An Integrated Technology Demonstration of Continuous Passive DAC and Green Methanol Production (DE-FE0032419)

2024 FECM/NETL Carbon Management Research Project Review Meeting

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Acknowledgment

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Disclaimer

Project Overview

Funding:

- ❑Federal: $400,000
- ❑Cost-Share: $100,000

Overall Project Performance Dates:

12/20/2023 - 12/19/2024

Project Participants:

- ❑RTI International (Prime)
- ❑Creare, LLC.
- ❑EPRI

Project Objectives:

The overall objective of the proposed project is to perform conceptual design and feasibility studies of an integrated laboratory-scale process for carbon-neutral MeOH synthesis from CO_2 removed from air by DAC and green H_2 from H_2O electrolysis

1. Develop dynamic models for carbon-neutral MeOH synthesis
2. Demonstrate heat integration between process steps (e.g., DAC and MeOH synthesis)
3. Develop a process intensification strategy
4. Conduct a detailed TEA and LCA to demonstrate progress towards target costs of $800/tonne of MeOH

Project Plan

Task 1.0

Project Management and Planning

Task 2.0

Societal Considerations and Impacts

Task 3.0

Wind-Driven Contactor Design

Task 4.0

Carbon-Neutral MeOH Synthesis Process Modeling

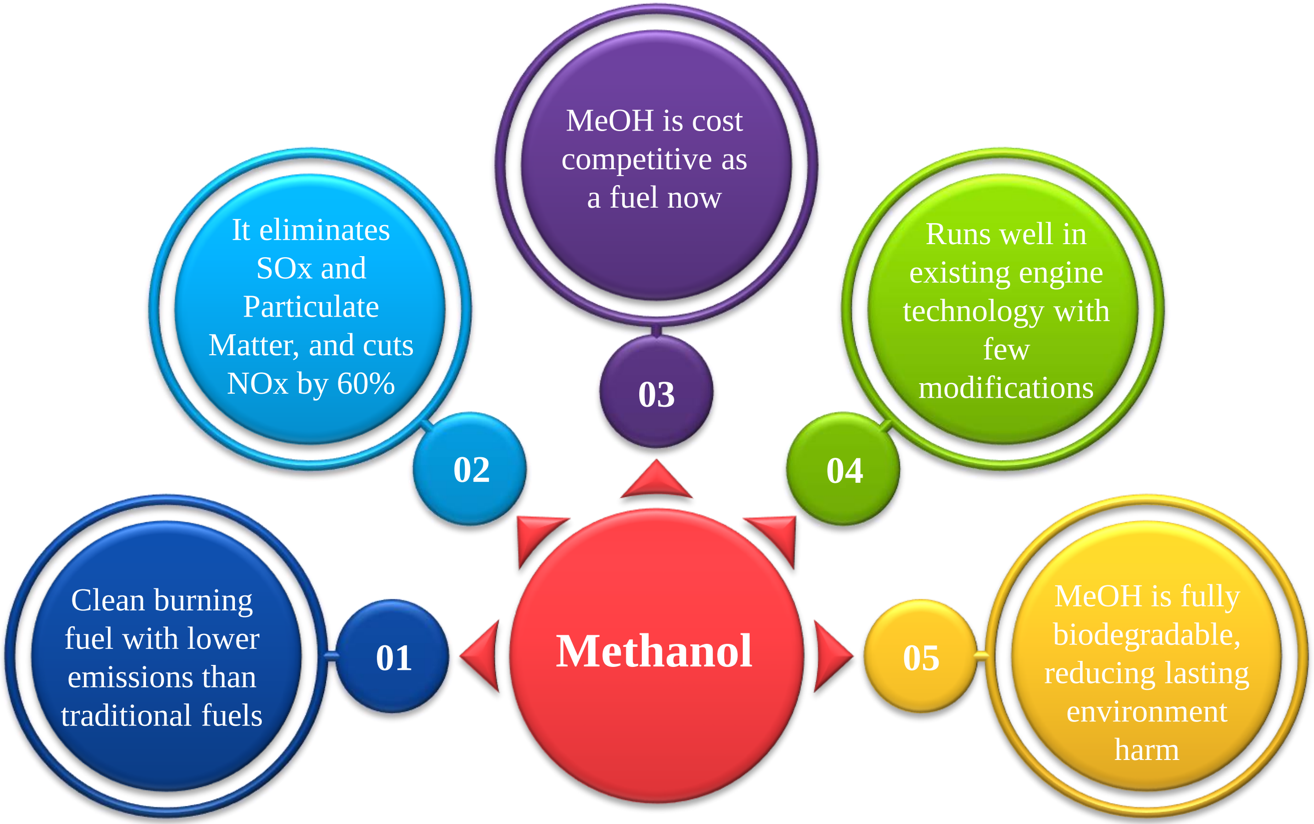
Task 5.0

Process Design of the Integrated 5.5 ton/yr MeOH system

Task 6.0

TEA, LCA, and Technology EHS Risk Assessment

Why Methanol?



