A Process with Decoupled Absorber Kinetics and Solvent Regeneration through Membrane Dewatering and In-Column Heat Transfer

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Capture

2020 Integrated Review Webinar

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Project Objectives

Developing transformative post-combustion CO_2 capture through:

1. Enhanced mass transfer via applying 3-D printed two-channel structured packing material to control the absorber temperature profile

2. Lower the regeneration energy via
   - Implementing a zeolite membrane dewatering unit capable of >15% dewatering of the carbon-rich solvent prior to the stripper
   - Use of rich split-feed with two-phase flow heat exchanger prior to the stripper providing a secondary point of vapor generation

Project Team and Funding

Project Manager
DOE/NETL
David Lang

	DOE-NETL	Cost Share	
Total:	$2,986,182	$748,068	$3,734,250
Percent Share:	80%	20%	100%

Project Dates	BP1	BP2
Start:	5/1/2018	11/1/2019
End:	10/31/2019	4/30/2021

UK CAER
Project Management
Process development and integration
Bench Scale Analysis
Zeolite Development

Center for Applied Energy Research

Media and Process Technology Inc.

Trimeric

Lawrence Livermore National Laboratory

SMG

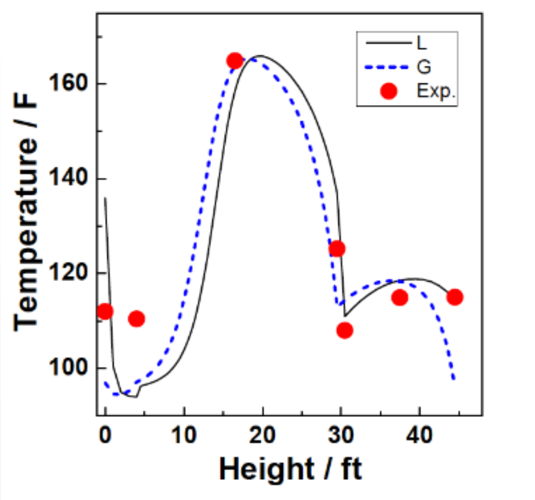
Lawrence Livermore National Laboratory (LLNL)
Packing Material

Media & Process Technology (MPT)
Membrane Module Design and Fabrication

Trimeric
Techno-Economic Analysis

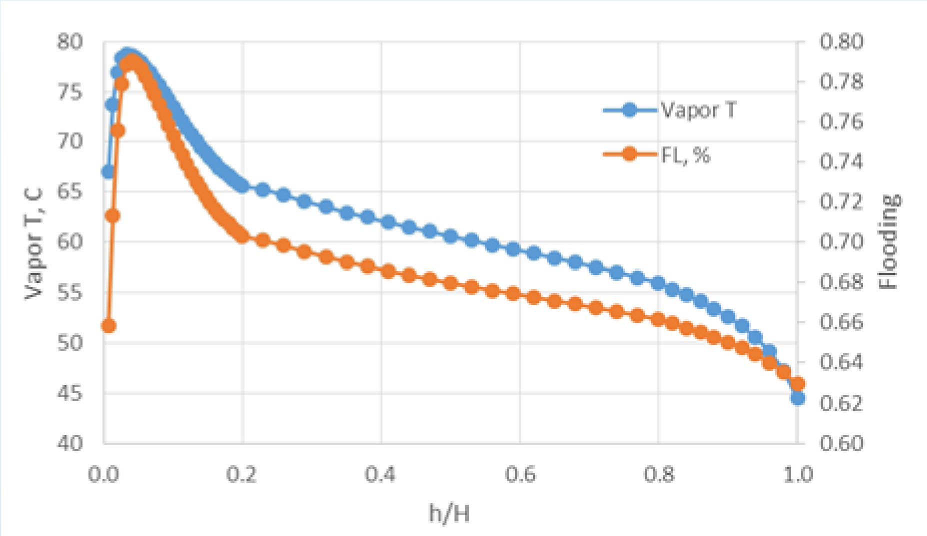
Smith Management Group (SMG)
Environmental Health & Safety

Background – Absorber Profile

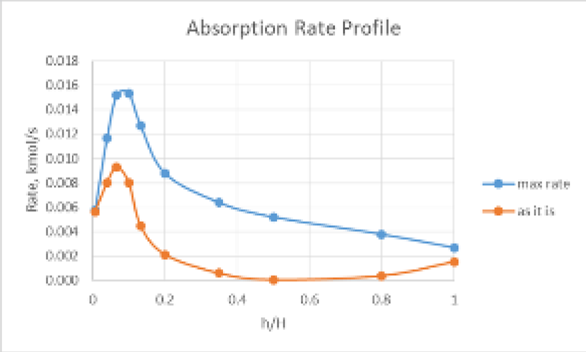


A "temperature bulge" is present near the middle of the column.

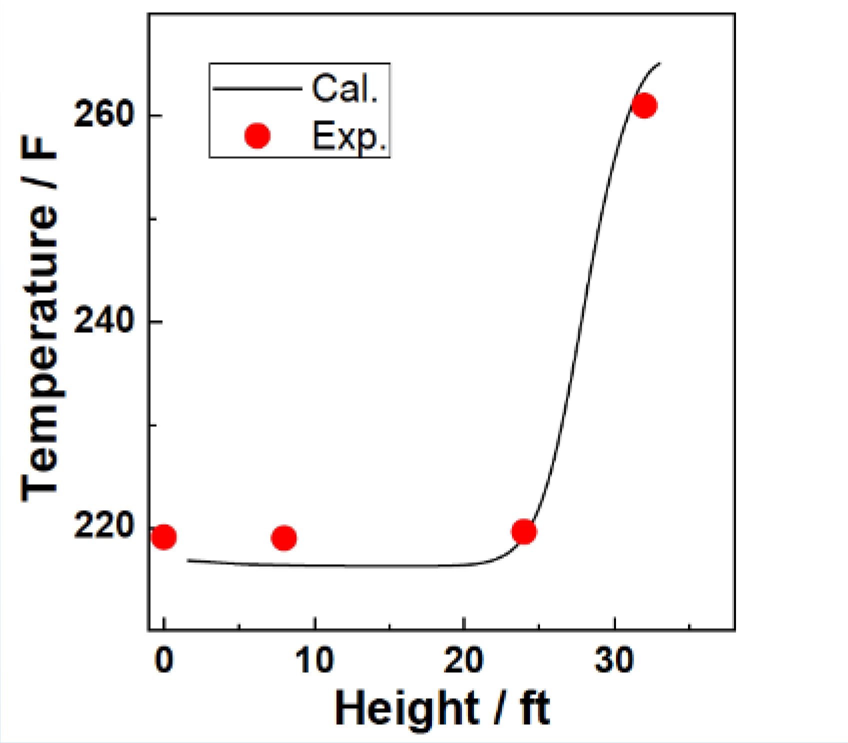
Higher temperature will impede additional absorption of CO_2.

