GEN2NAS Solvents for CO_2 Capture from NGCC Plants

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DE-FE0032218

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Acknowledgement

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Disclaimer

Objective:

Develop a novel GEN2NAS solvent that lower the cost of CO_2 capture at NGCC plants by 40% by solvent formulation and process configuration optimization.

Key Metrics

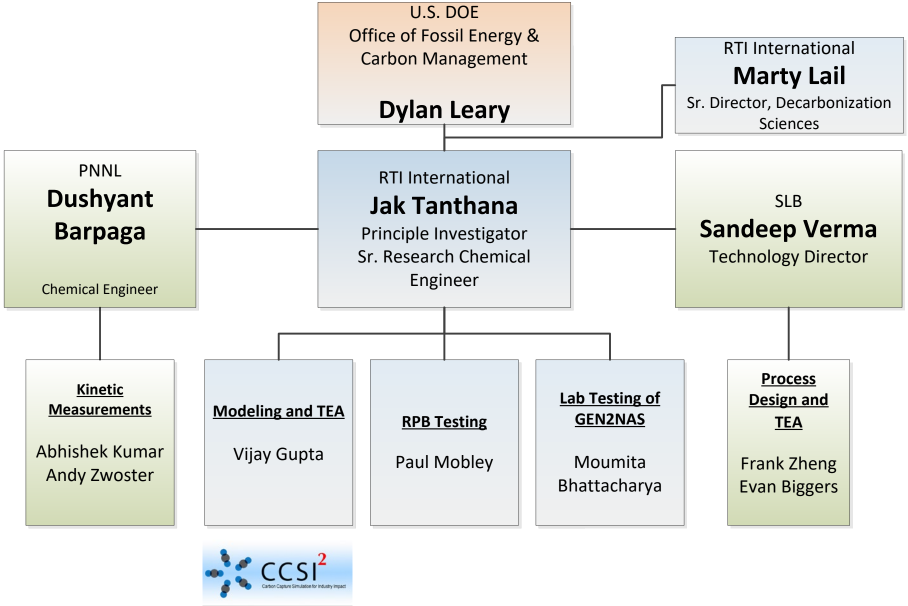
- >97% capture rate
- SRD: 2.1-2.5 GJ/ton-CO_2
- Low vapor pressure, < 0.05 kPa (MEA's)
- Technoeconomic and Environmental Health, and Safety (EHS) evaluation

Specific Challenges

- Solvent scale-up
- Formulation optimization
- Process configuration

Timeframe: 04/01/23 - 09/30/24

	Federal	Cost Share	Total Costs
Total	**$1,000,000**	**$250,000**	**$1,250,000**



Technology Overview – NAS Research, Development, and Demonstration

Coal

Lab-Scale Development & Evaluation (2010-2013)
Solvent screening and lab-scale evaluation

0.0015 t-CO_2/day (0.08 kW)

Large Bench-Scale System (RTI, 2014-2016)
Demonstration of key process features and ≤ 2.3 GJ/t CO_2

0.11 t-CO_2/day (6 kW)

Pilot Testing at SSTU (NCCC, 2018)
Degradation, emission, and corrosion characterizations under real flue gas

1.1 t-CO2/day (60 kW)

Pilot Testing at Tiller Plant (Norway, 2015-2018)
Demonstration of all process components at pilot scale

1.0 t-CO2/day (55 kW)

Engineering-Scale Validation at TCM (Norway, 2018-2022)
Pre-commercial demonstration AACE class 3 FEED study

220 t-CO2/day (12 MW)

slb

Natural Gas

GEN2NAS Lab-Scale Development & Evaluation (2023-2024)
Solvent screening and lab-scale evaluation

0.0005 t-CO_2/day (0.05 kW)

Natural Gas

FLECCS Phase 1 – Dynamic CO_2 Capture (2021-2022)
Process intensification to enable flexible capture, reduce capital expense

0.05 t-CO_2/day (10 kW)

Natural Gas

FLECCS Phase 2 – Dynamic CO_2 Capture (2023-2025)
Process intensification to enable flexible capture, reduce capital expense

100 t-CO_2/day (10 MW)

Iron Pelletization

Large Bench-Scale System (RTI, 2021)
Demonstration of key process features, handling of particulates, capture performance and energy usage

0.02 t-CO_2/day

Cement

Process Intensified Pilot Testing for Cement Flue Gas (Texas, 2021-2024)
Process intensified absorbers to reduce CAPEX from cement flue gas capture

1 t-CO_2/day

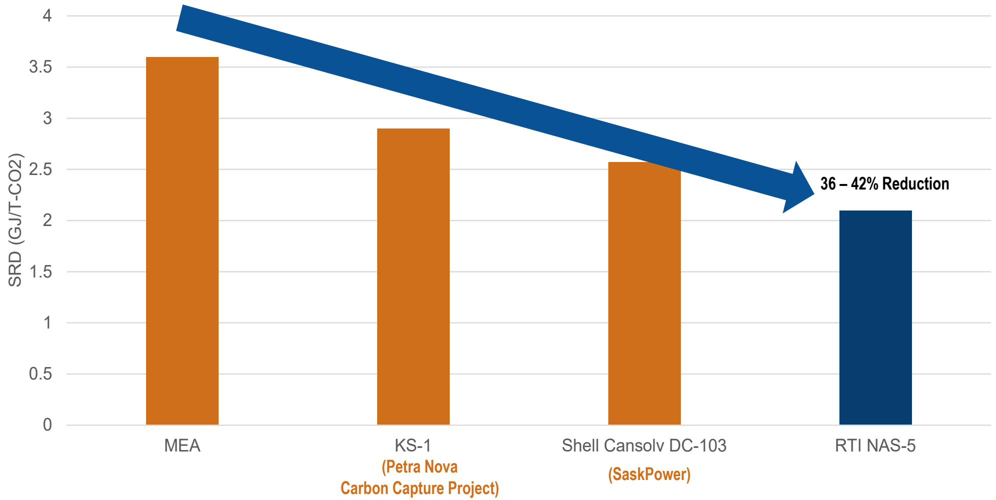
Carbon Capture Plant FEED Study for Cement Plant (Texas, 2023-2024)
Full-scale FEED study with AACE class 3 for CEMEX's Balcones plant

