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Reimagining the carbon ecosystem

Bench-Scale Development of Promoted High-Capacity Structured Sorbents

DE-FE0032254

Presented by
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2024 Carbon Management Research Project Review Meeting

Project Overview

Title	Bench-Scale Development of Promoted High-Capacity Structured Sorbents
Funding Solicitation	DE-FOA-0002614 AOI2A
Award No.	DE-FE0032254
Period of Performance	7/01/2023 – 06/30/2025
Project Funding	DOE: $1.5M Cost-Share: $0.375M
Overall Project Goal	Development of a high-capacity structured sorbent (HCSS) to reduce CapEx and OpEx of a DAC system
Project Participants	Susteon Inc. and TotalEnergies
DOE/NETL Project Manager	Mr. Zachary Roberts

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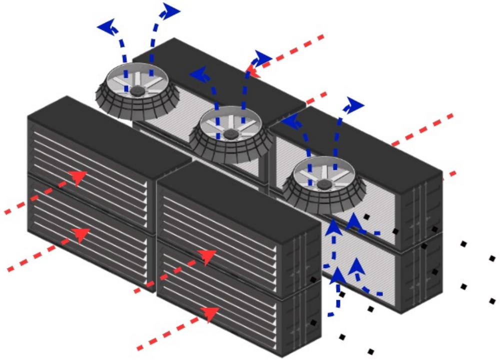
DAC Technology: Challenges and Opportunity

FE0032118: Initial Design and TEA



Component	COC ($/t$CO_2$)	% Cost Contribution (Excl T&S)
Capital	**$172**	**49%**
Fixed	$63	18%
Variable	$100	29%
CO_2 T&S	$14	4%
Total (Excluding T&S)	**$335**	
Total (Including T&S)	**$349**	

- **Low sorbent sorbent working capacity:** low CO_2 purity, high desorption energy
- **High structured sorbent manufacturing cost:** high replacement cost, and initial loading cost
- **Low adsorption/desorption rate:** low volumetric productivity
- **Water co-adsorption:** high energy demand for CO_2 desorption
- **High thermal mass:** high sensible heat loss, high CO_2 desorption energy

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Technical Approach and Project Scope

Objective:

Develop an advanced, high-capacity sorbent with scalable, low-cost structured substrate and demonstrate the sustained performance in a bench-scale system at a scale of about 1-kg/day of CO_2.

Approach

1. Develop next generation sorbent(s) with high adsorption/desorption rates, low water co-adsorption, and good thermal and oxidative stability
2. Develop a scalable structured substrate with high sorbent loading and low cost of manufacturing
3. Demonstrate the assembled structured sorbent in bench-scale test system

Sorbent Concept

Polymer Backbone + **Proprietary Amine** + **Promoter**

- **Polymer Backbone** → **Low Water Adsorption**
- **Proprietary Amine** → **High Oxidative Stability**
- **Promoter** → **Enhanced Adsorption Rate**

- ❑ **Macroporous polymer backbone** for reduced water adsorption
- ❑ Sorbent **resistant to deactivation in air**
- ❑ Promoters assist in **enhancing the adsorption rate**
- ❑ **Non-volatile** for reduced vapor emissions and amine loss

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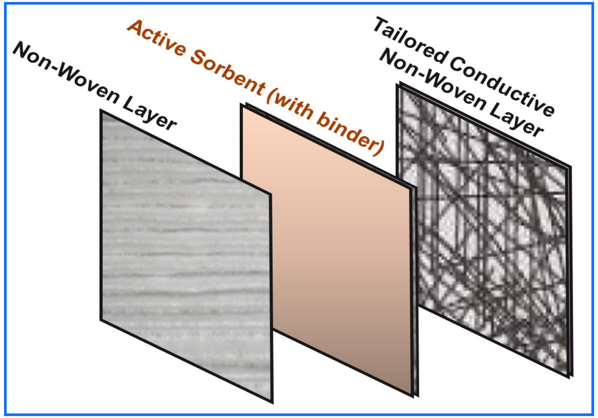
- ❑ Can be **locally heated** by Joule heating to 60 to 80°C
- ❑ Can be easily incorporated onto a standard air filter