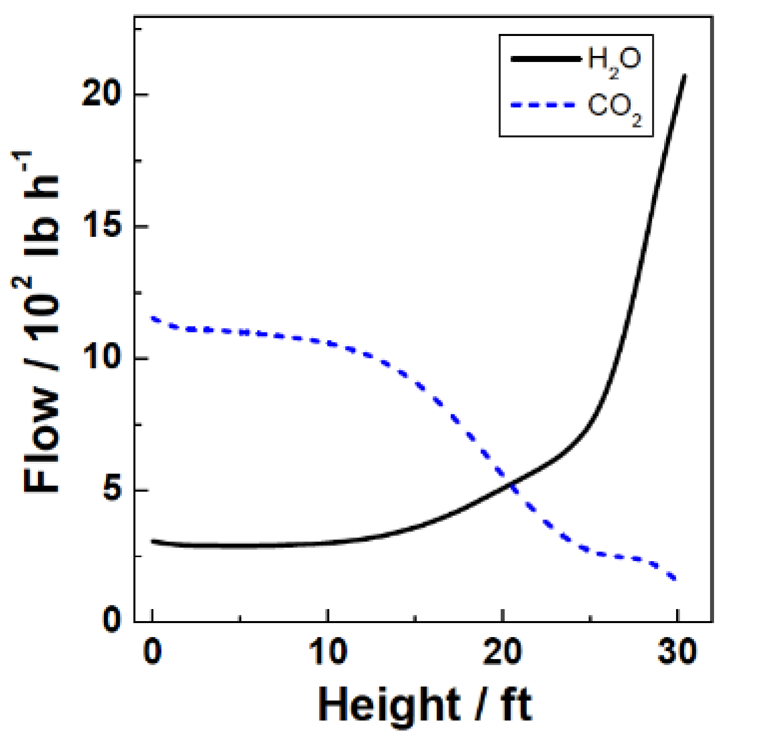


Absorber ID and height will be reduced if the internal temperature is managed.



Background – Advanced Stripping and Secondary Vapor Generation

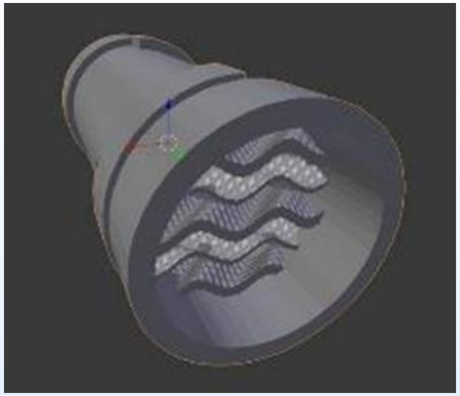




Temperature (left) and flow (right) conditions inside a stripping column. Towards the top of the column, the temperature will rise and significant energy will be expended to vaporize water (lower CO_2/H_2O ratio).

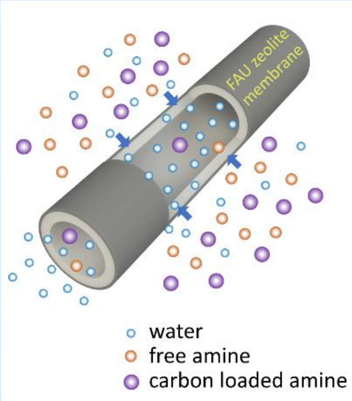
Project Approach

1. Use of 3D printing to implement heat transfer channels into the packing material, providing cooling (>150 W on the UK CAER small bench unit) without need for both packing and intercooling sections.



2. Achieving >100 m^2/m^3 of membranes for a dewatering module, lowering the footprint/volume of the dewatering process while demonstrating fluxes of >10 $kg/m^2/h$ to decrease membrane area/cost.

3. Use of a secondary entry point between two packing sections in the stripper with a high-end heat exchanger (using the lean amine stream).

