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

S. James Zhou, Jak Tanthana, Paul Mobley, Aravind Rabindran, Mustapha Soukri, Nandita Akunuri, Thomas Gohndrone, Markus Lesemann, and Marty Lail

Thor Mejdell, Andrew Tobiesen, Kristin Lauritsen, Ugo Aronu, Lars Hovdahl

DOE Program Manager: Steve Mascaro

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Project Summary

Funding: Federal:$2,705,013, Cost Share:$931,990; Total: $3,637,003

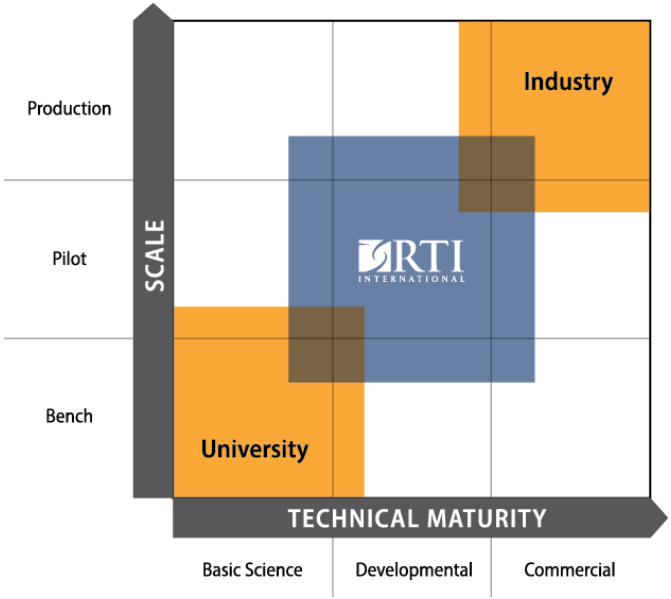
Objective: Continue the advancement of the NAS CO_2 Capture Process

- 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: 10/1/15 to 12/31/16 (BP1, 15 months, $1.67MM)
01/1/17 to 06/30/18 (BP2, 18 months, $1.96 MM)

Project Participants

- RTI develops advanced process technologies in partnership with leaders in energy
- From concept to large scale demonstration
- RTI responsibilities
  - NAS improvement
  - Engineering and process design
  - Process Modeling
  - Techno-economic analysis
- SINTEF responsibilities
  - Baseline testing
  - Tiller plant modification
  - Parametric testing
  - Long-term testing



SINTEF

Technology Development Roadmap

Previous Work	DOE ARPA-E Project	DOE NETL Project	Current & Future Development	
2009 – 2010	2010 – 2013	2014 – 2016	2016 – 2018(Current)	2018+
Proof of Concept / Feasibility				Pre-Commercial Demonstration

Lab-Scale Development / Evaluation

Total Budget: ~$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

Total Budget: ~$3,000,000

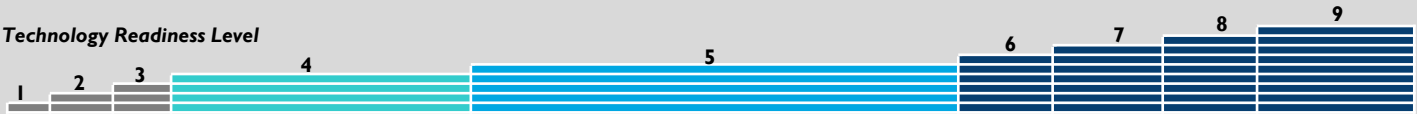
- Finalize NAS formulation
  - Address evaporative losses and costs
- Develop critical process components
- Bench-scale testing with in a process unit with major process components
- Demonstrate ≤ 2,100 kJt/kg CO_2 using bench-scale system
- Detailed solvent degradation and preliminary emissions studies
- Detailed Techno-Economic & EH&S Assessments

Combined SINTEF (Tiller) / TCM Pathway

Total Budget: ~3,600,000

- Tiller Plant (40 kWe)
  - *Large bench / small pilot testing*
  - *Demonstrate all process components for NAS process in adiabatic system*
- (10 MWe) (Future Option)
  - *Complete process unit with all components at minimum size required for confident scale-up*

