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 Management Project Review Meeting
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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

EPRI ELECTRIC POWER RESEARCH INSTITUTE

SINTEF

PRESSURA

CCSI² Carbon Capture Simulation for Industry Impact

TEXAS The University of Texas at Austin

UNIVERSITY OF OSLO

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

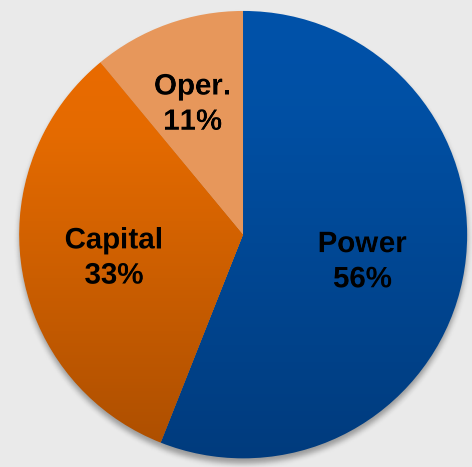
Solvent	C_p [J/g K]	ΔH_{abs} [kJ/mol]	ΔH_{vap} [kJ/mol]	x_{solv} [mol solvent/mol solution]	$\Delta\alpha$ [mol CO_2/ mol solvent]	Reboiler Heat Duty [GJ/t-CO_2]
30 wt% MEA-H_2O	3.8	85	40	0.11	0.34	3.75
RTI's NASs	2.0	85	negl.	0.47	0.45	2.40

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

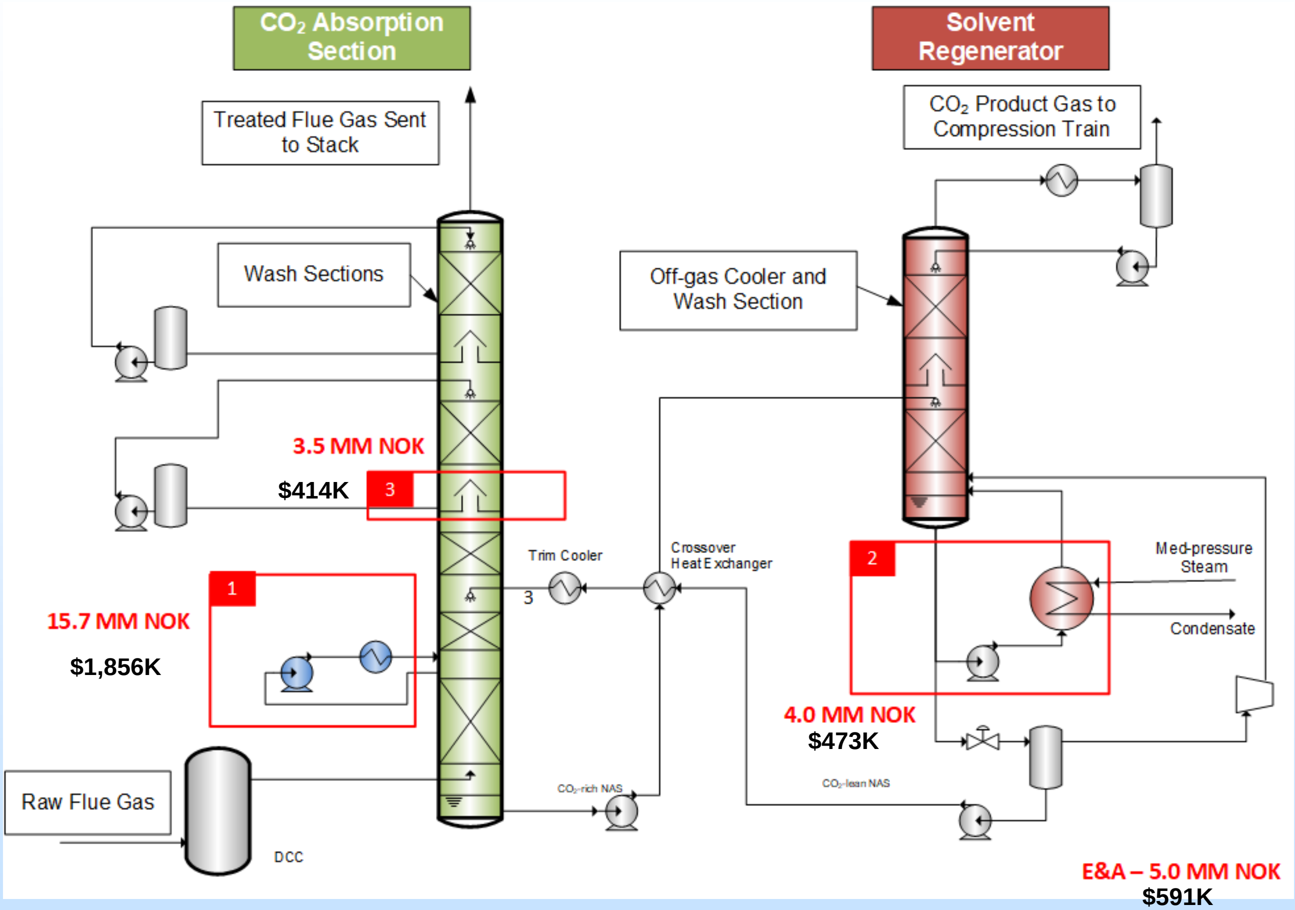
From lab to large scale (12 MW) demonstration through series of projects