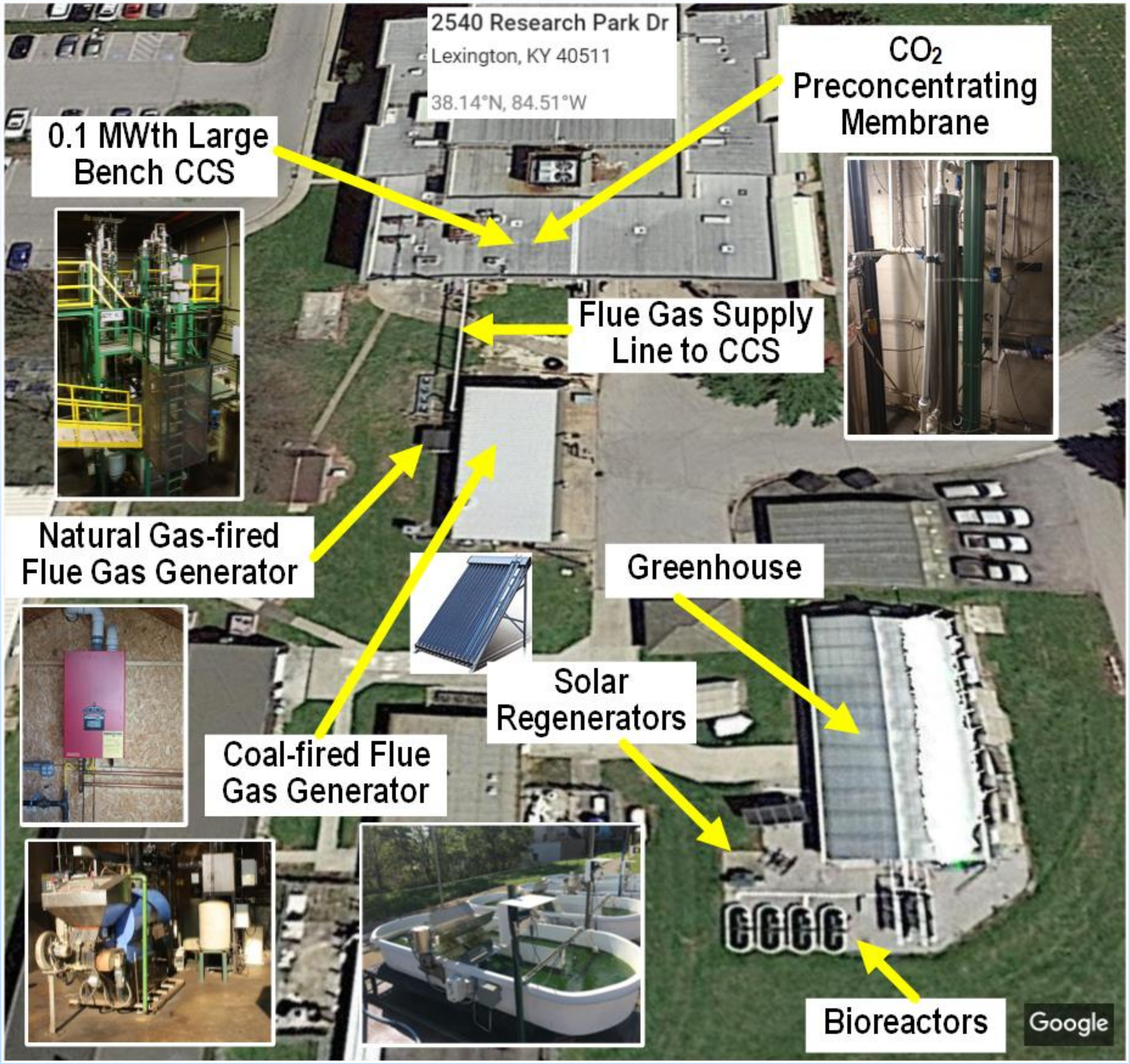


Project Task Schedule and Success Criteria

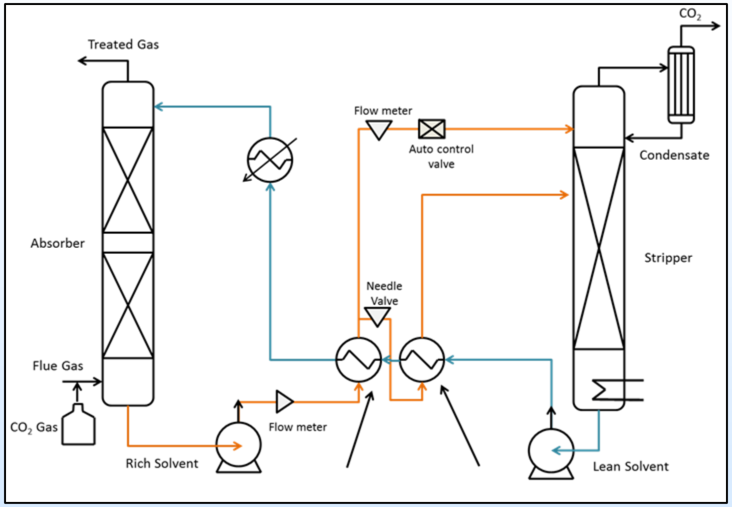
Task	Title	Year 1	Year 2	Year 3
1	Project Management and Planning			
2	3-D Printed Packing Material for Absorber			
3	Zeolite Dewatering Module Development and Fabrication			
4	30 L/min CO2 Capture Bench Unit Evaluation			
5	Test Plan Development			
6	Evaluation of Proposed Technique at 0.1 MWth Post Combustion CO2 Capture Facility			
7	High Packing Density and Performance Zeolite Y Membranes			
8	Composite Zeolite and Alternative Dewatering Membrane			
9	Techno-Economic Analysis			
10	Topical Report Preparation and Submission			

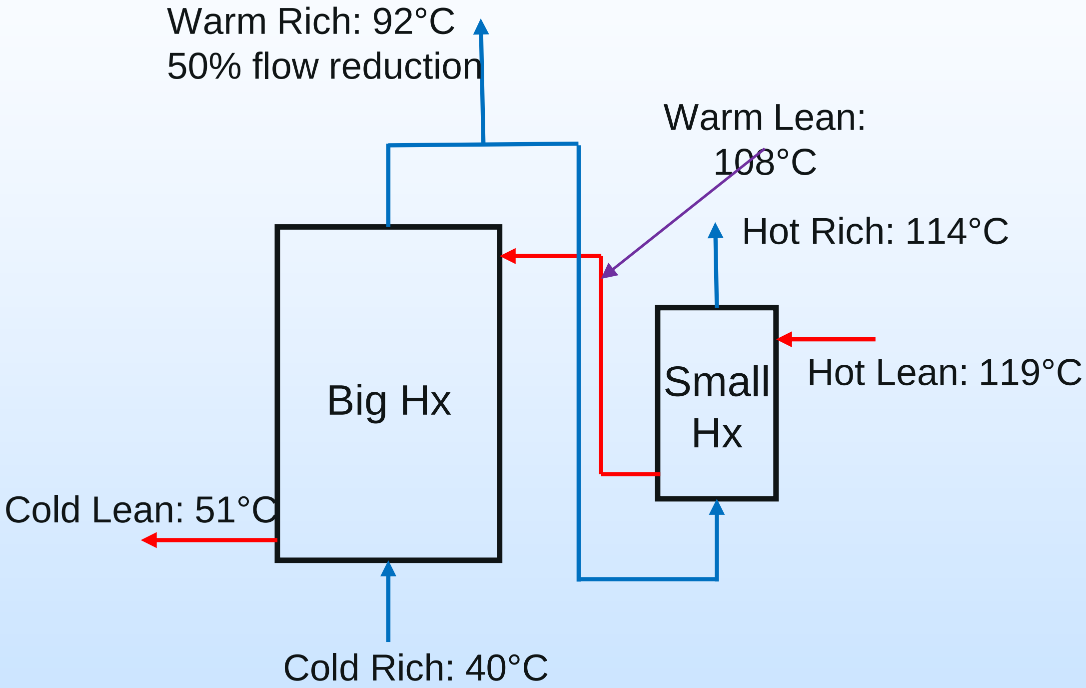
Decision Point	Success Criteria
Budget Period 1	1. Peak Absorber Temperature Reduced by >10 °C Confirmed 2. Zeolite Y Membranes with Fluxes >10 kg/m^2/h at Rejection Rates >90% 3. Dewatering Zeolite Y Module Design Complete with >200 m^2/m^3 4. Test Plan Complete for 0.1 MWth Capture Unit
Budget Period 2	1. Stripper Heat Int. >10% Energy Savings on 0.1 MWth Capture Unit 2. Long-Term Energy Savings of >15% from 1000-hour Process Study 3. Dewatering Membrane Packing Density Increase to >400 m^2/m^3 4. Aspen Model for Entire Integrated System 5. TEA Complete for Integrated Process 6. EH&S Assessment Complete for Integrated Process 7. Updated State Point Data Table for Membrane 8. Technology Gap Analysis Complete