Technology Readiness Level



R&D Strategic Approach

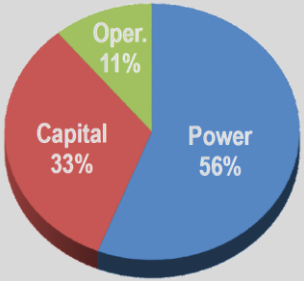
Breakdown of the Thermal Regeneration Energy Load

$$q_R = \left[\frac{C_P(T_R - T_F)}{\Delta\alpha} \cdot \frac{M_{sol}}{M_{CO_2}} \cdot \frac{1}{x_{sol}}\right] + \left[\Delta H_{V,H_2O} \cdot \frac{p_{H_2O}}{p_{CO_2}} \cdot \frac{1}{M_{CO_2}}\right] + \left[\frac{\Delta H_{abs,CO_2}}{M_{CO_2}}\right]$$

Reboiler Heat Duty | Sensible Heat | Heat of Vaporization | Heat of Absorption

Path to Reducing LCOE and Cost of CO_2 Avoided

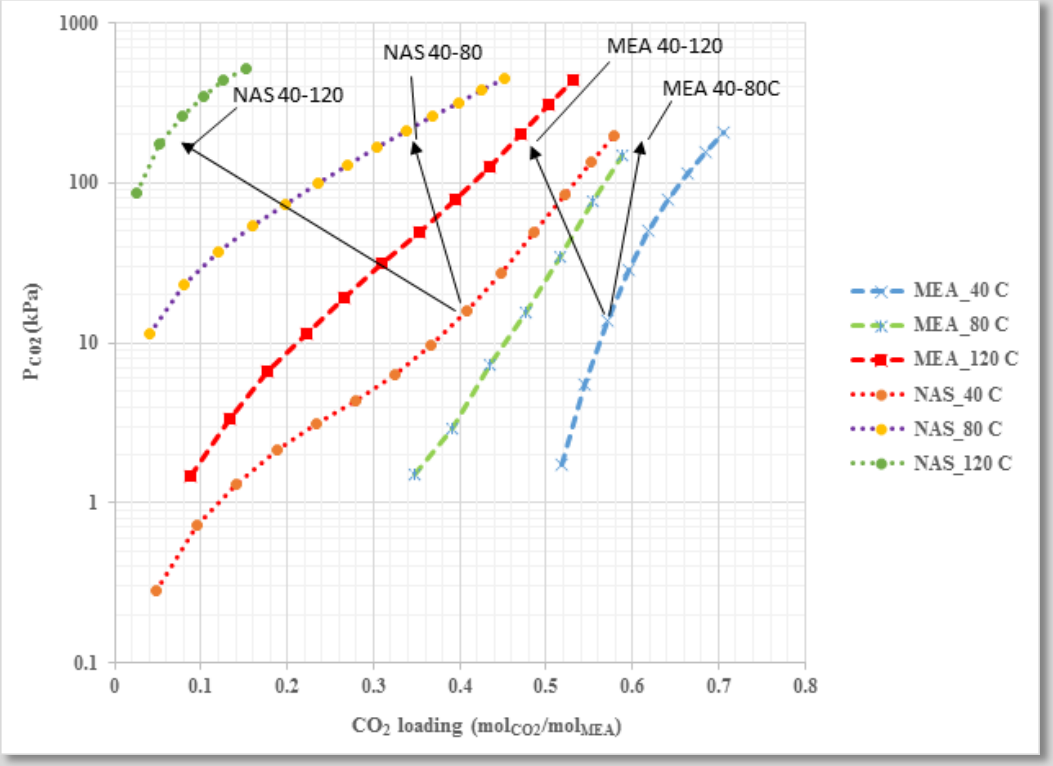
- Focus on reducing energy consumption – reboiler duty
- Reduce capital expenditure
  - Simplify process arrangement
  - Materials of construction
- Limit operating cost increase



