An Integrated and Continuous Bench-Scale Passive DAC Demonstration (DE-FE0032241)

2024 FECM/NETL Carbon Management Research Project Review Meeting
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Acknowledgment

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Disclaimer

Project Overview

Funding:

- ❑Federal: $3,000,000
- ❑Cost-Share: $750,000

Overall Project Performance Dates:

- ❑BP1: 6/15/2023 - 6/14/2024
- ❑BP2: 6/15/2024 - 6/14/2025
- ❑BP3: 6/15/2025 - 6/14/2026

Project Participants:

- ❑RTI International (Prime)
- ❑Creare, LLC.
- ❑Edare, LLC.
- ❑GE Vernova

Project Objectives:

The overall objective of the project is to design, fabricate, and continuously test a wind-driven bench-scale DAC integrated process and measure key performance metrics

- ❖**BP1**
  - ➢Sorbent scale-up to up to 10kg and coating formulations optimization
  - ➢Wind-driven contactor performance modeling
- ❖**BP2**
  - ➢Design, fabricate and commission a wind-driven bench-scale contactor system
- ❖**BP3**
  - ➢Continuous long-term testing (≥1 month)
  - ➢Refine the DAC process TEA and LCA

BP1 Project Milestones

Milestone 2.1

3 Kg sorbent material synthesized to support bench-scale field testing

Milestone 2.1

7 Kg sorbent material synthesized to support bench-scale field testing

Milestone 2.2

Uniform sorbent coating with a CO_2 working capacity in excess of 1 mmol CO_2/g of sorbent and strong film adhesion to the SS plate surface.

Milestone 3.1

Deliver the Bench-scale contactor design

Milestone 3.1

Develop a system model to aid in data assessment.

Milestone 3.2

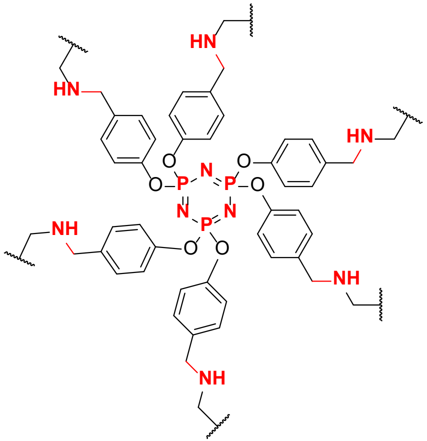
Deliver the design core plates that meet the thermal-fluid requirements for the contactor

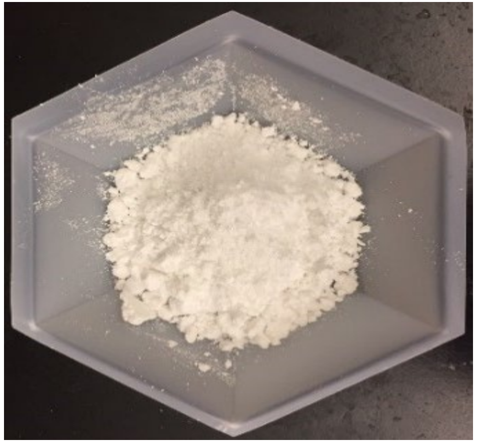
Sorbent Background –DAC

Amine-based Phosphorous (P) Dendrimer Sorbent for DAC

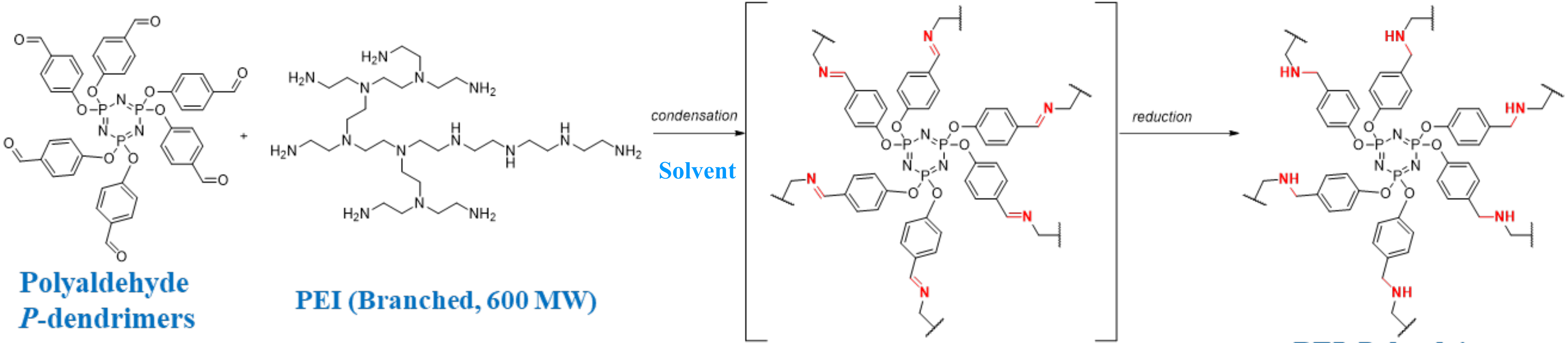
❖ Highly stable sorbent, which captures CO_2 from ambient air and then releases it when heated to moderate temperatures (80 ^{o}C) while demonstrating insensitivity to ambient humidity.

