Large Bench-scale Development of a Non-Aqueous Solvent CO_2 Capture Process for Coal-fired Power Plants

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Presentation Overview

- Project Overview and Objectives
- Project Summary and Budget
- Budget Period 1 Review
  - Milestones and Accomplishments
  - NAS Solvent
  - Process Engineering and Design
  - Bench-Scale Testing
- Budget Period 2 Update
  - Overview, Tasks, and Objectives
  - BP2 Progress
- Next Steps / Technology Development Pathway

Project Overview

Total Funding: $3,579,081

Federal: $2,705,013

Cost Share: $874,068

Objective: Continue the advancement of the NAS CO_2 Capture Process

- Increase solvent performance
- Design and build unique process modifications for Tiller
- Perform pilot testing of NAS on coal-derived flue gas
- Techno-economic and EHS evaluation

***Timeframe*:**

BP	Timeframe	Months	Proposed Budget	Actual Budget
1	10/01/15 – 12/31/2016	15 months	$1,670,000	$1,532,330
2	01/01/17 – 06/30/2018	18 months	$1,909,081	$2,046,751

BP1 Scope and Objectives

- **NAS Process testing at Tiller using propane+coal-derived flue gas**
- **Reduce the parasitic energy penalty to < 2.0 GJ_t/Tonne of CO_2 captured**

Other goals and objectives:

- Conduct baseline testing of MEA and
- Conduct NAS solvent degradation and material compatibility
- Design Regenerator and Absorber wash section,
- Improve the physical properties of NAS
- Improved NAS formulations and plan for scaled-up

BP1 Milestones

Milestone	Description	Completion	Status
A	Kick-off Meeting	12/31/15	***Milestone Achieved.*** Kick-off meeting held at DOE/NETL site on 12/17/2015.
B	Updated project management plan	5/5/16	***Milestone Achieved.*** Revision 1 of PMP was approved by DOE/NETL on 6/27/2016.
C	Completion of 250 hours baseline testing at SINTEF Tiller plant	3/20/17	***Milestone Achieved.*** Performed MEA baseline testing at SINTEF and verified 3.6 GJ/Ton-CO_2 reboiler heat duty consistent with values reported in literature. Completed 405 hours of NAS baseline testing,
D	Engineering design package for Regenerator delivered to SINTEF.	10/31/16	***Milestone Achieved.*** A final design and engineering package has been delivered and included updated P&IDs, stream tables, and bill of materials for modification recommendations to SINTEF for their CO_2 capture unit at the Tiller plant.
E	Experimental data from formulation improvement confirming that the NAS solvents absorb less than 5wt% water..	12/31/16	***Milestone Achieved.*** Some NAS formulations are able to achieve the < 5 wt% target, however, the optimal formulations have a preferred water absorption target between 5 to 10 wt%.