Structured Substrate Design

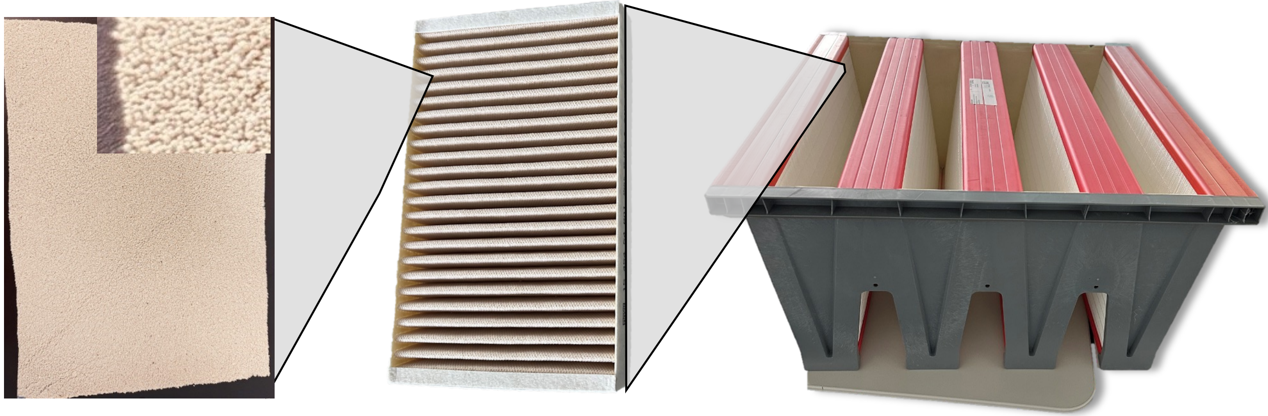
Concept Design



Electrically conductive structured sorbent filter assembly

Pleated Filter Panel

V-Shaped DAC Air Contactor



Nonwoven filter with sorbent (ECCOsorb 1). Up to **1.2 kg sorbent/m^2 loading**

24”x24”x12” Size module capable of holding up to **10 m^2** of sorbent surface area

Nonwoven layered filter assembly capable of high sorbent loading and continuous, automated production

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Sorbent Development: Performance Targets

Parameter	Impact	Target
1. CO_2 Adsorption Rate	Productivity	$> 0.035 \frac{\text{mmol } CO_2}{\text{g sorbent} \cdot \text{minute}}$
2. CO_2 Desorption Rate	Productivity	$> 0.3 \frac{\text{mmol } CO_2}{\text{g sorbent} \cdot \text{minute}}$
3. CO_2 Working Capacity	CO_2 Product Purity, Desorption Energy	> 1.14 mmol CO_2/g sorbent (5 wt% CO_2)
4. Sorbent Stability	Sorbent Lifetime	> 10,000 cycles
5. Water Co-Adsorption	Desorption Energy Requirement	< 1:1 H_2O:CO_2 mass ratio

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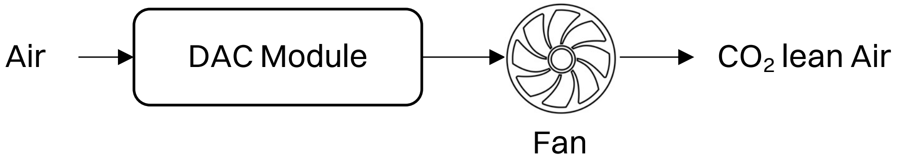
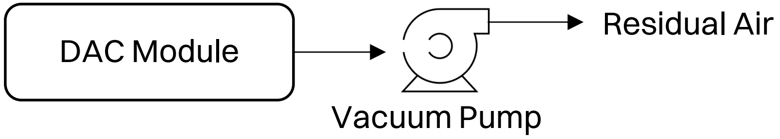
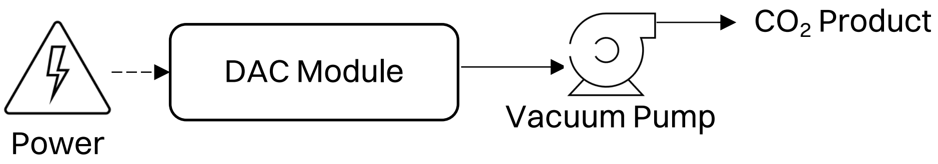
Process Sequence

Step	**Duration**
Adsorption	32 Minutes
Vacuum Purge	3 Minutes
CO_2 Desorption	4 Minutes

