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

(DE-FE0031604)

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National Energy Technology Laboratory

Carbon Management and Natural Gas & Oil Research Project Review Meeting

Virtual Meetings August 2 through August 31, 2021

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

Project Team and Funding

	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	10/31/2021

Project Manager
DOE/NETL
David Lang

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

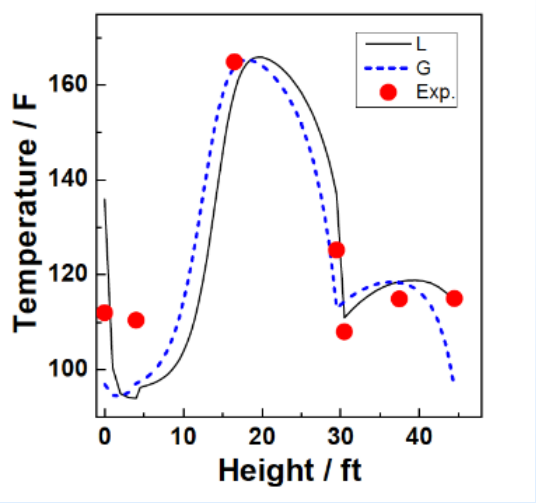
Lawrence Livermore National Laboratory (LLNL)
Packing Material

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

Trimeric
Techno-Economic Analysis

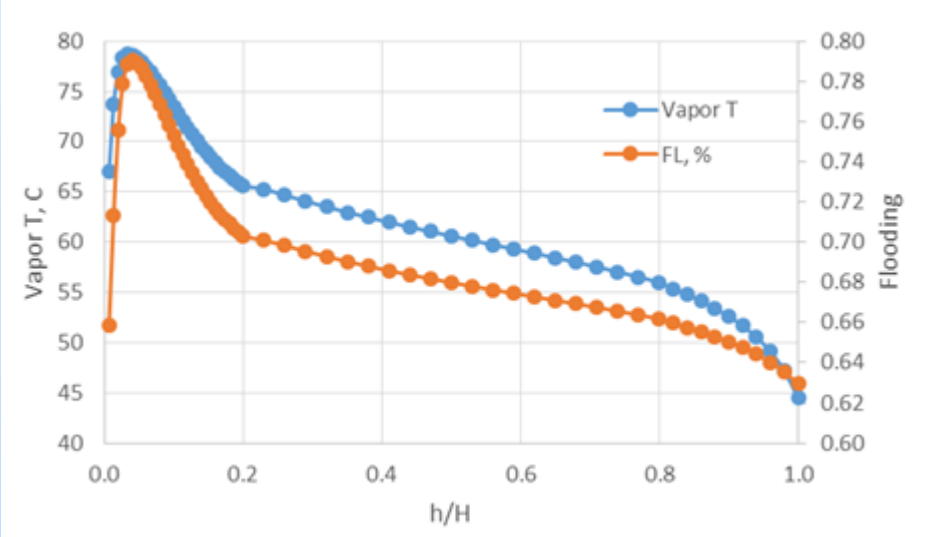
ALL4 (formerly SMG)
Environmental Health & Safety

Background – Absorber Profile

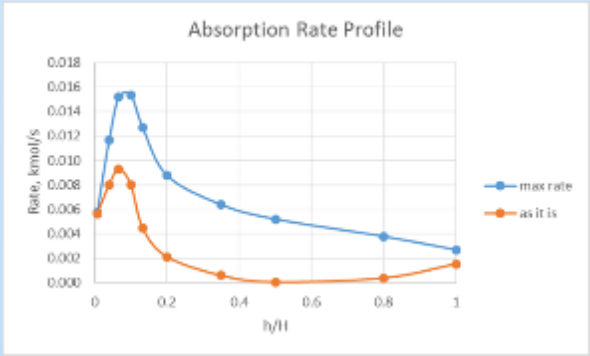


A “temperature bulge” is present near the middle of the column.

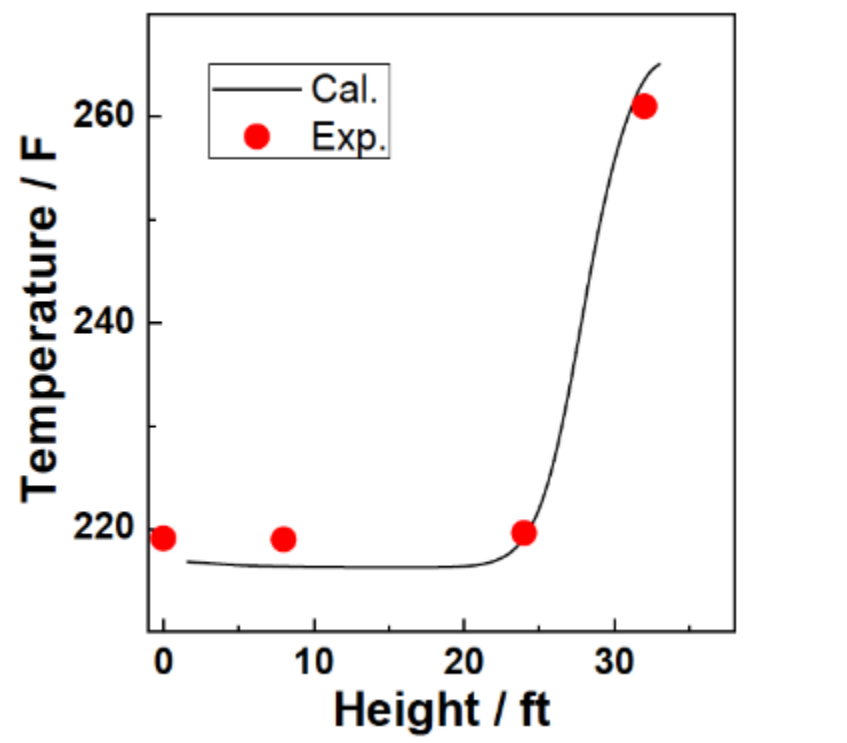
Higher temperature will impede additional absorption of CO_2.