- ❑ Robust performance
- ❑ No leaching issue
- ❑ Low regeneration temperature
- ❑ High tolerance to water
- ❑ Excellent thermal stability





Polyamine *P*-Dendrimer Sorbent Synthesis



Polyaldehyde *P*-dendrimers

PEI (Branched, 600 MW)

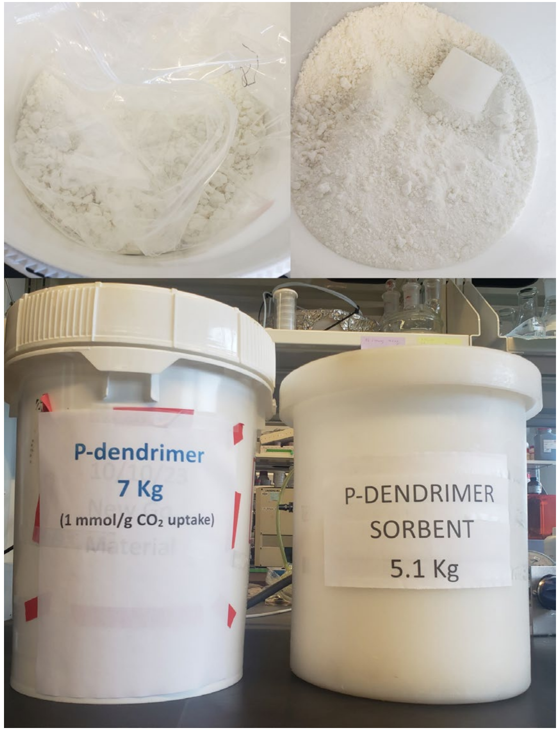
PEI-*P*-dendrimers

PEI

Solvent

Optimizing Sorbent Morphology

