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

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DE-FE0031590
DOE Program Manager: Steve Mascaro

Project Kickoff Meeting

Oct. 2, 2018

Outline

- ***Background and Development Status***
  - ***Tiller test results***
  - ***NCCC test results***

- ***Current Project***
  - ***Objectives***
  - ***Project team***
  - ***Tasks***
  - ***Schedule***
  - ***Goals and success criteria***
  - ***Risks and risk mitigation***
  - ***Milestones***
  - ***Summary***

Background: Progress to Date

- **Parametric and Long-term Testing**
  - At SINTEF's Tiller Plant - 543 h on parametric testing and 1,043 h on stream for long-term testing with coal-fired flue gas.
  - At NCCC's SSTU - Completed 580 hrs. of time on stream (target 400 hrs.) with coal-fired flue gas.
- **HSS formation**
  - Low levels of HSS formation during the course of testing
- **Water Balance**
  - Can be controlled at desired level
- **Corrosion**
  - Lower rate of corrosion than MEA
- **Performance**
  - 90% capture, stable operation, SRD = 2.1 to 2.3 GJ/t-CO2
- **Viscosity**
  - Lean: 4.38-4.7 cP
  - Rich: 17 to 20 cP

Background: Long-term test of NAS-5

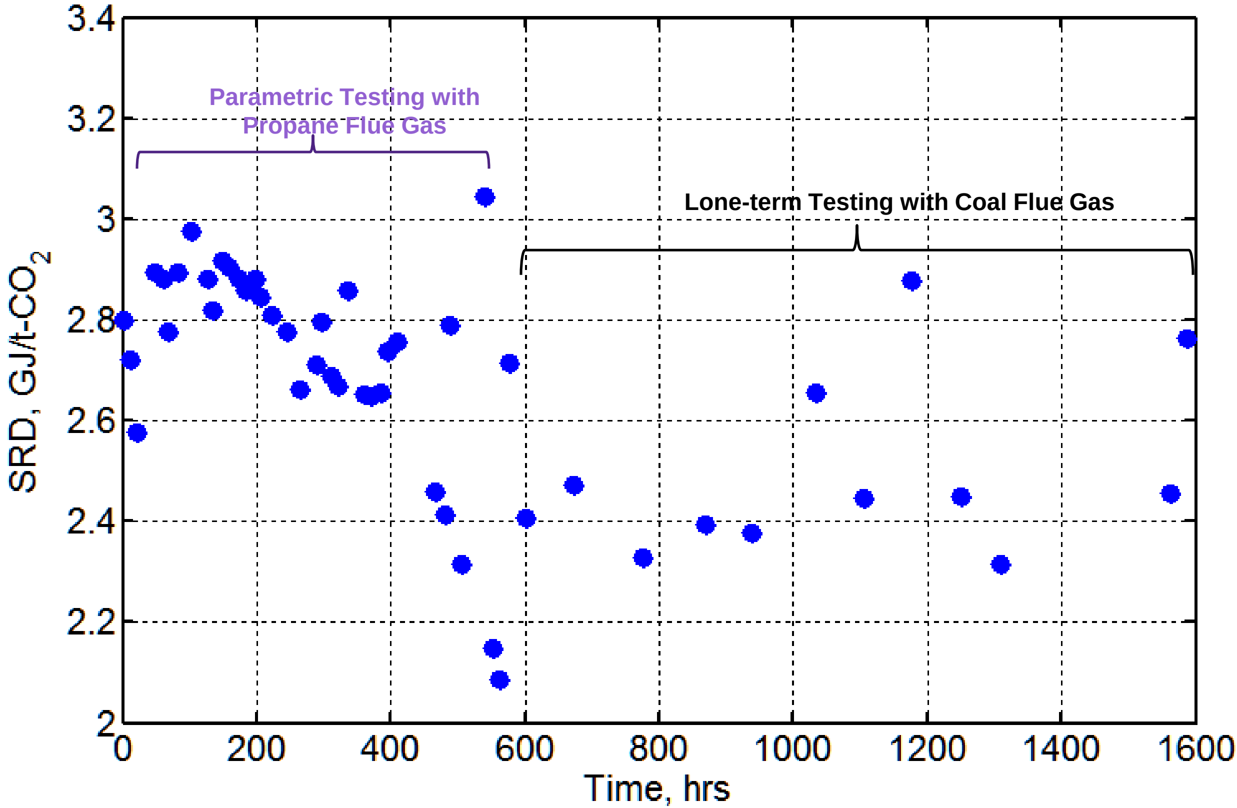
Tiller coal flue gas composition

H2O	CO2	CO	NO	NO2	N2O	SO2	NH3	HCl	HF	HCHO	O2	
vol%	vol%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	vol%	
5.5	16.0	11.5	79.8	0.5	0.8	198.8	0.1	2.1	0.4	0.3	7.2	Before DCC
3.1	15.9	11.2	81.0	0.6	1.2	2.7	0.3	0.4	0.2	0.2	7.3	After DCC