UK CAER CO_2 Capture and Utilization Facilities



Progress and Current Status: Large Bench (Split Feed to Stripper)

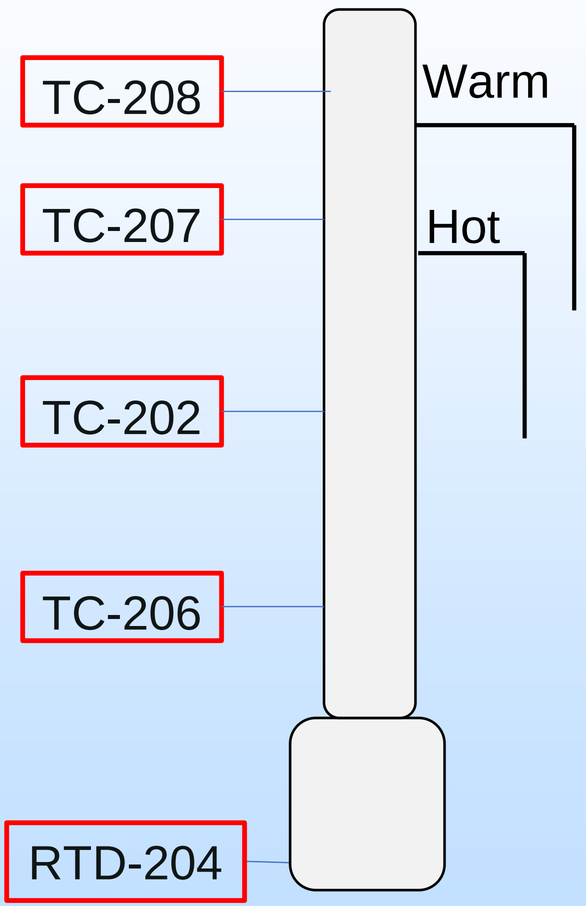


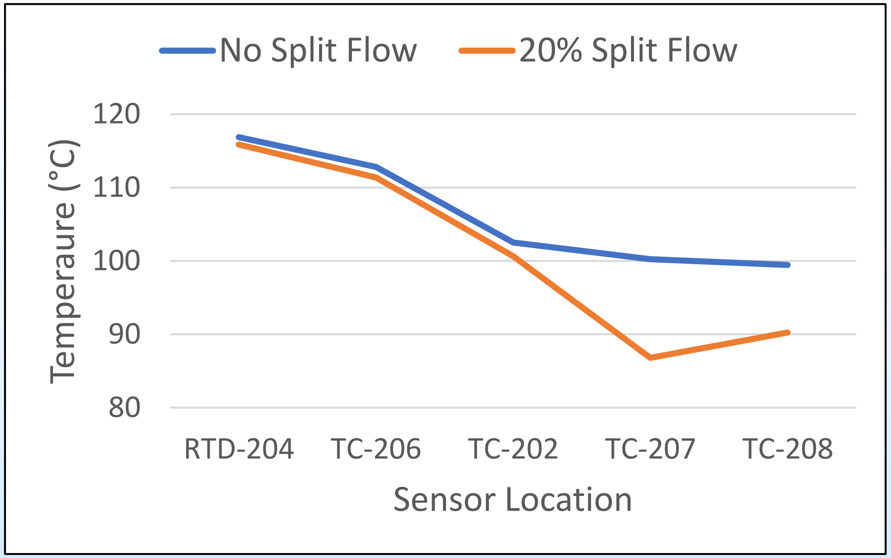


Preliminary model developed with 50% split ratio to estimate temperatures around heat exchangers and stripper

Split ratios varied from 20-50% experimentally to assess optimal performance

Progress and Current Status: Large Bench (Split Feed to Stripper)

