Emissions Mitigation Technology for Advanced Water-Lean Solvent Based CO_2 Capture Processes

DE-FE0031660

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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

Objective:

Develop and optimize the emission control solutions to reduce the amine emission for advanced, 2nd generation solvent – Water-Lean Solvent (WLS) class

Key Metrics

- Emissions from absorber & regenerator
- Solvent loss and make-up cost reduction
- Technoeconomic and Environmental Health, and Safety (EHS) evaluation

Specific Challenges

- Aerosols generation and characterization
- Amine reclaiming unit and process integration
- Organic wash solvent screening

Timeframe:

BP1 10/01/18 to 03/31/20
BP2 04/01/20 to 09/30/21

	Federal	Cost Share	Total Costs
Budget Period 1	$1,696,161	$416,027	$2,112,188
Budget Period 2	$1,203,839	$372,973	$1,576,812
Total	**$2,900,000**	**$789,000**	**$3,689,000**

Project Team

Team Member	Role	Expertise
RTI INTERNATIONAL	Prime recipient, project management, developer of NAS technology, emissions characterization, solvent screening, Emission Control Technology (ECT) design and modeling, and economic analyses	▪ Effective project management and execution under DOE cooperative agreements ▪ Lead developer of NAS CO_2 capture technology ▪ Process design, modeling, and engineering capabilities ▪ Process technology scale-up and operation from lab to large precommercial demonstration systems ▪ Aerosol emissions characterization
THE LINDE GROUP Linde	Technical advisory	• Leading industrial gas supplier • CO_2 capture plant design and pre-commercial scale demonstration • Advance front-end emission control equipment design and fabrication
TECHNOLOGY CENTRE MONGSTAD	Technical advisory and EH&S support	• World leading test facility for CO_2 capture • EH&S and quality standards

Technology Background-1

Technology Status

- Cumulative DOE funding > $10 MM and more than $2 MM funding from RTI industrial partners
- Solvent development work finalized
- Pilot testing completed at SINTEF, Norway and National Carbon Capture Center (NCCC)
- Pre-commercial demonstration (12 MW) planned at Technology Center Mongstad (TCM), Norway in FY22

Key Technical Advantages

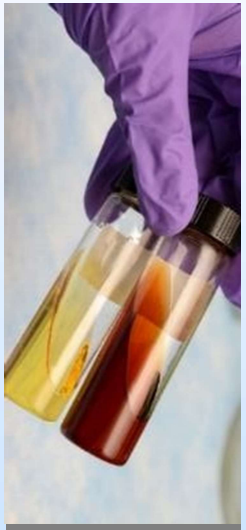
- CO_2 Capture Technology with substantially reduced energy consumption
- Minimum changes to existing process to realize NAS optimal performance
- Commodity-scale production ready

Impact

- Low cost, large-scale CO_2 capture applications
- Commercialization path via process technology licensing
- Application potential for high-efficiency acid gas separations

Technology Background-2

From lab to large scale (12 MW) demonstration through series of projects



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, 2018-2021)

Effective emissions mitigation strategy for WLS at engineering-scale

~$3.5MM
60 kW

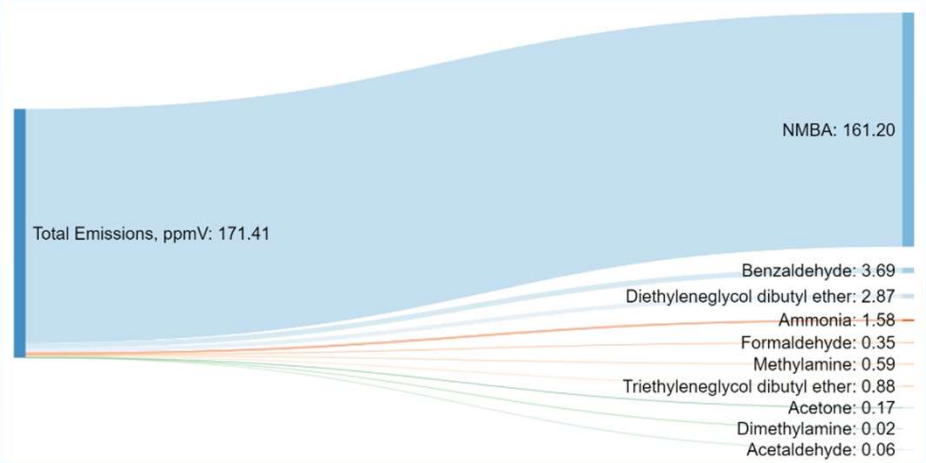
Engineering-Scale Validation (2018-2023)

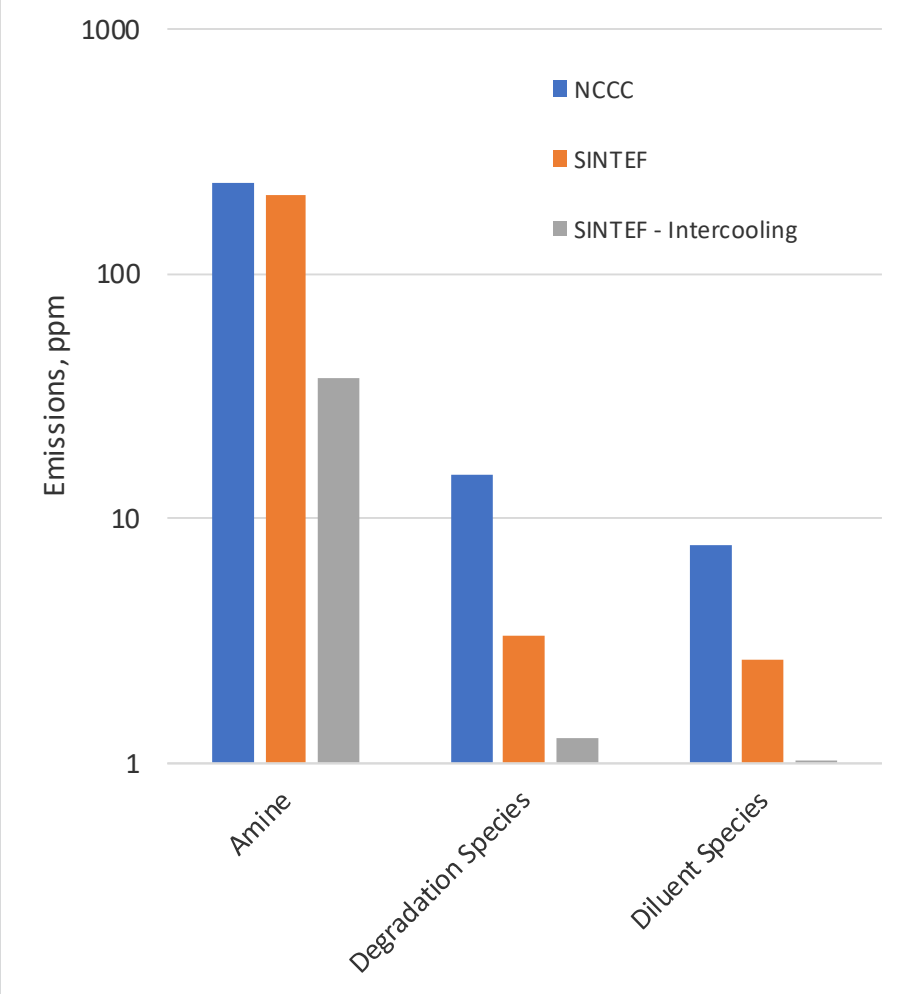
Pre-commercial Demonstration at Technology Centre Mongstad, Norway (~12 MWe). Test in early 2022

