Emissions Mitigation Technology for Advanced Water-Lean Solvent Based CO_2 Capture Processes

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Project Kickoff Meeting

Nov. 15th, 2018

Overview

- Background Information
- Project Information, Goals and Objectives
- Timeline
- Focused Tasks
- Upcoming Deliverables

Development History for Novel, Non-Aqueous Solvents

Technology Status

- Cumulative DOE funding > $9 MM and more than $2 MM funding from RTI industrial partners
- Solvent development work finalized
- Pilot testing completed at SINTEF, Norway and National Carbon Capture Center (NCCC)
- Pre-commercial demonstration (12 MW) planned at Technology Center Mongstad (TCM), Norway for FY19

Key Technical Advantages

- CO_2 Capture Technology with substantially reduced energy consumption
- Minimum changes to existing process to realize NAS optimal performance
- Commodity-scale production ready

Impact

- Long-term potential for large scale CO_2 capture applications
- Commercialization path via process technology licensing
- Application potential for high-efficiency acid gas separations

NAS CO_2 Capture Technology Path to Market

From lab to large scale (12 MW) demonstration through series of projects

Lab-Scale Development & Evaluation (2010-2013)

Solvent screening and Lab-scale evaluation

~$2.7MM

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

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

~$3 MM
6kW

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

Demonstration of all process components at pilot scale

~$3MM
60 kW

Pilot Testing at SSTU (NCCC, 2018)

Degradation, emission, and corrosion characterizations under real flue gas

~$0.75MM
50 kW

Emissions control (Tiller, 2018+)

Effective emissions mitigation strategy for WLS at engineering-scale

~$3.5MM

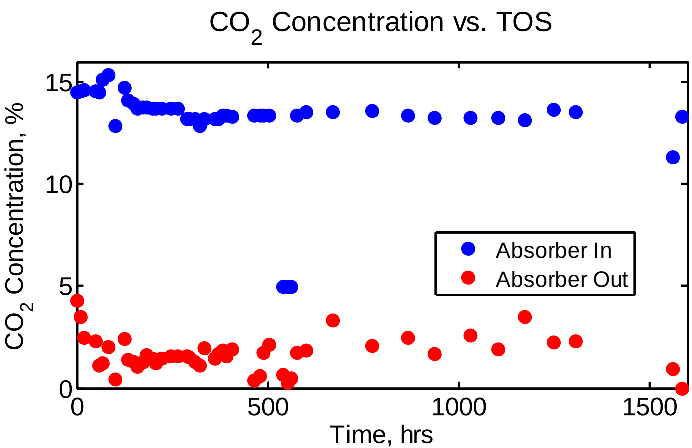
Engineering-Scale Validation (2018+)

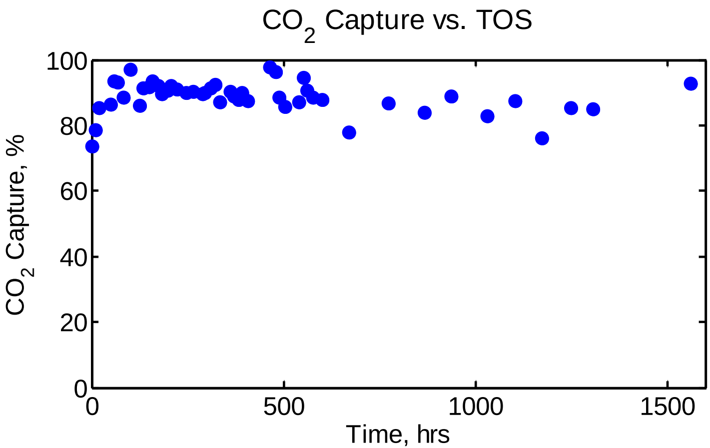
Pre-commercial Demonstration at Technology Centre Mongstad, Norway (~10 MWe)