Step Description



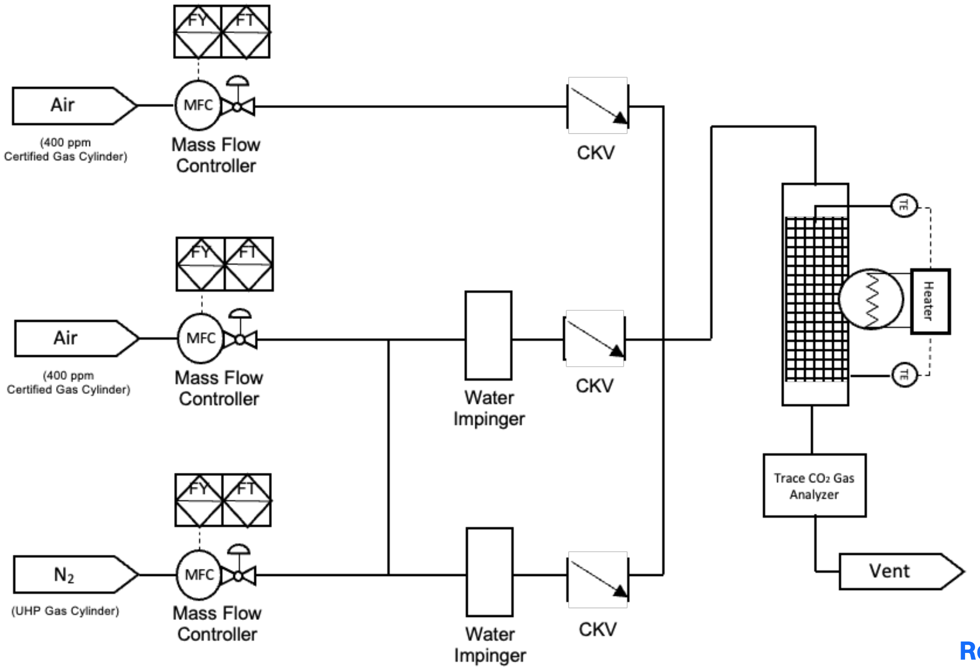




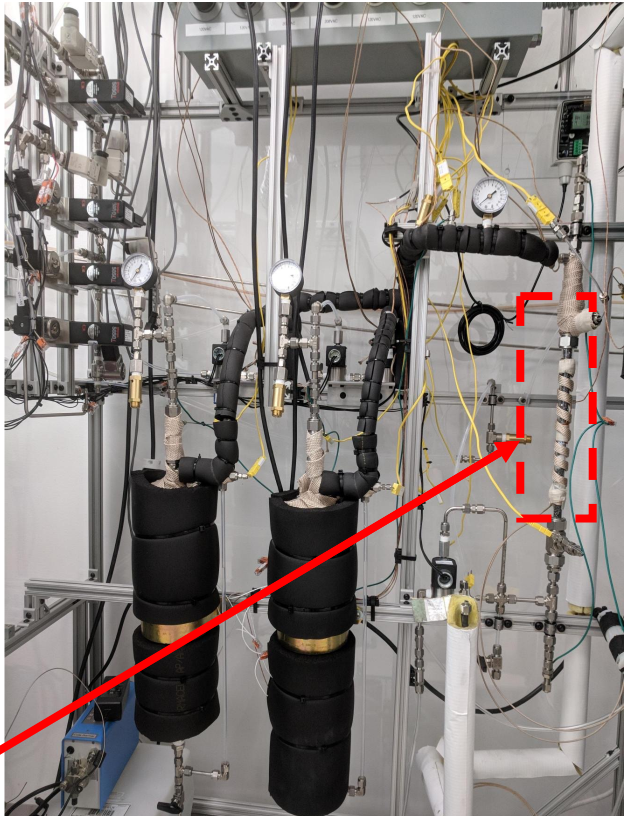
Target durations defined by KPPs

Sorbent Development: Lab Screening Reactor

Simplified PFD



Reactor:
0.45g Sorbent sample mixed with 6g SiC grit
Packed Volume: 4.5 mL
Air Flow Rate: 900 sccm
GHSV*: 12,000 hr^{-1}
*on packed volume and dry gas feed basis



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Sorbent Development: Lab Screening Reactor

Sorbent Compositions Tested

Sorbent	Adsorption Capacity (mmol CO_2/g)	Regeneration Capacity (mmol CO_2/g)
ECCOsorb-1	**2.20**	**2.32**
ECCOsorb-5	1.41	1.34
ECCOsorb-E1	1.41	1.36
ECCOsorb-E15	0.95	0.89
ECCOsorb-E2	1.05	1.09
ECCOsorb-T1	**1.89**	**1.95**

ECCOsorb-1 and ECCOsorb-T1 show comparable working capacities and adsorption/desorption rates

