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Reimagining the carbon ecosystem

Integrated Bench-Scale Testing of a Structured Sorbent for Direct Air Capture

DE-FE0032243

Presented by
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Arnold C. Toppo
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2024 Carbon Management Research Project Review Meeting

Project Overview

Title	**Integrated Bench-Scale Testing of a Structured Sorbent for Direct Air Capture**
Funding Solicitation	DE-FOA-0002614 AOI2B
Award No.	DE-FE0032243
Period of Performance	7/01/2023 – 06/30/2026
Project Funding	DOE: $3M Cost-Share: $0.75M
Overall Project Goal	Design, build, and test an integrated bench-scale DAC system for continuous production of >1 TPY CO_2 using the electrically heated structured material assembly (SMA)
Project Participants	Susteon Inc. and TotalEnergies
DOE/NETL Project Manager	Mr. Zachary Roberts

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Technical Approach and Project Scope

Objective:

Reduce the overall cost of DAC through the development of a structured material assembly (SMA) and integrated DAC system design with sorbent regeneration using low-carbon electricity (TRL 4 to TRL 5).

Approach

1. Perform a detailed technical risk assessment to identify high-risk areas.
2. Design and optimize SMA manufacturing and performance.
3. Design, build, test integrated Bench-scale system for >1TPY CO_2 production.
4. Refine and update process and economic model.
5. Refine commercialization plan.

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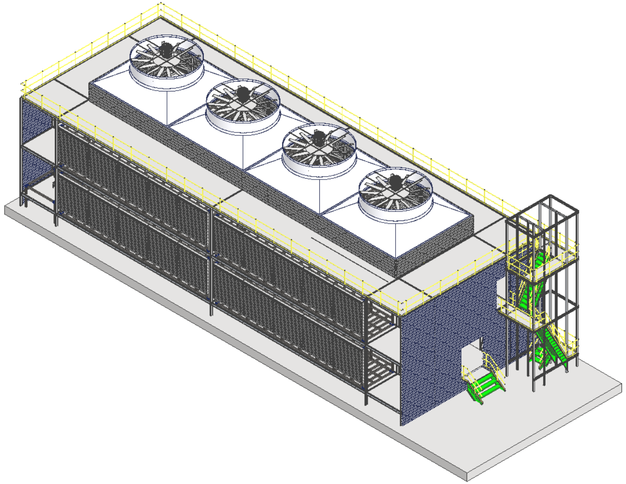
Susteon’s Sorbent-Based DAC Technology

Innovative
Efficient heating to minimize heat losses

Synergistic
Beneficial effect of atmospheric moisture

Efficient
Low desorption energy (~65 kJ/mol)



Inexpensive
Abundantly available sorbent precursors

Accelerated
Fast adsorption + desorption kinetics

Scalable
Modular design utilizing existing supply chains

Technology Roadmap

TRL

4

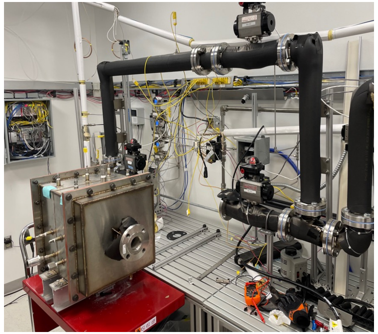
3

2

1

Bench-Scale Component Testing

(1 kg/day)

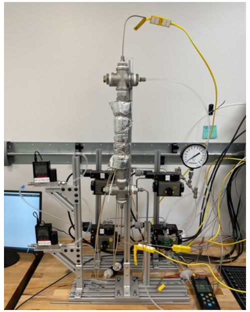


- ❑ Optimized sorbent and heating material washcoat synthesis on selected structured sorbent
- ❑ Verified performance of structured sorbent for adsorption and desorption under Joule heating

Lab-scale Reactor Testing

(3 g/day)

- ❑ Verified sustained performance of structured sorbent
- ❑ Proof of concept resistive layer coating showing high CO_2 desorption rates