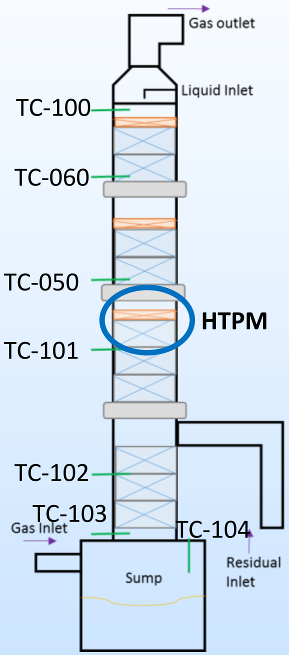


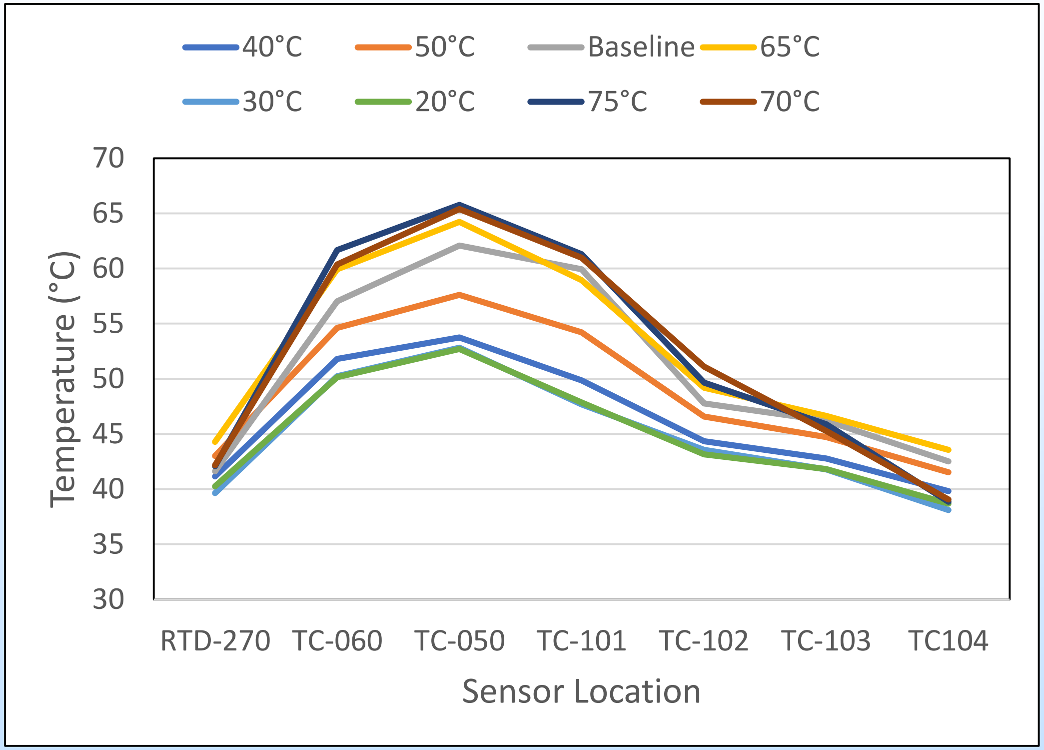


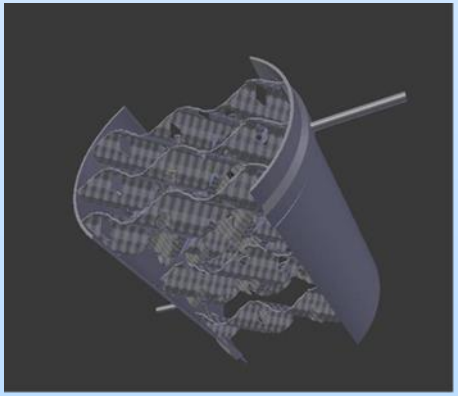
	Split Flow % (Warm/Hot)	% Capture Stripper Bottom Temp (°C)	TC 208 TC 207	P_{H2O}/P_{CO2}	$BTU/lbCO_2$
No Split Flow	0	67.5 116.8	99.4 100.2	**1.45**	1268
Split Flow	20	68.5 115.6	90.6 87.5	**0.79**	1080

Split feed to stripper reduced exhaust stripper temperature by ~10 °C
With 20% split flow, energy of regeneration reduced by ~15%

Progress and Current Status: Large Bench (Heat Transfer Packing)

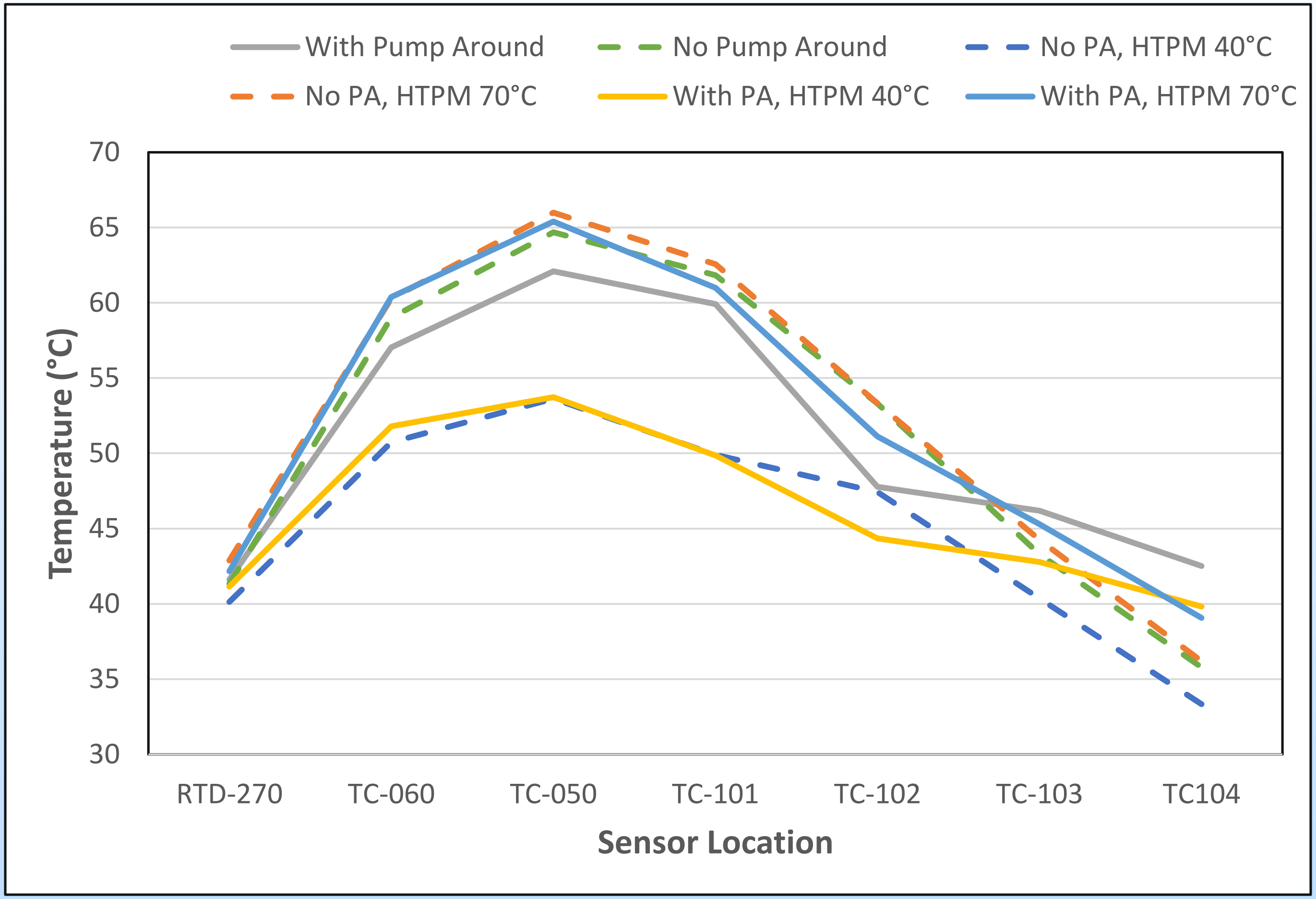






Heat transfer packing installed in large bench unit and used to to tailor the bulge temperature and temperature profile in the absorber.

