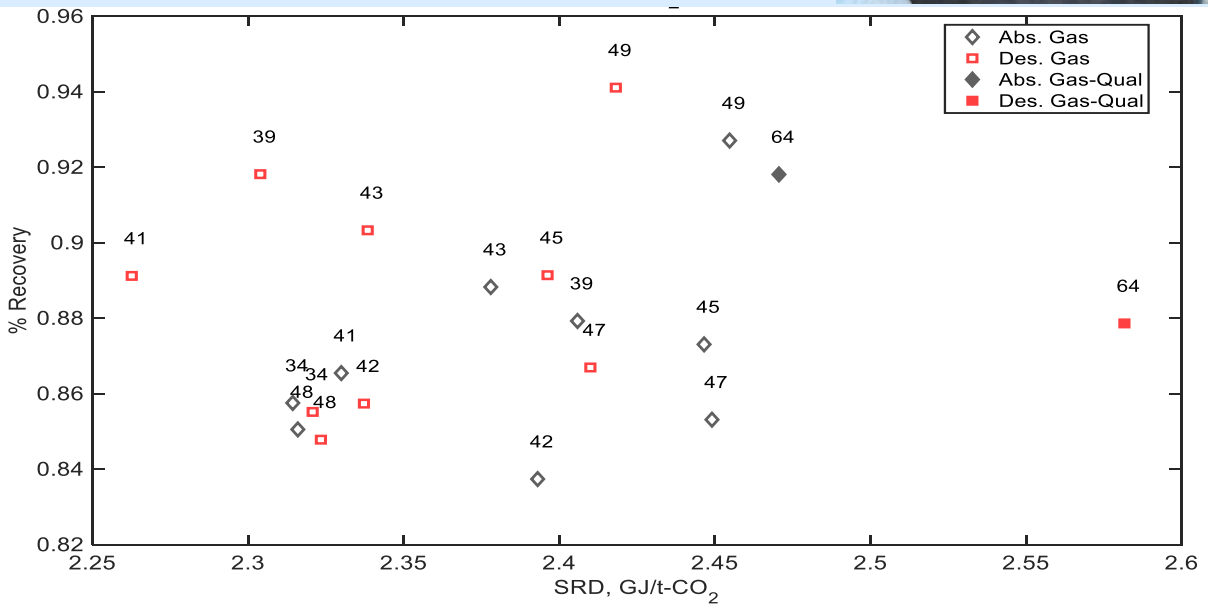
Task 2: TCM EH&S Risk Evaluation and Permitting