4000 t-CO_2/day

RTI's non-aqueous solvent (NAS)

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

Technology Status
- Completed technology demonstration at 12 MW Technology of Mongstad (TCM)
- Signed licensing agreement with SLB to accelerate the industrialization and scale-up of NAS technology



RTI evaluates wide range of low-cost, commercially-produced amines with the following characteristics:

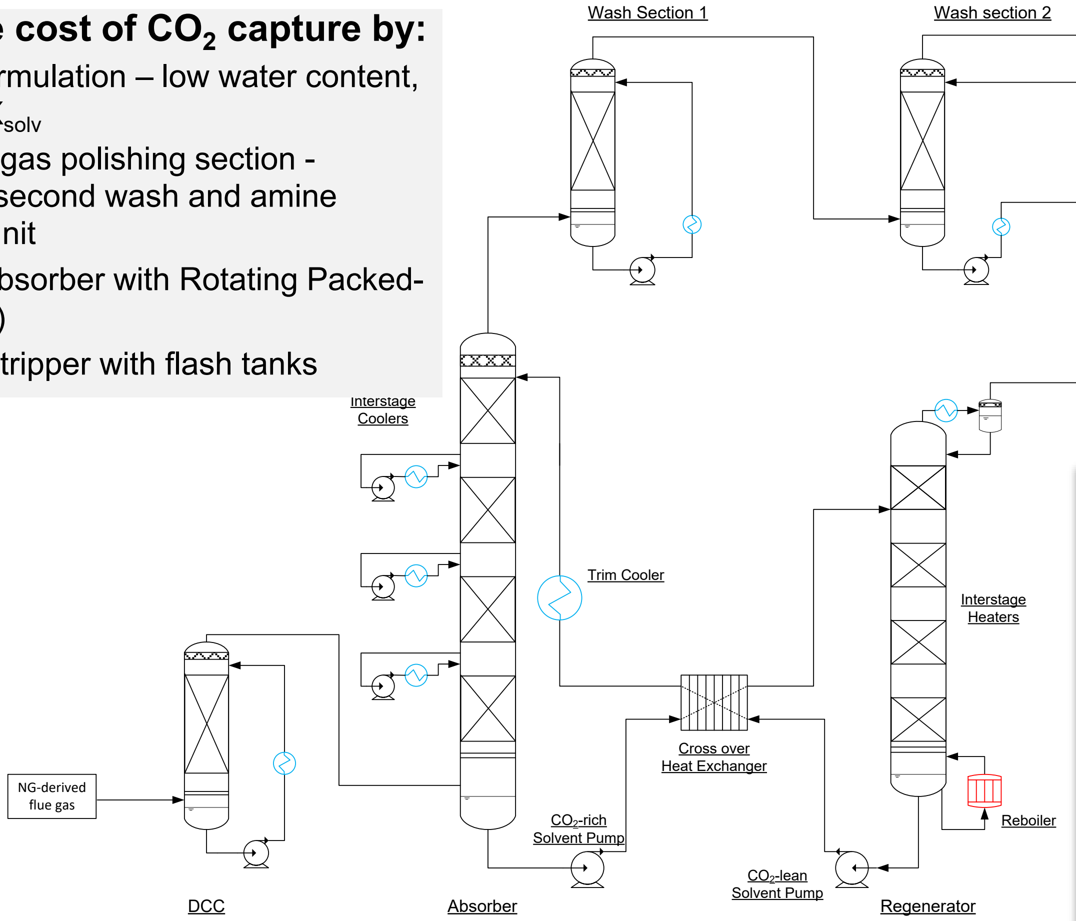
- Low water solubility
- Low heat of absorption
- High working capacity
- Low regeneration temperature
- Low specific heat capacity
- Low heat of vaporization
- Low corrosion

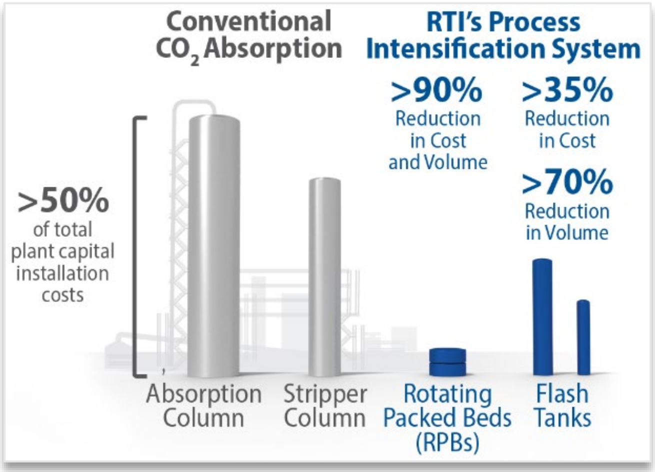
Areas for Improvement
- Amine emissions
- Simplified and intensified process configuration