~$21MM
12 MW

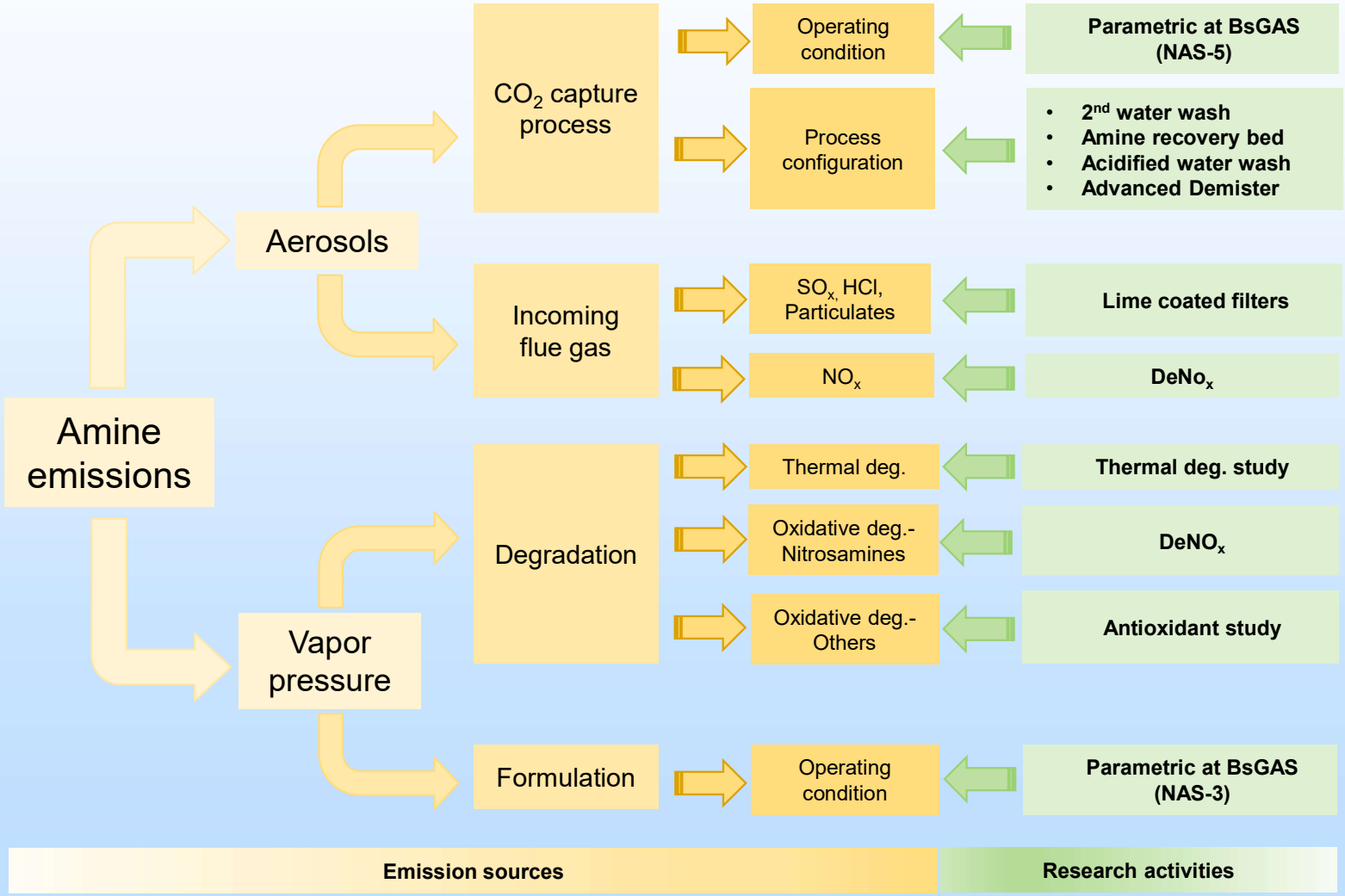
Technology Background-3

- Tiller – SINTEF spring 2018: NAS-5
- NCCC – summer 2018:NAS-5
- Similar emissions levels and species seen at SINTEF and NCCC
- Intercooling reduces emissions by almost 10x





