FWP-FEAA 384

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

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National Energy Technology Laboratory
Carbon Capture, 2021 Integrated Review Webinar

August 12, 2021

Program Overview

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

- **Overall Project Performance Dates:**
  January 1, 2021 – December 31, 2022

- **Project Participants:**
  Costas Tsouris, Josh Thompson, Gyoung Jang, Jim Parks

- **Previous Project: FWP-FEAA375**
  January 1, 2020 – December 31, 2020
  Objective: Test intensified process with low-aqueous solvent

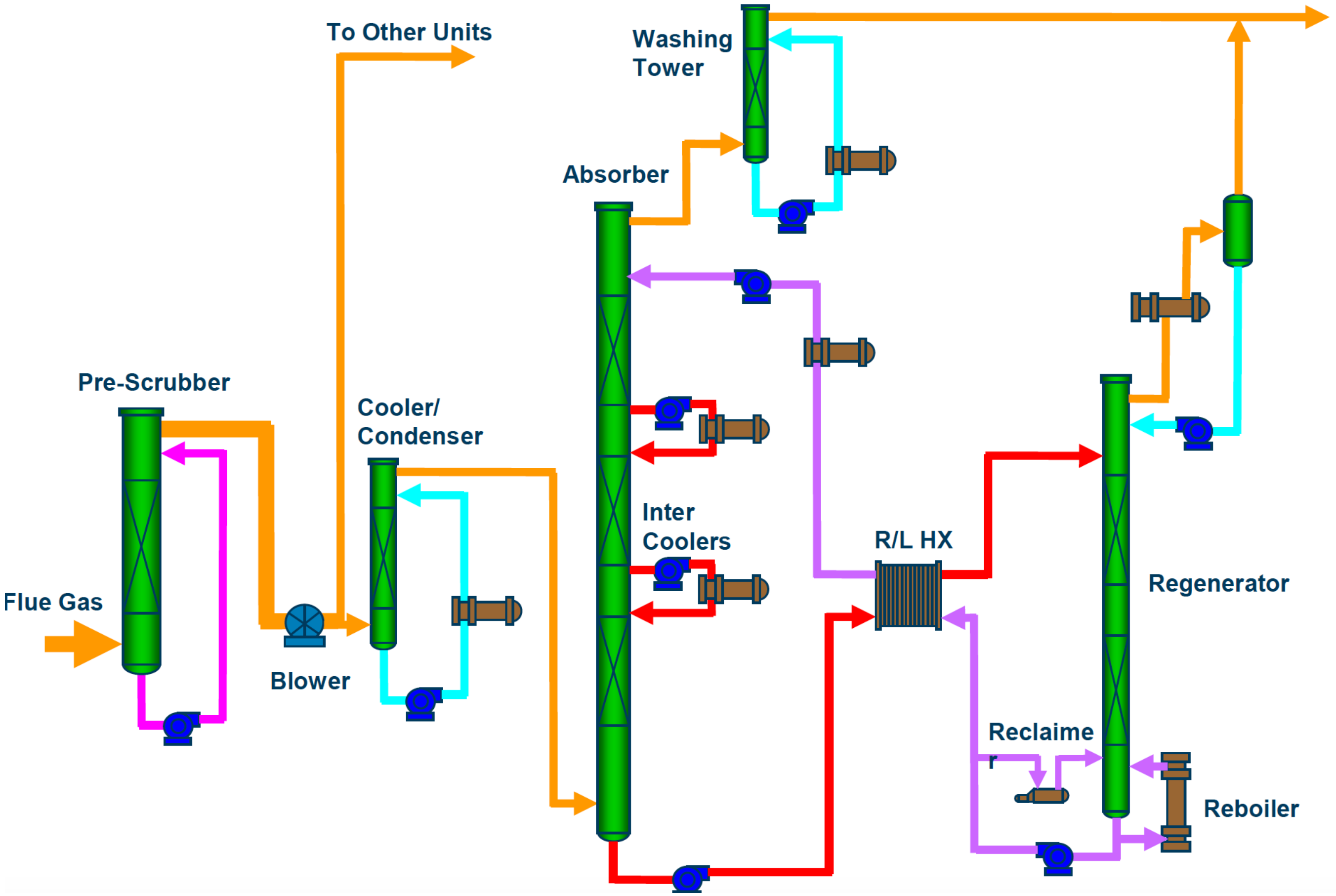
Overall Project Objectives

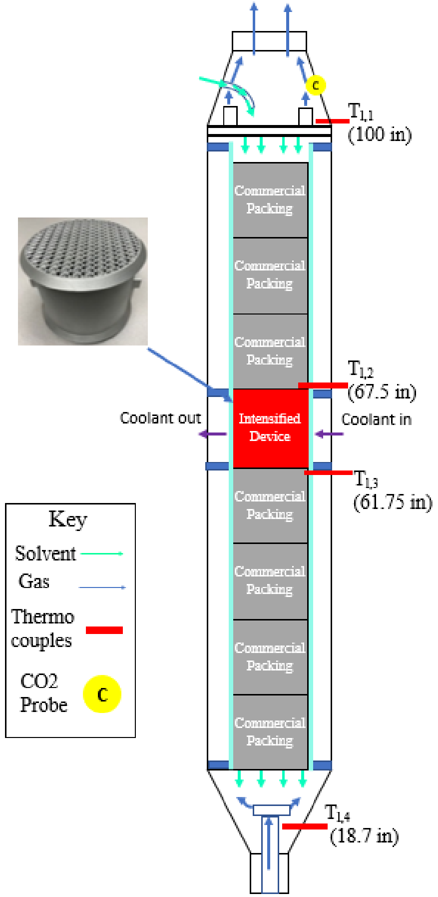
– Design, and construct a larger-scale column (Column B) than the one previously tested at ORNL to:

- Further demonstrate enhanced CO_2 capture with 3D printed intensified devices for aqueous amine-based capture at realistic operating conditions
- Demonstrate that Column B can be modularized with segmented packing elements and intensified devices for low-aqueous-solvent based capture
- Demonstrate that Column B can be used to effectively capture CO_2 from different CO_2 gas compositions and during process transients (i.e., capacity ramping up and down anticipating the intermittent nature of renewable generations).

