Demonstration of a Continuous Motion Direct Air Capture System

DE-FE0031957

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Global Thermostat Operations

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management and Natural Gas & Oil Research Project Review Meeting

Virtual Meetings August 2 through August 31, 2021

Program Overview

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

Budget Period 1: 1/1/2021 – 1/31/2022

Budget Period 2: 2/1/2022 – 1/31/2023

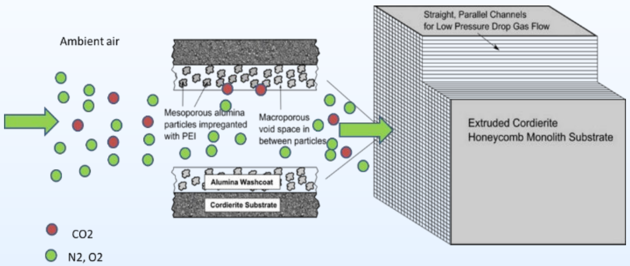
Budget Period 3: 2/1/2023 – 7/31/2023

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

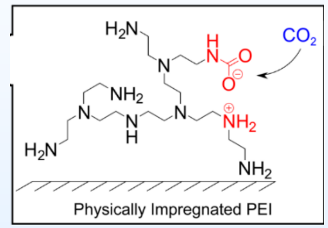
Technology Background: Concepts

1. Moving Large Air Volumes Efficiently



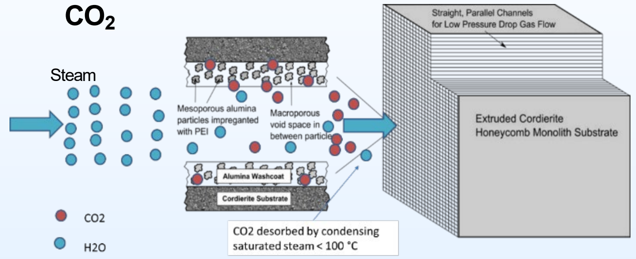
Honeycomb monoliths significantly outperform all other designs, enabling low pressure drop and minimum energy cost

2. Capturing CO_2 Selectively at 400 ppm



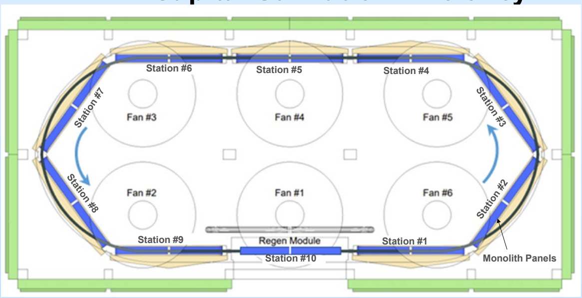
Amine-based polymers, incorporated in proprietary coatings, yield selectivity, capture efficiency, and compatibility with honeycomb monolith approach

3. Energy Efficient Regeneration of Captured CO_2



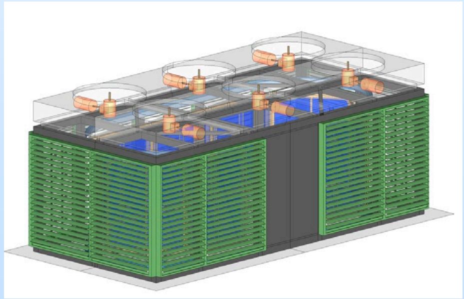
Temperature-Vacuum Swing Adsorption (TVSA) with steam as direct phase-change heat transfer fluid

4. Capital Utilization Efficiency



Process and mechanical movement design enable low pressure drop multi-bed adsorption configuration

5. Design for Continuous Improvement



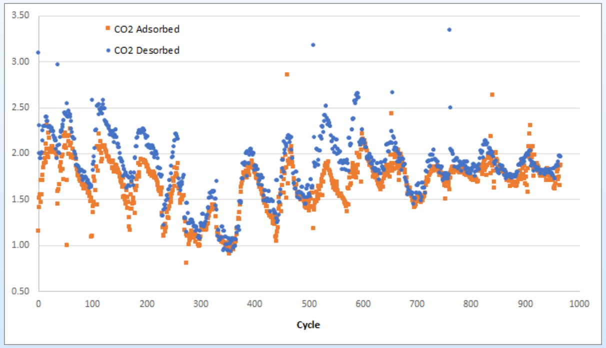
Base capital design capable of receiving improved generations of monolith adsorbents to regularly upgrade capture capacity

