FWP-FEAA 384

Intensified, Flexible, and Modular Carbon Capture Demonstration with Additively Manufactured Multi-Functional Device

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National Energy Technology Laboratory
2022 Carbon Management Project Review Meeting

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Project Overview

- **Funding provided by DOE-FECM:** $1.5M

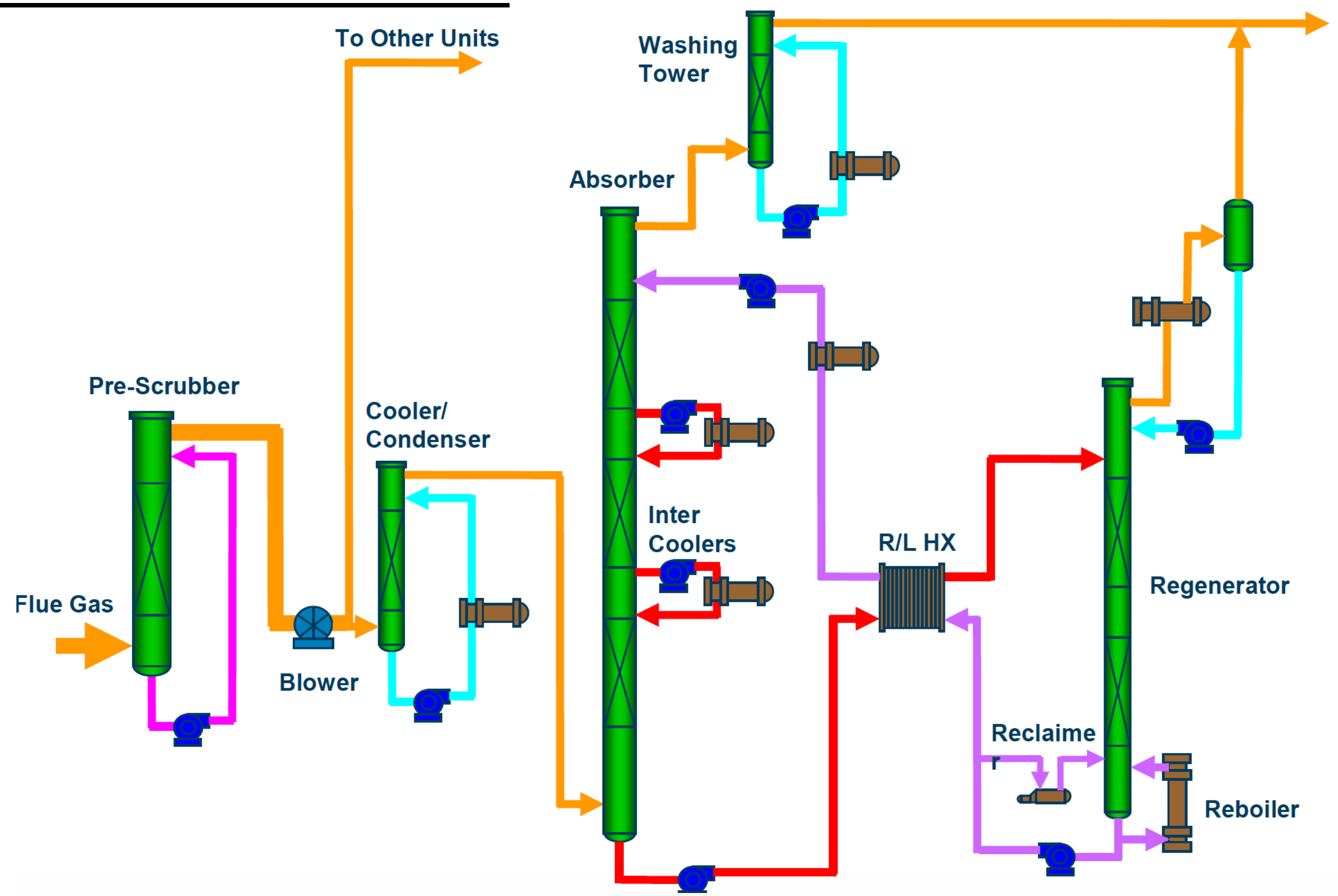
- **Overall Project Performance Dates:**
  January 1, 2021 – December 31, 2022 (extension will be requested)

- **Previous Project: FWP-FEAA375**
  January 1, 2020 – December 31, 2020
  Focused on validation of additively manufactured intensified device for enhanced carbon capture using a low aqueous solvent

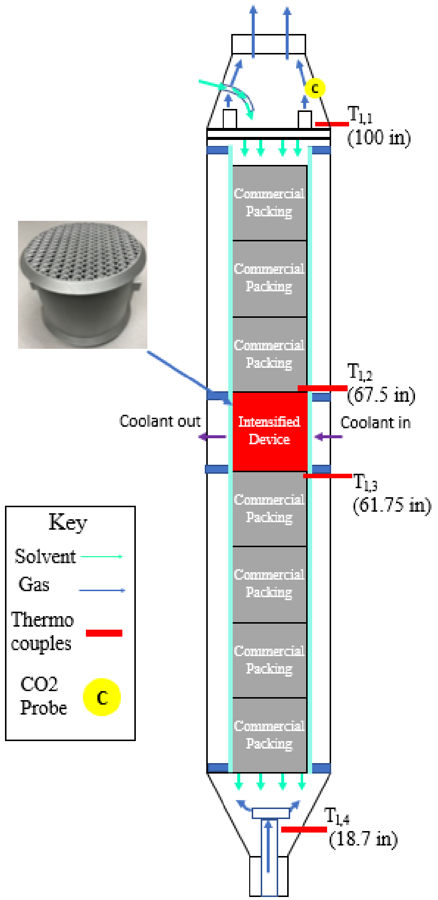
Motivation for this Project

- Opportunities for additive manufacturing to improve carbon capture
- Intensified packing device for flexible, modular carbon capture from point sources
  - Intensified device enhances mass transfer, just like commercial packing, and allows a third fluid (coolant) to remove the heat of reaction between CO_2 and amines
- Demonstrate pathway to scalability for the intensified device

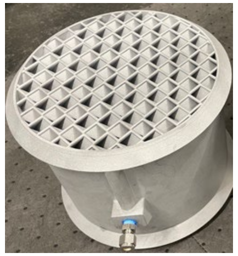
Technology Background: How the technology is envisioned to work: <u>A Brief Review</u>



Absorption/Desorption System at the National Carbon Capture Center (NCCC)



Column A



Intensified Devise

$$2MEA + CO_2 \rightleftarrows MEAH^+ + MEACOO^-$$ (+ 79-100 KJ/mol) (Exothermic)

<u>Motivation:</u> Intrastage cooling with intensified devices may have economic and operational advantages over interstage cooling

