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# Demonstration of a Continuous Motion Direct Air Capture System

DE-FE0031957
2023 Carbon Management Research Project Review Meeting

Eric W. Ping
August 29, 2023

# Project Overview

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

Budget Period 1: 1/1/2021 – 7/31/2022

Budget Period 2: 8/1/2022 – 7/31/2024

Budget Period 3: 8/1/2024 – 1/31/2025

Project participants:

- Global Thermostat
- Georgia Institute of Technology
- National Renewable Energy Laboratory
- VADA, LLC
- Zero Carbon Partners

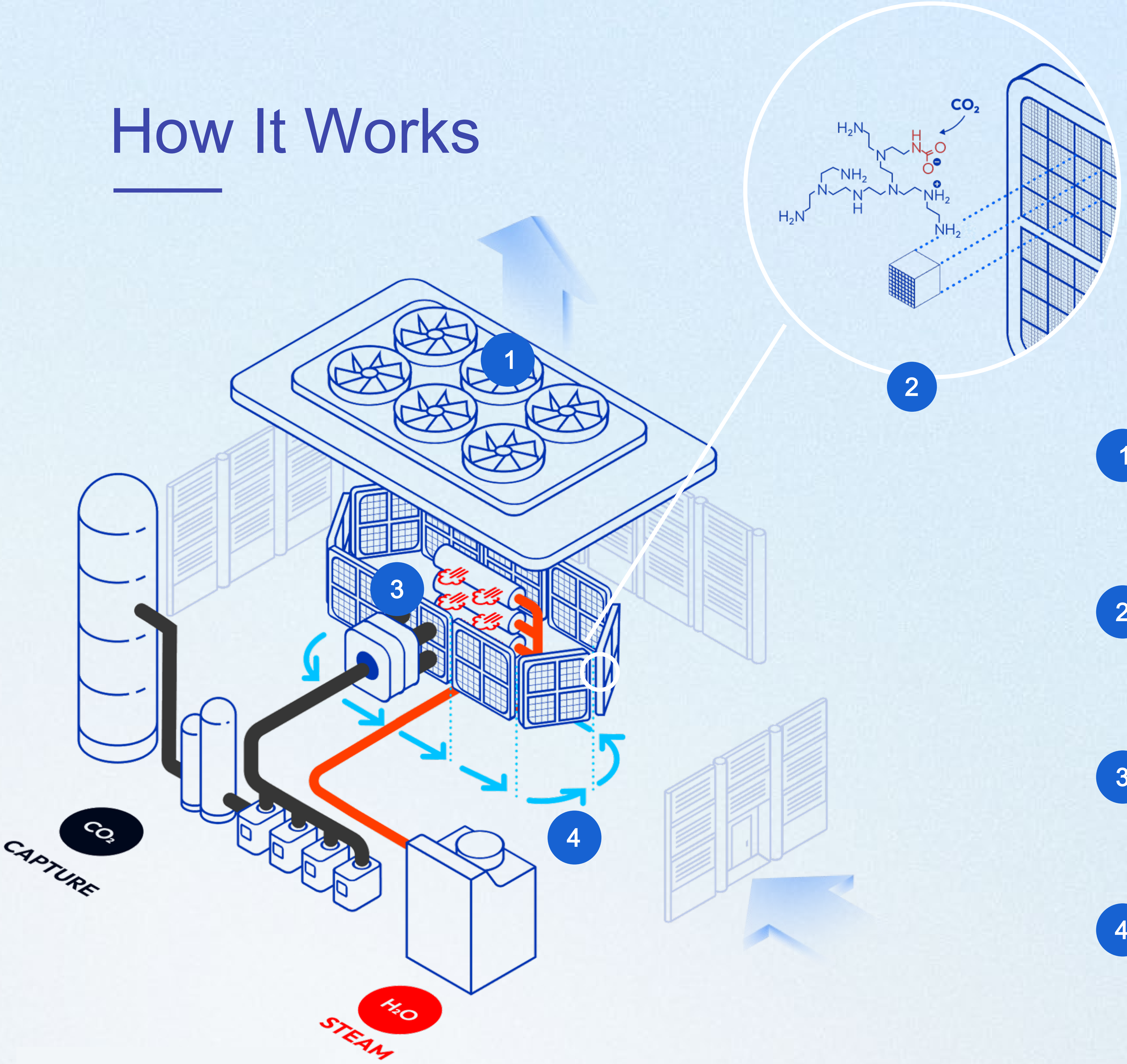
Primary Objectives: Design and construction of a field-test unit demonstrating a continuous-motion direct air capture process, reducing complexity, CAPEX, & OPEX while increasing reliability

# Technology Background: Key Drivers of Low Cost

| Factor | Significance | Barriers |
|---|---|---|
| Move Air | Dilute atmospheric $CO_2$ requires significant movement of air | Fan cost and energy requirements |
| Capture $CO_2$ | Materials to selectively adsorb $CO_2$ | Sorbent efficiency, robustness, lifetime |
| Release $CO_2$ (Regeneration) | Time spent releasing $CO_2$ is time not spent capturing | Thermal energy requirements<br>Cycle timing |
| Efficient Capital | DAC $CO_2$ cost is dominated by Capex | Mechanical complexity<br>High cycle rate |
| Scalability | Effectiveness as a climate solution | Fabricability, Modularity<br>Reliability, Operability |

# Global Thermostat DAC Module: Simple, Modular & Highly Efficient

# How It Works




## A Low Temperature, Solid Adsorbent Process

1. Air is pulled through our custom-designed contactors via high-efficiency, cooling-tower style fans

2. CO2 molecules are selectively trapped by proprietary amine sorbent embedded in our ultra-high surface area, low pressure drop contactors

3. Low temperature steam directly injected onto the contactor rapidly releases the $CO_2$,concentrating it for collection, use, or storage

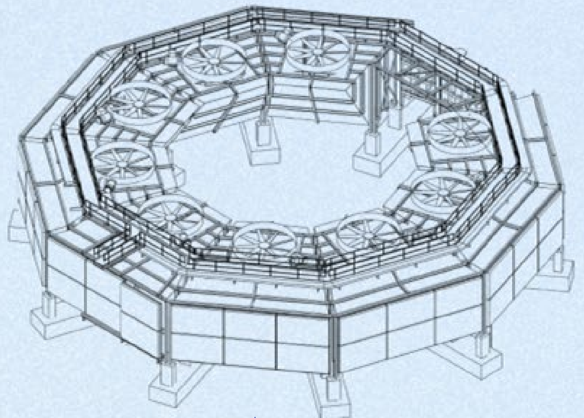
4. The regenerated contactor panel reenters airflow to capture more $CO_2$, restarting the cycle

# DAC Products – GT Commercial Modules

| REQUIREMENTS | OUR SOLUTION |
|---|---|
| • Make efficiently deployable at many scales | • Capture occurs in stackable mm-sized channels, enabling scaling to almost any capacity<br>• DAC modules designed for mass fabrication |
| • Enable operations across a broad spectrum of ambient conditions | • Capable of operating across a wide range of temperatures, humidities, and other ambient factors |
| • Utilize existing, scalable supply chains | • Contactors & sorbent produced by global industrials |

All scales use the same core contactor and regen process:

Move, Seal
Evacuate
Steam Desorption
Cool Down
Unseal, Move

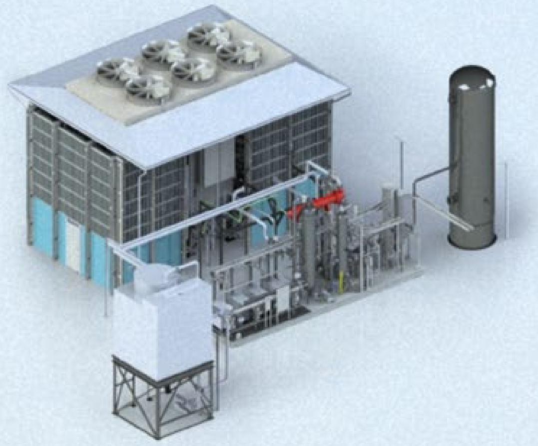


**M-Series** (Megatonnes)

For Climate-Scale Applications

NETL-Funded Engineering Design with Sargent & Lundy, Black & Veatch,

Thursday X:Xxam



**K-Series** (Kilotonnes)

For Commercial & Industrial Applications

Operated Since Q4 2022

**T-Series** (Tonnes)

For Value Chain Pilots

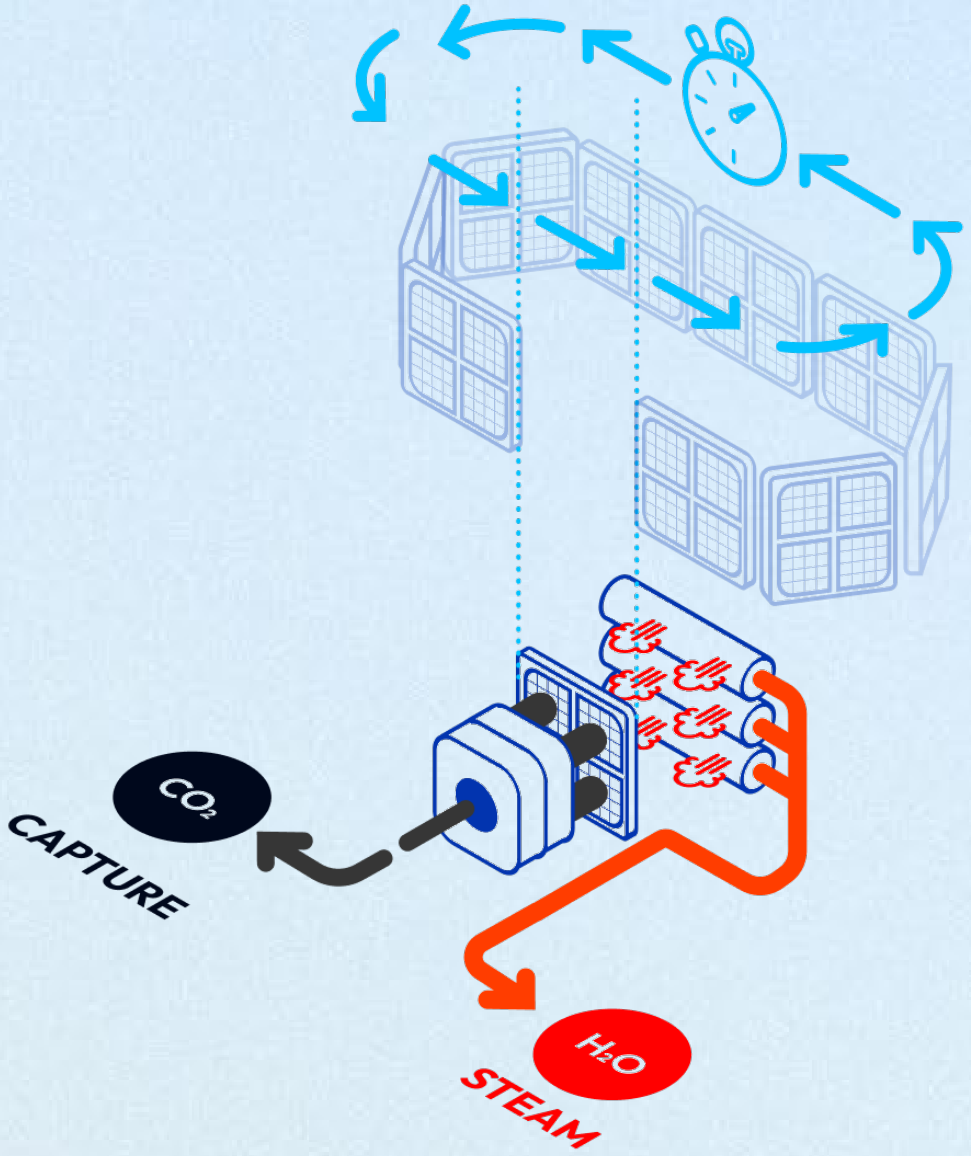
Built & Operated Continuously, Semi-Autonomously since 2021

# Project Drivers

Advantages to Retain:
- High efficiency and selectivity
  - Proprietary amine sorbent
  - Monolithic contactor
- Rapid cycling
  - Direct steam regeneration
- High capital utilization
  - Multibed adsorption
  - Contactor movement

Benefits of applying multibed adsorption paradigm via continuous movement of active media through a regeneration zone:

- Reduction in mechanical force requirement, complexity
  - No acceleration, deceleration
- Steady-state utility & energy flows
- Simplifies direct heat & mass integration
  - No intermediate storage necessary
  - Steady-state zone effluent recycling




Requires careful consideration of movement, sealing methodologies to minimize impact of continuous movement on CO2 product purity, adsorbent lifetime, and utility minimization

# Technical Approach/Project Scope

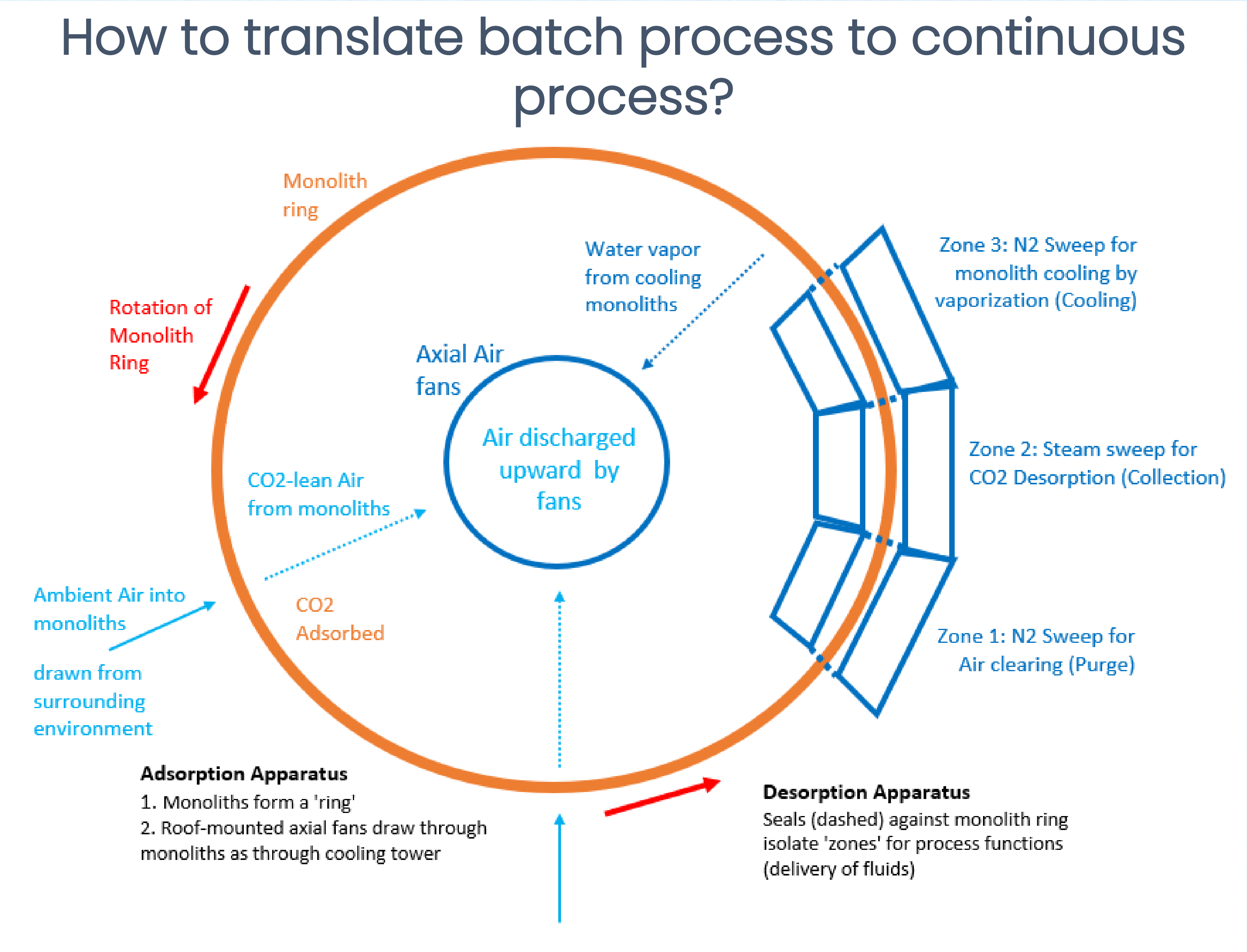
Project Scope & Goal: Develop and demonstrate *continuous DAC* prototype based on the GT technology platform

Development philosophy: design big, build small: prototype the elements to enable successful climate-scale DAC deployments