Flue gas composition and conditions at Tiller plant in comparison with those at NCCC

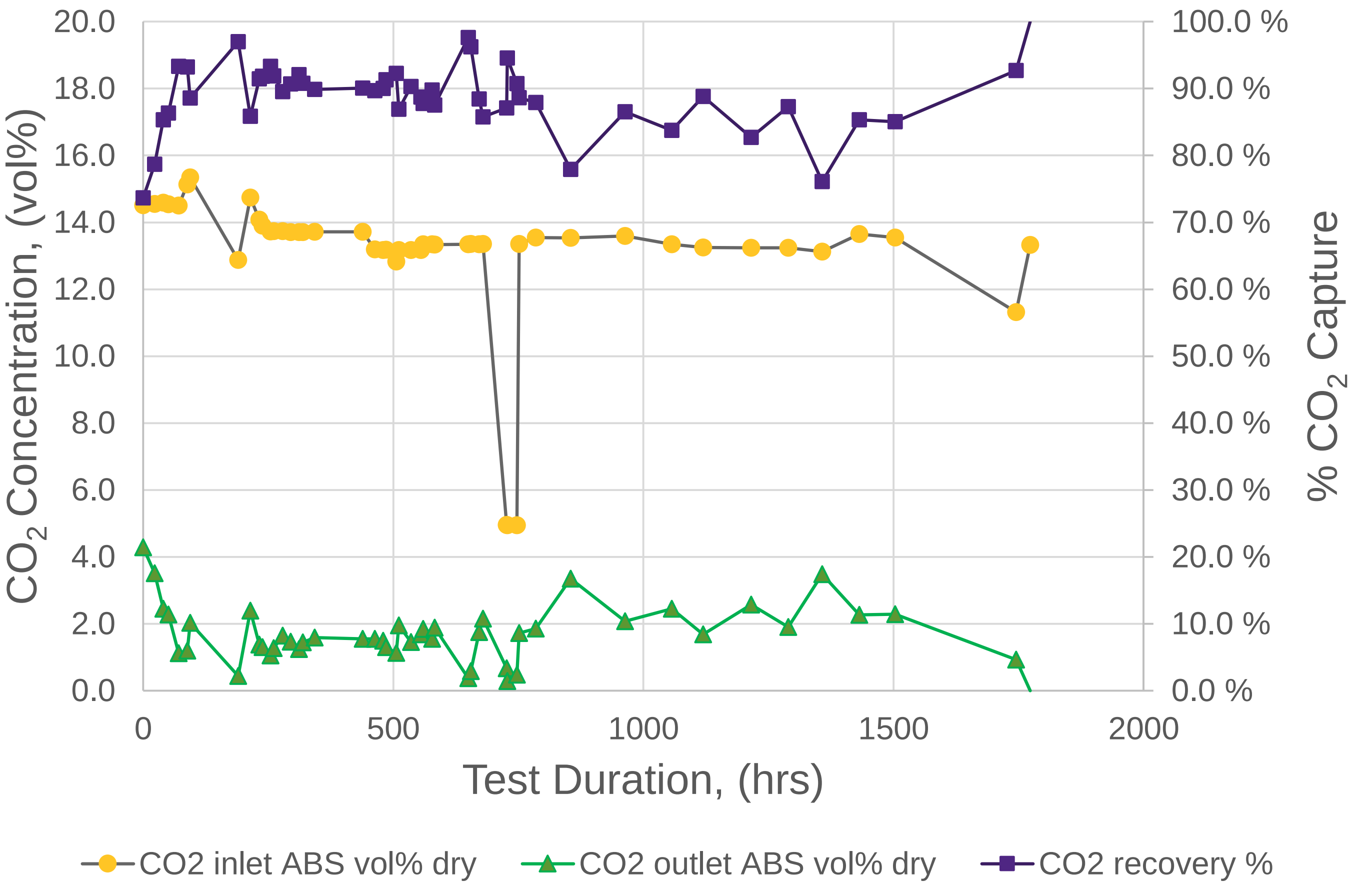
Component	Unit	Tiller Flue Gas	Design (NCCC)	Average (NCCC)
CO2	vol %	12 - 15	12.14	14
O2	vol %	4.0 – 7.3	5.20	4.5
N2 + Ar	vol %	66 - 69	69.36	68.5
H2O	vol %	3 - 6	13.30	13
SO_2	vppm	3	1	2.5
NO_x	vppm	80	80	-
Temperature	°C (F)	40 – 70 (100 – 160)	71 (160)	68 (155)
Pressure	mBar-g (H2O)	25 (10)	25.4 (10)	50.8 (20)