Technical Approach



Project Schedule-1

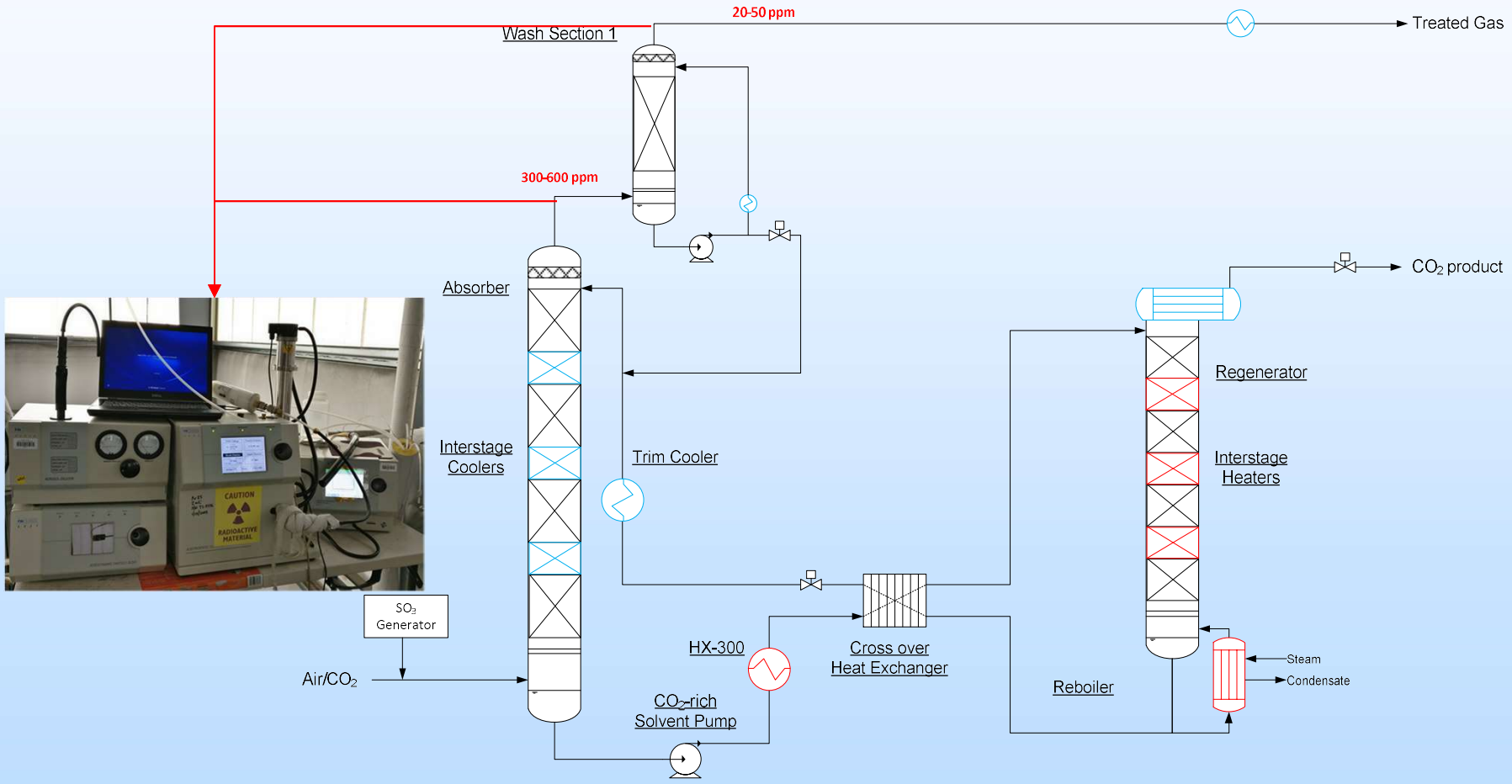
Task No.	Milestone No.	Milestone Description	Planned Completion Date	Actual Completion	Status
1.0	A	Updated Project Management Plan (PMP)	Nov. 30, 2018	Dec. 13,2018	**Completed**
1.0	B	Project kickoff meeting	Nov. 30, 2018	Nov. 15, 2018	**Completed**
2.0	C	Establish emission monitoring method and tie in analytical tools to (BsGAS)	Jan. 31, 2019	Jan. 31, 2019	**Completed**
2.1	D	Develop method to monitor and quantify emissions at the BsGAS	Jan. 31, 2019	Jan. 31, 2019	**Completed**
2.2	E	HAZOP analysis for H_2SO_4 particulate generator	Jan 31, 2019	Dec. 31, 2018	**Completed**
2.3	F	Baseline data for amine emissions using two water-lean solvents	Aug. 31, 2019	Oct. 14, 2019	**Completed**
2.4	G	Empirical process model for amine emissions from water-lean solvents with < 10% average absolute deviation based on critical process parameters	Mar. 31, 2020	Mar. 05, 2020	**Completed**
3.1.1	H	Identify two best-candidate wash organic solvents	Aug. 31, 2019	Jul. 31, 2019	**Completed**
3.1.2	I	Identify suitable amine extraction sorbents with > 95% amine recovery	Aug. 31, 2019	June 30, 2019	**Completed**
3.3	J	Update BsGAS flow sheet with emission control equipment necessary to reduce amine emissions	Aug. 15, 2019	Jul. 15, 2019	**Completed**
3.4	K	HAZOP analysis and complete BsGAS modification and commissioning	Dec. 31, 2019	Dec. 31, 2019	**Completed**
3.5	L	Complete testing of emission reduction performance at BsGAS to demonstrate amine emissions reduction to approximately < 10 ppm	Mar. 31, 2020	Mar. 31, 2020	**Completed**
3.6	M	Evaluate acidified water wash process	Mar. 31, 2019	Aug. 31, 2018	**Completed**
3.7	N	Incorporate acidified water wash section in the empirical process model	Aug. 28, 2019	Aug. 28, 2019	**Completed**

Project Schedule-2

Task No.	Milestone No.	Milestone Description	Planned Completion Date	Actual Completion	Status
4.1	O	Complete BsGAS emission control system design	Jun. 30, 2020	Dec. 13,2020	**Completed**
4.2	P	Complete BsGAS modification and commissioning	Nov. 30, 2020	Mar. 15, 2021	**Completed**
4.3	Q	Complete emission reduction performance testing at BsGAS to demonstrate amine emissions reduced to < 1 ppm	Jun. 30, 2021		**Ongoing**
5.1	R	Complete empirical model development with average absolute deviation < 10%	Sep. 30, 2021		**Ongoing**

