Demonstration of a Continuous Motion Direct Air Capture System

DE-FE0031957

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Global Thermostat

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management and Natural Gas & Oil Research Project Review Meeting

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Program Overview

Federal: $2,499,996 Cost Share: $850,000 Total: $3,349,996

Budget Period 1: 1/1/2021 – 6/30/2022

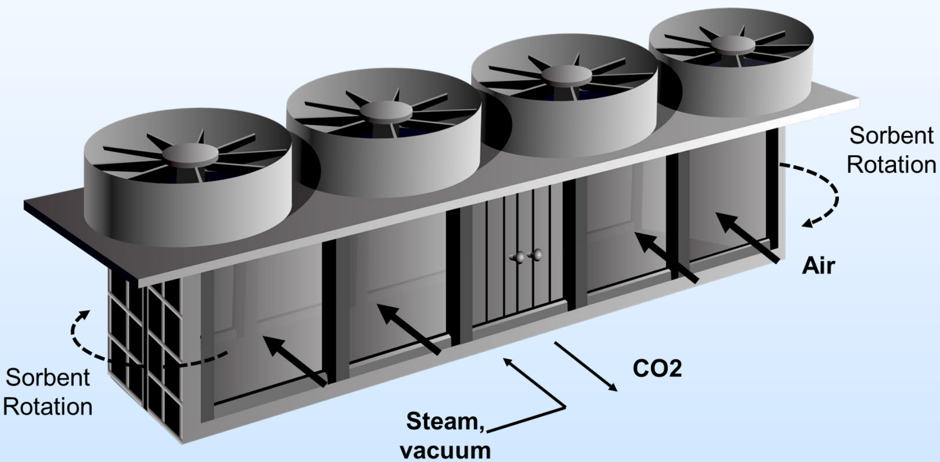
Budget Period 2: 9/1/2022 – 8/31/2023

Budget Period 3: 9/1/2023 – 2/28/2023

Project Participants:
- Global Thermostat
- Georgia Institute of Technology
- National Renewable Energy Laboratory
- VADA
- Zero Carbon Partners

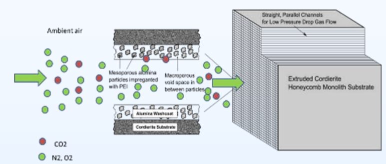
Primary Objectives: Design and construction of a field-test unit demonstrating a continuous-motion direct air capture process, reducing complexity, CAPEX, & OPEX while increasing reliability

Technology Background: Concepts



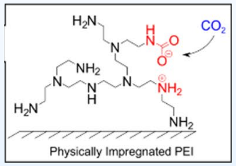
GT DAC Module: Fluid – Sorbent Contacting Area

1. Moving Large Air Volumes Efficiently



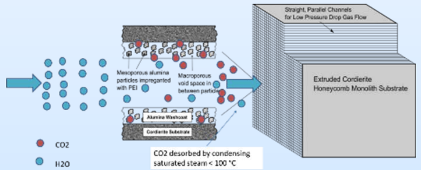
Porous honeycomb monolith fluid contactors

2. Capturing CO_2 Selectively at 400 ppm



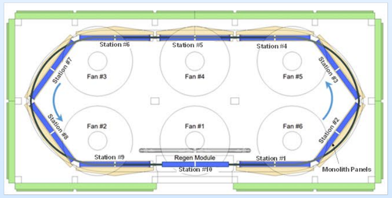
Amine sorbents

3. Rapid, Efficient Regeneration



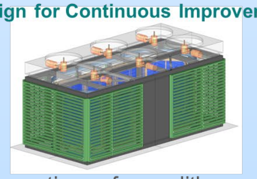
Direct-contact steam stripping fast and efficient CO_2 production