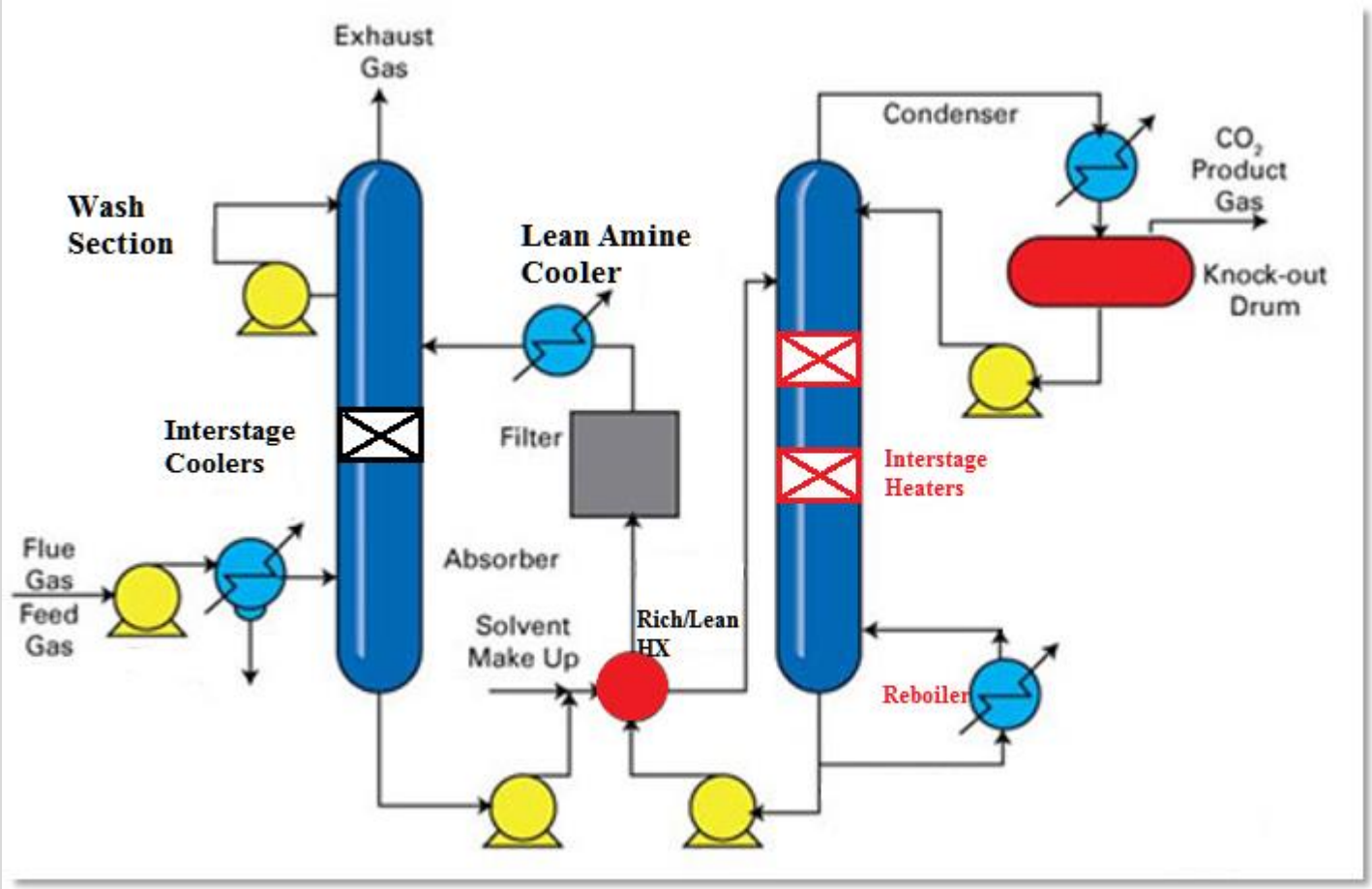
[1] Rochelle, G. T. Amine Scrubbing for CO_2 Capture. *Science* **2009,** 325, 1652-1654.

Thermodynamic Properties

- Solvent has low heat of absorption
- No precipitates
- Low viscosity
- High CO_2 capacity
- No need for stripping agent



NAS Process


Exhaust Gas
Wash Section
Lean Amine Cooler
Condenser
CO_2 Product Gas
Knock-out Drum
Interstage Coolers
Filter
Interstage Heaters
Flue Gas Feed Gas
Absorber
Solvent Make Up
Rich/Lean HX
Reboiler

Project Scope and Timeline

	Large Bench-Scale Development of a Non-Aqueous Solvent Process (October 2015 through June 2018)
Task	
1	**Project Management and Planning**
2	**Baseline Evaluations of NAS in SINTEF Tiller Plant, 12/16**
3	**Design of NAS-Specific Components for SINTEF Plant, 09/16**
4	**Solvent Formulation Improvement, 10/16**
BP2	
5	**Procurement, Construction, Integration, and Shakedown of Modular NAS-Specific Components in SINTEF Tiller Plant, 08/17**
6	**Bench-Scale Testing of the NAS CO_2 Capture Process in Coal-fired Flue Gas at Tiller, 02/18**
7	**Detailed Techno-Economic Analysis, 06/18**

