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

DE-FE0013865

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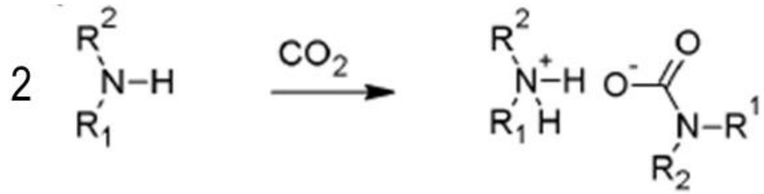
www.rti.org

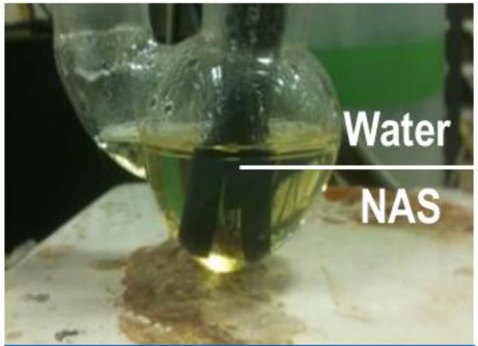
RTI's Non-Aqueous Solvents (NASs)

Background

- In development since 2009
- Hydrophobic, sterically-hindered, carbamate-forming amines with low-water solubility solubilized in a diluent having low vapor pressure, low viscosity, and low-water solubility



- Low heats of absorption
- Generate high CO_2 partial pressures at low temperatures
- Potential to reduce the thermal regeneration energy to ~2,000 $kJ_t/kg\ CO_2$



Formation of a second liquid phase

Desirable Characteristics

- Low water solubility
- Favorable thermodynamics
- Low vapor pressure
- Low conductivity – low corrosion rates
- Low oxygen solubility

Key Challenges

- Undesirable reactions with water
- Solids formation in rich solvent
- Water balancing
- Viscosity and foaming tendency
- Solvent cost and availability
- Emissions in process water and treated flue gas

Precipitation during absorption (Undesirable)

Laboratory Development of NASs

Key Achievements

- Work performed under a DOE/ARPA-E funded project
    - Project Partners: BASF
- Developed promising 1st-generation NAS formulations
    - Large working capacities with moderate temperature swing
    - Regenerable at low temperature (P_{CO2} > 2bar @ 90°C)
    - Heat of absorption: 55-75 kJ/mol CO_2
    - Low specific heat capacities: 1.2-1.5 kJ/kg K
    - Viscosity of CO_2-rich solvent < 30 cP; Non-foaming
- Patent Portfolio: 6 patents appl. filed; 1 granted to date
    - 3 formulation oriented
    - 3 process oriented
- Min. thermal regen. energy: 1,700-2,300 kJ/kg CO_2
- Preliminary T&E assessment indicate that parasitic energy penalty can be reduced by ~ 25-40%
- Experimental demonstration of NAS process concept
- Constructed bench-scale system to evaluate NASs

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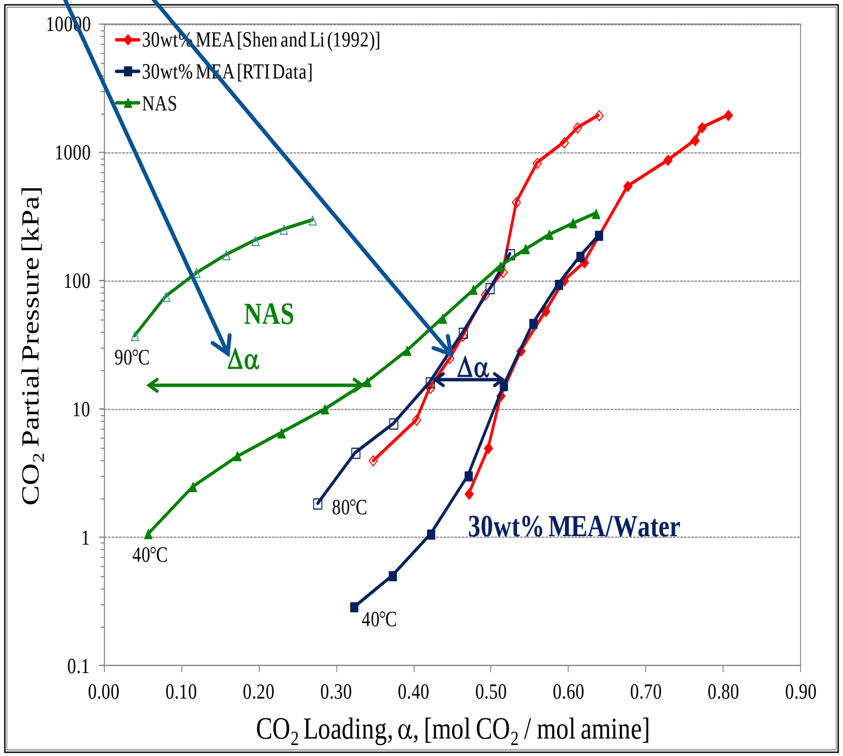