Test in late 2019

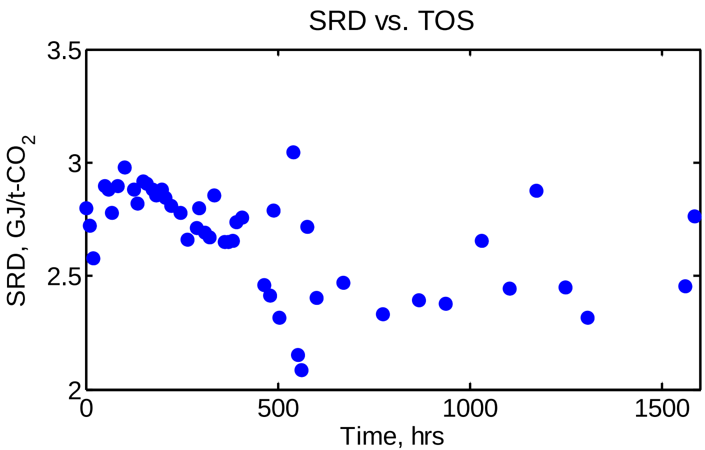
~$21MM
12 MW

Specific Reboiler Duty from Tiller





	Hours
Parametric testing	543
Long-term testing	1,043
Total hours	**1,587**



Preliminary TEA

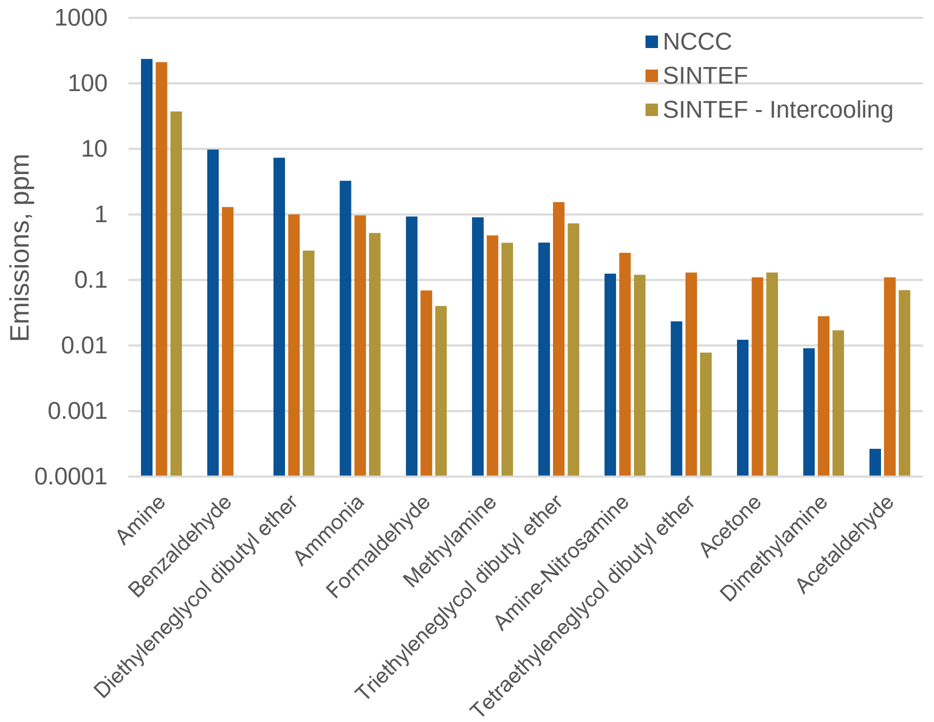
	Base Case 1	Base Case 2	Case 1	Case 2	Case 3
Description	No Capture (DOE Case 11)	CO_2 Capture (DOE Case 12) using 30Wt % MEA	RTI NAS @HP optimized	10% CAPEX increase due to EC	RTI NAS w/EC @HP optimized NOAK
Solvent		MEA	NAS	NAS	NAS
SRD (GJ/t-CO_2)		3.6	1.9	1.9	1.9
Regenerator pressure (bar)		1.6	4.4	4.4	4.4
Coal flow rate (lb/hr)	409,528	565,820	495,610	495,610	495,610
Gross power output (kWe)	580,400	662,800	637,350	637,350	637,350
Aux. power req. (kWe)	30,410	112,850	87,350	87,350	87,350
Net power output (kWe)	549,990	549,950	550,000	550,000	550,000
Net plant HHV efficiency (%)	39.28%	28.43%	32.46%	32.46%	32.46%
Power plant cost ($MM)	1,090	1,361	1,250	1,250	1,250
CO_2 capture cost ($MM)		506	243	267	267
CO_2 compression cost ($MM)		88	58	58	58
TPC ($MM)	1,090	1,955	1551	1575	1575
TOC ($MM)	1,349	2,409	1917	1946	1946
Total OPEX ($MM)	199.1	297.6	254.8	255.9	255.9
COE, excl CO_2 TS&M, mills/kWh	83.7	137.2	113.0	114.0	110.3
Cost of CO_2 Capture ($/t-$CO_2$)[a]		56.45	36.72	37.83	33.59

Table 1. Results from the High-Level Techno-economic Analysis for CO_2 Capture Using NAS with ECTs

