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

DE-FE0032243

Andrew Tong, Raghubir Gupta, Arnold Toppo

Susteon, Inc.

2023 Carbon Management Research Project Review Meeting
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Project Overview

Total Funding: $3,750,000

DOE Funding: $3,000,000

Cost Share: $750,000

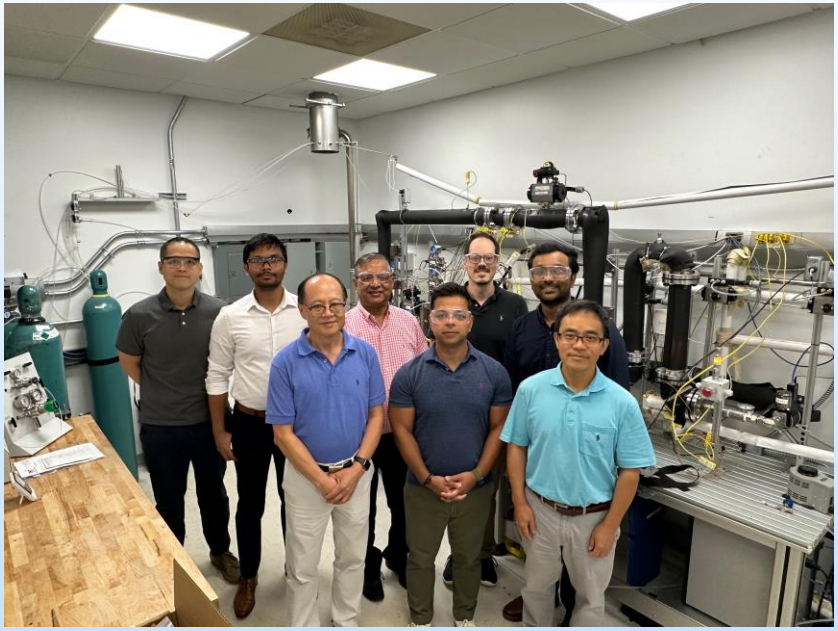
Overall Project Performance Dates:

BP1: 07/01/2023 – 12/31/2024

BP2: 1/01/2025 – 6/30/2026

DOE Project Manager: Mr. Zachary Roberts

Project Team



Project Objectives

Overall Objective:

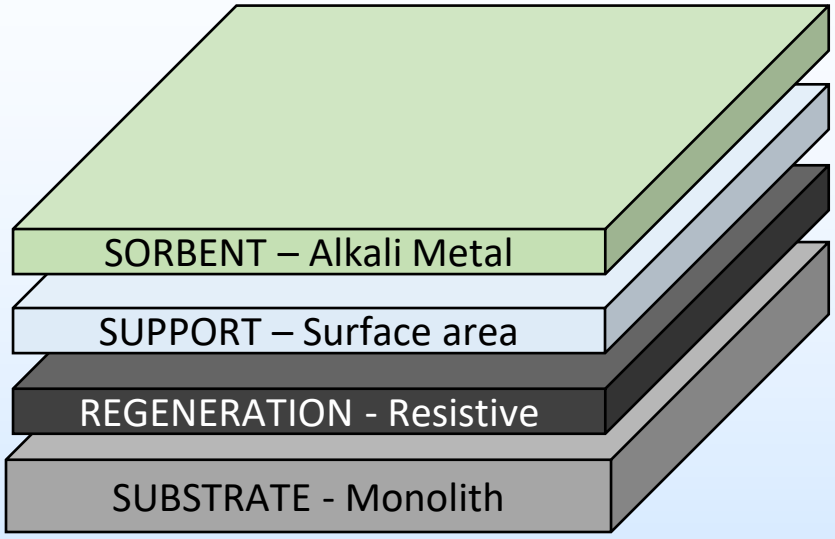
Lower the overall cost of DAC through the development of a structured material assembly (SMA) and integrated DAC system design which will be regenerated with low-carbon electricity (TRL 4 to TRL 5).