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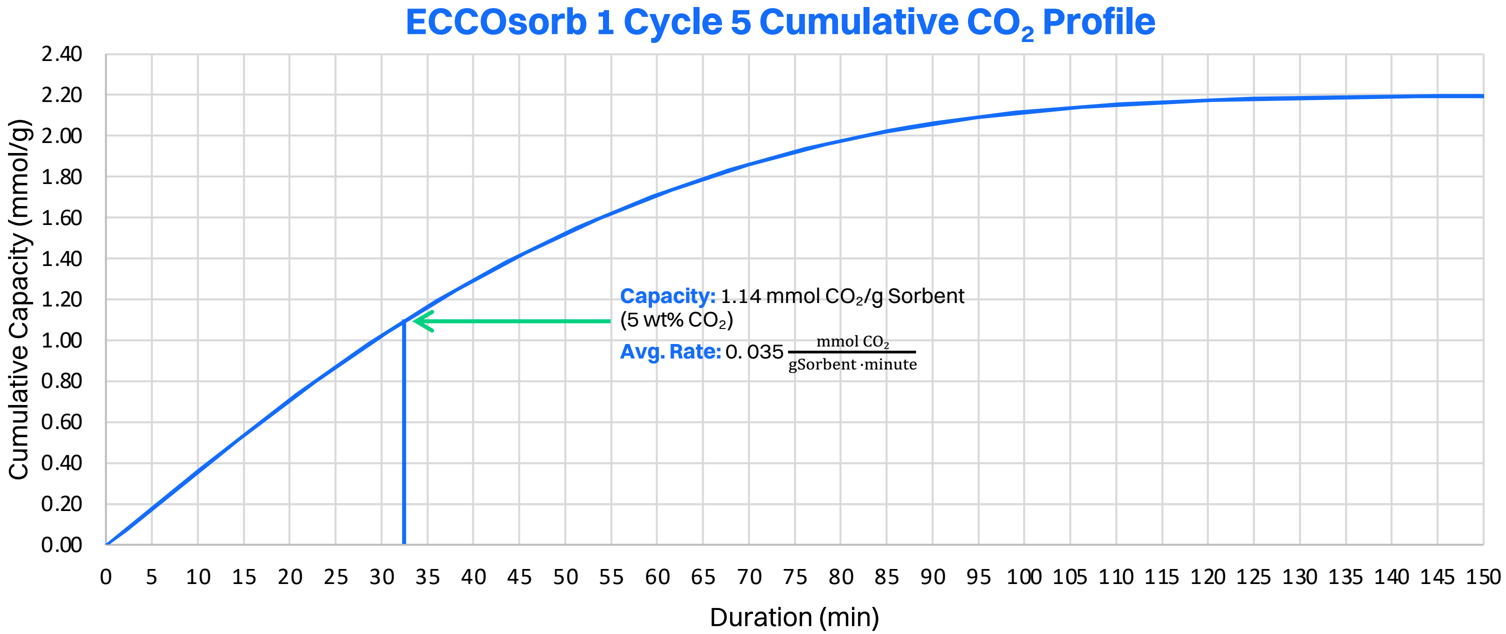
Sorbent Development: CO_2 Adsorption Rate

ECCOsorb 1

Sorbent Form Factor: Granules in Packed Bed
Sorbent Mass: 0.45 g
Adsorption: 900 sccm humid air
Regeneration: 70°C



ECCOsorb 1 shows potential to achieve target adsorption rate and working capacity

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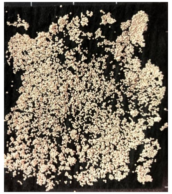
Sorbent Development: CO_2 Desorption Rate