Technology Background

How the technology is envisioned to work in operation:





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

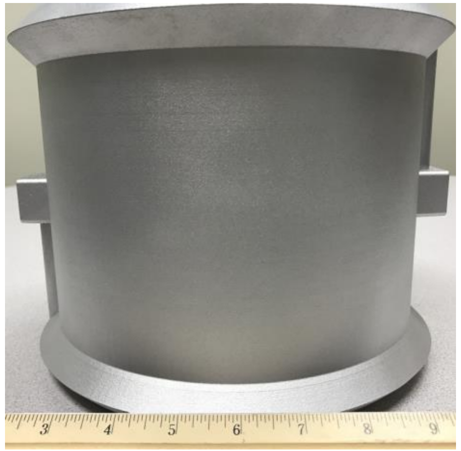
$2MEA + CO_2 \rightleftarrows MEAH^+ + MEACOO^-$ (+ 79-100 KJ/mol) **(Exothermic)**

Intensified packing device to allow *in situ* cooling

Oak Ridge National Laboratory

Technology Background

Technology development efforts prior to current project:

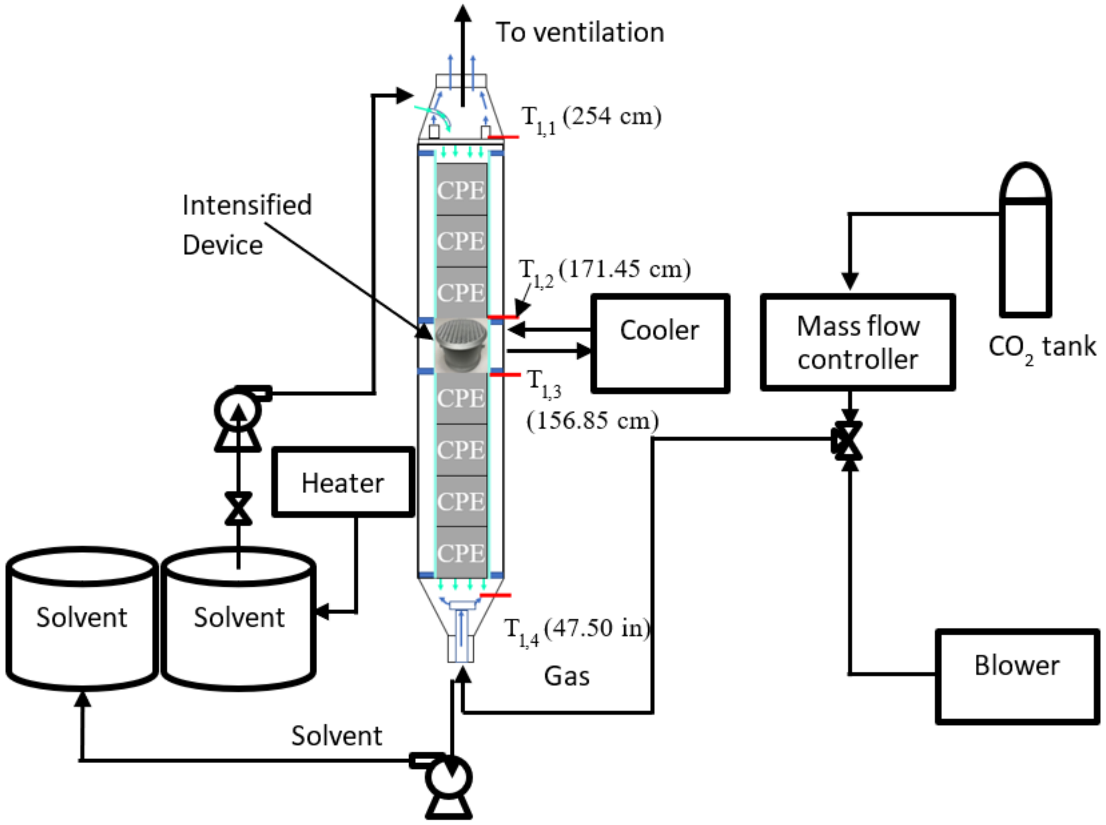


- System tested for hydraulic and heat transfer performance with favorable results

Miramontes, E.; Love, L.J.; Lai, C.; Sun, X.; Tsouris, C. Additively Manufactured Packed Bed Device…, *Chem. Eng. J.*, **388**, 124092, (2020).

Technology Background

Tests for CO_2 capture enhancement:



Schematic of testing facility and absorption column

CPE: Commercial Packing Element

Technology Background

Testing of intrastage cooling with aqueous 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).