Risks and Risk Mitigation

Description of Risk	Prob.	Impact	Risk Management (Mitigation and Response Strategies)
Technical Risks:			
NAS Make-up Costs	Mod.	Mod’	• Reduce solvent loss by adding wash section • Low vapor pressure formulation
Process Risks:			
Scalable NAS Regenerator Design	Low	Mod.	• NAS regeneration process development underway
Management Risks:			
Cost Share	Mod.	Mod	• SINTEF cost share suffers from exchange rate risk

Milestones and Success Criteria

Budget Period	Task/ Subtask	Milestone Description	Planned Completion
1	1	A. Kick-off Meeting	10/30/2015
1	1	B. Updated project management plan	10/30/2015
1	2	C. Completion of 250 hours baseline testing at SINTEF Tiller plant	12/31/2016
1	3	D. Engineering design package for regenerator delivered to SINTEF.	10/31/2016

Decision Point	Date	Success Criteria
End of BP1	12/31/2016	• Completion of 250 hours baseline NAS testing at Tiller plant on flue gas from an existing propane boiler • Regenerator design package completed and agreed upon by project team

- Reboiler heat duty < 2.0 GJ/T-CO_2
- 90% CO_2 capture from coal-fired flue gas
- 95% CO_2 purity
- Cost of capture <= \$40/T-CO_2

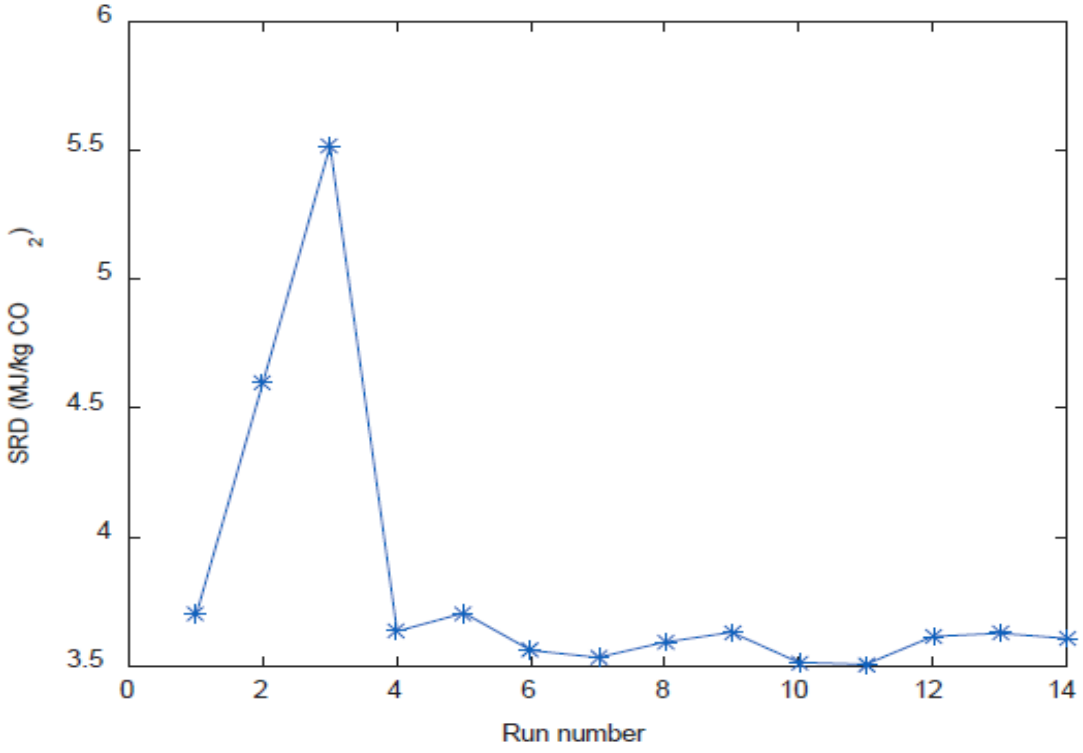
Task 2 - Baseline Testing of NAS in Tiller Pilot Plant