Progress and Current Status:
Heat Transfer Packing – Pump Around

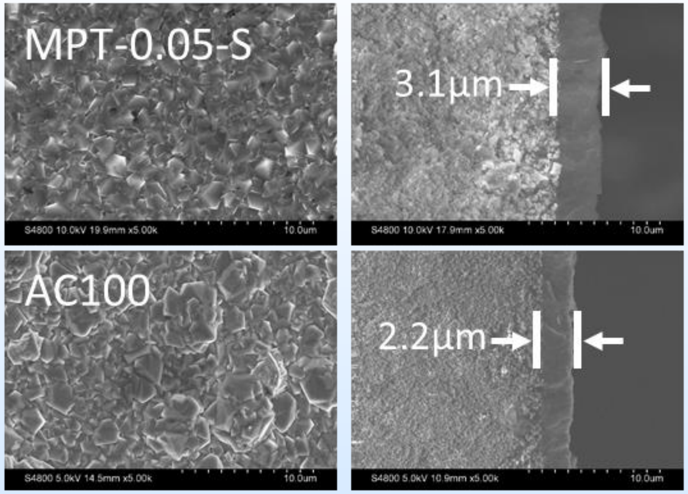


Pump around impacts bottom temperatures and profile at lower section of packing

Progress and Current Status: Zeolite Membrane

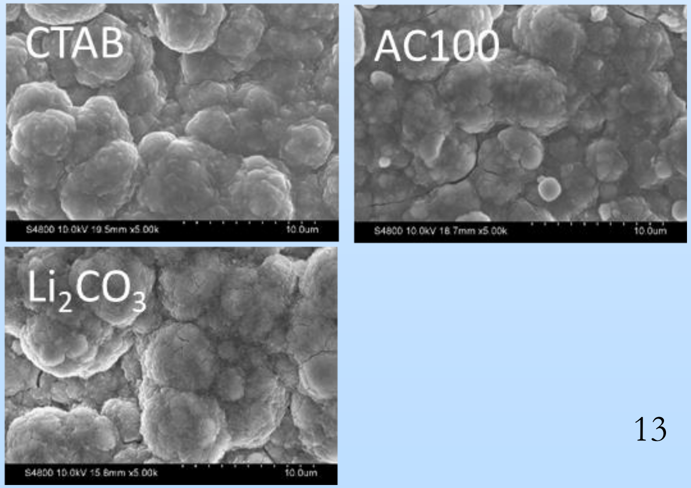
Effect of substrate materials

The Dewatering Test: 30 wt.% MEA					
Substrate materials	**Dimension O.D./I.D. (mm)**	**Porosity**	**Pore size/µm**	**Total flux kg/m²/h**	**Rejection rate**
FerroCeramic Mullite	12.2 x 8.0	25-35%	1.5-2.0	0.71	30.1%
Nikkato Mullite	11.7 x 8.9	44%	1.8	0.79	85.3%
MPT-0.5-S	5.7 x 2.9	21-23%	0.5	1.83	77.6%
MPT-0.5-L	11.8 x 8.5	21-23%	0.5	1.05	49.8%
MPT-0.05-S	5.7 x 2.9	25-35%	0.05	8.36	69.2%
NJTECH AC100	12.4 x 7.3	30-40%	0.1	10.12	88.3%



Effect of structure directing agents

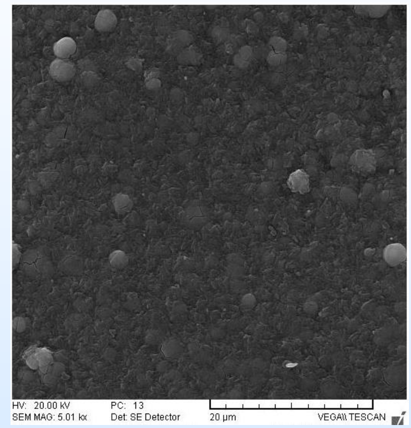
The Dewatering Test: 30 wt.% MEA		
Structure directing agents	**Total flux kg/m²/h**	**Rejection rate**
Hexadecyltrimethylammonium bromide (CTAB)	12.95	27.6%
Dimethyloctadecyl[3-(trimethoxysilyl)propyl]ammonium chloride (TPOAC)	10.67	15.2%
Lithium carbonate (Li_2CO_3)	13.44	24.3%

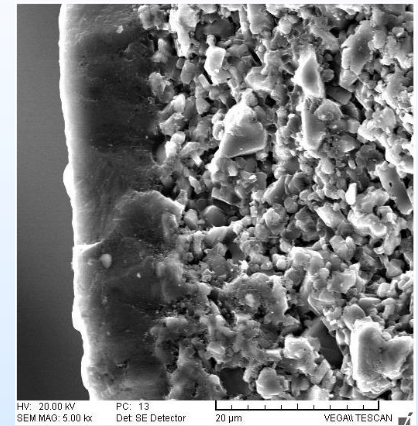


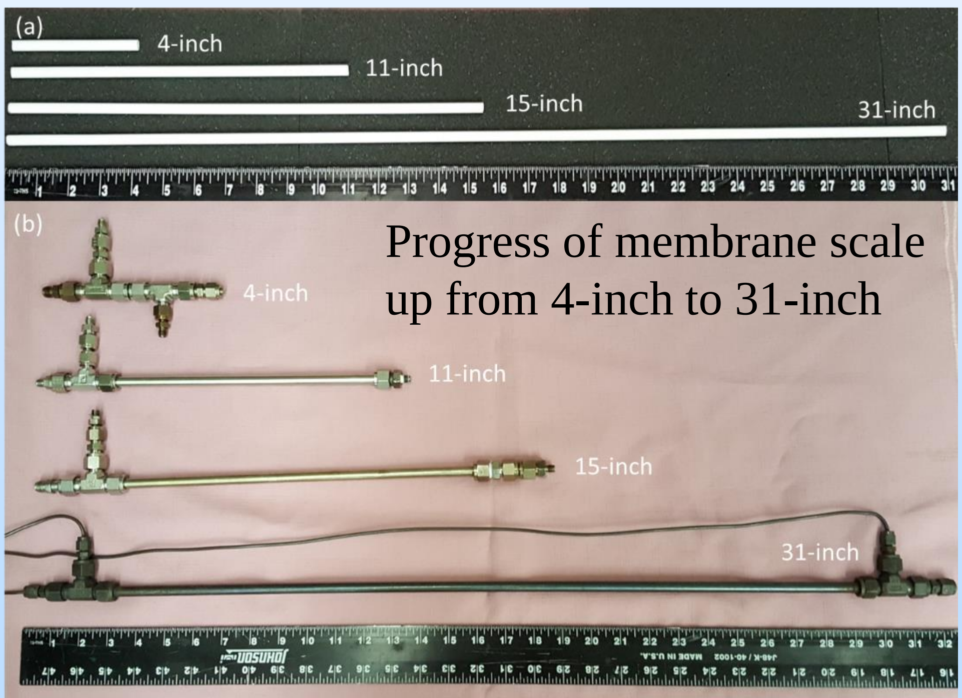
Progress and Current Status: Zeolite Membrane

Fabrication of Zeolite Y Membrane Module by Media & Process Technology

Methanol was used as alternative seed solution solvent for conventional seeding method. Dewatering performance of 31-inch long membranes showed 4.4-5.4 kg/m^2/h flux and >96% rejection rate in CO_2 loaded 30 wt% MEA.