Indirect Heating Condition

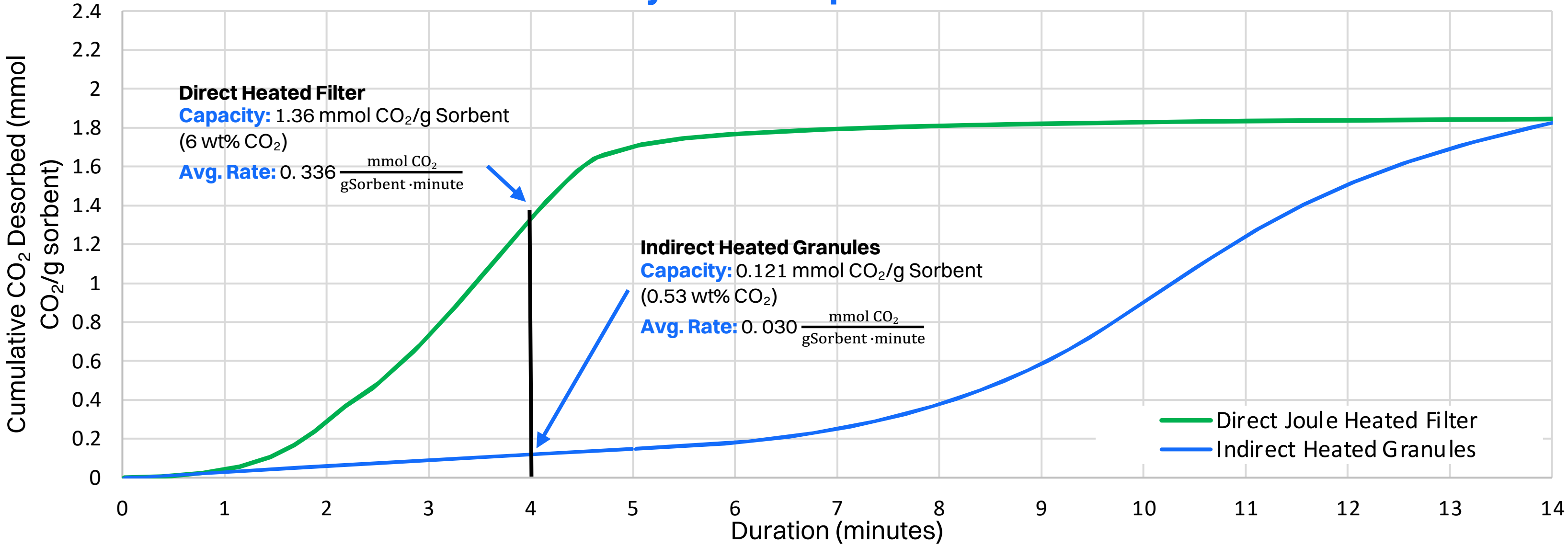
Sorbent Form Factor: ECCOsorb 1 Granules in Packed Bed
Sorbent Mass: 0.45 g
Adsorption: 900 sscm humid air
Regeneration: 70°C @ 10°C/min

Direct Joule Heating Condition

Sorbent Form Factor: conductive nonwoven filter with ECCOsorb 1
Sorbent Mass: 0.42 g
Adsorption: 1,020 sccm humid air
Regeneration: 70°C



Cycle 5 Comparison



Direct Joule heated filter shows 10x increase in desorption rate – can achieve performance targets

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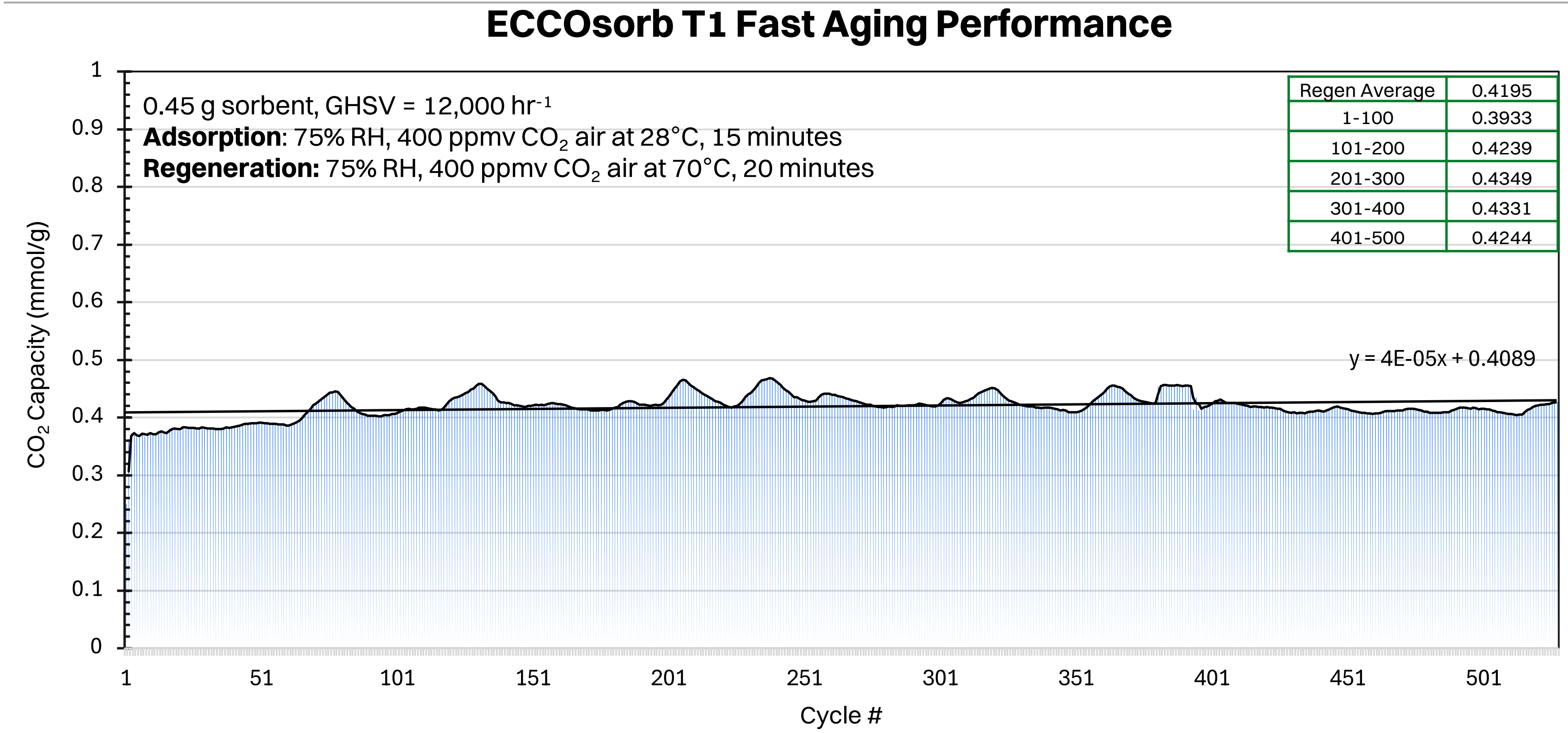
Sorbent Development: Cyclic Stability