Technology Background: Previous Work

Global Thermostat Single Panel Pilot (SPP)

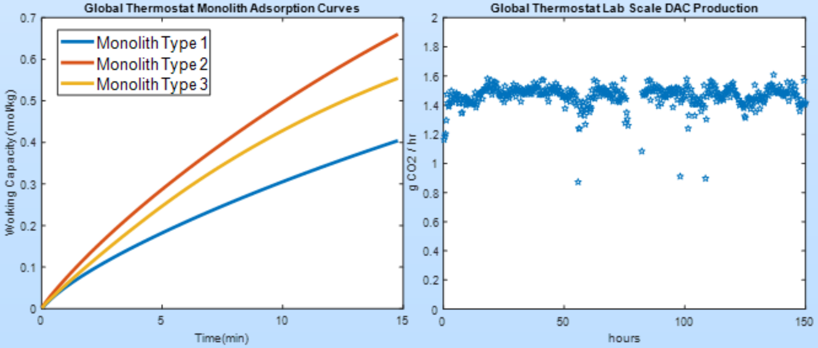
R&D Pilot Plant for process development

Batch process with wide range of available conditions



Example SPP Operating Data

Monolith Development



Monolith Development Data
(Uptake Curves, Operating Data)

- DAC Monoliths developed via GT Joint Development Agreement utilized in project
- Substantial technical knowledge gained through previous project leveraged for success

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:

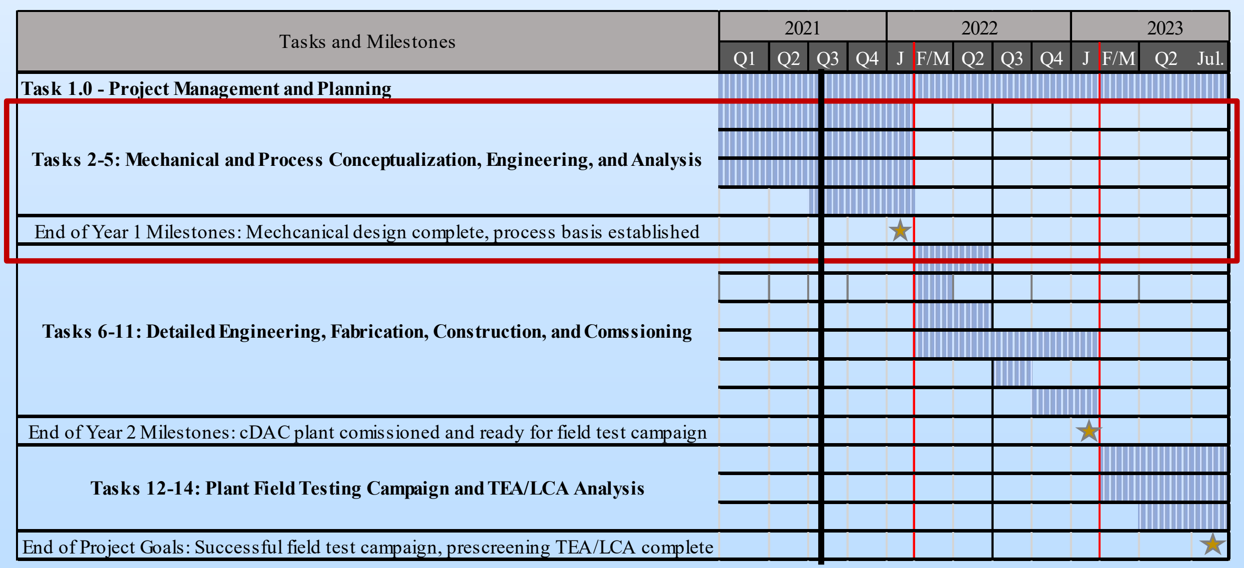
- Physical movement of large components can be mechanically challenging, particularly in a batch process (start/stop)
- Maintaining adequate sorbent lifetime over many cycles
- Wide parameter space with limited resources