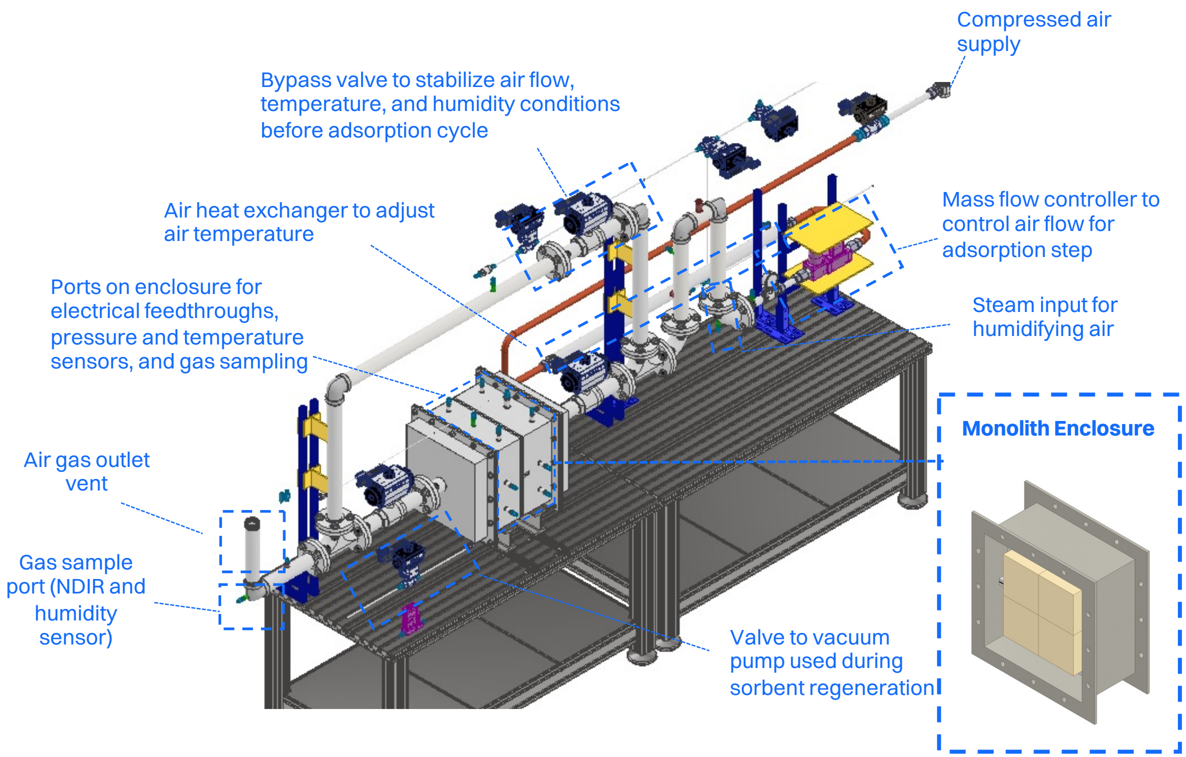
Lab-scale TGA Testing

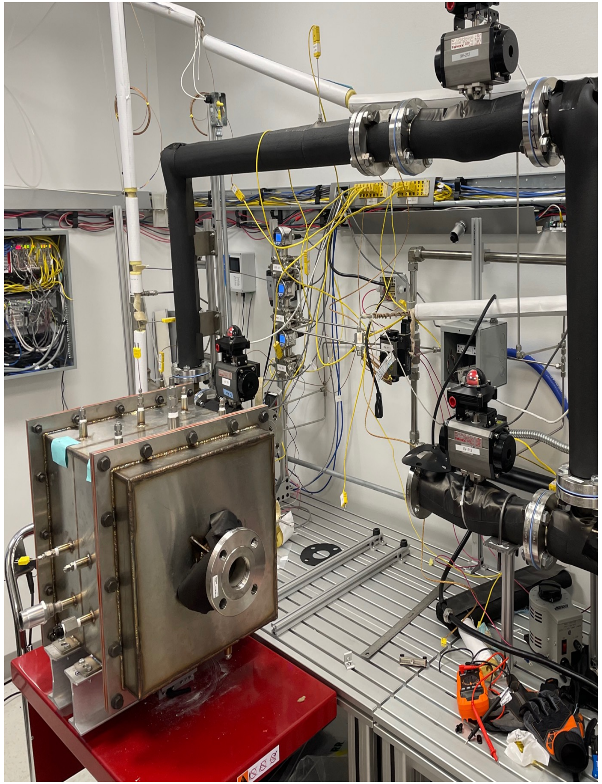
- ❑ Na-based sorbent selected
- ❑ Elucidation of reaction pathway

2020 | 2021 | 2022 | 2023

Bench-Scale Component Testing (FE0032118)

1 kg/day Bench Unit Design





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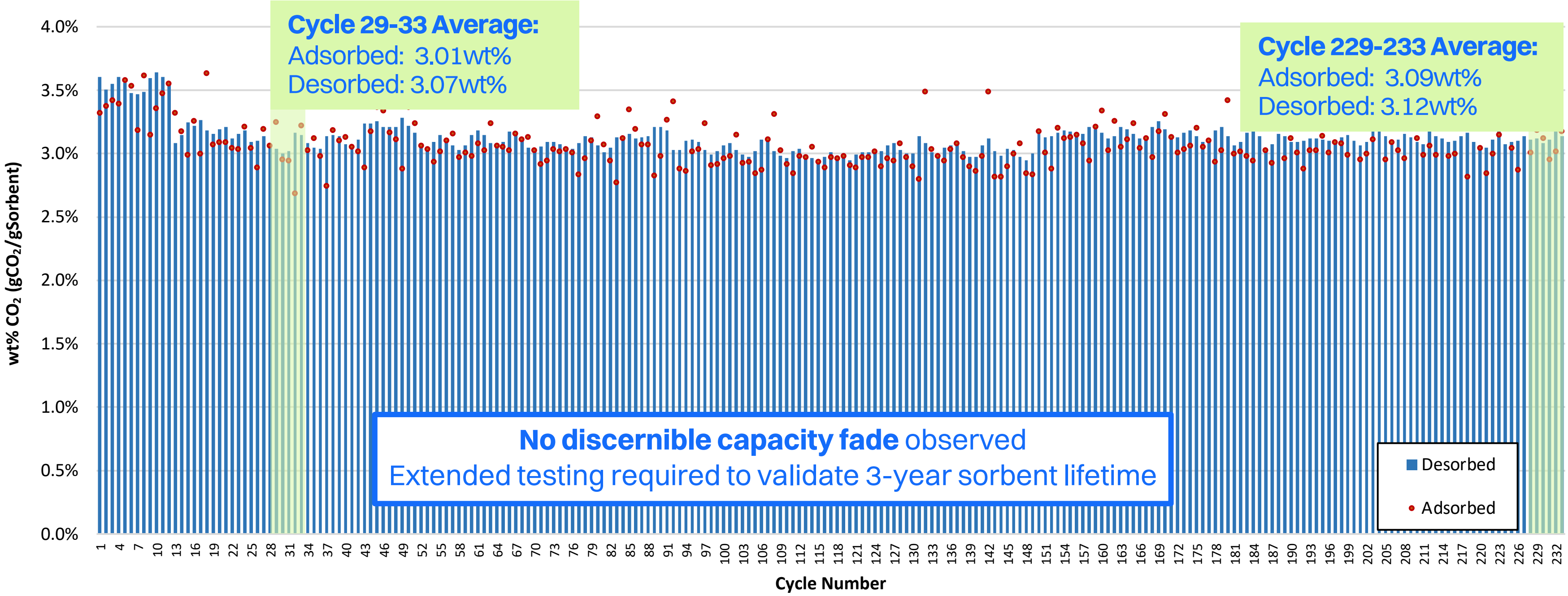
Bench-Scale Component Testing (FE0032118)

CO_2 Capacity Summary

Adsorption
Air Flow: 413 slpm (65 lb/hr)
Temperature: 20-30°C
WHSV: 270 hr^{-1} (based on sorbent mass)
Relative humidity: ~ 50%
Duration: 45 minutes

Desorption
N_2 flow: 4 slpm
Max temperature: 100° C
Ramp rate: 8°C/min
Vacuum purge pressure: -8 psig
Duration: 120 minutes



No discernible capacity fade observed
Extended testing required to validate 3-year sorbent lifetime

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Technology Roadmap

TRL

8

7

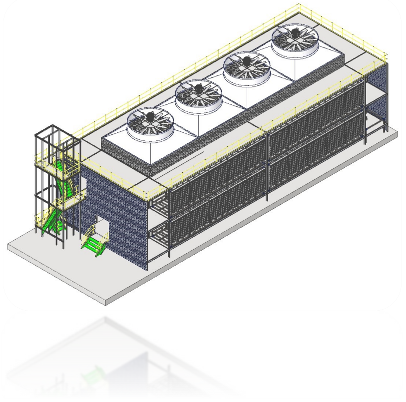
6

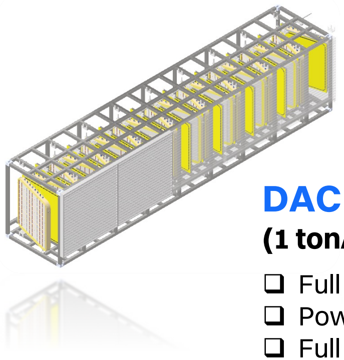
5

DAC Plant Demonstration Plant

(15 ton/day)

- ❑ Fully integrated DAC unit operations
- ❑ Heat integration
- ❑ Variability in site ambient conditions
- ❑ CPU performance, BOP performance and reliability





DAC Module Demonstration

(1 ton/day)

- ❑ Full scale Module testing
- ❑ Power distribution (at module scale) validation
- ❑ Full scale sealing performance

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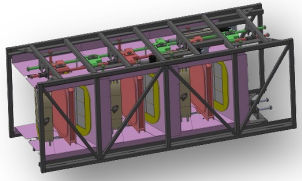

Integrated Bench-scale System **(>3 kg/day)**

- ❑ Continuous, high purity CO_2 production
- ❑ Engineering design validation
- ❑ >1000 cycle stability