4. Capital Efficiency



Low pressure drop multibed adsorption through panel movement

5. Design for Continuous Improvement



Future generations of monoliths are drop-in compatible

GTTC = Accelerated Development

Brighton, Colorado

TRL1 ⟷ TRL8+

Fundamental Rates, Material Properties

Laboratory-based testing
10^{-6} - 10^{-3} kg

Bench-scale Controlled Conditions

Core Adsorption Tester

Multi-core Tester

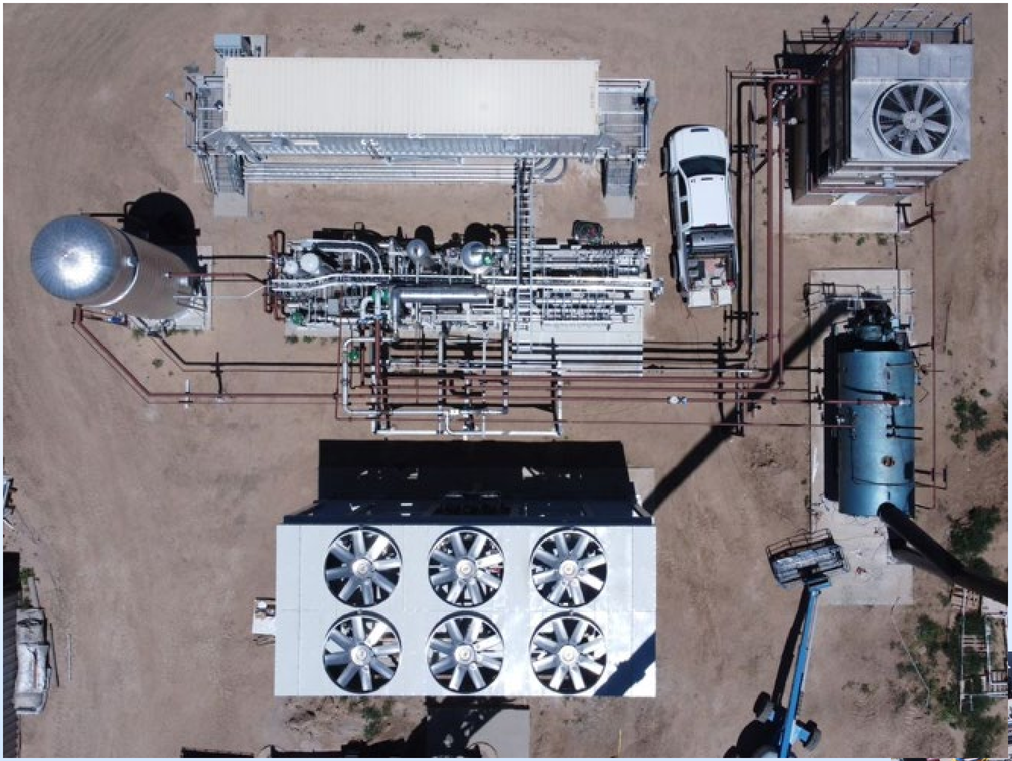
Bench-scale testing
10^{-2} - 10^{1} kg

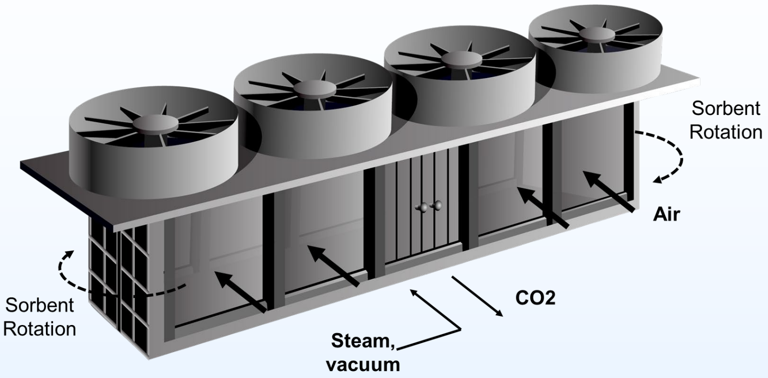
Relevant environment operating data

Pilot-scale testing
10^{3} - 10^{4} kg

Commercial-scale testing
10^{5} - 10^{6} kg

Kilotonne-scale GT DAC Demonstration





GT DAC Module: Fluid – Sorbent Contacting Area

- GT Batch Process
- Furthest developed process and capital embodiment
- Continuous process and capital embodiment is currently lower TRL

Technology Background: Advantages & Challenges

Technical / Economic Advantages:

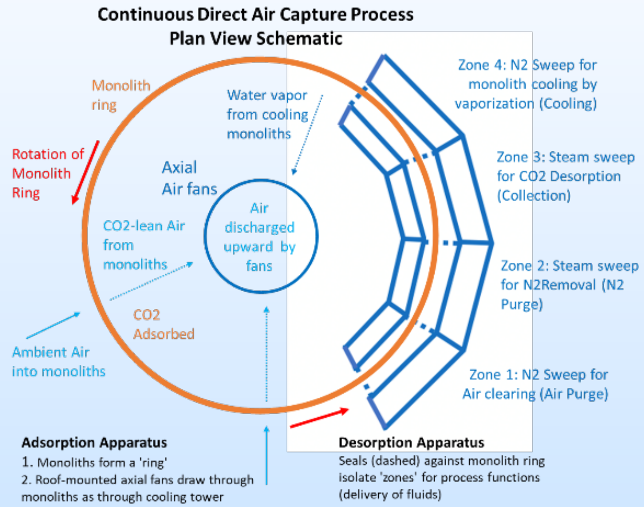
- Rapid cycles (<20min) enabled by monolith contactor (adsorption) and steam regen (desorption). Reduced amortized CAPEX
- High capital utilization efficiency (improved CAPEX) while maintaining low pressure drop (improved OPEX) via panel movement
- High uptakes enabled by amine dense sorbent (improved CAPEX and OPEX)

Technical / Economic Challenges:

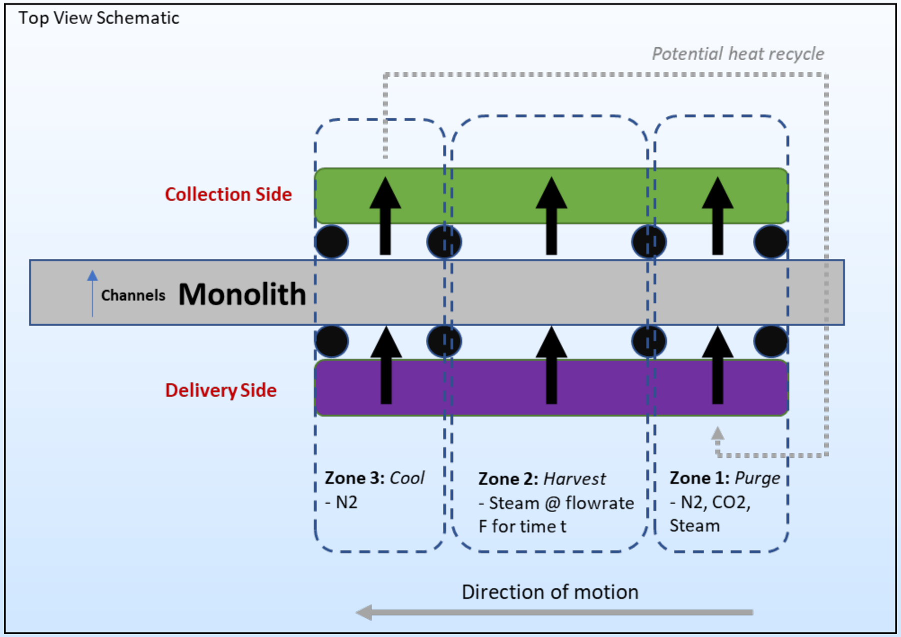
- Physical movement of large components can be mechanically challenging, particularly in a batch process (start/stop)
- Maintaining adequate sorbent lifetime over many cycles
- Wide parameter space with limited resources

Continuous Process Concept

How to translate batch process to continuous process?



Version 1 Technology Concept



DAC Module Regeneration Concept

GT R&D: <u>Process Innovation</u>:
*Novel DAC embodiments utilizing core technology features, but realized in a different **process** and **capital design** offering potential economic advantages*

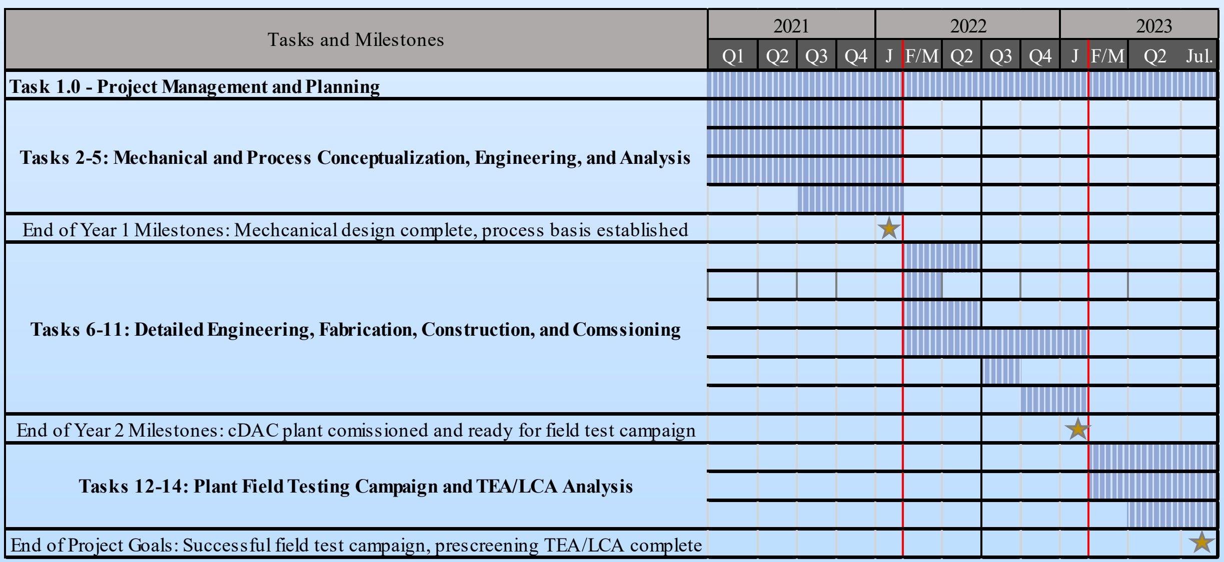
Area	Approach
<u>Capital Design</u>: Movement, sealing, airflow	Iterative design and mockup testing
<u>Process Design</u>: Cooling, purging	Experiment & Modeling

Technical Approach/Project Scope

<u>Project Scope & Goal:</u> Develop and demonstrate *continuous DAC* prototype based on the GT technology platform