Background: Long-term test of NAS-5 – SRD



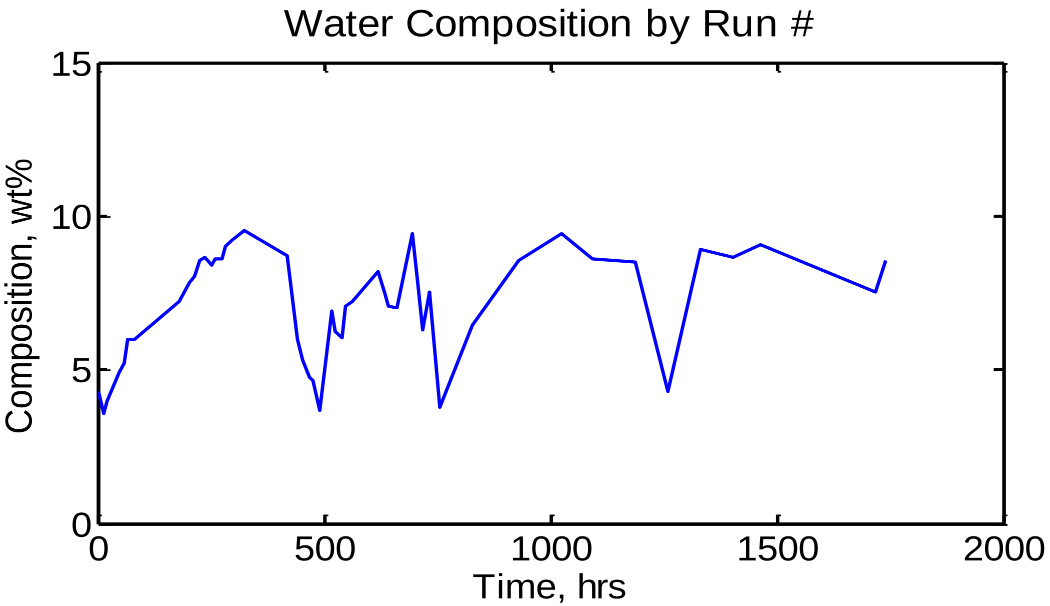
- 543 h on parametric testing and 1,043 h on stream for long-term testing, total of 1,587 h

Background: Long-term test of NAS-5 – CO_2 capture

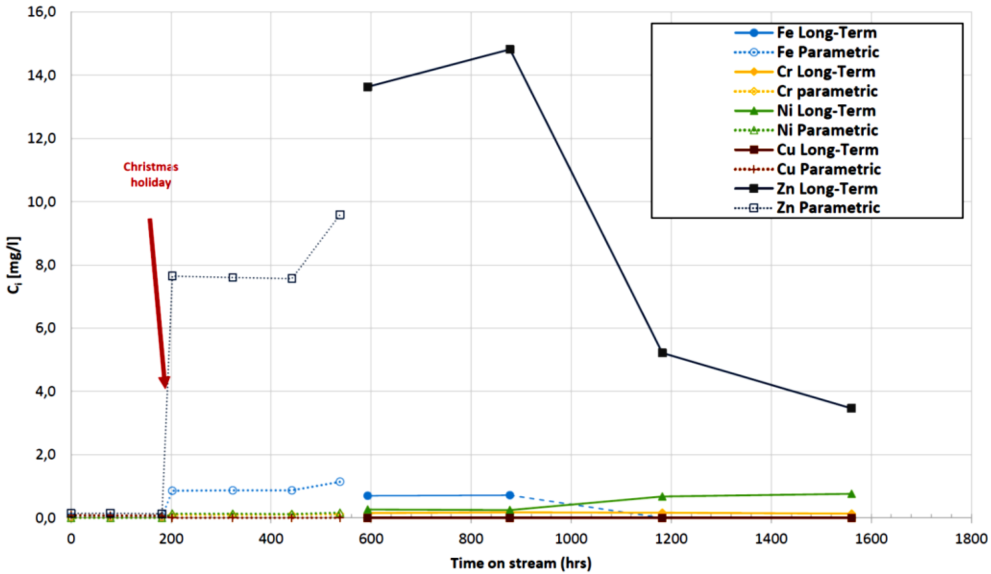


Water Management

- The water balance was demonstrated successfully at the small pilot scale (60 kW at SINTEF)
  - Water content controlled at 5-8% for > 1,400 hours
  - Controlled by water wash temperature ~1-2° C higher than inlet flue gas saturation temperature



Parametric and long-term testing of NAS-5 – Corrosion



- **Corrosion at Tiller**
  - No corrosion issues encountered at Tiller
  - PP liner evaluated at Tiller and result shows good compatibility

- **Material Compatibility**
  - Excellent compatibility
    - SS316
    - PTFE
  - Good compatibility
    - EPDM

- **Metal coupons at NCCC**
  - Samples being analyzed
    - Carbon steel
    - SS304
    - PP