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

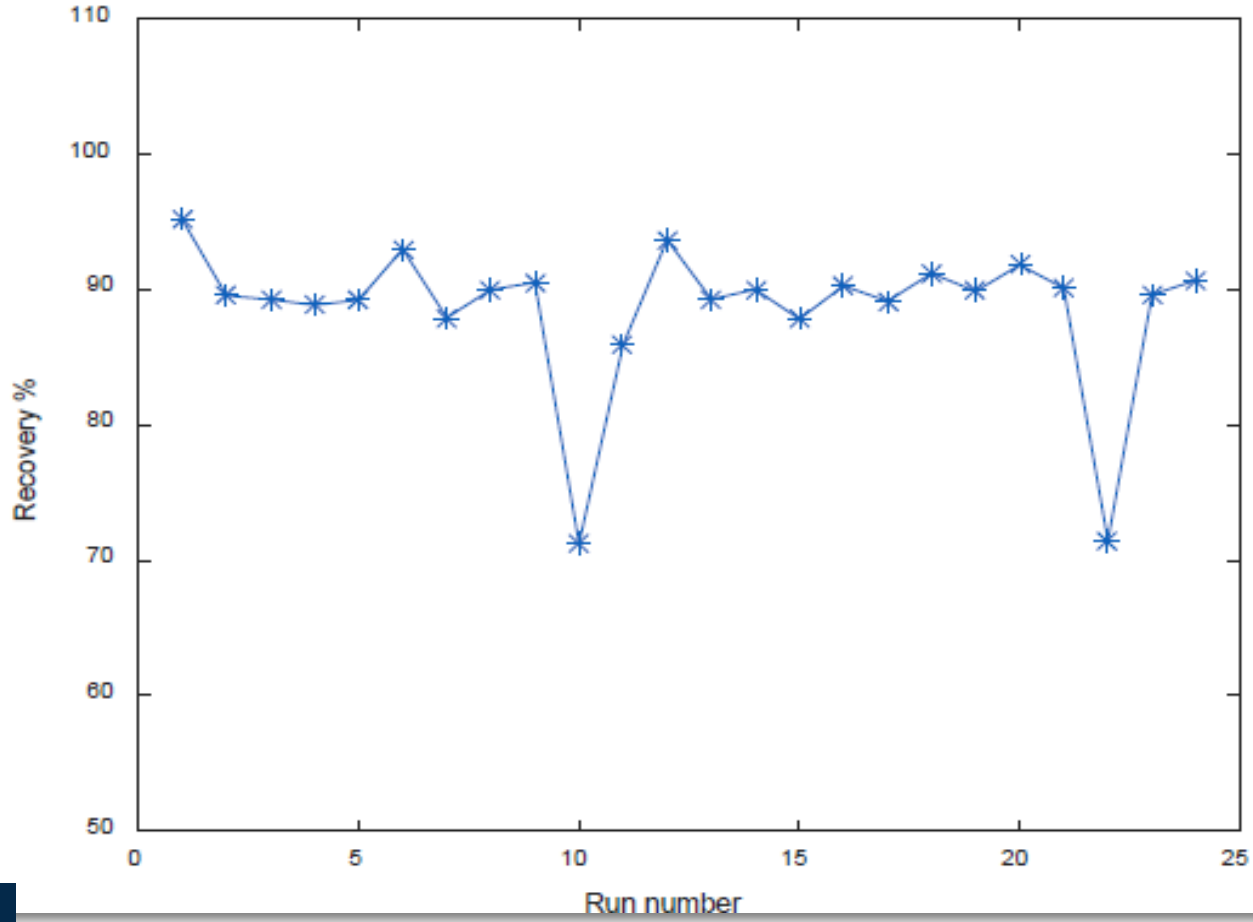
- **MEA baseline testing completed at Tiller plant**
  - **Confirms reboiler heat duty of 3.5 - 3.6 GJ/T-CO_2**
- **NAS baseline testing to start in August 2016**
- **All test to be completed by 12/31/2016**