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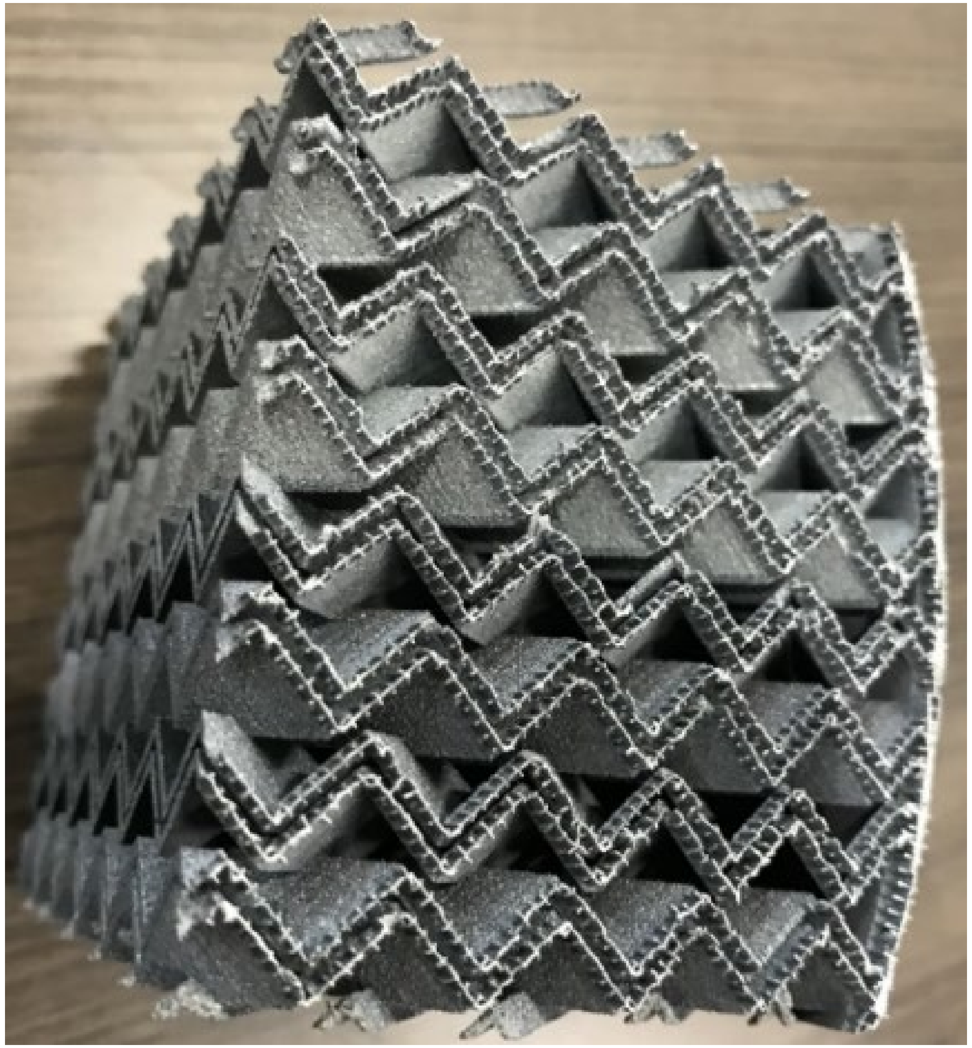
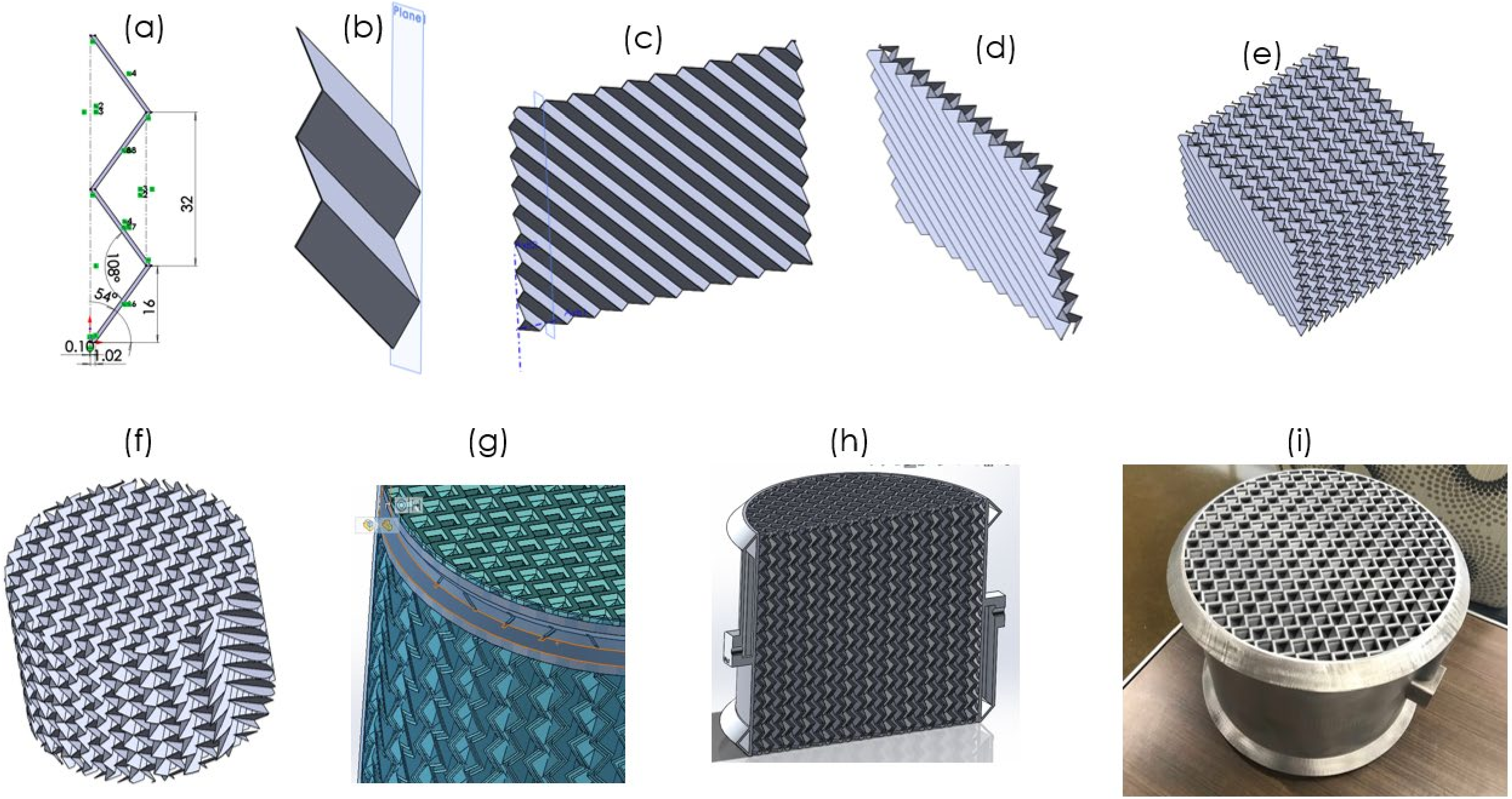
Technology Background: Intensified Device Concept

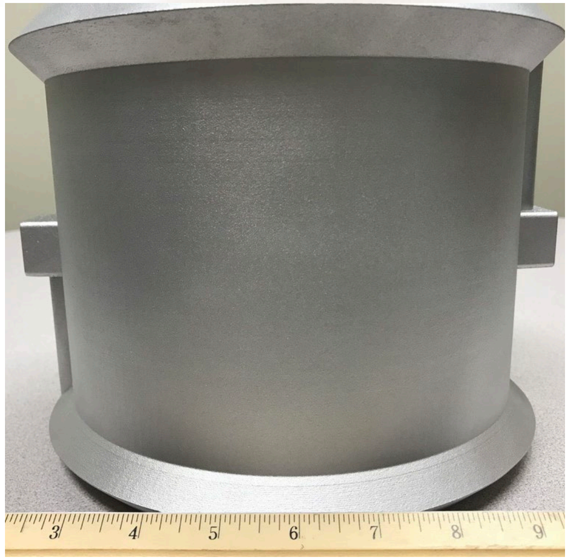


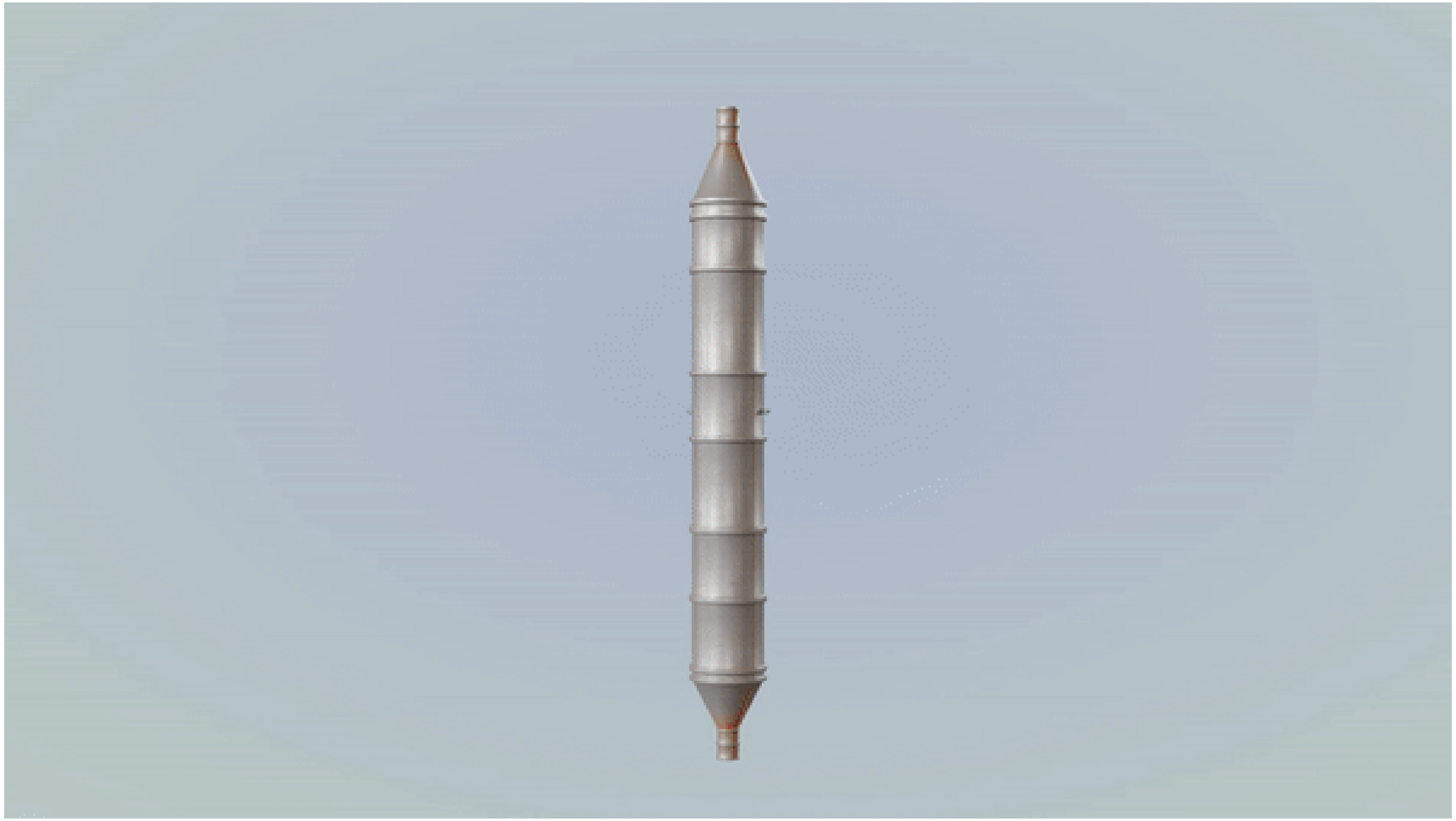
Technology Background: Intensified Device Design & Manufacturing



(a) Create profile of packing cross section, (b) extrude segment of packing at 45 degrees, (c) pattern into two parallel panels with gap for fluid, (d) mirror and rotate the adjacent panels, (e) pattern into a full packing, (f) cut into a cylinder, (g) create a manifold for coolant to flow into heat exchanger, (h) create inlet and outlet ports, (i) manufacture from CAD to part.