Technology Background

	DOE Case 11	DOE Case 12	RTI Case 1	RTI Case 2
Description	No Capture (DOE Case 11)	CO_2 Capture (DOE Case 12)	RTI-Case 1	RTI-Case 2
Solvent		30 wt%MEA	RTI-NAS	RTI-NAS
SRD (GJ/t-CO_2)		3.6	2.30	2.37
Regenerator pressure (bar)		1.6	1.95	4.8
Coal flow rate (lb/hr)	409,528	565,820	513,122	505,487
Gross power output (kWe)	580,400	662,800	650,110	638,080
Aux. power req. (kWe)	30,410	112,830	100,110	88,080
Net power output (kWe)	549,990	549,970	550,000	550,000
Net plant HHV efficiency (%)	39.28%	28.43%	31.35%	31.82%
Power plant cost ($MM)	1,090	1,361	1,290	1,276
CO_2 capture cost ($MM)		506	345	345
CO_2 compression cost ($MM)		88	78	47
TPC ($MM)	1,090	1,955	1,714	1668
TOC ($MM)	1,349	2,409	2,116	2060
Total OPEX ($MM)	199.1	297.6	270	266
COE, excl CO_2 TS&M, mills/kWh	80.95	137.28	122.27	119.55
Cost of CO_2 Capture, ($/t-CO2)		56.44	45.66	43.30

All costs are on 2011 US$ basis

Technology Background



TCM
- Amine plant modifications
- Leadership in detailed engineering, fabrication, and construction
- Process modeling expertise
- Excellence in operations

Absorber Modifications
- One interstage cooler
- Equipment within budget
- Control temperature bulge at top to decrease emissions

Regenerator Mods
- Higher capacity pump for reboiler
- Force recirculation due to high boiling points of solvent components
- Equipment within budget

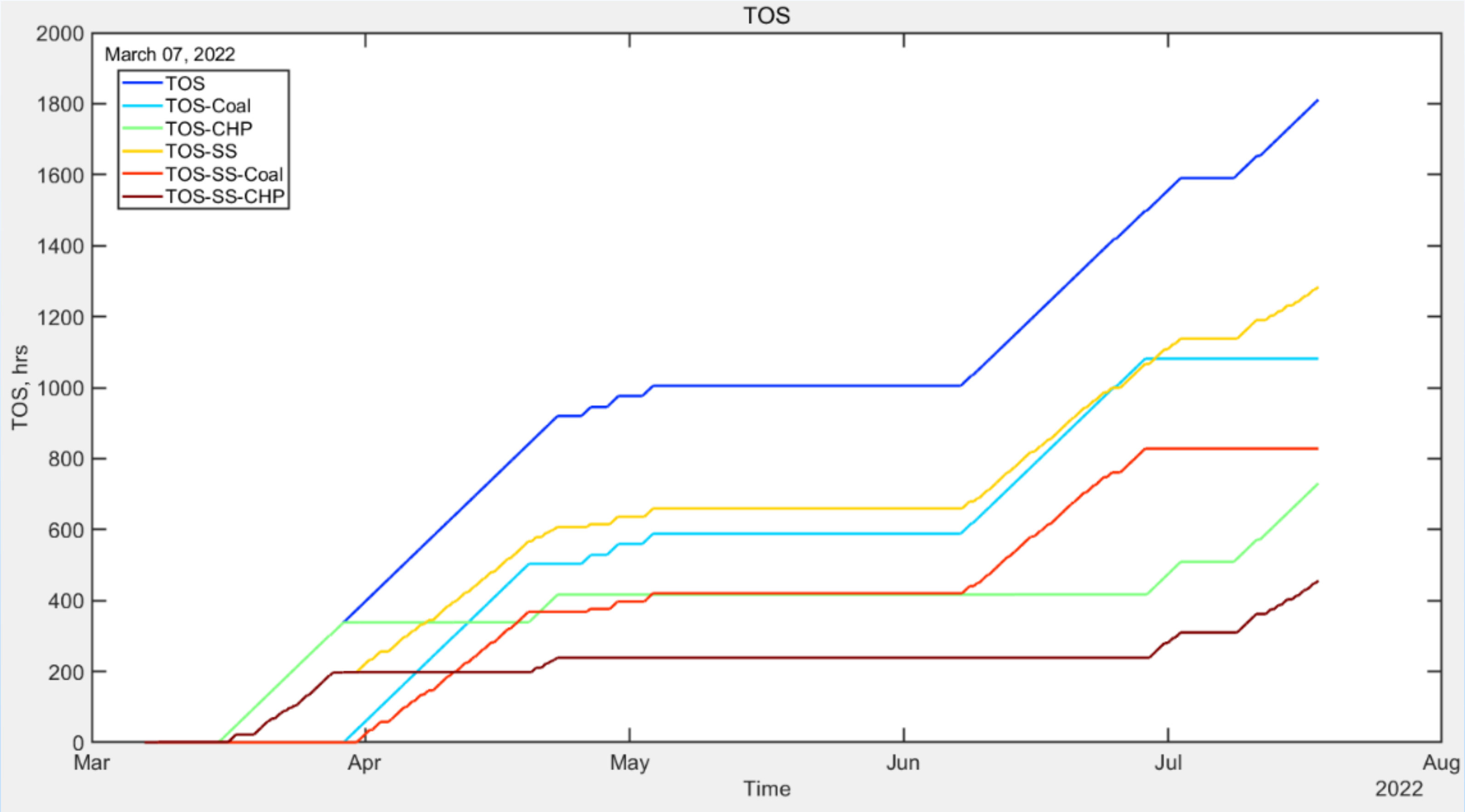
Technical Approach/Project Scope

- 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

Progress and Current Status

Task No.	MS 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 24, 2021	Quarterly report
5.0	8	Submission of purchase order to manufacturer for initial solvent fill	May 31, 2021	June 25, 2021	Quarterly report
5.0	9	Receive forced recirculation pump for regenerator for installation at host site	November 15, 2021	January 6th, 2022	Quarterly report
6.0	10	NAS solvent batch (75 tons) delivered to TCM site	December 31, 2021	January 31, 2022	Quarterly report
5.0	11	Commissioning of the revamped unit	January 31, 2022	March 07, 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	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

