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

S. James Zhou, Paul Mobley, Jak Tanthana, Aravind Rabindran, Mustapha Soukri, Vijay Gupta, and Marty Lail

DE-FE0031590
DOE Program Manager: Steve Mascaro

2018 NETL CO_2 Capture Technology Meeting

August 13 - 17, 2018

RTI at a Glance

Diverse Global Workforce & Worldwide Presence and Financial Strength

4,905 Staff Members Worldwide

90 Languages

250 Degree Fields

100 Nationalities

Staff By Region

- **3,236** United States and Canada
- **425** Asia
- **92** Europe
- **137** Latin America and the Caribbean
- **55** Middle East and North Africa
- **951** Africa
- **3** Australia

$972 M
FY2017 Revenue

3,852 Projects
(fiscal year 2017)

1,198 Clients
(fiscal year 2017)

Project Summary

Objective: Testing and evaluation of the transformational Non-Aqueous Solvent (NAS)-based CO_2 capture technology at engineering scale 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: 8/8/18 to 1/15/21

Accelerated Technology Pathway

DOE ARPA-E Project	DOE NETL Project	DOE NETL Project (Current)	Large-scale Testing	Commercial
2010 – 2013	2014 – 2016	2015 – 2018	2018 – 2021	2021+
1 – 2 TRLs	2 - 3 TRL	3 – 4 TRL	5 – 6 TRL	7 - 9 TRL

Lab-Scale Development / Evaluation

Funding: ~$2,700,000

- Solvent screening to identify promising solvent formulations
- Lab-scale evaluation of NAS Process
- Preliminary technical and economic assessments

Large Bench-scale System / Relevant Environment Testing

Funding: ~$3,000,000

- Finalize NAS formulation
  - *Address evaporative losses and solvent costs*
- Develop critical process components
  - *NAS wash / recovery section*
  - *NAS regenerator*
- Bench-scale testing within a process unit with major process components
- Demonstrate ≤ 2,000 kJt/kg CO_2 using bench-scale system
- Detailed solvent degradation and preliminary emissions studies
- Detailed techno-economic and EH&S assessments
  - *Demonstrate T&EA competitiveness and environmental permitability*

Combined SINTEF (Tiller)

Funding: ~$2,700,000

- Tiller Plant (~60 kWe)
  - *Demonstrate all process components for NAS process in adiabatic system*
  - *Accurately quantify solvent losses and emissions*
  - *Test campaign on coal derived flue gas*
  - *Determine materials (metals, polymers, gaskets) compatibility*
  - *Collect critical process data to support scale up, develop engineering package for TCM*

TCM Pathway Large Scale Demonstration

- ***Funding: ~$10,000,000***
- TCM (~10 MWe)
  - *Complete process unit with all components at minimum size required for confident scale-up*
  - *Collect critical process information to support detailed T&E assessments, emissions monitoring, long-term testing to develop reliability, availability and maintainability (RAM) metrics*

Background: Progress to Date

- **Parametric and Long-term Testing**
  - 543 h on parametric testing and 1,043 h on stream for long-term testing, total of 1,587 h 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-CO_2
- **Viscosity**
  - Lean: 4.38-4.7 cP
  - Rich: 18 to 20 cP