Bench-Scale Testing of Solvent Formulations

Absorber
3” Sch. 10 SS316
(8.5 m height)
Mellapak 350X

Temp: 30-55° C
Pressure: Up to 200 kPa

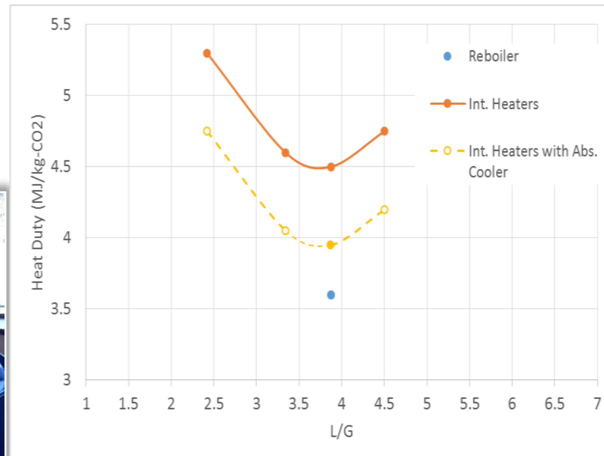
Gas Vel: 0.33-1.5 m/s
L: 15-75 kg/h

Regenerator
3” Sch. 10 SS316
(7.1 m height)
Mellapak 350x

Temp :Up to 150° C

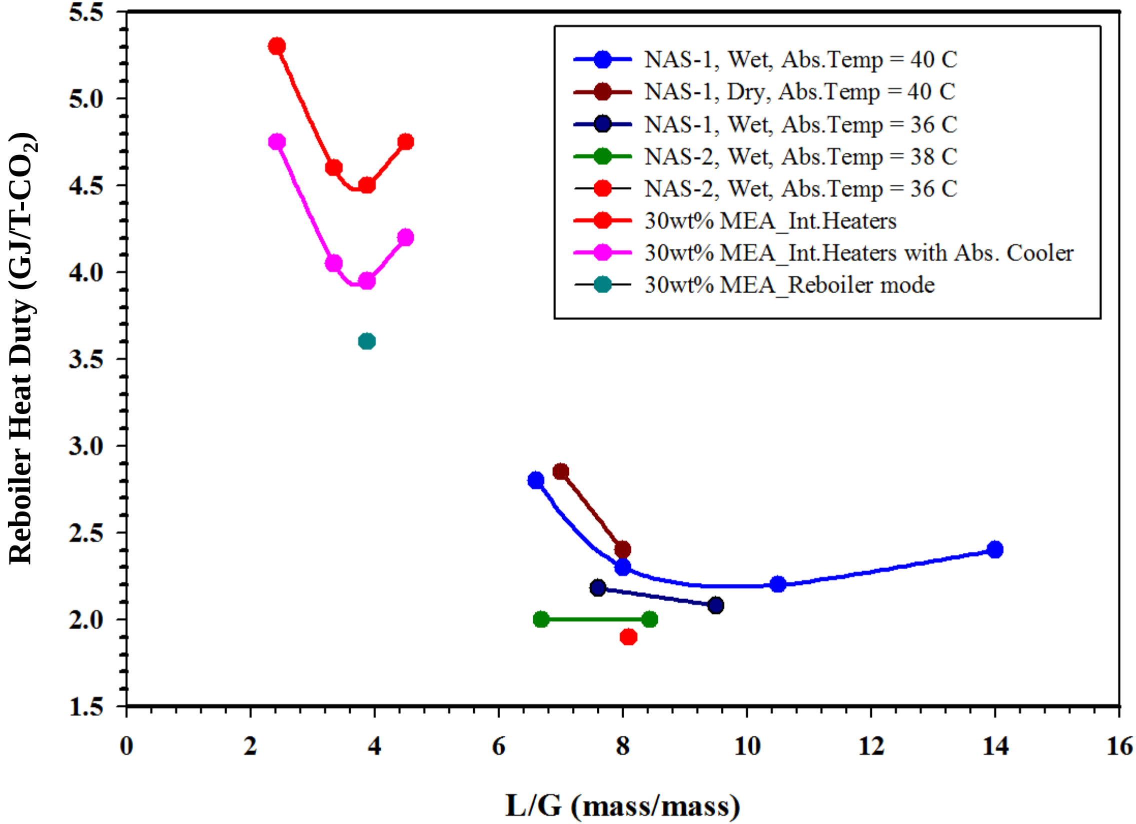
Pressure: Up to 1MPa

Simulated Flue Gas Properties	
FG Flow Rate:	100 to 485 SLPM
CO_2 Feed Rate:	1.8 to 8.6 kg/h
Feed Temp.:	30 to 50°C
Target Comp:	CO_2: 13.3%; H_2O: 6.1%; O_2: 2.35%; N_2: bal.
CO_2 Content:	up to 20 %vol
Water Content:	~0 to 12.3%vol