2024 2025 2026 2028

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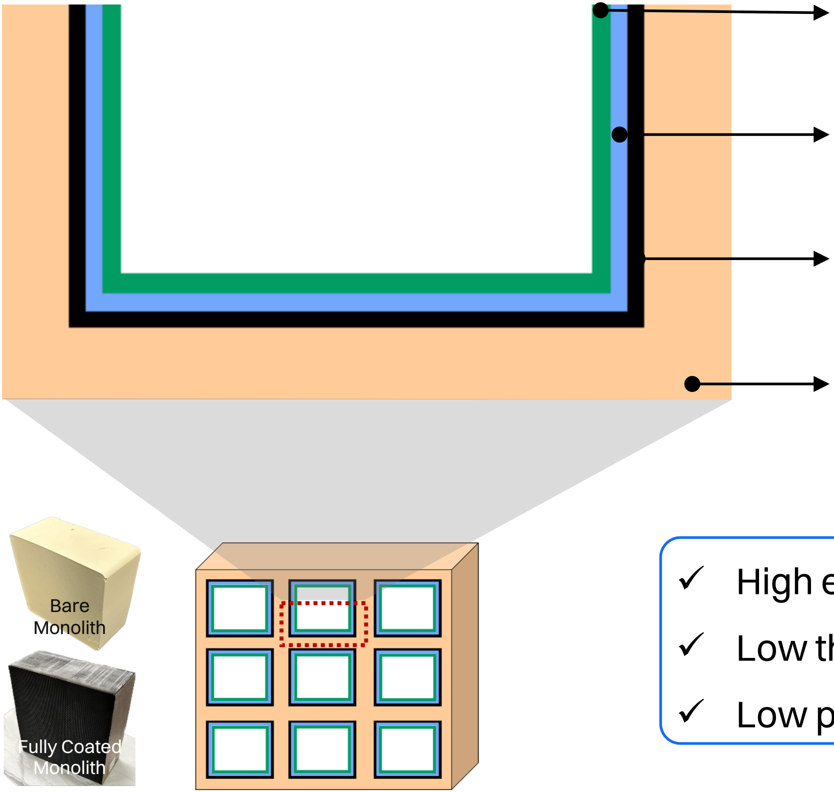
Structure Material Assembly (SMA)



Sorbent Layer

Tailored composition for enhanced CO_2 capacity in humid air

Support Layer

Porous, high surface area support for sorbent

Resistive Heating Layer

Direct, targeted, electric heating of sorbent

Substrate

Excellent structural support, surface area, porosity, and mechanical strength

- ✓ High electric to thermal heating efficiency (up to 95%)
- ✓ Low thermal mass (~50 wt% washcoat loading)
- ✓ Low pressure drop (<200 Pa)

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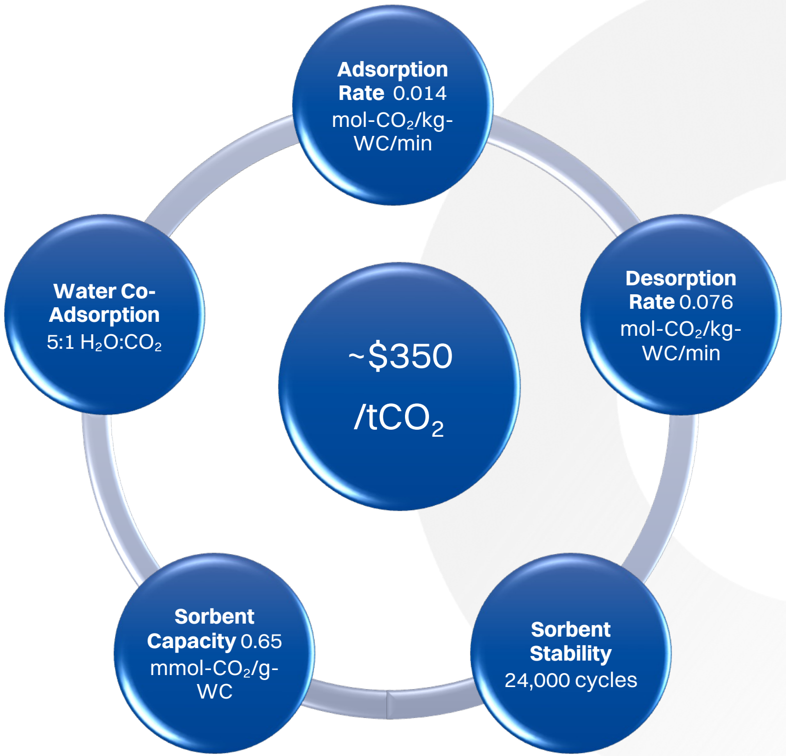
Initial TEA Results

SMA Performance Drives Cost of CO_2 Production

KPI		Impact
1. CO_2 Capture Kinetics	→	Productivity
2. CO_2 Working Capacity	→	CO_2 Purity CO_2 Desorption Energy
3. Stability	→	SMA Lifetime
4. Water Co-Adsorption	→	CO_2 Desorption Energy
5. Pressure Drop	→	Adsorption Energy



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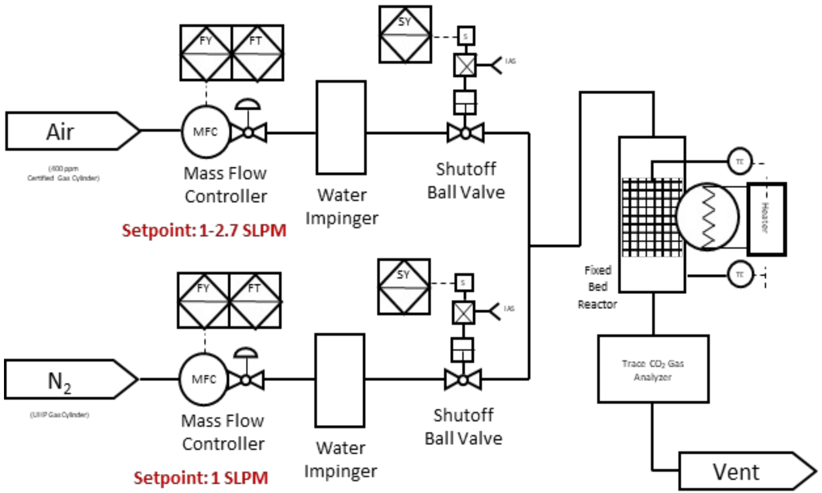
SMA Manufacturing: Adsorption Enhancement