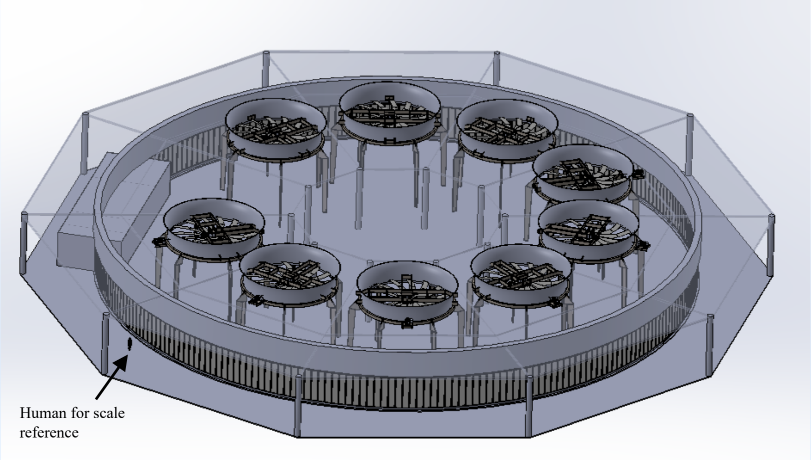
<u>Development philosophy:</u> *design big, build small*: prototype the elements to enable successful climate-scale DAC deployments

<u>Project Arc:</u>



cDAC Module Concept

Modularize around air movement



~50 kta plant module used for scale assessment

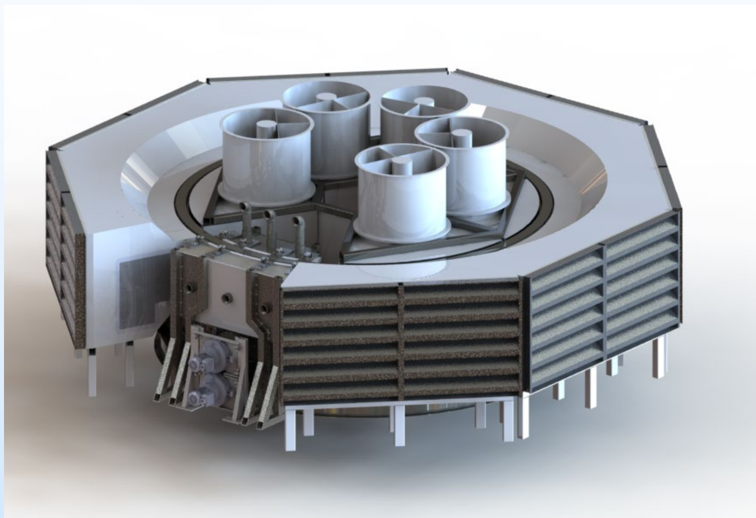
- 9 fan plant module as base scale for mechanical concept evaluation
- Base module from which large installations are scaled up or out (in a variety of ways)

<u>Development philosophy:</u>
design big, build small

Module subareas:

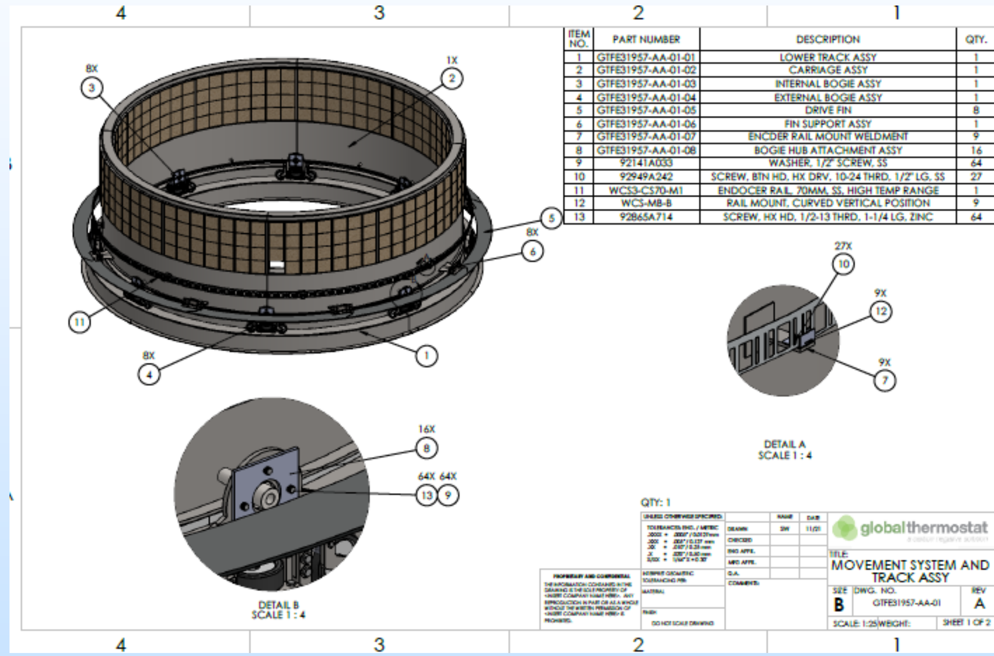
- **Movement** system
- **Regeneration** area (zones)
- **Air processing** (adsorption)

Prototype Module Development



- 20’ diameter cDAC module prototype to be constructed
- Phase 1 build focused on monolith movement system