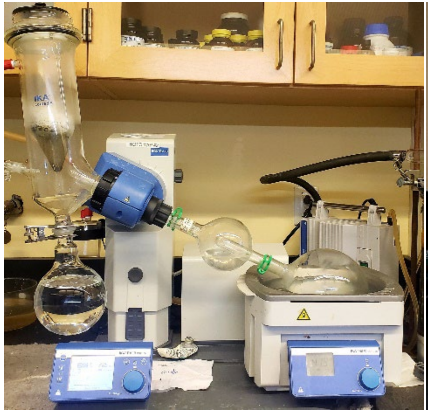
Sorbent Scale-Up

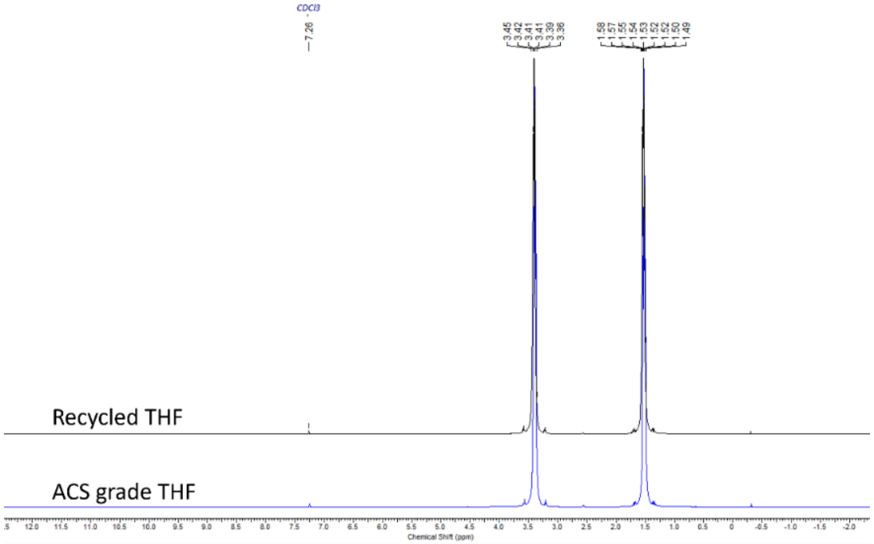


We've prepared ≥12Kg of P-dendrimer sorbent.

Solvent Recycling

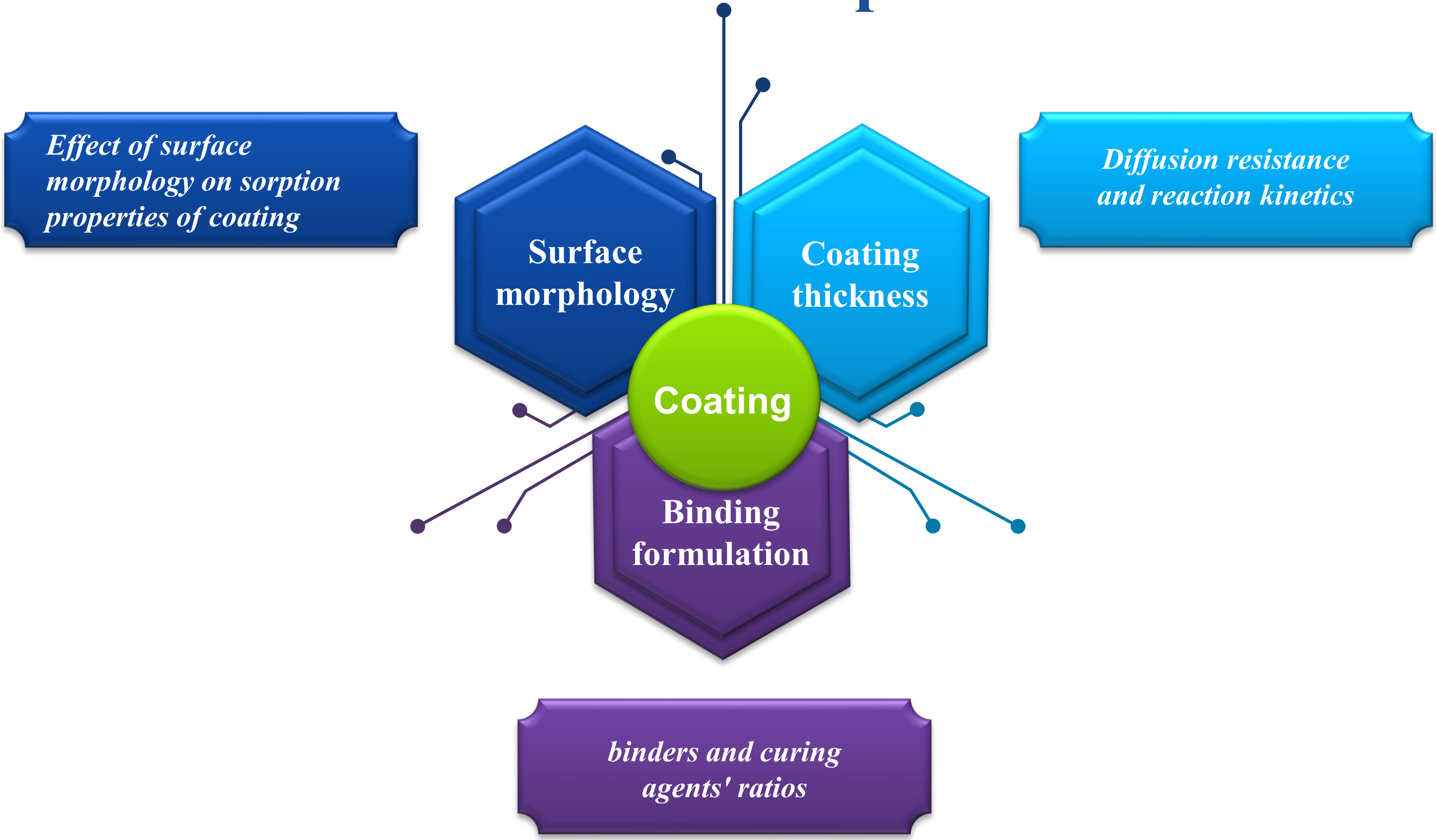
- Solvents constitute major portion of sorbent production expenses.
- We recover about 75% of the solvents used in the synthesis.