Background: Long-term test of NAS-5

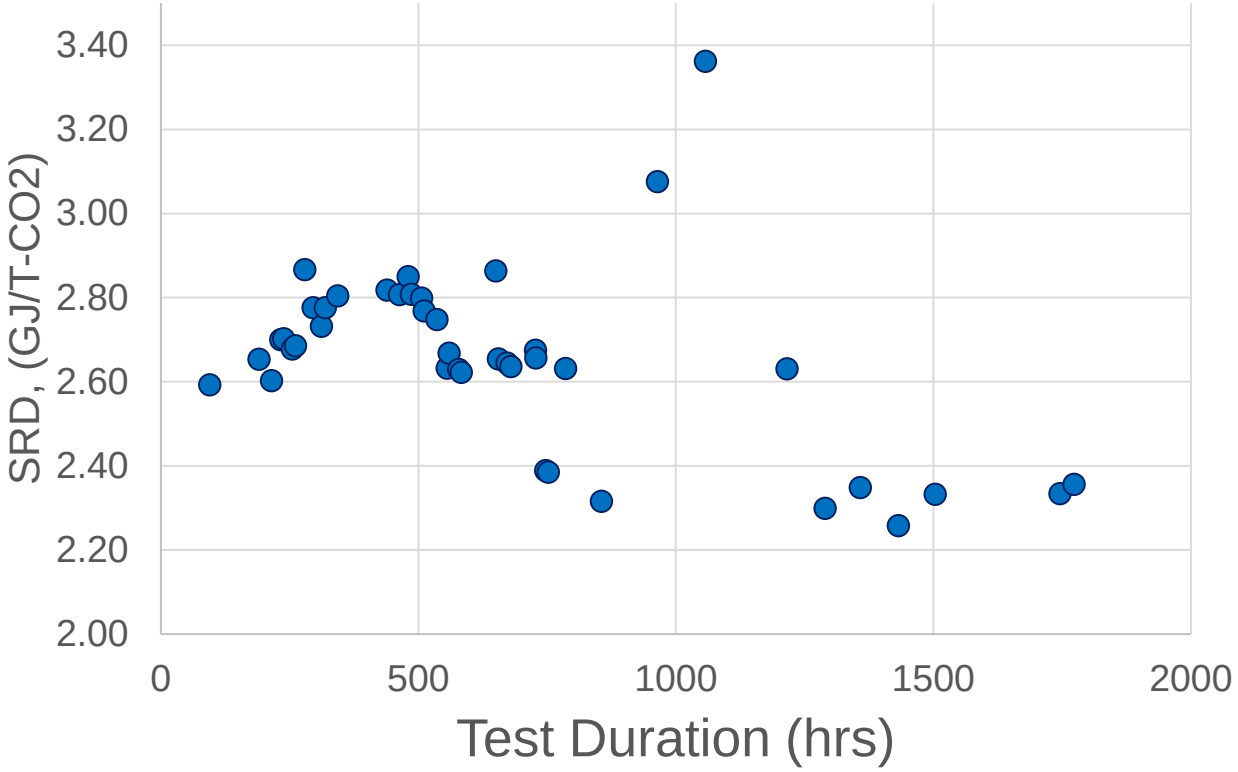
Tiller coal flue gas composition

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

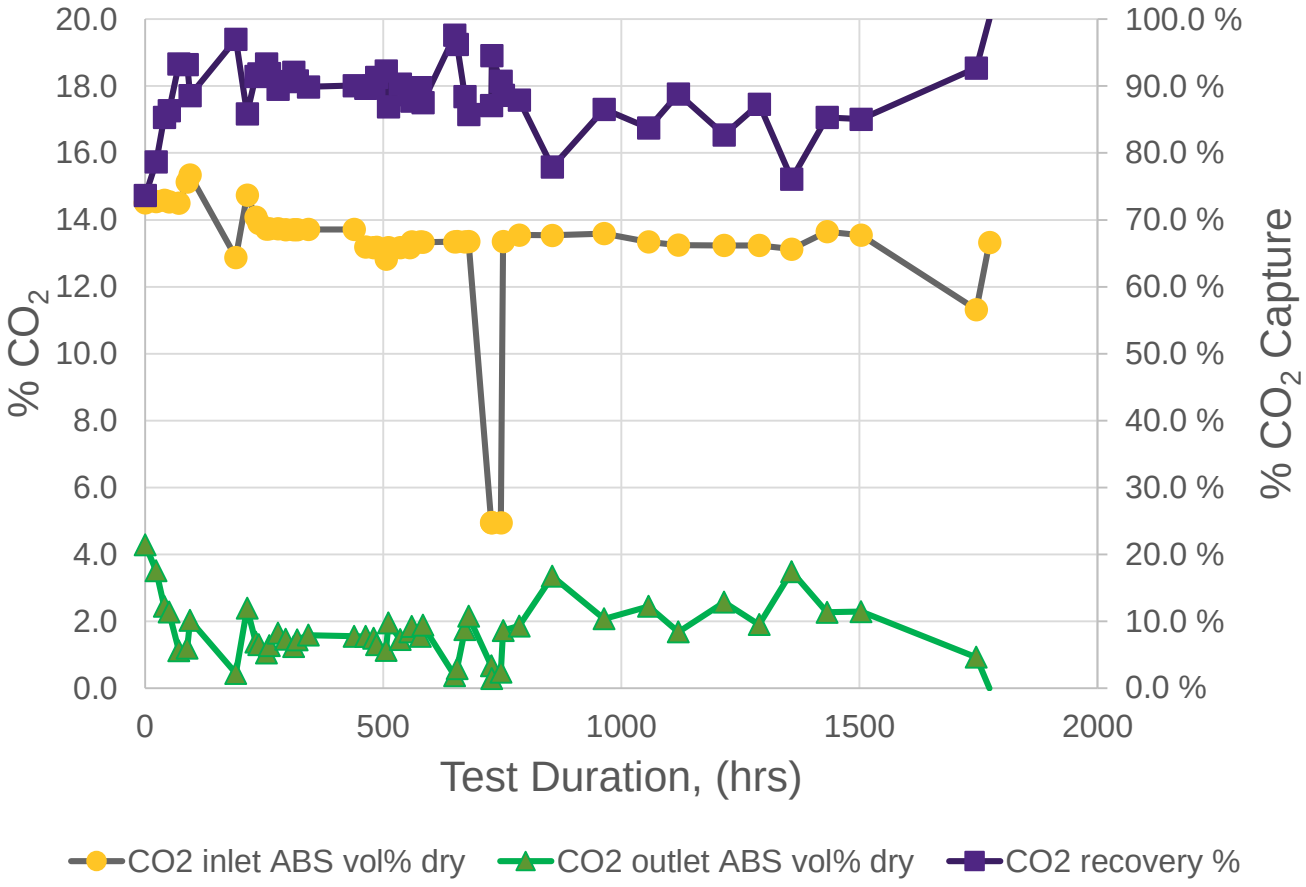
Component	Unit	Tiller Flue Gas	Design (NCCC)	Average (NCCC)
CO2	vol %	12 - 15	12.14	14
O2	vol %	4.0 – 7.3	5.20	4.5
N2 + Ar	vol %	66 - 69	69.36	68.5
H2O	vol %	3 - 6	13.30	13
SO_2	vppm	3	1	2.5
NO_x	vppm	80	80	-
Temperature	°C (F)	40 – 70 (100 – 160)	71 (160)	68 (155)
Pressure	mBar-g (H2O)	25 (10)	25.4 (10)	8. (20)