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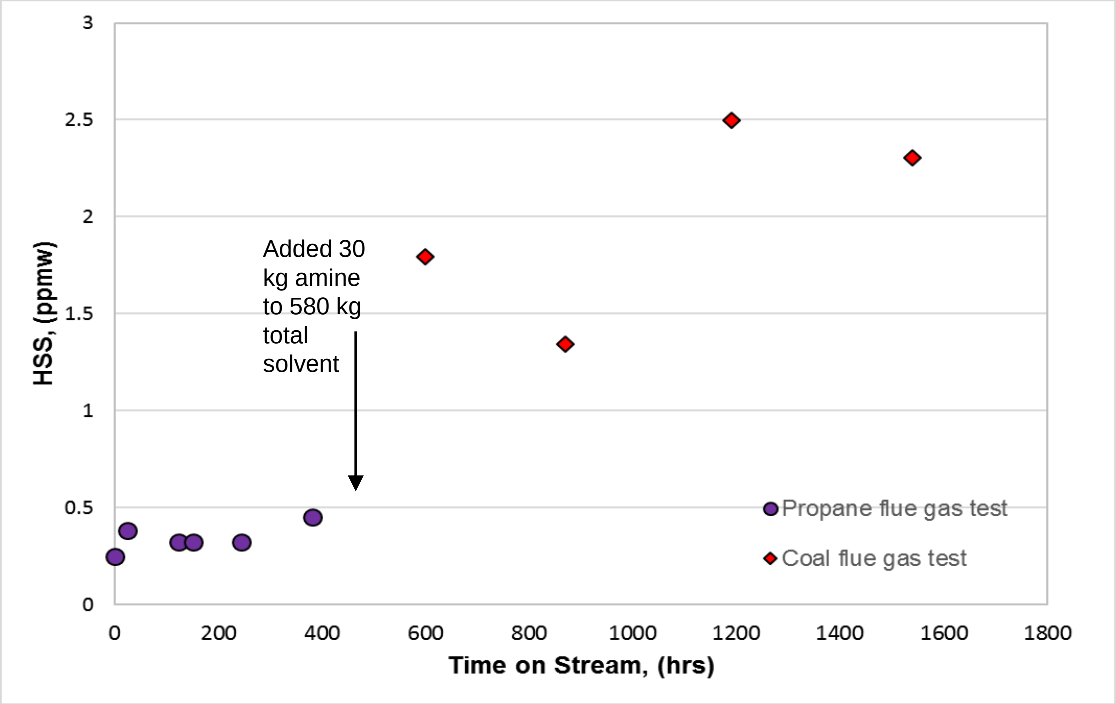
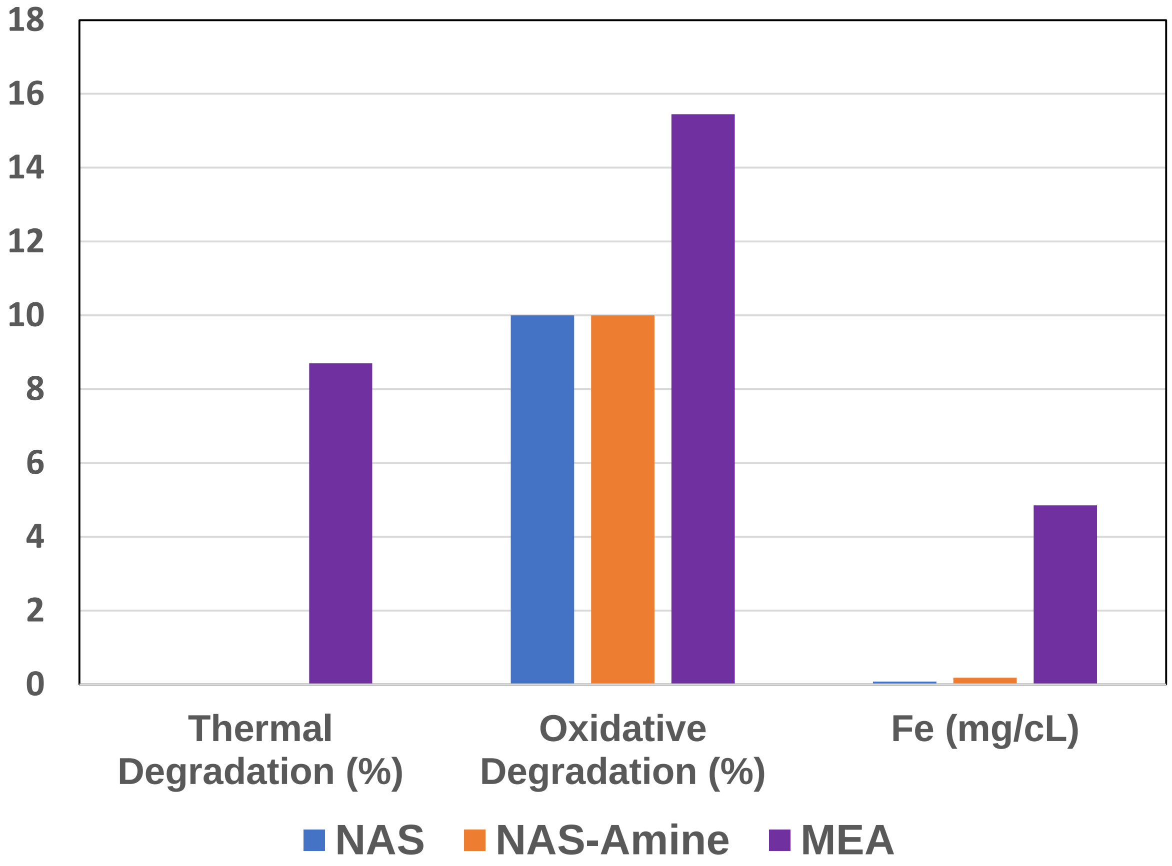
Heat-Stable Salts (HSS)