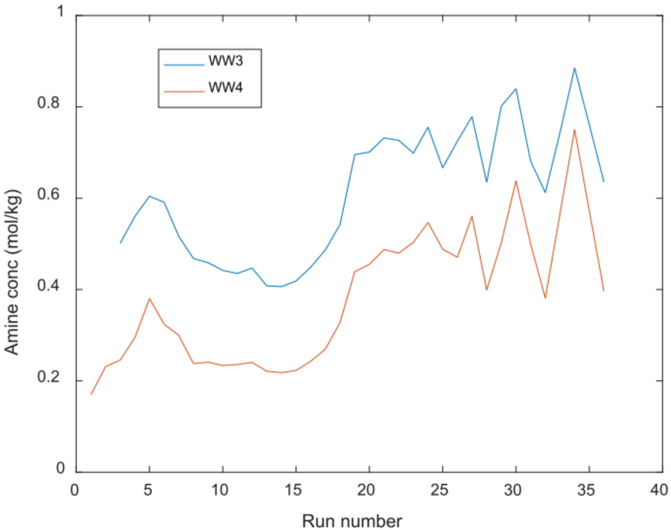
Note: @HP = High Pressure; COE = Cost of Electricity; EC = emissions control; HHV = High Heating Value; NOAK = n^{th}-of-the-kind; TOC = Total Overnight Cost; TPC = Total Plant Cost; TS&M = Transport, Storage, and Monitoring.

NCCC and Tiller Emission results

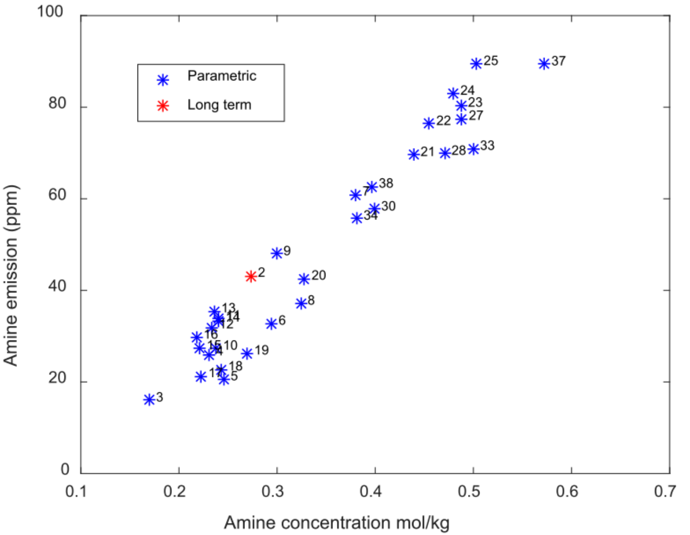
- Similar emissions levels and species seen at SINTEF and NCCC
- Intercooling reduces emissions by almost 10x
- Largest minor emissions include hydrophobic diluent species and other degradation species: benzaldehyde, methylamine, ammonia, nitrosamine in both campaigns



Background – Tiller results



Amine conc. in WW3 and WW4 liquid



Amine conc. in WW4 liquid compared to the amine in the gas

- Lower water content in WLS reduces the efficiency of build-in wash columns
- Higher activity coefficient of NMBA in water lowers the effectiveness of the water wash sections.
- 2-stage water wash is effective for aqueous systems (e.g., MEA)

Water wash is not an effective solution to suppress emission for WLS systems

Project Summary

Objective:

Develop and optimize the emission control solutions to reduce the amine emission for advanced, 2nd generation solvent –WLS class

Key Metrics

- Fugitive emissions from absorber/desorber
- Solvent loss and make-up cost reduction
- Technoeconomic and EHS evaluation

Specific Challenges

- Aerosols generation and characterization
- Amine reclaiming unit and process integration
- Organic wash solvent screening

Timeframe:

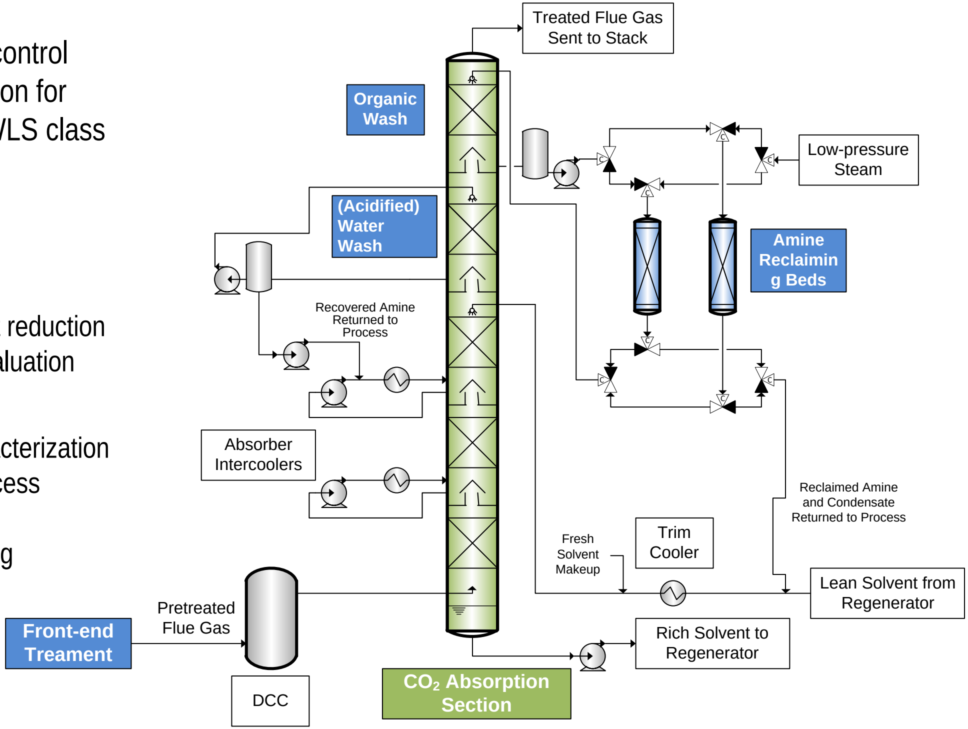
BP1 10/01/18 to 03/31/20

BP2 04/01/20 to 09/03/21

Budget:

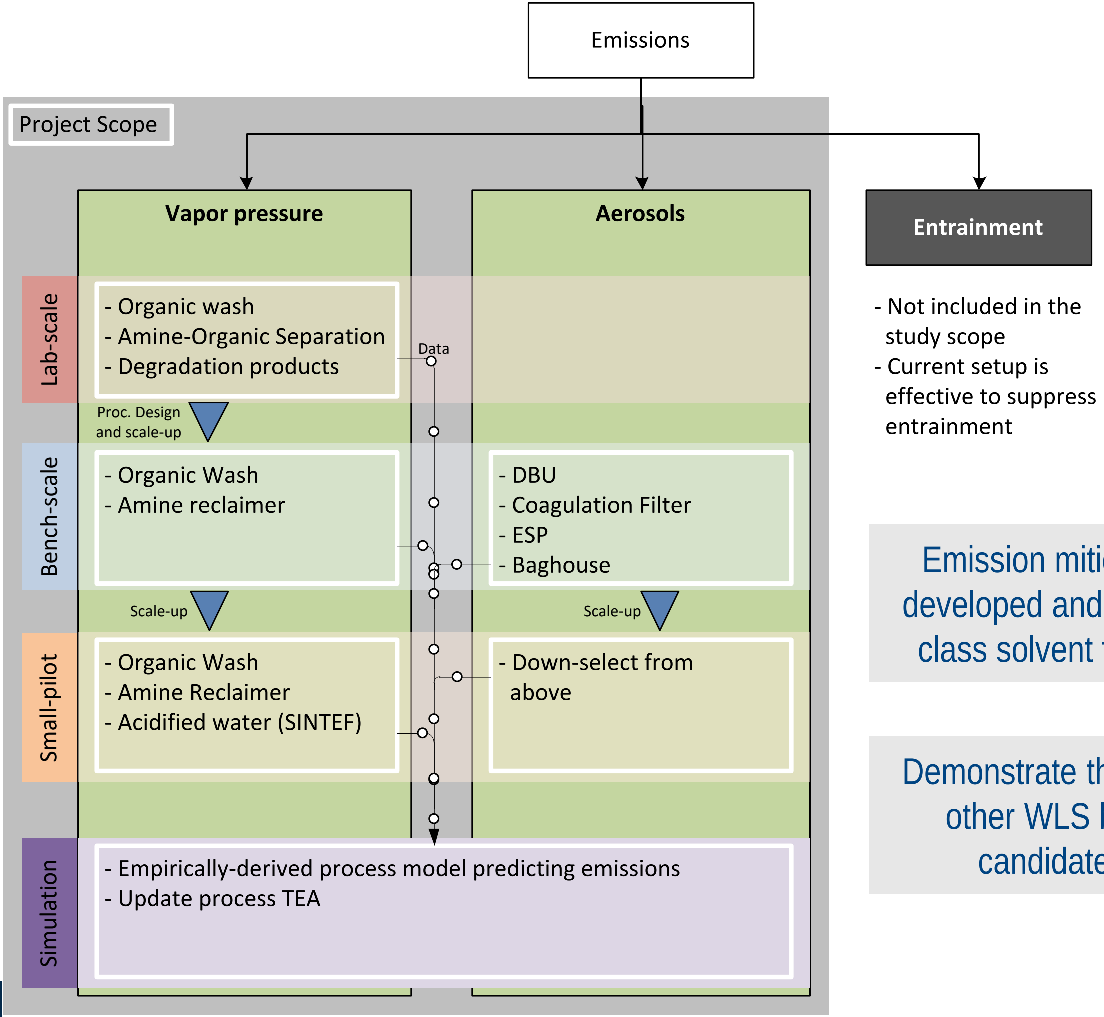
BP1 Federal $1.7MM Cost Share $0.4MM

BP2 Federal $1.2 MM Cost Share $0.4 MM



Potential emissions control technologies for WLS systems to be incorporated at the CO_2 capture plant