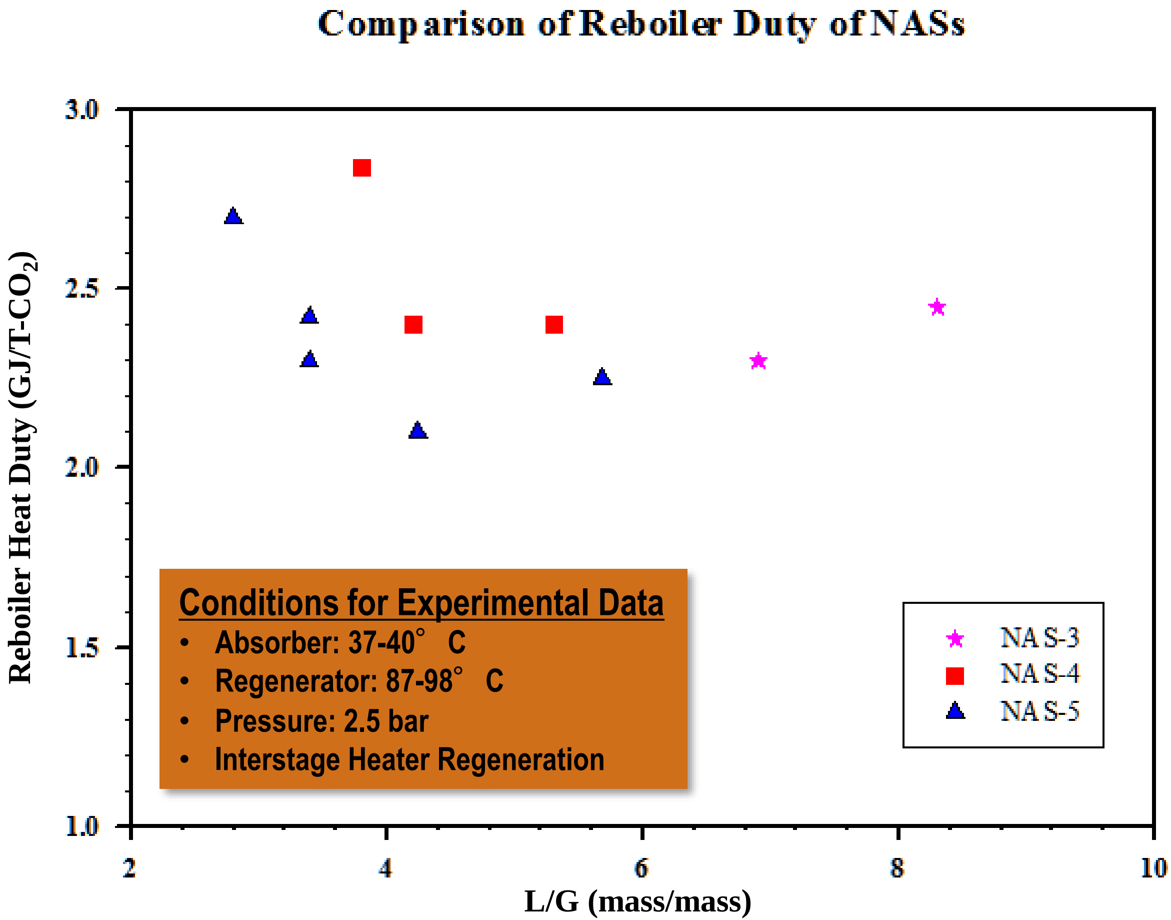
Baseline testing with aqueous MEA

Bench Scale Test Results



RTI non-aqueous solvents showing substantially reduced reboiler heat duties

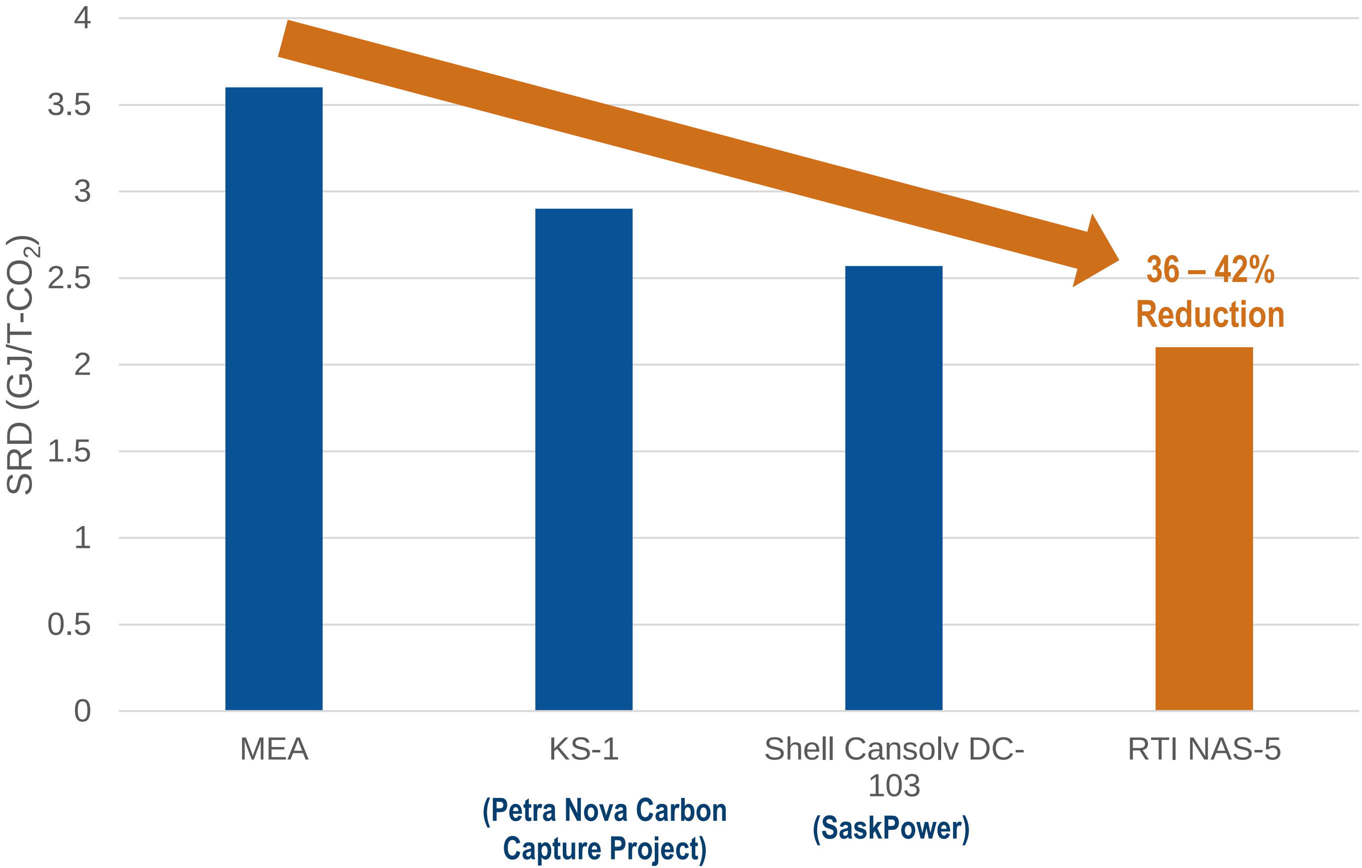
Experimental Reboiler Duty Data



Conditions for Experimental Data

- Absorber: 37-40° C
- Regenerator: 87-98° C
- Pressure: 2.5 bar
- Interstage Heater Regeneration

Specific Reboiler Duty Comparison



Baseline Testing of NAS at Tiller Pilot Plant

- Compare MEA and NAS in conventional system
- Water balance
- Confirm reboiler heat duty
- Emission measurement

- **MEA baseline testing completed at Tiller plant**
- **NAS baseline testing completed**
  - **350 hours of testing with propane + 50 hour with coal flue gas**
  - **Coal flue gas testing cut short due to particulates clogging filters and sample lines**
  - **Confirmed the reduction in reboiler duty**

Budget Period 2 Update

BP2 Scope and Objectives

- Procurement, construction, integration, and shakedown of NAS-specific components in SINTEF's Tiller plant,
- Execution of systematic NAS solvent testing using coal-derived flue gas at SINTEF's Tiller plant which incorporates the NAS-specific process modifications,
- Completion of 400 hours cumulative testing on coal-derived flue gas at the Tiller plant, achieving 90% CO_2 capture and proper water balancing,
- Completion of a detailed Techno-Economic Analysis (TEA) to confirm that RTI's NAS-based technology can reduce the cost associated with CO_2 capture from coal-fired power plants.

Task 5.0 - Baseline Testing of NAS Using Coal-Fired Flue Gas

Subtask 5.1 – Materials degradation testing - Completed

Impact of the NAS on the materials of construction used in the Tiller plant

Subtask 5.2 – NAS Baseline testing in the Tiller Plant

- Baseline testing of the NAS solvent completed
- Reboiler heat duty 2.7 GJ/T-CO_2