By recycling solvents such as THF, Ethyl acetate, and MeOH, we could reduce ~20% of the Sorbent Synthesis Cost.

Sorbent Structure Optimization



Sorbent Structure Optimization

Surface morphology

Investigate the effect of surface morphology on sorption properties of coating

- *Additives with lower boiling point/sublimation points*
- *Gas additive such as CO_2 gas*
- *Solids with inherent porosity such as mesoporous carbon*

Coating thickness

- *Total CO2 capture capacity increased with film thickness but decreased amine efficiency, as additional diffusional resistance for thicker films limits access to available amine sites*
- *The mechanical stability was evaluated by the tape test. Our coating formulation exhibit an excellent adhesion to the Stainless Steel.*

Binder modification

- *RTI binders lead to a much smoother surface structure with minimized porosity, reducing the sorbent-gaseous interaction*
- *This necessitated revisiting our formulation by minimizing the component responsible while still retaining the sorbent-support adherence.*

Lessons Learned

- Small particle size has a positive effect, resulting in high intra-particle mass transfer, but is negative as well, since it produces high inter-particle resistance to gas flow.

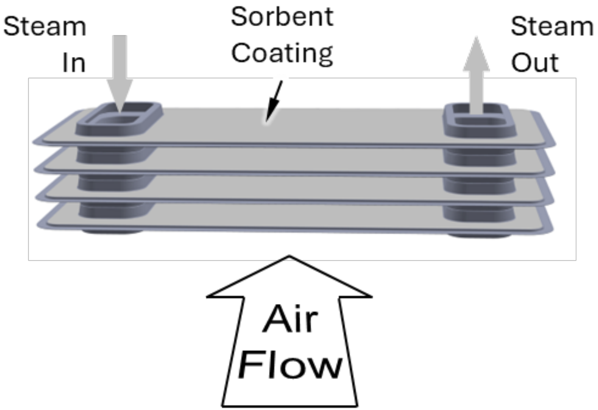
- Varying the coating thickness will impact the diffusion resistance and reaction kinetics
  - Chemical reaction is the dominant step during the entire regime,
  - Pore diffusion is important during the initial stages,
  - Solid diffusion resistance increases over time as the number of accessible amines decreases with capture

Wind-Driven Bench-Scale Contactor

- Bench-Scale Contactor Design
  - Low resistance to wind-driven flow through the contactor (CFD)
  - Features that can be fabricated using hybrid additive manufacturing (fabrication experiments)
  - We specified the overall system layout and identified rugged, durable seals (mechanical design)
- System Model
  - We formulated a MATLAB/Simscape™ model for overall system performance
  - Accounts for heat and mass transfer phenomena that govern capture rate and energy consumption
  - Using model to assess key design and operational tradeoffs, provide data for TEA
- Contactor Plate Design
  - We specified key features of the tooling needed to produce contactor plates
    - Based on results of CFD analysis and fabrication experiments
  - We used these parameters to produce tooling designs for the A and B contactor plates

Contactor Design Concept

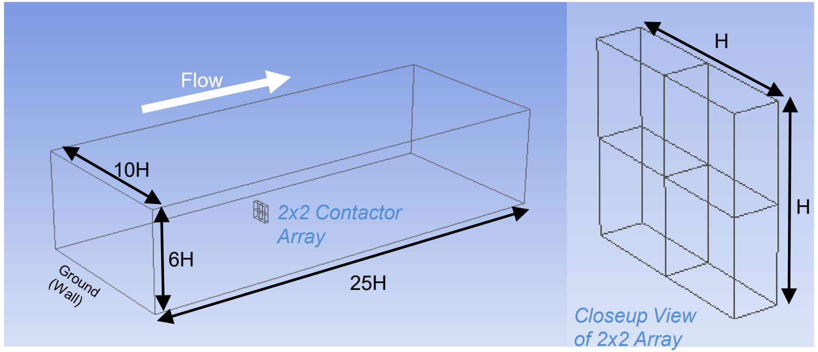
- Based on a compact, cross-flow heat exchanger
  - Open channels: Air side
  - Enclosed channels: Steam side
- CO_2 Capture
  - Wind drives air flow through coated, open channels
  - Wind provides post-regeneration cooling as well
- Regeneration
  - Indirect heating
  - Partial vacuum