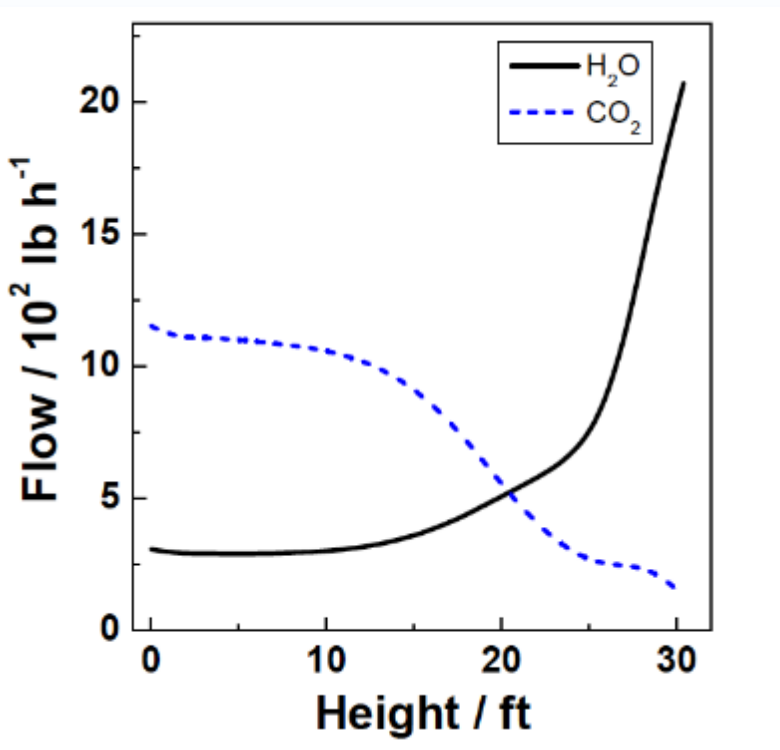


Absorber ID and height will be reduced if the internal temperature is managed.



Background – Advanced Stripping and Secondary Vapor Generation





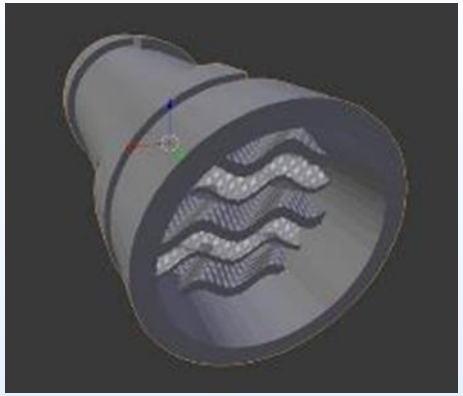
Temperature (left) and flow (right) conditions inside a stripping column. Towards the top of the column, the temperature will rise and significant energy will be expended to vaporize water (lower CO_2/H_2O ratio).

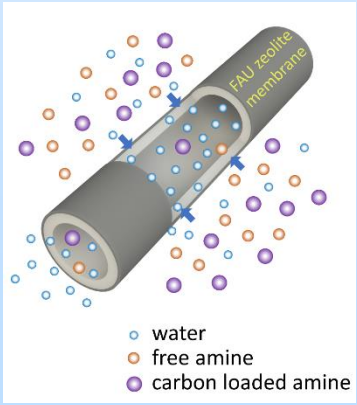
Project Approach

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

3. 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.