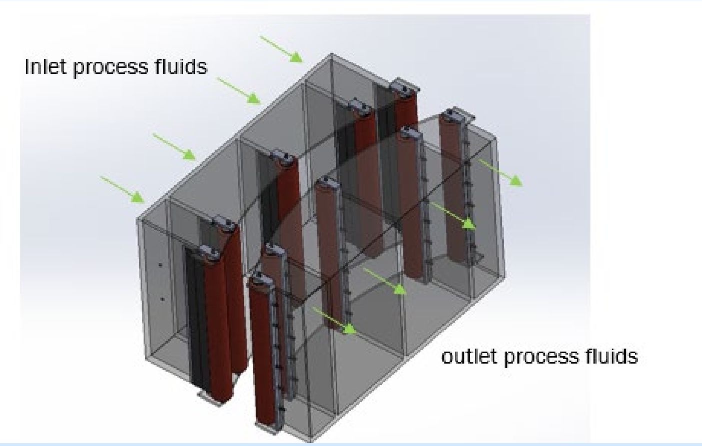
Movement System



- Engineering package developed to full set of fabrication drawings
  - Developed in-house
- Package at local, specialized fabricator for bid

Regeneration Zones

Dynamic sealing system to create zone boundaries



Regeneration Unit with Roller Seals

Development of Direct Contact Roller Seals:

Cylindrical roller seals that contact the face of the monolith

Create separation between fluid zones to enable temporal process steps

Two zone, cold flow prototype

- Test of current detailed design, assessment of component fit ups and seal movement
- Measurements of leak rates

Zone Sealing Performance

Dynamic sealing system to create zone boundaries

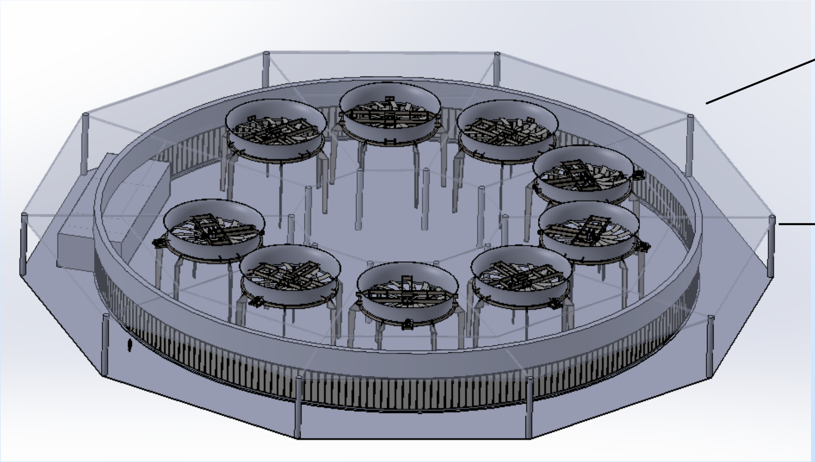
Measurements of leak rate (per unit length of seal) vs differential pressure across seal

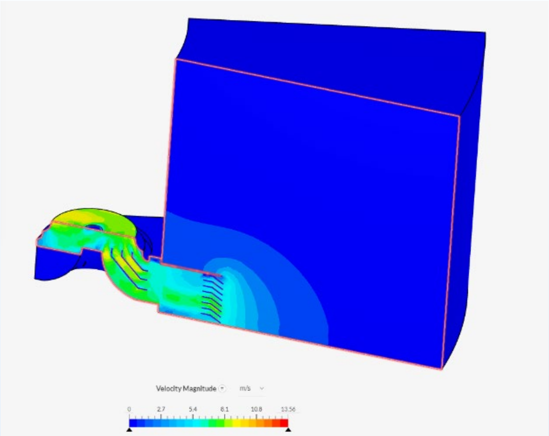
Quantify fluid losses zone to zone to assess relationship between seal complexity, available differential pressure range, and fluid loss across seals

Interplay between capital design and process design: Small differential pressures available for process design

Air Processing

Low cost DAC requires efficient air movement



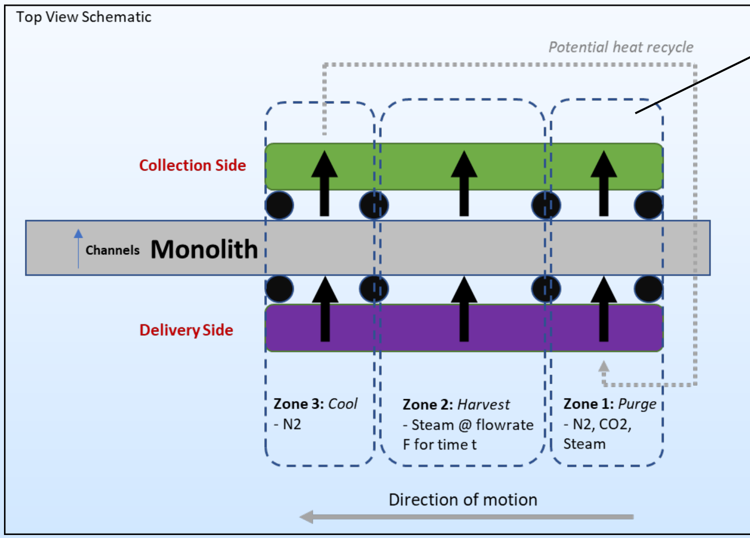


CFD analysis to analyze airflow uniformity (% RMS) and air movement efficiency (kWh / CFM)