Basic Contactor Design

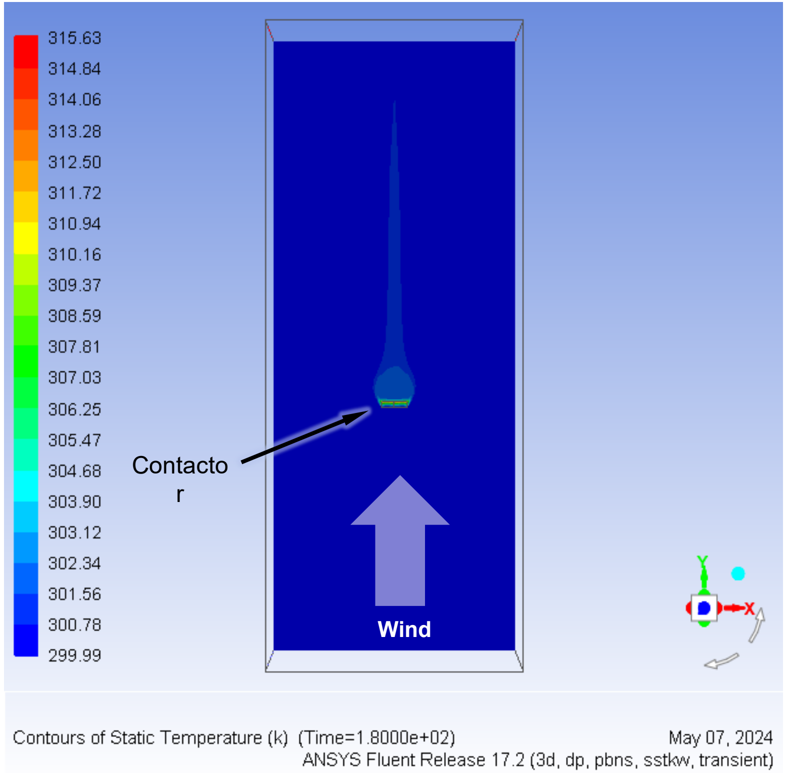
Early Contactor Prototype for Long-Term Durability Testing

Contactor Core Design Modeling



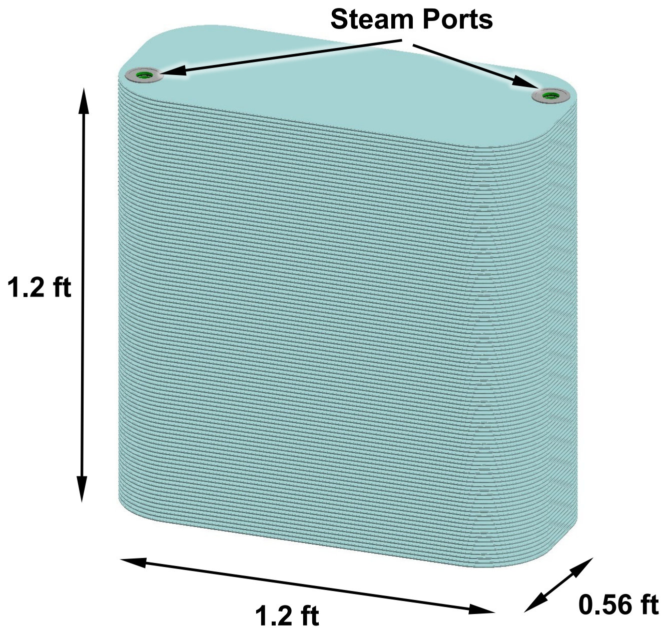
- CFD model for contactor in open flow
  - Modeled core as a porous element
  - Anisotropic permeability based on CFD calculations for individual channels
  - Composite properties based on contactor design features
- Initial array temperature = 85ºC (desorption temperature)
- Simulated three minutes of cooldown time
  - Monitored temperatures to determine time to reach adsorption temperature
- For final design: CFD and spreadsheet analysis show that the contactor cools down fast enough for nominal 4 m/s wind speed