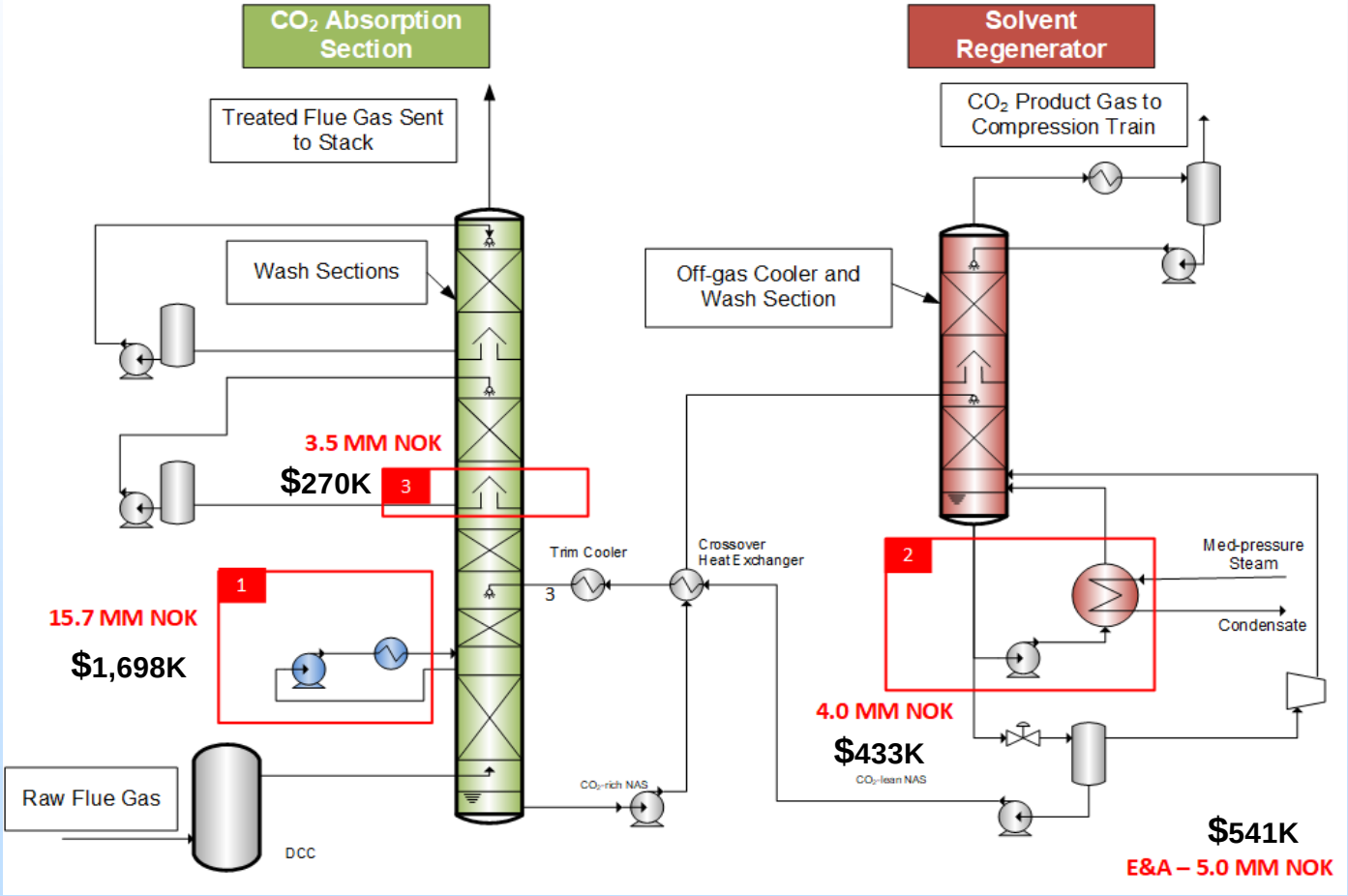
- Showed it to be effective for reduction of amine emissions
- Uses water only (no acid)
- Amine is recovered from wash 2 and returned to solvent
- Acceptable as a commercially viable approach to reducing amine loss

Task 3: Solvent Qualification

- 700-liter solvent batch produced by Clariant
- First qualification testing took place in September 2019
- Testing hampered by significant water addition by malfunctioning valve, high water content and second liquid phase in reboiler
- Second solvent qualification successfully completed January 2020



Task 4: FEED Study of NAS-Specific TCM Amine Plant Modifications



- Selected EPC Pressura to perform FEED study
- Commenced August 19th, 2019
- Determined coarse cost estimate for modifications +/- 20%
- Absorber intercooler
- Forced recirculation pump in reboiler
- Water wash tightening
- Within budget

Progress and Current Status

Success Criteria Description	Status / BP1 Achievement
Successful completion of all work proposed in Budget Period 1	**Completed.** All work proposed in BP1 was completed culminating in the FEED study conducted by Pressura and delivered February 4th, 2020.
Submission of a Preliminary Technology Maturation Plan (TMP)	**Completed**. An initial TMP was provided December 31, 2018.
Completion of large batch NAS qualification testing at Recipient (100 hours) and Sub-Recipient (100 hours) with results showing L/G ratio of 2.5 to 4 with 90% CO_2 capture from coal flue gas composition and a specific reboiler duty < 2.3 GJt/tonne CO_2.	**Completed with modification.** A large batch of NAS was manufactured by Clariant and tested only at SINTEF's Tiller plant, due to closer analogy to TCM, with successful demonstration being achieved January 20-24, 2020 (100 hours). L/G was varied from ~2.5 - ~6.5 and demonstrated an SRD of 2.47 GJ/tonne CO_2 at 92% capture.
Acceptance of Recipient's detailed design and final cost estimate for TCM amine plant modifications to accommodate NAS testing at engineering scale	**Completed**. FEED study estimating cost of plant modifications ±20% was completed in February and shows cost estimates for absorber and regenerator mods which are well within earlier cost projections.
Submission of TCM Test Agreement and TCM Signed Cover Letter	**Completed.** Test agreement has been signed and is presently under review by DOE.

- Only outstanding item is the official NETL authorization for BP2

Future Plans

- Engineering scale testing of NAS at TCM expected in Jan-Jun 2022 during BP2.
- Actively pursuing opportunities for large pilot-scale testing at an industrial site under DOE/commercial funding.
- In early talks with an engineering firm to commercialize the RTI-NAS technology.