References:
Mitsubishi Heavy Industries (https://gcep.stanford.edu/pdfs/energy_workshops_04_04/carbon_iijima.pdf)
Shell Global Solutions / Cansolv (http://www.ieaghg.org/docs/General_Docs/12%20cap/3-3%20Sec.pdf)

Lower the cost of CO_2 capture by:

- Solvent formulation – low water content, increase X_{solv}
- Simplified gas polishing section - removing second wash and amine recovery unit
- Replace absorber with Rotating Packed-Bed (RPB)
- Replace Stripper with flash tanks





Comparison of Cost and Performance against DOE Reference Cases

	B31A	B31B	RTI-Gen2NAS	RTI-Gen2NAS w/HP regeneration
CO_2 Capture Technology		Cansolv	Gen 2 NAS	Gen 2 NAS
Parasitic Energy Penalty, GJ/t-CO2		2.9	2.4	2.40
Solvent Regen Pressure (bar)		2.0	2	4.4
Combustion Turbine Power, MWe	477	477	477	477
Steam Turbine Power, MWe	263	213	222	222
Total Gross Power, MWe	**740**	**690**	**699**	**699**
CO_2 Capture/Removal Auxiliaries, kWe	-	11	8	8
CO_2 Compression, kWe	-	17	17	14
Balance of Plant, kWe	14	16	16	16
Total Auxiliaries, MWe	**14**	**44**	**42**	**38**
Net Power, MWe	**726**	**646**	**657**	**660**
NGCC Plant CAPEX ($1000)	$566,969	$601,238	$604,232	$604,232
CC Plant CAPEX ($1000)		$619,914	$310,529	$310,529
Compression CAPEX ($1000)		$60,170	$60,170	$37,986
TOTAL CAPEX ($1000)	**$755,721**	**$1,281,322**	**$974,932**	**$952,748**
NGCC Plant Capacity Factor	0.85	0.85	0.85	0.85
Fixed Charge Rate	0.0707	0.0707	0.0707	0.0707
TASC ($MM)	756	1,700	1,293	1,264
FOPEX ($MM)	19.5	41.3	31.6	31.6
VOPEX ($MM)	10.9	31.9	23.3	23.3
FUEL ($MM)	179.0	179.0	179.0	179.0
MWh	6,363,684	5,658,417	5,752,067	5,783,516
LCOE	$ 43.3	$ 70.8	$ 60.3	$ 59.6
Cost of CO_2 Capture ($/tonne-$CO_2$)	**$ -**	**$ 79.4**	**$ 49.9**	**$ 48.0**

- TEA based on NETL methodology outlined in the Baseline study
- All costs are on 2018 US$ basis
- Natural gas-derived flue gas
- Absorber replaced with RPB
- Regenerator replaced with 2-stage flash

Project Tasks and Outputs

Task	Task title	Start date	End date	Budget Period 1 (BP1)																	
				2023									2024								
				Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1.0	Project Management and Planning	04/01/23	09/30/24																		
1.1	Project Management Plan	04/01/23	09/30/24																		
1.2	Technology Maturation Plan	04/01/23	09/30/24																		
2.0	Lab Testing of GEN2NAS	04/01/23	03/31/24																		
2.1	Optimization of solvent blend	04/01/23	12/31/23																		
2.2	Lab-scale gas absorption testing of selected solvent blends	10/01/23	03/31/24																		
2.3	Characterization of pure solvent blend components	04/01/23	03/31/24																		
3.0	Kinetic Measurements of GEN2NAS	04/01/23	03/31/24																		
4.0	RPB Testing	01/01/24	09/30/24																		
4.1	Capture efficiency and Specific Reboiler Duty (SRD) measurements	01/01/24	06/30/24																		
4.2	Oxidative degradation measurements	04/01/24	09/30/24																		
5.0	Technoeconomic Assessment and Technology Maturation Plan Update	01/01/24	09/30/24																		
Milestone Log		*(proposal*	*table)*	A		B							C		D,E			F			G,H
Deliverables		*(As noted)*	*(As noted)*	D1		D2			D10				D3		D4,D5			D6-D9			D11
Reporting		*(See footnote.)*	*(See footnote.)*				Q			Q			Q			Q			Q		
Project Meeting		*(See footnote.)*	*(See footnote.)*	K				B												B	

Q = Quarterly report due one month after quarter's end; FR = Final report due three months after project end.

K = Project kick-off meeting; B = Project briefing (annual);

Risks and mitigation strategies

Perceived Risk	Prob-ability	Impact	Overall	Mitigation and Response Strategies
Financial Risks				
Cost share	Low	Moderate	Low	- RTI and Schlumberger have been approved individually by their institutions to provide the required amounts
Equipment replacement	Low	Moderate	Low	- RTI could use its capital equipment funds in FY23/FY24 to cover the cost of a replacement RPB if needed. - PNNL contract includes maintenance cost of PVT and WWC.
Cost/Schedule Risk				
Cost and availability of GEN2NAS components	Moderate	Moderate	Moderate	- The amine is used in the pharma industry as a precursor for an antifungal agent. - Diluent components needed for Task 2 are available commercially.
Technical Risks				
GEN2NAS physical properties and degradation	Low	Low	Low	- Thermal degradation is particularly sensitive to molecular structure, and the GEN2NAS amine does not contain the -OH functional group that leads to thermal degradation in alkanolamines. - The boiling point of the amine is high, indicating it should be even more stable than in previous NAS formulations - RTI has identified an antioxidant that can be used in the formulation to minimize oxidative degradation
Water management	Low	Moderate	Low	- Water balancing has now been proven for several non-aqueous formulas and is not expected to be an issue.