Laboratory SMA Testing

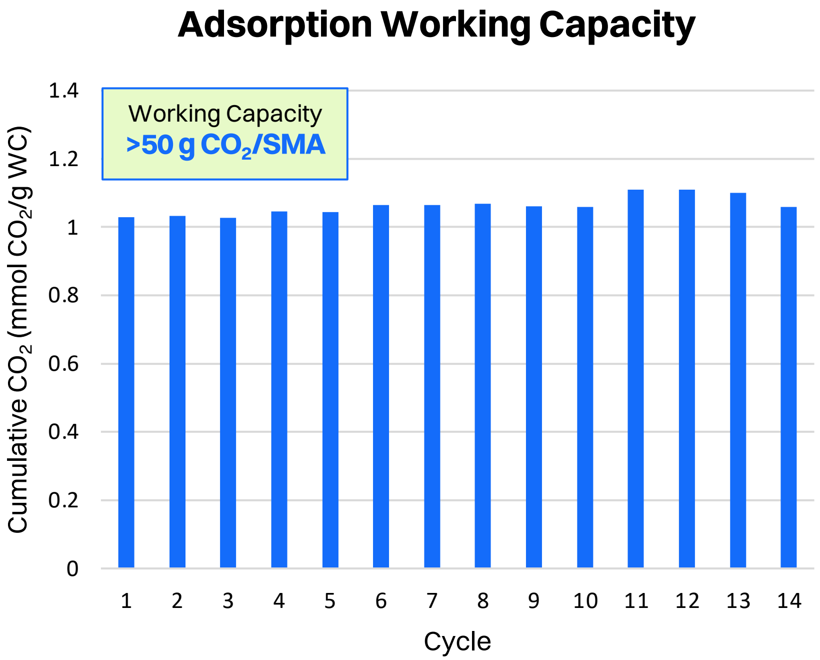


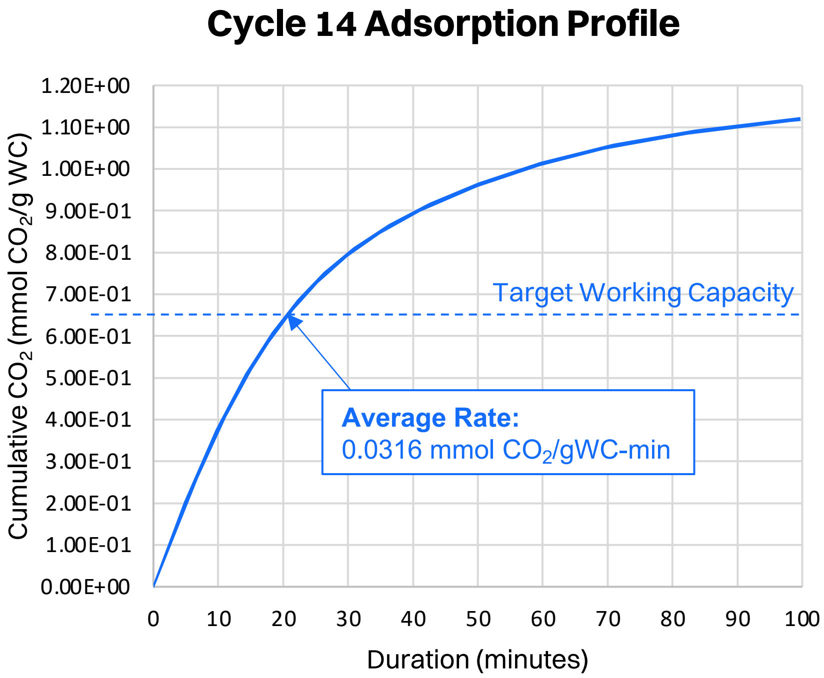
Increased CO_2 capacity of SMA by over 4x

via SMA Optimization

- **Sorbent**
  Tuned promoter and alkali carbonate ratio
- **Support**
  Doubled surface area and pore volume for greater sorbent active site accessibility to CO_2 in air
- **Substrate**
  Enhanced surface area resulting in 80% increase in washcoat loading

SMA Manufacturing: Adsorption Enhancement





Exceeded target adsorption rate by **125%**
Increased volumetric productivity = lower CAPEX

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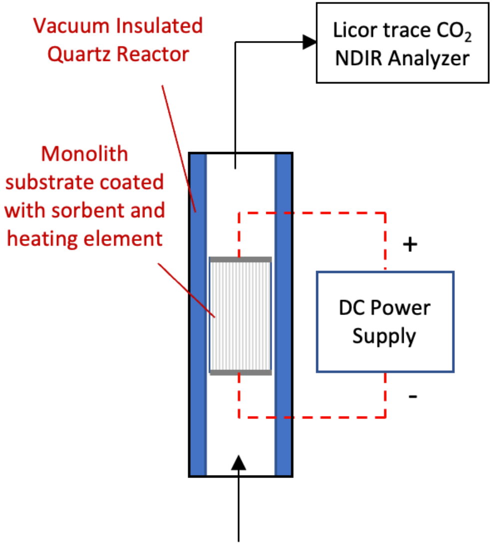
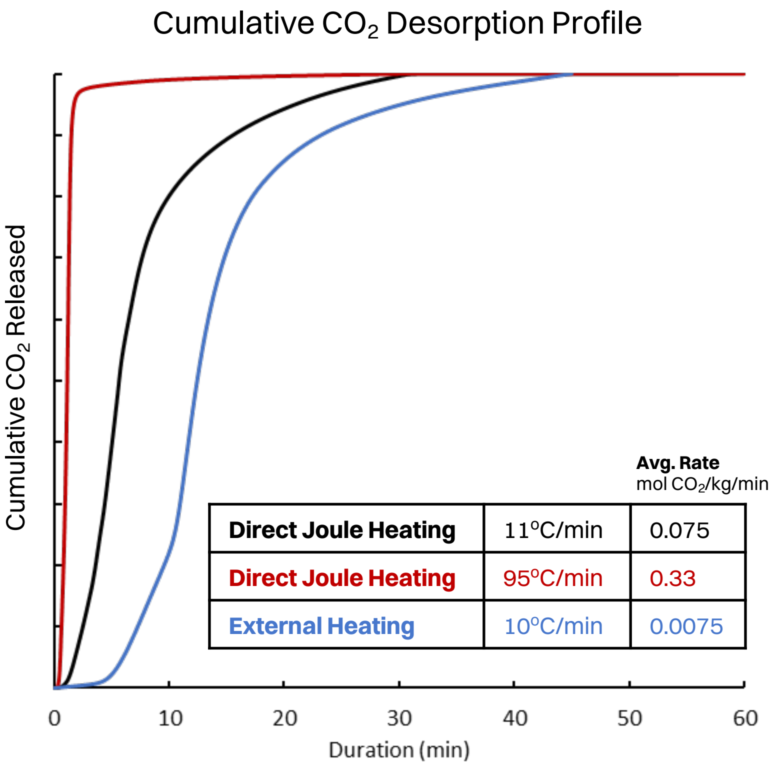
SMA Manufacturing: Desorption Performance