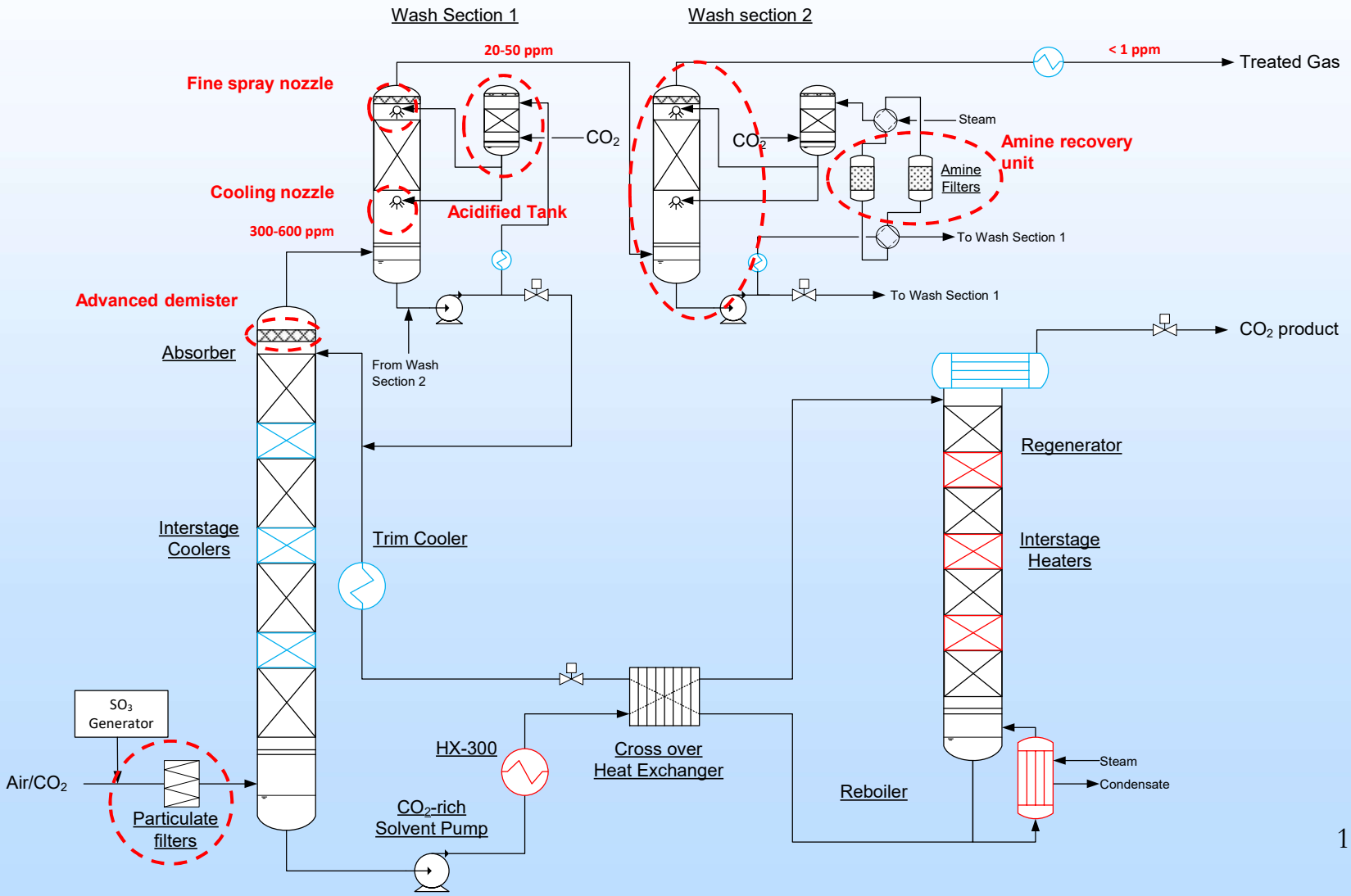
BP1 Success Criteria	Criteria 1	Establishment of an emission model of the capture system without mitigation reduction controls with average absolute deviation < 25% for critical process factors	**Completed**
	Criteria 2	Selection at least one candidate for wash organic solvents that are applicable to developing water-lean solvents	**Completed**
	Criteria 3	Demonstration of emission reduction devices at bench-scale gas absorption system (BsGAS) with RTI's non-aqueous solvent (NAS) and another selected water-lean solvent to reduce emissions < 10 ppm	**Completed**
Completion of project Success Criteria (09/30/2021)	Criteria 4	Demonstration of emission reduction devices at BsGAS with NAS and another selected water-lean solvent to reduce emissions < 1 ppm	**Ongoing**
	Criteria 5	Emission model of a CO_2 capture system with mitigation reduction control with average absolute deviation < 10% for critical process parameters	**Ongoing**
	Criteria 6	Techno-economic analysis of the emission mitigation system	**Ongoing**