Progress and Current Status



- By end of July over 1800 hours on stream
- Approximately 1300 hours at steady state

- 1100 hours with RFCC gas
- 700 hours with CHP gas
- TCM added time to end of campaign

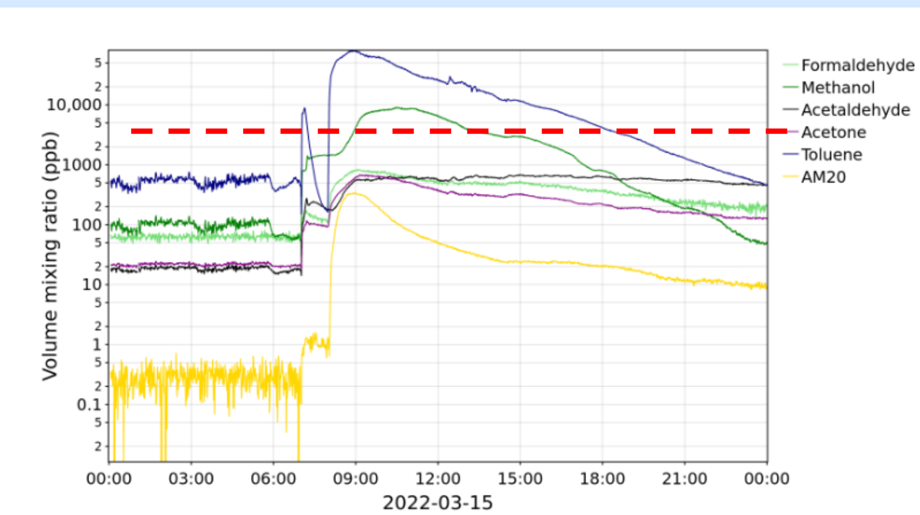
Progress: Start Up

Magnetic flow meters not registering initially

- Low conductivity of lean, anhydrous NAS solvent
- Flow meters do register flows after small H_2O and CO_2 loading
- Added ultra-sonic flow meters as back-up to ensure desired flows are measured
- Flow meters on reboiler loop and interstage cooler loop

Unexpected emissions during start-up

- Initial flue gas flow through absorber (no circulation) caused emissions spike
- Emissions became lower with time
- Solvent circulation led again to higher emissions
- Identified components as minor impurities from solvent synthesis
- Levels decreased after prolonged circulation
- Became under control in ~12 hours