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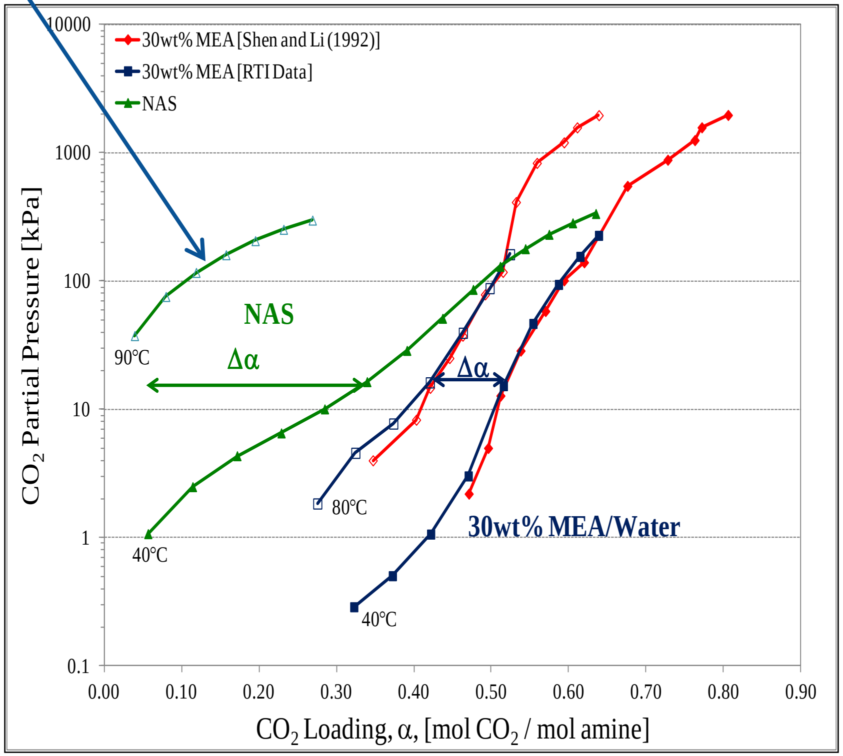

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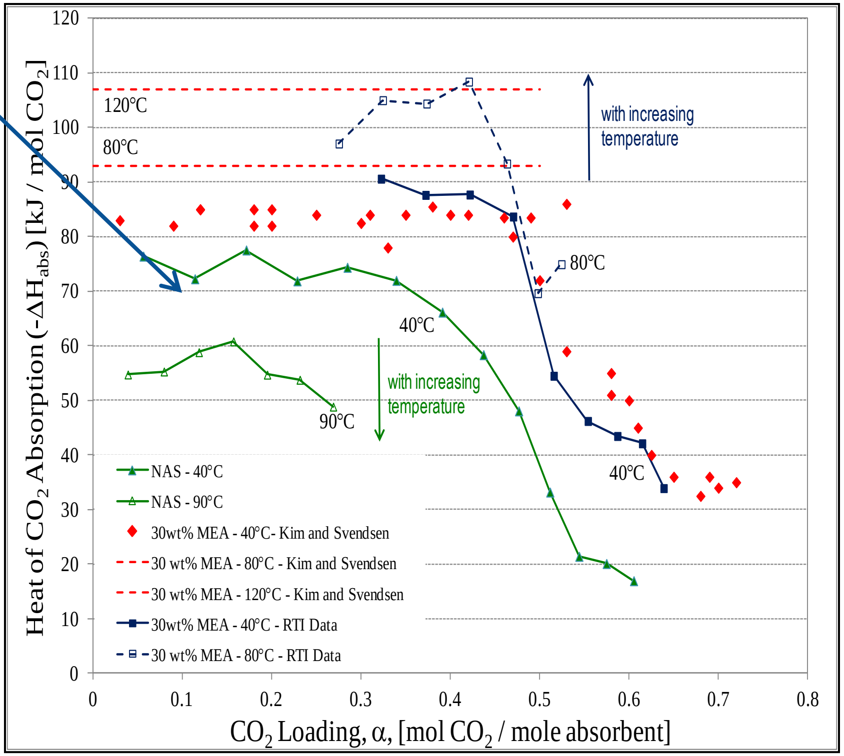