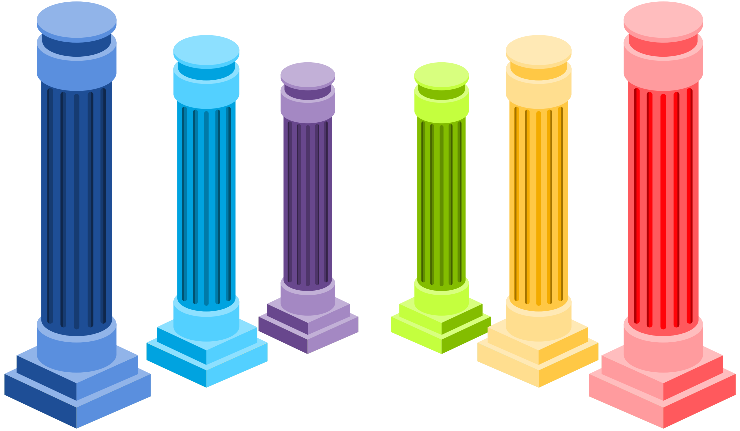
Green Methanol

The global gMeOH (bio & e-MeOH) market is valued at $1.9B in 2024 and is projected to reach $11.1B by 2030

Environmental regulations

Sustainability goals

Demand for clean fuels

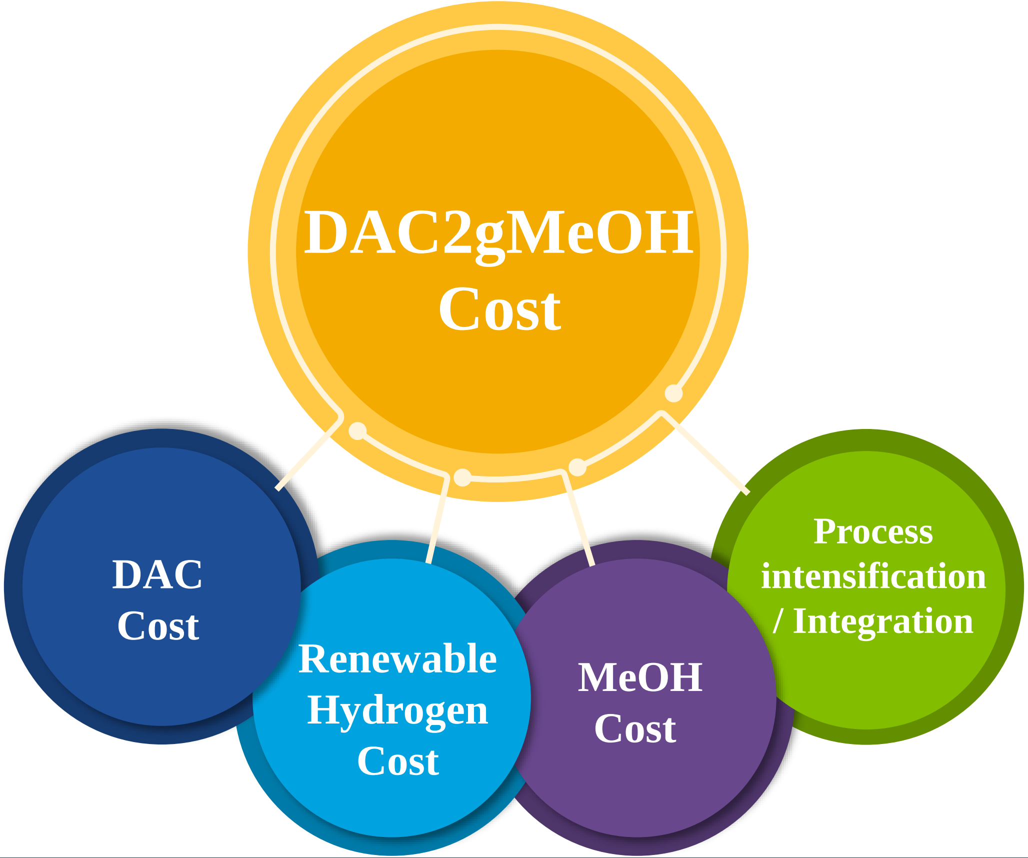


Consumer preferences for eco-friendly products

Climate change concerns

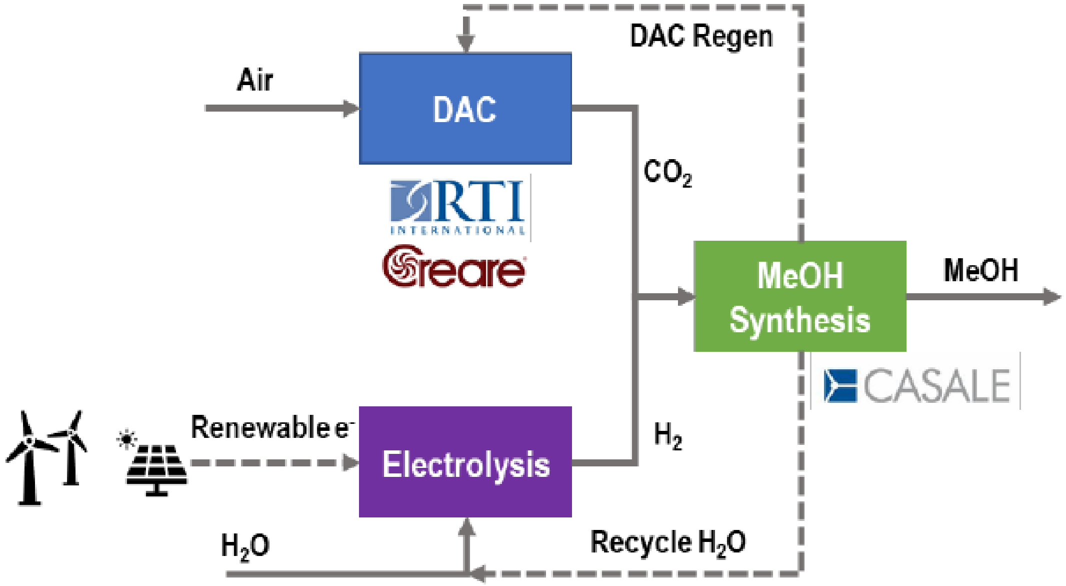
Government regulations

DAC to gMethanol



Integrated DAC to gMeOH Approach

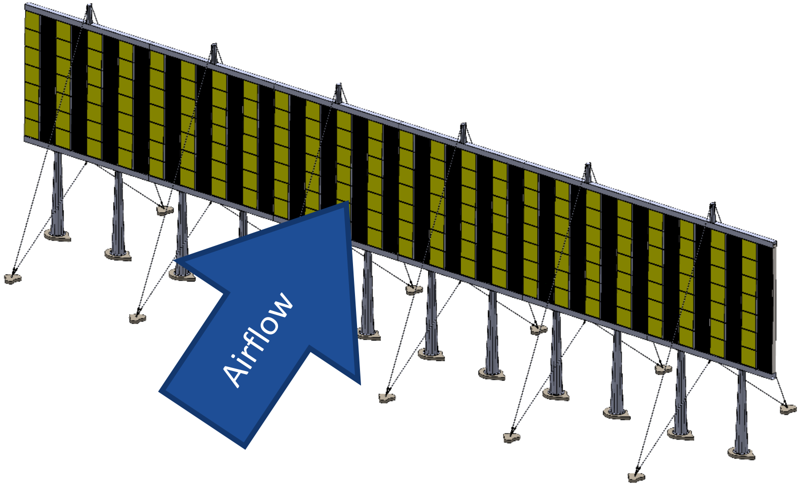
- **Key Innovations**