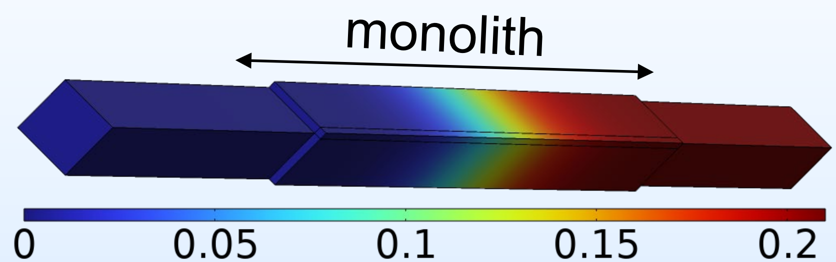
Front Facing View

Air Processing Prototype

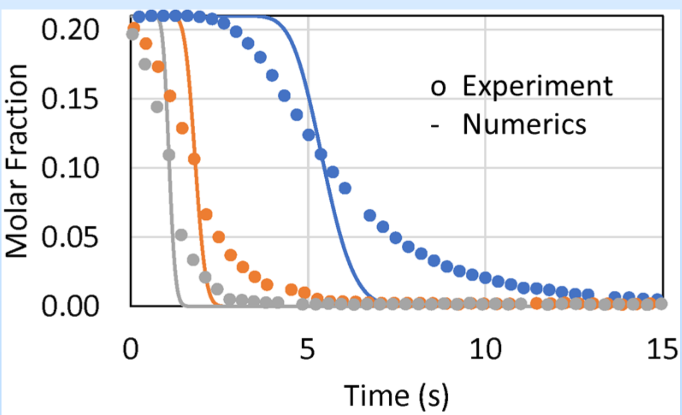
Process Development: Purge



Pre-steam purge



Computed O_2 molar fraction in a (quarter of) single channel



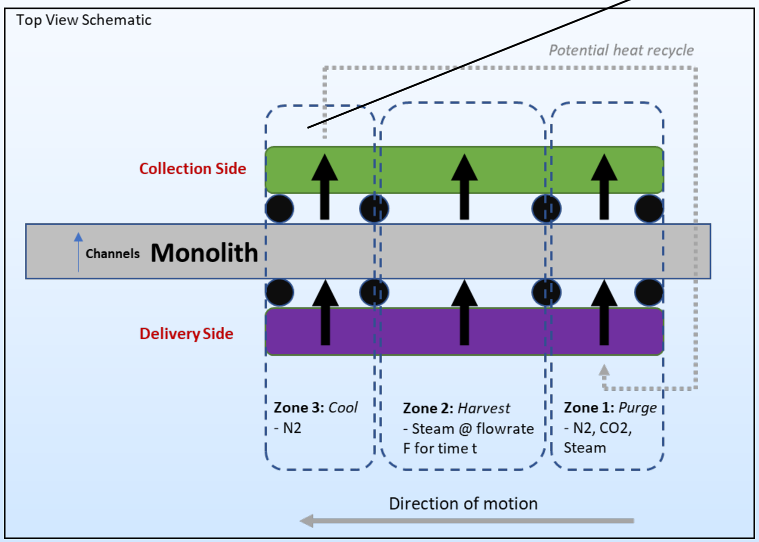
Convection/ diffusion of O2 from channels and pores of monolith

- How to design efficient front and back end purge steps
- Front end purge step: remove oxygen and increase CO2 purity

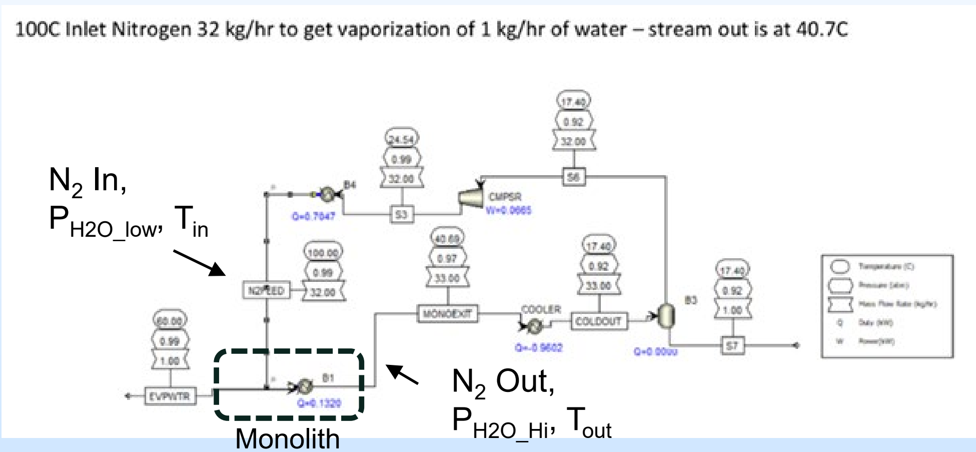
Rapid, efficient purging step possible – what are effects of monolith internal structure?