Adsorption: 1 slpm 400 PPM CO_2 Air
Desorption: 0.5 slpm UHP N_2



Target desorption rates achieved using direct Joule Heating

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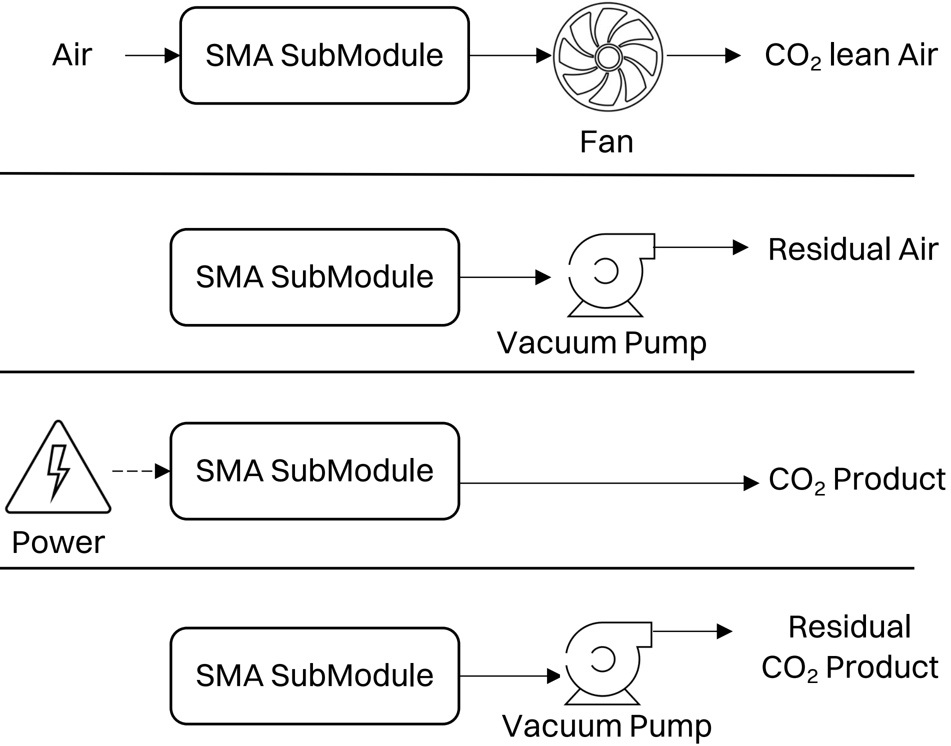
Integrated DAC Bench System: Process Sequence

State	Step	Duration
Open	**Adsorption**	45 Minutes
Closed	**Air Evacuation**	2.5 Minutes
Closed	**CO_2 Desorption**	9 Minutes
Closed	**CO_2 Recovery**	5 Minutes

Step Description



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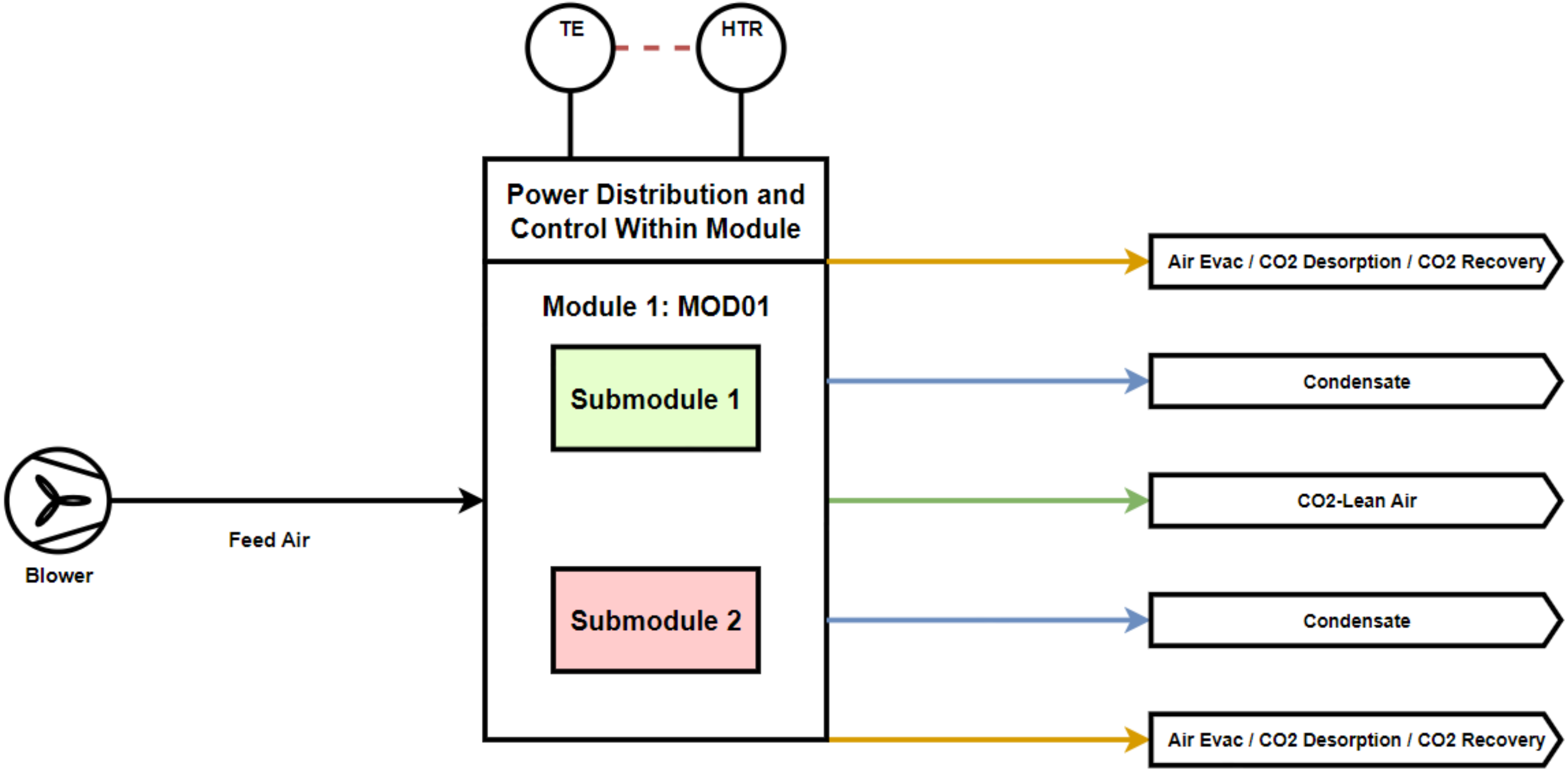
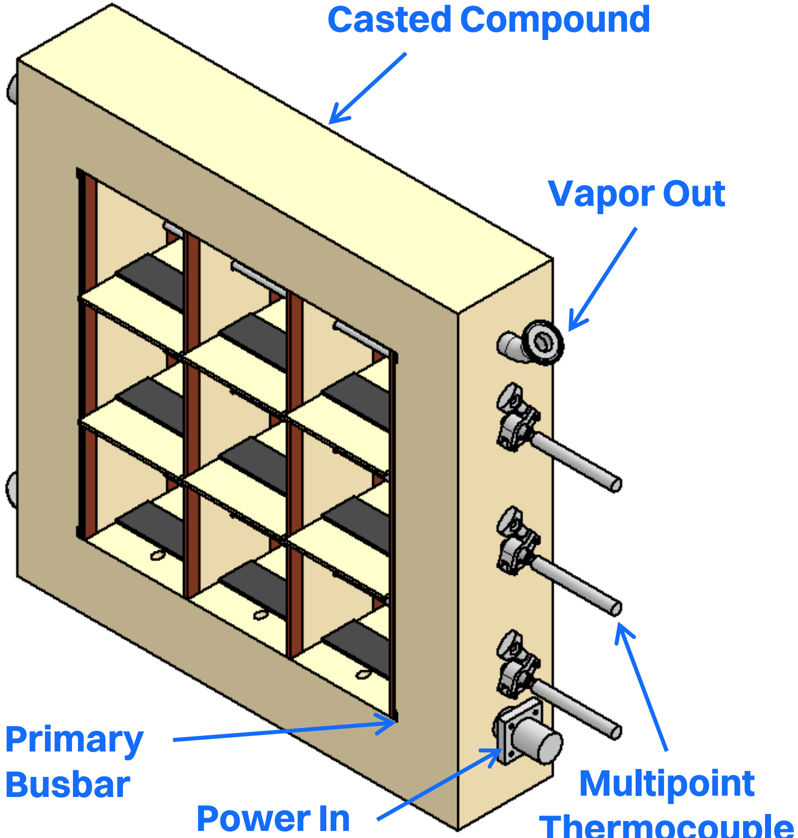
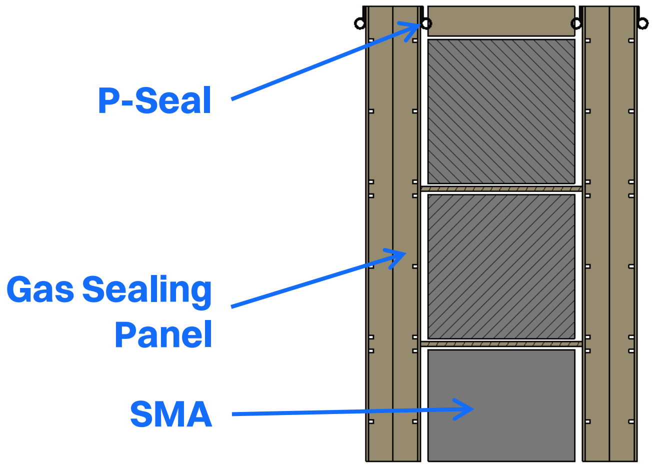
Integrated DAC Bench System: Process Flow Diagram