- HSS formation
  - Low levels of HSS measured throughout the campaign
- For 30 wt% MEA solvent tested under post-combustion CO_2 capture conditions, HSS accumulates to 0.47 wt% in 100 hours of pilot testing at a rate of 48 ppm/h.[1]

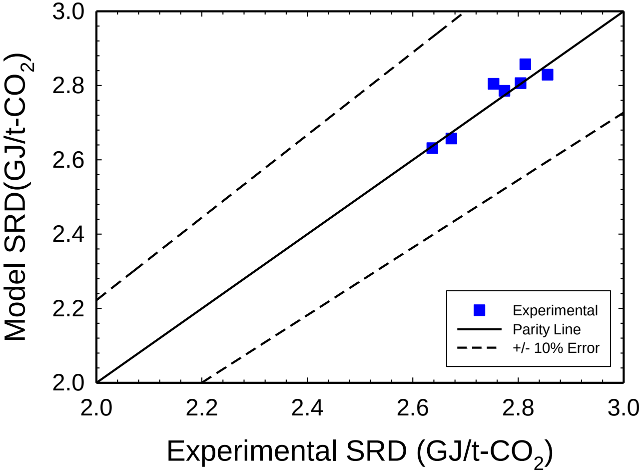
1. J. G. Thompson, et al. Aerosol and Air Quality Research, 14: 550–558, 2014

Thermal and Oxidative Degradation of NAS and MEA

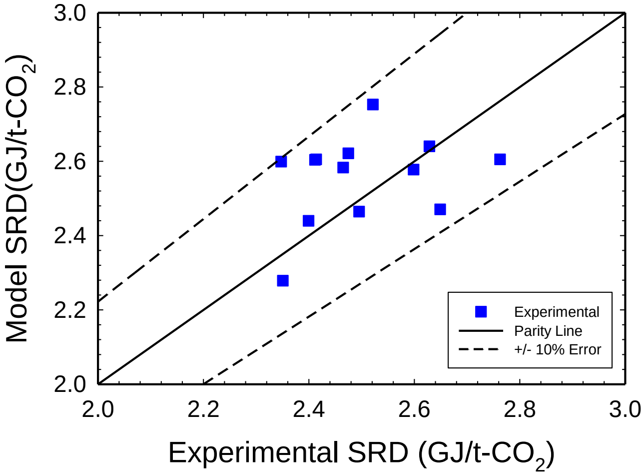


Process Model for Non Aqueous Solvents

Experimental data from SINTEF Tiller



Experimental data from RTI BsTU



- Aspen Plus process model validated using data from the RTI Bench-scale Gas Absorption System (BsGAS) and SINTEF Tiller plant data

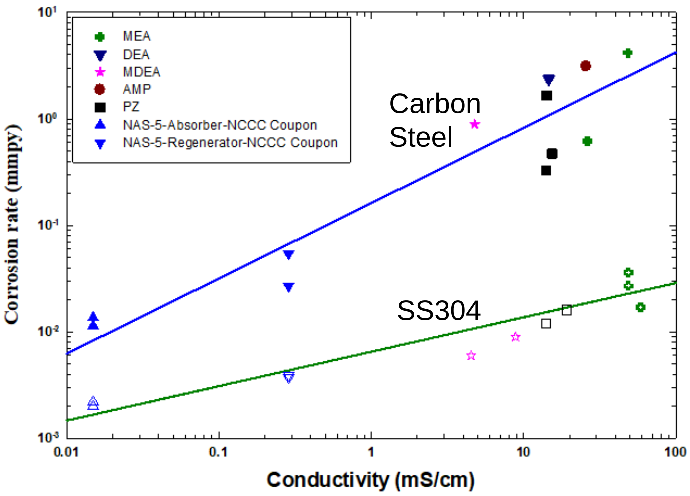
NAS Process Testing at NCCC

- ***Objectives:***
  - Continuous run of NAS-5 using coal-derived flue gas from power plant
  - Further reduce the deployment risk, particularly on fugitive emissions and solvent degradation
  - Tested NAS at NCCC's SSTU
  - Test advanced NAS-5 formulation at NCCC to determine:
    - operating windows
    - solvent degradation
    - water balance
    - emissions
    - amine loss
    - other operational issues
- ***Timeline: May-Aug 2018***

Corrosion Measurements with NAS-5

- SINTEF
  - EPDM gaskets
  - Polypropylene liner for concrete absorber towers
  - No significant weight/thickness/visual changes were observed on the gaskets or liners
- NCCC
  - Corrosion coupons showed significantly less corrosion compared to other solvents
  - Polypropylene discs showed some NAS absorption, ~4%
- The low conductivity of the NAS allows for orders of magnitude lower corrosion