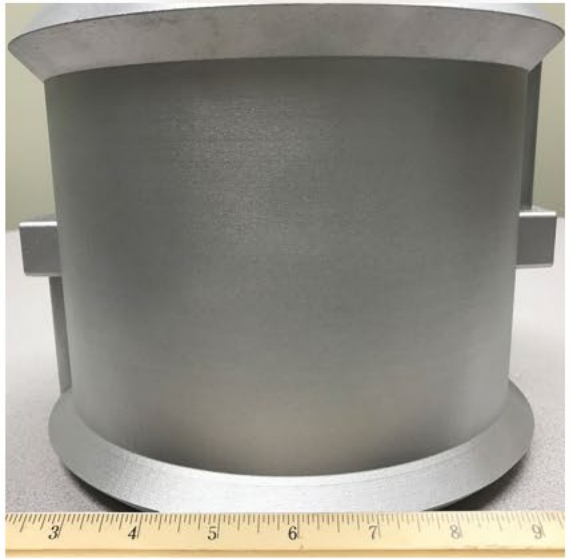
Technology Background: Intensified Device Installation on Column

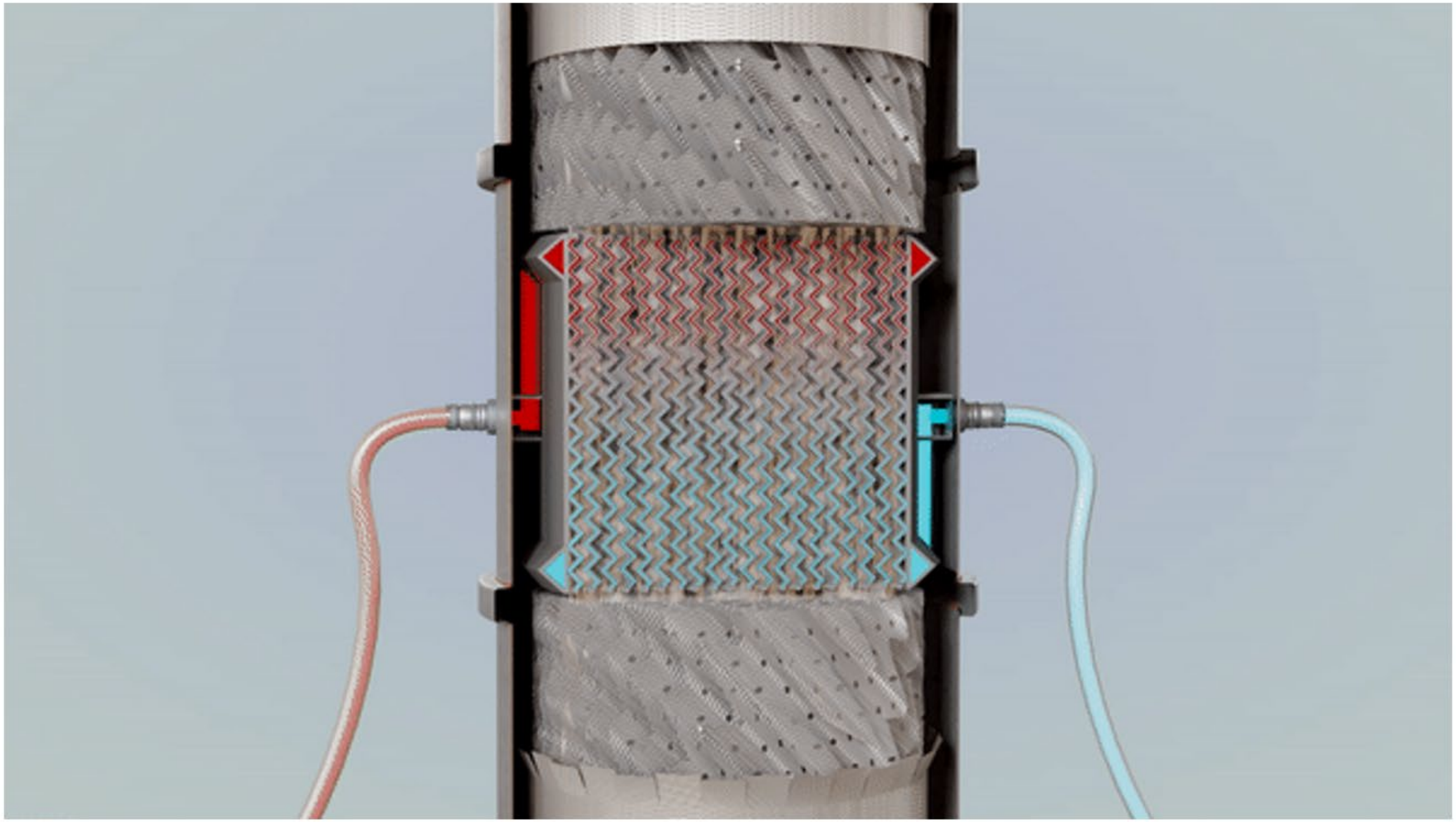




8-inch diameter column

Technology Background: Intensified Device <u>Installation on Column</u>





8-inch diameter column

Technology Background: Intensified Device Demonstration for MEA

Air Flow Rate (LPM)	CO_2 Flow Rate (LPM)	CO_2 Conc. (%)	Molar Capture Rate Before Cooling (mol/min)	Molar Capture Rate After Cooling (mol/min)	Fractional Increase (%)	Capture Efficiency (%) (Before → After Cooling)
810	**90**	10	2.24	2.30	2.7	59.9 → 61.2
510	**90**	15	2.75	2.90	5.5	73 → 77
360	**90**	20	2.95	3.29	11.5	78 → 88
264	**90**	25	3.52	3.57	4.3	94 → 98
360	**40**	10	1.38	1.45	5.1	83 → 87
360	**63.5**	15	1.53	1.77	15.7	58 → 67
360	**90**	20	2.95	3.29	11.5	78 → 88
360	**120**	25	3.07	3.28	6.9	62 → 66

Solvent flowrate: 3.2 LPM   Solvent input temperature: 70 °C

- Miramontes, E.; Jiang, E.A.; Love, L.J.; Lai, C.; Sun, X.; Tsouris, C. Process Intensification of CO_2 Absorption Using a 3D Printed Intensified Packing Device, *AIChE J*. **e16285,** (2020).

Technology Background: Intensified Device Demonstration for LAS

Exp.	Solvent Condition	Solvent Flowrate (LPM)	Air Flowrate (SLPM)	CO_2 Flowrate (SLPM)	CO_2 Amount (%)	CO_2 output before cooling (%)	CO_2 output after cooling (%)	Capture efficiency (%) (before → after)	Fractional Improvement (%)*	Feed temp. (℃)	Average Temp.	
											No-cooling	Cooling
1	Pristine	3.26	510	90	13.8	2.21	0.64	84 → 95.4 (**11.4**↑)	**13.5**	59	60.7	52.2
2	Pristine	3.26	510	90	14.0	1.95	0.47	86 → 96.6(**10.6**↑)	**12.3**	52	59.6	50.4
3	Pristine	3.26	510	90	13.8	1.61	0.64	88.3 → 95.4 (**7.1**↑)	**8.0**	45	58.6	50.0
4	1st Regen.	3.26	510	90	14.7	3.18	1.57	78.4 → 89.4(**11.0**↑)	**14.0**	41	54.5	45.3
5	2nd Regen	3.26	608	107	13.1	3.75	2.23	71.3 → 82.9(**11.6**↑)	**16.3**	44	55.2	46.8
6	2nd Regen + DI H_2O(5L)	3.26	608	107	13.0	2.94	2.08	77.4 → 84.0(**6.6**↑)	**8.5**	44	55.4	46.9
7	3rd Regen	3.26	425	75	13.3	1.19	0.67	91.1 → 95.0(**3.9**↑)	**4.3**	41	52.8	44.9
8	3rd Regen	2.82	510	90	13.1	2.75	1.75	79.1 → 86.7(**7.6**↑)	**9.7**	41	53.8	46.6
9	4th Regen	3.26	353	62	13.3	0.79	0.44	94.0 → 96.6(**2.6**↑)	**2.8**	41	49.8	39.7
10	4th Regen	3.65	510	90	12.8	2.16	1.13	83.2 → 91.2(**8.0**↑)	**9.7**	41	52.7	44.2
11	5th Regen	2.39	510	90	13.1	5.85	4.71	55.3 → 64.0(**8.7**↑)	**15.7**	41	52.3	45.5
12	5th Regen	2.82	510	90	13.0	4.92	3.25	62.2 → 75.0(**12.8**↑)	**20.7**	41	54.2	46.4
13	6th Regen	3.26	510	90	13.2	5.74	3.86	56.7 → 70.9(**14.2**↑)	**25.1**	41	53.5	45.0
14	6th Regen + DI H_2O(5L)	3.26	510	90	13.1	5.33	4.73	59.3 → 63.9(**4.6**↑)	**7.8**	41	52.1	43.5