Technical Scope

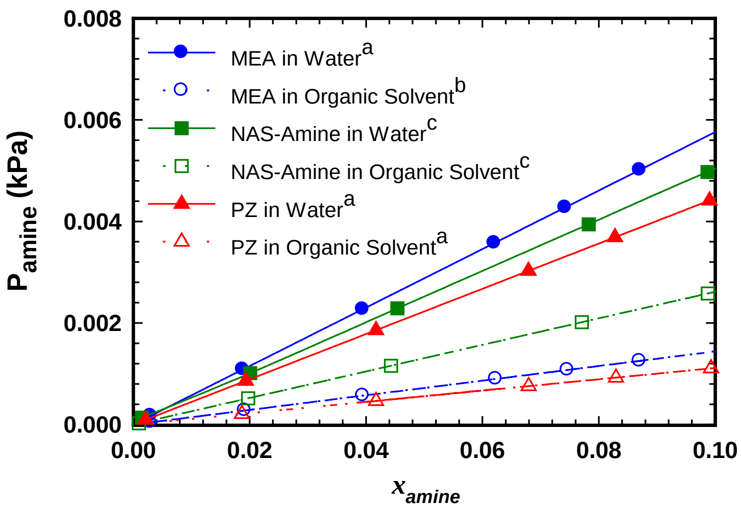


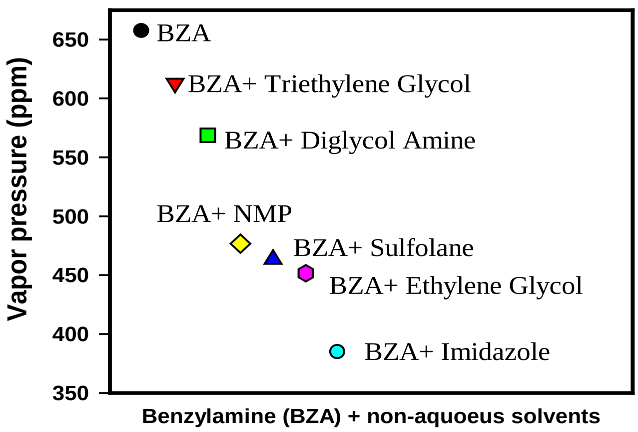
- Not included in the study scope
- Current setup is effective to suppress entrainment

Emission mitigation package developed and benefit the WLS class solvent for CO_2 capture