Technical Objectives

- Design, build, and test an integrated bench-scale DAC system for continuous CO_2 production at 1 ton/yr (TPY)
- Complete >1000 adsorption-desorption cycles to confirm sustained performance of SMA and integrated DAC system design
- Process real, unconditioned air under multiple climate conditions to assess structured material assembly (SMA) and overall system performance
- Perform a high-fidelity TEA and LCA to develop a technology commercialization plan

Structured Material Assembly (SMA) Concept

- Adsorption with a sorbent is different with 400 ppmv CO_2 in air compared to high concentrations of CO_2 in point sources.
- Humidity in air plays a critical role in CO_2 capture from air.
- Our SMA integrates the sorbent, regeneration method, and substrate into an optimized form, which;
  - Increases productivity by enabling fast CO_2 adsorption rate and rapid regeneration
  - Lowers the energy utilization by reducing pressure drop during adsorption and energy losses during desorption
  - Powered by low-carbon electricity for maximum net removal efficiency (no steam needed)



Bare Substrate

Fully Integrated SMA

Project Success & Milestones

Project Success Criteria

- CO_2 working capacity is >3 wt% (g-CO_2/g-sorbent)
- Confirm <1.25% degradation in CO_2 working capacity over 1,000 adsorption/desorption cycles
- Achieve sustained >80% purity CO_2 production
- Verify startup, shutdown, and trip performance of prototype system

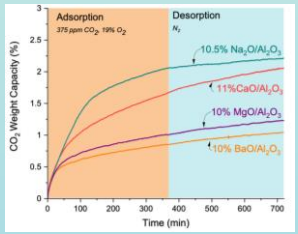
Technology Background & Accomplishments

Current Project

Scale

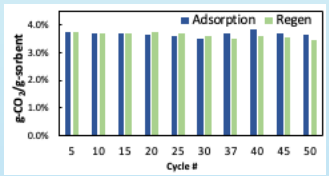
TGA Testing
SC0020795

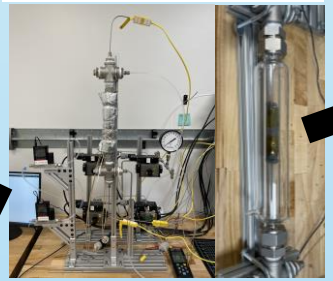
- Na-Based Sorbent Material Selected
- Proof of concept of on reaction pathway



Laboratory Testing
(3 g/day)
FE0032118

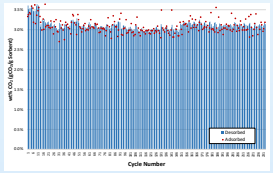
- Verified sustained performance of structured sorbent
- Proof of concept resistive layer coating showing high CO_2 desorption rates

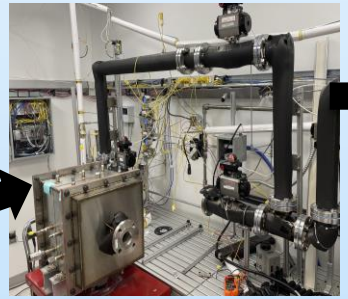




Bench Component Testing
(Intermittent 1 kg/day)
FE0032118

- Sustained performance of fully integrated SMA over 300 Cycle





Integrated Bench Testing
(1 TPY)
FE0032243

Validate continuous operation with gas-gas sealing design and CO_2 production under real environment condition