LAS was provided by RTI International, thanks to Marty Lail

Overall Project Objectives for FEAA 384

– Design and construct a larger-scale column (Column B) than the one previously tested (Column A) to:

- Scale up CO_2 capture from 0.1 t/day to 1 t/day
- Demonstrate 15% enhancement in CO_2 capture with a 3D printed intensified device for aqueous and low-aqueous amine-based capture at realistic operating conditions
- Demonstrate that Column B can be constructed with modular packing elements and intensified devices
- Demonstrate that Column B can effectively capture CO_2 from different CO_2 gas compositions and during process transients, with capacity ramping up and down anticipating the intermittent nature of renewable energy

Technical Approach/Project Scope
Project Schedule: Two-year project

- **Task 1.0** – Project Management and Planning (1-24 Months)
- **Task 2.0** – Design, Evaluation, and Construction of Column B based on Results from FEAA375 (1-12)
- **Task 3.0** – Advanced Manufacturing and Core Metrics Testing of Intensified Device for Column B (1-15)
- **Task 4.0** – Using NTRC Engine Combustion Exhaust to Simulate Various Flue Gas Compositions (1-15)
- **Task 5.0** – Test Plan Development for Subsequent Tasks (13-15)
- **Task 6.0** – Aqueous Solvent Capture with Simulated Coal-Fired Power Plant Flue Gas (13-16)
- **Task 7.0** – Aqueous Solvent Capture with Simulated Natural Gas-Fired Power Plant Flue Gas (17-19)
- **Task 8.0** – Aqueous Solvent Capture under Process Transients (20-21)
- **Task 9.0** – Column B Modification and Demonstration of Modular Capture with Low-aqueous Solvent (22-24)
- **Task 10** – Collaboration with $CCSI^2$ on Modeling of Process Intensification with Column B Results (1-24)

Progress and Current Status of Project
Task 1.0 – Managing Design and Construction of CO_2 Capture Column

Process Design
CO_2 Capture Simulations
Mass and Energy Balances
Hydraulic Calculations
Equipment Sizing

Modular Carbon Capture Demonstration Column

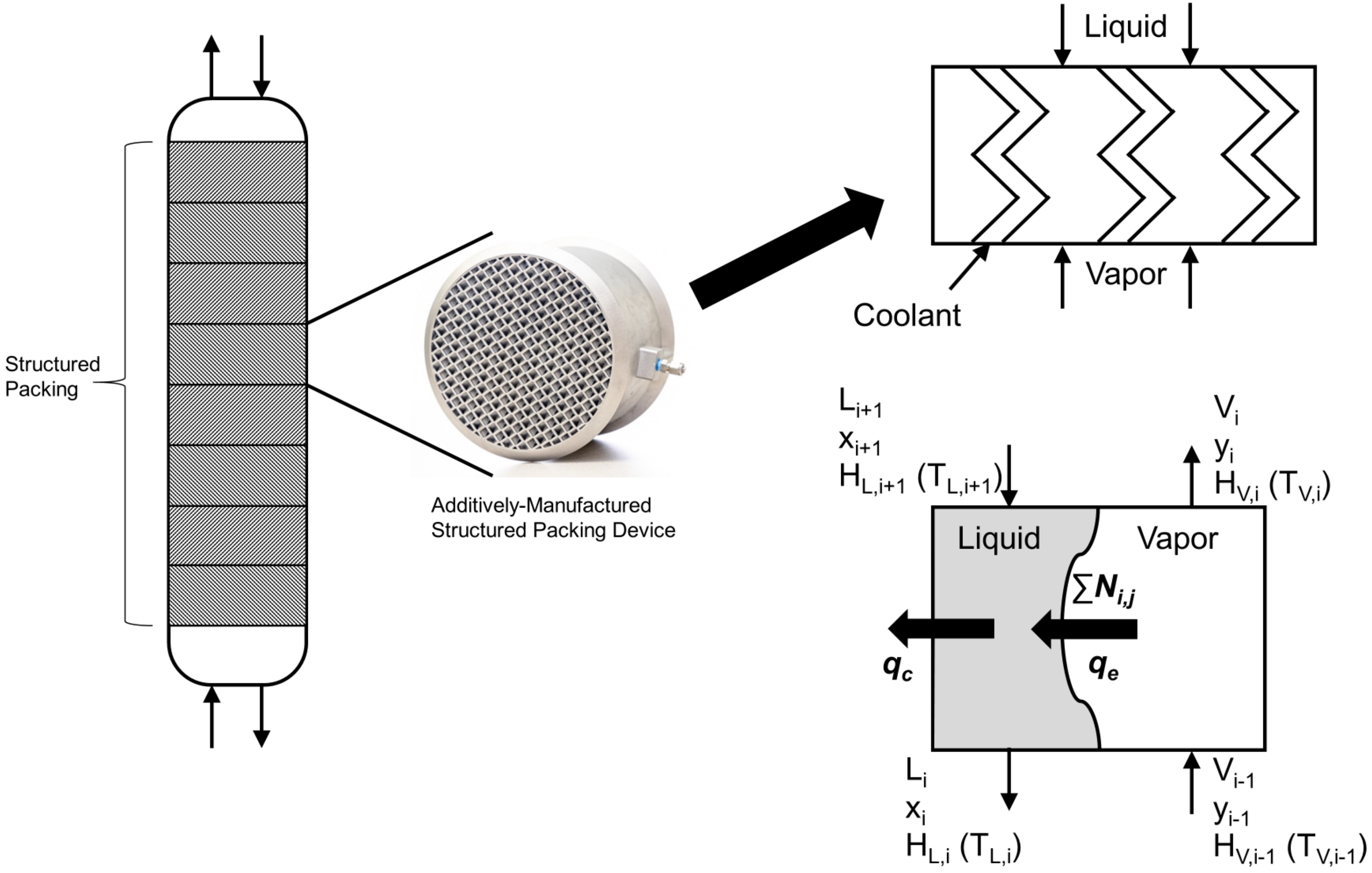
Sub-systems
- Intensified Device
- Gas Generation (GenSet, load bank)
- Solvent (tanks, pumps)
- Columns (capture & regeneration)
- Exhaust Gas Conditioning
- Temperature Control (heat exchangers, cooling water)

Facility Management
Shared spaces at NTRC
Proper Engagement w/ 3rd Parties
Lab Space Management

Safety & Reliability
Structural & Electrical
Interlocks & Controls
Solvent Inventory Management

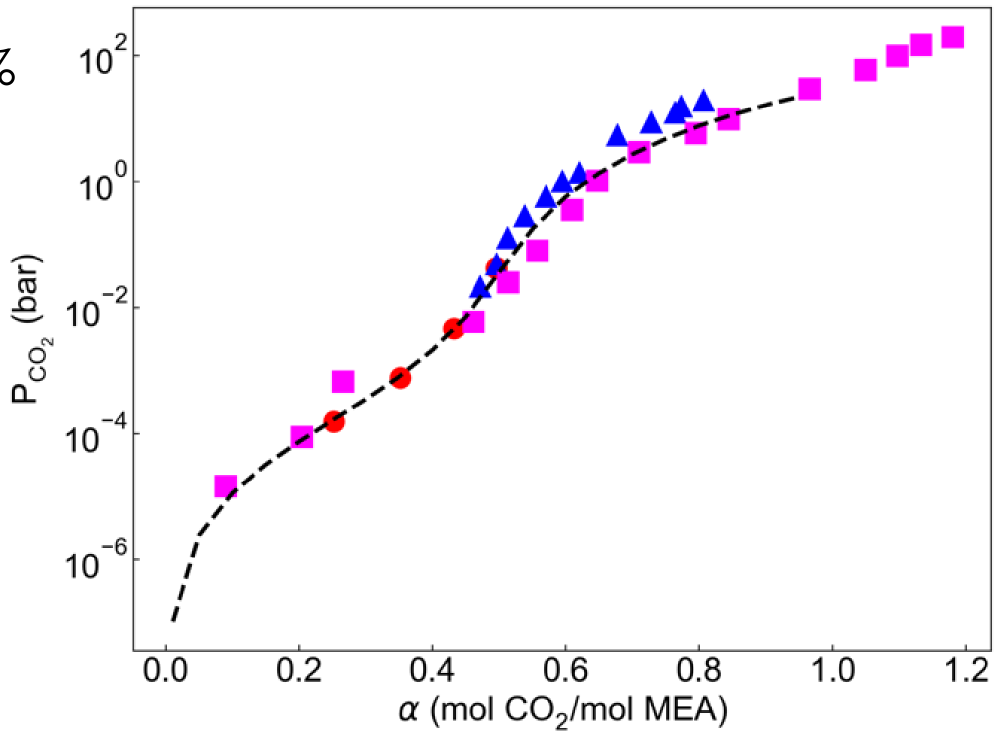
Task 2.0 – Design Evaluation and Construction of Column B (1-12)