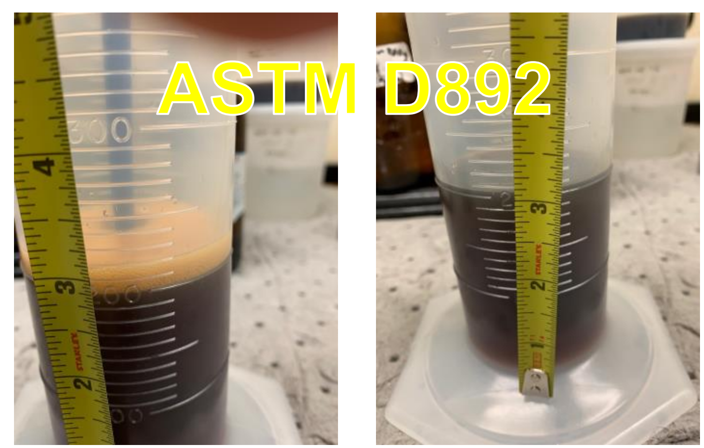


Emissions control after start-up

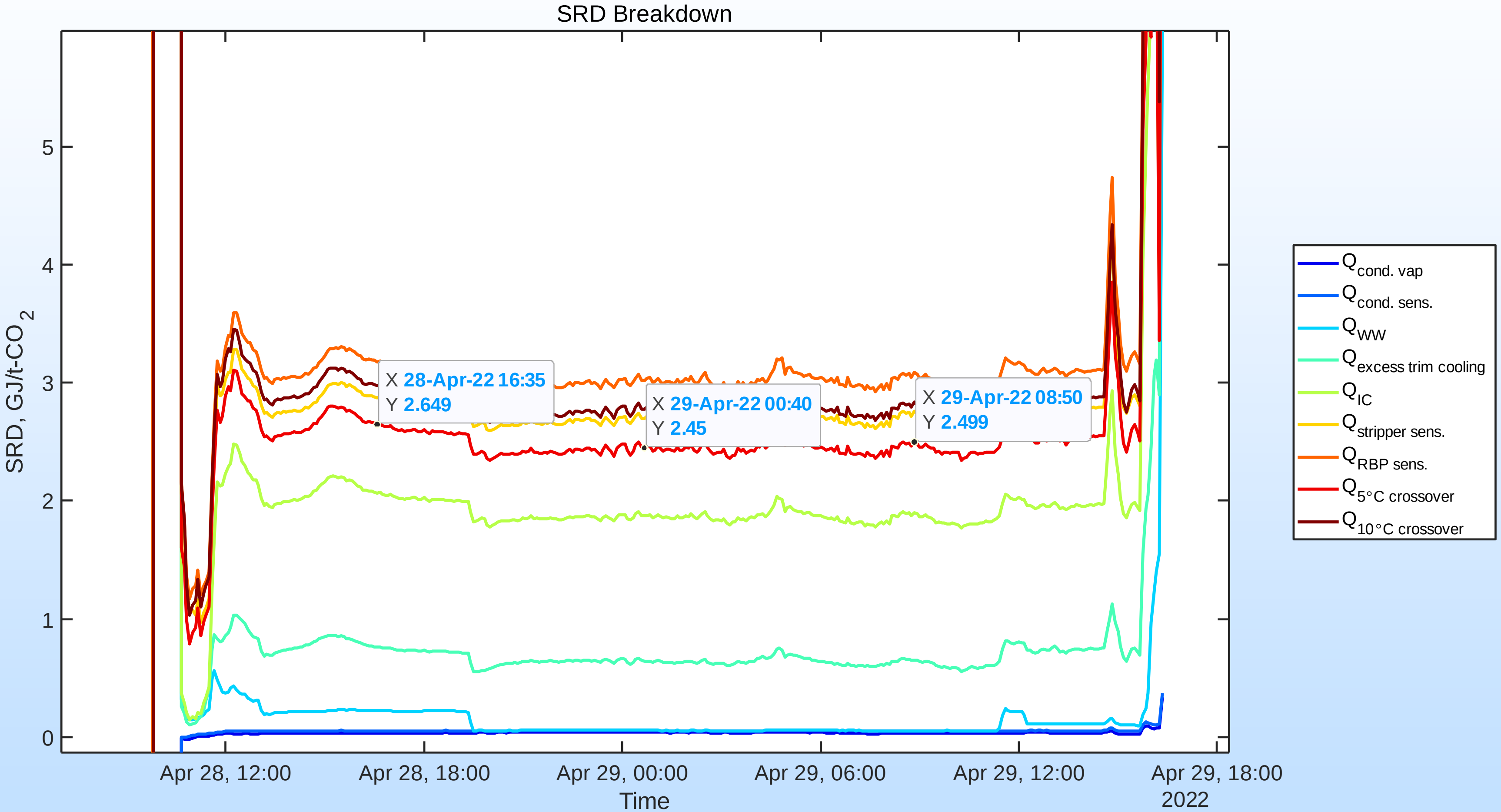
- Amine emission levels well below 1 ppm
- Aldehyde levels also below permitting limits
- Emission mitigation with acid wash is working well
- First two weeks of campaign focused on emissions

Foaming in the Regenerator

- During initial CHP testing observed instability in regenerator
- Suspected foaming or rapid solvent degassing
- Shifted regenerator to higher pressure
- Increased solvent loading
- Added antifoam
- Currently not experiencing foaming, but has been intermittent