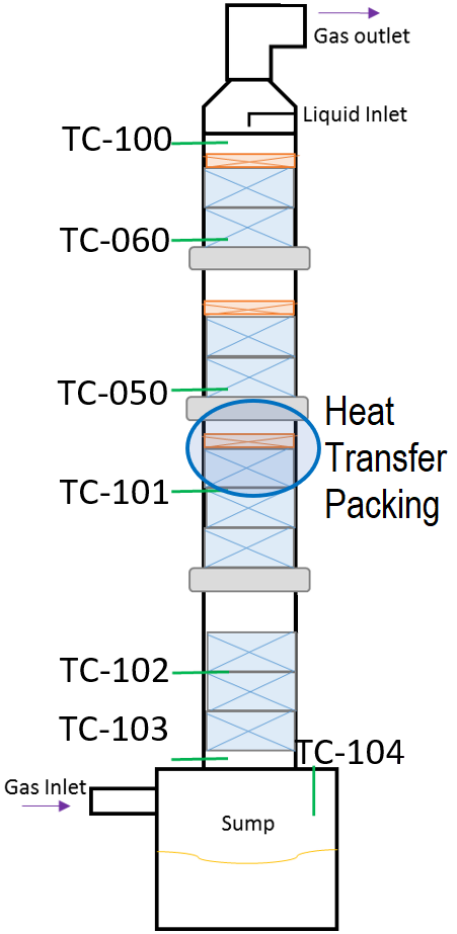


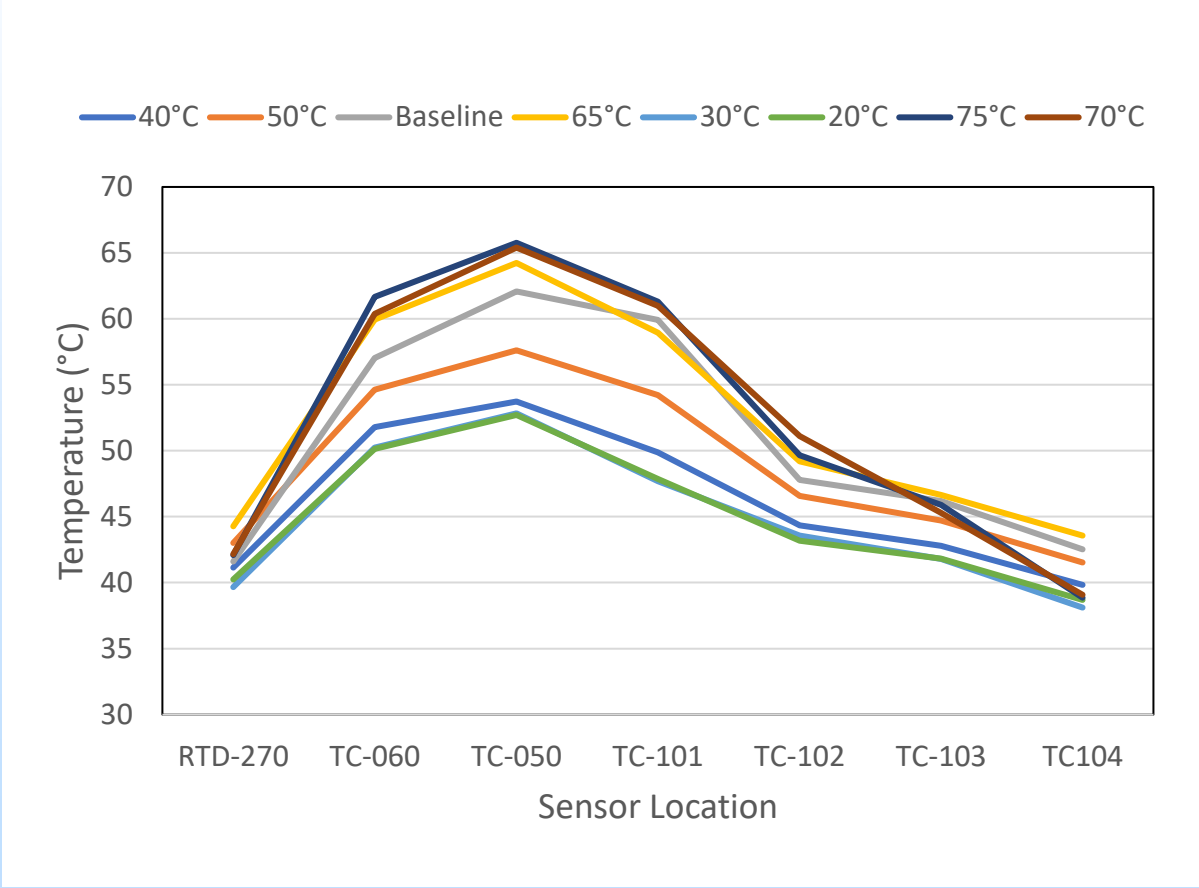
Project Task Schedule and Success Criteria

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			

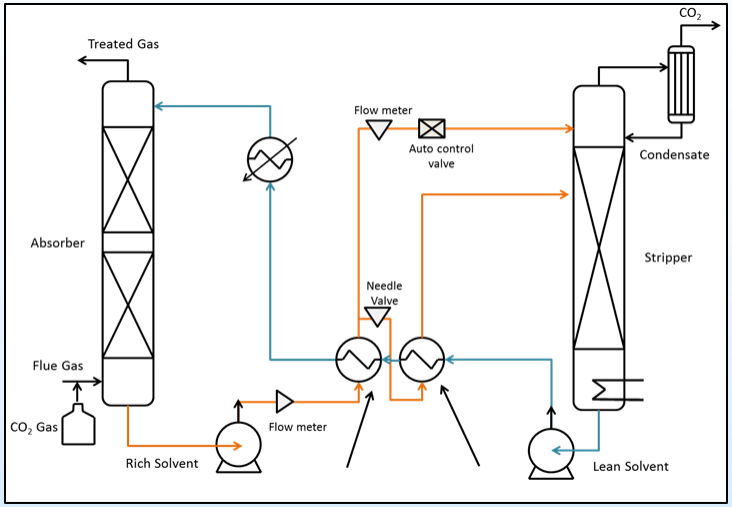
Decision Point	Success Criteria
Budget Period 1	1. Peak Absorber Temperature Reduced by >10 °C Confirmed 2. Zeolite Y Membranes with Fluxes >10 kg/m^2/h at Rejection Rates >90% 3. Dewatering Zeolite Y Module Design Complete with >200 m^2/m^3 4. Test Plan Complete for 0.1 MWth Capture Unit
Budget Period 2	1. Stripper Heat Int. >10% Energy Savings on 0.1 MWth Capture Unit confirmed 2. Long-Term Energy Savings of >15% from 1000-hour Process Study completed 3. Dewatering Membrane Packing Density Increase to >400 m^2/m^3 achieved 4. Aspen Model for Entire Integrated System constructed and preliminary H&MB stream tables generated 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

Progress and Current Status:
4” Bench Unit (Absorber Temperature Profile)





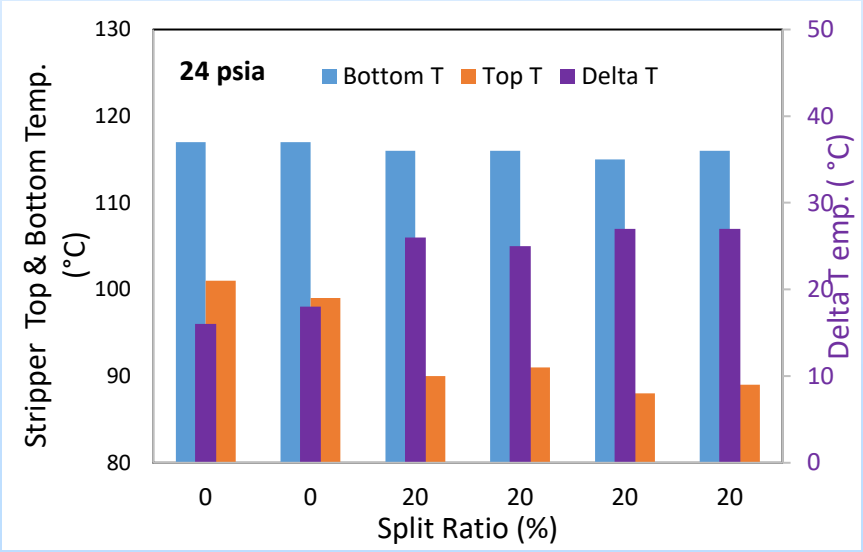
Progress and Current Status: 4” Bench Unit (Split Feed to Stripper)