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



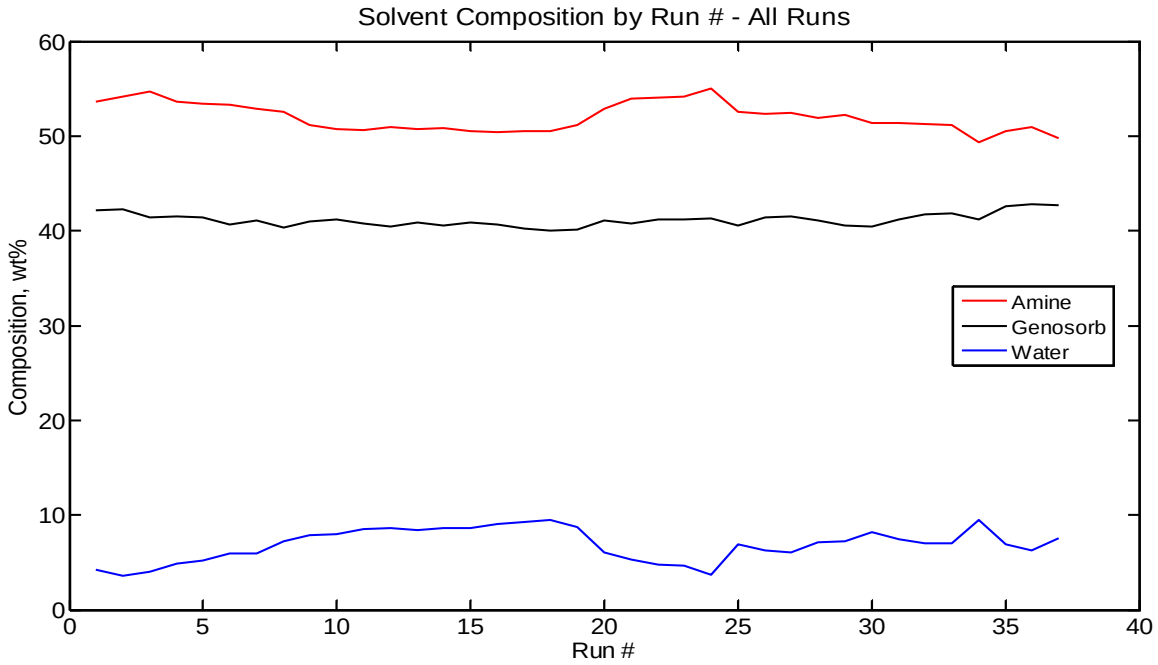
- 543 h on parametric testing and 1,043 h on stream for long-term testing, total of 1,587 h