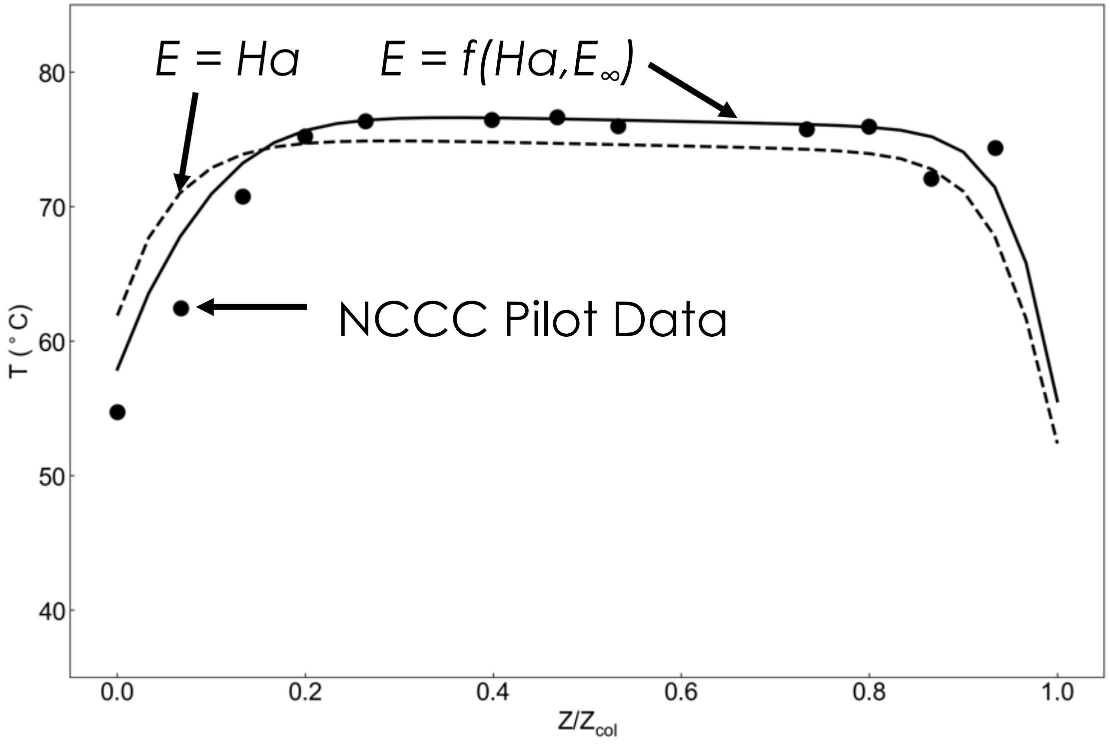
Modeling Framework:



Modeling Framework

MEA
30 wt%





Model validated with published CO_2 solubility and pilot data

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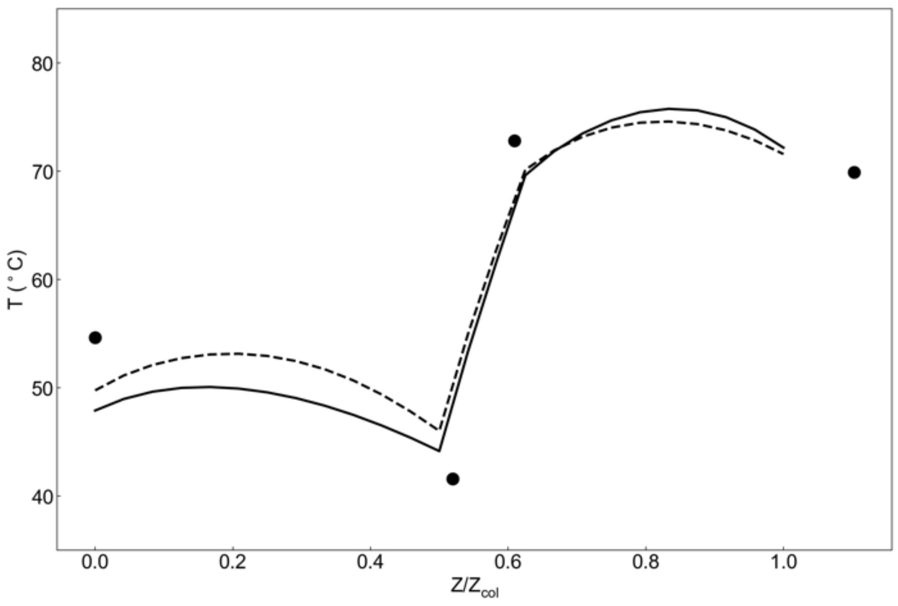
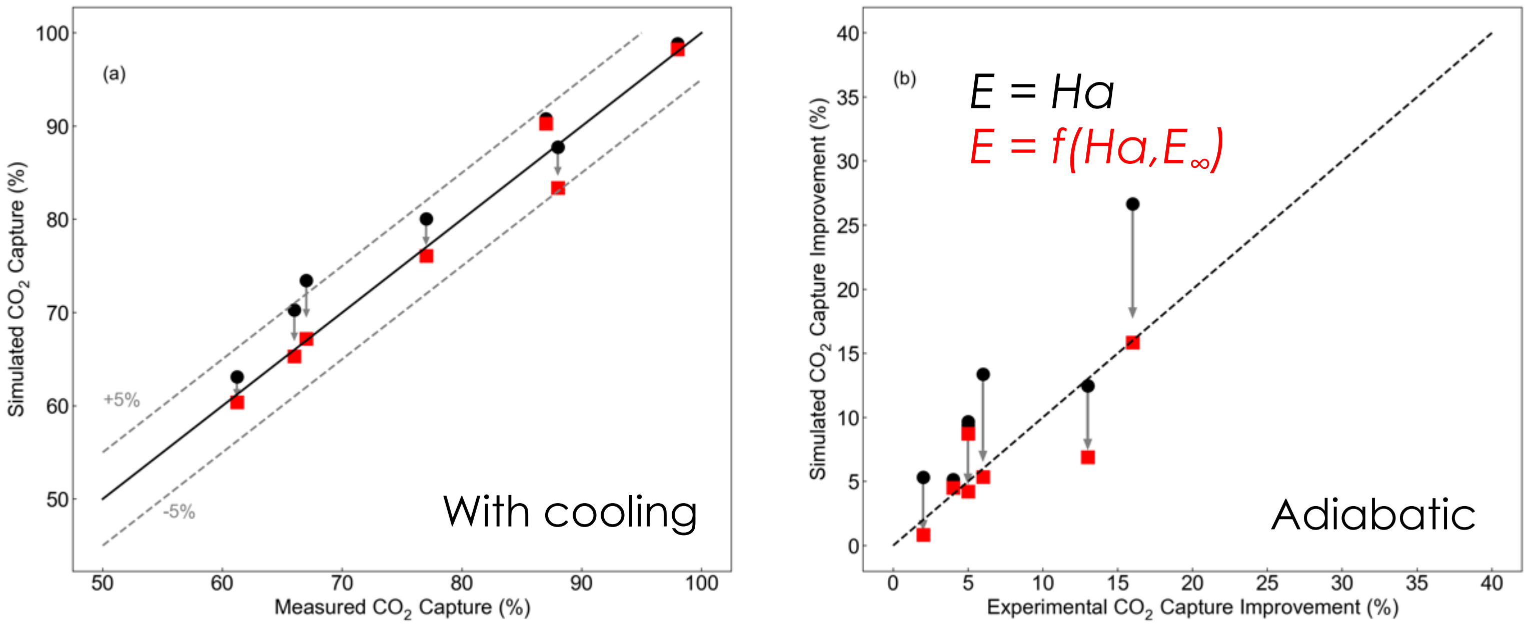
Thompson, Tsouris, "Rate-Based Absorption Modeling for Post-Combustion CO_2 Capture with Additively-Manufactured Structured Packing", *Ind. Eng. Chem. Res.*, **2021**, *60(41)*, 14845-14855.