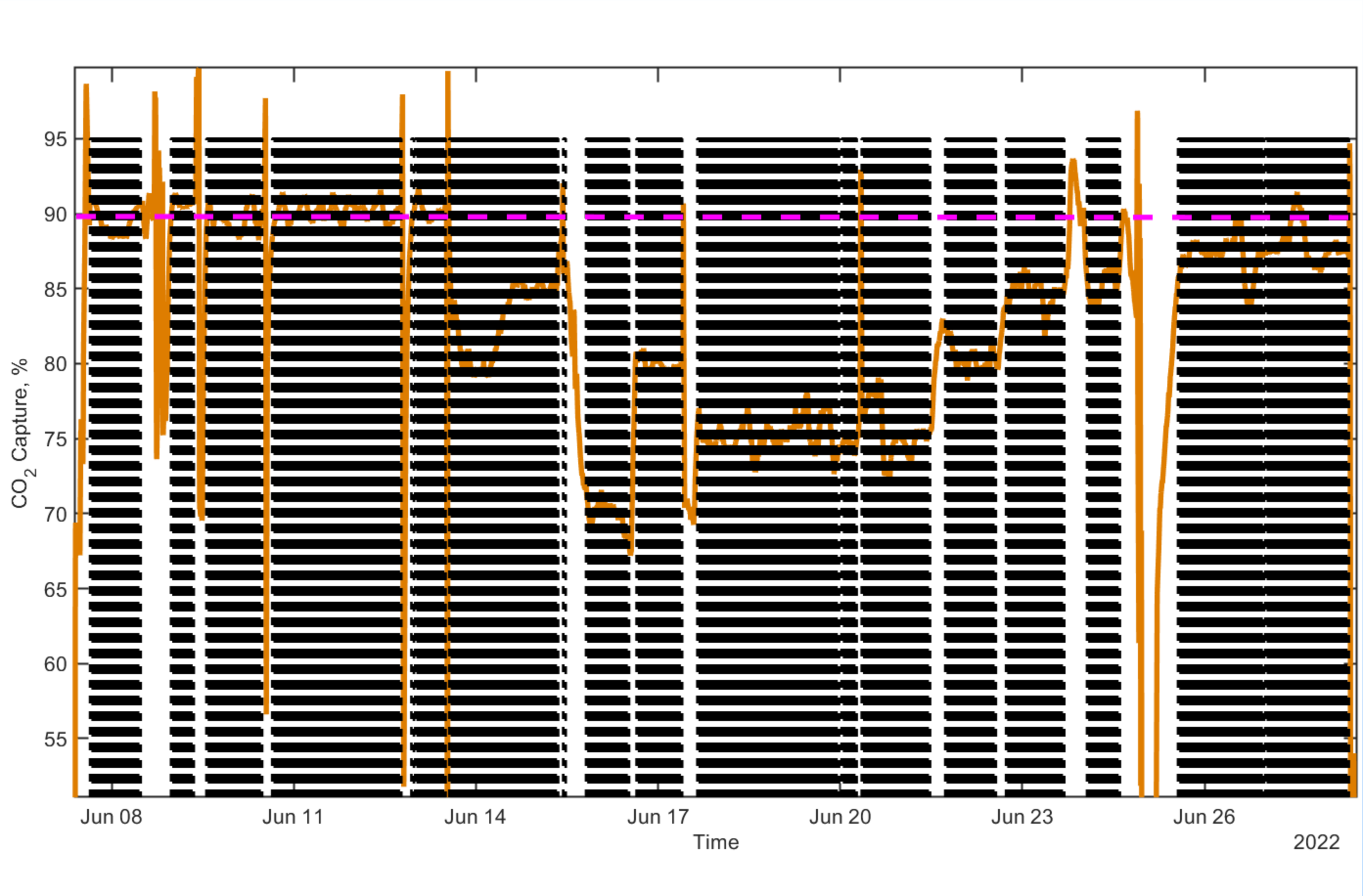


Progress and Current Status Coal



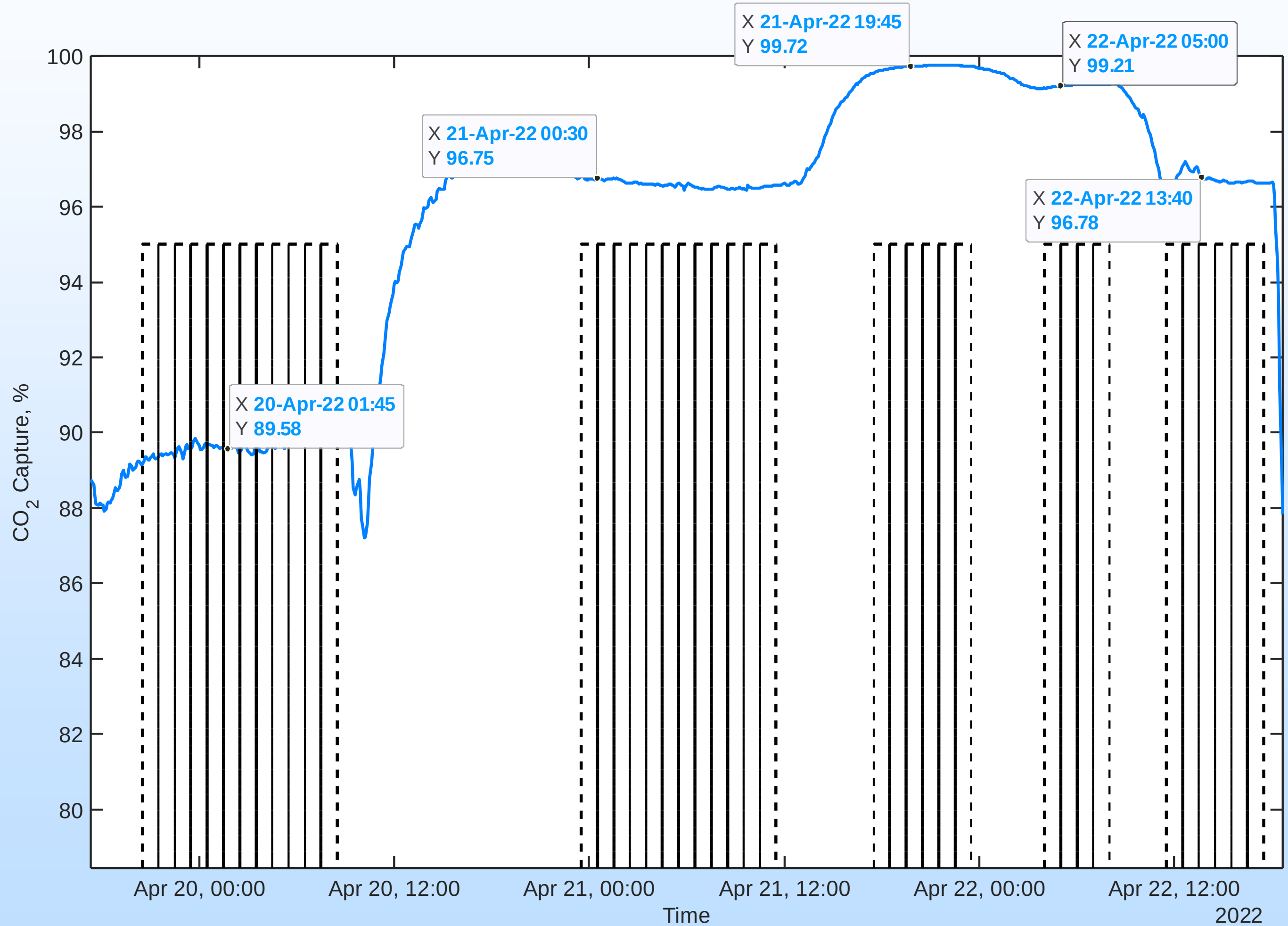
- Success criteria to demonstrate SRD of 2.6 GJ/tonCO_2 or lower on coal flue gas (13.5% CO_2, 90% capture)
- Aligned with process modeling of plant configuration
- Confirms energy penalty observed in previous demonstrations