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Measured Viscosity

Sample Name	Viscosity [cP]	Temp [°C]
NAS-1, CO_2-Lean	4.5	40
	1.6	80
NAS-1, CO_2-Rich	20.7	40
Gen2 NAS, CO_2-rich	9.34	40

Aq. Amine Solvent

NAS

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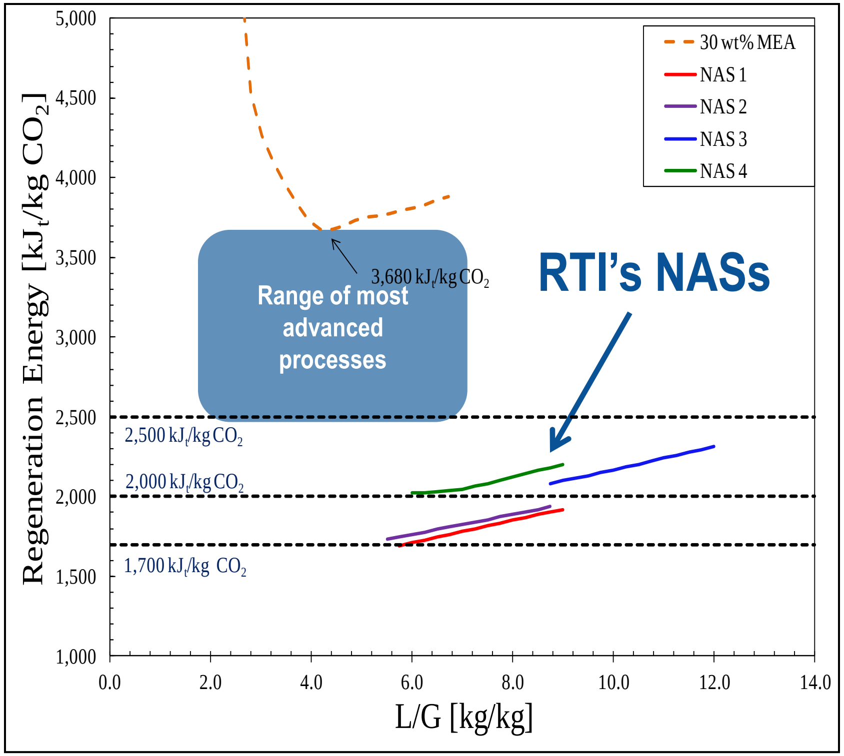