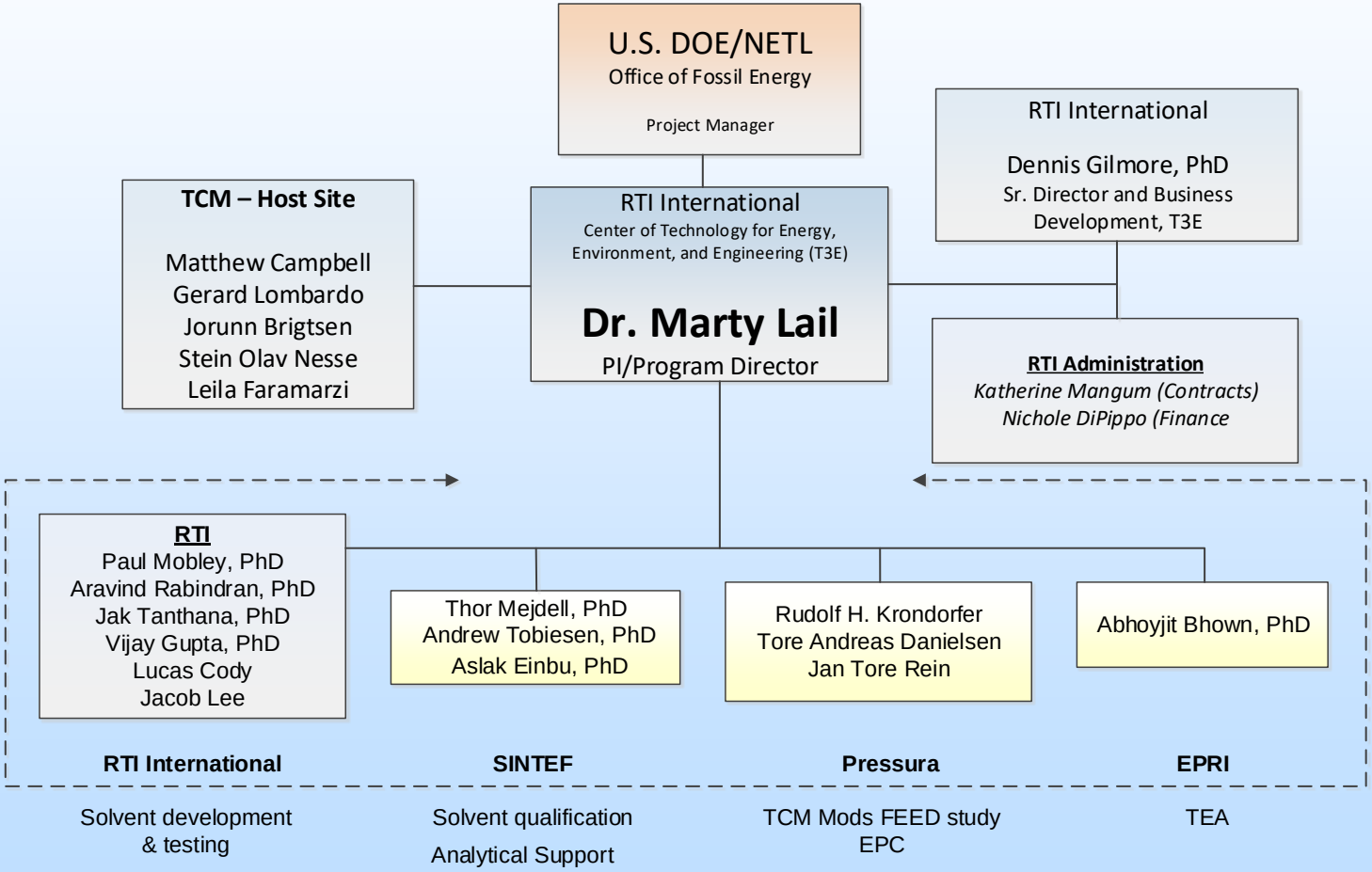
Summary

- Methods identified and demonstrated for reducing amine emissions <1 ppm at TCM
- Solvent qualification completed at SINTEF to demonstrate performance of manufactured solvent
  - SRD (observed 2.4 GJ/t-CO_2)
  - Amine Emissions (<1 ppmv)
- Commercially viable amine emissions prevention demonstrated
- FEED study for mods completed and are within the anticipated budgeted amounts for BP2 equipment expenses
- Solvent supplier is engaged and anticipating the production of ~65 tons solvent in FY21
- Met the BP1 budget ($1,564,530)
- Poised to begin BP2 ($17,173,981)