MEA/H_2O Baseline Test at Tiller

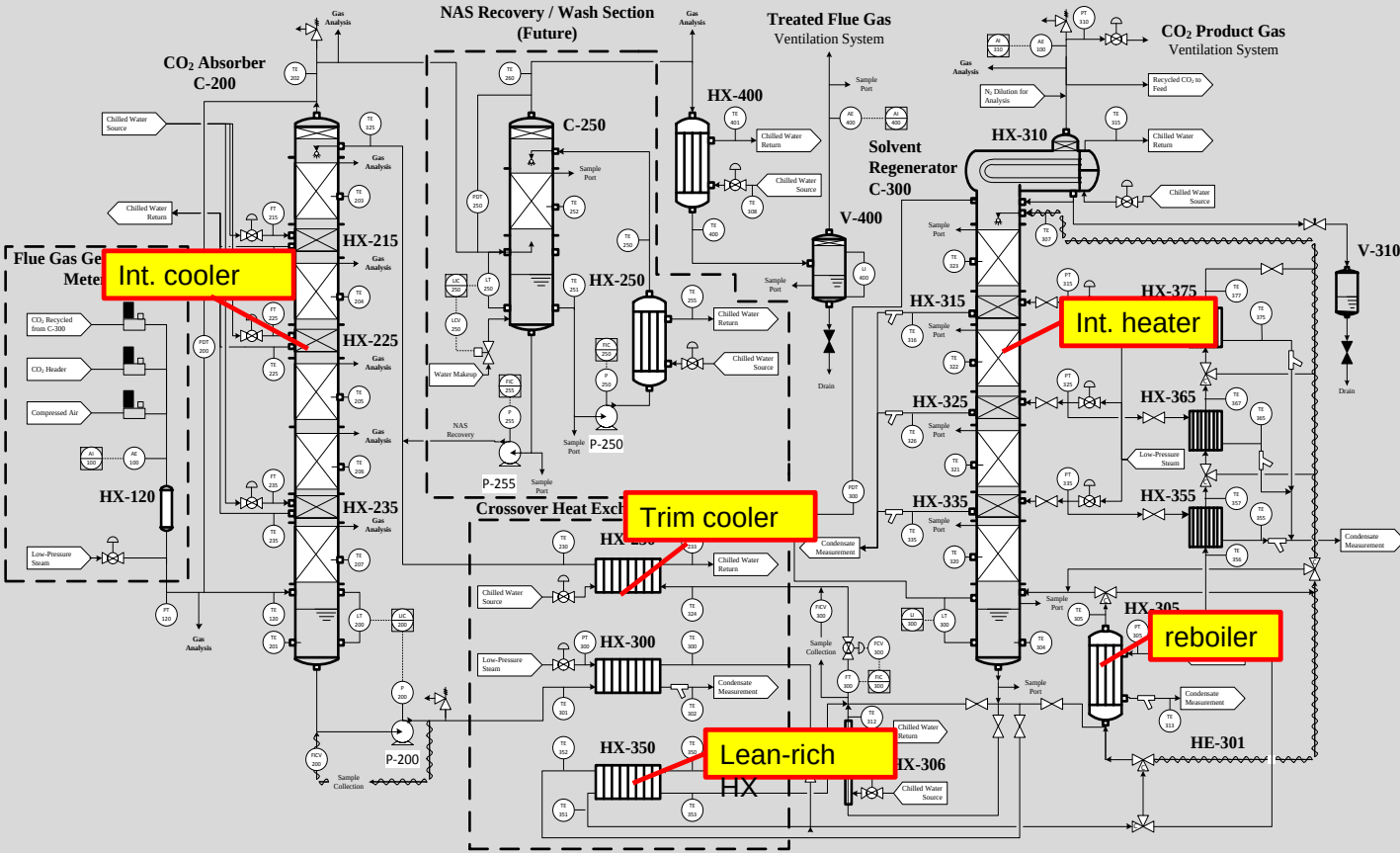
Specific reboiler duty:



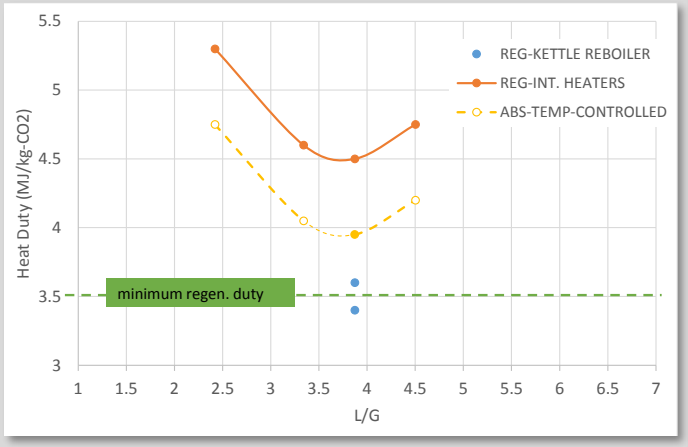
MEA/H_2O Baseline Test at Tiller/CO_2 Capture Rate