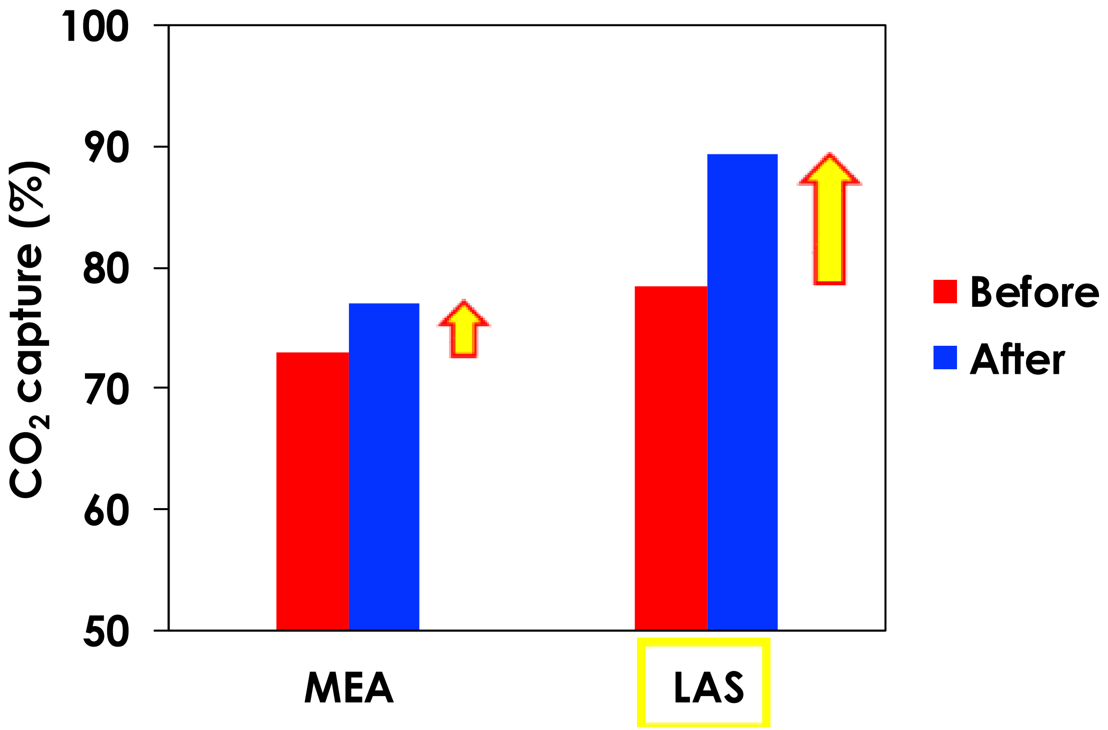
Technology Background – Testing with RTI's low-aqueous solvent

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

- Jang, G.G.; Thompson, J.A.; Sun, X.; Tsouris, C. "Process Intensification of CO_2 Capture by Low-Aqueous Solvent," *Chemical Engineering Journal*, **426**, 131240, (2021).

Comparison of MEA and LAS Performance

	MEA	LAS
Feed temperature (℃)	70	40
Avg. Temperature **before cooling**	72.0 ± 9.9	54.5 ± 5.5
Avg. Temperature **after cooling**	60.5 ± 13.9	45.3 ± 6.8



15% CO_2 600 LPM/ Solvent flowrate of 3.2 LPM

LAS is more heat-sensitive compared to aqueous MEA

- Jang, G.G.; Thompson, J.A.; Sun, X.; Tsouris, C. "Process Intensification of CO_2 Capture by Low-Aqueous Solvent," *Chemical Engineering Journal*, **426**, 131240, (2021).

Technical Approach/Project Scope

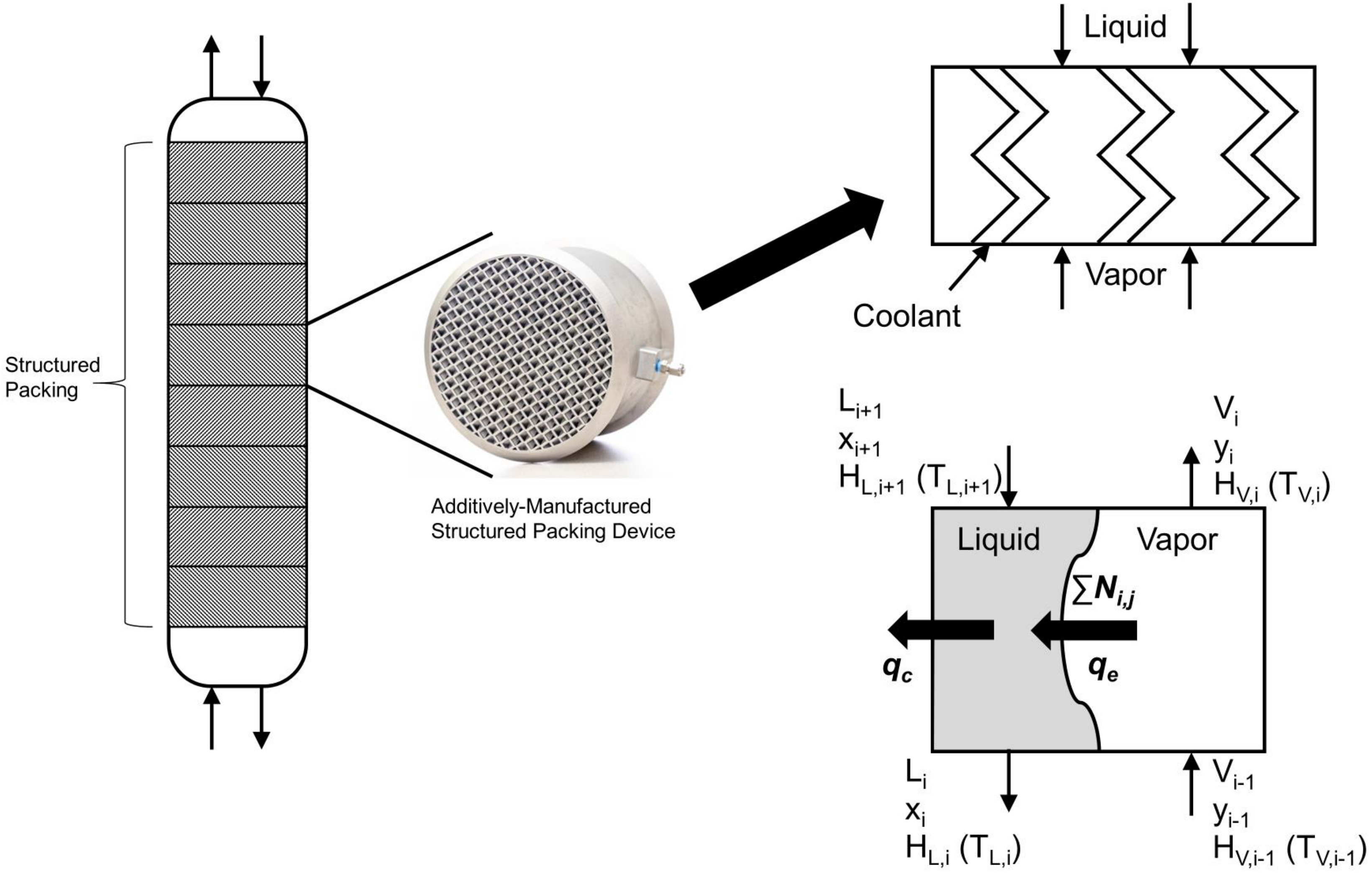
- Scale up CO_2 capture rate by a factor of 10 from Column A to Column B
  - Construct Column B
- Scale up intensified device
- Demonstrate enhanced capture by aqueous MEA using intrastage cooling
- Demonstrate enhanced capture by LAS using intrastage cooling
- Demonstrate modularization with one or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