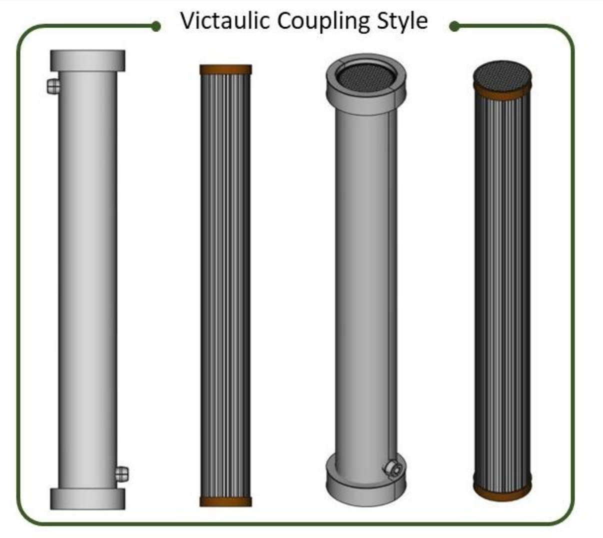






Membrane ID	The Dewatering Test: 30 wt.% MEA, 10 mL/min			
	Temperature (°C)	Pressure (psi)	Total Flux (kg/m^2/h)	Rejection Rate
NaY-31in-B1	125	78	5.0	95.7%
NaY-31in-B2	127	79	5.1	96.2%
NaY-31in-B3	124	81	5.0	97.2%
NaY-31in-B4	128	74	4.4	95.3%
NaY-31in-B5	123	81	5.4	96.1%

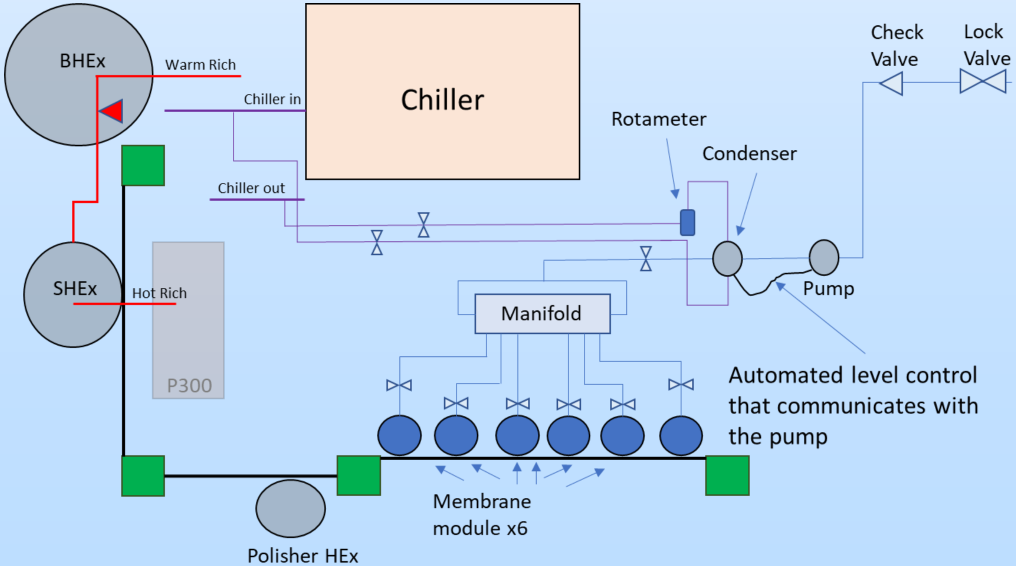
Progress and Current Status: Zeolite Membrane



6" Bundle in Steel Module

Length of Bundle	38	inches
Bundle Diameter	6.125	inches
Tube Outer Diameter	5.7	mm
Approximate Tubes	550	each
Surface Area	9.51	m2
Bundle Volume	0.01835	m3
Housing Volume (OD)	0.02163	m3
Packing Density	439.5	m2/m3

Design of dewatering membrane module can achieve packing density of ~440 m^2/m^3.



The first 19-membrane module with total membrane area of 0.13 m^2 installed in UK CAER's large bench unit.

Future testing:
Dewatering Membrane Integration

Conditions under evaluation for the zeolite dewatering module (**Table 1**), and the split-feed to the stripper (**Table 2**) for the 0.1 MWth large bench unit.

Table 1. Zeolite Dewatering Evaluation Data.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Solvent Inlet Temperature	90 °C	95 °C	100 °C	100 °C	105 °C	110 °C	120 °C
Feed Pressure	100 psi	100 psi	100 psi	150 psi	100 psi	100 psi	150 psi

Table 2. Spilt-Feed Two-Phase Flow to Stripper Evaluation Data.

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Zeolite Module Temperature	90 °C	90 °C	100 °C	100 °C	110 °C	110 °C	110 °C
Fraction Flow Through High-End Heat Exchanger, Two-Phase Flow to the Middle Packing of Stripper	0.6	0.8	0.6	0.8	0.6	0.7	0.8

Summary

- Split stream cooled stripper exhaust stream by ~10 °C, less water evaporation resulted in energy savings of ~15%
- Heat transfer packing used to tailor bulge temperature and temperature profile in absorber to enhance solvent performance
- Integration of dewatering membrane would increase solvent rich loading to stripper to further enhance observed energy savings with split streams