Process Development: Cooling

Post-steam cooling



System level evaluation



- How to design efficient front and back end purge steps
- Back end step: monolith cooling prior to introduction to airflow, H2O recovery

Thermal swing in N_2 loop to drive evaporative cooling is primary cost driver

Capex/opex tradeoff with loop size, extent of cooling, H_2O recovery, monolith lifetime

Site specific factors such as cooling water temperature become important

Plans for future testing/development/ commercialization

BP2

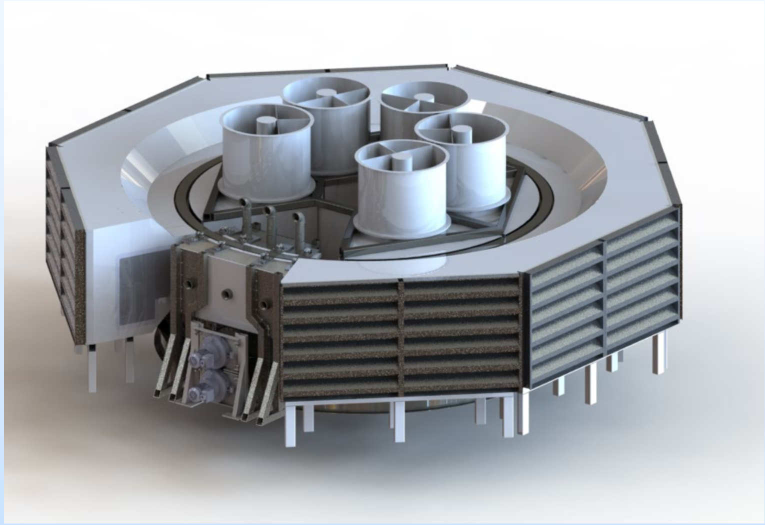
- Fabricate and test DAC module (movement, sealing, airflow)
- Fabricate and install process area of plant
- Continued development and learnings from each prototype

BP3

- Operate cDAC plant, collect data, evaluate TEA/LCA

Summary

GT cDAC development proceeding through structured approach:



DAC module design areas of focus:

- **Movement** system
- **Sealing** system
- **Air Processing**

Process design focused on pre and post steam purge step development

- **Purge step** to remove O2 and increase CO2 purity
- **Cooling step** to recover H2O and reduce monolith temperature prior to reintroduction to airflow

<u>GT cDAC concept offers cost saving potential if challenges can be overcome. Project focus is on these technical hurdles</u>

Team

Global Thermostat

Eric Ping – Project Coordinator
Miles Sakwa-Novak – Co-PI
Sarah Wyper
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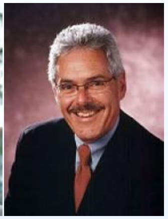
Yanhui Yuan
Ron Chance

Georgia Institute of Technology



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VADA
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Zero Carbon Partners
David Elenowitz

Appendix

Summary

GT cDAC development proceeding through targeted approach:

Development Areas: *design big, build small*

Area	Approach
Mechanical: Movement, sealing, airflow	Iterative design and mockup testing
Process: Cooling, purging	Experiment & Modeling

Design in progress for

- direct contact roller seals
- monolith continuous movement system
- airflow module design
- ASPEN process model
- physiological cooling dynamics model

Demonstration of cDAC remains on target for 2023

Organization Chart

Global Thermostat

Engineering, Manufacturing, Fabrication Team

- Global Thermostat – mechanical engineering
- VADA – design concepts, design support, fabrication, consulting
- Specialty Vendors and Engineering Consultants – niche tasks