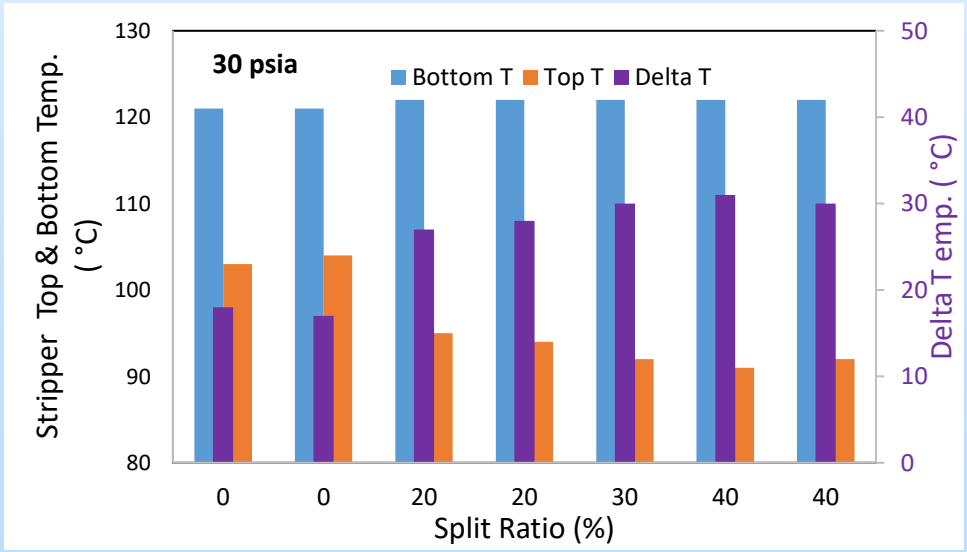


Split ratios varied from 20-40% experimentally to assess optimal performance

Heat recovery lowered stripper top temperature by about 12 °C

$$Q_{total} = Q_{des} + Q_{sen} + Q_{strip} \text{ -- } \frac{P_{CO2}}{P_{H2O}}$$





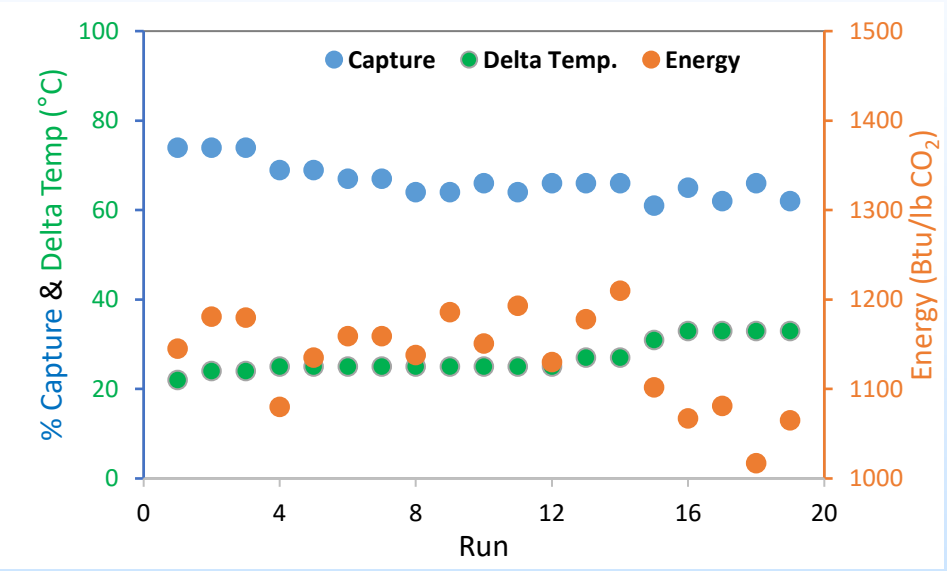
Progress and Current Status: 4” Bench Unit(Split Feed – Energy)

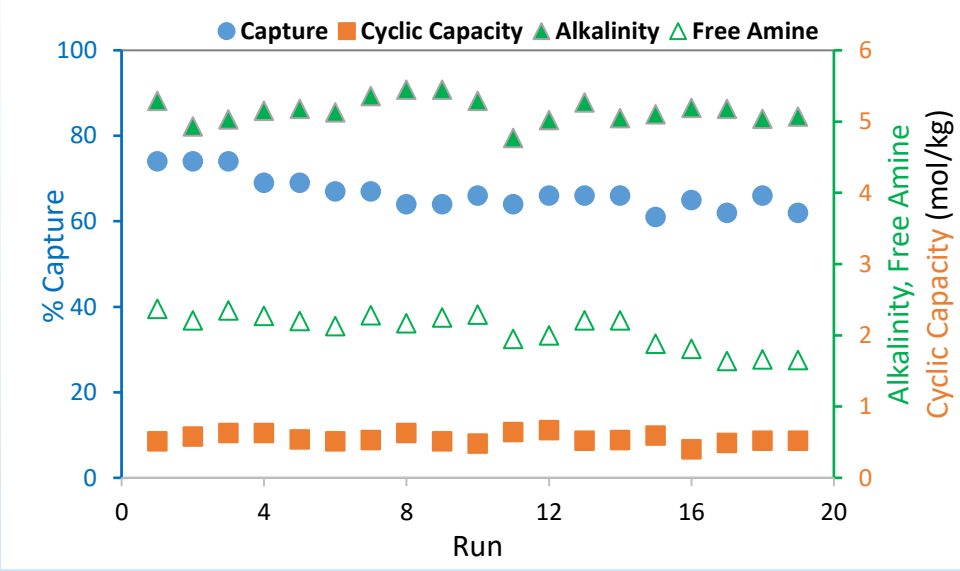
Stripper Pressure	Split Flow (%)	% Capture	Stripper Bottom Temp (°C)	Stripper Top Temp (°C)	H_2O/CO_2 Ratio	Lean C/N	Rich C/N	Energy Btu/lb CO_2
30 Psia	0	63	121	104	1.30	0.33	0.43	1449
	20	74	122	95	0.69	0.27	0.43	1201
	30	72	122	92	0.58	0.31	0.46	1152
	40	70	118	91	0.54	0.31	0.47	1186
24 psia	0	68	117	99	1.45	0.28	0.39	1268
	20	64	116	95	1.05	0.29	0.39	1322
	20	74	117	93	0.90	0.28	0.40	1181
	20	69	116	91	0.79	0.27	0.41	1080