Appendix

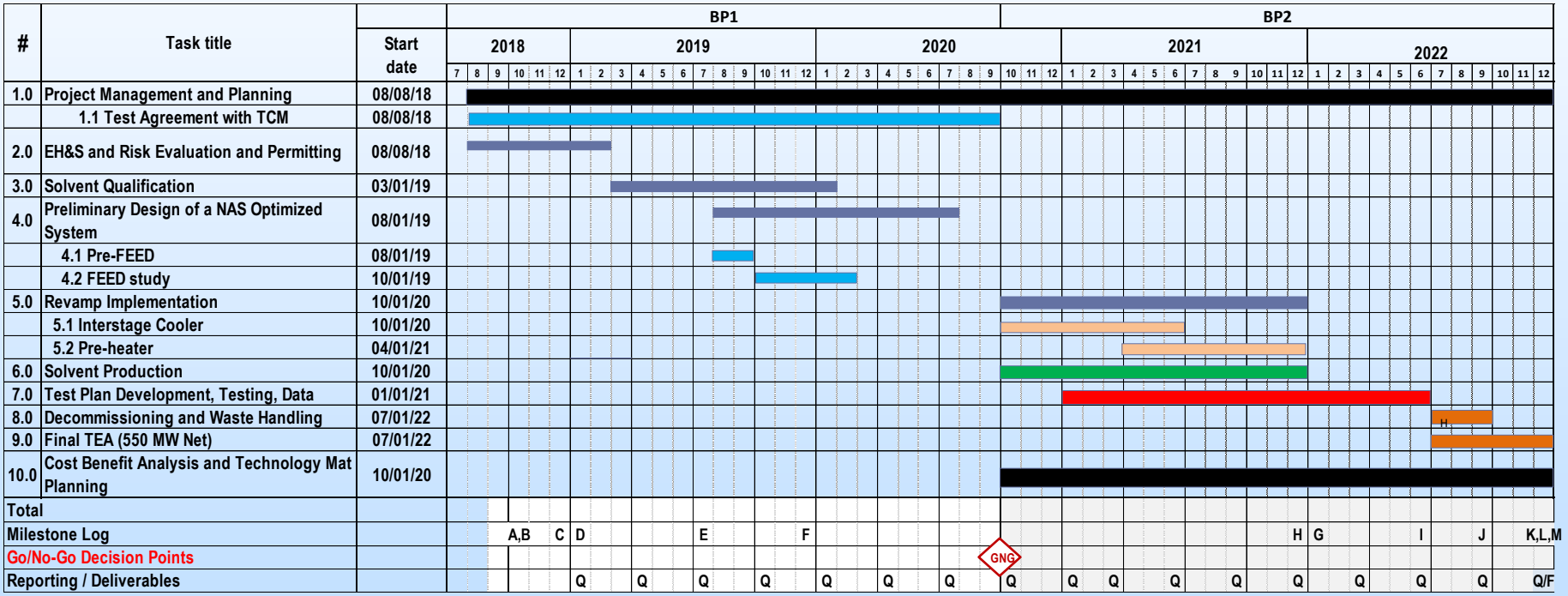
– These slides will not be discussed during the presentation, but are mandatory.

Organization Chart



Development Team

Gantt Chart



#	Task title	Start date
1.0	Project Management and Planning	08/08/18
	1.1 Test Agreement with TCM	08/08/18
2.0	EH&S and Risk Evaluation and Permitting	08/08/18
3.0	Solvent Qualification	03/01/19
4.0	Preliminary Design of a NAS Optimized System	08/01/19
	4.1 Pre-FEED	08/01/19
	4.2 FEED study	10/01/19
5.0	Revamp Implementation	10/01/20
	5.1 Interstage Cooler	10/01/20
	5.2 Pre-heater	04/01/21
6.0	Solvent Production	10/01/20
7.0	Test Plan Development, Testing, Data	01/01/21
8.0	Decommissioning and Waste Handling	07/01/22
9.0	Final TEA (550 MW Net)	07/01/22
10.0	Cost Benefit Analysis and Technology Mat Planning	10/01/20
Total		
Milestone Log		
Go/No-Go Decision Points		
Reporting / Deliverables		

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