Progress and Current Status of Project-1

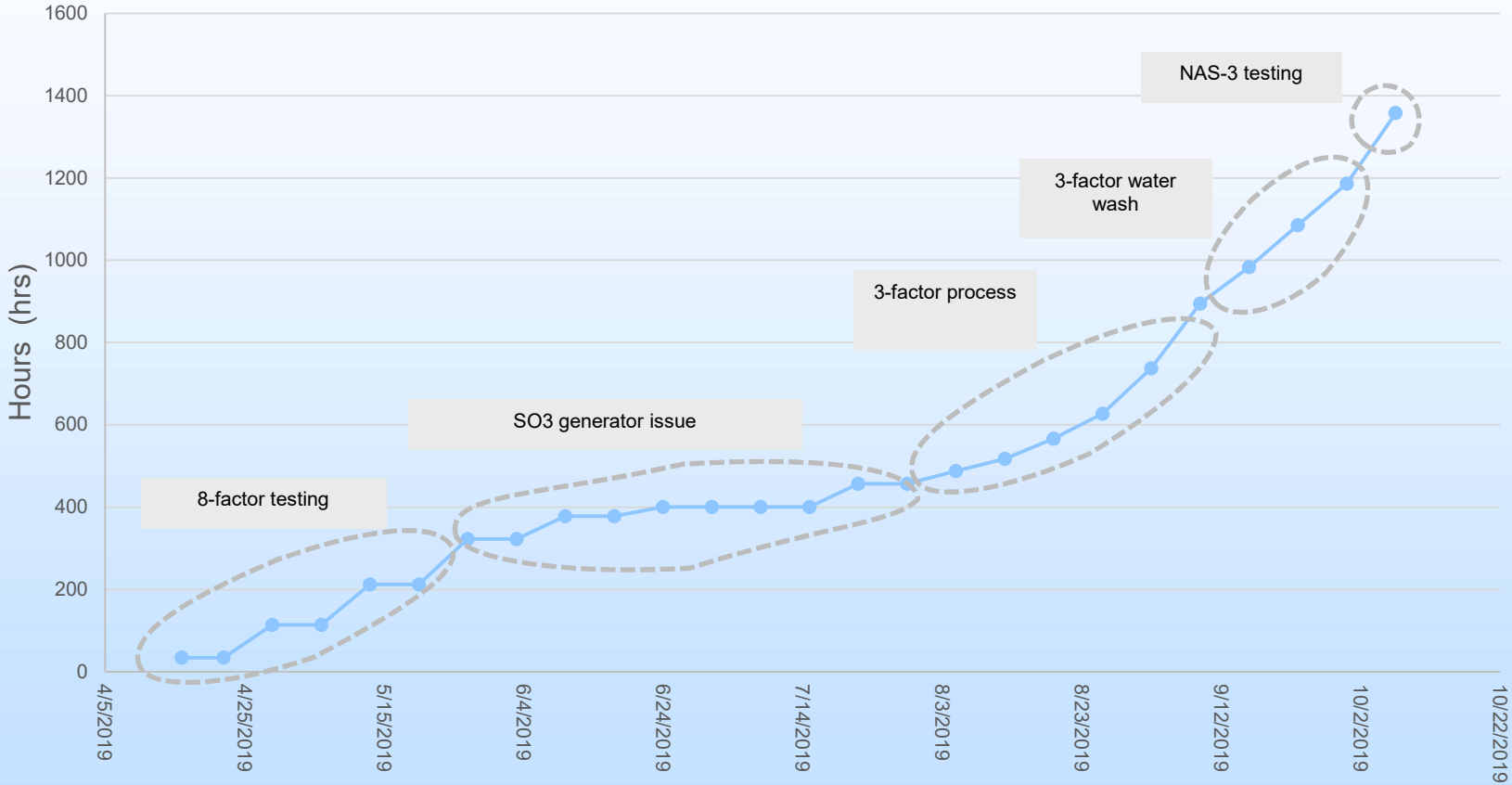


RTI's Bench-scale Gas Absorption System (BsGAS)

Progress and Current Status of Project-2



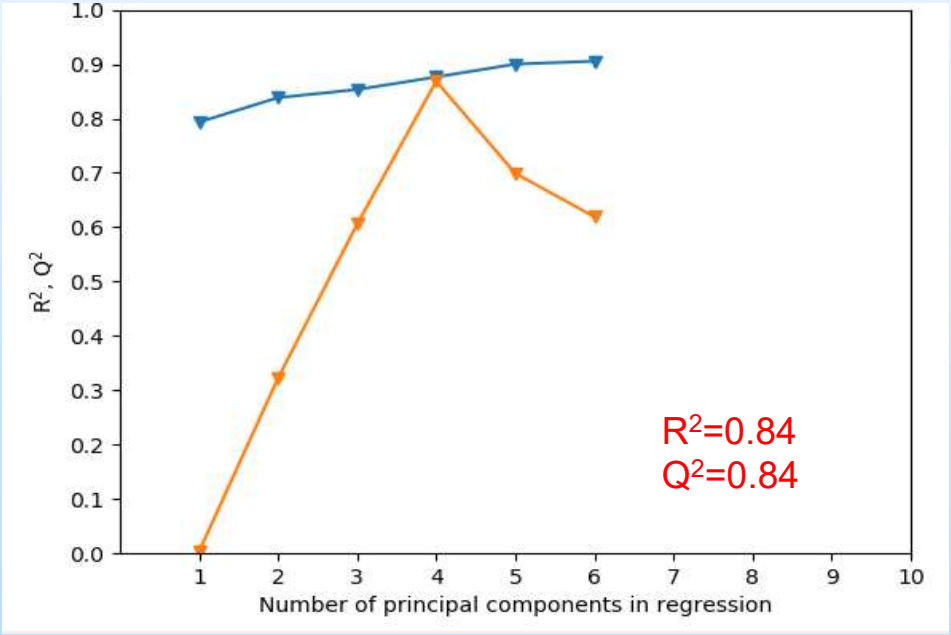
Progress and Current Status of Project-3

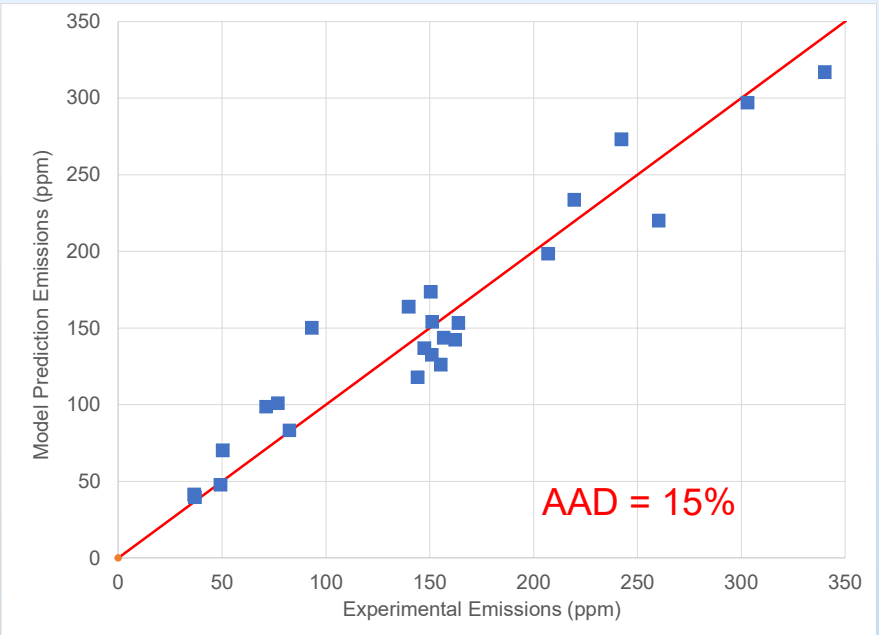


- About 1,400 hours of system TOS, > 50 runs performed over the course of parametric campaign
- 2 hours at steady state prior collecting process data, aerosol data, and liquid samples
- Parameter of interests: CO_2 capture rate, Regen. temp., Lean return temp., cooling duty, Gas inlet saturation temp., process L/G, wash L/G, wash column temp.