- Energy savings of ~ 15% obtained with split flow to the stripper @ low C/N in the rich solution
- Expected higher energy saving when applied to large unit with rich carbon loading around 0.5 C/N

Progress and Current Status: 4” Bench Unit (Long Term Performance)

Condition: 20% split feed ratio, 24 psia stripper pressure



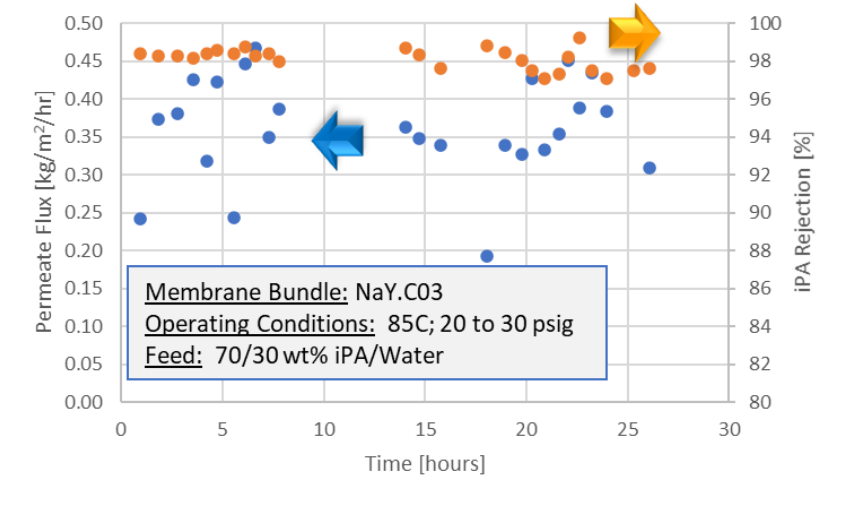


Sustained solvent performance (capture and cyclic capacity) over extended run period

Energy savings demonstrated over long term operation

Progress and Current Status: Zeolite Membrane

Fabrication of Zeolite Y membrane modules by Media & Process Technology



21*31inch membrane bundle, surface area 0.30 m^2

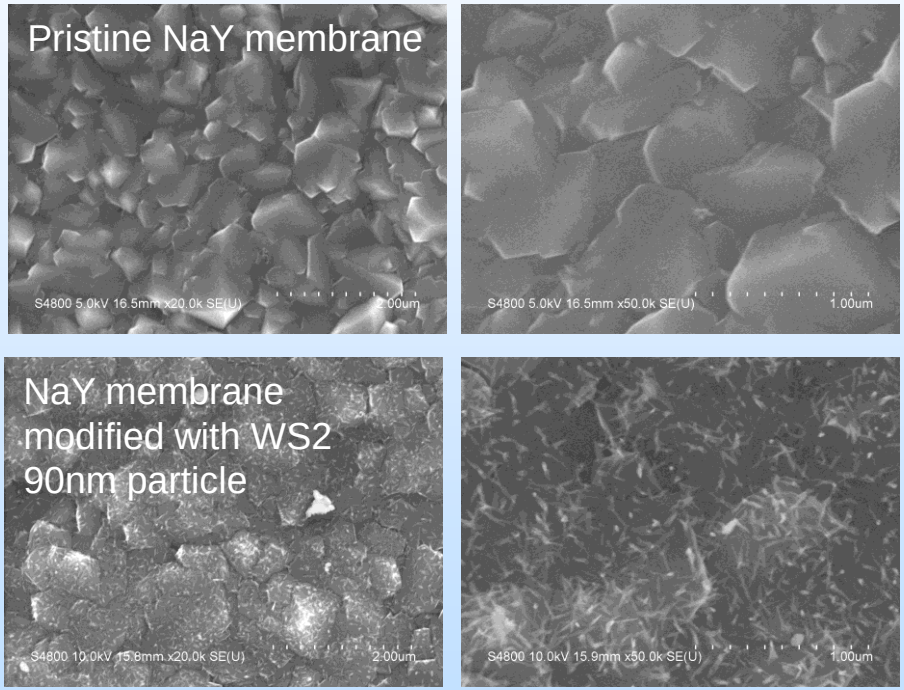
Bundle ID	Test Temperature (°C)	Test Pressure (psig)	Feed Water Content (wt%)	Water Flux (kg/m²/hr)	iPA Rejection (%)
Bundle C-02	88	20	30	0.33	98.5
Bundle C-03	88	20	28	0.38	97.8
Bundle C-07	88	23	25	0.44	99.4
Bundle C-08	88	22	25	0.41	98.3
Bundle C-09	88	22	25	0.43	99.2
Bundle C-10	88	22	27	0.51	99.1