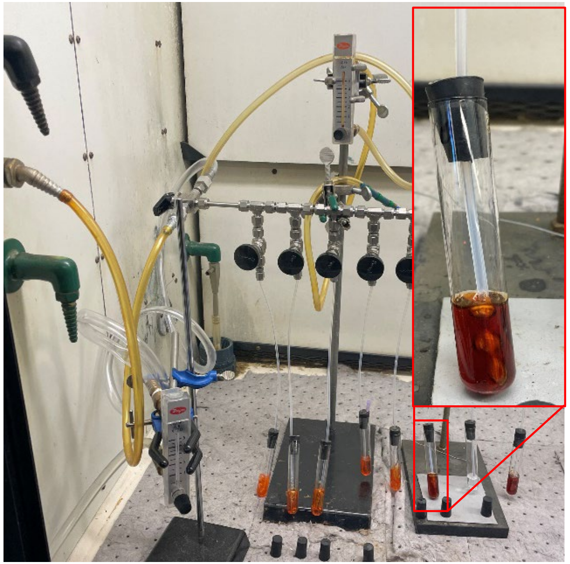
Risks and mitigation strategies/Success criteria

Perceived Risk	Prob-ability	Impact	Overall	Mitigation and Response Strategies
Management, Planning, and Oversight Risks				
Contractual/ performance/ intellectual property	Low	Moderate	Low	- PNNL subcontract is being worked on - RTI has the ownership of the background IP. - SLB has also reviewed required proposal documents and does not anticipate any issues.
ES&H Risks				
Safety of GEN2NAS solvent	Low	Low	Low	- GEN2NAS is formulated with components used in pharma that are deemed safe in their application to humans.
External Factor Risk				
COVID-19 impacts	Moderate	Moderate	Moderate	- The United States is emerging from the COVID-19 pandemic, and restrictions are being eased. However, some uncertainty exists with respect to seasonality that we may see in 2022–2024, which could affect the test schedule.

#	Success Criteria
1	GEN2NAS RPB process can remove at least 97% CO_2 from simulated NGCC flue gas.
2	TEA based on experimental findings indicating a cost reduction of at least 40% in the cost of CO_2 capture compared with DOE Case B31B rev 4.

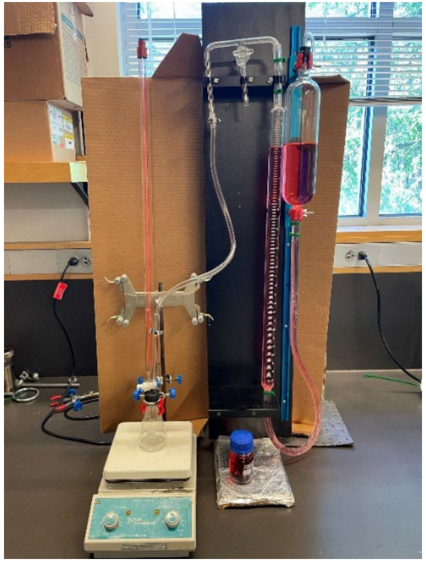
Task 2 - Lab testing

CO_2 saturation station



- 8 separate saturation stations
- 10-20 ml sample size
- Adjustable CO_2 content and flow rates

Chittick apparatus



- Determine sample CO_2 loading
- 3-5 ml per test
- Titration method
- CO2 quantified by gas volume displacement

Thermal conductivity measurement

- 20 ml sample size
- Temperature-controlled: 10-90 C
- Gas/liquid samples
- Ambient pressure cell

Viscometer

- cup-spindle design
- Jacketed cup for temperature control
- Ambient pressure

Task 2 - Lab testing

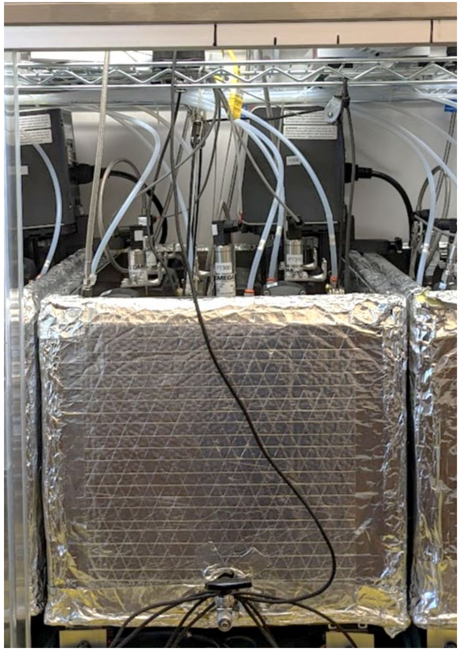
Setaram Calorimeter

- Determine heat capacity, heat of absorption
- Solid/liquid samples
- 10 ml per test

ATR-FTIR

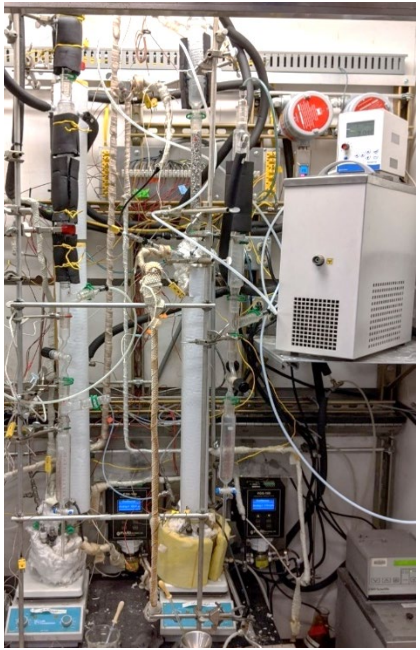
- 1 ml sample size
- Open cell measurement
- CO_2/H_2O suppression built-in
- Identify functional groups
- Measure at ambient condition