Integrated Bench System Testing

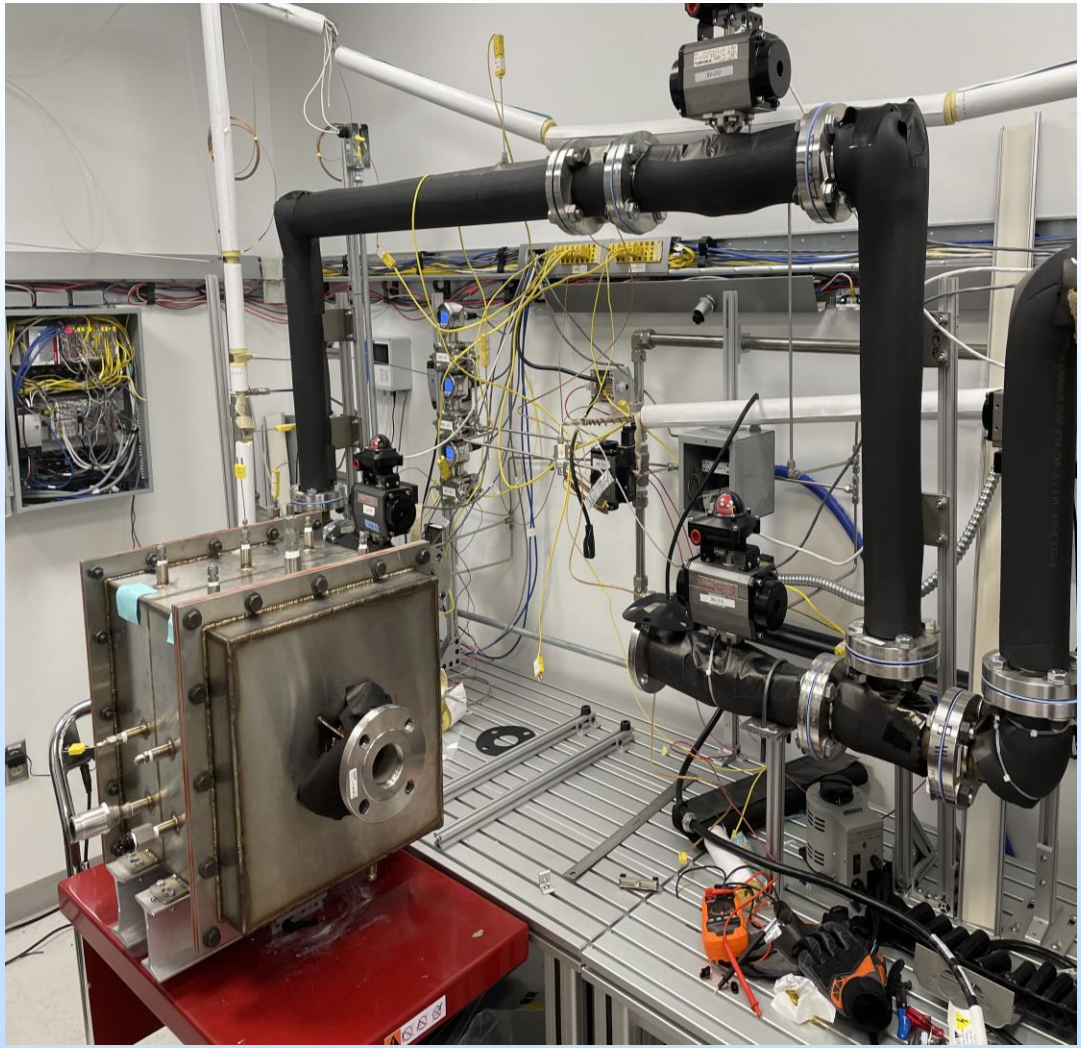
DAC Unit Demonstration
(10-30 ton/day)