  - Passive DAC System that capture ***25kg/day of CO_2***
  - Dynamic gMeOH Process
  - Heat integration between the two processes

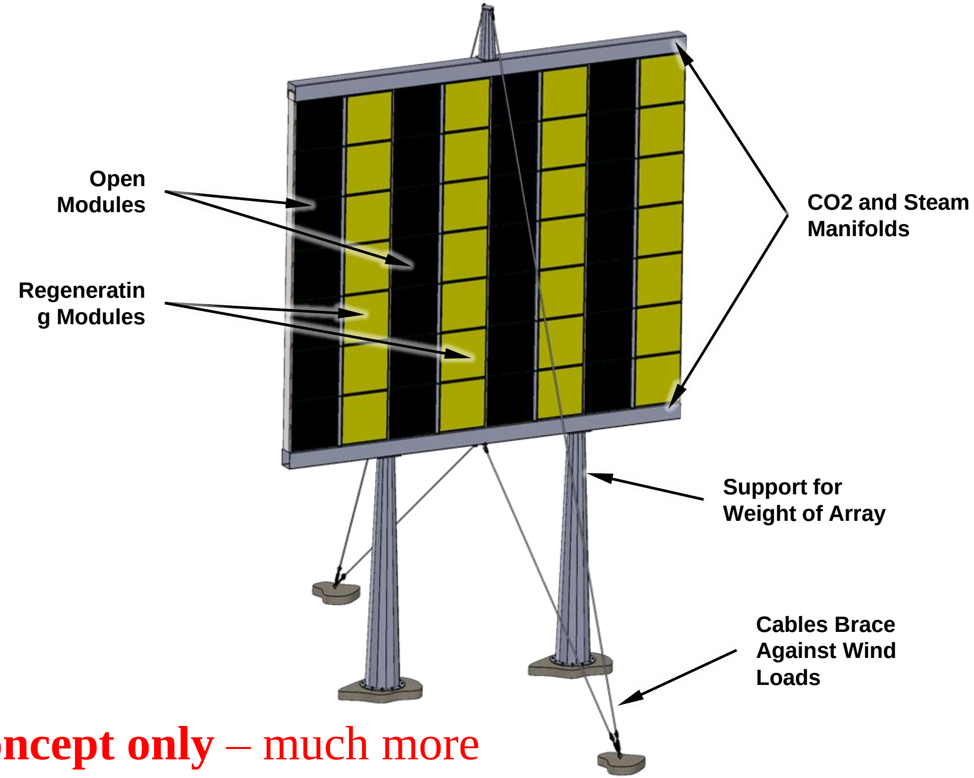


- **Key Deliverables**
  - Process design for ***15 kg/day MeOH***
  - TEA and LCA for DAC to gMeOH (1000 t_{MeOH}/yr)
    - Demonstrate path towards \$800/t_{MeOH}

DAC Contactor Concept

- **Large stationary array of contactor modules**
- **Sited in locations with strong steady winds**
- **Weight support like wind turbine support pylons**
- **Tension cables support against wind loads**