NAS Baseline Testing Results at Tiller

Tiller	Unit	Run 18	Run 22
Date		12.01.2017	16.03.2017
Time		06:50-07:50	16:00-17:00
Solvent		NAS	NAS
Source		Mimicked Coal	Coal
Gas inlet ABS	m^3/hr	110.0	110.0
CO_2 inlet ABS	V%	14.87	14.42
CO_2 outlet ABS	V%	1.832	0.659
CO_2 recovery	%	89.3 %	96.1 %
Liquid inlet Absorber	Kg/min	18.00	18.00
L/G ratio	kg/kg	8.5	8.4
Lean amine (tit)	mol/kg	2.695	2.348
Lean Loading	mol/mol	0.121	0.074
Rich Loading	mol/mol	0.273	0.290
Water Lean	Wt%	7.9	6.84
Temp Liq Reboiler	℃	99.3	104.8
Desorber press top	kPa	100.68	97.08
Reboiler duty	kW	17.82	17.80
Preheat rich flow	kW	2.53	2.53
SRD (w/ heat loss)	GJ/T	3.06	2.80
Temp Gas outlet DCC	℃	24.7	23.7
Temp Lean amine inlet	℃	34.8	34.9
Temp Intercooling	℃	38.1	38.7

Mimicked coal flue gas using propane burner flue gas (runs 18, and 22 respectively)

SRD with account of heat loss amounts to about **2.8 GJ/t**, assuming 1.5kW loss in the hot lines.

In the coming months, several modifications will be made at Tiller to run NAS under optimum conditions

It is expected that the Tiller plant modifications will bring the SRD further down (next slide).

Task 6.0 –Solvent Formulation Improvement

- NAS-5 formulation testing
- Parametric testing of NAS-5
- Water balance testing
- Wash section/emissions testing
- NAS reaction kinetics improvement
- NAS oxidative/thermal degradation improvement

Task 7 - Construction, Integration, and Shakedown of NAS-Specific Components in Tiller Plant

Customized changes for the NAS solvents

Installation of:
- New particulate filter
- Updated coal-burner control software
- Two additional absorber inter-coolers (total of three intercoolers)
- Improved water-wash (additional water wash section)
- Two custom made regenerative "inter-heaters"
- One additional cross-flow heat exchanger (that can work in series, or bypass, with the current).

Improved solvent:
- To run NAS-5, capable of operating with lower L/G ratios.

Plant modification to Tiller is expected to be completed by mid September 2017.

Drums of current NAS formulation components

Task 8 - Bench-scale Testing of the NAS CO_2 Process in Coal-Fired Flue Gas

- Led by SINTEF in BP2 and completed at the Tiller plant.
- Testing using coal-derived flue gas
- Configuration incorporates the NAS-specific process modifications built in Task 7
- Completion of 400 hours cumulative bench-scale testing on coal-derived flue gas at 90% CO_2 capture and water balanced

Subtask 8.1 – Parametric testing campaign at Tiller Plant

- Will determine optimal operating parameters for the NAS solvents
- Process parameters such as absorber temperature, regenerator temperature, L/G ratio, and humidity of the flue gas will be varied
- Optimal parameters will be chosen for the long-term evaluation
- Anticipated to be completed in three months

Subtask 8.2 - Long-term performance testing campaign at Tiller Plant

- SINTEF will lead this sub-task
- Duration of the testing is planned for forty-one days.

Task 9 - Detailed Techno-Economic and EHS Analysis

- Will conduct a technical and economic feasibility study as described in Attachment 2 of DE-FOA0001235.
- Shall follow the analysis documented in the NETL report *"Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity (Rev 2a, September 2013),"* aka Bituminous Baseline Study (BBS). The assessment shall follow Case 12, super-critical pulverized coal (PC) with CO_2 capture.
- RTI will also conduct an EH&S risk assessment as described in Attachment 3 of the FOA
- Evaluation of air, water, and solid wastes, toxicological impact, flammability, and corrosivity.

Subtask 9.1 – Updated process modeling

- Led by RTI
- Rate-based process model will be updated with data from coal-derived flue gas testing
- Model will be used to predict energy penalty for Case 12 using NAS solvents

Subtask 9.2 – Technoeconomic analysis

- Led by RTI
- Energy penalty from 7.1 to be used in the techno-economic analysis to compare the cost of a non-aqueous CO_2 capture to aqueous CO_2 capture

Subtask 9.3 – EH&S evaluation

- Led by RTI
- Conduct EHS assessment of emissions to air, contamination of water, and hazards of solid wastes as well as any toxicological effects that are known regarding NAS formulation components, fire danger, or concerns about the potential of the NAS solvents to corrode materials of construction.

Next Steps: NAS-Specific Components for SINTEF Plant

- Complete incorporation of new design at Tiller plant
- Testing to start beginning of Oct. 2017 with:
  - Optimal components at Tiller Plant for NAS testing
  - Optimized NAS formulation; initial bench tests show reduced L/G with similar heat duty

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