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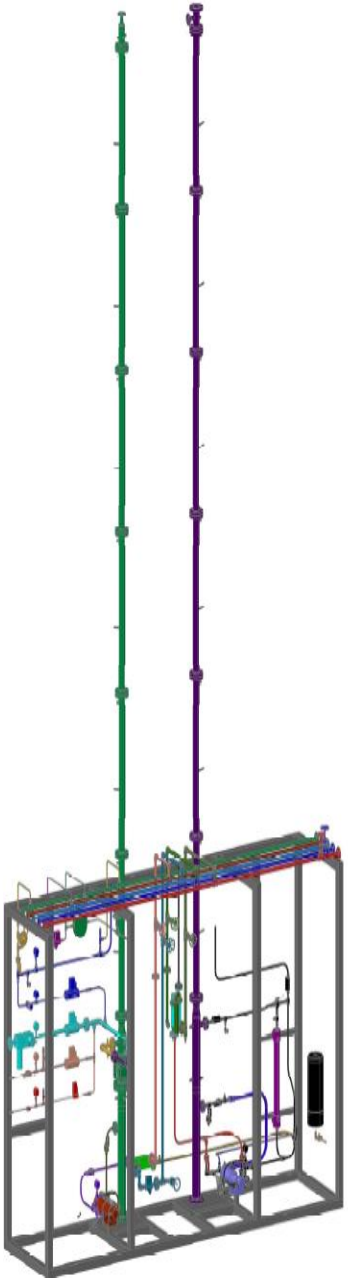
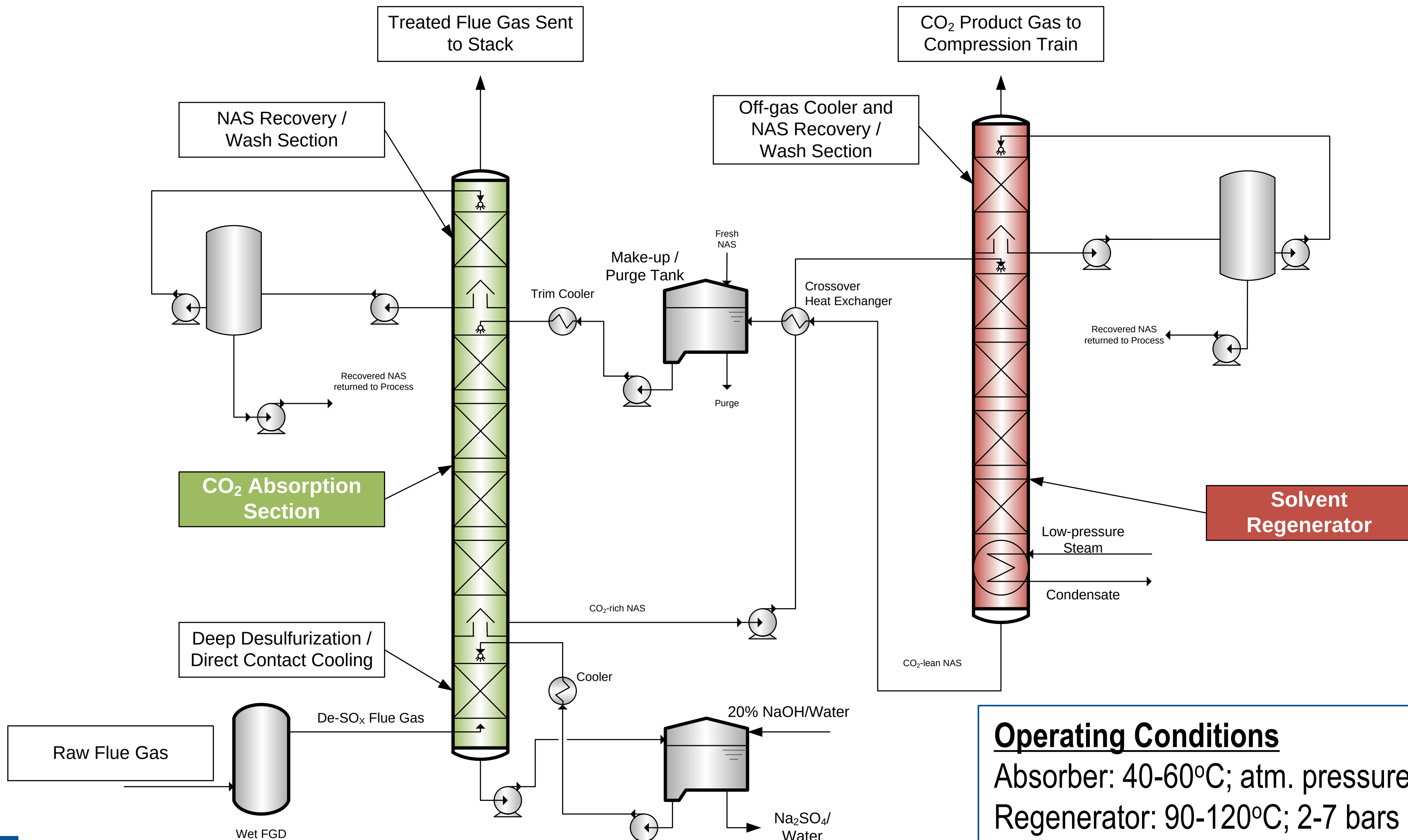