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

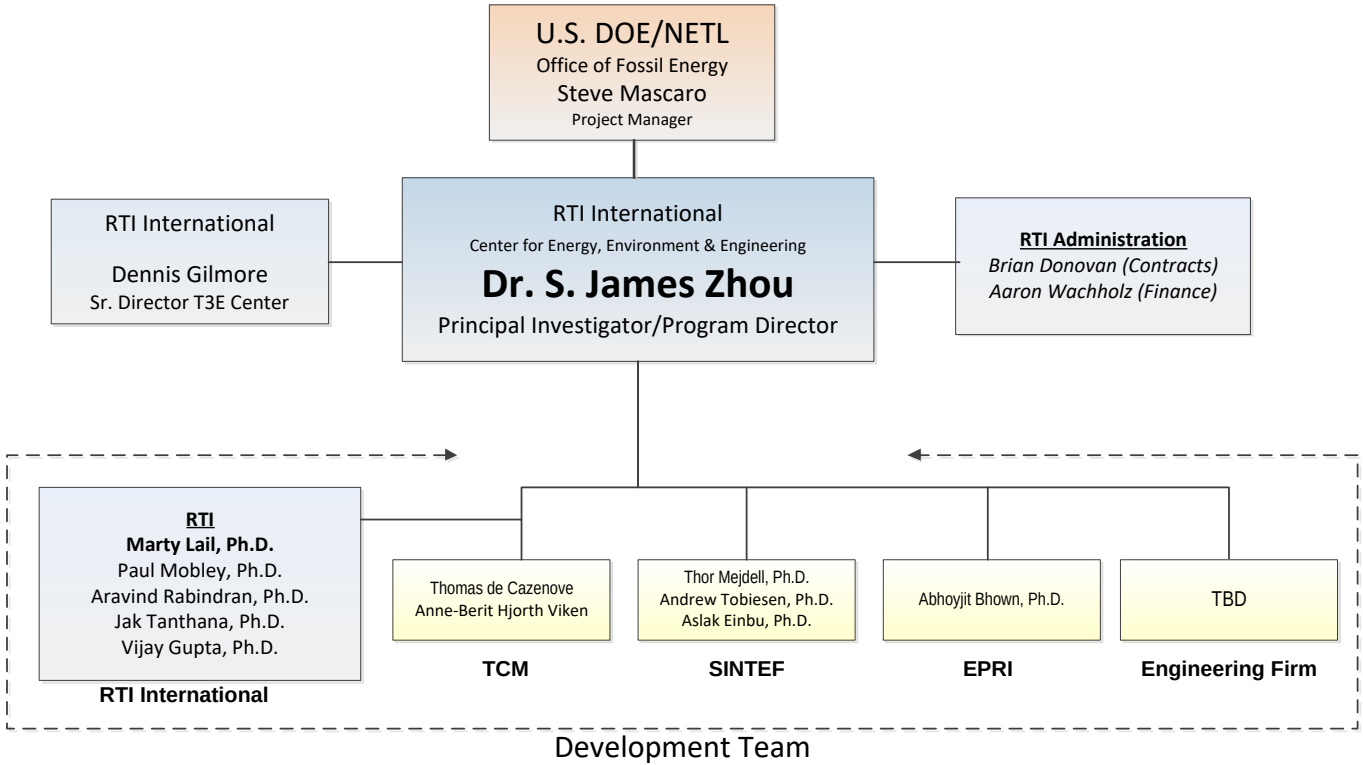


Background: Water Balance

- Water content maintained near 5-8%
- Controlled by water wash temperature ~2°C higher than inlet flue gas saturation temperature



Project Team



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 Optimized System
Task 6.0	Test Period I Drop-in Test

BP2 Tasks

Task 7.0	Revamp Implementation
Task 8.0	Test Period II: Revamp Unit
Task 9.0	Decommissioning and Waste Handling
Task 10.0	Final Techno-Economic Analysis
Task 11.0	Technology Gap Analysis

Project Goals and Success Criteria

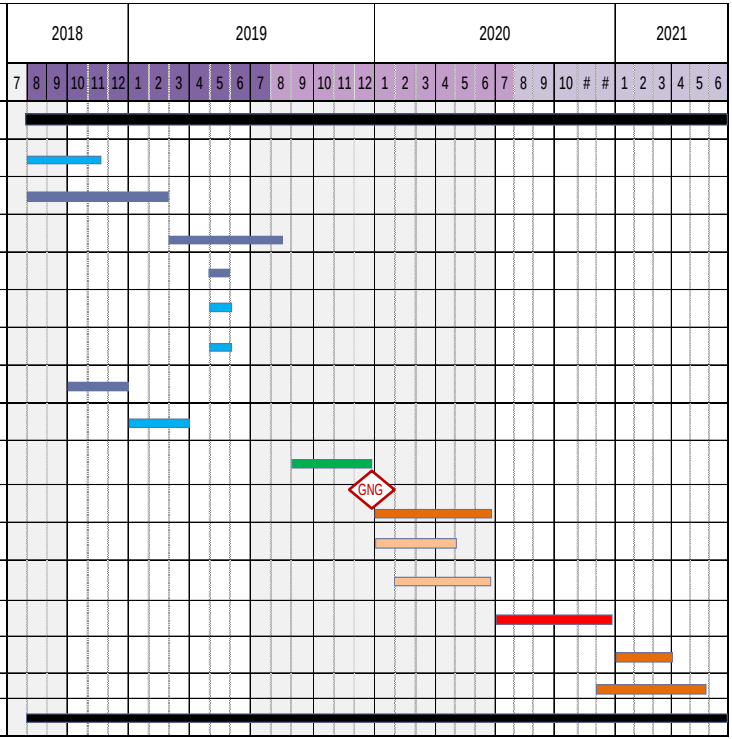
- Confirm that the conventional aqueous amine system can be operated without issue with NAS
- Confirm NAS pilot-scale baseline performance results
- Confirm NAS pilot-scale optimal performance results
- Refine Techno-economic analysis
- Control and manage emissions
- Control and manage water balance 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