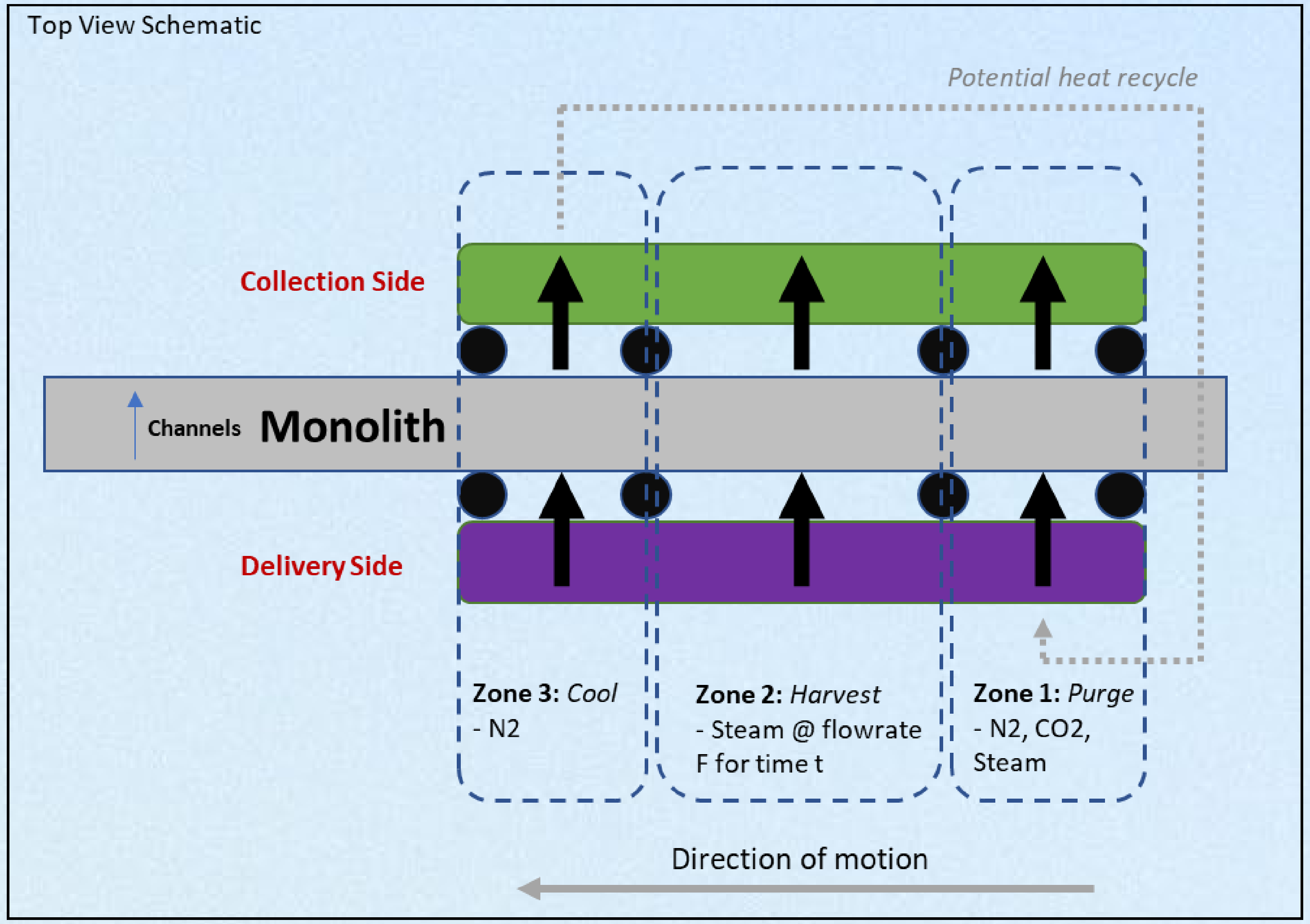
Key Project Milestones:

- ✓ Mechanical design complete, process basis established
- ✓ Fabrication & commissioning of mechanical movement system complete
- Installation & commissioning of full balance of plant for cDAC pilot, ready for field test campaign (upcoming)
- 30 day field test campaign demonstrating targeted performance metrics (BP3)

# Continuous Process Concept




*Initial Technology Concept*



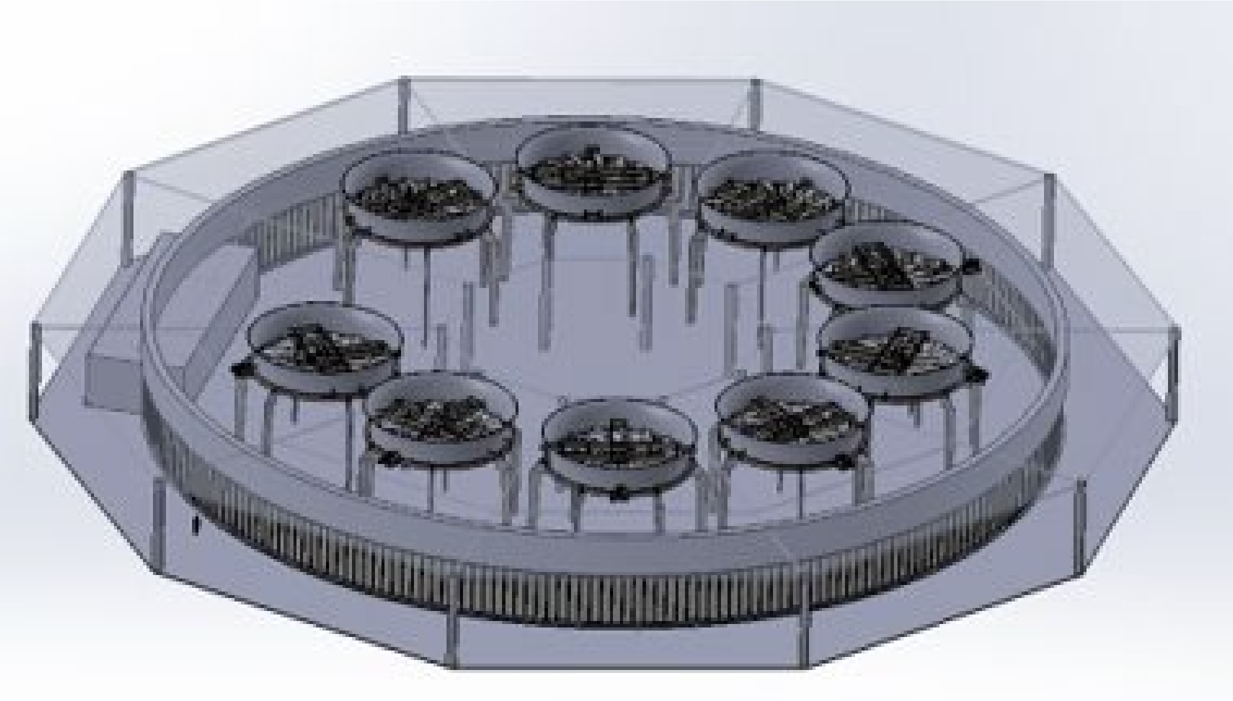

*DAC Module Regeneration Concept*

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 |

# 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)

Development philosophy: *design big, build small*

## Module subareas:

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

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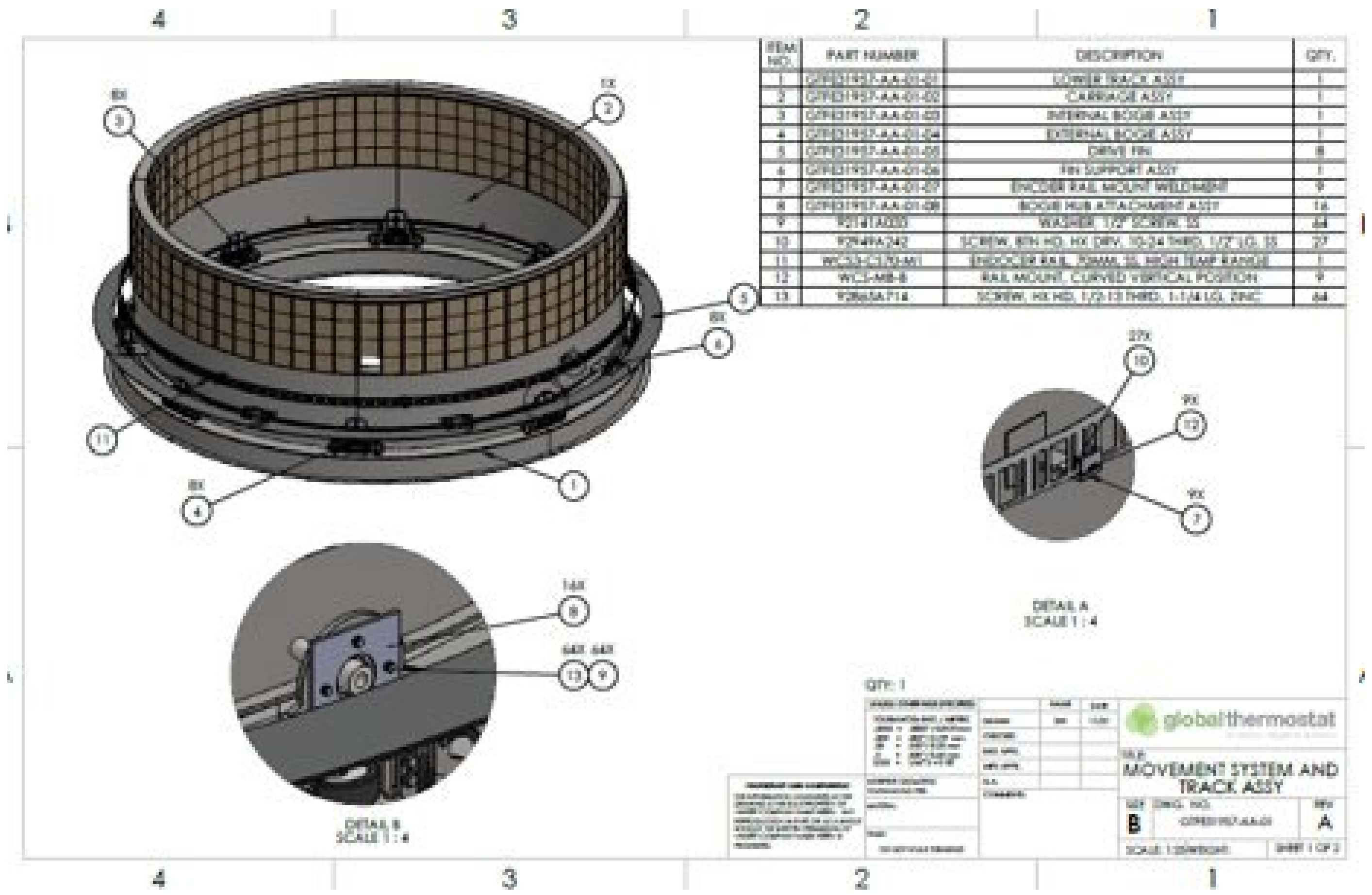
# cDAC FTU Design Recap