Demonstrate the applicability to other WLS by selecting a candidate for testing

Technical Drive: low activity coefficient in organic solvent

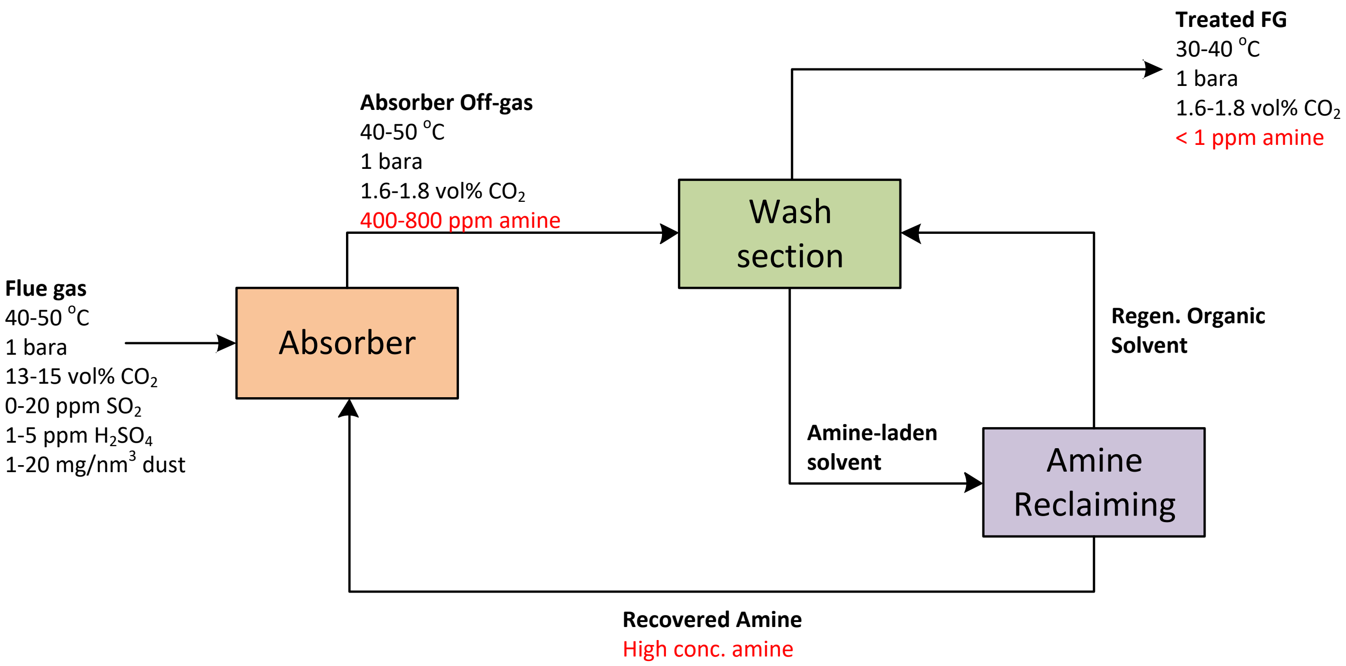




- Optimal selection of the organic solvent that allows high amine solubility while minimize the gas phase amine vapor pressure
  - Non-aqueous system
  - Organic solvent with low vapor pressure
- Effective separation between organic solvent and reclaimed amine
  - Separation process selection – Sorbents?
  - Amine reclaiming integration

Vapor pressure of pure amines at different temperatures. (a) Measured values in RTI. (b) Calculated values from DIPPR, 2010.[19]
Partial pressure of amine in water and organic solvent at 40°C. (a) Calculated from experimental values of Nguyen et al.2010,[20] (b) Estimated value from correcting activity coefficient of amines in organic solvent based on the emission from BsGAS experiments in RTI. (c) Measured values from RTI experiments.

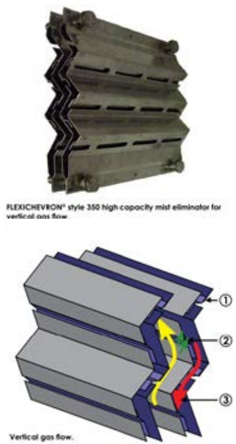
Reclaiming Process Integration



Comprehensive BACT for ECTs

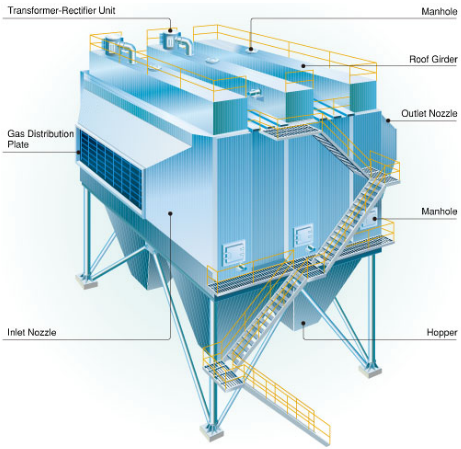
- Augmented emission control with commercially available devices
  - Coagulation filters
  - Brownian Diffusion Unit (BDU)
  - [front-end] Electrostatic precipitation (ESP)
  - [front-end] Baghouse with advanced filter
- Cost-effective evaluation at small-scale
- Down-select equipment for evaluation at Tiller

Coagulation filters



DBU

Baghouse with advanced filter



Electrostatic Precipitator (ESP)

Project Team

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  (The Linde Group – Linde)
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  (CO2 Technology Centre Mongstad)

Project Team

Team Member	Role	Expertise
RTI	Prime recipient, project management, developer of NAS technology, emissions characterization, solvent screening, ECT design and modeling, and economic analyses	▪ 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 ▪ Aerosol emissions characterization
SINTEF	Emissions modeling support, engineering support, and operation of plant with integration of new emission control units	▪ Tiller Plant for solvent-based CO_2 capture processes, operational and EH&S expertise ▪ Engineering design of process components ▪ Analytical equipment for solvent testing
Linde	Technical advisory and contributor to joint-emission report	• Leading industrial gas supplier • CO2 capture plant design and pre-commercial scale demonstration • Advance front-end emission control equipment design and fabrication
TCM	Technical advisory and EH&S support	• World leading test facility for CO_2 capture • EH&S and quality standards

Project Tasks

Task 1.0 Project Management and Planning

<u>BP1 Tasks</u>

Task 2.0 Establish emission baseline without ECT

- Aerosol generation at BsGAS
- Method development + baseline measurement
- Empirical model