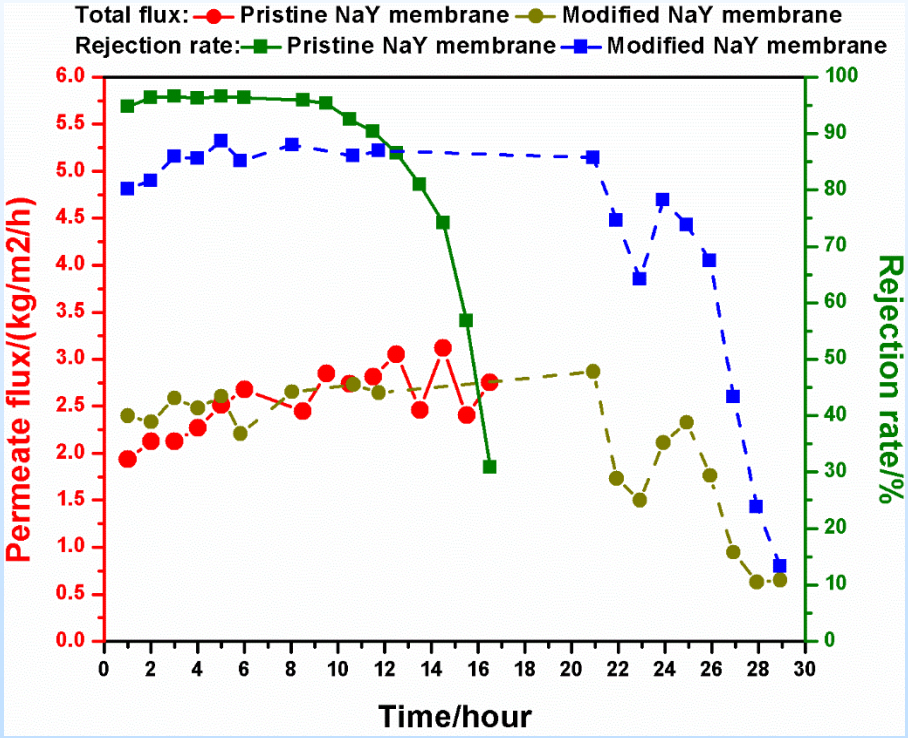
*Feed solution: isopropanol/water mixture

Progress and Current Status: Zeolite Membrane

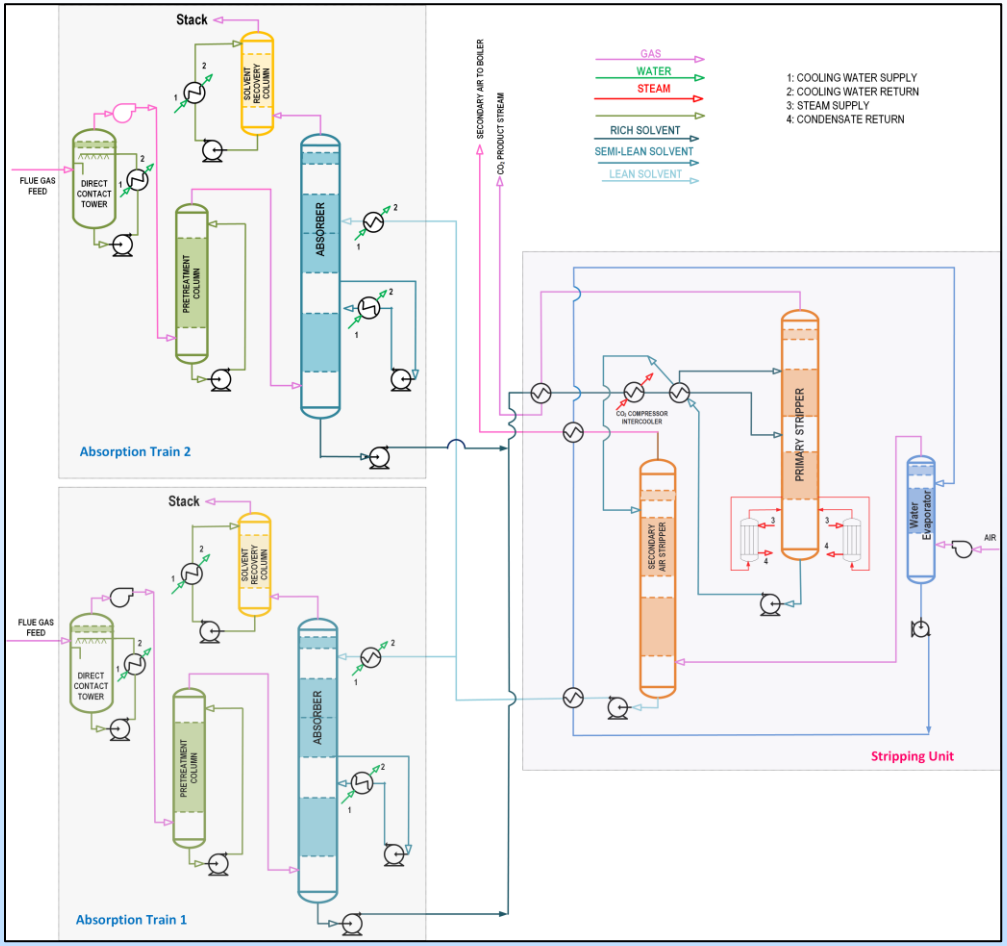
Membrane modification by WS2 to fix the intercrystal boundary

Materials: WS_2 powders (99%, size~ 90 nm), 2-propanol (IPA, 99%), concentration 0.2 g/L