Modeling MEA w/Intrastage Cooling





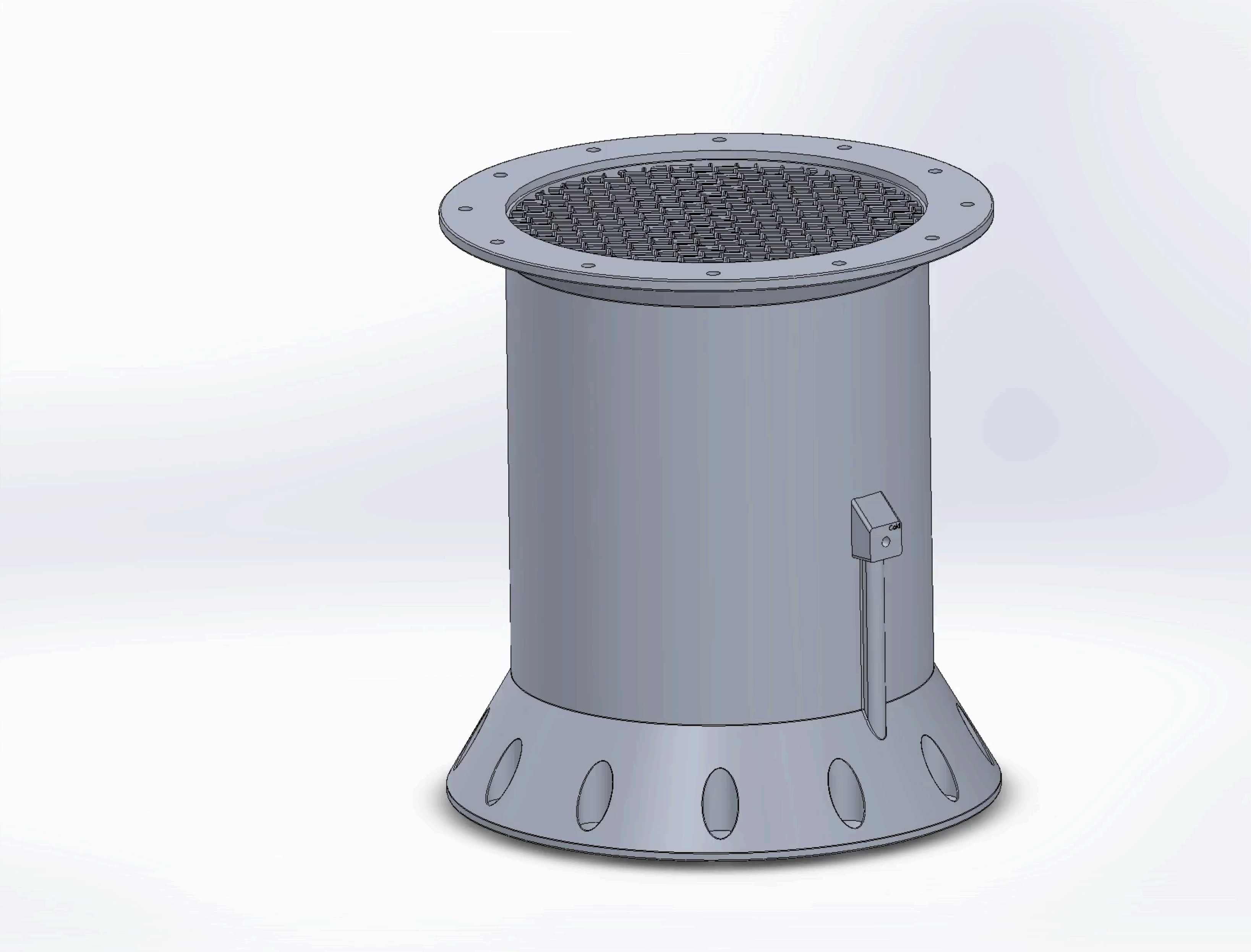
- Simulation of intrastage cooling with device shows good agreement with experiments from Miramontes *et al*. (2020)
  - CO_2 capture difference: all <= 5%
- CO_2 capture improvement and temperature profile agreement suggest modeling framework for heat transfer is accurate in predicting device performance

Task 3.0 – Advanced Manufacturing and Core Metrics Testing of Intensified Device for Column B (1-15)
Scale-up from 8” to 12” Diameter

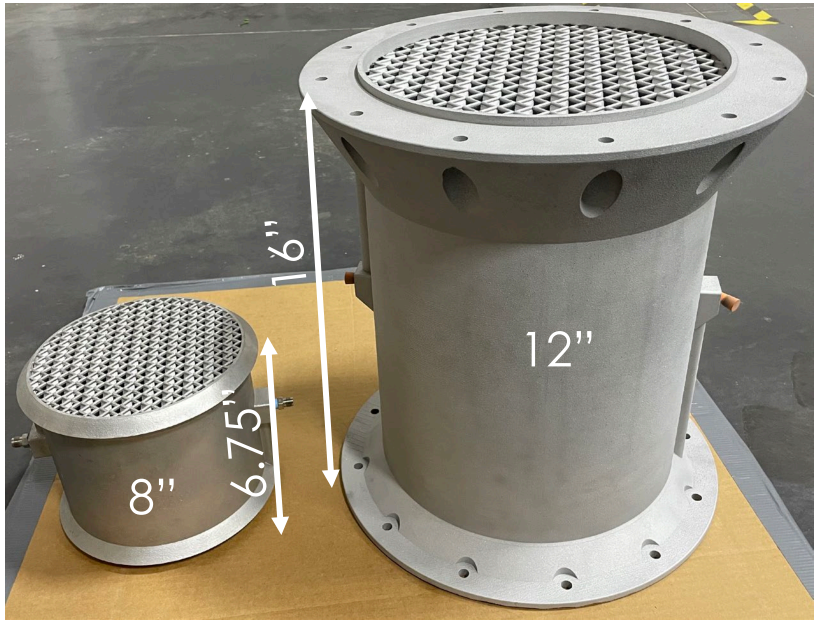
- New unit cell geometry: Column A

- Added flanges for device integration with the column
- Added supports for printability