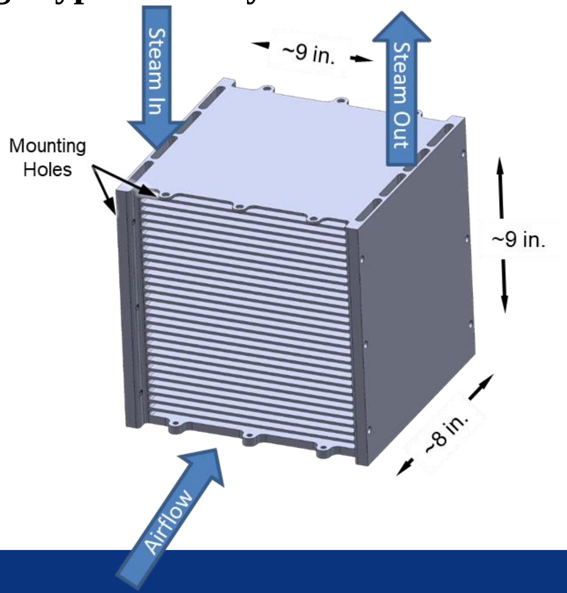


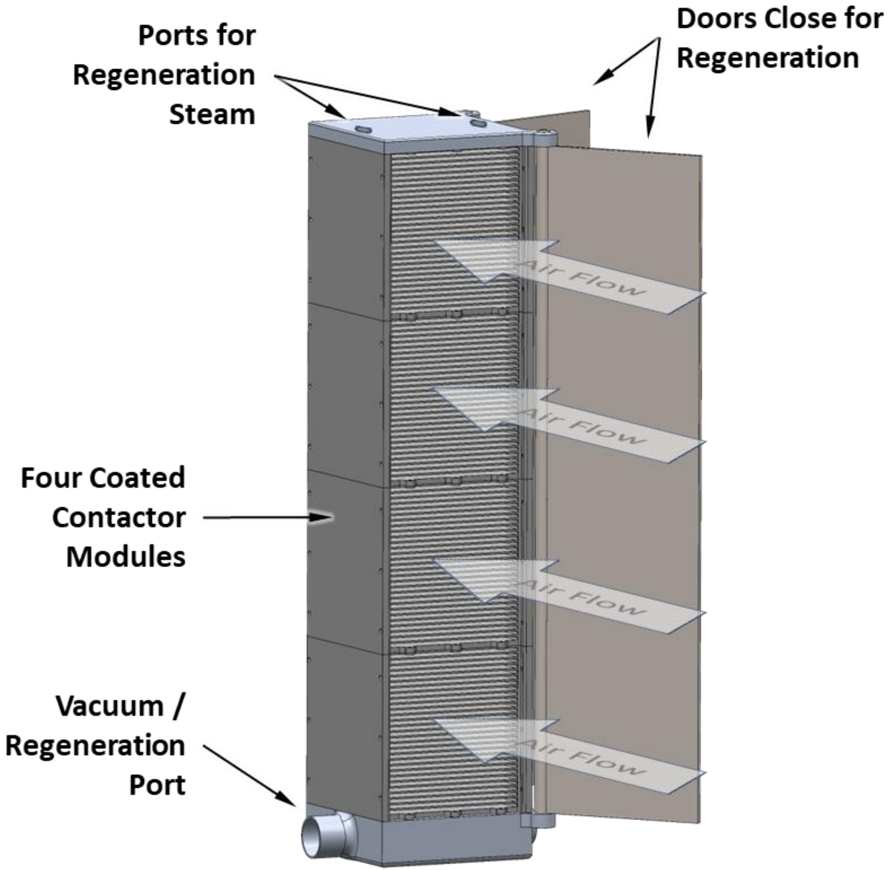


Concept only – much more structural and mechanical analysis and design are needed!