Front Facing View

- Prototypes for testing dynamic sealing for **regeneration** zones, and flow uniformity and efficiency of **air processing**
- Carriage design concept for **mechanical movement** system

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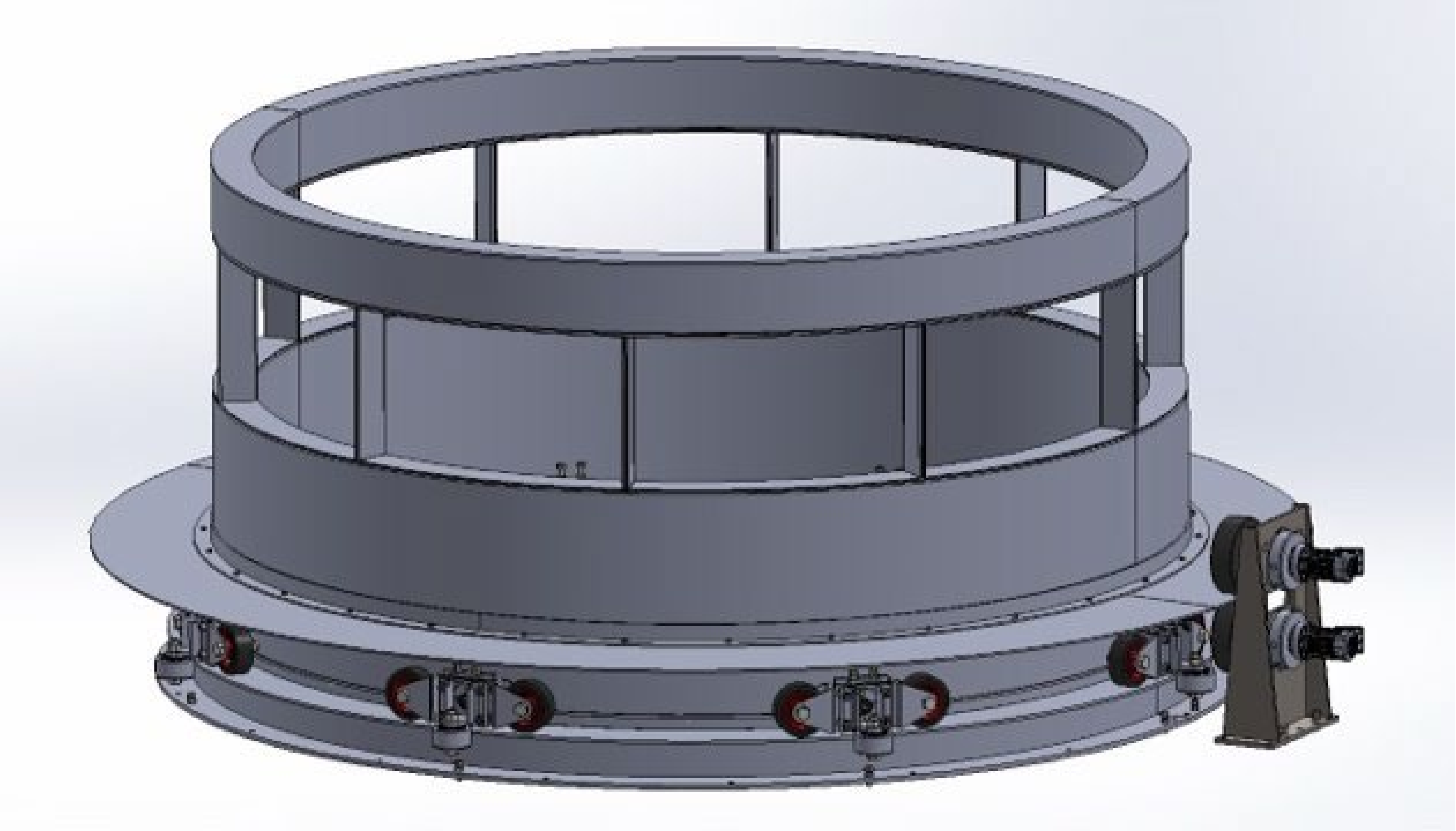
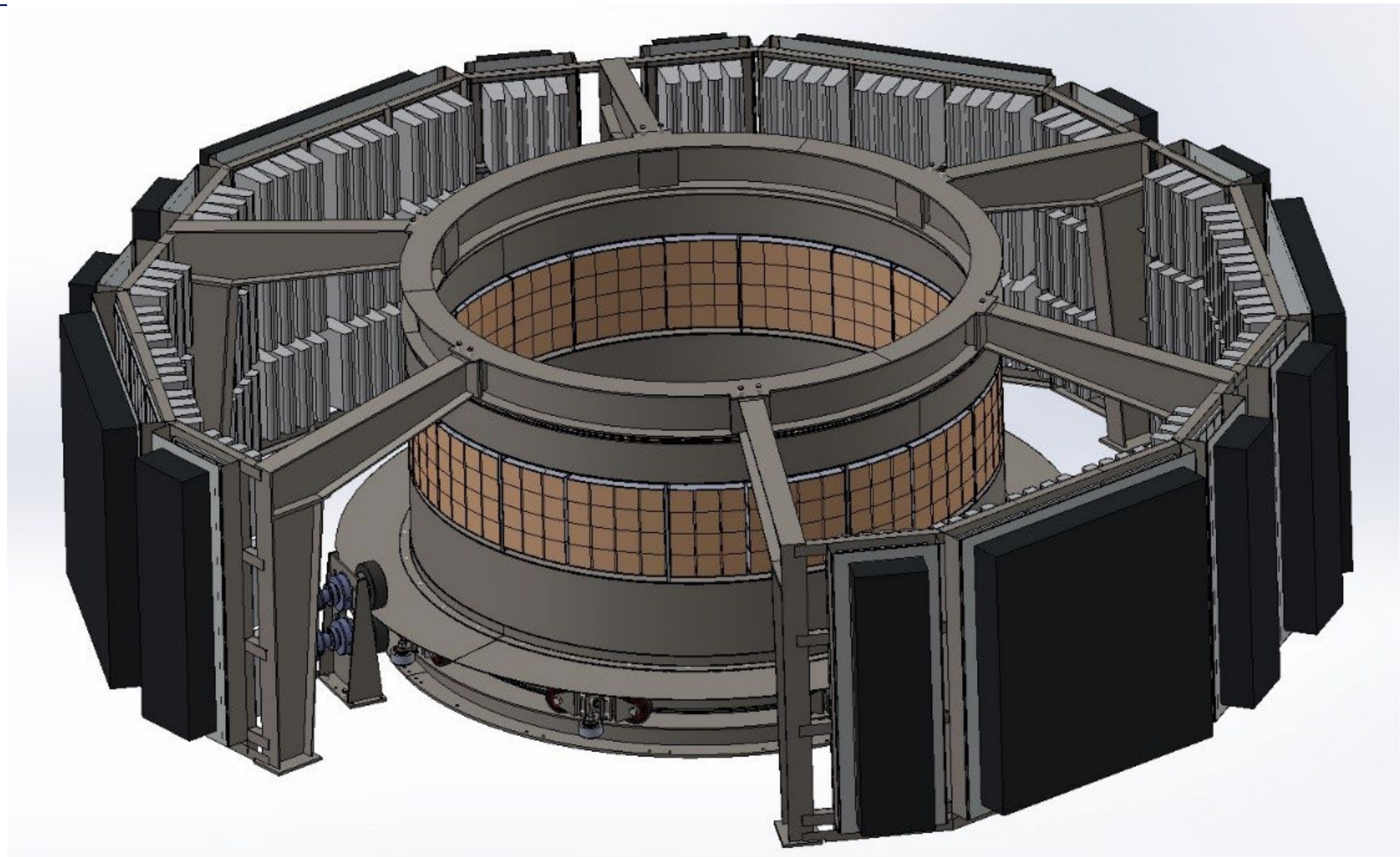
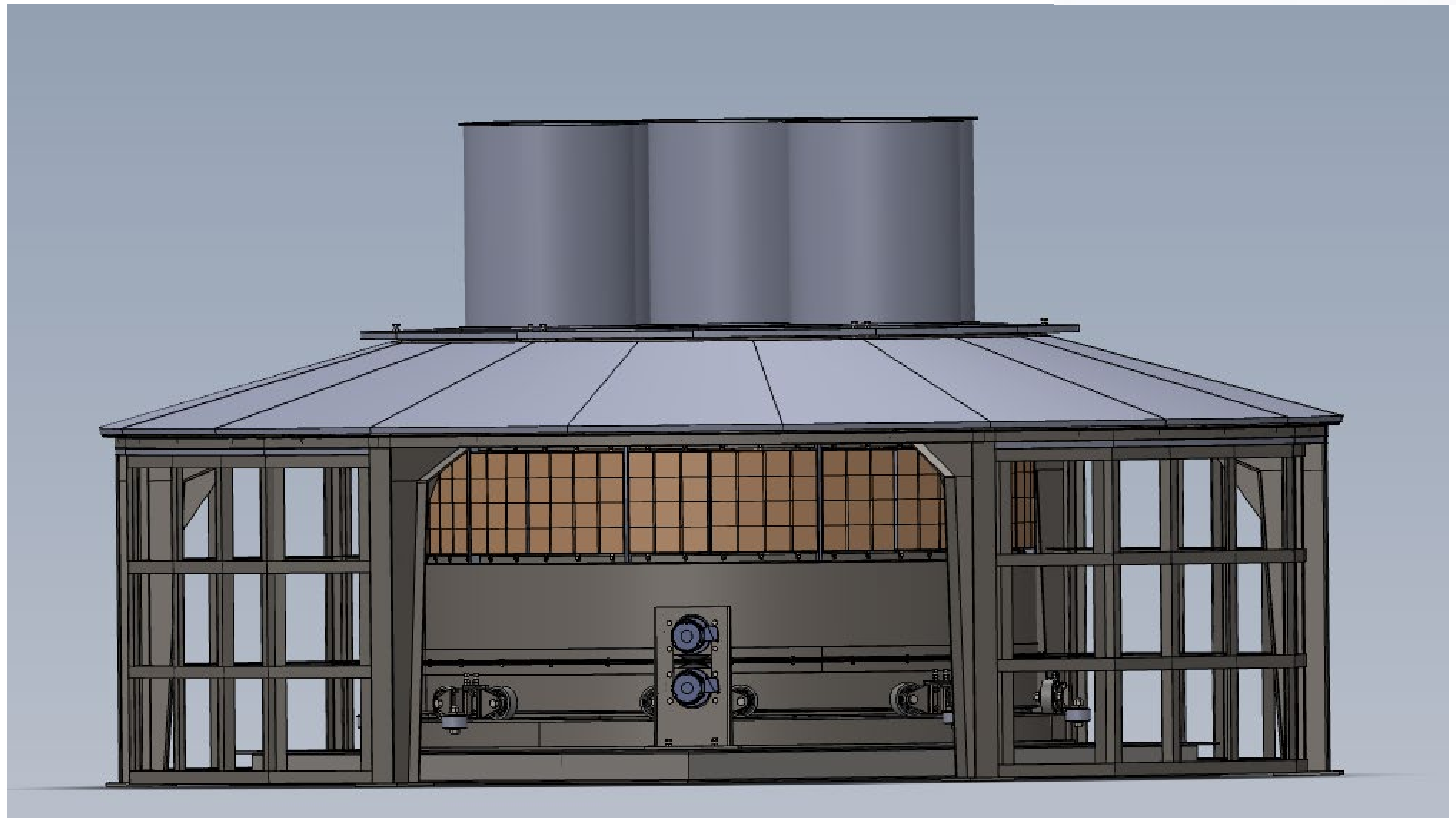
# Phased cDAC FTU Fabrication