Task 3.0 Prototype ECT for WLSs evaluation at RTI's BsGAS

- Organic wash and amine reclaiming process
- BsGAS with ECTs + evaluation
- Acidified water wash at Tiller

<u>BP2 Tasks</u>

Task 4.0 ECT evaluation at Tiller

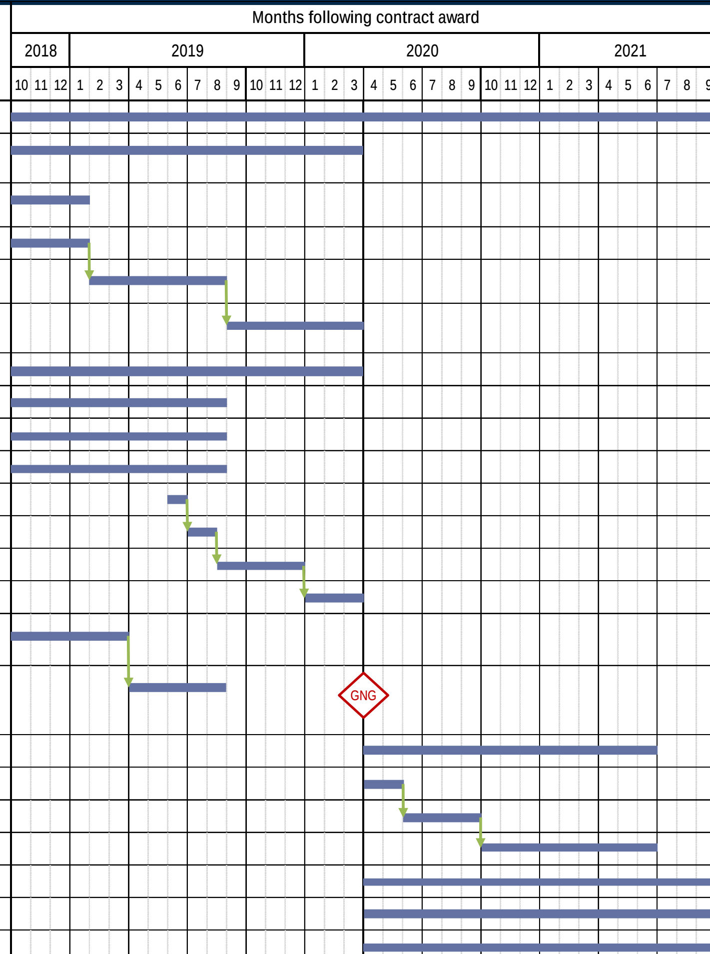
Task 5.0 Process simulation and TEA

Project Goals

- Control and manage emissions
- Identify emission pathways for WLSs
- Model the amine emission
- Suppress emission and aerosols by ECTs
- Refine Techno-economic analysis
- Gain operational experience on WLS process with ECTs

Overall Project Timeline

Task	Task title	Start date	End date
1.0	Project Management	10/01/18	09/30/21
2.0	Evaluation of Amine Emission for Water-Lean System Without Emission Control	10/01/18	03/30/20
2.1	Develop a Method to Monitor, Differentiate, and Quantify Emissions at BsGAS	10/01/18	01/31/19
2.2	Particulate Generator Modification at BsGAS	10/01/18	01/31/19
2.3	Establish Baseline Amine Emission for Water-Lean System Without Emission Controls	02/01/19	08/31/19
2.4	Development of Empirical Process Model for Amine Emission from Water-Lean Based Solvent Systems	09/01/19	03/31/20
3.0	Prototype Emissions Control System for Water-Lean Solvent	10/01/18	03/31/20
3.1	Organic Solvent and Amine Extraction Sorbent Evaluation	10/01/18	08/31/19
3.1.1	Wash Organic Solvent Characterization	10/01/18	08/31/19
3.1.2	Amine Reclaiming Evaluation	10/01/18	08/31/19
3.2	Define Emission Control Approach	06/01/19	06/30/19
3.3	Preliminary Design for Emission Mitigation Process	07/01/19	08/15/19
3.4	Detailed Design and Construction	08/15/19	12/31/19
3.5	Performance Evaluation at BsGAS	01/01/20	03/31/20
3.6	Evaluation of pH Control Concept Using CO_2 Acidification Method at Tiller	10/01/18	03/31/19
3.7	Development of Empirical Process Model for Amine Emission from First-Stage Water Wash Using the CO_2 Acidification Concept	04/01/19	08/31/19
4.0	Implementation at a Large Bench-Scale Unit (SINTEF)	04/01/20	06/30/21
4.1	Update Tiller's Emissions Control Design	04/01/20	05/31/20
4.2	Construction and Commissioning	06/01/20	09/30/20
4.3	Performance Evaluation of Emissions Control System	10/01/20	06/30/21
5.0	Process Simulation and Techno-Economic Assessment	04/01/20	09/30/21
5.1	Update Empirical Emission Model	04/01/20	09/30/21
5.2	Refine Techno-economic Evaluation	04/01/20	09/30/21