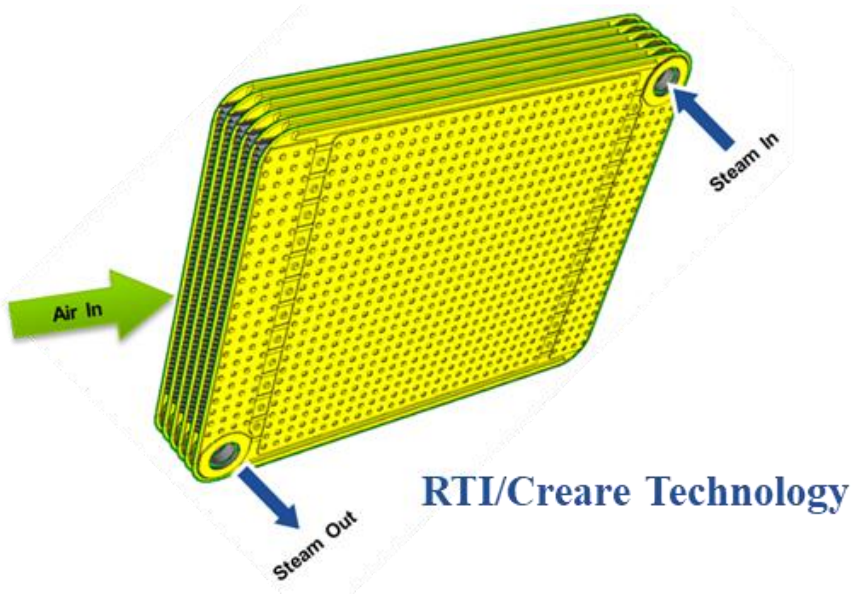
Contactor Module

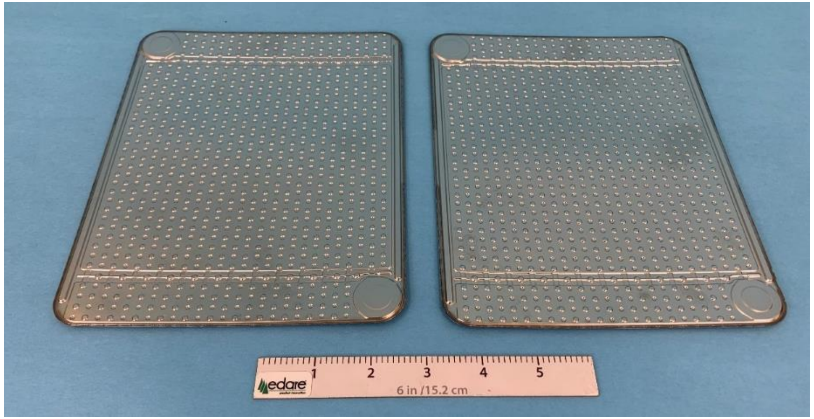
- Contactor module (~9 in. cube)
  - Can be fabricated using laser-welded flat plates
- Steam ports are sealed using formed-in features on top and bottom plates
- Modules stack to form larger unit cells
- Lego-type assembly of modules





Wind-Driven DAC Contactor





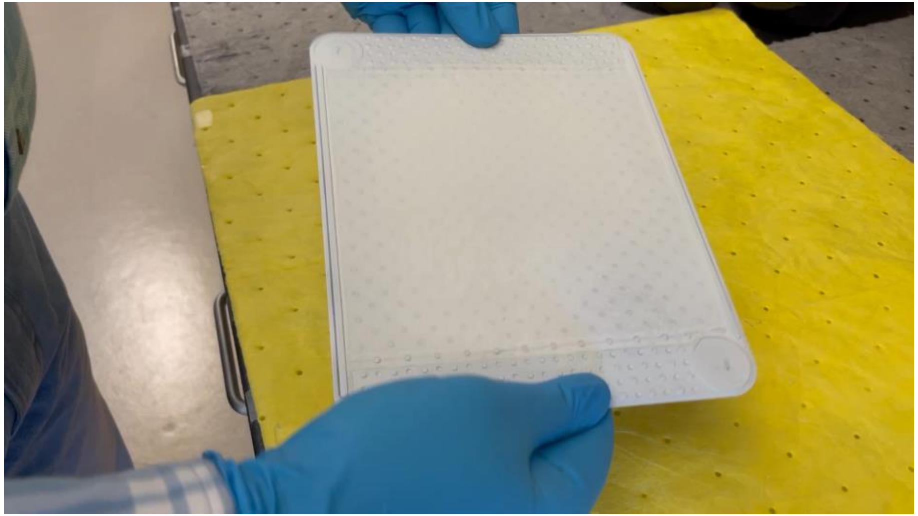
Advantages:

- Controlled coating
- High surface area
- Low thermal mass
- Excellent mass/heat transfer
- Minimal pressure drop

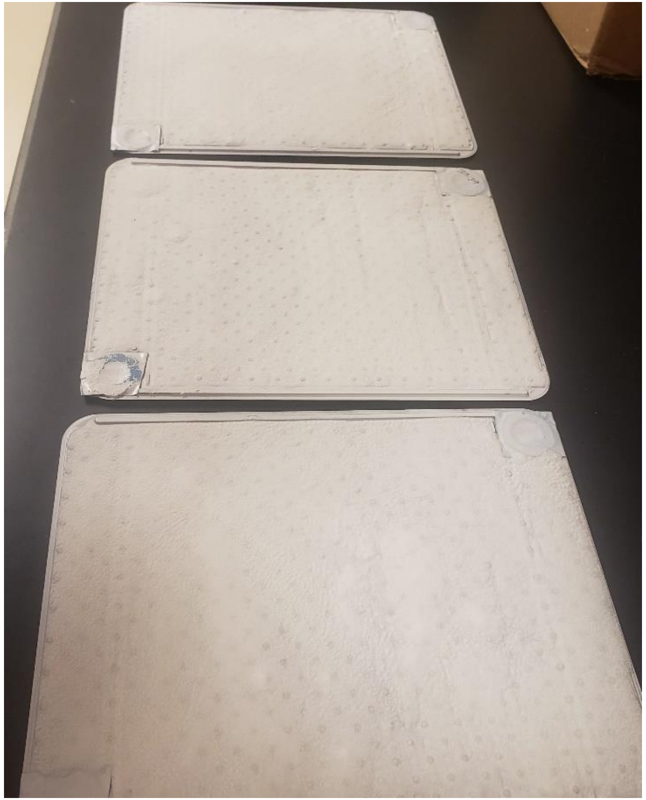
Sorbent Background –DAC

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 ^oC) while demonstrating insensitivity to ambient humidity.
  - Robust performance
  - No leaching issue
  - Low regeneration temperature
  - High tolerance to water
  - Excellent thermal stability



Demonstrated Coating of 120 pair plates (240 plates)