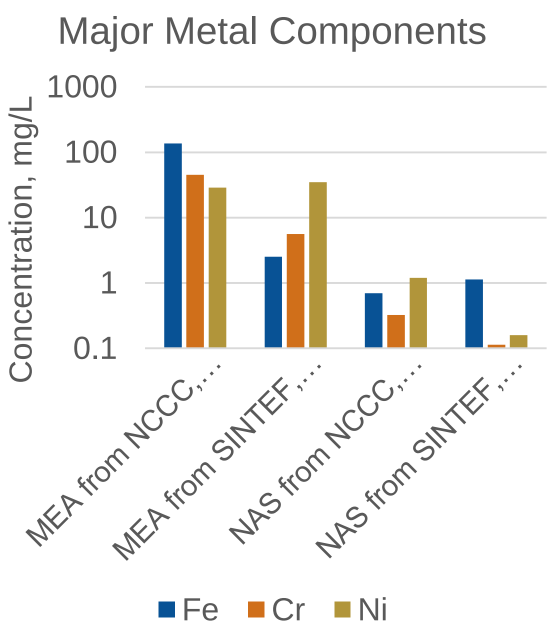
Extremely low corrosion, ~100X lower than aqueous solvents for

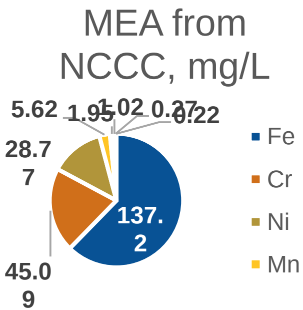


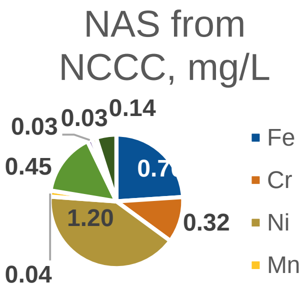
Metals in Solvent

- Metals analysis shows significantly lower metals found in NAS compared to MEA at NCCC and SINTEF
- Major components in MEA often more than two orders of magnitude larger than in NAS

Metal	MEA:NAS ratio NCCC	MEA:NAS ratio SINTEF
Fe	196.0	2.2
Cr	138.9	49.3
Ni	24.0	218.8







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Current Project

Project Summary

Objective: Testing and evaluation of the transformational Non-Aqueous Solvent (NAS)-based CO_2 capture technology at engineering scale (~12MWe) at TCM

Key Metrics

- Solvent performance including capture rate, energy requirements, solvent losses
- Solvent degradation rates, corrosion rates, emissions due to vapor and aerosol formation
- Operational efficiency over static and dynamic operating conditions
- Existing technical and process risks and their mitigation
- Technoeconomic and EHS evaluation

Specific Challenges

- Operate TCM plant within emission requirements
- Minimize rise in absorber temperature
- Maximize NAS performance with existing hardware limitations

Timeframe: **BP1** 8/8/18 to 9/15/19
BP2 9/16/19 to 1/15/21

Project Team

Team Member	Role	Expertise
RTI International	Prime recipient, owner and developer of NAS technology (process design, NAS formulation), project management, economic analyses, environmental assessment	• 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
TCM	Host site (existing infrastructure) for large scale (~10 MW) pilot, EH&S support, operational support	• World leading test facility for CO_2 capture • Dedicated operations staff • Actual flue gas supply (similar to coal) • Full analytical labs • EH&S and quality standards
SINTEF	Solvent qualification, engineering support, and operational support	• Pilot plant (Tiller) for solvent-based CO_2 capture processes, operational and EH&S expertise • Engineering design of process components • Analytical equipment for solvent testing
EPRI	TEA, process validation	• Development of techno-economic models and testing with stakeholders to drive common methodology guidelines • Experience with TCM project assessment • TEA performance following DOE guidelines • Perform third-party process verification
Clariant	Solvent supplier under RTI license	• Commercial-scale manufacturing and shipping of suitable solvent quantities according to solvent specifications and permitting requirements

Project Tasks

Task 1.0 Project Management and Planning (spans both BP1 and BP2)