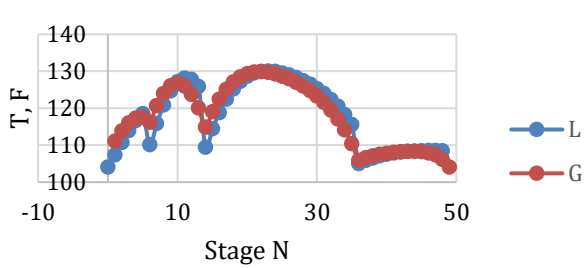


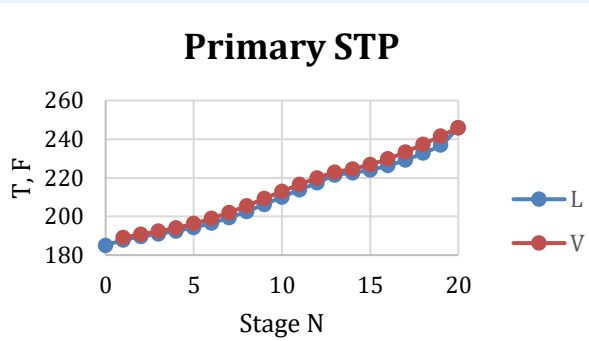


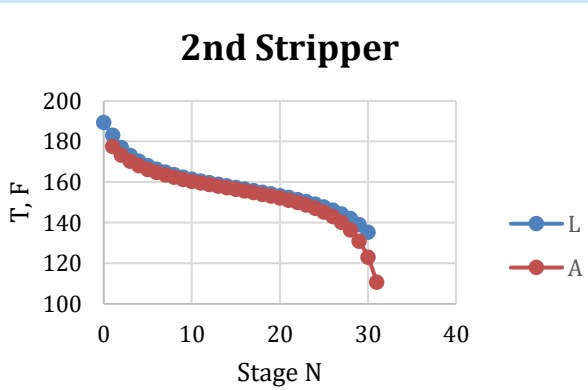
Process Simulation and TEA



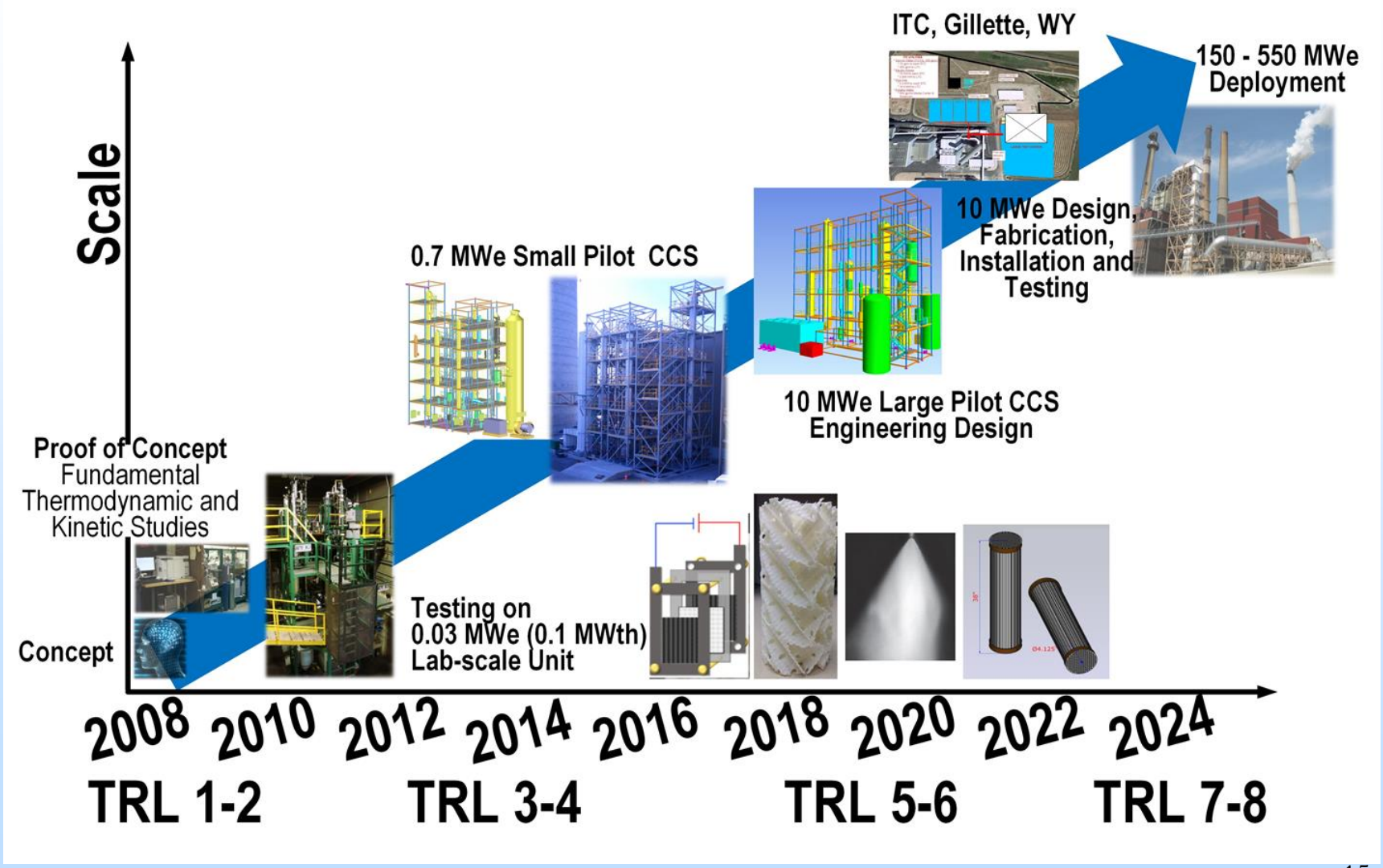
Process model tuning for techno-economic analysis of scaled technology







Future Testing



Summary

- Heat recovery from split streams cooled stripper exhaust stream by ~12 °C, less water evaporation resulted in energy savings of ~15%
- Demonstrated sustained long term performance of solvent in terms of capture and solvent capacity for select conditions
- Pump around increases liquid turbulence, enhances gas-solid contact and reduces diffusion limitation to enhance capture efficiency