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

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)
    - Model needed
- **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)

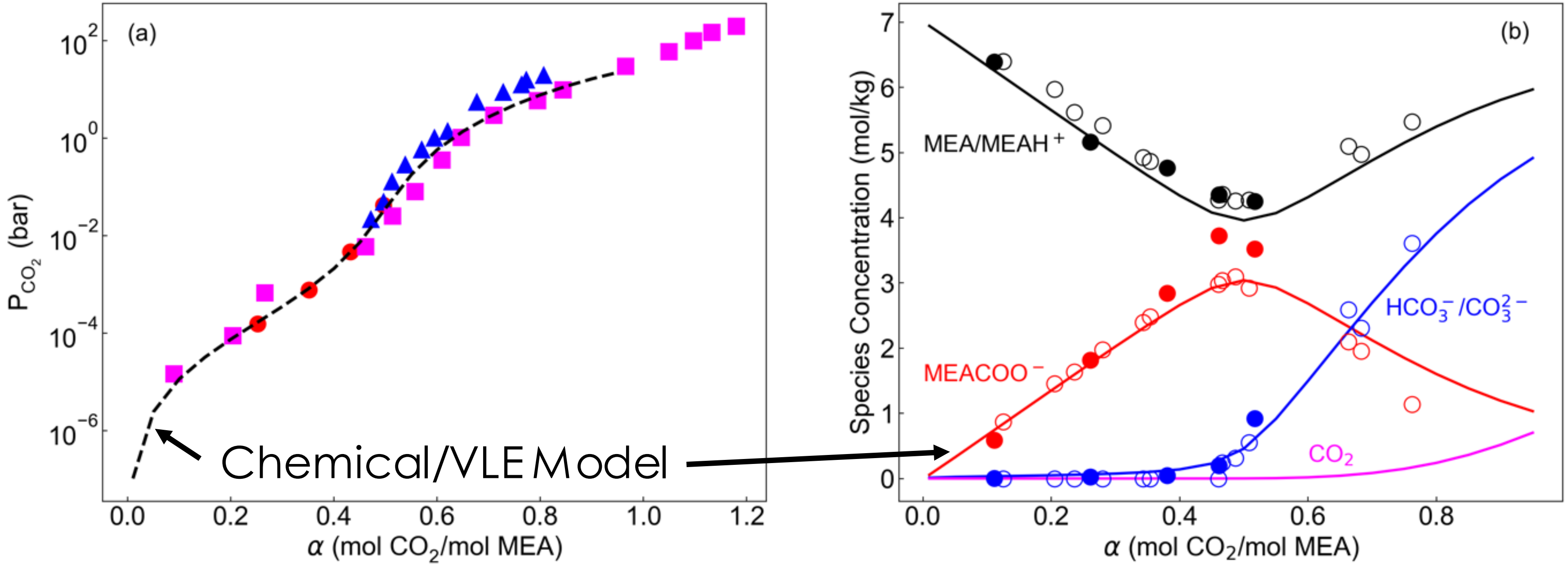
Progress and Current Status of Project
Modeling Framework:



Thompson, Tsouris, "Rate-Based Absorption Modeling for Post-Combustion CO_2 Capture with Additively-Manufactured Structured Packing", *Submitted*.

Modeling Framework

MEA
30 wt%



- Chemical & Vapor-Liquid Equilibria with Kent-Eisenberg Equations
- Rate-based model utilizes Wang-Song-Rochelle correlations for mass transfer and Enhancement factor models for reaction
- Model validated with published CO_2 solubility and pilot data

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Modeling Framework

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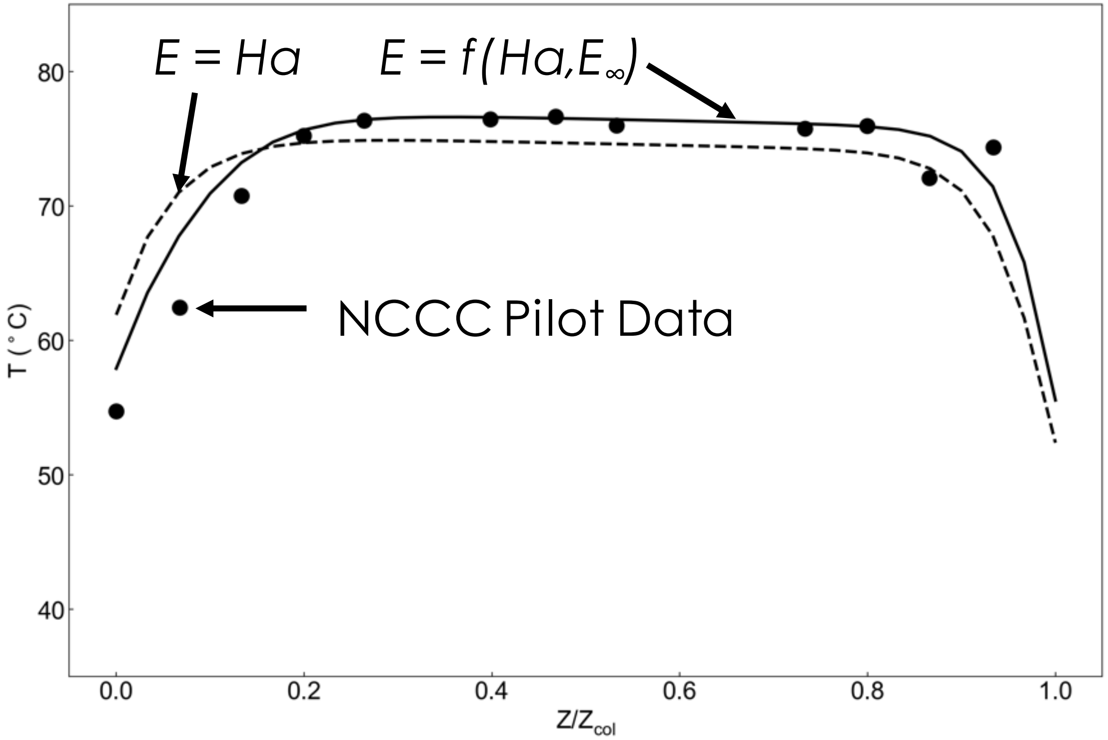