Automated HP-VLE cell



- Generate VLE at different CO_2 partial pressures and temperatures
- Fully automated system
- 50 cc sample size
- 6 stations with multiple fee gases (CH_4, C_2H_6, H_2S, CO_2, N_2)
- Up to 120 C and 1,000 psig

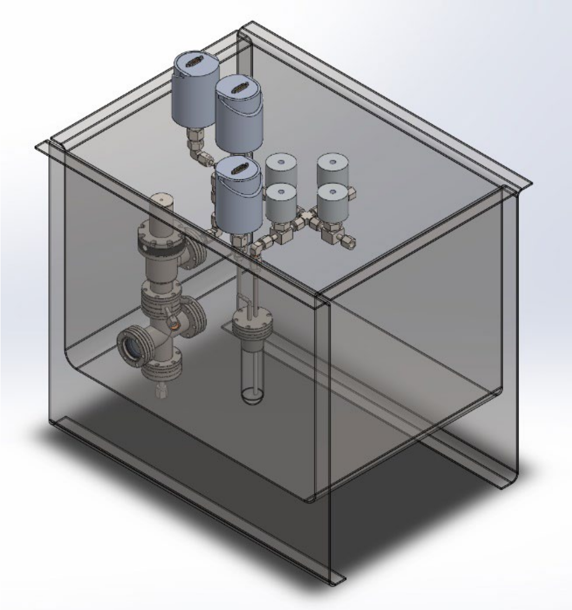
Lab-scale Gas Absorption System



- Continuous capture operation
- Fully automated system
- Qualitative energy evaluation
- Emission monitoring and quantification
- 400 ml sample
- Ambient pressure operation

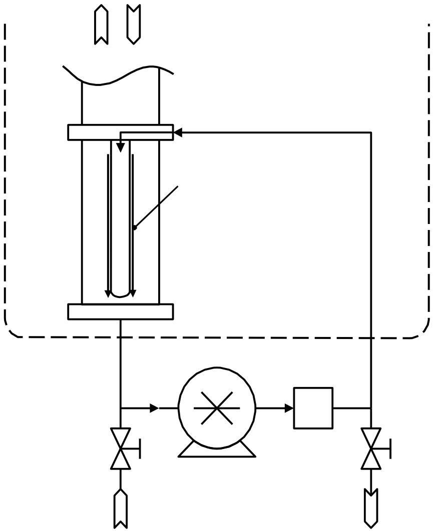
Task 3 – Kinetic measurements

Pressure/Volume/Temperature (PVT) Cell



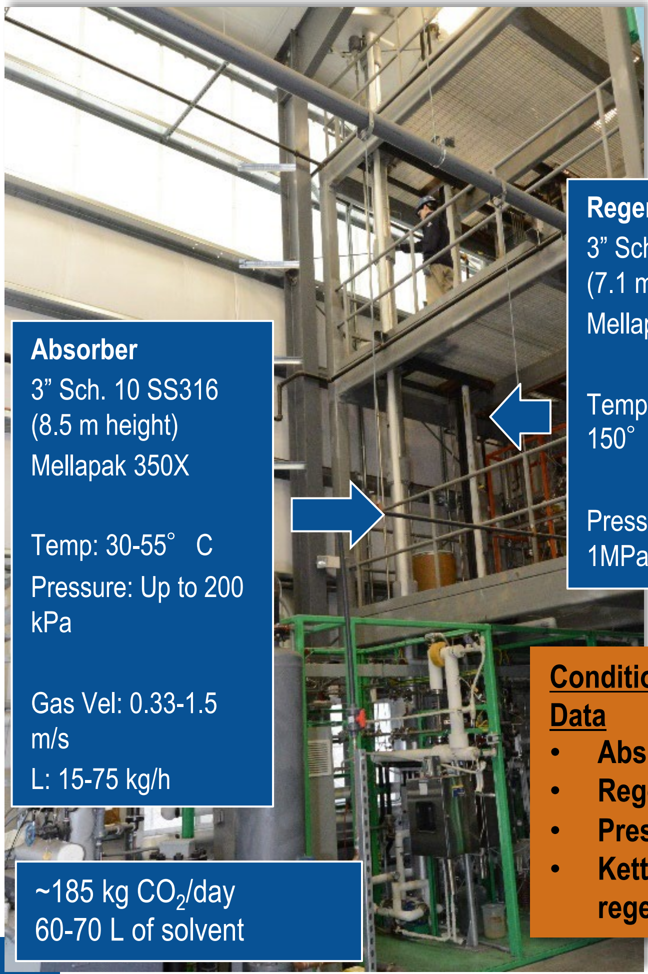
- comprehensive measurements of vapor-liquid equilibria (PTxy), mass transfer, and rheology on a single 50 mL sample

Wetted-Wall Column (WWC)



- Part of the PVT cell
- Kinetic data is collected with an internal mini wetted-wall contactor, where controlled adjustments of the cell volume allow for measurements of CO_2 flux