RTI's bench-scale solvent testing unit

NAS CO_2 Capture Process

Similar to conventional scrubbing systems with key design features:

- NAS Recovery and Wash Section – Similar to water washing but NASs have low water-solubility
- Solvent Regenerator – lack of low-boiling component (conv. reboilers not applicable)



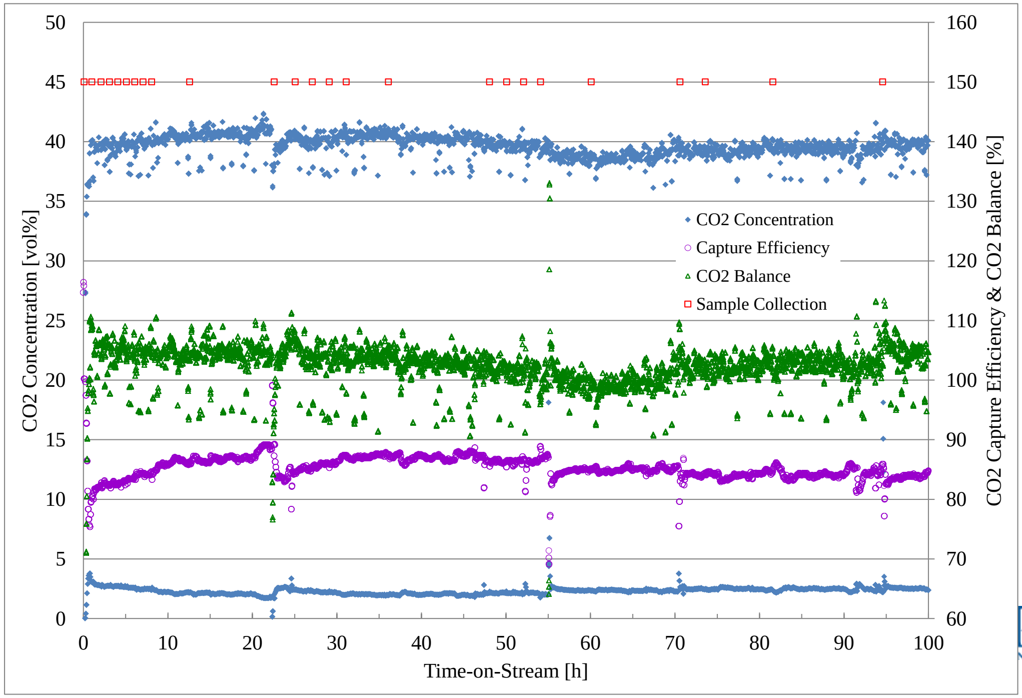
Operating Conditions

Absorber: 40-60°C; atm. pressure

Regenerator: 90-120°C; 2-7 bars

Lab-scale Testing

- Stable operation in a continuous flow system representative of a realistic process arrangement
- Evaluated/demonstrated key process concepts specific to NAS process
    - Water balancing; effectiveness of several regenerator types
- Compared performance of the NAS process and 30 wt% MEA-H_2O
    - Prelim. data indicates a 30-40% reduction in thermal regen. energy
        - *Needs to be verified and validated at larger scale*
- Evaluated the effect of long-term (>500 h) exposure to common flue gas contaminants



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Project Overview

Continue advancement of the NAS CO_2 Capture Process by address specific challenges facing T&E potential

- refine solvent formulation to minimize solvent make-up and reduce solvent costs
- develop NAS-specific process modifications
- bench-scale demonstration of the potential to reduce the energy penalty to <2,000 $kJ_t/kg\ CO_2$
- understand potential for scale-up through T&E and EH&S assessments

Details

- **DOE Project #:** DE-FE0013865
- **Funding**
  - Total: $ 3,099,080
  - DOE: $ 2,387,072
  - Cost-share $ 712,008
- **Timeline:** Oct. 1, 2014 to Dec. 31, 2015
- **DOE Project Manager:** Steven Mascaro

Project Team

NETL, GASSNOVA

RTI International
- Inventor of non-aqueous solvent chemistry
- Lead bench-scale testing campaign to optimize process performance

Linde (The Linde Group)
- Global leader in gas separation & purification solutions
- Expertise in design, engineering, and operation of gas treatment processes
- Techno-economic and EH&S assessments of novel processes