Project Goals

Decision Point	Date	Success Criteria
End of BP1	03/31/2020	1. Establishment of an emission model of the capture system without mitigation reduction controls with average absolute deviation < 25% for critical process factors 2. Move forward with at least one wash organic solvents 3. Demonstration of emission reduction devices at bench-scale gas absorption system (BsGAS) with RTI's non-aqueous solvent (NAS) and another selected water-lean solvent to reduce emissions < 10 ppm
Completion of Project	09/30/2021	1. Demonstration of emission reduction devices at Tiller with NAS and another selected water-lean solvent to reduce emissions < 1 ppm 2. Mission model of a CO_2 capture system with mitigation reduction control with average absolute deviation < 25% for critical process parameters 3. Techno-economic analysis of the emission mitigation system

Risks and Risk Mitigation-1

Description of Risk/Area		Prob.	Impact	Risk Management (Mitigation and Response Strategies)
Technical Risks:				
Process	Amine reclaiming unit	Moderate	High	• A suitable separation column with amine absorbent will be carefully selected and evaluated during the solvent screening activity • Criteria: high separation efficiency, low pressure drop and energy.
Process	Amine emission remains high after organic wash section	Moderate	High	• Screen solvents based on log-P to ensure the low-amine vapor pressure and high-amine solubility.

Risks and Risk Mitigation-2

Description of Risk/Area		Prob.	Impact	Risk Management (Mitigation and Response Strategies)
Resource Risks:				
Cost-Share	Cost-share from CLIMIT is not secured	Low	Moderate	• Clarify with the scope and objective with GASSNOVA staff in Aug. • CLIMIT proposal resubmitted in October
Suppliers	Solvent synthesis schedule and delivery	Low	Moderate	• RTI will identify and communicate the minimum required amount of water-lean CO_2 capture solvent and the delivery deadline with the suppliers.

BP1 Key Tasks - 1

Key Tasks	Milestone Number and Task	Approaches/ planned Activities	Planned Completion Date
Develop method to monitor and quantify emissions at the BsGAS	D/Task 2.1	• Install SO_3 injection at BsGAS • Particle counter and aerosols quantification equipment tie-in	01/31/19
Baseline data for amine emissions using two water-lean solvents	F/Task 2.3	• Parametric testing on 2 solvent candidates	08/31/19
Empirical process model for amine emissions from water-lean solvents with < 10% average absolute deviation based on critical process parameters	G/Task 2.4	• Regression on experimental results • Co-develop model with SINTEF	03/31/20

BP1 Key Tasks - 2

Key Tasks	Milestone Number and Task	Approaches/ planned Activities	Planned Completion Date
Update BsGAS flow sheet with emission control equipment necessary to reduce amine emissions with > 99% efficiency	J/Task 3.3	• Install, commission, and evaluate ECTs at BsGAS • SINTEF participates during the test	08/15/19
Complete testing of emission reduction performance at BsGAS to demonstrate amine emissions reduction to < 10 ppm	L/Task 3.5	• Parametric testing	03/31/20
Evaluate acidified water wash process at Tiller	M/Task 3.6	• Minor alteration to Tiller for concept evaluation	3/31/19

BP2 Key Tasks

Key Tasks	Milestone Number and Task	Approaches/ planned Activities	Planned Completion Date
Complete Tiller modification and commissioning	P/Task 4.2	• Guideline from test results at BsGAS • Procure long lead-time items in advance	09/30/20
Complete emission reduction performance testing at Tiller to demonstrate amine emissions reduced to < 10 ppm	Q/Task 4.3	• Parametric testing on 2 solvent candidates based on results from BsGAS in BP-1	06/30/21
Complete empirical model development with average absolute deviation < 10%	R/Task 5.1	• Update emission model with SINTEF data	09/30/21
Complete techno-economic evaluation of the emission mitigation package	S/Task 5.2	• Update TEA from TCM project with ECTs	09/30/21

Summary

Project Objectives:

- Develop and demonstrate effective emissions control for WLSs
- Accelerate development efforts by leverage existing systems and external collaboration
- Develop process emission model with aerosols
- Evaluate impact on capture cost of capture unit with ECT

Challenges

- Organic wash and amine recovery optimization
- Aerosols characterization
- Particle and aerosol formation modeling and integration with ASPEN
- Testing and modification schedule at Tiller

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- TCM:Project support

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