ECCOsorb T1 shows excellent long-term thermal and oxidative stability.

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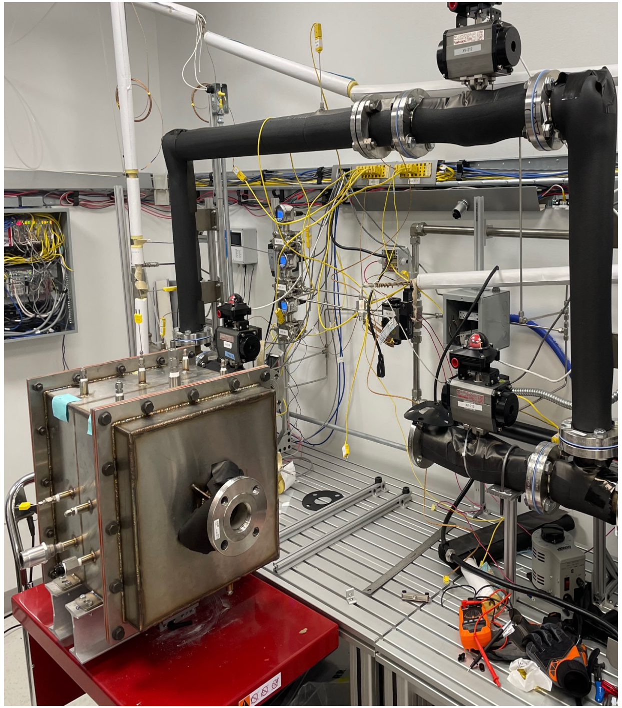
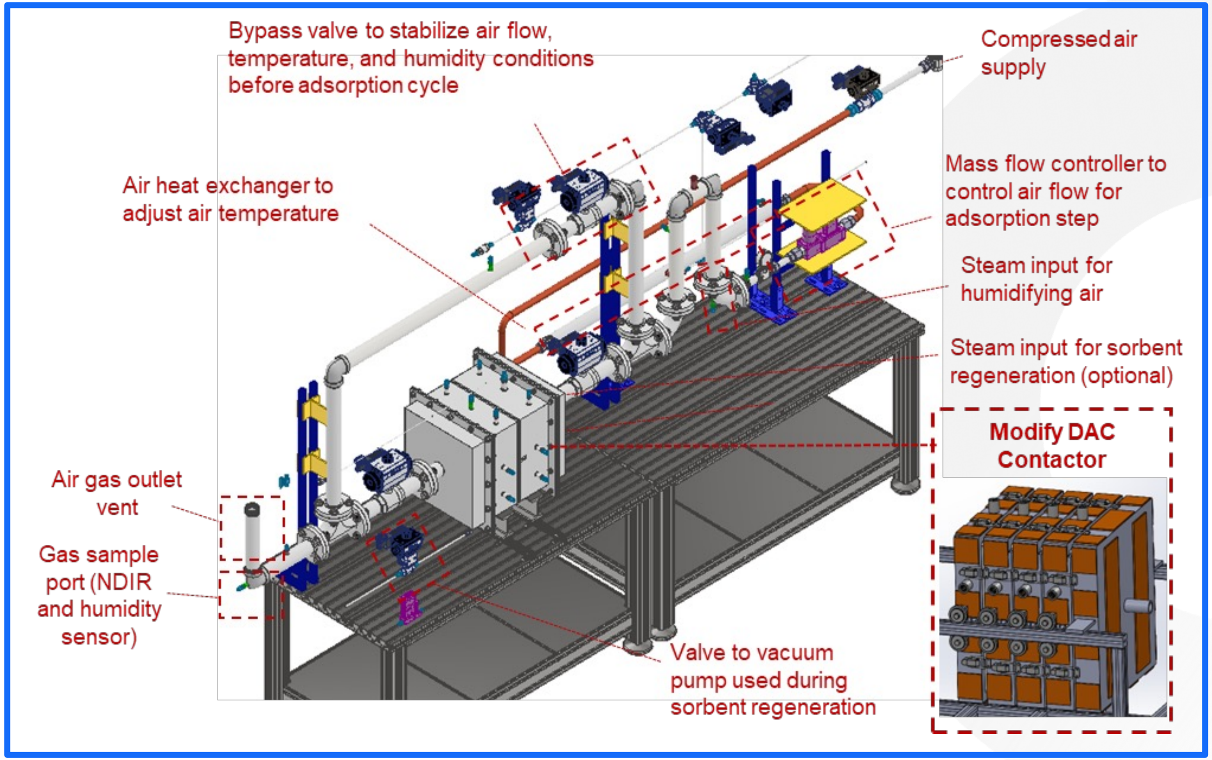
Bench-Scale Test System