Top-Down View of Temperature Contours Through Array Centerplane after 3 Minutes of Cooldown



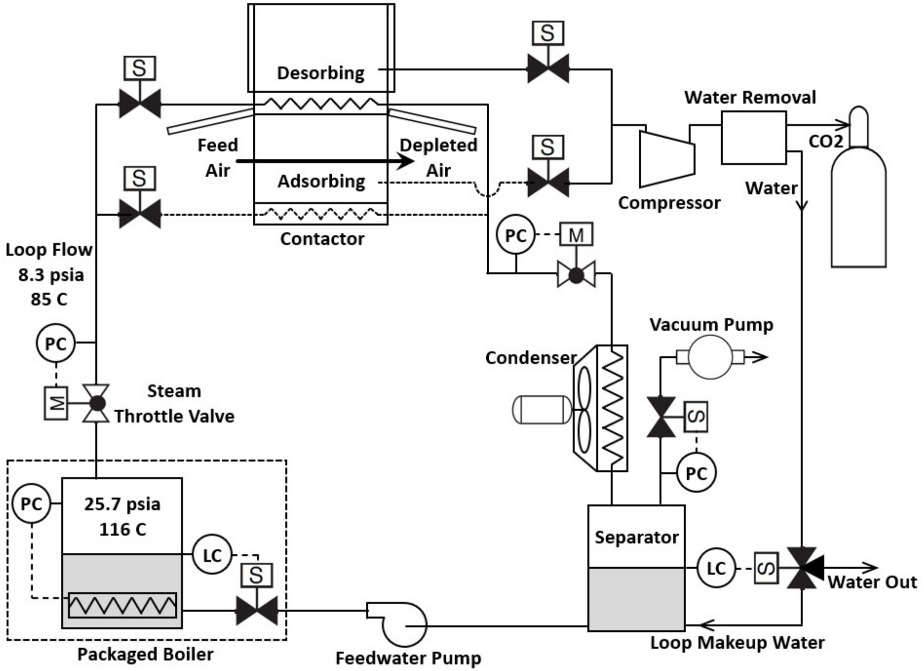
Contactor Module: Key Design Parameters

- **Design for a 1 kg/day contactor**
  - CFD results
  - Requirements for fabrication and sorbent coating
- **Key design features**
  - Channel pitch and spacing
  - Features to maintain uniform channels
- **Coating mass: 2.9 kg**
- **Performance estimated based on**:
  - Detailed laboratory measurements of sorbent performance
  - Average hourly climate data for southeastern US

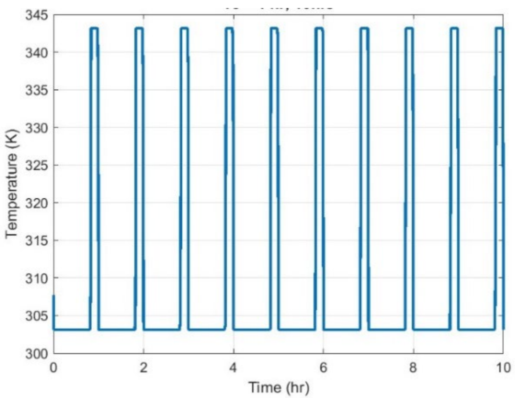


DAC System

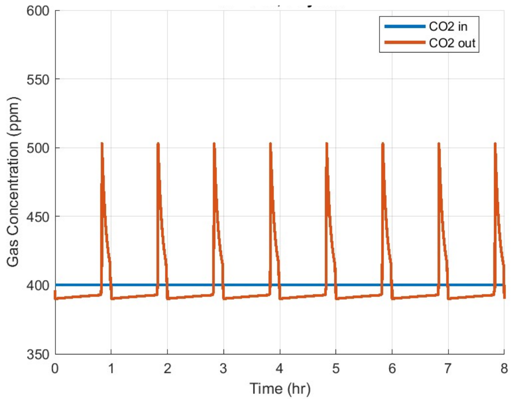
- **Contactor Modules**
  - Four modules ≈ ***1.5 t_{CO2}/yr***
  - Regeneration in pairs
- **Indirect Heating System**
  - Commercial steam boiler
  - Valves control flow through contactors
  - Condenser controls regeneration temperature
  - Replenished as needed using water recovered from contactor
- **Carbon Concentration System**
  - Contactor isolation subsystem
  - Commercial scroll compressor
  - Condenser for first-stage water separation
  - CO_2 storage under pressure
- **Key measurements**
  - Environmental conditions
  - Isolation panel position
  - Steam temperature & pressure during regeneration
  - Mass of CO_2 in storage tank