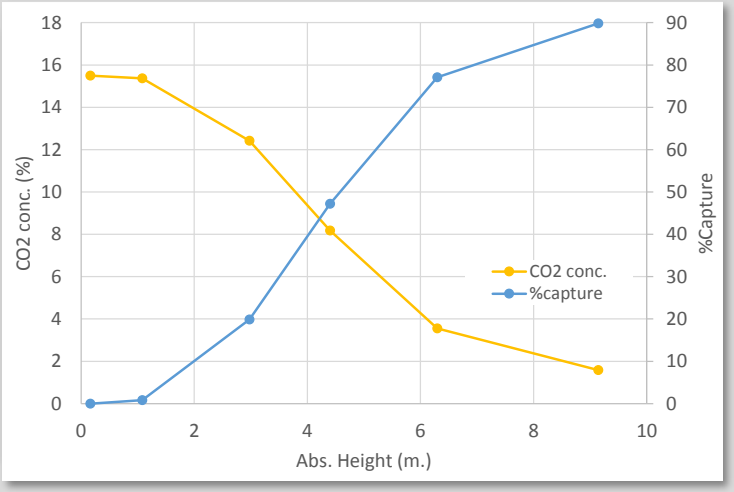


RTI's Bench-Scaled Testing Unit (BsTU)