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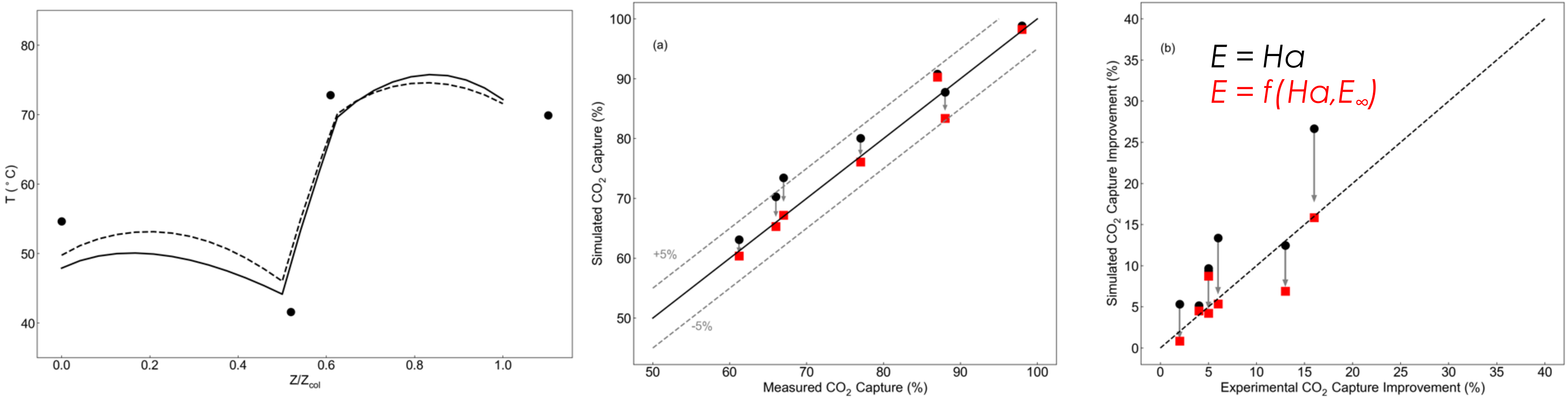
Modeling MEA w/Intrastage Cooling