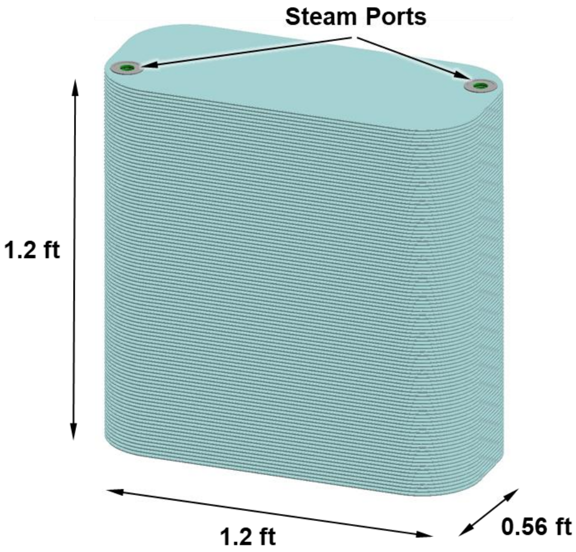


Project Status

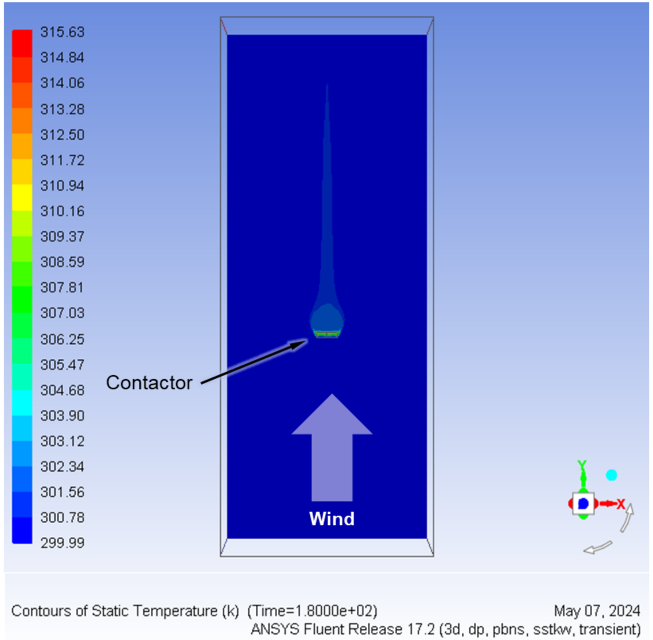
- **Baseline Contactor Design**
  - From parallel effort to develop a bench-scale, 1.5 t_{CO2}/yr contactor
  - Wind-driven, modular, inexpensive fabrication methods
  - Based on lab measurements of adsorption and desorption rates at RTI
- **System Model**
  - We formulated a MATLAB/Simulink model for 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 and inputs to methanol production simulations

Contactor Module: Key Design Parameters

- Design for a 1 kg/day contactor module
  - 25 modules are needed (i.e., 25kg/day)
  - CFD results
  - Requirements for fabrication and sorbent coating
- Key design features
  - Channel pitch and spacing
  - Internal features to maintain uniform channels
- Coating mass: 2.9 kg
- Performance estimates based on:
  - CFD mass transfer calculations
  - Detailed laboratory measurements of sorbent performance
  - Average hourly climate data for southeastern US

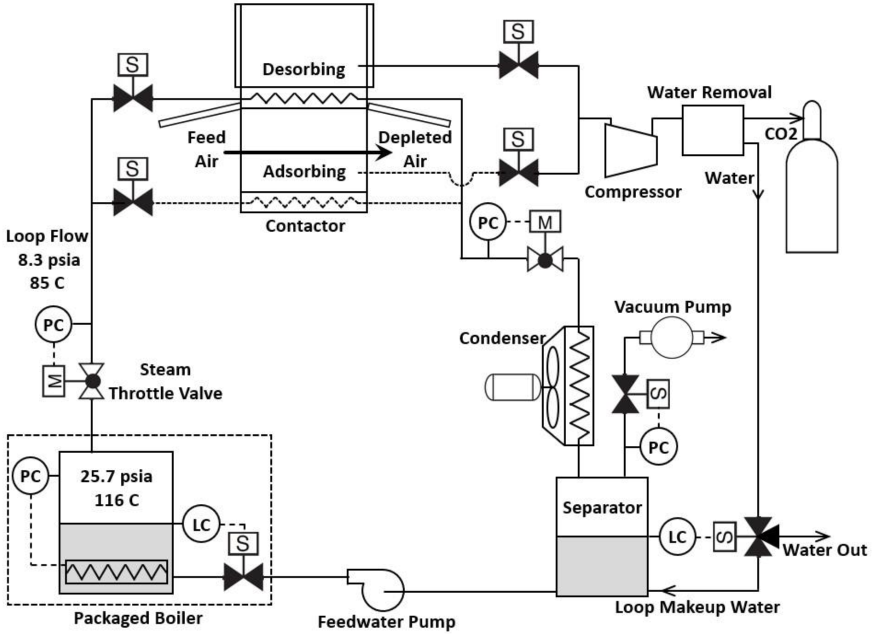


Top Down View of Temperature Contours Through Array Centerplane after 3 Minutes of Cooldown (1 tCO2/yr benchtop system)