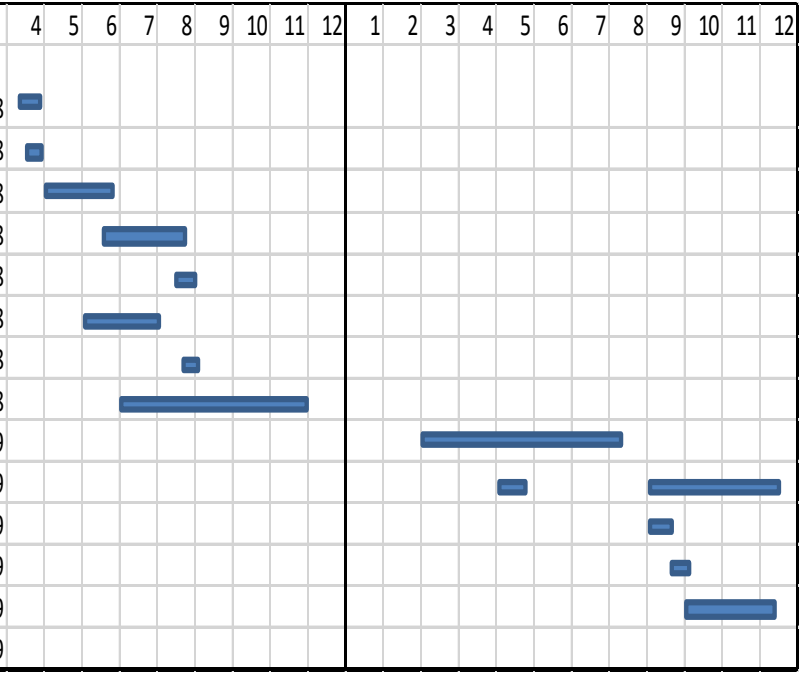
Overall Project Timeline

Task	Task title	Start date	End date
1.0	Project Management and Planning	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	08/08/18	03/15/19
3.0	Solvent Production	03/01/19	08/09/19
4.0	Solvent Qualification	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	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	09/01/19	11/30/19
7.0	Revamp Implementation	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	02/08/20	08/09/20
9.0	Decommissioning and Waste Handling	07/22/20	10/21/20
10.0	Final TEA (550 MW Net)	07/22/20	01/05/21
11.0	Cost Benefit Analysis and Technology Maturation Planning	08/08/18	01/15/21



Project Timeline – BP1 NAS Testing Details

Name	Start	Finish
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



Risks and Risk Mitigation

Description of Risk/Area		Prob.	Impact	Risk Management (Mitigation and Response Strategies)
Technical Risks:				
Material	Cost and Availability of NAS Components	• Low	High	• Solvent quotes from multiple vendors • Previous order of more than 2,000 Kg • Request discounts for larger order (~50,000 kg needed at TCM)
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

Risks and Risk Mitigation

Description of Risk/Area		Prob.	Impact	Risk Management (Mitigation and Response Strategies)
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
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:				
Suppliers	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

NAS CO_2 Capture Technology Path to Market

Lab-Scale Development & Evaluation (2010-2013)

Solvent screening

Lab-scale evaluation of process

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

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

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

Demonstration of all process components at pilot scale (~60 kWe)

Engineering-Scale Validation (2018+)

Pre-commercial Demonstration at Technology Centre Mongstad, Norway (~10 MWe)

Planning to start test in late 2018

From lab through large scale (10 MW) demonstration through series of projects

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

S James Zhou

Director, Gas Separation
Center of Technology for Energy, Environment & Engineering
RTI International
szhou@rti.org
+ 1 (919) 485 2601