BP1 Tasks

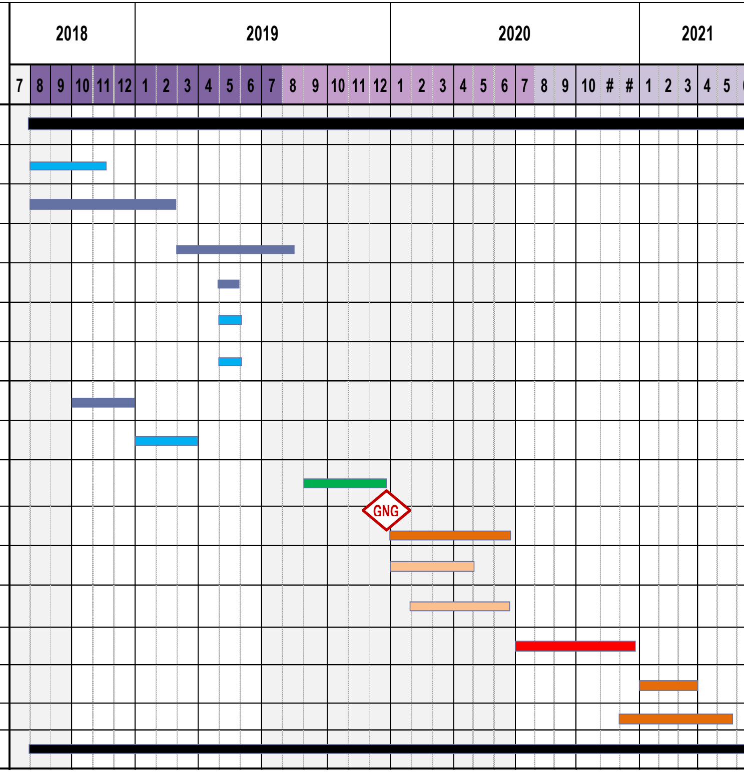
Task 2.0 TCM EH&S Risk Evaluation and Permitting
Task 3.0 Solvent Production
Task 4.0 Solvent Qualification
Task 5.0 Preliminary Design of a NAS-Specific TCM Amine Plant Modifications
Task 6.0: NAS Baseline Test Plan Development, Testing, and Data Analysis

BP2 Tasks

Task 7.0 TCM Amine Plant Equipment Procurement, Modification and Commissioning
Task 8.0 NAS Modified Amine Plant Test Plan Development, Testing, and Data Analysis
Task 9.0 Decommissioning and Waste Handling
Task 10.0 Final Techno-Economic Analysis and EH&S Risk Assessment
Task 11.0 Technology Gap Analysis

Overall Project Timeline

Task	Task title	Start date	End date
1.0	Project Management and Planning ($454,916)	08/08/18	01/15/21
	1.1 Test Agreement with TCM	08/08/18	11/15/18
2.0	EH&S and Risk Evaluation and Permitting ($80,120)	08/08/18	03/15/19
3.0	Solvent Production ($788,863)	03/01/19	08/09/19
4.0	Solvent Qualification ($157,746)	05/06/19	05/17/19
	4.1 RTI tests	05/06/19	05/17/19
	4.2 SINTEF Tiller tests	05/06/19	05/17/19
5.0	Preliminary Design of a NAS Optimized System ($340,378)	10/08/18	01/06/19
	5.1 Cost Benefit Analysis for NAS Optimized System	01/08/19	04/09/19
6.0	Test Period I: "Drop-In" Test ($656,731 Fed, $4,320,000 Cost Share)	09/01/19	11/30/19
7.0	Revamp Implementation ($5,127,000)	01/01/20	05/15/20
	7.1 Interstage Cooler	02/01/19	06/15/20
	7.2 Pre-heater	09/08/19	01/22/20
8.0	Test Period II: Revamped Unit ($1,071,675 Fed, $8,640,000 Cost Share)	02/08/20	08/09/20
9.0	Decommissioning and Waste Handling ($360,801)	07/22/20	10/21/20
10.0	Final TEA (550 MW Net) ($421,665 Fed, $85,000 Cost Share)	07/22/20	01/05/21
11.0	Technology Gap Analysis ($272,256)	08/08/18	01/15/21



Project Timeline – BP1 NAS Testing Details

Name	Start	Finish	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Initial Emission Reduction Recommendation to TCM	4/17/2018	4/20/2018																					
NAS Testing Project Description to TCM	4/17/2018	4/25/2018																					
Process and Emission Modeling for TCM Testing	5/1/2018	6/14/2018																					
RTI Emission Reduction Testing	6/11/2018	8/17/2018																					
Plant Washing Procedure to TCM	8/13/2018	8/22/2018																					
NCCC NAS Testing with Coal Flue Gas	5/29/2018	7/27/2018																					
Emission Reduction Recommendation to TCM	8/20/2018	8/30/2018																					
TCM Emission Permitting	7/2/2018	12/1/2018																					
NAS Prodcution/Delivery to TCM	3/1/2019	8/9/2019																					
NAS Solvent Qualification Testing	5/6/2019	5/17/2019																					
NAS Baseline Testing	9/2/2019	12/13/2019																					
Initial Testing with CHP Flue gas	9/2/2019	9/13/2019																					
Parametric Testing with RFCC Flue Gas	9/16/2019	9/27/2019																					
Long-term Testing with RFCC Flue Gas	9/30/2019	12/13/2019																					

Project Goals and Success Criteria

- Confirm that the conventional aqueous amine system can be operated without issue with NAS
- Confirm NAS pilot-scale baseline performance results
- Confirm NAS pilot-scale optimal performance results
- Refine Techno-economic analysis
- Control and manage emissions
- Control and manage water balance at this scale
- Determine the resulting impact on the reboiler heat duty
- Gain operational experience