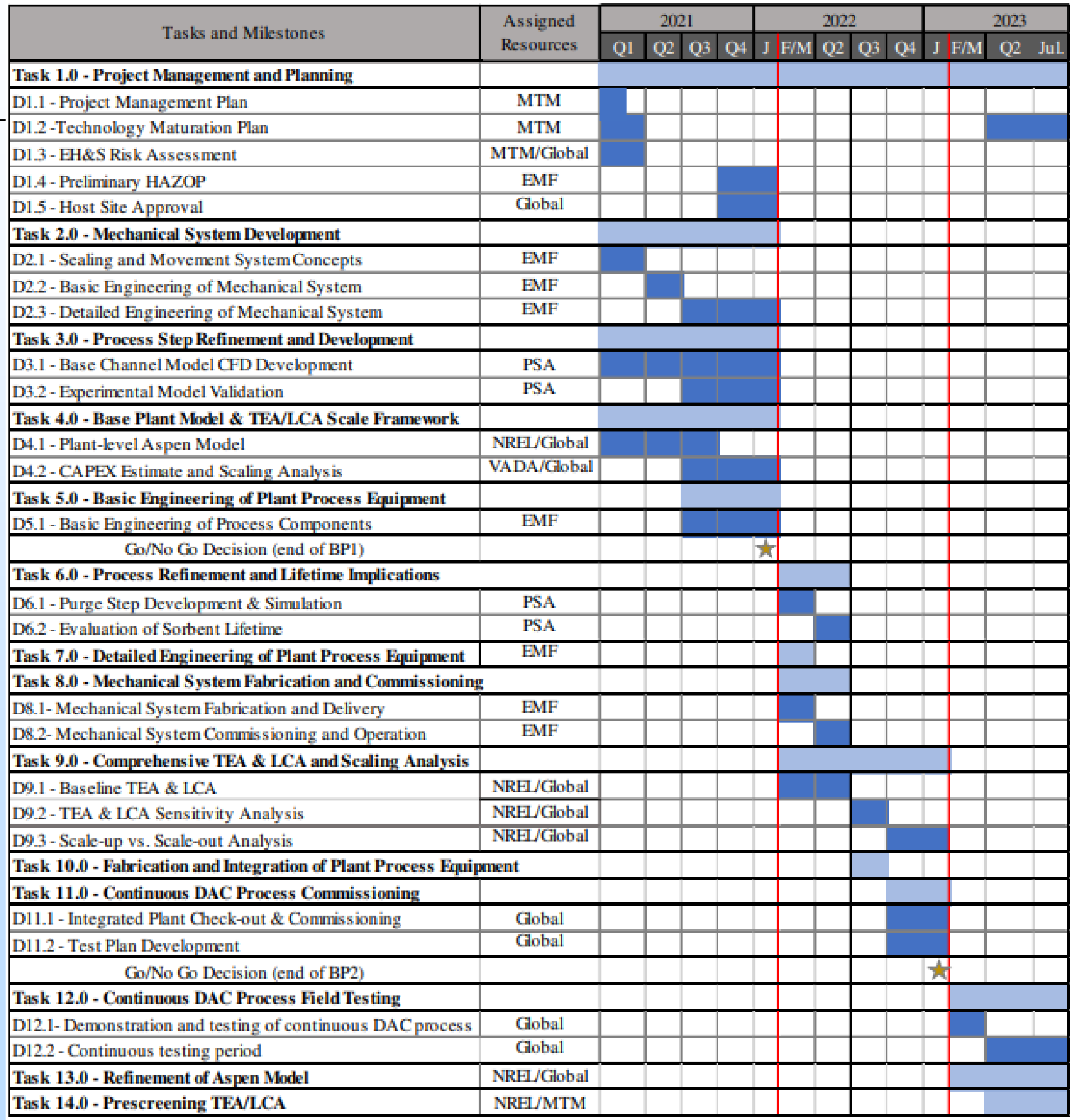
Process Systems and Analysis Team

- Global Thermostat – process engineering, pilot plant data
- Georgia Tech – phenomenological modeling, wetness experiments
- NREL – Aspen modeling, flowsheeting

Technology Maturation and Markets Team

- Global Thermostat – management
- ZCP - markets

Gantt Chart


Tasks and Milestones
Assigned Resources
2021
2022
2023
Q1 Q2 Q3 Q4 J F/M Q2 Q3 Q4 J F/M Q2 JuL
Task 1.0 - Project Management and Planning
D1.1 - Project Management Plan MTM
D1.2 -Technology Maturation Plan MTM
D1.3 - EH&S Risk Assessment MTM/Global
D1.4 - Preliminary HAZOP EMF
D1.5 - Host Site Approval Global
Task 2.0 - Mechanical System Development
D2.1 - Scaling and Movement System Concepts EMF
D2.2 - Basic Engineering of Mechanical System EMF
D2.3 - Detailed Engineering of Mechanical System EMF
Task 3.0 - Process Step Refinement and Development
D3.1 - Base Channel Model CFD Development PSA
D3.2 - Experimental Model Validation PSA
Task 4.0 - Base Plant Model & TEA/LCA Scale Framework
D4.1 - Plant-level Aspen Model NREL/Global
D4.2 - CAPEX Estimate and Scaling Analysis VADA/Global
Task 5.0 - Basic Engineering of Plant Process Equipment
D5.1 - Basic Engineering of Process Components EMF
Go/No Go Decision (end of BP1)
Task 6.0 - Process Refinement and Lifetime Implications
D6.1 - Purge Step Development & Simulation PSA
D6.2 - Evaluation of Sorbent Lifetime PSA
Task 7.0 - Detailed Engineering of Plant Process Equipment EMF
Task 8.0 - Mechanical System Fabrication and Commissioning
D8.1- Mechanical System Fabrication and Delivery EMF
D8.2- Mechanical System Commissioning and Operation EMF
Task 9.0 - Comprehensive TEA & LCA and Scaling Analysis
D9.1 - Baseline TEA & LCA NREL/Global
D9.2 - TEA & LCA Sensitivity Analysis NREL/Global
D9.3 - Scale-up vs. Scale-out Analysis NREL/Global
Task 10.0 - Fabrication and Integration of Plant Process Equipment
Task 11.0 - Continuous DAC Process Commissioning
D11.1 - Integrated Plant Check-out & Commissioning Global
D11.2 - Test Plan Development Global
Go/No Go Decision (end of BP2)
Task 12.0 - Continuous DAC Process Field Testing
D12.1- Demonstration and testing of continuous DAC process Global
D12.2 - Continuous testing period Global
Task 13.0 - Refinement of Aspen Model NREL/Global
Task 14.0 - Prescreening TEA/LCA NREL/MTM

Replaced