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# Mechanical System Fabrication & Commissioning – Phase 1 Complete

## Bogies & Motor Assembly

## FTU Carriage & Movement Assembly

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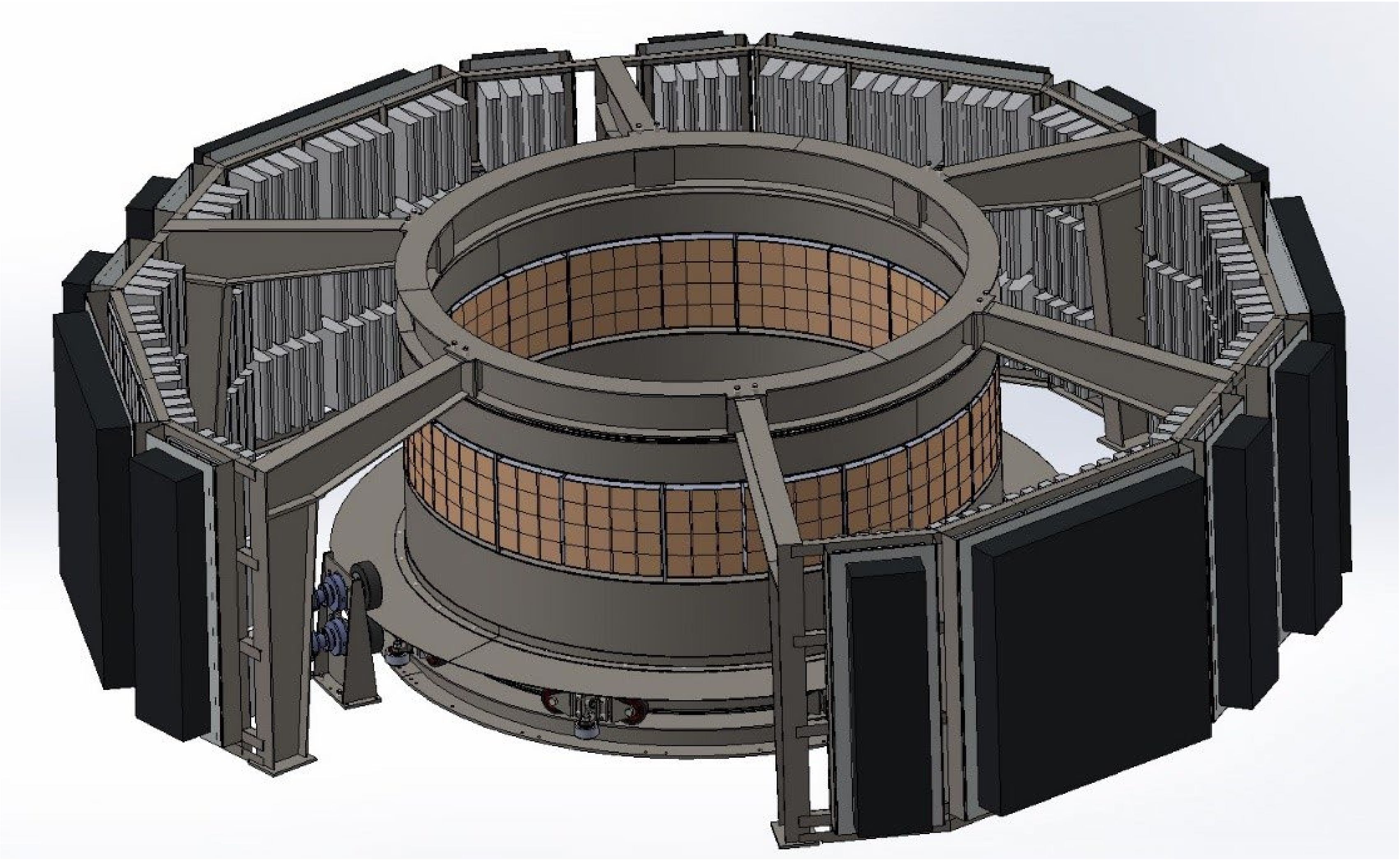
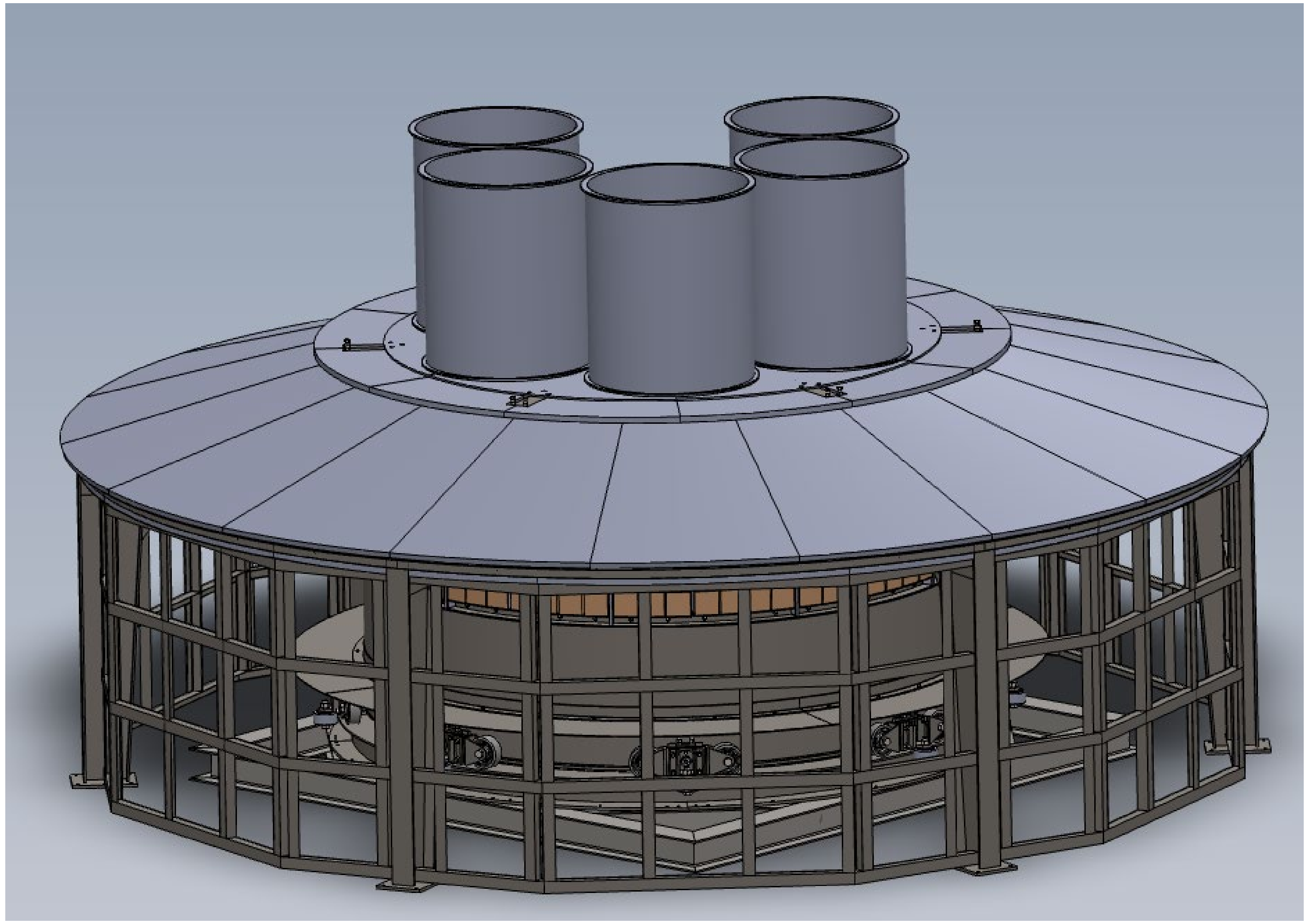
# Final Mechanical Fabrication Phase In Progress