Integrated DAC Bench System: SubModule Design





1. Minimizing dead volume **increases CO_2 purity**.
2. Increased CO_2 purity **reduces CAPEX and OPEX** in OSBL downstream CO_2 purification.
3. Inherently thermally and electrically insulating material **reduces parasitic energy loss and electrical safety risk.**

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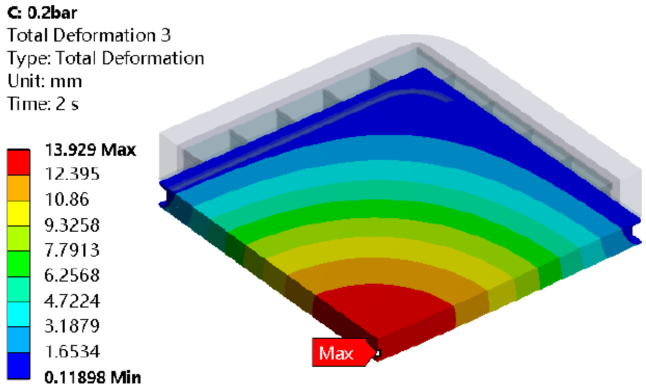
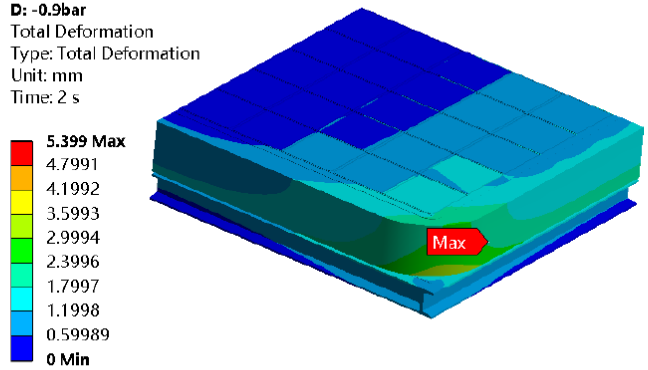
Integrated DAC Bench System: SubModule Design

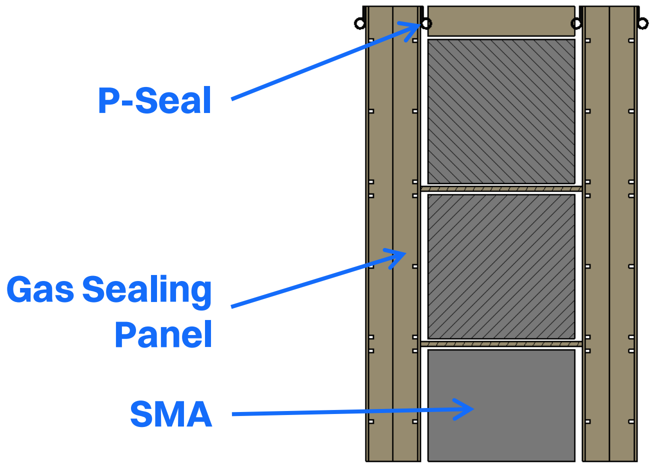
CO_2 Desorption



Air Evacuation, CO_2 Recovery



Aluminum Honeycomb Gas Sealing Panel
(3"/7.62mm core thickness, 0.003"/0.0762mm skin thickness)



1. Minimizing dead volume **increases CO_2 purity**.
2. Increased CO_2 purity **reduces CAPEX and OPEX** in OSBL downstream CO_2 purification.
3. Inherently thermally and electrically insulating material **reduces parasitic energy loss and electrical safety risk.**

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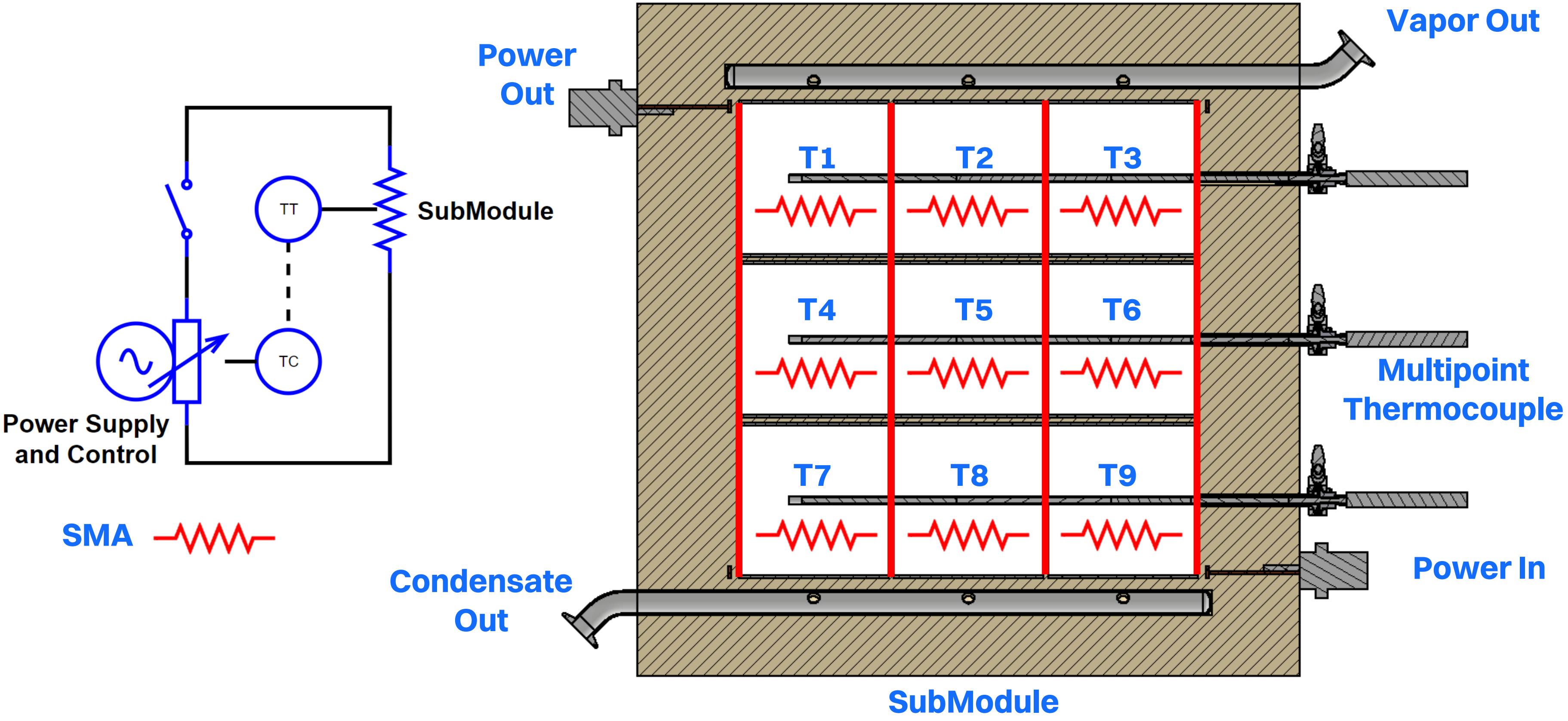
Integrated DAC Bench System: SubModule Electrical Circuit