SINTEF
- Extensive experience in amine degradation & amine plant emissions

Current Project Efforts

Overall Goals

- Finalize NAS formulation down selection
- Develop NAS-specific process modifications
- Experimentally demonstrate, at the bench-scale, the potential to reduce the thermal regeneration energy to <2,000 kJ_t/kg of CO_2 captured

NAS Refinement

- Formulation refinement to reduce emissions in treated gas streams, lower solvent cost, and ensure availability while maintaining desired characteristics
- Measurement of kinetics and thermodynamics properties of 'best-candidate' formulations
- Detailed solvent degradation and emission studies **[SINTEF / RTI]**

Process Development

- Develop model of NAS chemistry to support process development
- Develop NAS Recovery/Wash section
- Develop optimized regenerator design specific for NAS processes **[Linde / RTI]**

Bench-Scale Evaluation

- Demonstrate efficacy of developed NAS-specific process modifications
- Demonstrate 90% CO_2 capture and high CO_2 product purity (>95% CO_2) at an "optimal" L/G ratio with a regeneration energy of < 2,000 kJ_t/kg of CO_2.

Technology Assessments

- Complete technical, economic, and EH&S assessments to determine competiveness, identify/address EH&S concerns, and determine 'permitability' of pilot and commercial-scale units. **[Linde / RTI]**

Timeline and Milestones

		BUDGET PERIOD 1												BUDGET PERIOD 2											
		Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
		M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24
1	Project Management and Planning	A		B																					
2	Refining Solvent Formulation to Minimize Make-up Costs									C															
3	Rate-based Model Development																								
4	Process Development									D			E												
5	Construction and Testing of Upgraded Bench-scale System															F			G						
6	Solvent Degradation Studies																								
7	Process Modeling																								
8	TEA and Technology EH&S Assessment of a Commercial NAS CO_2 Capture Process																					H			I

	Task	Description	Date
A	1	Update Project Management Plan	Q1
B	1	Complete Kick-off meeting	Q1
C	2.2	Final selection of 'best-candidate' NAS formulations made which achieves targets	Q3
D	4.1	Lab-scale demonstration complete which shows NAS Recovery System achieves targets	Q3
E	4.2	Design package and cost estimate complete for the Bench-scale system modifications	Q4

	Task	Description	Date
F	5.1	Complete installation/integration of new process units into bench-scale system	Q5
G	5.2	Effectiveness of bench-scale system modifications verified	Q6
H	5.3	Data from bench-scale testing confirms that the NAS process can achieve target regeneration energy	Q7
I	8.1, 8.2	Complete technical, economic, and EH&S assessments	Q8

Bench-Scale Evaluation of NASs

RTI's Bench-scale Testing Unit

- Conventional Absorber-Regenerator design
- Flexible → Designed to operate with aqueous and non-aqueous solvents
- Column dim.: 3" dia. x ~ 35 ft total height (~ 28 ft packing)
- Commercial-grade structured packing: Mellapak 350.X
- Throughput: ~300 SLPM sim. flue gas (~120 kg/day CO_2)
- Solvent Inventory: 10-15 L
- Highly instrumented and easy to operate & control
- Capable of >90% CO_2 capture at realistic process cond.

Testing Program

- experimentally demonstrate that the NASs are capable of achieving 90% CO_2 capture and generating a high-purity CO_2 product (>95% CO_2) at an 'optimal' L/G ratio with a thermal regeneration energy of < 2,000 kJ_t/kg CO_2
- evaluate the effectiveness of the developed NAS Recovery/Wash section and Solvent Regenerator design, and
- develop a detailed understanding of the operational and performance differences between the NAS and conventional aqueous-amine CO_2 capture processes.