Features of Intensified Device



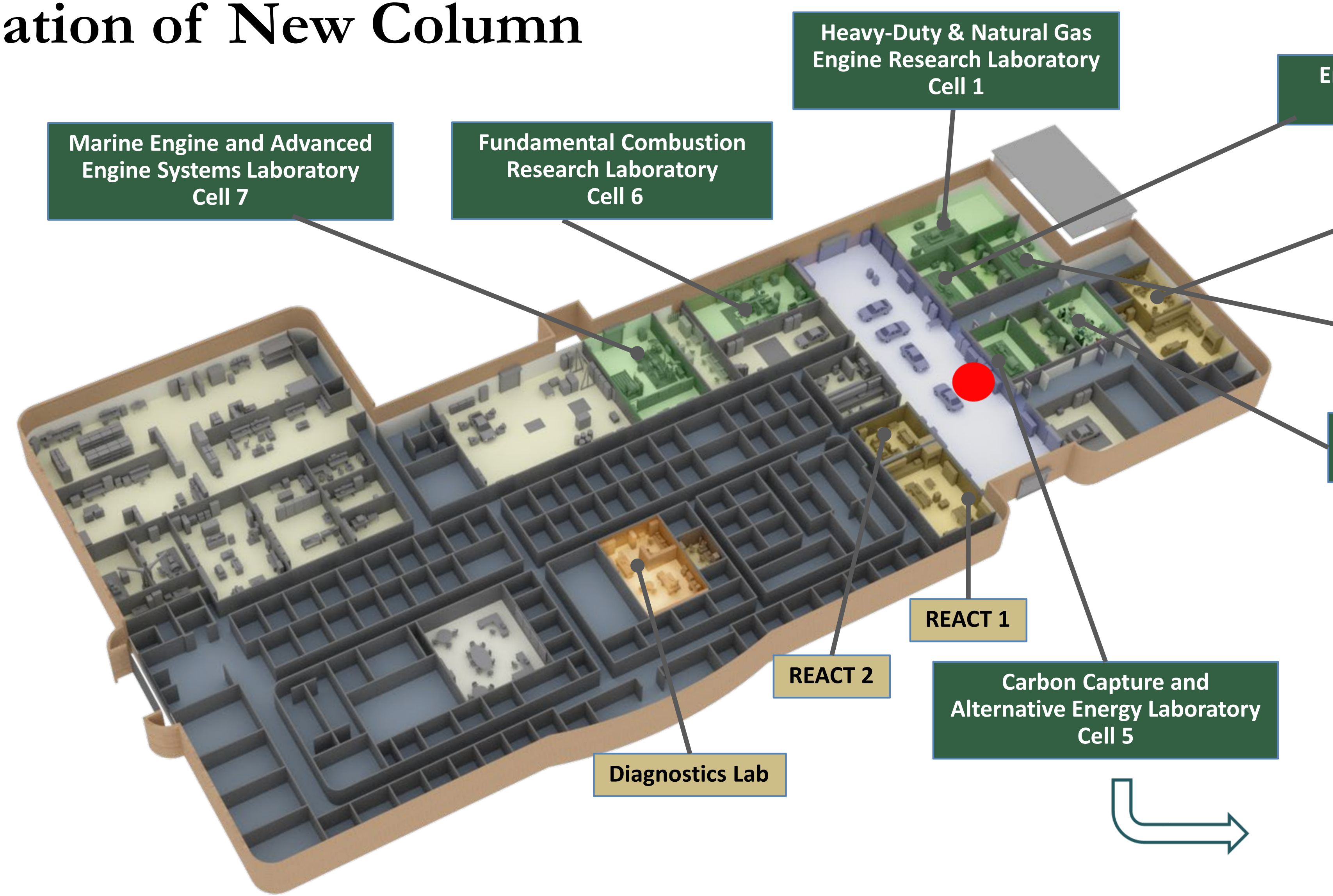
Scaled-Up Intensified Devices

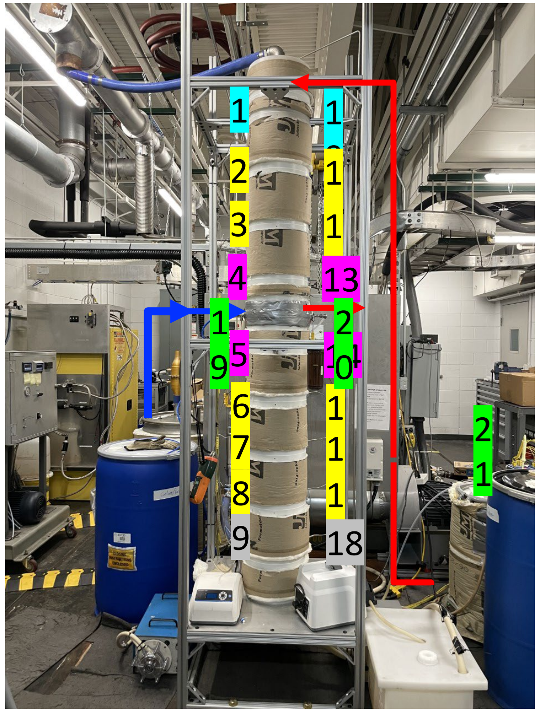


12-inch diameter, 16-inch height

August 18, 2022

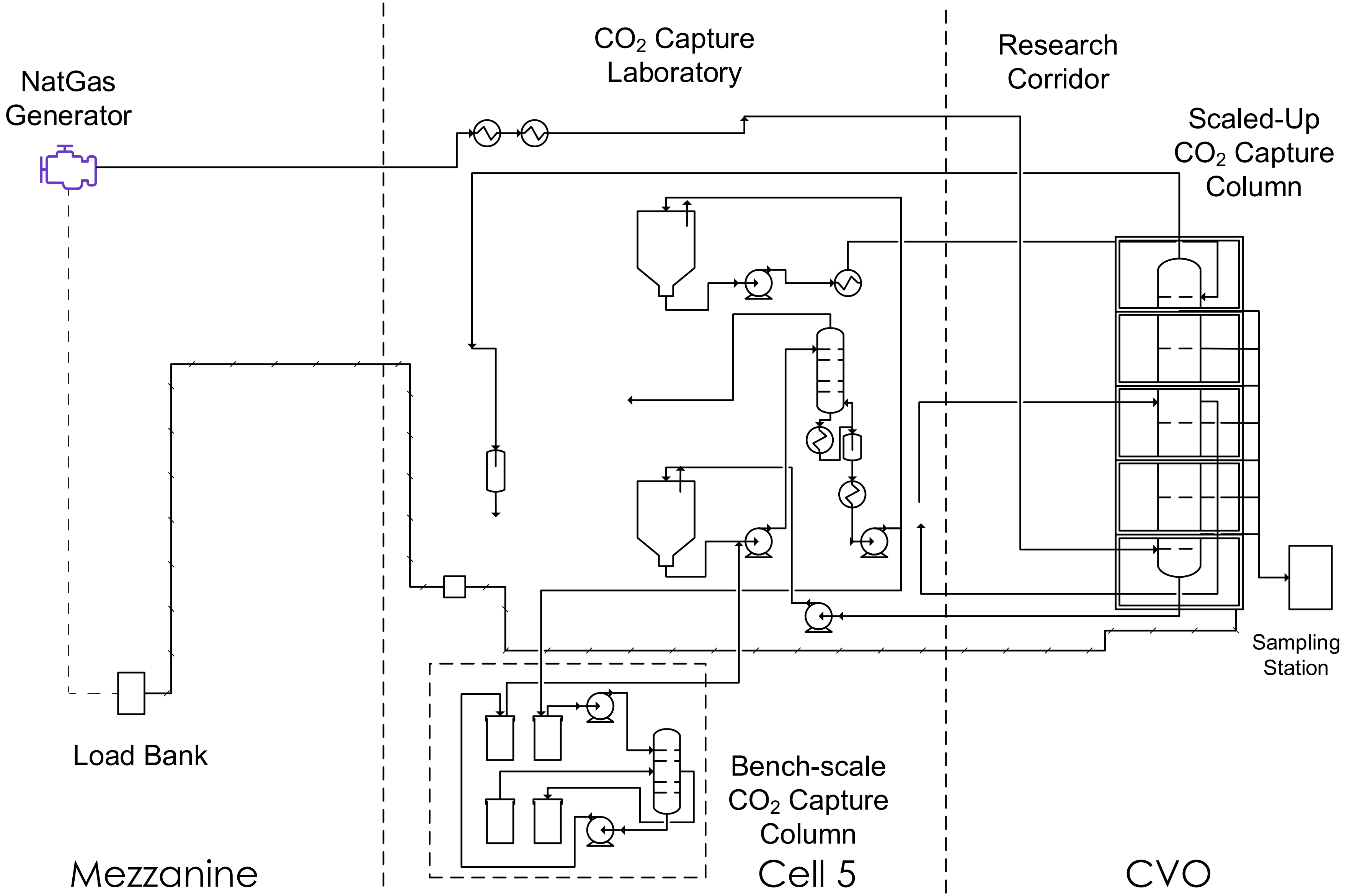
Location of New Column





National Transportation Research Center
ORNL Hardin Valley Campus

Process Flow Diagram for Column Design



Process flow and equipment essential to proper design around absorption column

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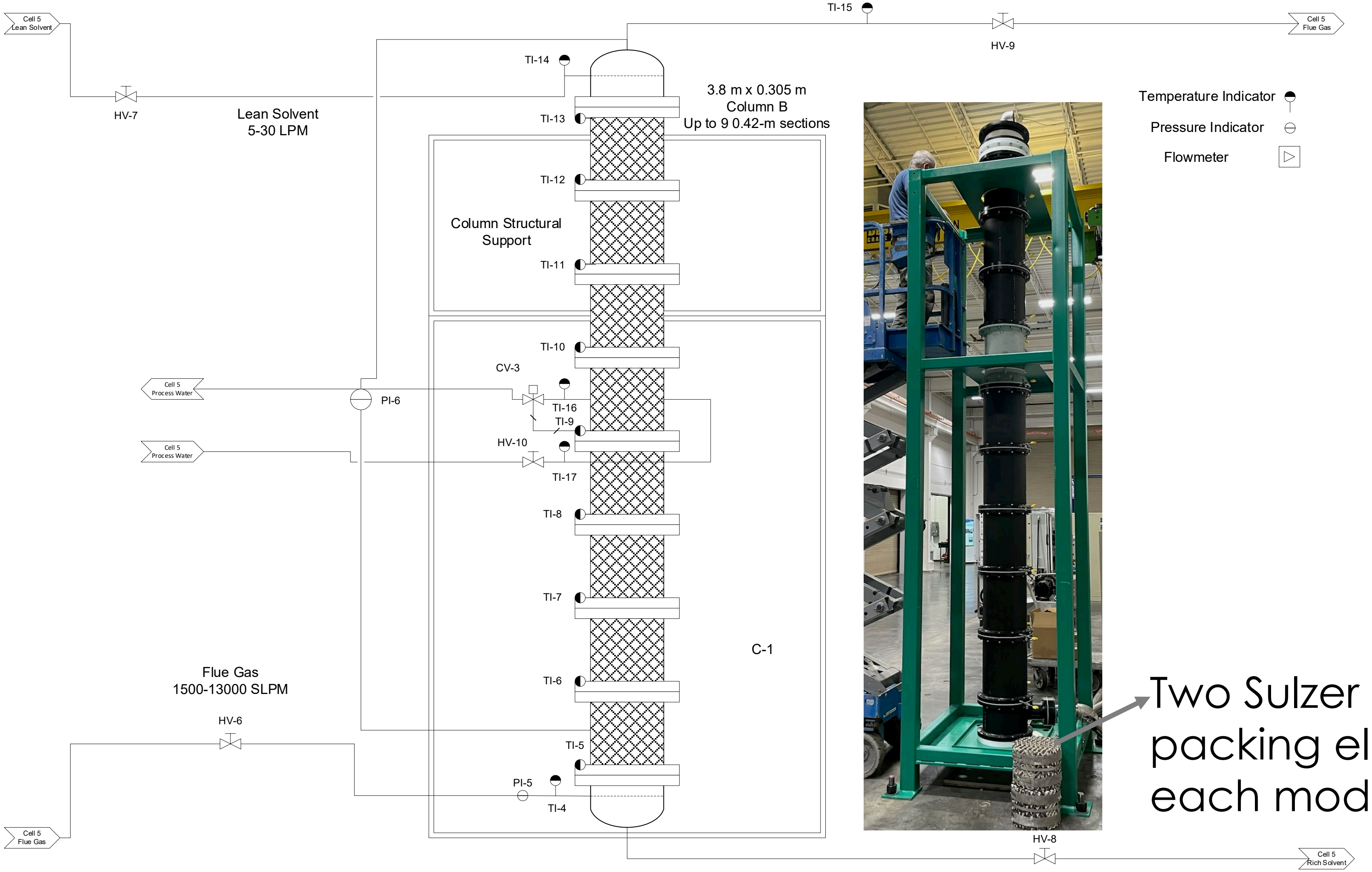
Improvements in High Bay, Laboratory, and Mezzanine Areas

Modular Column Design



Two Sulzer Mellapak 250Y packing elements per each module

Modular column design provides flexibility in testing packing locations and gas/liquid axial sampling

Task 4.0 – Using NTRC Engine Combustion Exhaust to Simulate Various Flue Gas Compositions (1-15)