Modify existing bench system to incorporate new contactor design

Finalizing design with the filter vendor

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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

- Minimizing water adsorption key factor in reducing energy for CO_2 removal
- Engage structured sorbent manufacturing early
- Utilizing existing manufacturing lines reduces cost of production and development work

Summary and Future work

Takeaway

- Structured sorbent developed - ready for bench-scale testing of assembled filter panel
- Filter assembly is simple, lower cost, scalable, and robust
- Clear pathway for reducing DAC CO_2 capture cost

Ongoing Work

- Build bench-scale filter assembly, demonstrate stability over 500 cycles
- Update process model, TEA, and LCA

Thank You!

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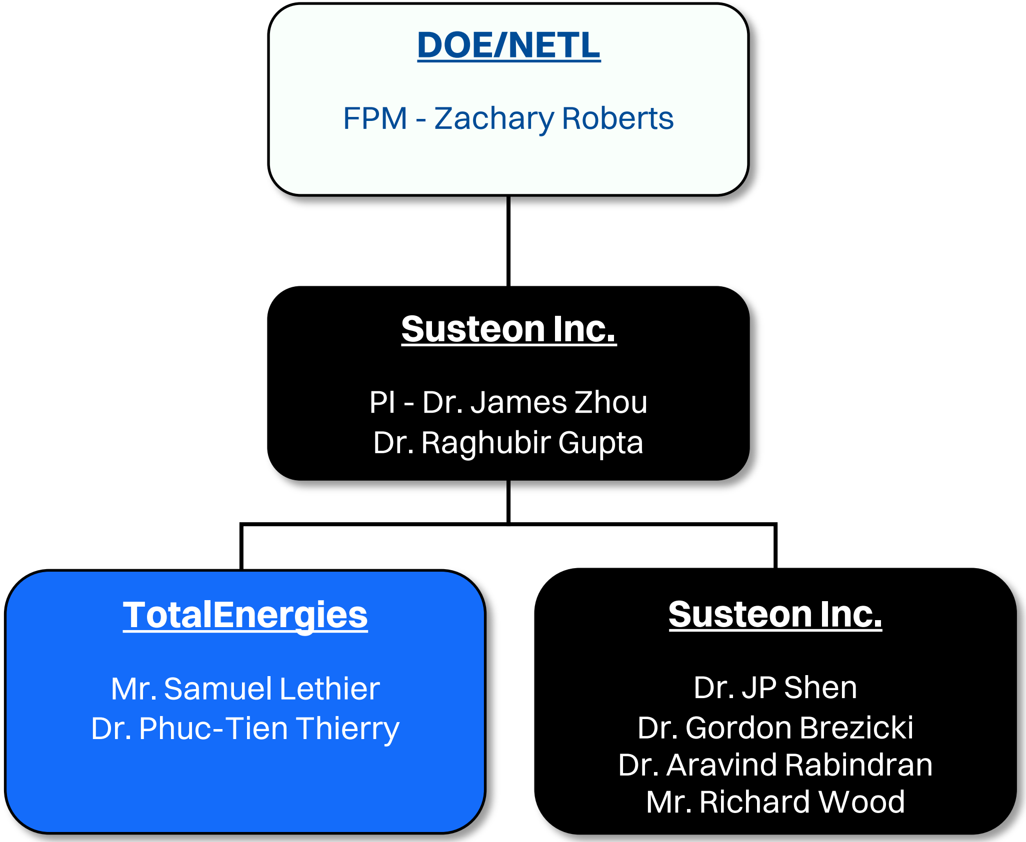
Appendix: Organizational Chart