Project Goals and Success Criteria

Decision Point	Date	Success Criteria
Beginning of BP2	01/15/2010	1. NAS drop-in test at TCM using its amine plant in its current configuration confirms small pilot SRD performance at SINTEF and predicted SRD from TCM plant model 2. Completion of revamp engineering and favorable cost-benefit analysis
Completion of Project	01/15/2021	1. Techno-economic analysis delivered to DOE 2. Final report shows techno-economic merit of the NAS process for CO_2 capture and confirms readiness for next TRL 3. Large NAS optimized pilot project cost estimate finalized 4. All other reports delivered according to FOA requirements

Risks and Risk Mitigation

Description of Risk/Area		Prob.	Impact	Risk Management (Mitigation and Response Strategies)
Technical Risks:				
Process	Solvent Loss	Low	Moderate	• Return water wash back to the process to control amine loss • Lean splitting and rich solvent washing
Process	Solvent Loss due to Aerosols, Solvent Emissions	Moderate	Moderate	• Water wash + acid wash to control emissions • Rich solvent to dry column • Reduced gas flow to control aerosol
Process	NAS Degradation due to Extended Solvent Exposure to Coal-derived Flue Gas	Moderate	Moderate	• Tiller performed 1400 hours of NAS testing with coal-derived flue gas with no apparent decrease in NAS performance
Process	Water Management	Low	High	• Tiller parametric and long-term tests show that water balance can be maintained

Risks and Risk Mitigation

Description of Risk/Area		Prob.	Impact	Risk Management (Mitigation and Response Strategies)
Legal	Permitting	Low	High	• RTI is working with TCM to supply all required information for permit application
Safety	Construction Risk, Plant Operation	Low	High	• TCM has existing safety rules • TCM has qualified personnel for operation and construction

Risks and Risk Mitigation

Description of Risk/Area		Prob.	Impact	Risk Management (Mitigation and Response Strategies)
Resource Risks:				
Supplier	Production Schedule and Delivery	Low	Moderate	• Order solvent on time • Communicate with supplier often
Management Risks				
Project Cost	Project Cost	Moderate	High	• RTI will employ cost control using earned-value management techniques • RTI will tack completion of tasks, schedule, and costs to remain within the budget • Cost deviations and/or projections of deviations will be reported to DOE immediately along with a corrective action plan.
Cost Share	Cost Share	Low	High	• Cost share depending on test duration at TCM • Exchange rate

BP1 Key Tasks

Key Tasks	Milestone Number and Task	Approaches/ planned Activities	Planned Completion Date
NAS solvent batch (~50 tons) delivered to TCM site	M5/Task 3	• Clariant is selected as a solvent manufacture • Validate pilot batch performance before bulk manufacturing	8/15/19
Revamp engineering design and cost estimate	M7/Task 5	• Update costing and sizing data based on Tiller revamp • Aker to assist in design • Validate sizing and equipment specs with a Norwegian engineering firm	06/30/19
Drop-in test according to DOE approved test matrix	M9/Task 6	• Design test matrix based on TCM model • Refine matrix on-the-go with sequential DoE	12/31/19

BP2 Key Tasks

Key Tasks	Milestone Number and Task	Approaches/ planned Activities	Planned Completion Date
Test reports for parametric and long-term testing in revamped capture unit	M11/Task 8	• Update State Point Data after testing completed	10/31/20
Final TEA according to DOE guidelines	M13/Task 10	• Update current TEA with TCM results	2/28/21
Technology Gap Analysis	M14/Task 11	• Analyze the current state of development of all the major/critical process components	3/31/21

Summary

– Key Findings to Date

- More than 2000 hours of testing completed at the small-pilot scale
- SRD measured at small pilot-scale to be 2.3 GJ/t-CO_2
  - Demonstrates accuracy of bench-scale system that measured 2.1-2.3 GJ/t-CO_2
- Heat stable salts found to not accumulate in system, ~10,000x less than MEA
- Low levels of corrosion from NAS in extended campaigns
  - MEA solvent tested under the same conditions showed about 100 times higher Fe concentration
- Low levels of degradation species found in long-term campaigns with coal-derived flue gas

Summary

Project Objectives:

- Confirm the potential to reduce the parasitic energy penalty for carbon capture by 20 to 40% compared with that for the MEA process
- Advance this transformational, low-cost technology solutions that allow competitive operation of our nation's fossil-based power generation infrastructure in a low-carbon future.
- Demonstrate the long-term process operational reliability
- Verify solvent degradation rate, emissions, solvent loss, and corrosion characteristics
- Demonstrate NAS as a drop-in replacement solvent in conventional capture systems
- Perform a NAS-specific revamp of the TCM unit to further lower the energy penalty

Project Challenges

- Combined strategies to reduce emissions
- Host site – developers testing schedule coordination
- Test run optimization using sequential design of experiment
- Leverage CCSI modeling capability

Acknowledgments

- Financial support provided by DOE NETL under DE-FE0031590

- DOE Project Manager: Steve Mascaro
- Project partner and host site TCM

- Project partner SINTEF
- Project partner EPRI
- Solvent supplier Clariant

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