Acknowledgements

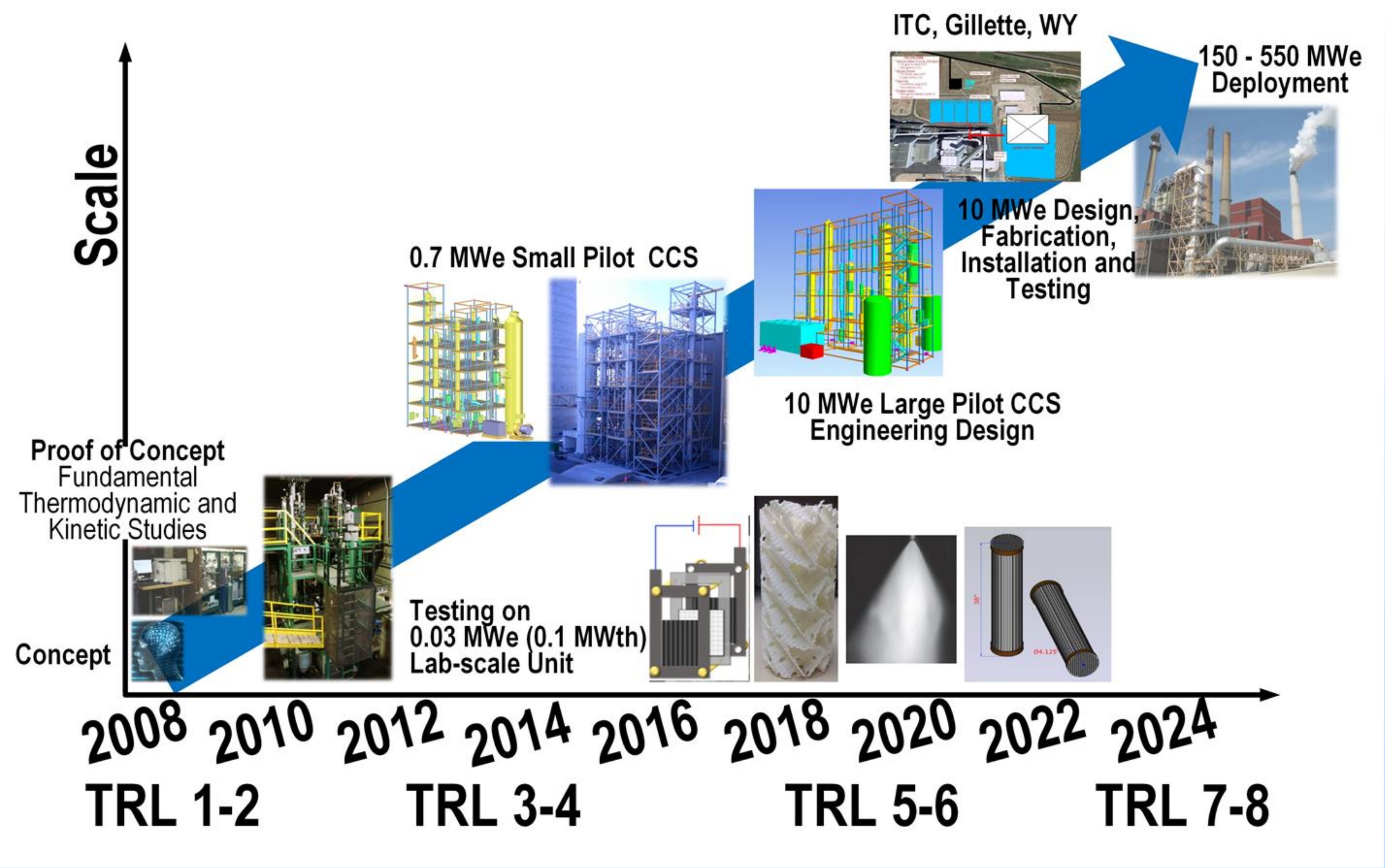
U.S. DOE NETL: David Lang, José Figueroa, Lynn Brickett and Dan Hancu

LLNL: Du Thai Nguyen

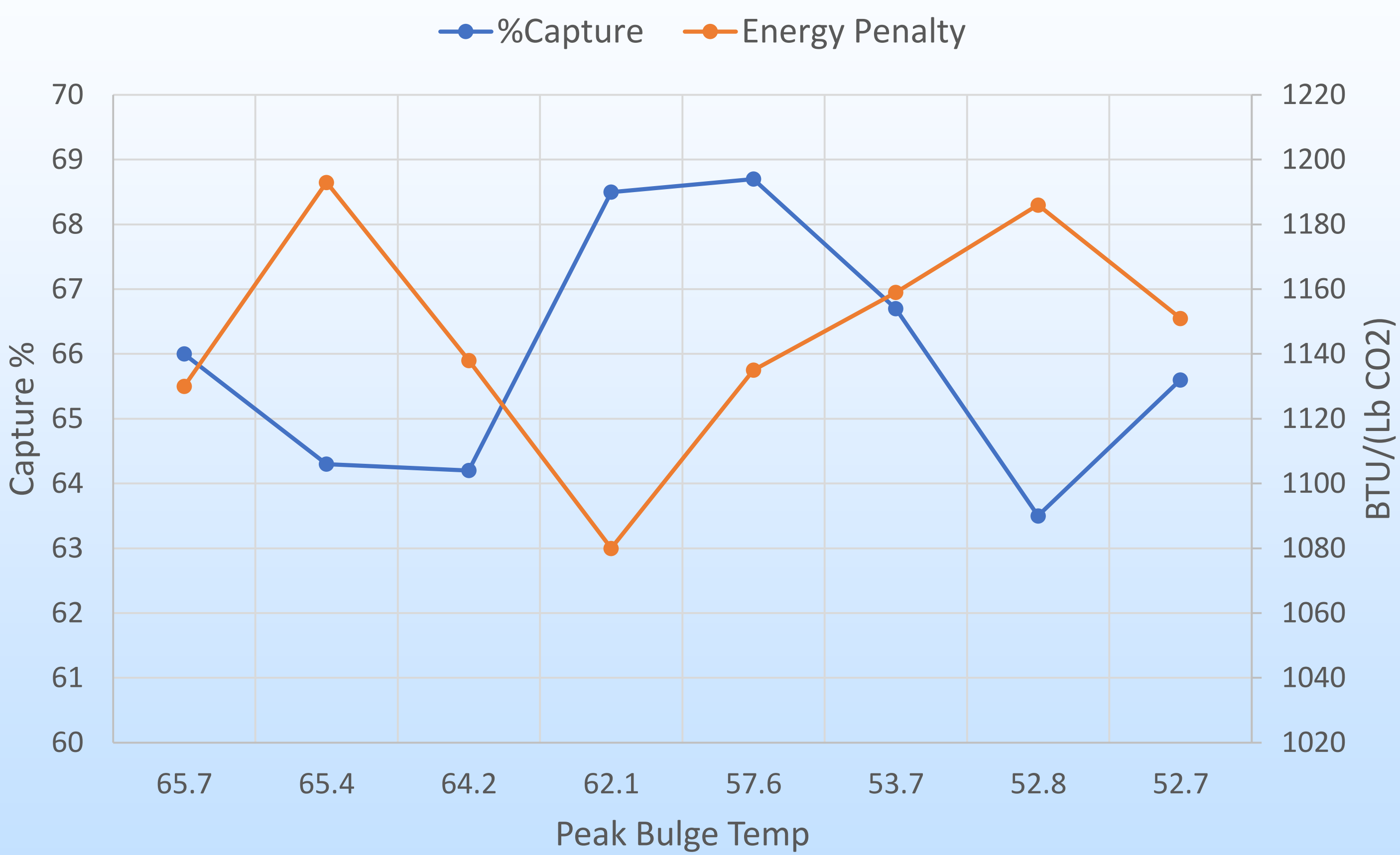
MPT: Rich Ciora and Amy Chen

UK CAER: Power Gen group

Appendix: Future Testing



Additional HTPM Testing



This is what we had expected to see as the ASPEN model predicted this outcome.