Acknowledgement

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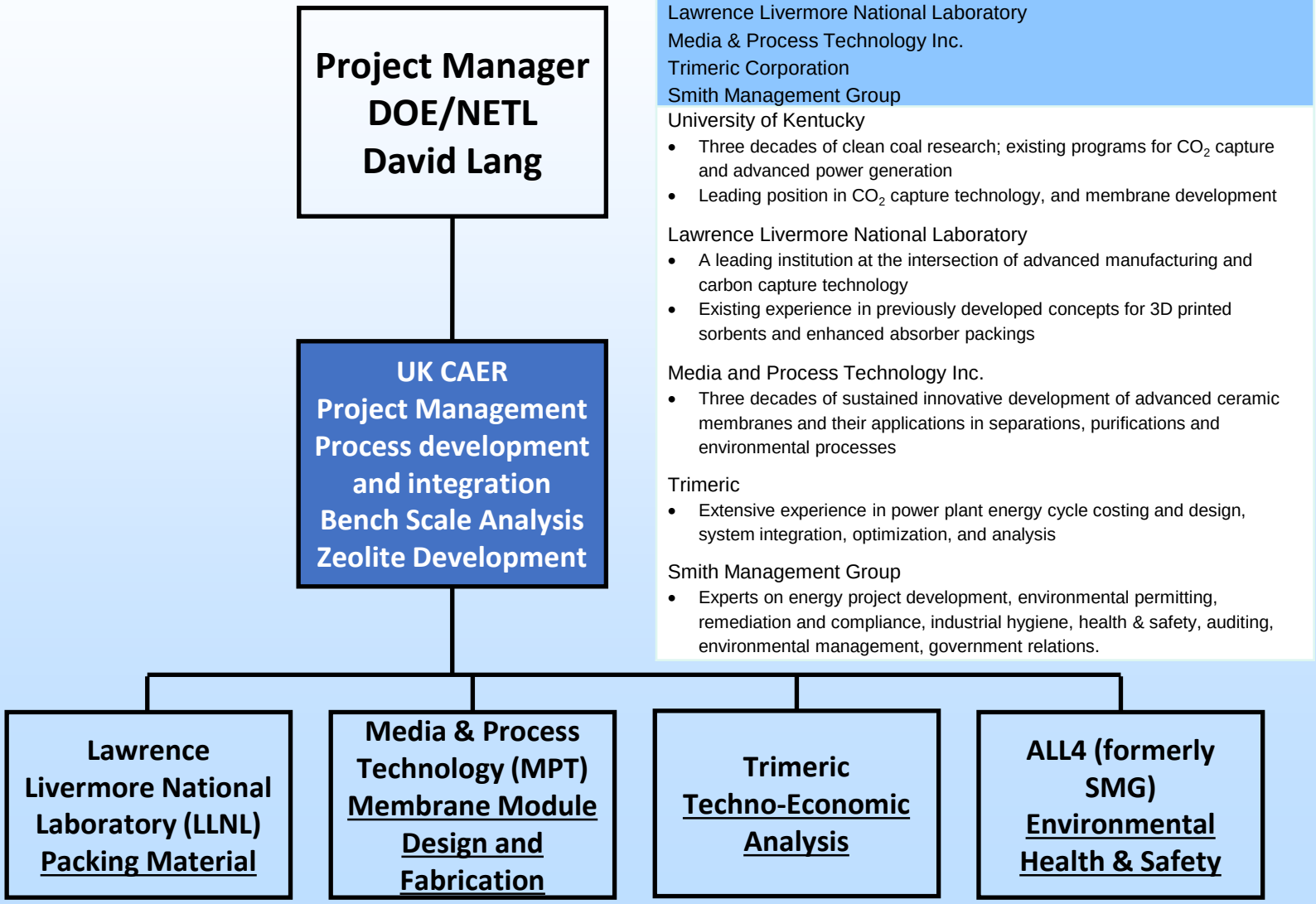
Trimeric: Andrew Sexton and Darshan Sachde

ALL4: Clay Whitney

UK CAER: Power Gen group

Appendix: Organization Chart



Appendix: Project Gantt Chart

ID	Task Name	Start	Finish
1	**1 Project Management and Planning**	5/1/18	10/31/21
8	**2 3-D Printed Packing Material for Absorber**	5/1/18	5/1/19
9	**2.1 Identification of Additive Manufacturing Compatible Heat Transfer Materials**	5/1/18	7/31/18
10	**2.2 Design and Fabrication of Packing Material using Additive Manufacturing**	8/1/18	3/5/19
11	**2.3 Manufacturer Identification and Technology Transfer**	3/5/19	4/30/19
13	**3 Zeolite Dewatering Module Development and Fabrication**	5/1/18	4/30/19
14	**3.1 Membrane Synthesis Optimization**	5/1/18	10/31/18
16	**3.2 Large-batch Synthesis of Zeolite Y Membranes**	11/1/18	4/30/19
17	**3.3 Design of Membrane Module**	10/31/18	4/30/19
19	**4 30 L/min CO2 Capture Bench Unit Evaluation**	1/31/19	10/31/19
20	**4.1 Advanced Structured Packing Study**	1/31/19	7/2/19
21	**4.2 Integration and Testing of Zeolite Y Module**	7/1/19	8/29/19
22	**4.3 Possible Modification/Improvement Identification**	9/2/19	10/31/19
24	**5 Test Plan Development**	7/1/19	10/31/19
26	**6 Evaluation of Proposed Technique at 0.1 MWth Post-Combustion CO2 Capture Facility**	11/1/19	10/31/21
27	**6.1 Stripper and Auxiliary Facility Modification and Retrofit**	11/1/19	2/2/20
28	**6.2 Packing Design Update and Acquisition of Packing**	11/1/19	2/2/20
29	**6.3 Fabrication of Zeolite Y Membrane Module**	11/1/19	4/30/21
30	**6.4 Installation and Verification Studies of Advanced Packing Material**	2/3/20	10/31/20
31	**6.5 Installation and Verification Studies of Zeolite Y Membrane Module**	5/1/21	10/31/21
33	**6.6 1000-hour Long-term Operation**	5/1/20	10/31/21
35	**7 High Packing Density and Performance Zeolite Y Membrane**	10/31/19	7/31/20
37	**8 Composite Zeolite and Alternative Dewatering Membranes**	7/31/20	1/31/21
39	**9 Techno-Economic Analysis**	10/30/20	10/31/21
40	**9.1 Modeling**	10/30/20	9/2/21
41	*9.1.1 Aspen Model. A detailed Aspen Plus model will be carried out on the entire hybrid system to confirm process component benefits.*	8/2/21	8/2/21
42	**9.2 Techno-economic Analysis**	4/2/21	10/31/21
43	*9.2.1 TEA complete*	10/31/21	10/31/21
44	**10 Topical Report Preparation and Submission**	5/4/21	10/31/21
45	**10.1 State Point Data Table**	5/4/21	10/31/21
46	*10.1.1 State Point Data Table complete*	10/31/21	10/31/21
47	**10.2 Technology Gap Analysis**	5/4/21	10/31/21
48	*10.2.1 TGA complete*	10/31/21	10/31/21
49	**10.3 Environmental, Health, and Safety (EH&S) Assessment**	5/4/21	10/31/21
50	*10.3.1 EH&S complete*	10/31/21	10/31/21