Task 4 – Bench-scale Testing



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

~185 kg CO_2/day
60-70 L of solvent

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

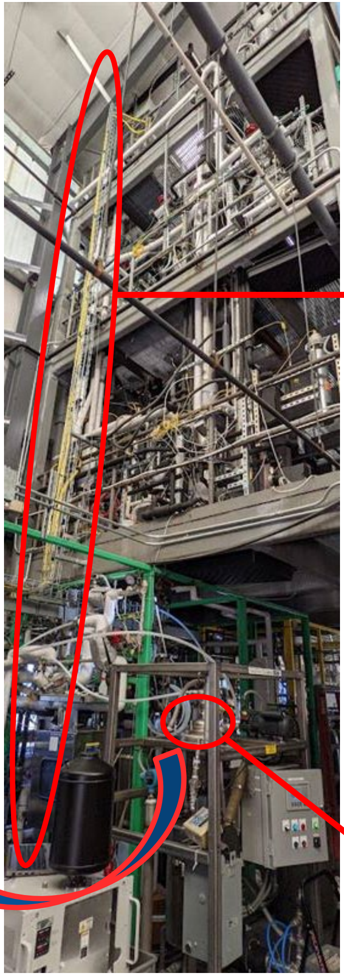
Temp :Up to 150° C

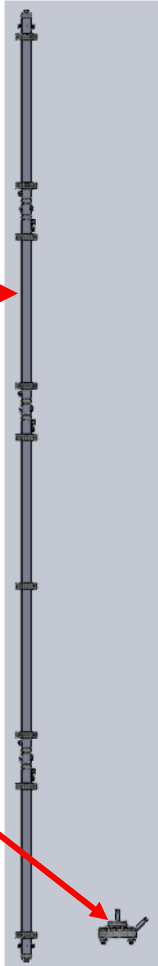
Pressure: Up to 1MPa

- Continuous operation, fully-automated
- Wide range of feed gas compositions – both simulated and real flue gases
- Capture rate, SRD, emissions, degradations

Conditions for Experimental Data

- **Absorber: 37-40° C**
- **Regenerator: 87-115° C**
- **Pressure: 1.5-7.5 barg**
- **Kettle reboiler/Flash regeneration**