Technical Approach/Project Scope

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

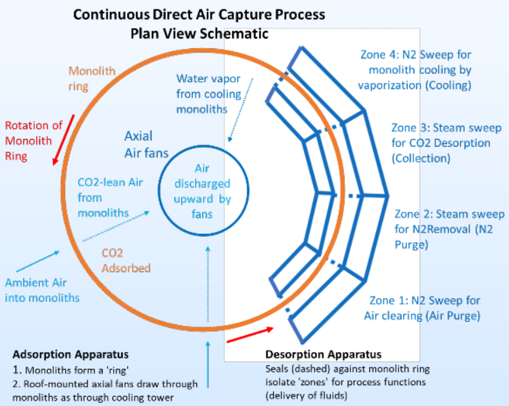
Development philosophy: *design big, build small*: prototype the elements to enable successful climate-scale DAC deployments

Project Arc:

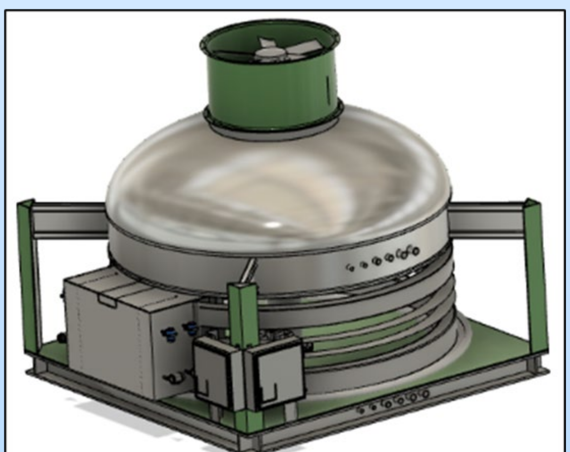


Continuous Process Concept

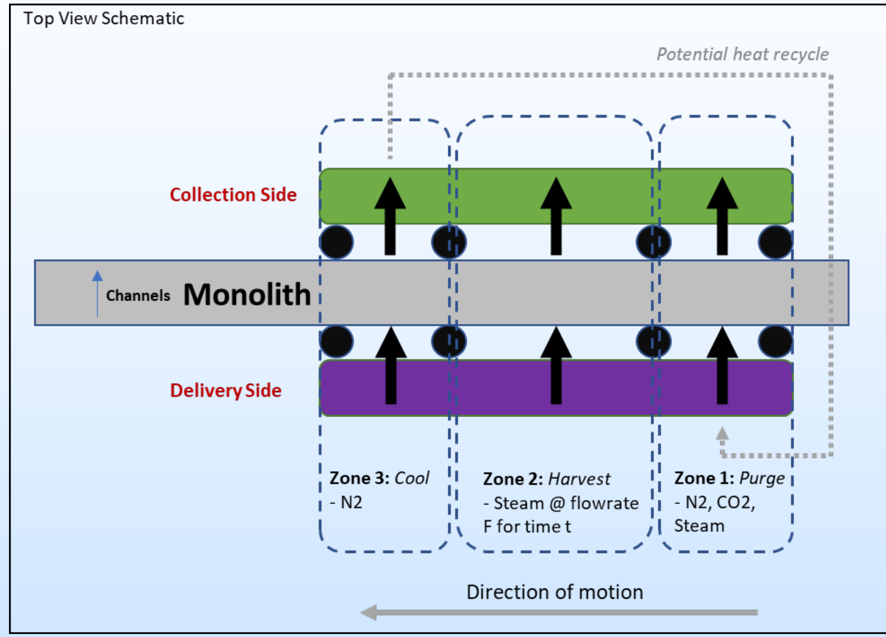
How to translate batch process to continuous process?