Progress and Current Status of Project-6

Variable ID	Variable	B_{PLS}
x1	T bulge, max temperature in the absorber	35.4
x2	Aerosol particle diameter at 50% cumulative mass fraction of the distribution	22.6
x3	Temperature of the water wash recirculation stream	– 22.6
x4	% water in CO_2-rich solvent	– 19.4
x5	Delta T_(max T in absorber – lean solvent return T)	17.8
x6	Extent of intercooling at absorber top (% valve opening) (IC_Bottom = 100 – IC_Top)	17.5
x7	L/G, liquid mass flow rate/gas mass flow rate	– 16.7





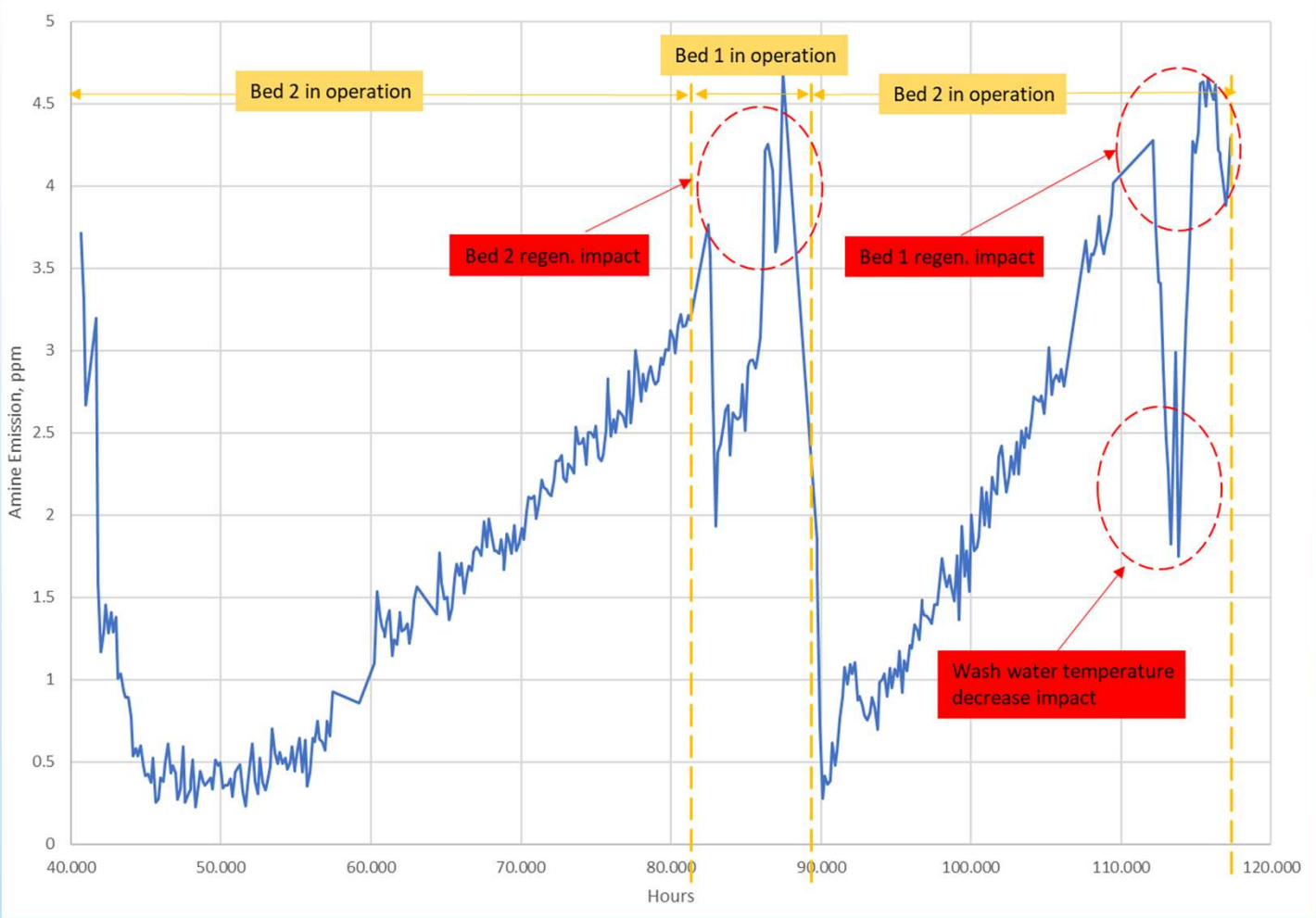
Gupta, V.; Mobley, P.; Tanthana, J.; Cody, L.; Barbee, D.; Lee, J.; Pope, R.; Chartier, R.; Thornburg, J.; Lail, M., Aerosol emissions from water-lean solvents for post-combustion CO2 capture. *International Journal of Greenhouse Gas Control* **2021,** *106*, 103284.