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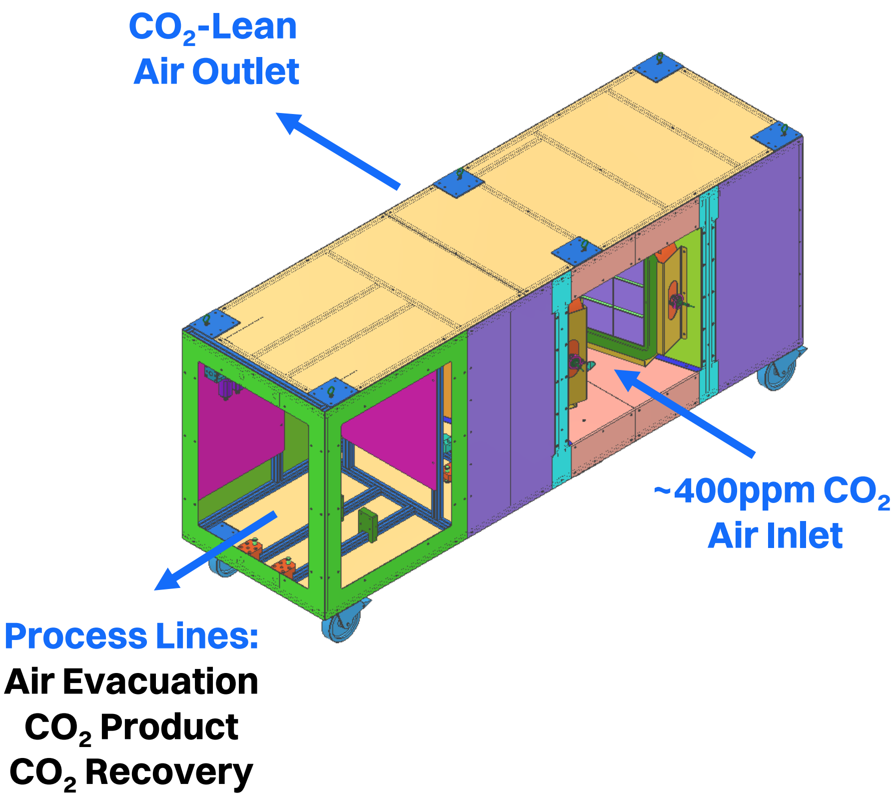
Integrated DAC Bench System: Module Assembly and Status



Deliverable Status

- PFD, P&IDs, H&MB, and Conceptual Mechanical Design Complete
- Fabricators identified and preliminary testing ongoing
- Vendors for components identified
- RFQs released and procurement ongoing

Key Milestone

- Module Fabrication and Testing **(Q4 2024)**

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Community Benefits / Societal Considerations and Impacts

- Engaged external DEIA practitioner
- Drafted a DEIA Statement
- Initiated implicit bias training for employees
- Developed repository of Minority Business Enterprises, Minority Owned Businesses, Woman Owned Businesses and Veteran Owned Businesses to solicit services, materials, equipment bids.
- Seminar and internship programs in development with Department of Chemistry in the College of Science and Technology (COST), at North Carolina Agricultural and Technical State University (NC A&T) for Fall 2024

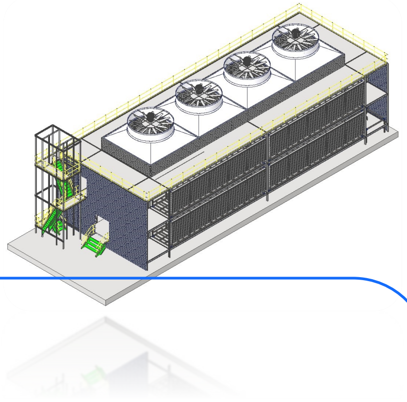
Lessons Learned

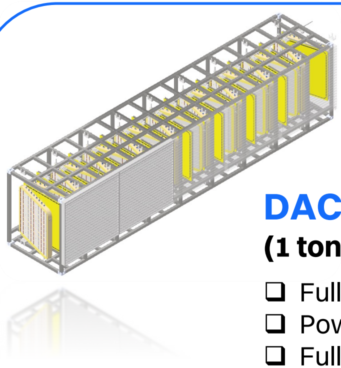
- SMA performance is the key driver for CO_2 production cost.
- Water in air (sensible and latent heat of vaporization) is the greatest contributor to DAC's energy intensity.
- Perform technology risk assessment early and structure prototyping and development around the risk mitigation.
- Modular design for technology, project, and financial risk mitigation.
- Solicit customer, supplier, and fabricator feedback early and often.
- Partner early with the first technology adapter and incorporate the feedback from this partner into design and operation of the bench/pilot units.

Ongoing Development: Technology Roadmap

TRL: 8, 7, 6, 5

DAC Plant Demonstration Plant
(15 ton/day)
- ❑ Fully integrated DAC unit operations
- ❑ Heat integration
- ❑ Variability in site ambient conditions
- ❑ CPU performance, BOP performance and reliability





DAC Module Demonstration
(1 ton/day)
- ❑ Full scale Module testing
- ❑ Power distribution (at module scale) validation
- ❑ Full scale sealing performance

Minimum Viable Product (MVP)

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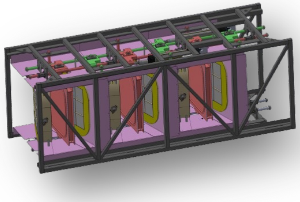

Integrated Bench-scale System **(3 kg/day)**
- ❑ Continuous, high purity CO_2 production
- ❑ Engineering design validation
- ❑ >1000 cycle stability

2024 2025 2026 2028

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Thank You!