Version 1 Technology Concept



Version 1 Pilot Concept



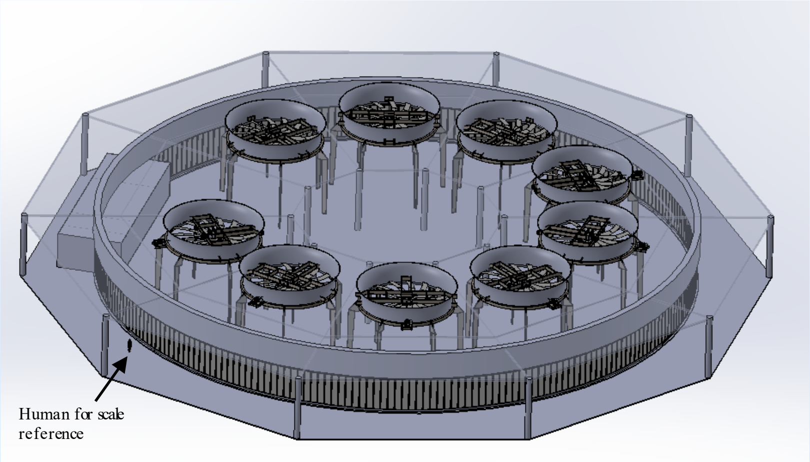
Version 1 Process Concept

Development Areas: *design big, build small*

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

Continuous Process Scale Plant Concept

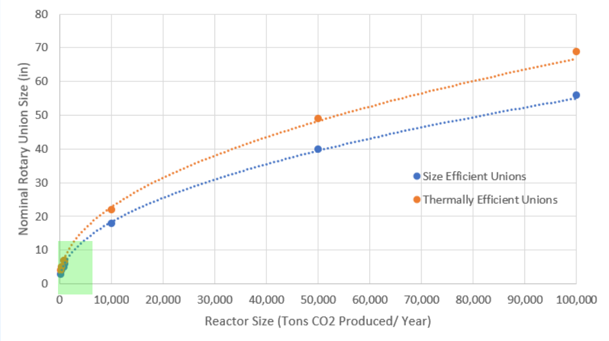
Modularize around air movement



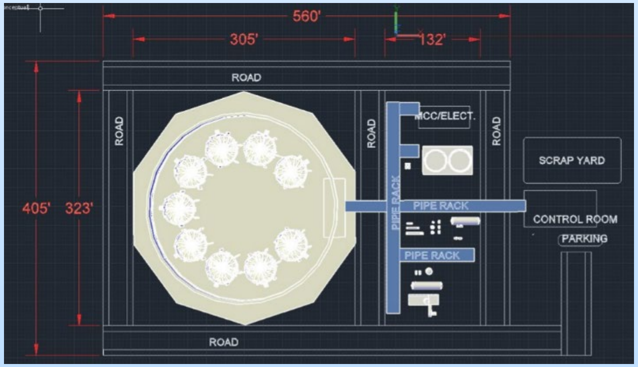
~50 kta plant module used for scale assessment

- 9 fan plant module as base scale for mechanical concept evaluation
- All design decisions made with consideration to application to the 'large' scale

Move monoliths instead of move regen assembly



- Rotating fluid and electrical unions do not scale well



~50 kta plant GA

Mechanical Development: Monolith Movement

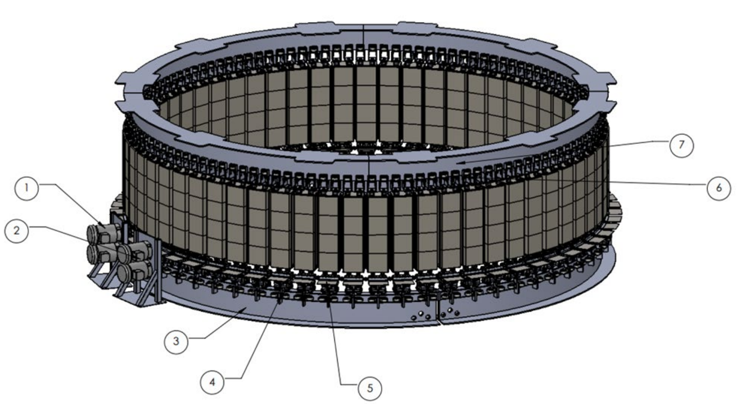
Commonalities:

Ring of monoliths

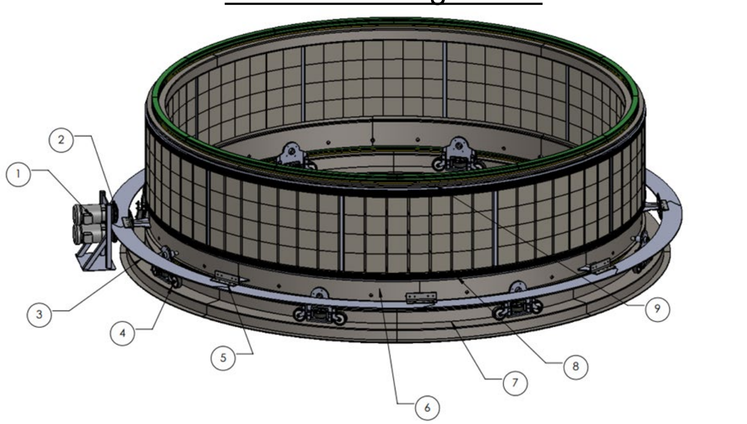
Drive wheel / fin engagement

Bottom load supporting

Individual panel model



Continuous ring model



Continuous Ring

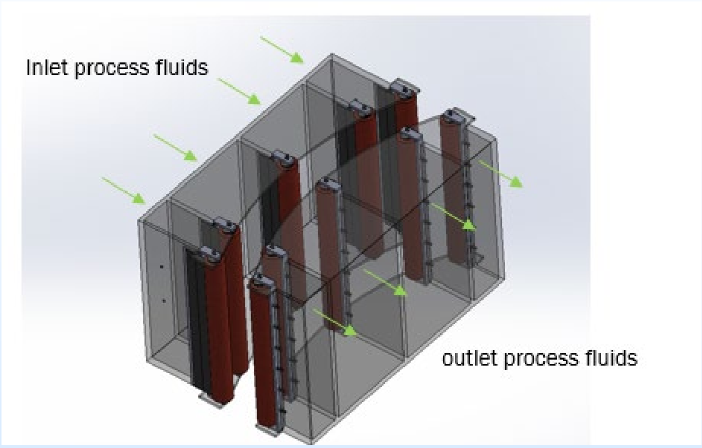
Two monolith movement system concepts:

Pros
• Shape flexibility: oval, irregular, circular • Modular to square monolith panel
Cons
• Panel-to-panel sealing • Many 'bogies' • Dual motors • High degrees of freedom in motion

Pros
• Rigid ring eliminates degrees of freedom • Single fin simplifies movement • Few components
Cons
• Rigid body becomes sensitive to tolerances at large scale • Less modularity on monolith • More curved components to fabricate

Mechanical Development: Seals

Regeneration area, zones, and seals



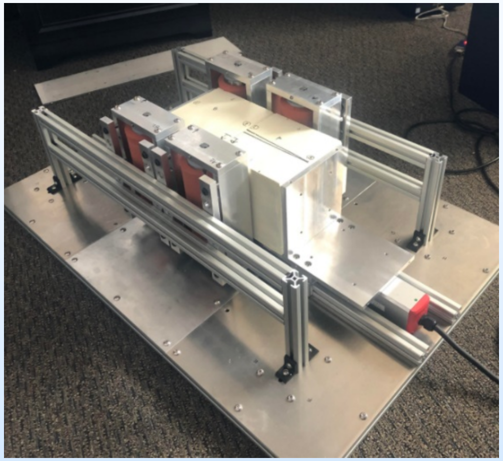
Regeneration Unit with Roller Seals

Development of Direct Contact Roller Seals:

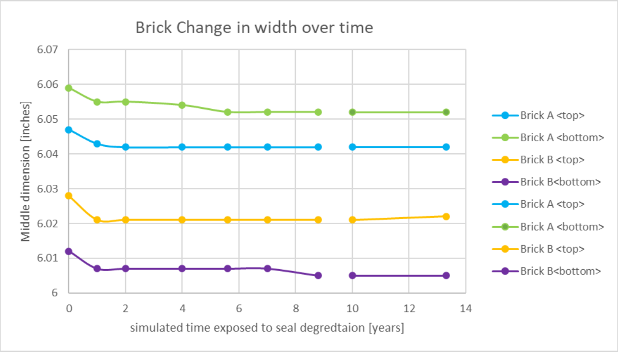
Cylindrical roller seals that contact the face of the monolith

Create separation between fluid zones to enable temporal process steps

Will direct seal contact damage monoliths?