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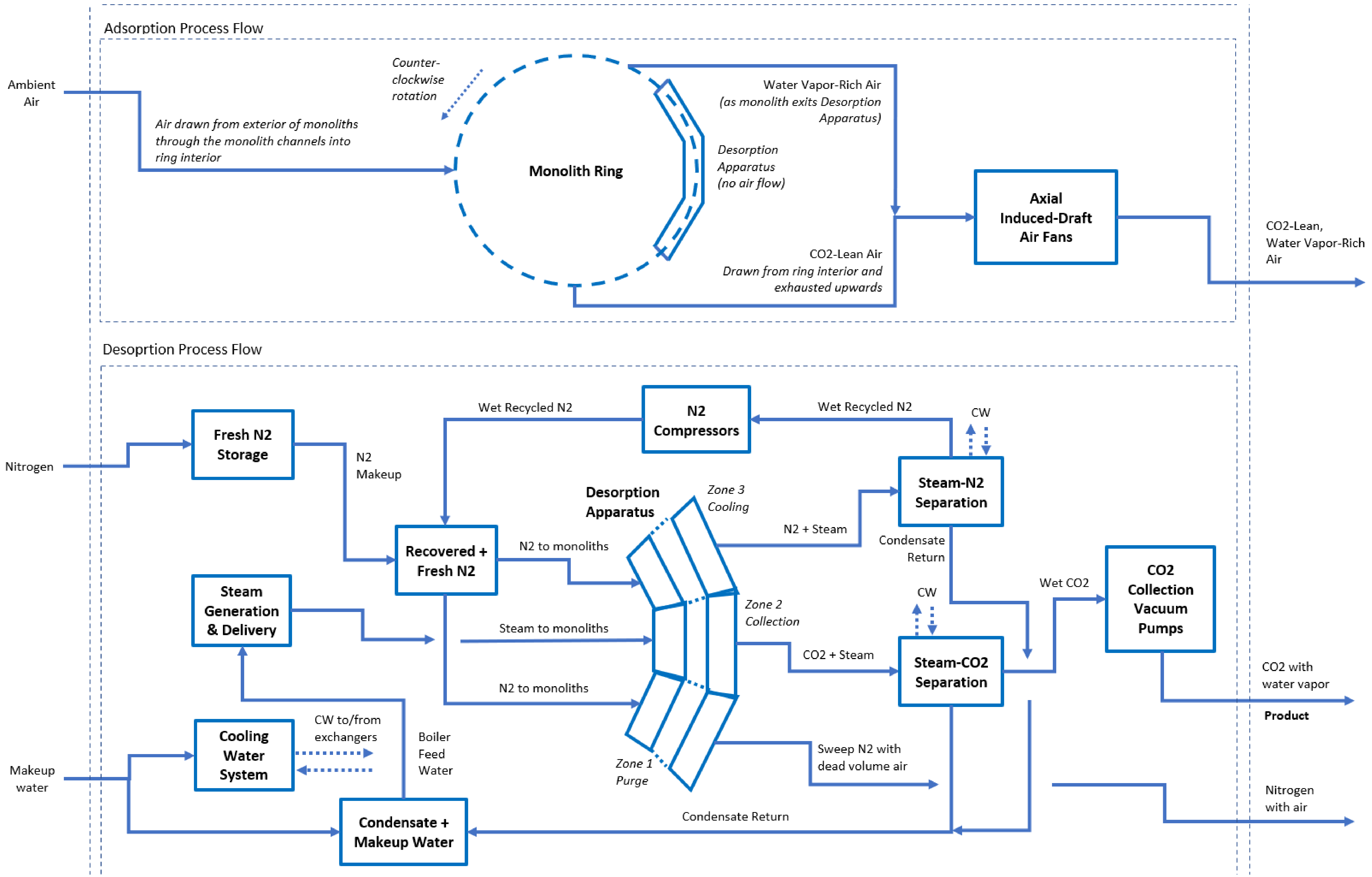
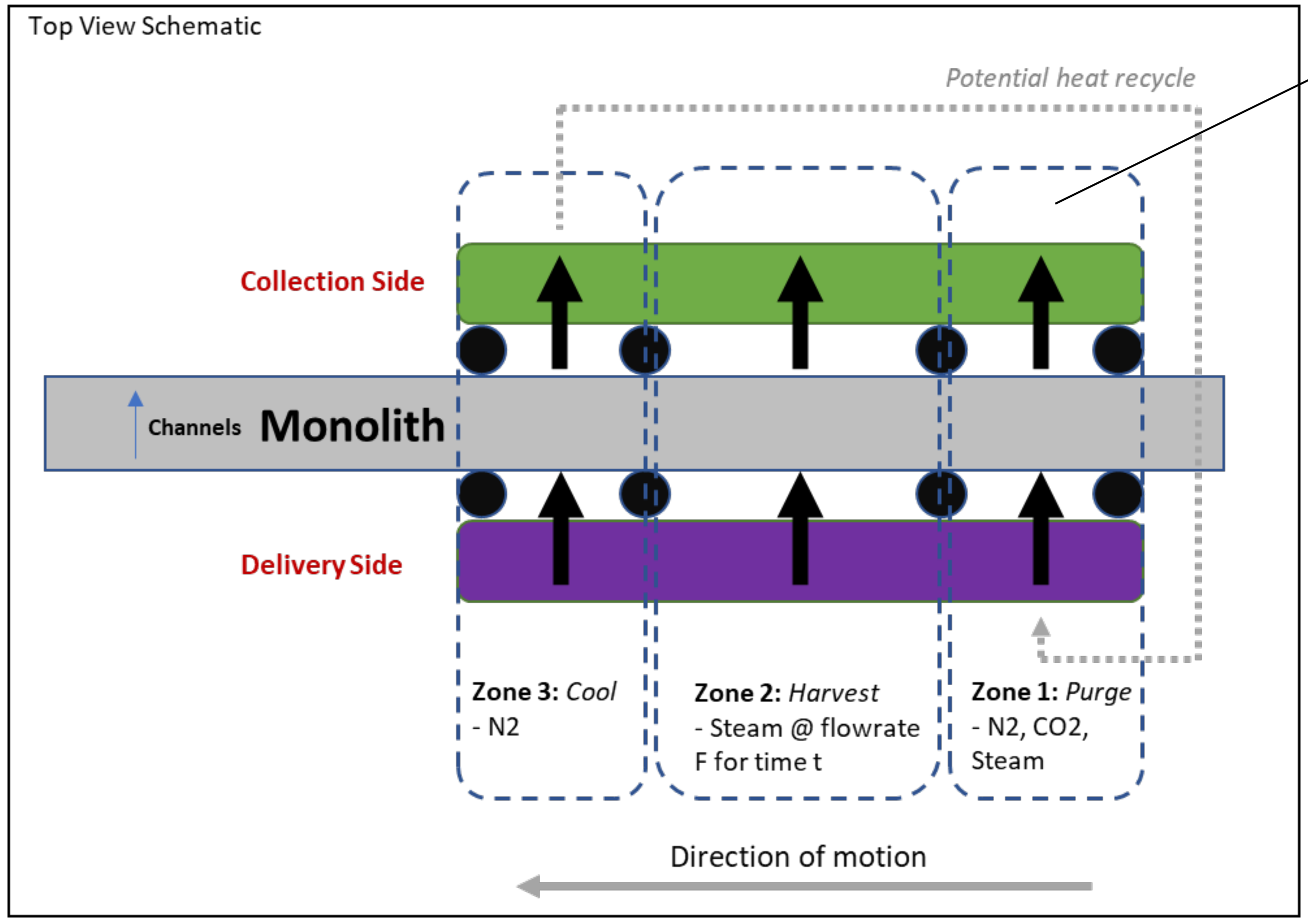
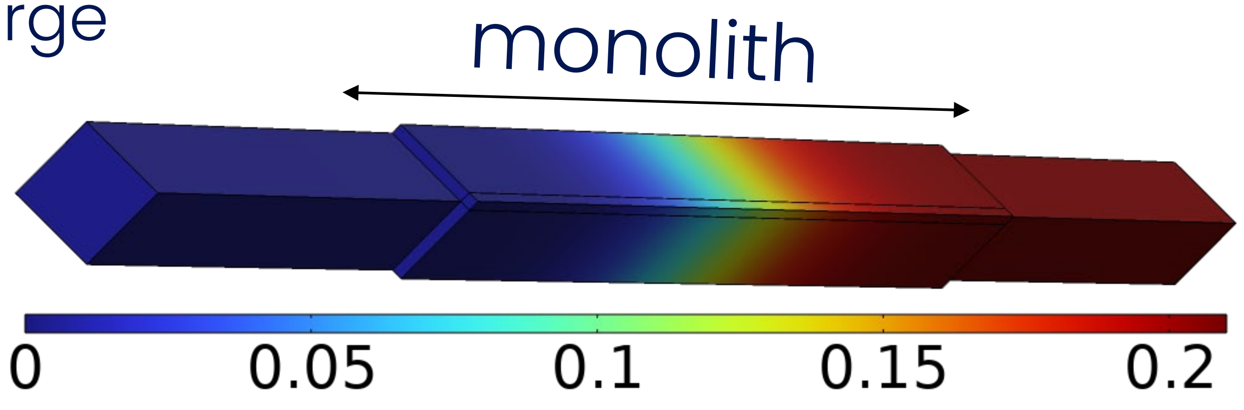
# cDAC Field Test Prototype Block Flow