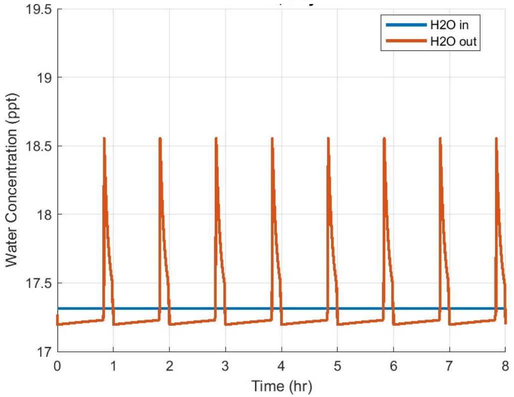


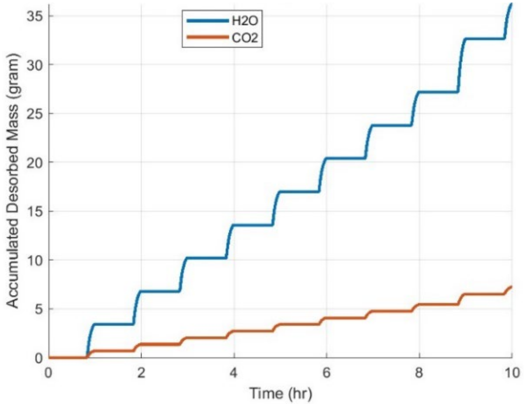
Simulation Results

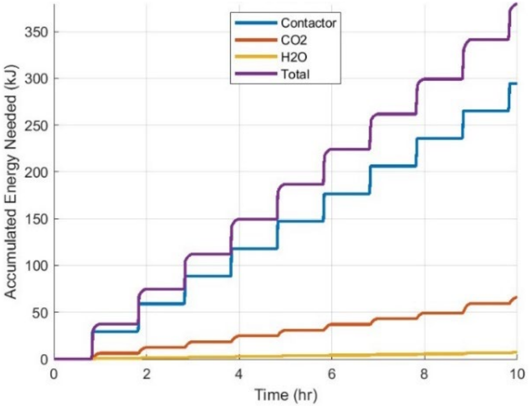


- System Operation
  - One-hour cycles
  - Regeneration at 70°C
- Environmental Conditions
  - 30°C, 75% RH
- Typical Results
  - Time dependent sorption and desorption rates
  - Integrated CO_2 and H_2O storage
  - Energy input broken down by system element









Summary of Community Benefits/Societal Considerations and Impacts

Community Benefits/Societal Considerations and Impacts

Identified community organizations and community leaders that are in or serve community members who live in disadvantaged communities

Developed task outreach materials

Conducted outreach activities

Coordinate and support presentations on Climate Change

Coordinate and collect feedback from the communities and assess the best path forward for technology demonstration and deployment.

Plans for Future Testing & Development

	Task	Milestone Title and Description	Planned Completion Date	Verification
BP2	4.1	Deliver the design of the contactor core and its integration hardware	9/15/2024	Quarterly report
	4.2	Deliver complete bench-scale contactor unit	6/14/2025	Quarterly report
	End of BP2	Go/No Go Decision – Build bench-scale, sorbent-integrated contactor system	6/14/2025	Quarterly report
BP3	5.0	Complete bench-scale contactor shakedown and commissioning	7/30/2025	Quarterly report
	6.0	1. Completion of parametric testing 2. Demonstrate Bench-Scale Passive DAC, 1-month, Continuous Operation	3/31/2026	Quarterly report
	7.0	Final TEA using all experimental data collected during the project	2/15/2026	Quarterly report
	8.1	Final LCA using all experimental data collected during the project	2/15/2026	Quarterly report
	8.2	Detail environmental health and safety risk assessment	3/15/2026	Quarterly report
	8.3	Technology Gap Analysis	3/15/2026	Quarterly report

Acknowledgment

- **DOE Project Manager**: Erika Bittner
- **CDR Team**

NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Fossil Energy and Carbon Managemen

Thank you

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