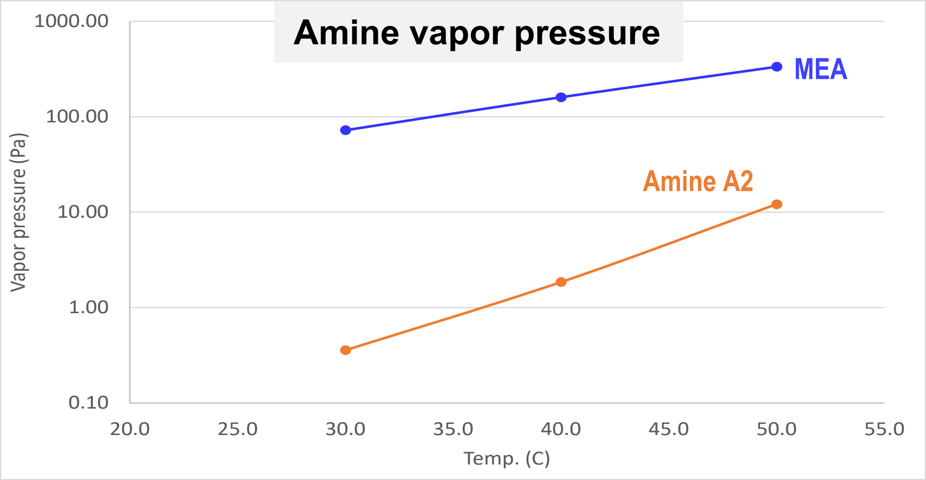


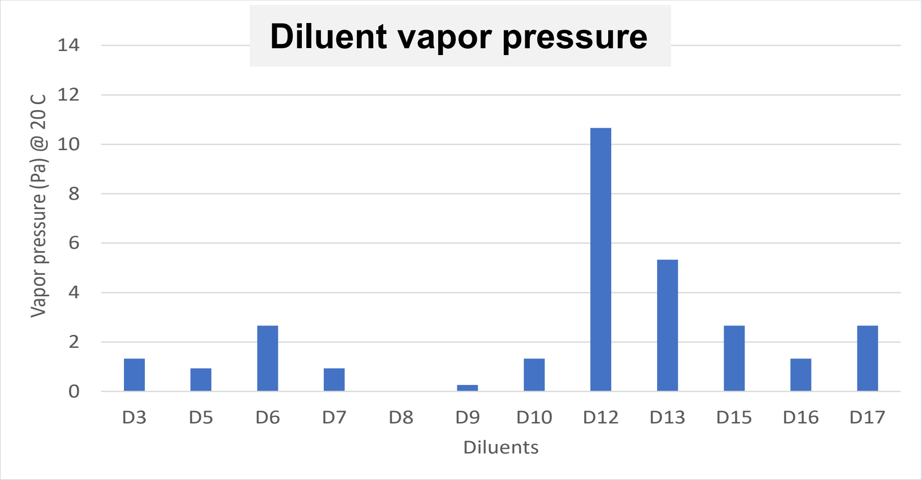


Task 5 – TEA and UQ

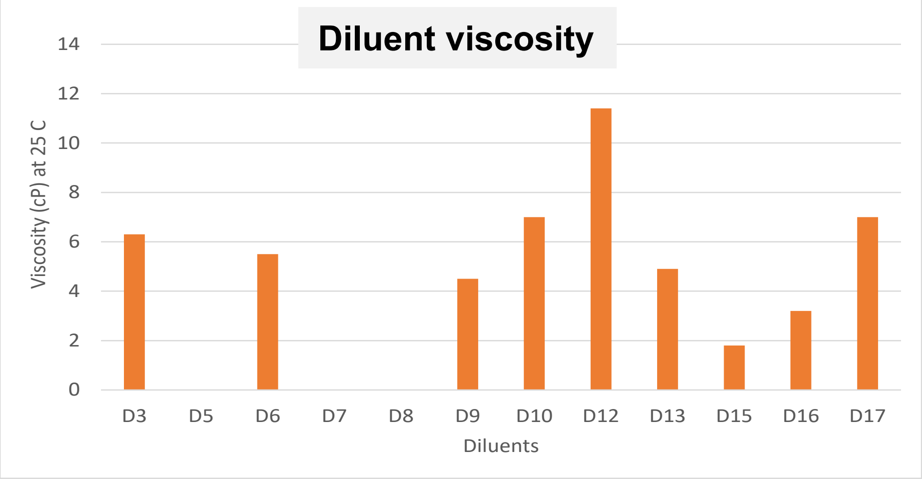
- Update preliminary TEA and TMP
- Collaboration with CCSI^2
  - Computational modeling to quantify effect of solvent properties (e.g., viscosity, thermodynamics) on equipment performance
  - Implement Uncertainty Quantification (UQ) work for assessment of risk associated with scale-up of process models
  - Explore use of Sequential Design of Experiment (SDoE) strategies to aid in data collection for model and sub-model validation