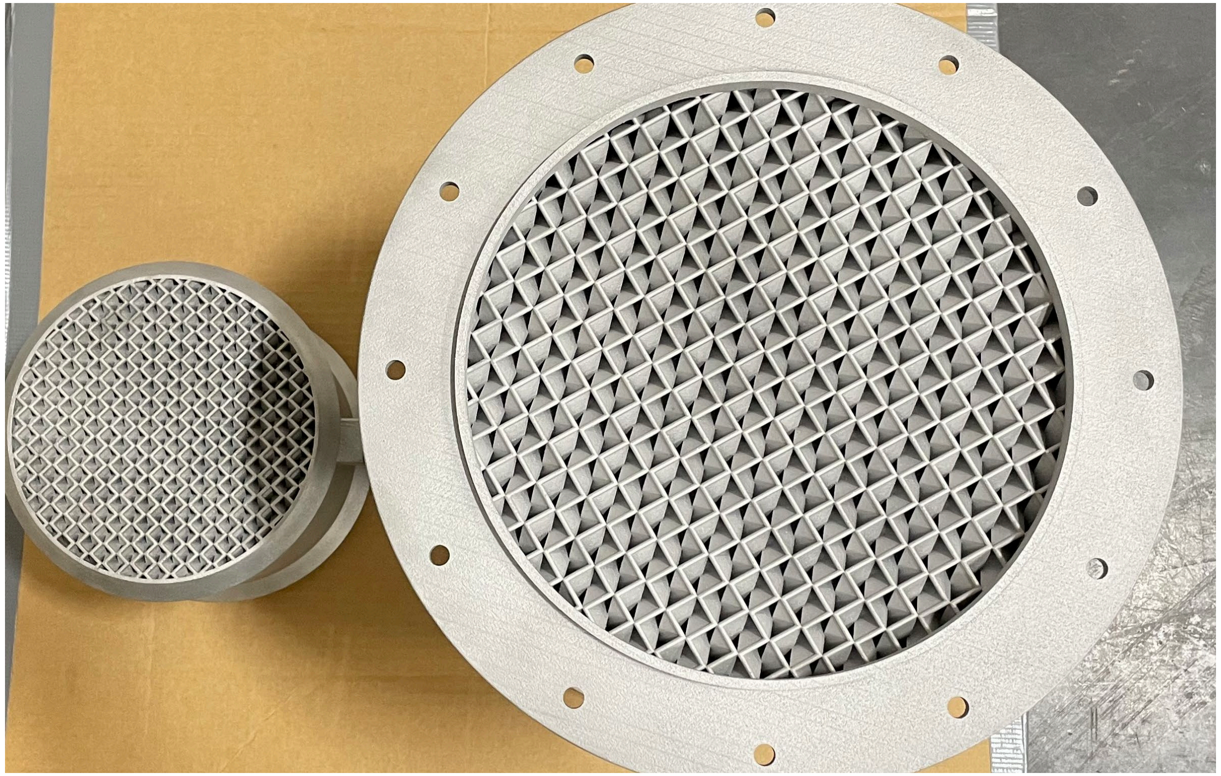
- Feed gas will be generated with natural gas generator set
  - 100 kW generator
  - 9L natural gas engine
  - Electricity dissipated by load bank
- Exhaust gas generation:
  - Up to 1.4 tons CO_2/day
  - Water dew point and temperature managed by heat exchangers

Genset installed in the Mezzanine area

Load bank installed in the Mezzanine area

Commercialization

- Need to demonstrate a path to scale-up
- Developed plan and looking forward to implementing it to demonstrate scalability in a future project
- For small-diameter columns, the intensified packing will be a section of the column
- For larger columns, it will just be a part of the column packing



Summary

- Modeling work was used for column design
  - Modeling framework developed was extended to other research projects at ORNL
- Project delays related to supply chain
- Delays impacted project schedule, anticipated to be up to two quarters
- Column construction is expected to be completed in August of 2022
- Hydraulic testing will follow, and then heat & mass transfer experiments

Future Work

- CO_2 capture experiments using aqueous MEA
- CO_2 capture experiments using LAS (RTI)
- Performance evaluation under transient conditions

} Tasks 6-9 (short term)

- Scale-up & TEA } Future project (long term)

Publications from FEAA384

- Thompson, Tsouris, "Rate-Based Absorption Modeling for Post-Combustion CO_2 Capture with Additively-Manufactured Structured Packing", *Ind. Eng. Chem. Res.*, **60**, 14845, (2021). https://doi.org/10.1021/acs.iecr.1c02756
- Tarancon, A., et al. "2022 Roadmap on 3D Printing for Energy," *JPhys Energy*, **4**, 011501 (2022). https://doi.org/10.1088/2515-7655/ac483d

Acknowledgments

- Office of Fossil Energy and Carbon Management
- RTI International and Marty Lail
- David Lang
- Lynn Brickett

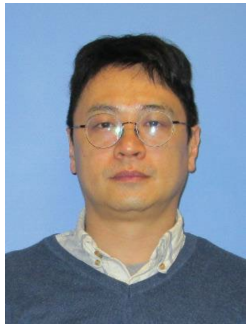
THANK YOU!

The Whole Project Team

Research Team:

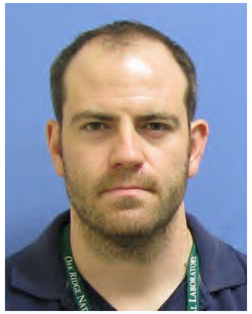

Costas Tsouris, PI

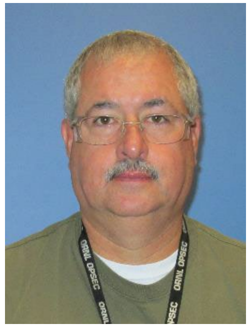

Joshua Thompson


Gyoung Jang


Jim Parks

Coordination, Construction, and Safety Team:


Scott Curran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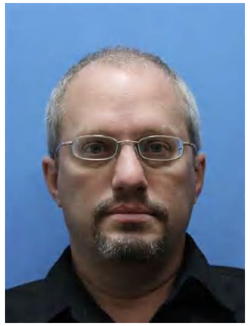
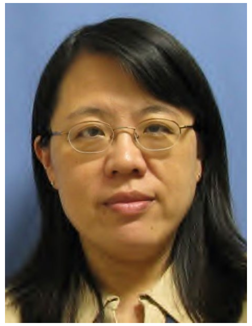
CCSI^2 Connection:


Charles Finney


Xin Sun, Consultant

Appendix

Project Schedule and Completion

August 2022

Timeline in Quarters	FY: 21			22				23		% Completed
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	
Task 1.0 – Project Management and Planning										
Task 2.0 – Design Evaluation and Construction of Column B based on Results from Task 3.0 in FWP-FEAA375										70
Subtask 2.1 Design Evaluation, Equipment Design and Sizing										100
Subtask 2.2 Column B Construction										75
Subtask 2.3 Instrumentation of Column B										90
Subtask 2.4 Initial Column Evaluation										0
Task 3 – Advanced Manufacturing and Core Metrics Testing of Intensified Device for Column B										50
Subtask 3.1 Advanced Manufacturing of Intensified MellaPak 250 Device for Column B Geometry										100
Subtask 3.2 Core Metrics Testing and Validation of the Intensified MellaPak 250 Device										0
Task 4 – Using NTRC Engine Combustion Exhaust to Simulate Various Flue Gas Compositions										90
Subtask 4.1 Engine, Fuel, and Load System Selection and Configuration										100
Subtask 4.2 Design and Installation of Auxiliary Systems to Supplement CO_2, Flow, and/or Temperature Control										90
Task 5.0 – Test Plan Development for Subsequent Tasks										
Task 6.0 – Aqueous Solvent Capture with Simulated Coal-Fired Power Plant Flue Gas										
Subtask 6.1 Baseline Experiments with Commercial Packing										
Subtask 6.2 Experiments with Intensified MellaPak 250										
Task 7.0 – Aqueous Solvent Capture with Simulated Natural Gas-Fired Power Plant Flue Gas										
Subtask 7.1 Baseline Experiments with Commercial Packing										
Subtask 7.2 Experiments with Intensified MellaPak 250										
Task 8.0 – Aqueous Solvent Capture under Process Transients										
Subtask 8.1 Baseline Experiments with Commercial Packing										
Subtask 8.2 Experiments with Intensified MellaPak 250										
Task 9.0 - Column B Modification and Demonstration of Modular Capture with Low-aqueous Solvent										
Subtask 9.1 Modify Column B to Demonstrate Modular Design										
Subtask 9.2 Baseline Experiments with Commercial Packing										
Subtask 9.3 Experiments with Intensified MellaPak 250										
Task 10 - Collaboration with CCSI[2] on Modeling of Process Intensification with Column B Results										

Supply chain delays since Jan 2022 have resulted in ~2-quarters delay of the project

Technical Approach/Project Scope

- Scale up CO_2 capture rate by a factor of 10 from Column A to Column B
- Scale up intensified device
- Demonstrate enhanced capture by aqueous MEA using intrastage cooling
- Demonstrate enhanced capture by LAS using intrastage cooling
- Demonstrate modularization with one or more packing elements for each module
- Demonstrate smooth operation with variable gas feed flowrate and CO_2 concentration