- Demonstrate full scale DAC unit
- Fits DOE DAC Hub target

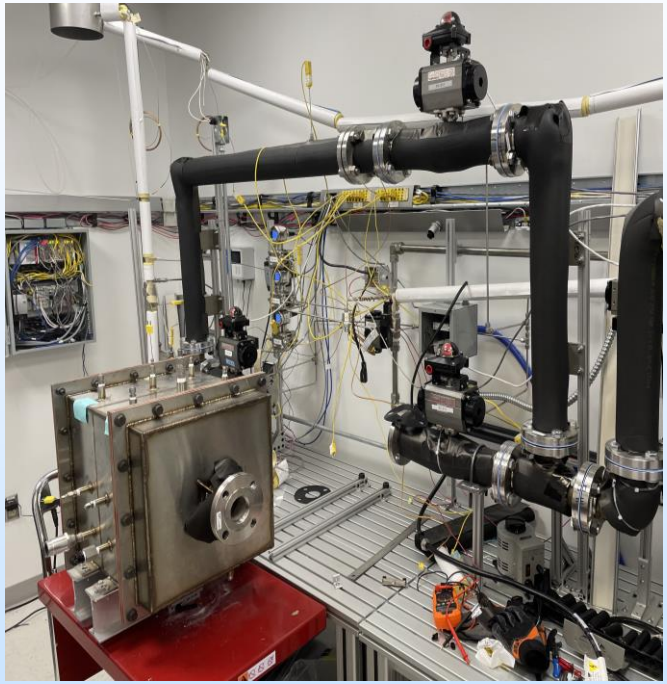
Progress

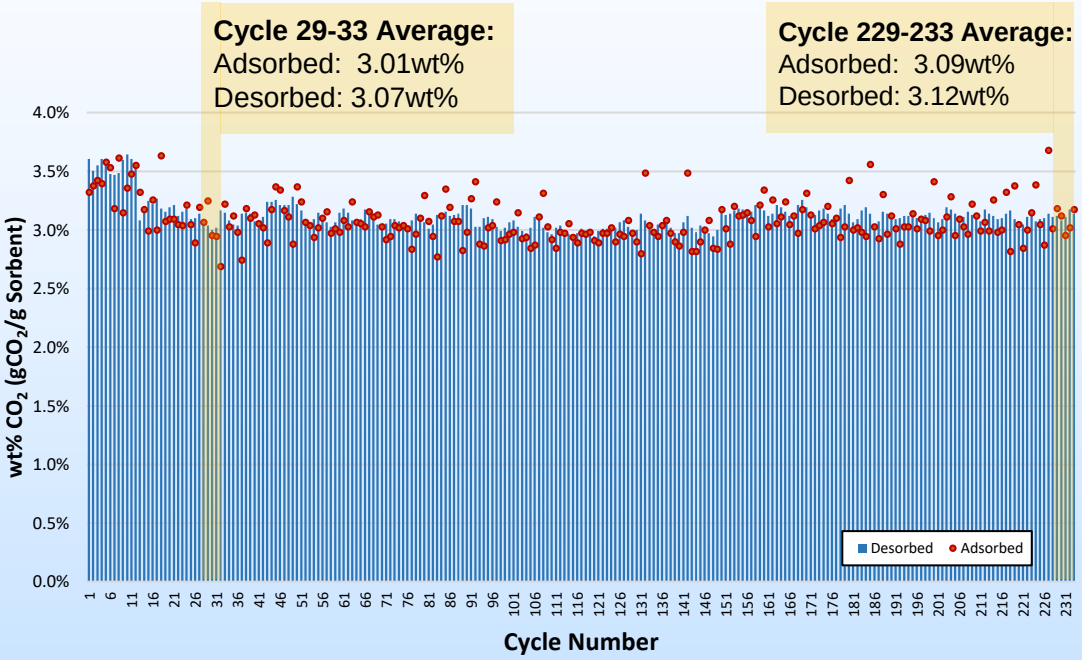
Bench-Scale Unit: Design

- Designed for 1-2 kg/day of CO_2 from ambient air
- Highly instrumented to obtain high-fidelity mass/energy balances
- All major process components representative of a scaled-up system included
- Full-scale four monolith bricks (150 mm cubes) can be tested
- System fully commissioned in Spring 22