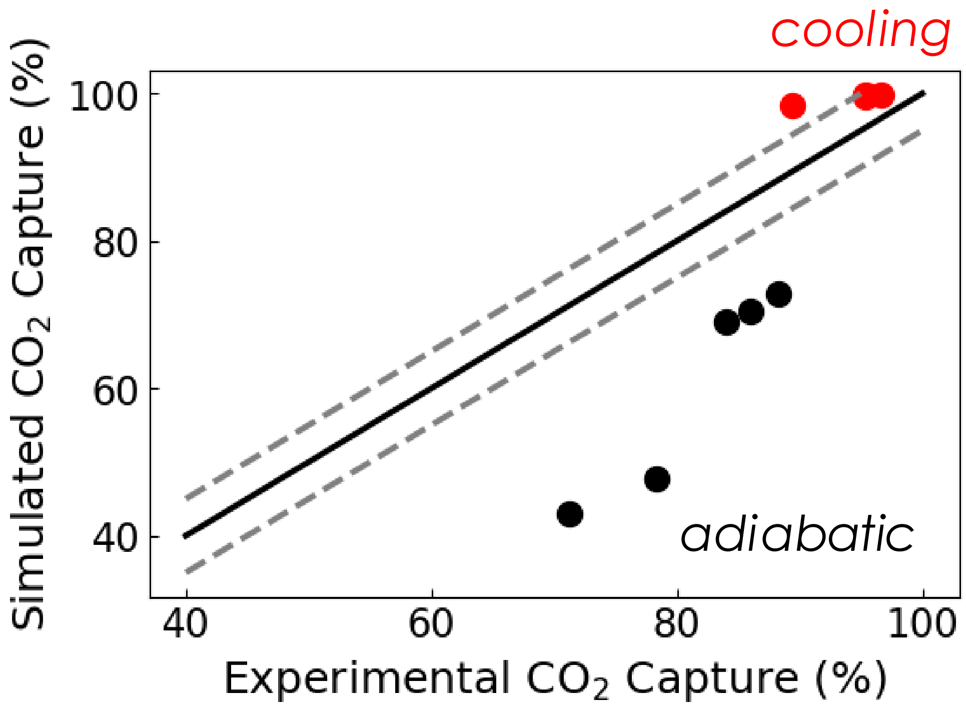


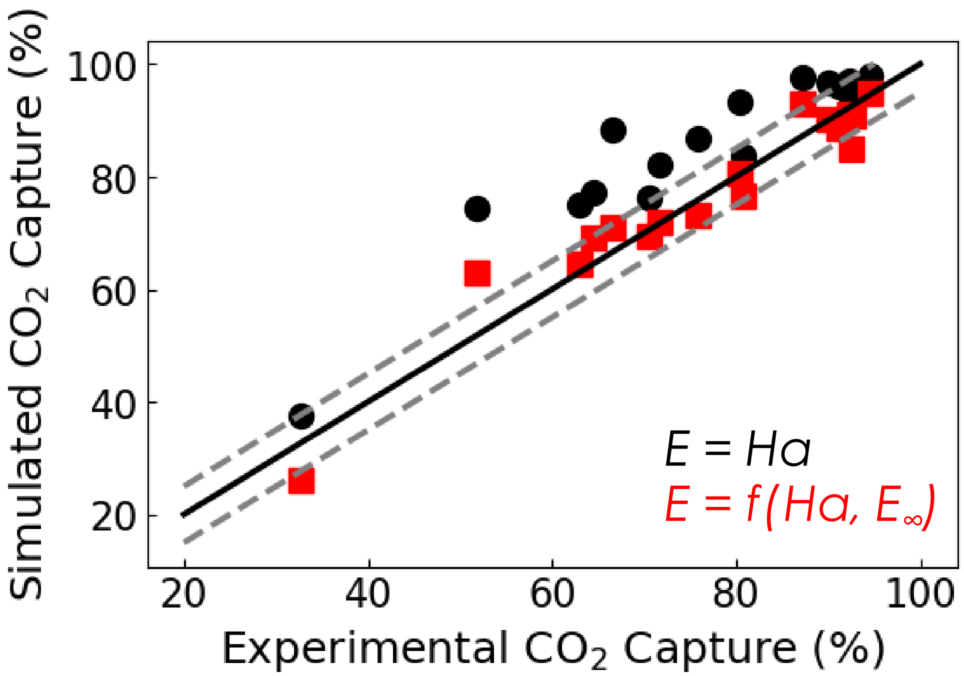
- Simulation of intrastage cooling with device shows good agreement with experiments from Miramontes *et al*.
  - CO_2 Capture difference all <= 5%
- CO_2 capture improvement and temperature profile agreement suggests modeling framework for heat transfer is accurate in predicting device performance

Thompson, Tsouris, "Rate-Based Absorption Modeling for Post-Combustion CO_2 Capture with Additively-Manufactured Structured Packing", *Submitted*.

Modeling Framework Applied to Other Solvents

- In process of extending modeling framework to other solvents
- Speed up evaluation of alternative solvents and how intensified device may improve CO_2 capture
- Currently applied to aqueous piperazine (PZ) and a low-aqueous solvent (LAS)