Progress and Current Status of Project-4

	Emission (ppm)			%reduction from baseline		
	Vapor	Aerosol	Total	Vapor	Aerosol	Total
Baseline	64	116	180	n/a	n/a	n/a
2nd water wash	**28**	**17**	**45**	-56	-86	-75
Fine spray nozzle	100	158	**259**	57	37	44
Cooling nozzle before packing	46	84	130	-28	-27	-27
Limed coated filter - bag (10 um)	64	104	168	0	-10	-6
Limed coated filter - pleated (25 um)	64	74	138	0	-36	-23
Limed coated filter - pleated (1 um)	64	61	125	0	-47	-30
Total gas flow – 100%	64	116	180	n/a	n/a	0
Total gas flow – 150%	64	100	164	0	-13	-8
Total gas flow – 50%	47	80	126	-27	-31	-30
acidified wash	**13**	n/a	**13**	-80	n/a	-80
advanced demister	64	**0**	64	0	-100	-64

- Combination of acidified wash, advanced demister, and 2 wash sections is sufficient to suppress the emissions to approx.10 ppm
- Fine spray nozzle produces 150 micron droplets and increases entrainment from both washes
- Cooling nozzle appears to suppress both vapor and aerosols
- Lime-coated filters slightly lowers aerosols entering the system
- High aerosols removal filters vs. pressure drop trade-off.
- Lower capture capacity (i.e., low total gas and liquid flow) improves emissions
- 2,000 hr of operation investigating aerosols and ECTs

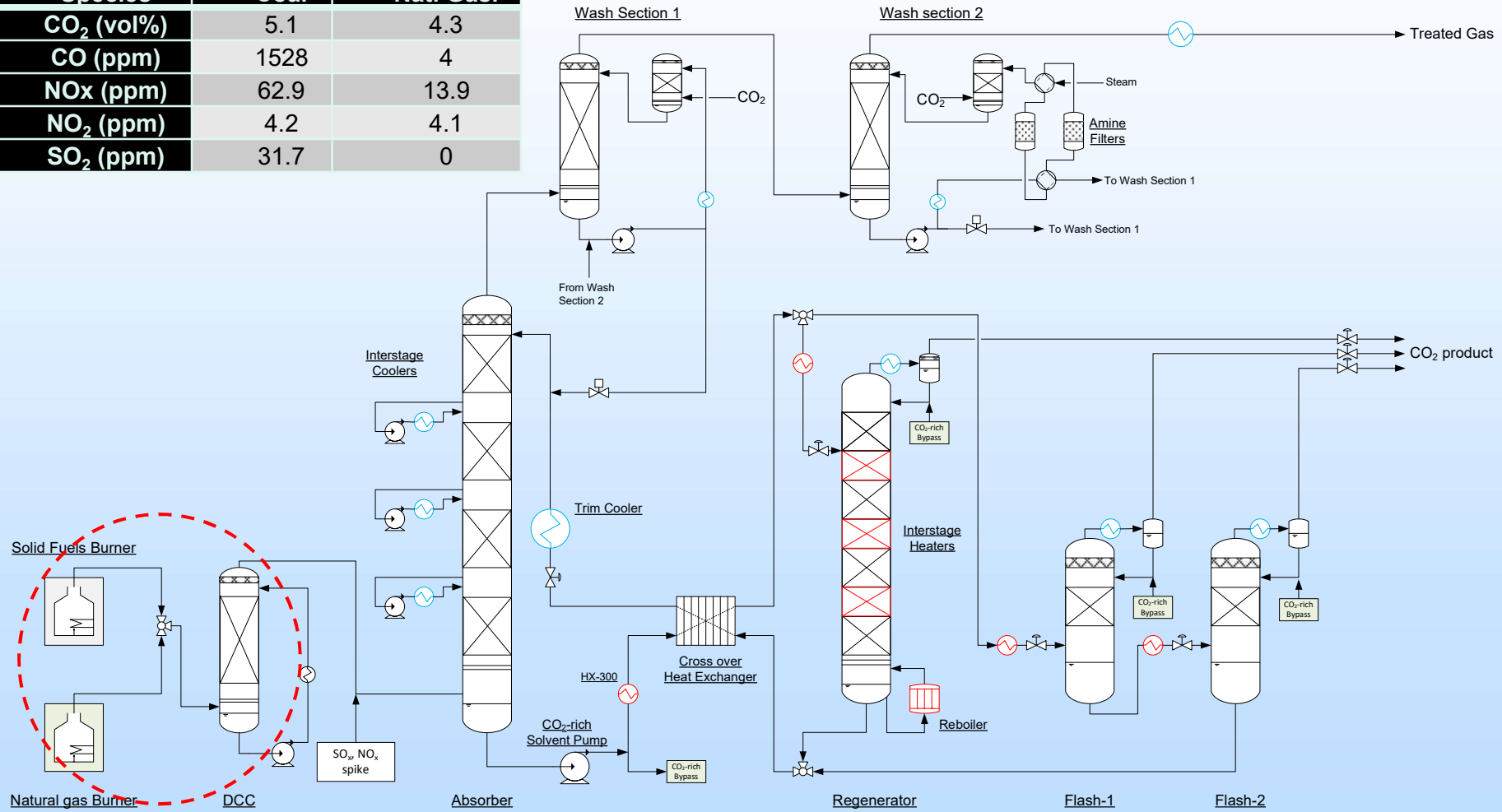
Progress and Current Status of Project-5



Amine recovery unit can effectively reduce the amine emission to be less than 1 ppm but require process/sequence optimization.

Progress and Current Status of Project-7

Species	Coal	Nat. Gas.
CO_2 (vol%)	5.1	4.3
CO (ppm)	1528	4
NOx (ppm)	62.9	13.9
NO_2 (ppm)	4.2	4.1
SO_2 (ppm)	31.7	0



RTI's Bench-scale Gas Absorption System (BsGAS) with ECT and flue gas generation system

Progress and Current Status of Project-8

- Roughly 100 hrs of CO_2 capture operation under synthetic coal flue gas with about 1 ppm amine emission was achieved.
- About 200 hrs of time-on-stream capturing CO_2 from coal and natural gas flue gas with amine emission about 10 ppm.
- Tests in May-July were disrupted from malfunction water wash pump, fines from amine recovery bed, and absorber flooding. These issues are being resolved.
- Process simulation and TEA are being updated to match cost and performance basis in NETL baseline study rev. 4.
- A 6-month no cost extension is requested with the project end date on 03/31/2022.