Task 2 – Lab testing of GEN2NAS – Results-1



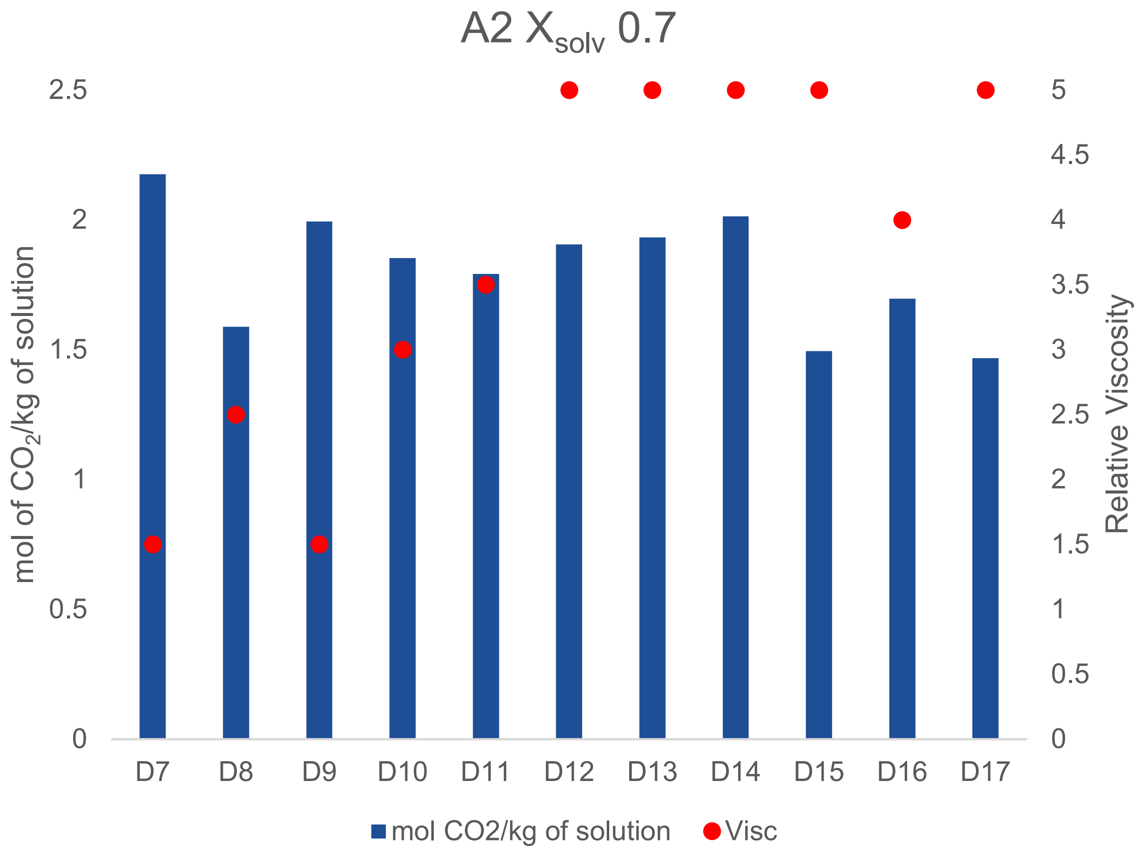


Amine	Cost, $/g
A2	0.17
A1	0.95
A5	1.35
A4	0.95

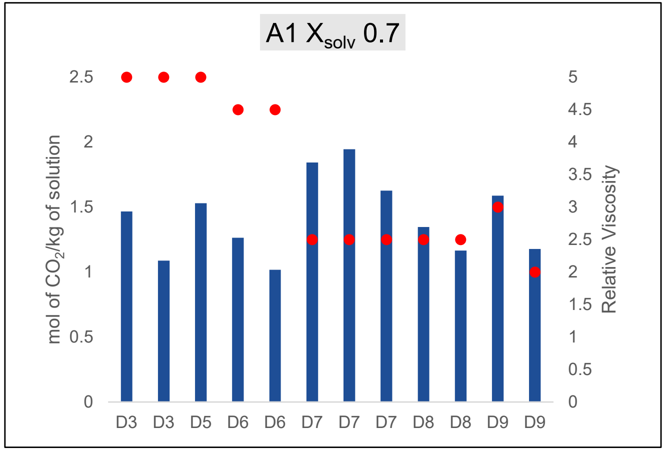


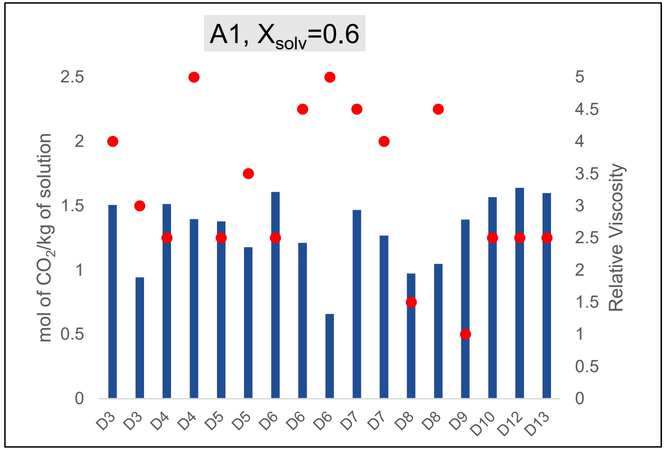
Task 2 – Lab testing of GEN2NAS – Results-2

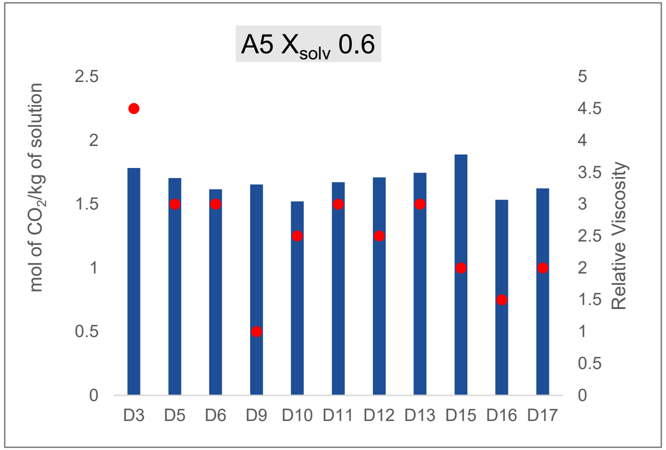
2-component formulation (amine + diluent)

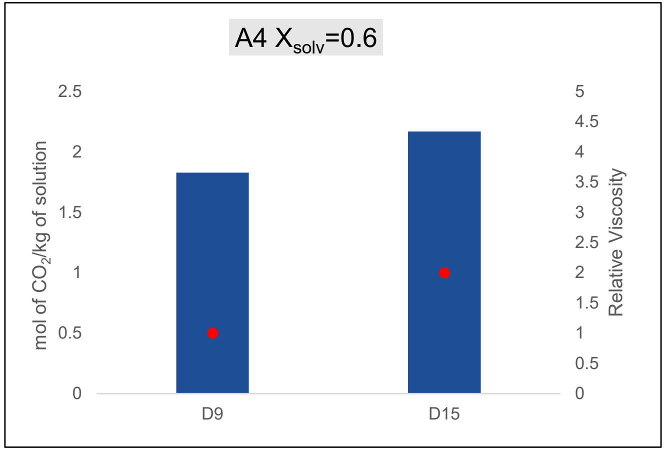


3-component formulation (2 amines + diluent)









Summary

- 65 formulations (5 amines + 12 diluents were screened based on the chemical structure, viscosity, density, cost, availability, vapor pressure)
- An amine candidate, A2, shows significantly lower vapor pressure than 1st generation NAS and MEA
- Regeneration temp. and presence of water will be tested on these candidates
- The two-component formulation containing A2 as an amine component and D9 as a diluent was chosen as a prime candidate due to its low vapor pressure, low viscosity, high working capacity
- Three-component formulations containing A2 and another amine with diluent were chosen to be further screened alongside A2+D9.
- The three-component formulation was devised as another solvent screening and optimization strategy as it could improve the CO_2 absorption kinetics as well as CO_2 loading.

Lessons Learned

Technical

- Cost reduction of 10X is possible even at bench scale
- Appreciation of differences in Coal vs. NGCC capture which led to re-prioritizing screening criteria
- Long lead-time items could be problematic
- Toxicity and vapor pressure of chemical components can be scarce at times

Contract

- Initiate early on to minimize delay
- First-time NL as sub-contract with certain clauses to be reviewed and negotiated

Budget:

- High inflation and changes in cost basis in recent years

Plans for future development

This project

- Screening formulations with 4 kPa CO_2 and 40 C.
- Down-select solvents to 2-3 formulations
- Determine VLE, Kg' (PNNL)
- Verify performance at bench-scale system: energy input, emissions, and operability
- Update TEA

After this project

- Demonstrate performance in large-bench/pilot-scale (TRL 4-5)
- Process component optimization (intensified packing absorber/RPB/flashes)
- Evaluate emission/degradation/toxicity studies
- Solvent scale-up and supply chain evaluation

Acknowledgements

- Financial support provided by DOE NETL under DE-FE0032218
- DOE Project Manager:
  - Dylan Leary
- SLB: Technical assistant/TEA/Cost-share contribution

Thank you
Questions?