RTI's bench-scale solvent testing unit

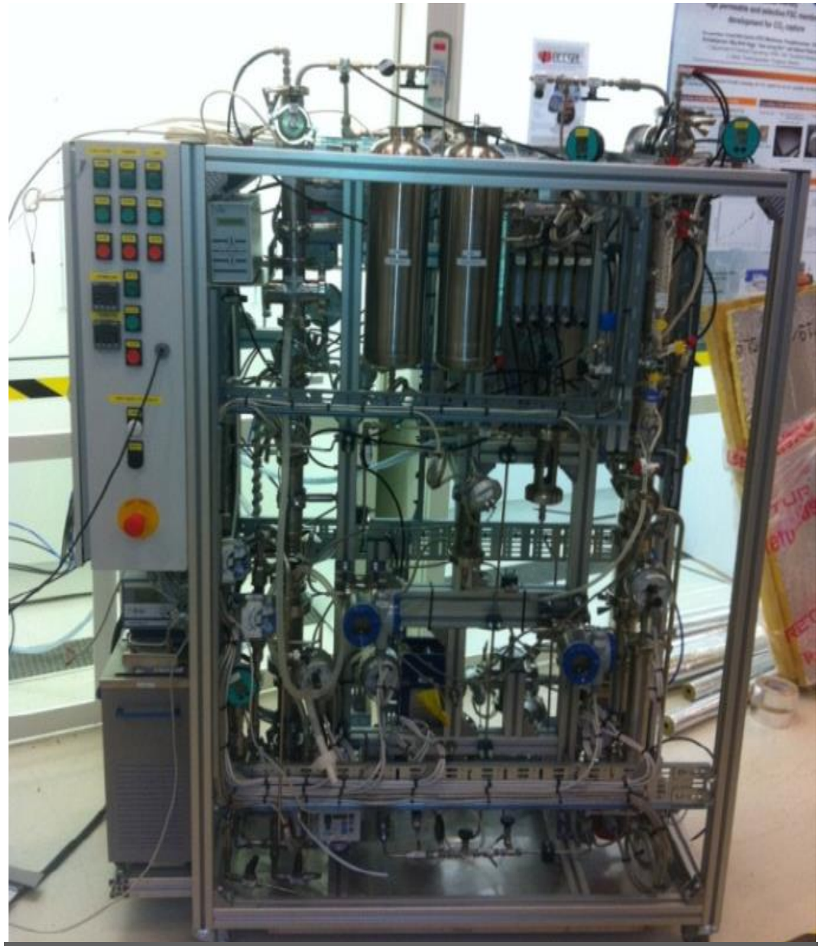
Solvent Degradation & Emission Studies

SINTEF

- largest independent research organization in Scandinavia
- more than 20 years of experience in research on amine based absorption processes
- extensive expertise in amine degradation and emission studies

Scope

- Estimate rate of solvent degradation and determine degradation pathways
- Determine the necessary flue gas pretreatment requirements specifically pertaining to SO_2 and NO_x
- Speciate and quantify emissions in treated flue gas stream
- Perform experiments in SINTEF's solvent degradation test rig (SDR) - a continuous flow system



SINTEF's SDR Unit

NAS CO_2 Capture Process: Technology Roadmap

	Previous Work			DOE ARPA-E Project	DOE NETL Project (Current)	Future Development		
Yr	2009-10			2010-13	2014-15	2016-20		2020+
TRL	1	2	3	4	5	6	7	8 & 9

Proof of Concept/Feasibility

Pre-Commercial Demonstration

Lab-scale Development (*Previous*)

- 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 (*Current*)

- Bench-scale testing with in a process unit with major process components
- Demonstrate ≤ 2 .0 GJ/tonne CO_2 using bench-scale system
- Address process, environmental, and economic challenges
- Detailed solvent degradation and emissions studies
- Detailed Techno-Economic & EH&S Assessments

Pilot-scale prototypical system demonstrated in a relevant environment (*Future*)

- Large pilot system (1-20 tonnes CO_2/day) using real flue gas and a complete process unit
- Collect critical process information to support detailed T&E assessments and scale-up efforts

Acknowledgements

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- Steven Mascaro (NETL Project Manager)
- Jeffrey Kooser (NETL CS/CO)
- Lynn Brickett
- Mike Matuszewski

RTI Team

- Marty Lail
- Mustapha Soukri
- Paul Mobley
- Jak Tanthana
- Thomas Nelson
- Justin Farmer
- Chris Boggs
- Aravind Rabindran
- Markus Lesemann

Linde Team

- Krish Krishnamurthy
- Stevan Jovanovich
- Satish Tamhankar

SINTEF Team

- Andreas Grimstvedt
- Aslak Einbu
- Kolbjorn Zahlsen
- Solrun Vevelstad