Plans for future testing/development/ commercialization

This project

- Complete demonstration of NAS CO_2 capture technology with amine emission of 1 ppm or less using real coal flue gas
- Update process model, cost model, and TEA with ECT

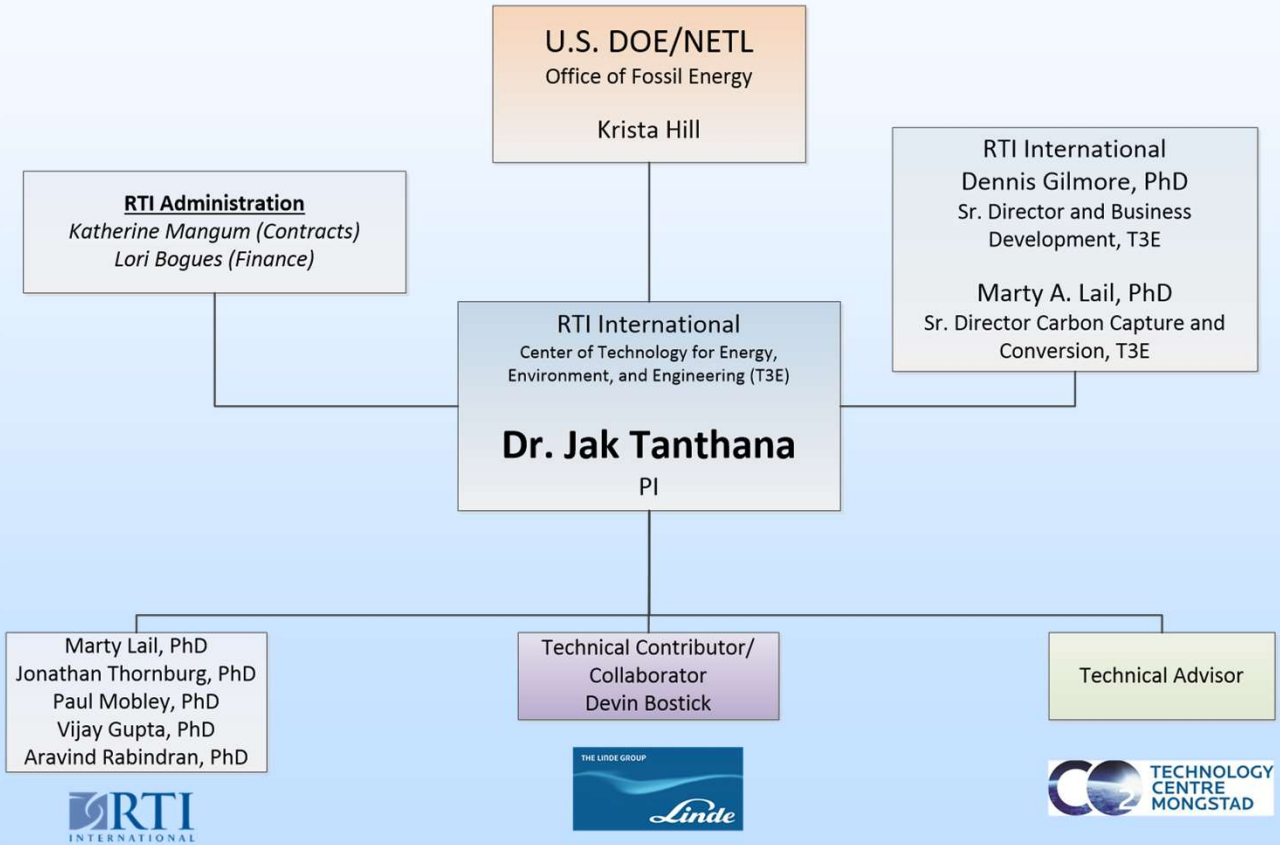
After this project

- Provide process and emission data to TCM and assist TCM process simulation/emission mitigation
- Scale-up amine recovery bed unit

Summary

- Emission reduction strategies for advanced water-lean solvents have been studied under the BP1 tasks.
  - Minimize aerosols through optimizing NAS running condition, addition of ECTs
  - Minimize degradation through antioxidant, thermal, and NO_x reduction studies
  - Minimize vapor pressure through solvent formulation
- BsGAS with ECTs showed < 10 ppm amine emission under simulated flue gas with aerosols
- High accuracy predictive emission model developed for WLS
- Flue gas generation system installed and commissioned, system is scheduled to run and achieve < 1 ppm emission by the end of BP2.
- Emission model and TEA will be updated and submitted at the end of BP2.

Appendix - Organization Chart



Appendix - Gantt Chart

Task	Task title	Start date	End date
1.0	Project Management	10/01/18	09/30/21
2.0	Evaluation of Amine Emission for Water-Lean System Without Emission Control	10/01/18	03/30/20
2.1	Develop a Method to Monitor, Differentiate, and Quantify Emissions at BsGAS	10/01/18	01/31/19
2.2	Particulate Generator Modification at BsGAS	10/01/18	01/31/19
2.3	Establish Baseline Amine Emission for Water-Lean System Without Emission Controls	02/01/19	08/31/19
2.4	Development of Empirical Process Model for Amine Emission from Water-Lean Based Solvent Systems	09/01/19	03/31/20
3.0	Prototype Emissions Control System for Water-Lean Solvent	10/01/18	03/31/20
3.1	Organic Solvent and Amine Extraction Sorbent Evaluation	10/01/18	08/31/19
3.1.1	Wash Organic Solvent Characterization	10/01/18	08/31/19
3.1.2	Amine Reclaiming Evaluation	10/01/18	08/31/19
3.2	Define Emission Control Approach	06/01/19	06/30/19
3.3	Preliminary Design for Emission Mitigation Process	07/01/19	08/15/19
3.4	Detailed Design and Construction	08/15/19	12/31/19
3.5	Performance Evaluation at BsGAS	01/01/20	03/31/20
	Go-No Go decision		
4.0a	RTI 's Bench-scale modification	04/01/20	06/30/21
4.1a	Detail modification and design	04/01/20	06/30/20
4.2a	Procurement, Construction and commisionning	07/01/20	11/30/20
4.3a	Performance evaluation of emission control system	03/01/21	03/31/21
5.0	Process Simulation and Techno-Economic Assessment	04/01/20	09/30/21
5.1	Update Empirical Emission Model	04/01/20	09/30/21
5.2	Refine Techno-economic Evaluation	04/01/20	09/30/21
Milestone Log		*(proposal*	*table)*
Reporting / Deliverables		*(See footnote.)*	*(See footnote.)*
Project Meeting		*(See footnote.)*	*(See footnote.)*