Progress and Current Status Coal



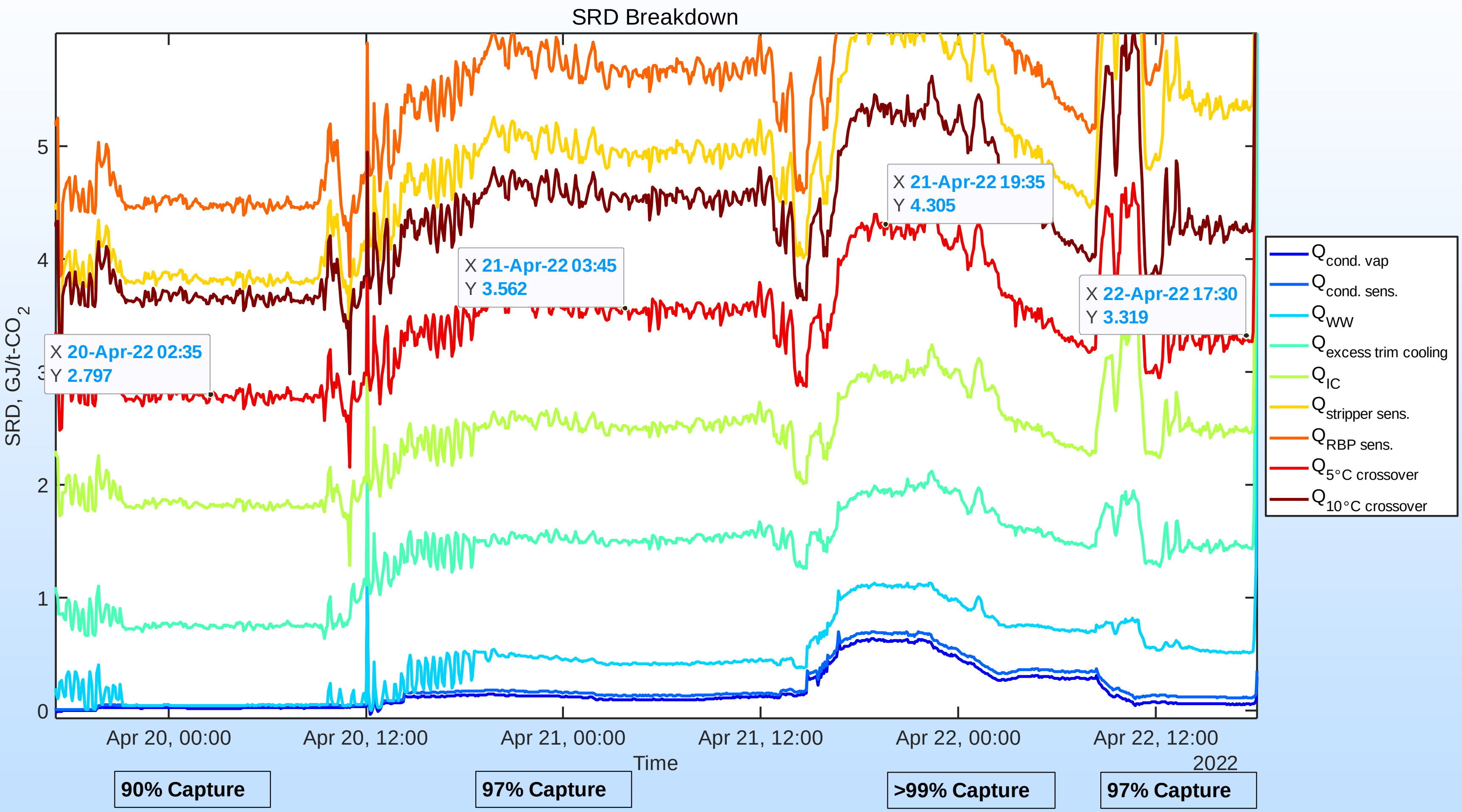
- Long-term testing
- 3.2 barg regen pressure
- Elevated aerosols in June
- Reduced capture rate to stay below permitting limit
- Hypothesize that the PM levels in the gas temporarily elevated and gas became cleaner over time

Progress and Current Status NGCC



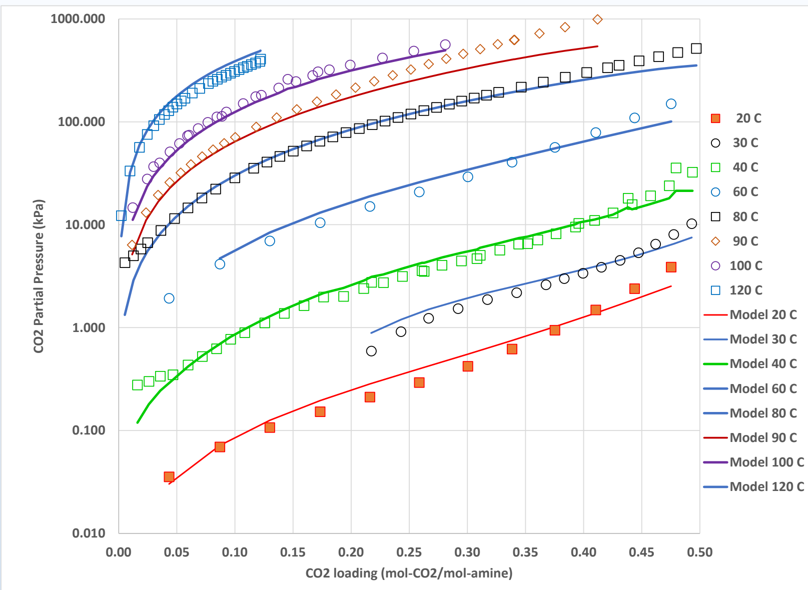
- Explored high capture efficiency with CHP (NGCC) flue gas in April
- Able to achieve >99% CO_2 capture
- Requires higher reboiler temperature (115-120°C)