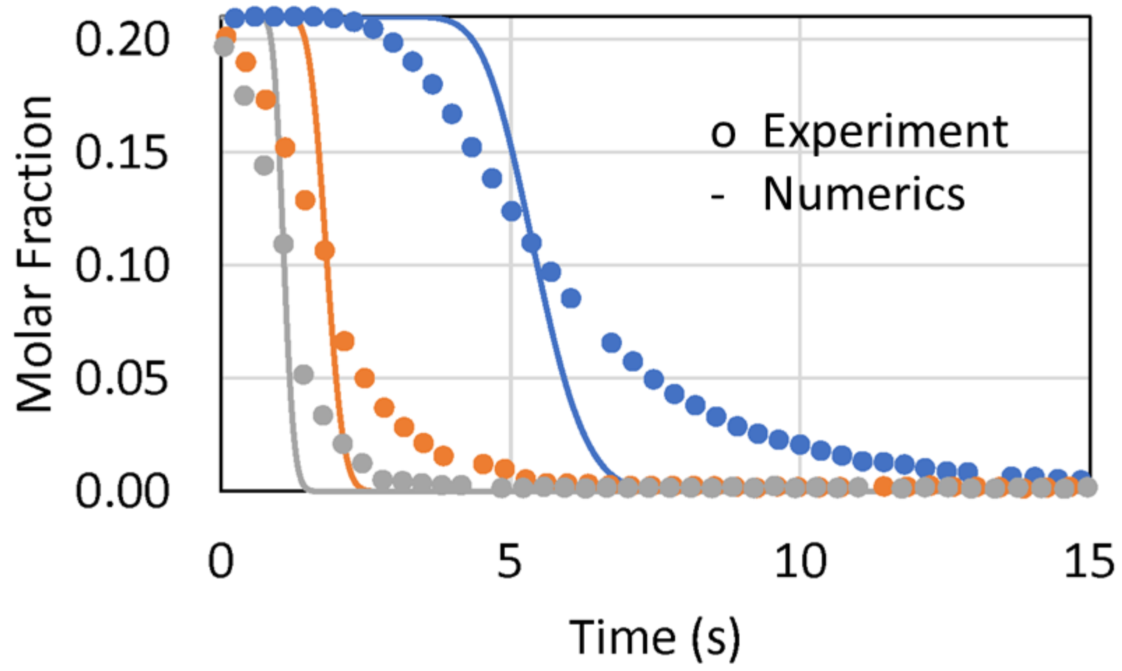
# Pre-Steam Purge Dynamics: Modeling & Validation




**Pre-steam** purge




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




Convection/ diffusion of O2 from channels and pores of monolith

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

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

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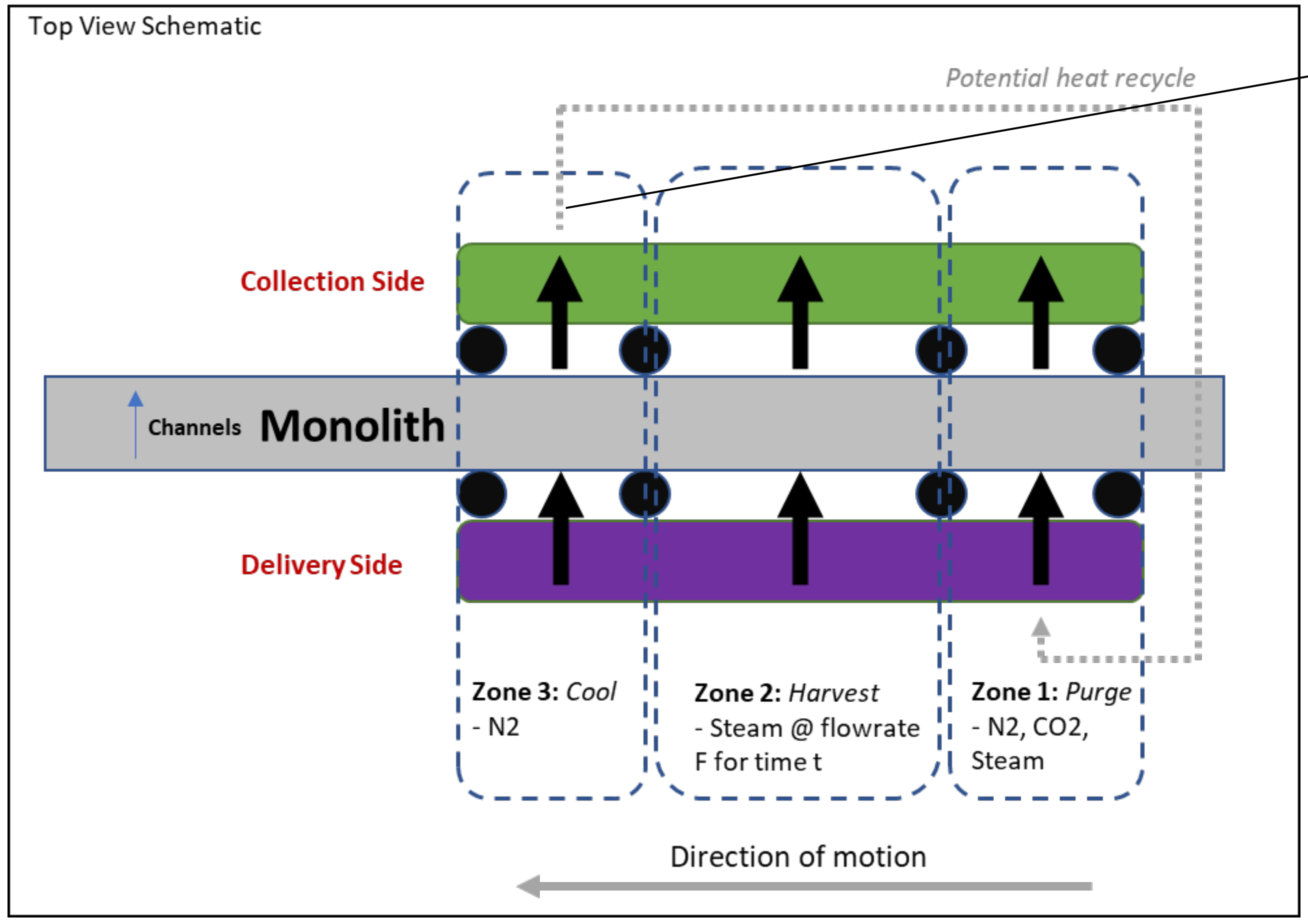
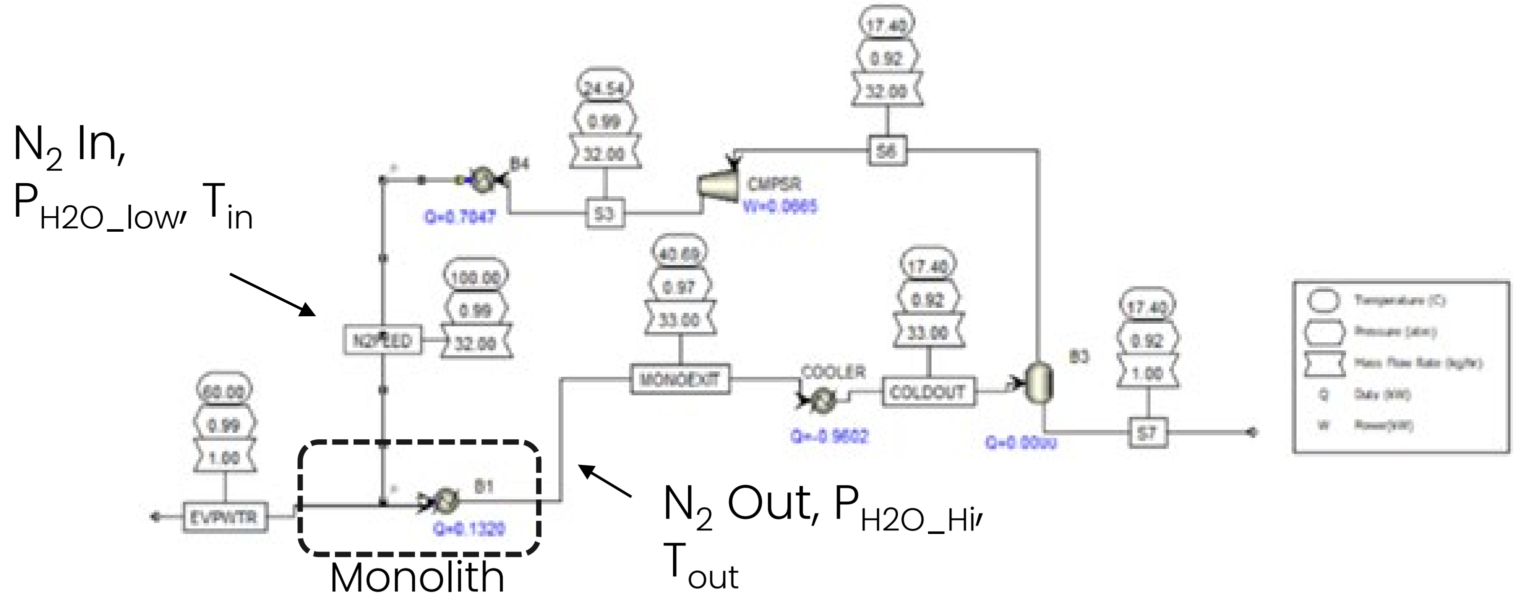
# Post-Steam Cooling Dynamics: Modeling & Sizing