MEA/H_2O runs at BsTU

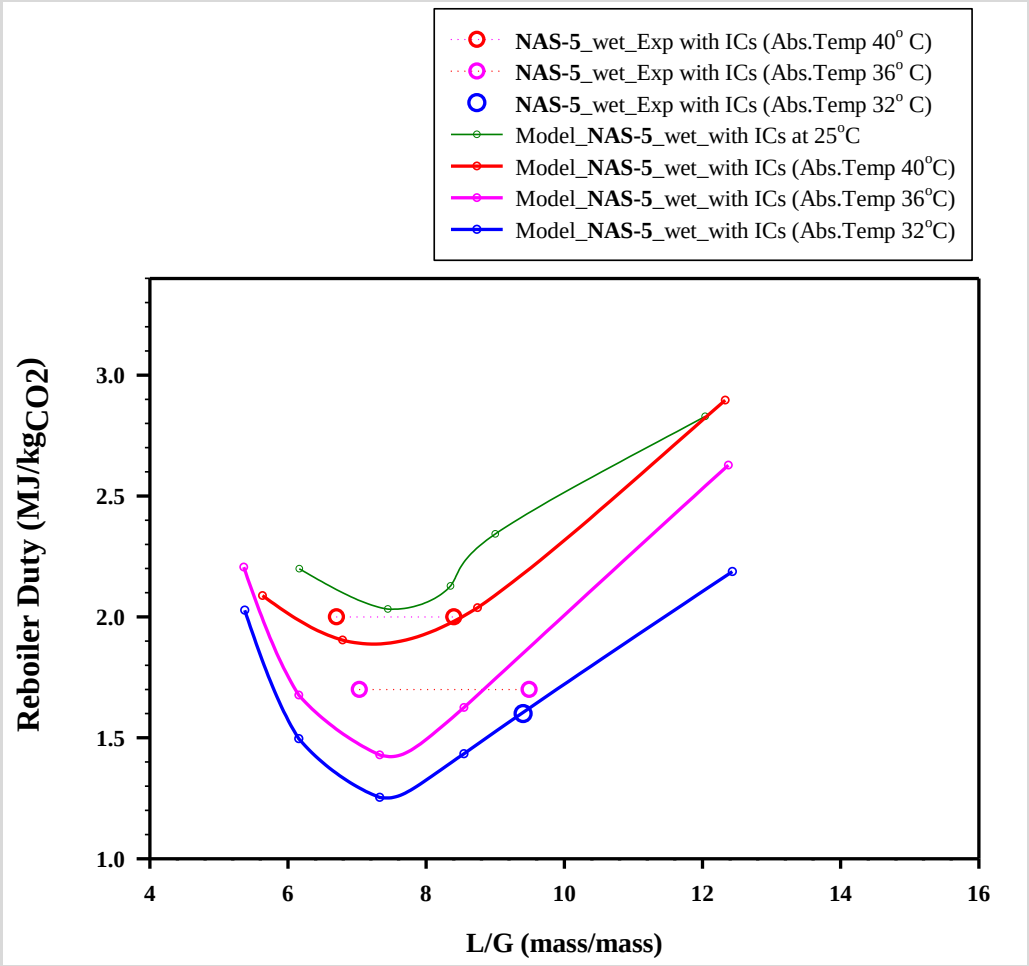




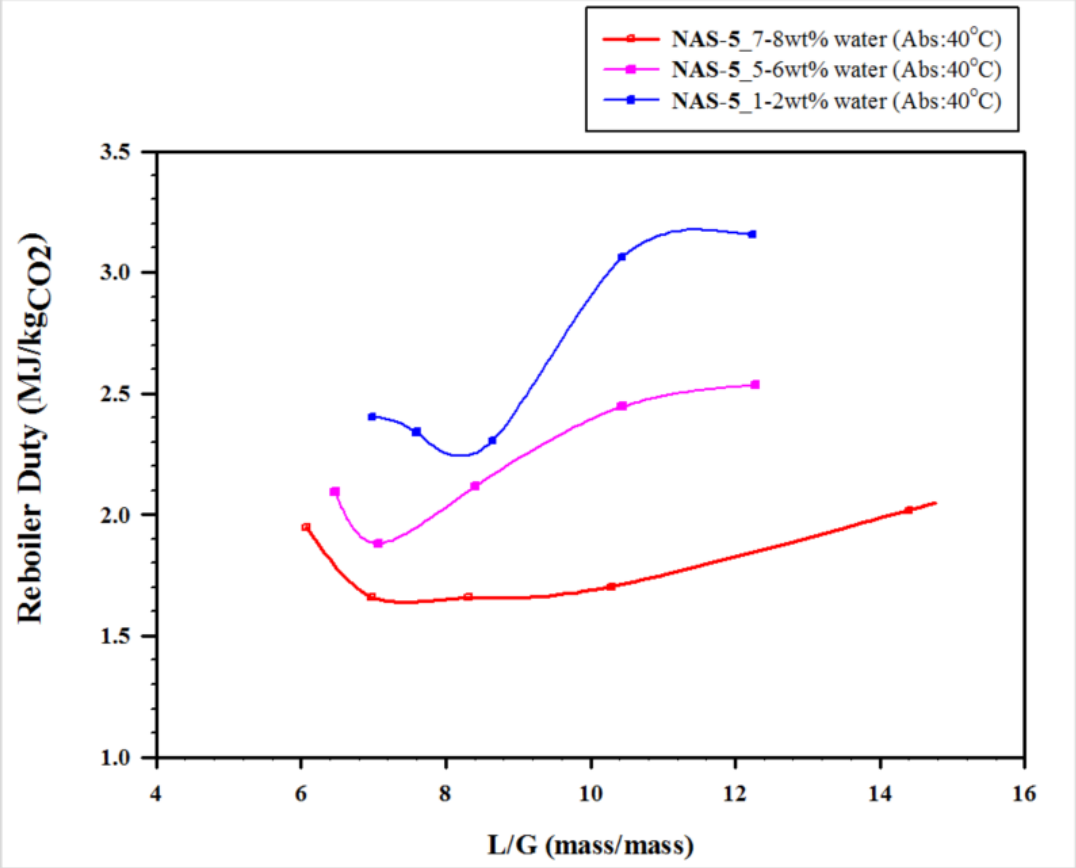
Task 3 - Design of NAS-Specific Components for SINTEF Plant

- Scale-up an optimal regenerator unit for NAS
- Regenerator process design
- How to incorporate new design at Tiller plant
- Conceptual design to SINTEF in a few weeks
- Complete design by 09/30/2016

Task 4 - Solvent Formulation Improvement



Effect of water on Reboiler Duty in NAS-CO_2 process



Where Are We Today?

- Third generation NAS solvent developed
- NAS-3 went through several 100's hours of continuous bench scale testing (100 L total solvent charge)
- NAS-5 testing in progress
- Obtained system operating conditions and design parameters
- Reboiler heat duty < 2 GJ/Tonne CO_2 from RTI small bench-scale testing. Needs to be confirmed at Tiller plant in Norway
- Baseline testing at Tiller with MEA complete

Next Steps: BP2 Scope of Work

- **Procurement, Construction, Integration, and Shakedown of Modular NAS-Specific Components in SINTEF Tiller Plant, 08/17**
- **Bench-Scale Testing of the NAS CO_2 Capture Process in Coal-fired Flue Gas at Tiller, 02/18**
- **Detailed Techno-Economic Analysis, 06/18**

Next Steps: Large Pilot Testing

- Large pilot testing for non-aqueous solvent technology targeted for 2018+
  - ~ 1 - 10 MW equivalent
  - Range of flue gas compositions (including coal, NGCC, etc)
  - Extended operation with finalized NAS formulation and process design
- Technology Center Mongstad and U.S. National Carbon Capture Center are potentially suitable sites

Acknowledgments

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- DOE Steve Mascaro

- RTI cost share and project partner SINTEF

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