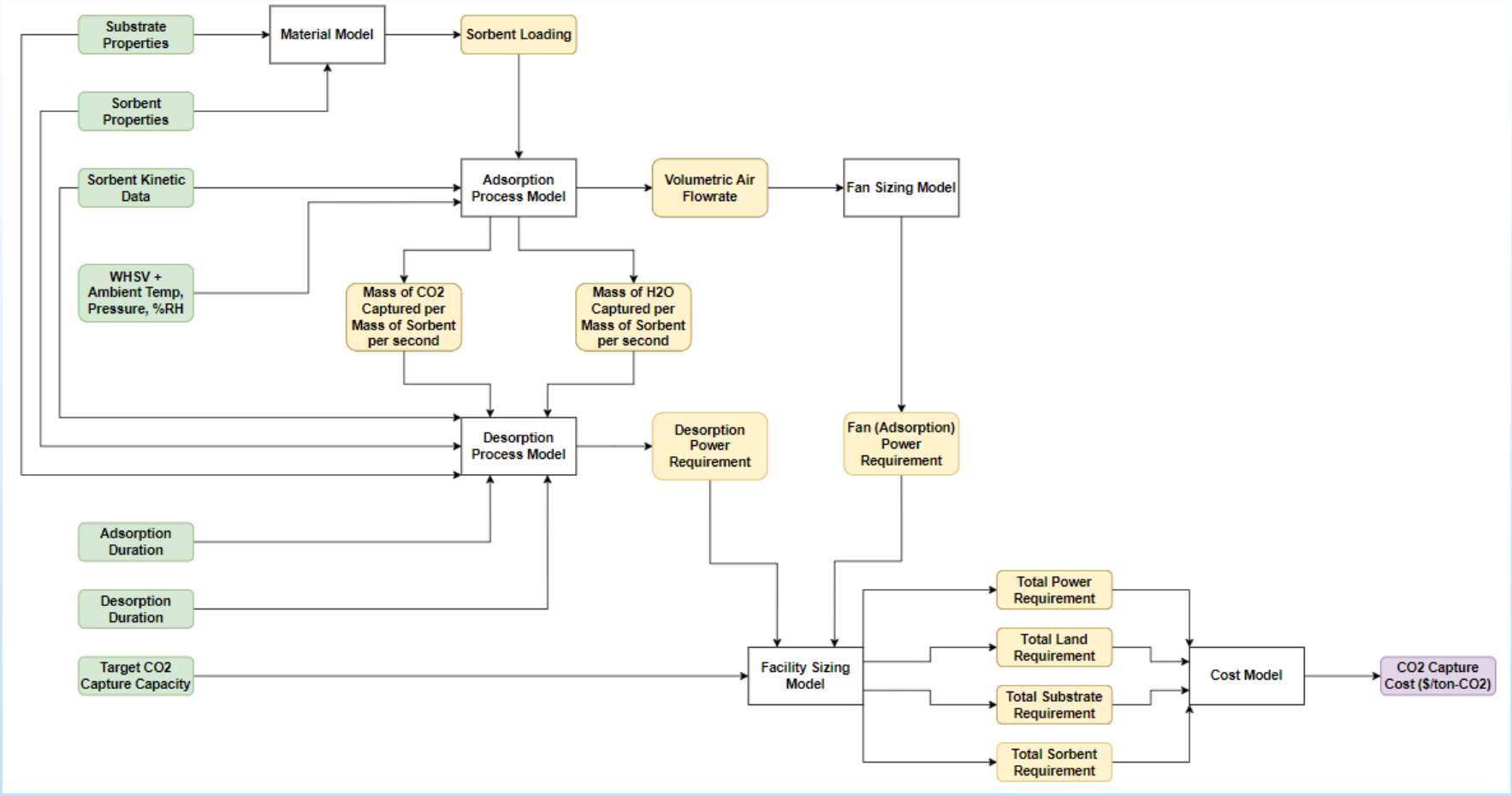
Bench Unit Test Results





Integrated SMA stable after >300 cycles of operation

Process Model Development



Technical Approach

- **Design, build and demonstrate** in an integrated DAC bench-scale prototype system by processing air from a real, outdoor environment and capturing 3 kg/day CO_2 (1 TPY)
- **Prepare and synthesize** sufficient SMAs coated with promoted sorbent and heating layer to complete integrated DAC prototype system operation (>20 structured sorbents) with consistent heating and capture performance
- **Develop a robust gas seal design and purge operation** capable of >1,000 cycle operation without loss in SMA or system performance
- **Design an efficient process cycle** for adsorption, heating, desorption, to maximize sorbent productivity and minimize the overall capex and opex for the technology. Cycle design to be validated in the integrated DAC bench-scale prototype system operation.

Project Tasks

Task 1: Project Management

Task 2: Detailed Design and Fabrication of Prototype System

- Completed design of 1TPY integrated DAC system for fabrication
- DAC enclosure design, P&IDs, process control design, safety review

Task 3: Structured Sorbent Synthesis for Bench Unit

- Prepare and verify performance of SMAs for integrate system testing

Task 4: Construction, Installation and Commissioning

- Build integrated test system

Task 5: Parametric and Long-Term Testing

- Assess system performance under varied operating conditions and weather conditions
- Complete >1,000 adsorption and desorption cycles