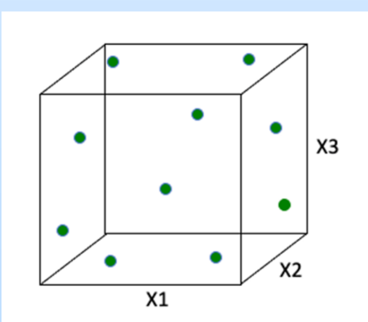
NGCC High Capture Efficiency

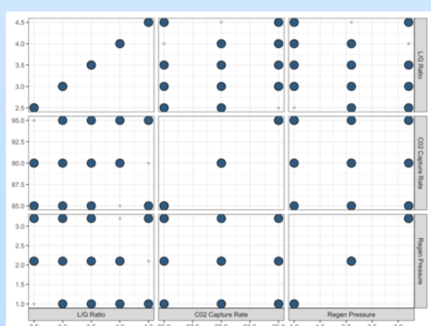


- Reboiler duty increases with higher capture efficiency

Ongoing collaboration with $CCSI^2$

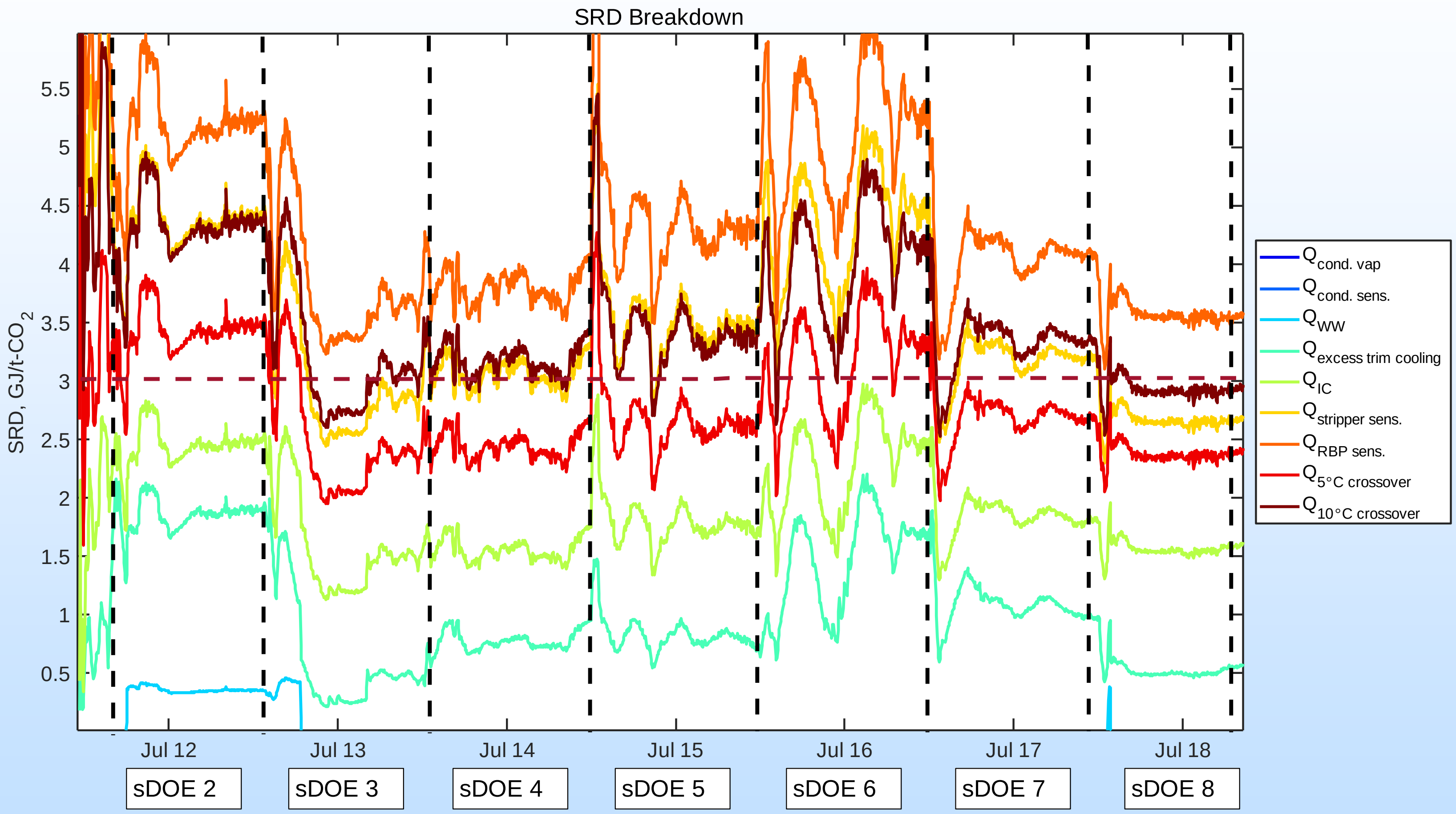






- Working with $CCSI^2$ on NAS thermodynamic model refinement and uncertainty quantification.
- Updated model will be validated using experimental data from TCM demonstration.
- Worked with $CCSI^2$ to develop a test matrix using the sequential design of experiment approach for testing at NGCC and coal flue gas conditions at TCM.
- Design factors of interest:
  - CO_2 Capture: 85 - 95%
  - Absorber L/G Ratio: 2.5 – 6.5 kg/kg
  - Stripper Pressure: 0.9 – 3.2 barg

Progress of NGCC sDOE



- TCM well-suited to perform sDOE studies
- Identified promising conditions at 90% capture and low L/G