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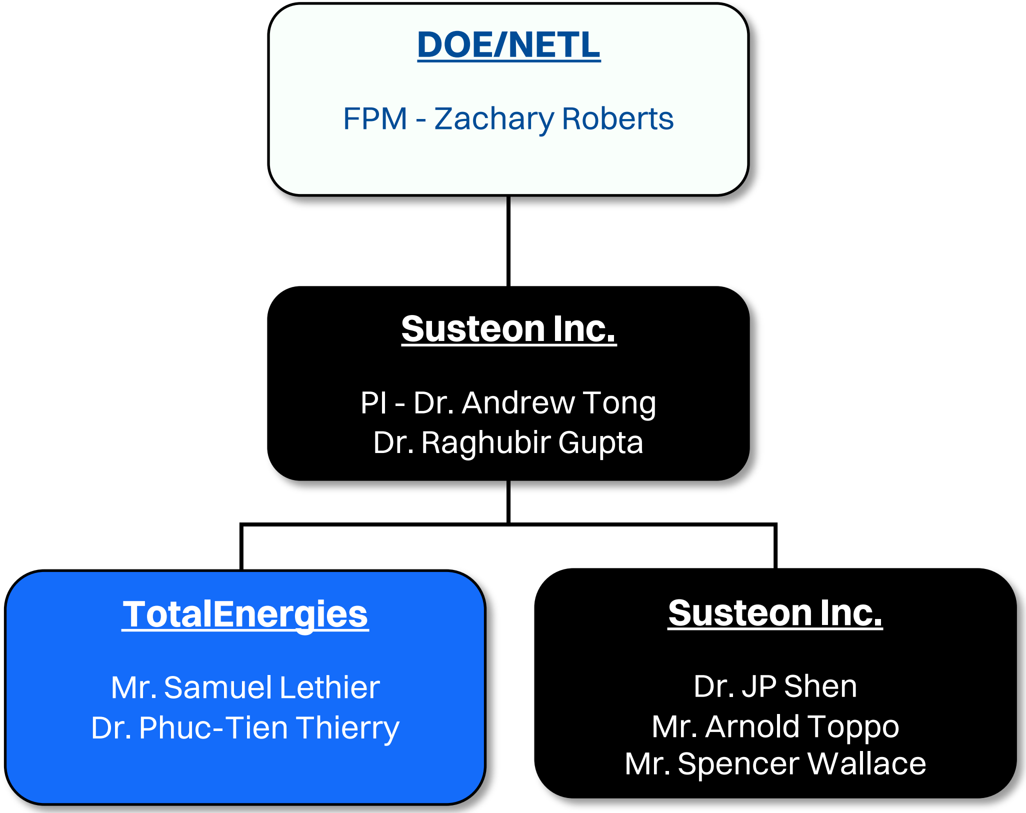
Appendix: Organizational Chart



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Project Schedule

Project Timeline	Start Date	End Date
Task 1.0 - Project Management and Planning		
Subtask 1.1 Project Management Plan	1-Jul-23	30-Jun-26
Subtask 1.2 Technology Maturation Plan	1-Jul-23	31-Mar-26
Subtask 1.3 – State Point Data Table (SPDT)	1-Jan-26	31-Mar-26
Milestone 1.1: Initial TMP within 90 days of project start		30-Sep-23
Milestone 1.2: Final TMP within 90 days prior to project completion		31-Mar-26
Milestone 1.3: Final state point data table due 90 days prior to project completion		31-Mar-26
Task 2.0 – Detailed Design of Integrated DAC Prototype System		
Subtask 2.1 – Develop Functional Design Specifications	1-Jul-23	31-Aug-23
Subtask 2.2 – Complete Piping and Instrumentation Diagram (P&ID), Control Specifications	1-Aug-23	31-Oct-23
Subtask 2.3 – SMA Reactor Module Design	1-Sep-23	31-Dec-23
Subtask 2.4 – PHA, Instrument List, and Equipment and Fabricator Selection	1-Jan-24	31-Mar-24
Subtask 2.5 – Balance of Plant Design	1-Feb-24	31-Mar-24
Milestone 2: DAC prototype rig design complete and ready for fabrication		31-Mar-24
Task 3.0 – Structured Sorbent Synthesis for Bench Unit		
Subtask 3.1 – Procurement of equipment and coating components	1-Sep-23	31-Mar-24
Subtask 3.2 – Monolith Substrate and Coating Material Procurement	1-Jan-24	31-Mar-24
Subtask 3.3 – SMA Synthesis and Characterization	1-Mar-24	30-Jun-24
Subtask 3.4 – Sorbent Synthesis for Integrated Bench Prototype Testing	1-Jul-24	31-Dec-24
Milestone 3: SMA synthesis equipment installed and protocol is verified. CO2 adsorption and desorption on synthesized samples >3.0 wt% (gCO2/gSorbent)		30-Jun-24
Task 4. Integrated Bench Unit Construction, Installation and Commissioning		
Subtask 4.1 – Completion of Vendor Design Drawings and Initiate Component/Equipment Procurement	1-Mar-24	30-Jun-24
Subtask 4.2 – Integrated Bench Unit Construction and Installation	1-Jul-24	30-Sep-24
Subtask 4.3 – Bench Unit Commissioning and PSSR	1-Sep-24	31-Dec-24
Milestone 4: DAC prototype rig setup and ready to operate		31-Dec-24
Go/No-Go Decision Point 1 to Enter BP2	**31-Dec-24**	
Task 5. Parametric and Accelerated Long Term of Integrated Bench Prototype Test Rig		
Subtask 5.1 – Parametric Testing with Integrated Prototype Test Rig	1-Jan-25	30-Jun-25
Subtask 5.2 – Accelerated Long Term of Integrated Bench Prototype Test Rig	1-Jul-25	30-Mar-26
Milestone 5.1: Projected adsorption and desorption rates achieved (Adsorption: >0.01 mol CO2/kg sorbent/min; Desorption: >0.01 mol CO2/kg sorbent/min)		30-Jun-25
Milestone 5.2: Sustained CO2 Loading, CO2 purity, and adsorption/desorption rate achieved over 1000 adsorption/desorption cycles		30-Mar-26
Task 6. Techno-Economic Analysis & Life-Cycle Assessment		
Subtask 6.1 – Process Model Update	1-Apr-25	31-Dec-25
Subtask 6.2 – Techno-Economic Analysis	1-Apr-25	30-Jun-26
Subtask 6.3 – Life Cycle Analysis	1-Jul-25	31-Mar-26
Milestone 6.1: Initial TEA and LCA report due 120 after project start		31-Oct-23
Milestone 6.2: Final TEA and LCA report due 90 prior to project completion		31-Mar-26
Task 7. Technology Environmental Health and Safety (EH&S) Risk Assessment		
Milestone 7: Final EH&S analysis due 90 prior to project completion		31-Mar-26
Task 8. Technology Gap Analysis (TGA)		
Milestone 8: Final TGA within 90 days prior to project completion		31-Mar-26

Months from Project Start Date: BP1 (months 1–18), BP2 (months 19–36)

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