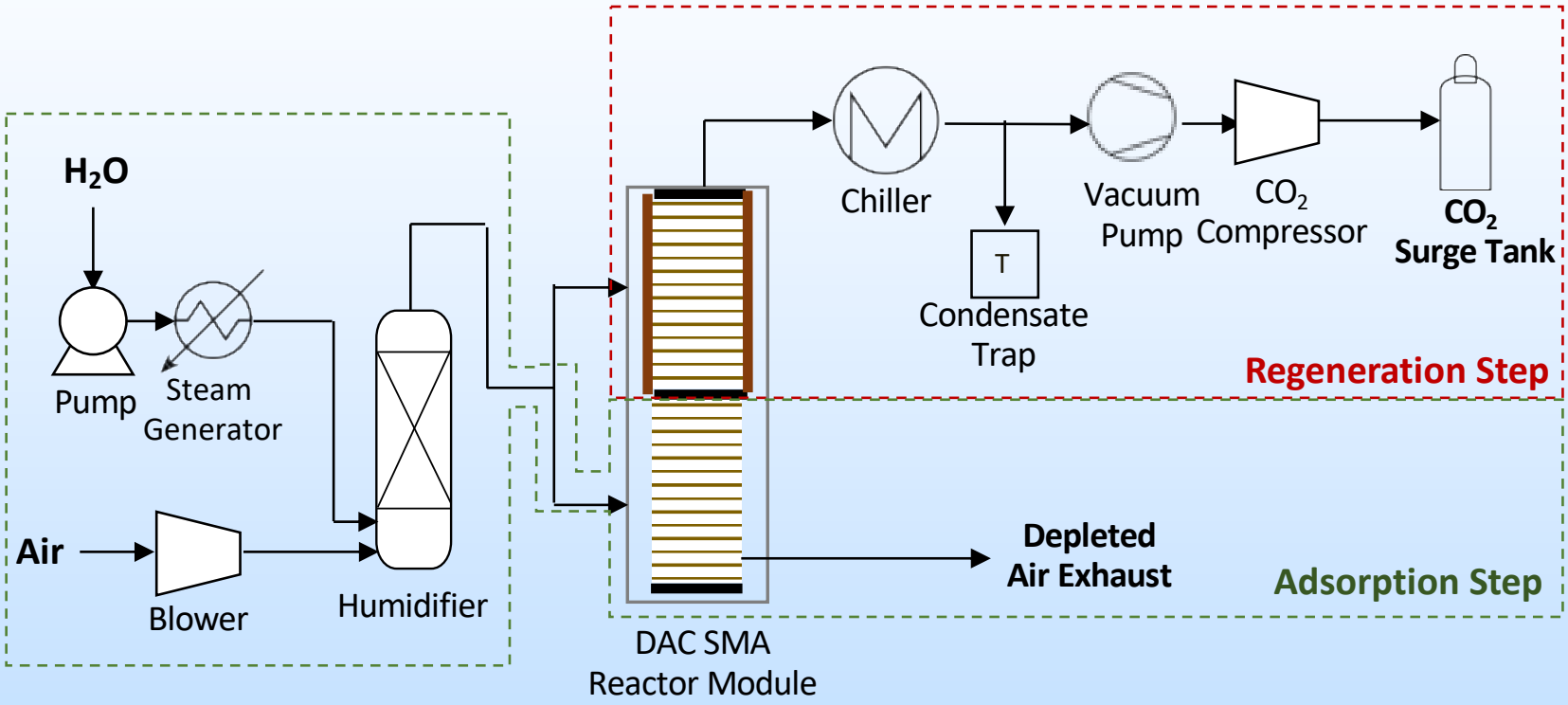
Task 6: Techno-Economic Analysis & Life-Cycle Assessment

- Update existing DAC process model and assessments with integrated bench system results

Task 7: Technology Environmental Health and Safety (EH&S) Risk Assessment

Task 8: Technology Gap Analysis (TGA)

Preliminary Design



Detailed integrated bench system design in progress

Summary

- SMA developed with sustained CO_2 adsorption and desorption capacity and reliable direct electric heating regeneration
- Project Objective: Advanced DAC technology readiness from TRL-4 to TRL-5
  - Design, build, and test an integrated bench-scale DAC system for continuous CO_2 production at 1 TPY
- System will test direct, unconditioned outdoor air for CO_2 capture and concentration up to 90%
- 1 TPY test unit currently in design

Appendix

Gantt Chart

Project Timeline			Months from Project Start Date																																							
			BP1																		BP2																						
	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	25	26	27	28	29	30	31	32	33	34	35	36
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.		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		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																																	✦			