Plans for future testing/development/ commercialization

Remainder of TCM test campaign

High Level Test Plan Last Update: Jul 20, 2022					
RFCC					
CHP					
RHP (+ w/recycle)				Tentative Aug 30 ->	
RHP w/dilution					
START DATE	15-Aug	22-Aug	29-Aug	5-Sep	12-Sep
CALENDAR WEEK	33	34	35	36	37
Test Plan	**Dynamic Testing**	**Misc Testing**	**FORCE Valid./ LTT**	**long term testing - RHP w/recycle**	
Gas in use					
CO_2 Concentration	3.7	3.7 - 20	13.5	13.5	13.5
RTI person on site	JT	VG	VG	PM	PM

- Complete dynamic testing
- Complete high removal efficiency testing
- EPRI third party verification
- Finish long-term testing

Future Development

- Targeting opportunities to build pilots for cement, iron, and NGCC
- Engineering scale project underway for load–following NGCC (ARPA-E FLECCS)
- Engineering scale demonstration of advanced water wash for GEN1NAS
- GEN2NAS with substantially lower vapor pressure bench-scale development

Key Findings and Lessons Learned

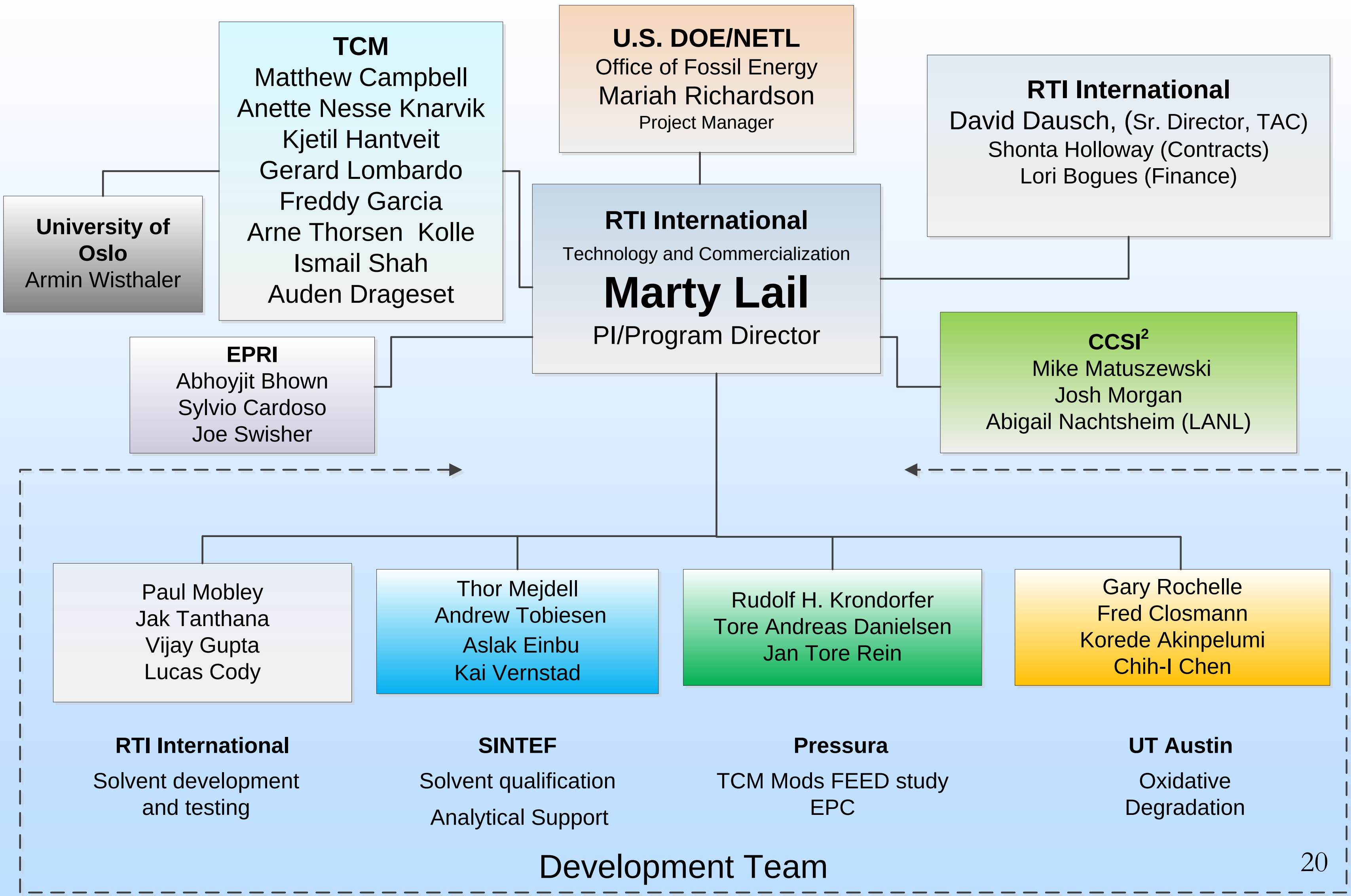
Key Findings

- RTI GEN1NAS is able to achieve target SRD for flue gas at ~13.5% CO_2 concentration in the TCM amine plant with new configuration.
- Aerosol emissions can be controlled in response to fluctuations in flue gas conditions by reducing the capture efficiency
- High efficiency capture >99% from NGCC flue gas is achievable and has been demonstrated with NAS at TCM
- sDOE testing in collaboration with $CCSI^2$ under NGCC conditions has identified several promising operating conditions

Lessons Learned

- Small concentrations of volatile impurities from synthesis can exceed emissions limits at start-up and should be purged from the solvent as a final step of manufacturing
- Certain aspects of non-aqueous solvent operation require additional modification of conventional amine plants such as the overhead condenser operation and size of heat exchanger

Organization Chart



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