Appendix: Project Schedule

Project Timeline			Months from Project Start Date																							
	Start Date	End Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Task 1 - Project Management and Planning			BP1																							
Subtask 1.1 Project Management Plan	7/1/23	6/30/25																								
Subtask 1.2 Technology Maturation Plan	7/1/23	9/30/23																								
Subtask 1.3 State Point Data Table	2/1/25	3/31/25																					★			
Milestone 1a: **Initial TMP within 90 days of Project Start**		9/30/23			★																					
Subtask 6.1 and 6.2 Initial Techno-econimic Analysis and Life Cycle Analysis	7/1/23	10/31/23																								
Milestone 1b: **Initial TEA and LCA within 120 days of Project Start**		10/31/23				★																				
Task 2 – Structured Sorbent Optimization																										
Subtask 2.1: Low-pressure Drop Support Evaluation	8/1/23	10/30/23																								
Subtask 2.2: Sorbent Washcoat Optimization	9/1/23	2/29/24																								
Subtask 2.3. Structured Material Characterization	10/1/23	4/30/24																								
Subtask 2.4. Structured Sorbent Short-term Testing	10/1/23	1/30/24																								
Subtask 2.5. Structured Sorbent Long-term Testing	1/1/24	4/30/24																								
Milestone 2: **Successful optimization of structured sorbent in the lab with cyclic CO_2 capacity > 6.0 wt%**		4/30/24										★														
Task 3 – Bench-Scale Design and Fabrication																										
Subtask 3.1. Bench-Scale System Design	1/1/24	4/30/24																								
Subtask 3.2. Bench-Scale System Fabrication	3/1/24	6/30/24																								
Milestone 3: Completion of design and fabrication of a bench-scale system		6/30/24												★												
GO/NO-GO Decision to Enter BP2	**6/30/24**													★	BP2											
Task 4 - Structured Sorbent Testing																										
Subtask 4.1. Bench-Scale Structured Sorbent Fabrication	7/1/24	1/31/25																								
Subtask 4.2. Structured Sorbent Characterization	7/1/24	1/31/25																								
Subtask 4.3. Structured Sorbent Bench-Scale Testing	7/1/24	2/28/25																								
Milestone 4: **Less than 5% capacity fade after 100 cycles**		2/28/25																				★				
Task 5 - Process Design and Modeling																										
Subtask 5.1. Process Model Development and Validation	7/1/24	1/31/25																								
Subtask 5.2. Desorption Energy Optimization	9/1/24	3/31/25																								
Subtask 5.3. Process Cycle Design	10/1/24	6/30/25																								
Milestone 5: **Process model which accurately predicts performance (adsorb/desorb rate, capacity, desorb heat) within 5% validated against experimental results to date.**		6/30/25																								★
Task 6 - Techno-Economic Analysis and Life-Cycle Assessment																										
Subtask 6.1 – Techno-Economic Analysis (TEA)	11/1/24	3/31/25																								
Subtask 6.2 – Life Cycle Analysis	11/1/24	3/31/25																								
Milestone 6: **High-fidelity TEA and LCA to assess the cost of CO_2 capture and impact on GHG emissions from the proposed technology compared to SOTA.**		3/31/25																					★			
Task 7 - Technology Maturation Plan (TMP)																										
Final Technology Maturation Plan	12/1/24	3/31/25																								
Milestone 7: **Final TMP within 90 days of Project Close Out**		3/31/25																					★			

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