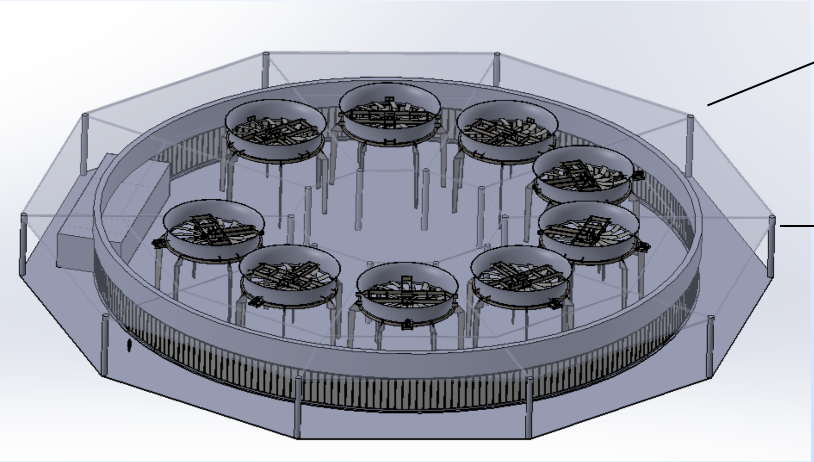
Assembled Seal Tester

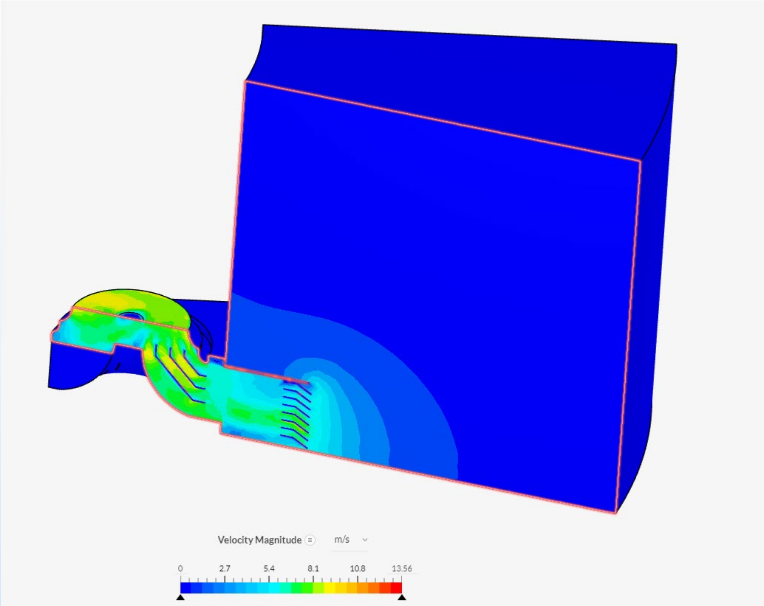


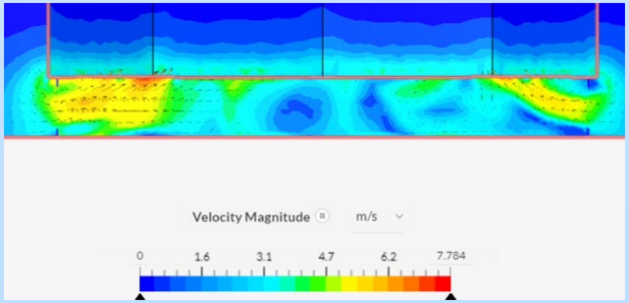
<u>Negligible damage to monoliths after 13 years of simulated contact!</u>

Mechanical Development: Air Movement

<u>Low cost DAC requires efficient air movement</u>





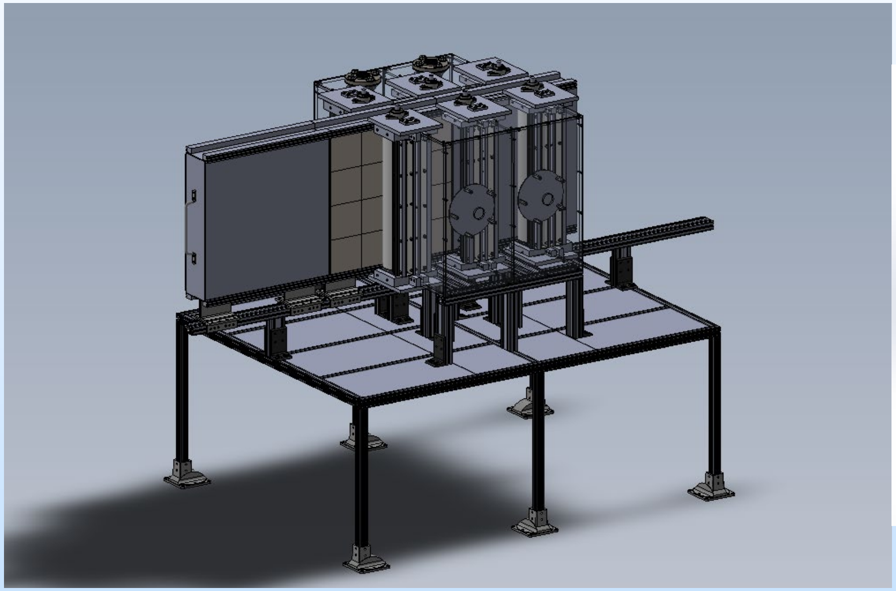


CFD analysis to analyze <u>airflow uniformity</u> (% RMS) and air movement efficiency (kWh / CFM)