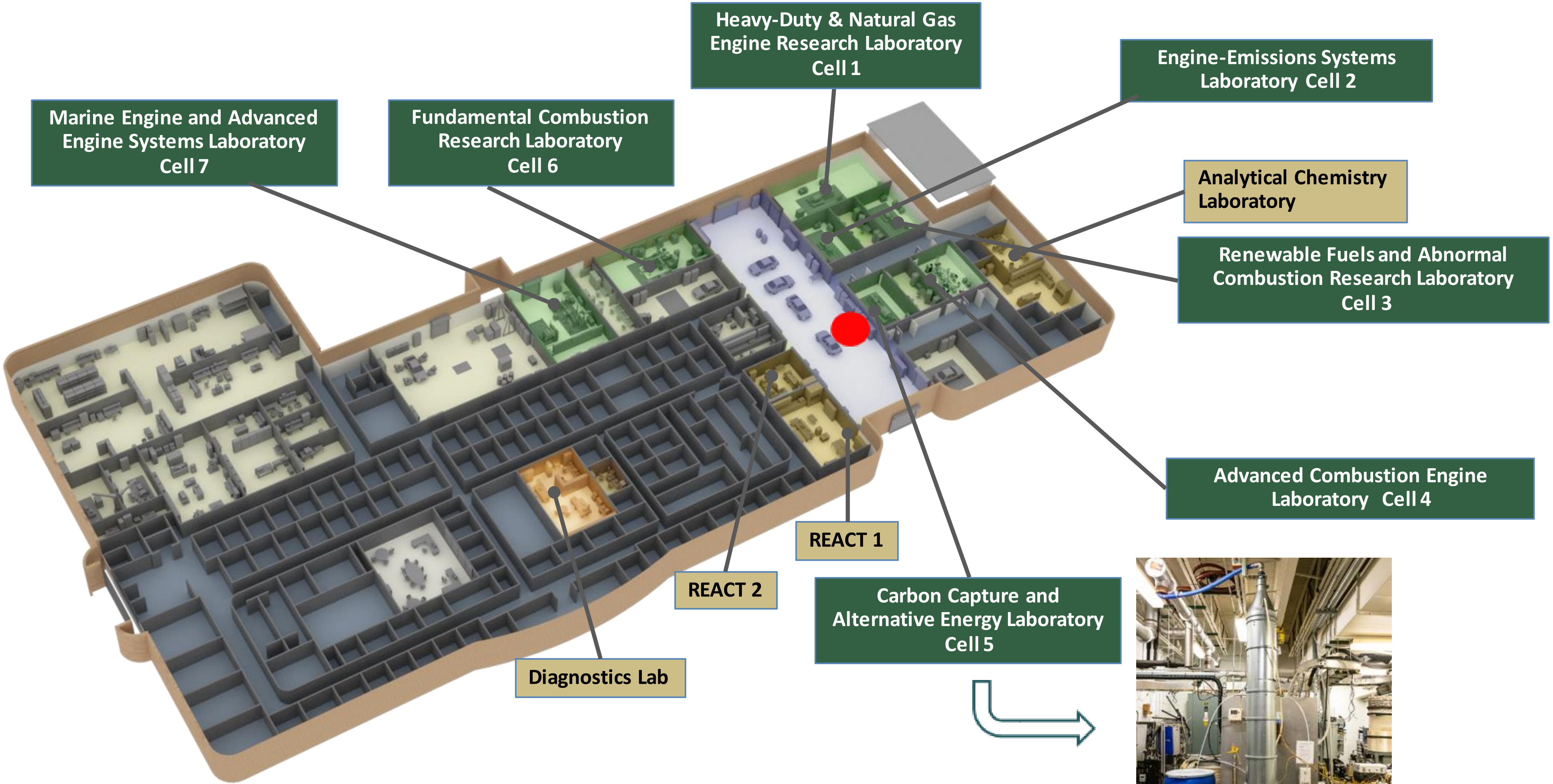




LAS Pilot Data Jang et al., Chem. Eng. J., 2021, Vol. 426, 131240

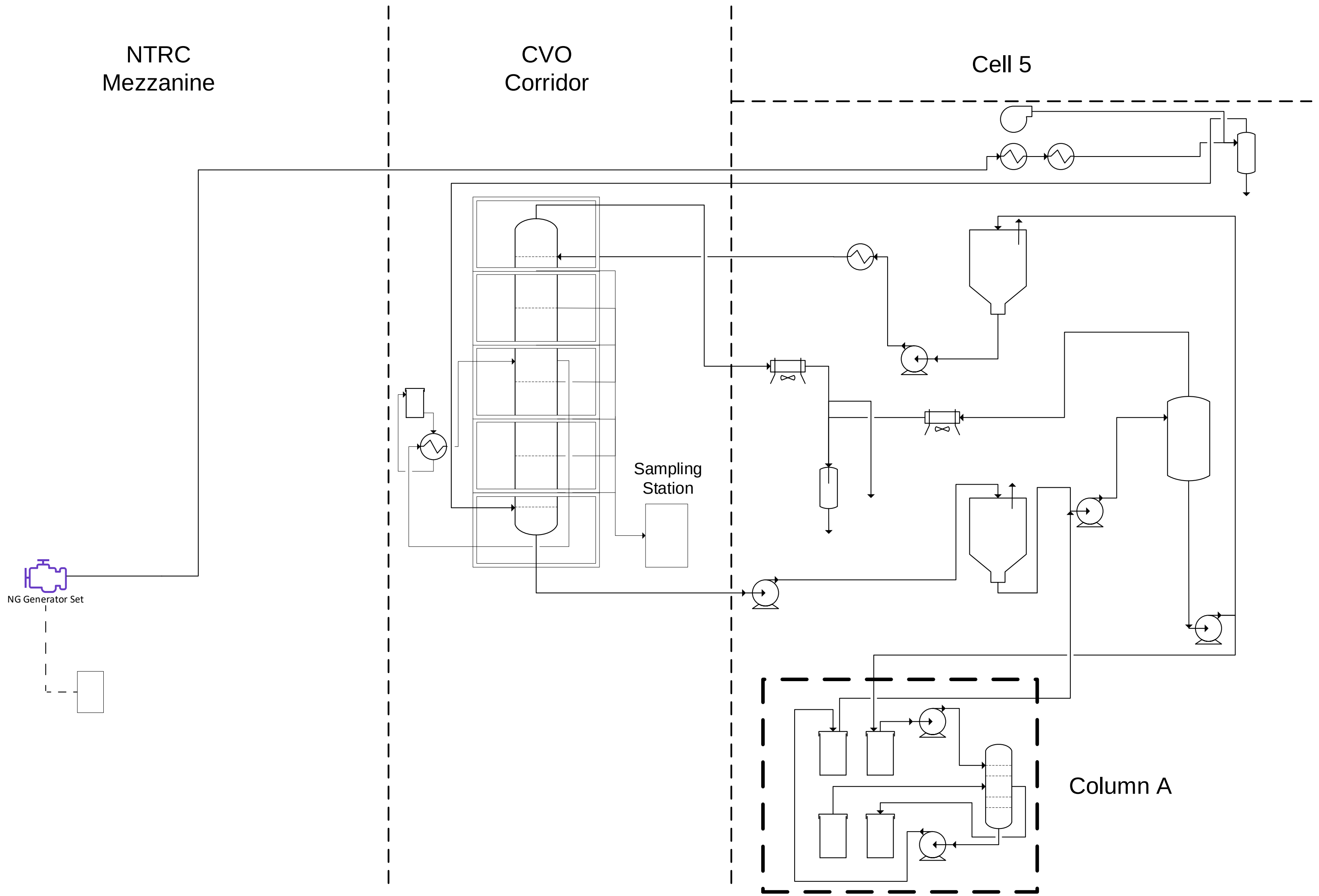
PZ Pilot Data Plaza, Ph.D. Thesis 2012

Location of New Column



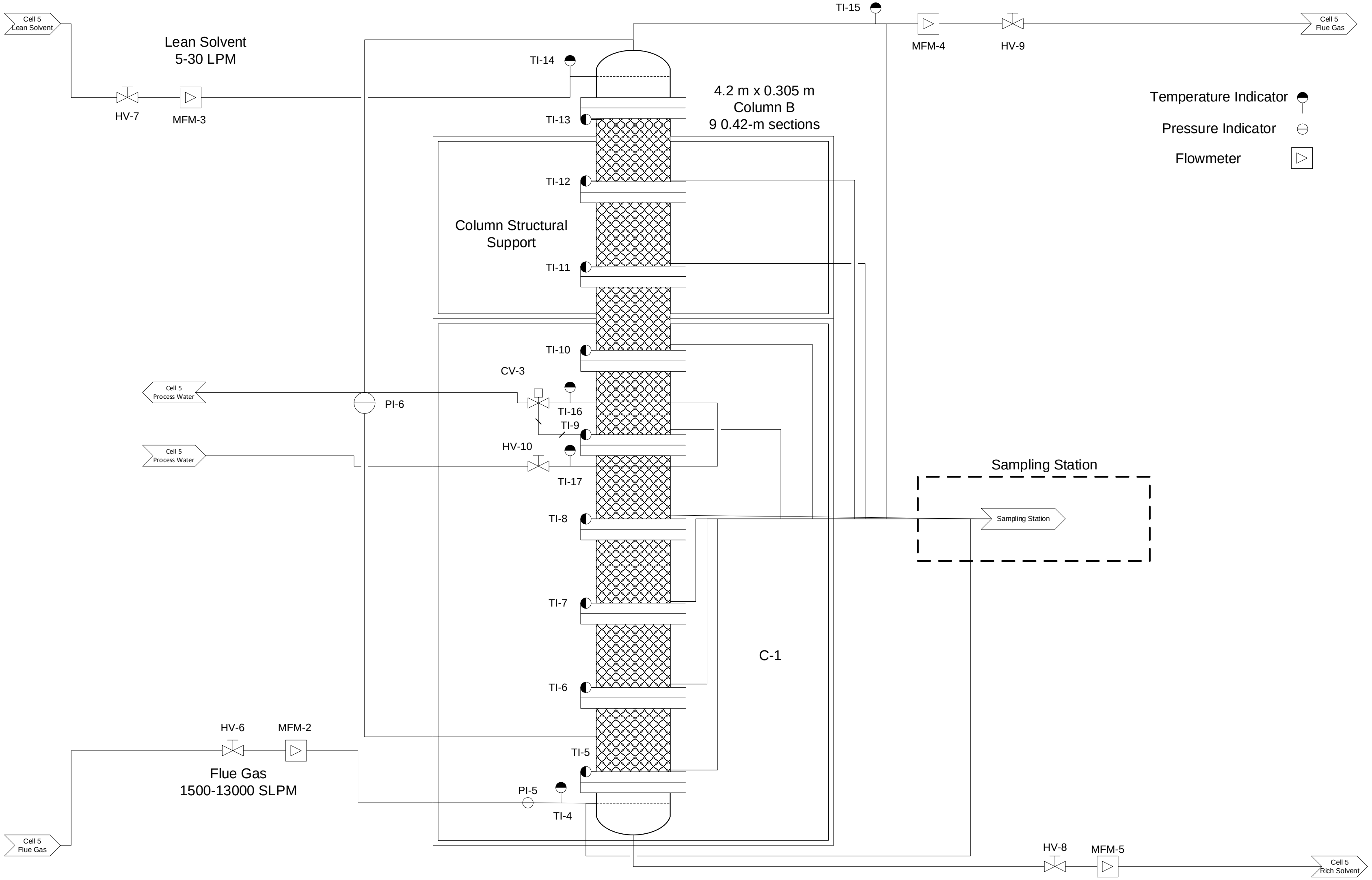
National Transportation Research Center
ORNL Hardin Valley Campus