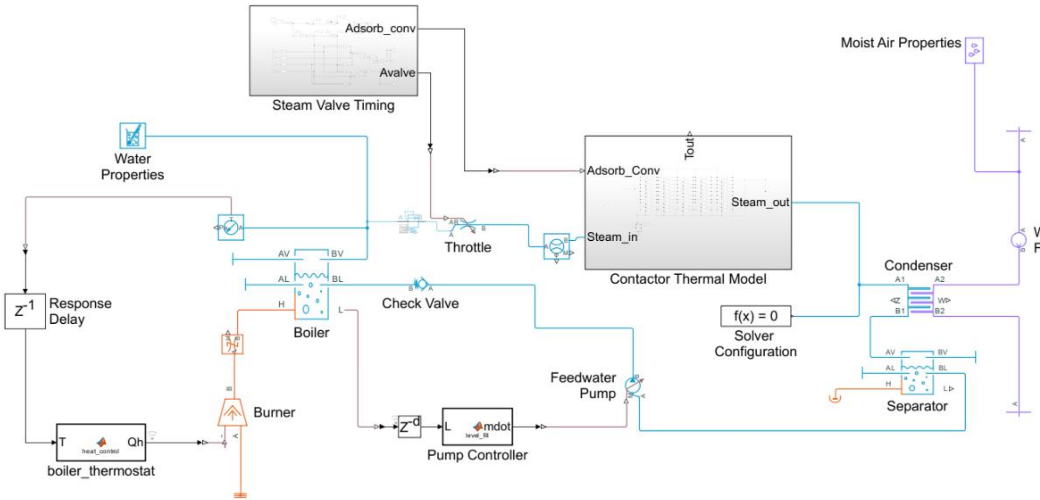


DAC System

- **Contactor Modules**
  - ≥ 9 tCO_2/yr
  - At any time: 5/6 modules adsorb; 1/6 desorb
- **Indirect Heating System**
  - Low-temperature steam generation system
  - Valves control flow through contactors
  - Condenser controls regeneration temperature
  - Replenished as needed using water recovered from contactor
- **Carbon Concentration System**
  - Contactor isolation subsystem
  - Compression system also produces partial vacuum
  - Condenser for first-stage water separation
  - CO_2 storage under pressure
- **Key operating variables**
  - Environmental conditions
  - Isolation panel position
  - Steam temperature & pressure during regeneration



System Model – Contactor Heat Transfer/Steam Flow

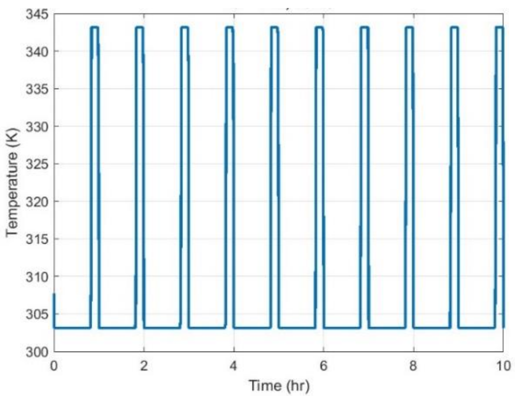


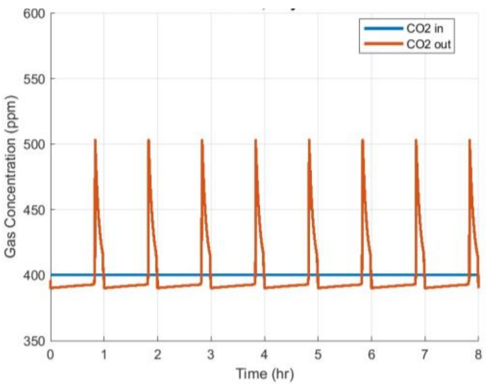
- Formulated a model for the DAC system using Simscape™
- Models key components and processes
  - Wind flow through contactor
  - Sorbent loading
  - Steam supply
  - Steam condenser

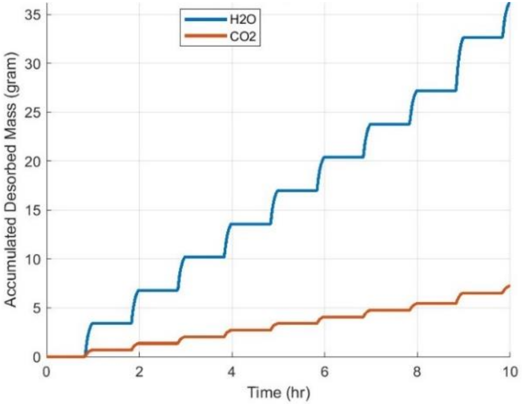
- **Inputs**
  - Environmental conditions
  - Empirical data for sorbent behavior
  - Setpoint for steam pressure and water level in boiler
  - Regeneration timing

- **Calculated Results**
  - CO_2 loading in sorbent
  - CO_2 and H_2O concentrations leaving contactor
  - Steam flow and required heat input

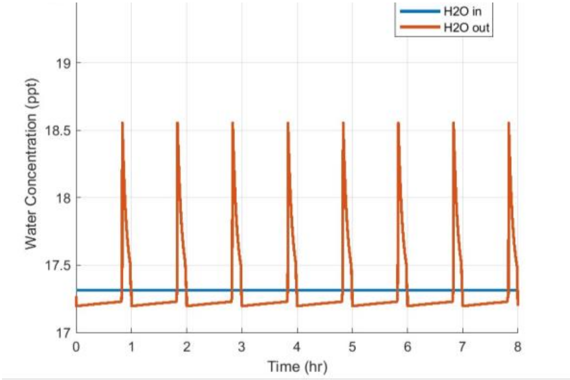
Simulation Results

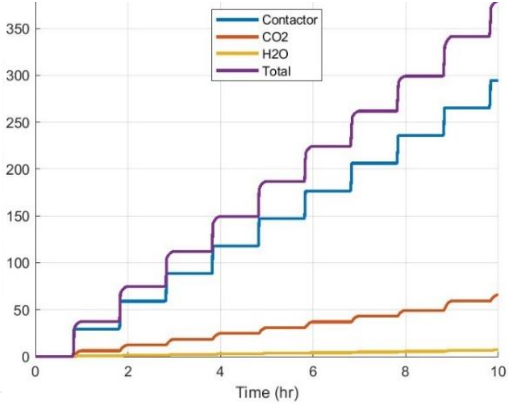






- System Operation
  - One-hour cycles
  - Regeneration at 70°C
- Environmental Conditions
  - 30°C, 75% RH
- Typical Results
  - Time dependent sorption and desorption rates
  - Integrated CO_2 and H_2O storage
  - Energy input broken down by system element