Project goals of 75% dP efficiency and < 10% RMS deviation of air inlet velocity

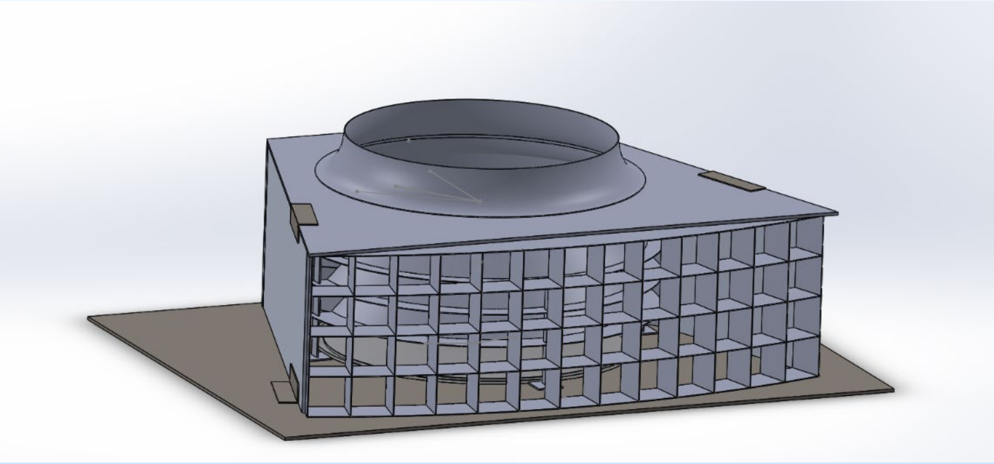
Regen and Airflow Mockups

Two zone regeneration assembly tester



Smoke tests, pressure tests, model validation

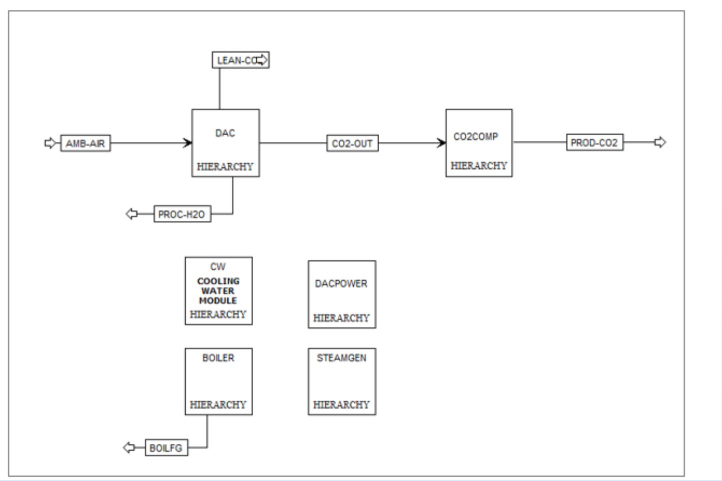
Fan module mockup tester



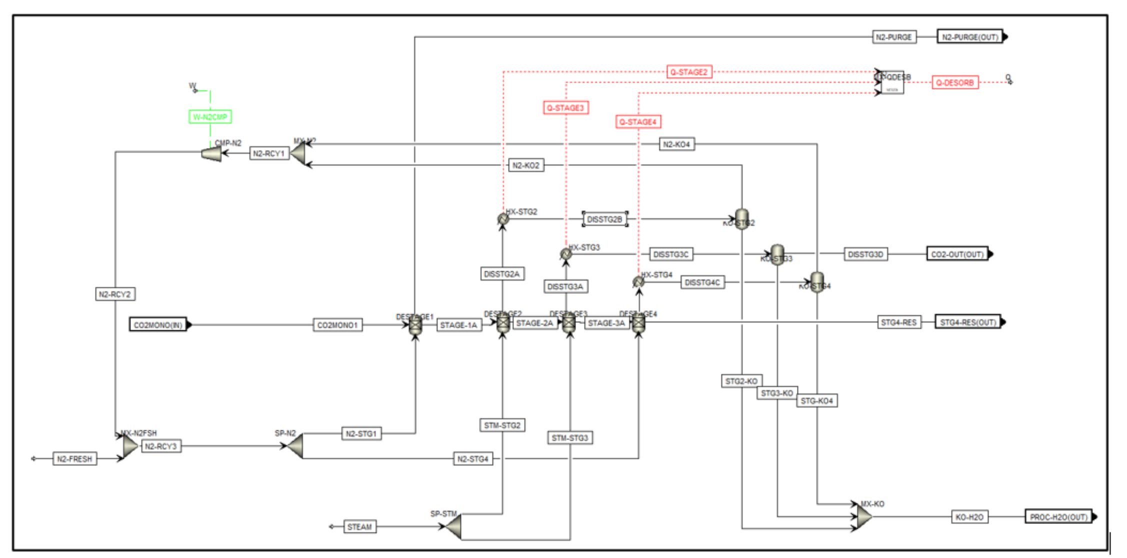
dP, air velocity testing, model validation