## **Post-steam** cooling

### System level evaluation

100C Inlet Nitrogen 32 kg/hr to get vaporization of 1 kg/hr of water – stream out is at 40.7C




- 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

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# Lessons Learned

- Panel movement drive drop-in capable in cDAC embodiment
- Labyrinth seals, wiper seals are not adequate to maintain product purity and sorbent lifetime
- GT contactors are mechanically robust enough to utilize direct contact rollers with high contact area to maximize effectiveness
- Optimizing evaporative cooling in inert flow is more complex than optimizing the air purge.

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# Plans for Future Testing & Development

- Finish construction and process commissioning of cDAC FTU

- CDAC FTU operational campaign will generate data demonstrating:
  - Reliability of dynamic sealing methodology
  - Effectiveness of purge and cooling steps
  - Overall impact on DAC TEA and LCA

- Assessment of the benefits of the cDAC paradigm against baseline commercialized GT DAC platform
  - GT K-Series scale
  - GT M-Series scale

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# Summary

- Continuous process flows have the potential to reduce cost and complexity of GT DAC process equipment
- Increased simplicity of internal and external heat, mass integration
- Small hydraulic diameter of contactor channels enables rapid inert purging of entrained air prior to CO2 recovery
- Speed and efficiency of inert gas evaporative cooldown highly tunable as a CAPEX/OPEX trade-off.
- Benefit over baseline GT commercial offerings TBD during upcoming operational campaign

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# Project Team

## Global Thermostat

Eric Ping – PI
Miles Sakwa-Novak – Co-PI
Steph Didas – Project Coordinator
Brianna Atherton
Brodie Bourgeault
Zach Foltz
Jed Pruett

## VADA

Bud Klepper

## Zero Carbon Partners

David Elenowitz

## Georgia Institute of Technology

Roman Grigoriev (Phys.)
Matthew Realff (ChBE)
Michael Schatz (Phys.)
Ari Glezer (MechE)
Alex Warhover (Phys.)
Marc Guasch (Phys.)
Brendan McCluskey (Phys.)

## National Renewable Energy Laboratory

Eric Tan
Ryan Davis

# Thank You

# Appendix

Slides that are mandatory but not discussed

# 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

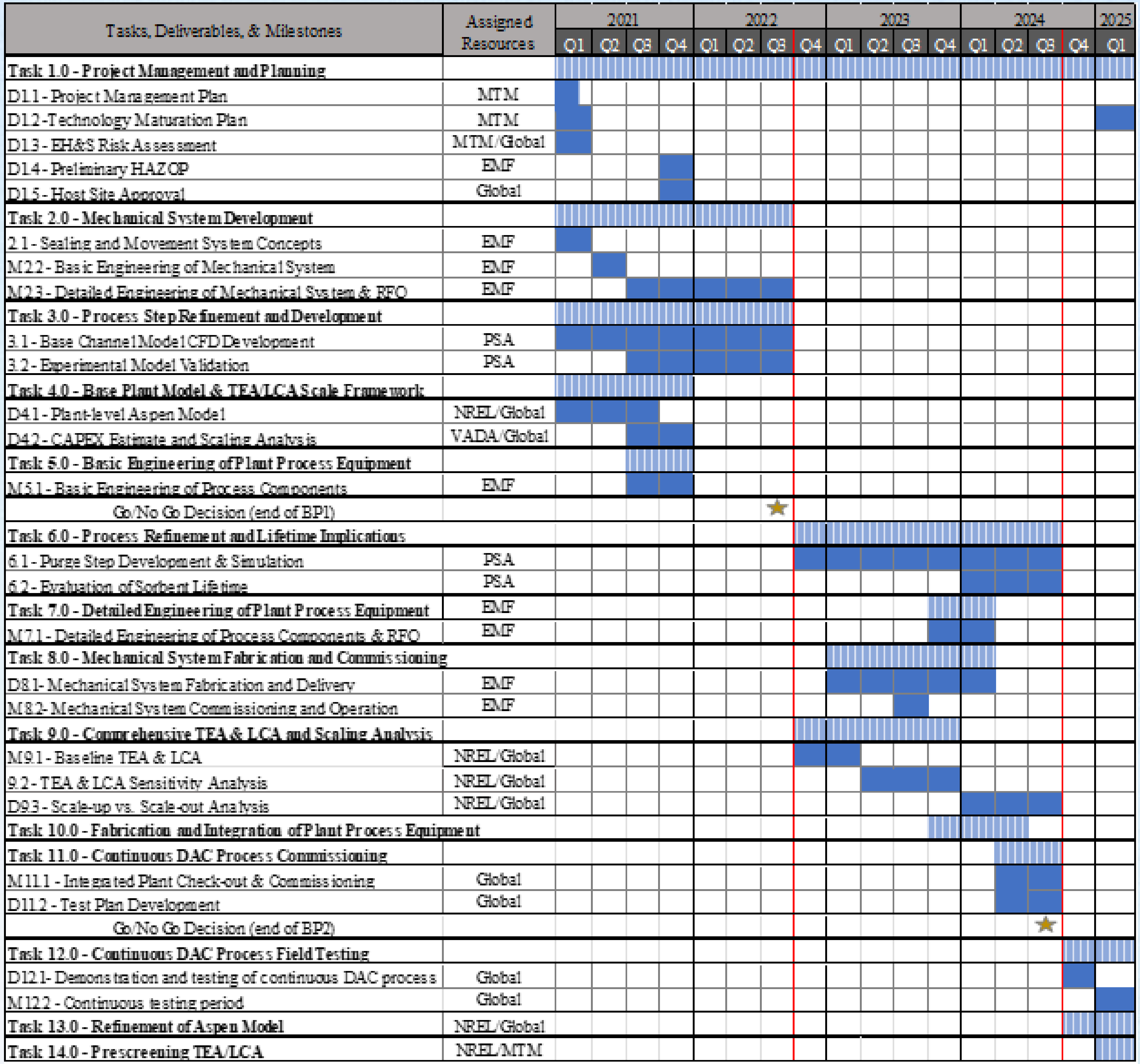
**Process Systems and Analysis Team**

- 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, Deliverables, & Milestones
Assigned Resources
2021
2022
2023
2024
2025
Q1 Q2 Q3 Q4
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
2.1 - Sealing and Movement System Concepts
EMF
M2.2 - Basic Engineering of Mechanical System
EMF
M2.3 - Detailed Engineering of Mechanical System & RFQ
EMF
Task 3.0 - Process Step Refinement and Development
3.1 - Base Channel Model CFD Development
PSA
3.2 - 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
M5.1 - Basic Engineering of Process Components
EMF
Go/No Go Decision (end of BP1)
Task 6.0 - Process Refinement and Lifetime Implications
6.1 - Purge Step Development & Simulation
PSA
6.2 - Evaluation of Sorbent Lifetime
PSA
Task 7.0 - Detailed Engineering of Plant Process Equipment
EMF
M7.1 - Detailed Engineering of Process Components & RFQ
EMF
Task 8.0 - Mechanical System Fabrication and Commissioning
D8.1- Mechanical System Fabrication and Delivery
EMF
M8.2- Mechanical System Commissioning and Operation
EMF
Task 9.0 - Comprehensive TEA & LCA and Scaling Analysis
M9.1 - Baseline TEA & LCA
NREL/Global
9.2 - 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
M11.1 - 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
M12.2 - Continuous testing period
Global
Task 13.0 - Refinement of Aspen Model
NREL/Global
Task 14.0 - Prescreening TEA/LCA
NREL/MTM