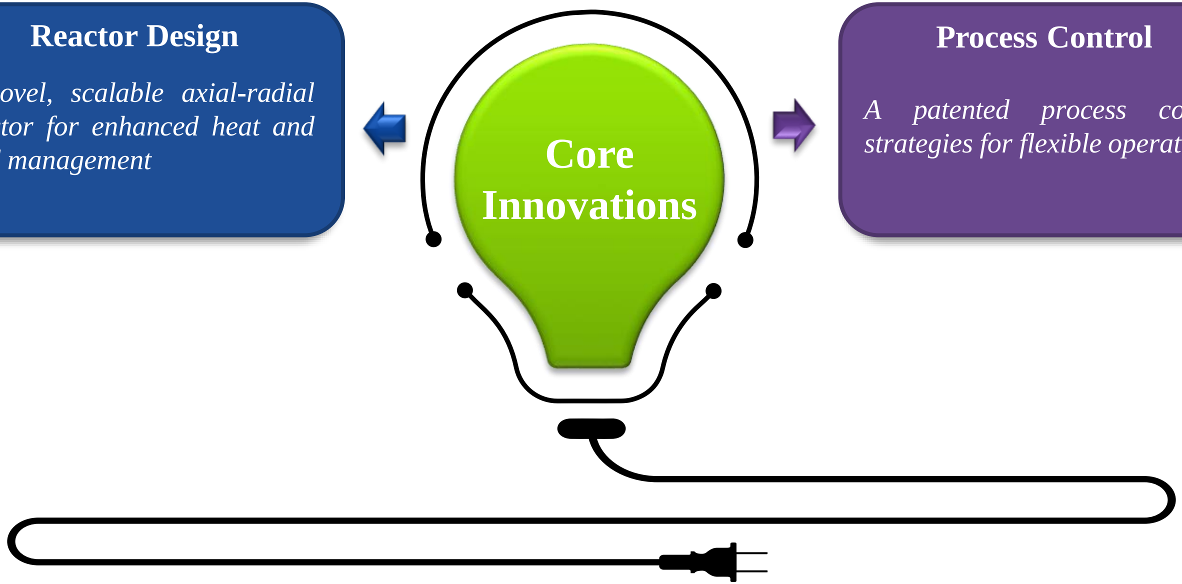
Direct Conversion of CO_2 and H_2 to e-MeOH

Catalyst

An advanced robust, low-cost mixed-metal oxide catalyst optimized for dynamic operating conditions

Reactor Design

A novel, scalable axial-radial reactor for enhanced heat and load management



Process Control

A patented process control strategies for flexible operation

Direct Conversion of CO_2 and H_2 to e-MeOH

A novel low-cost catalyst operating at temperatures and pressures like traditional syngas-to-MeOH processes

Pressure: 50–60 bar,
Temperature: 200°C–260°C,
Gas hourly space velocity: 3,000–30,000 h^{-1}

Catalyst

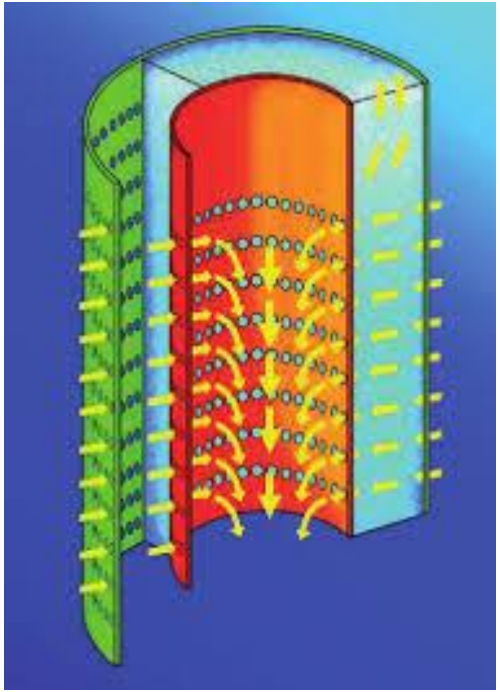
The key advantages

- 30% increase in resistance to temperature, pressure, and space velocity fluctuations
- Rapid recovery of steady-state operation after ramping
- Ability to operate in “active idle” or “dormant” state and resume activity without reactivation.

Current scale catalyst production is 200 g/batch

Novel Reactor Design

- A novel, scalable axial-radial reactor for enhanced heat and load management
- Novel upgrades to the reactor internals are ongoing based on
  - Additive manufacturing techniques for easy scaling,
  - Enhance heat transfer under variable loads,
  - Novel temperature control schemes
  - Ability to operate under variable flow rates and reduced pressure drops needed for direct CO_2 reduction.



Casale's axial-radial isothermal MeOH converter:

- Most of the gas crosses the catalyst bed in a radial direction, resulting in very low pressure drop.

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.

Acknowledgment

- **DOE Project Manager**: Akhil Sathish
- **CDR Team & CO_2 Conversion Team**

Thank you

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