Process Flow Diagram for Column Design



Process flow and equipment is essential to proper design around absorption column

Modular Column Design

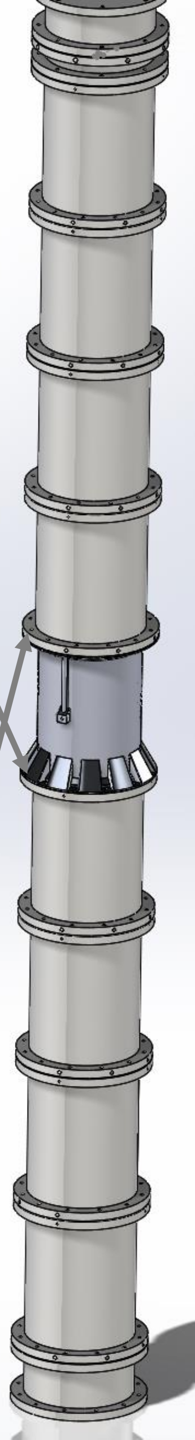


Modular column design provides flexibility in testing packing locations and gas/liquid axial sampling

Scale-up of Intensified Device from 8” to 12” Diameter

- New unit cell geometry
- Added flanges and hole pattern for system integration
- Added supports for printability

For Column A



For Column B

Current Status of Project

– Currently working on Column B construction with significant progress in all supporting subsystems:

- Column B, including modular sections with packing elements
- Intensified devices
- Gas generator and load bank systems
- Gas conditioning systems for the feed and exhaust gases
- Gas and solvent delivery systems
- Solvent storage and regeneration systems
- Sensors and controls for the column and data acquisition systems

Plans for Future Testing/Development/Commercialization

- Construction of Column B and hydraulic testing expected to be completed by end of Quarter 1 of FY 2022
- Testing with aqueous MEA will be initiated in Quarter 2 of FY 2022
- The geometry of the intensified device, as well as location of intensified devices along the column, are being optimized under a TCF project
- Under the TCF project, a surface coating has been successfully tested to prevent corrosion of the intensified device in aqueous MEA
- The partners on the TCF project including Volunteer Aerospace, RTI International, Oxford PM, and AristoSys are actively engaged and are willing to help toward commercialization

Summary

- Work in all tasks of the project has progressed well so far
- Spending rate has been slow because equipment purchasing has been slow, but it is expected to increase this Quarter
- Quotes for most of the equipment needed have been obtained
- Modeling work has been very helpful for column design
- Efforts toward commercialization are progressing well
- Previous work under FEAA130 and FEAA375 has been published
- Additional manuscripts supported by FEAA384 and the TCF project have been submitted for publication in July of 2021

Publications

- Bolton, S.; Kasturi, A.; Palko, S.; Lai, C.; Love, L.; Parks, J.; Sun, X.; Tsouris, C. "3D Printed Structures for Optimized Carbon Capture Technology in Packed Bed Columns," *Sep. Sci. Technol.*, **54**, 2047-2058 (2019). doi.org/10.1080/01496395.2019.1622566.
- Miramontes, E.; Love, L.J.; Lai, C.; Sun, X.; Tsouris, C. Additively Manufactured Packed Bed Device for Process Intensification of CO_2 Absorption and Other Chemical Processes, *Chem. Eng. J.*, **388**, 124092, (2020). doi.org/10.1016/j.cej.2020.124092.
- 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). doi:10.1002/aic.16285.
- Jang, G.G.; Thompson, J.A.; Sun, X.; Tsouris, C. "Process Intensification of CO_2 Capture by Low-Aqueous Solvent," *Chem. Eng. J.*, **426**, 131240, (2021). https://doi.org/10.1016/j.cej.2021.131240.
- Thompson, J.A.; Tsouris, C. "Rate-Based Absorption Modeling for Post-Combustion CO_2 Capture with Additively-Manufactured Structured Packing," *Ind. Eng. Chem. Res.*, submitted, 2021.
- Jang, G.G.; Jun, J.; Su, Y.-F.; Keum, J.K.; DeFelice, V.; Decarmine, T.; Jones, J.; Tsouris, C. "Corrosion Prevention of Additively Manufactured Aluminum Packing Devices Developed for Process Intensification of CO_2 Capture by Aqueous Amines," *Ind. Eng. Chem. Res.*, submitted, 2021.

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