To be built Q3 2021

Process Development: Plant Aspen Model



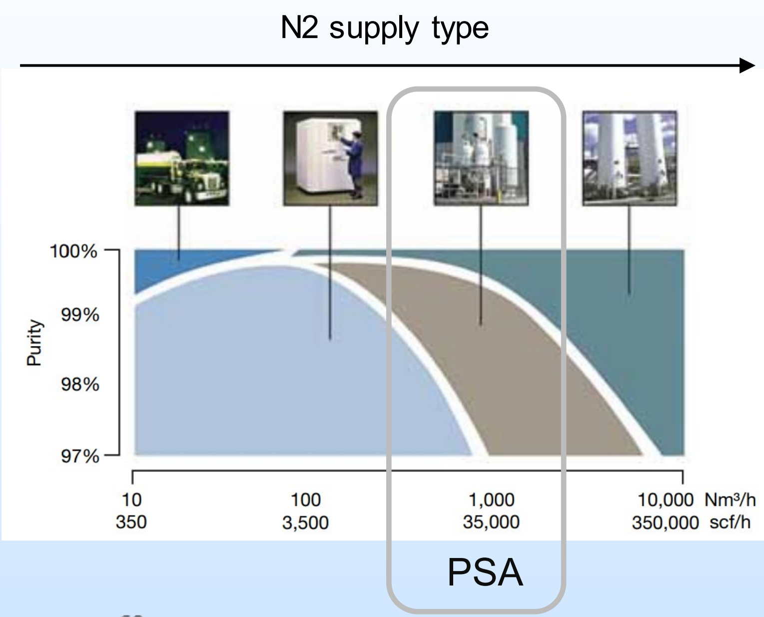
Overall Aspen Plus model of cDAC system including utilities

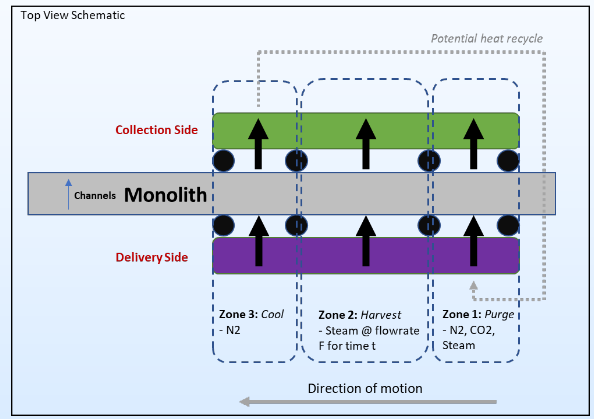


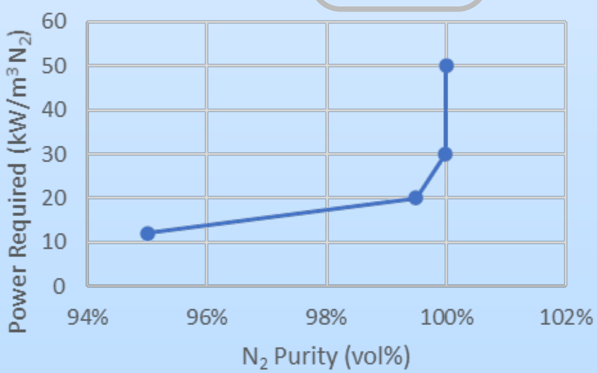
Aspen Plus model of 4-stage desorption system

- Scalable model to evaluate costs at large scale and at pilot scale
- Steam generation, cooling water utilities, CO2 compression in scope
- To be adjusted, refined once process basis established

Process Development: Cooling







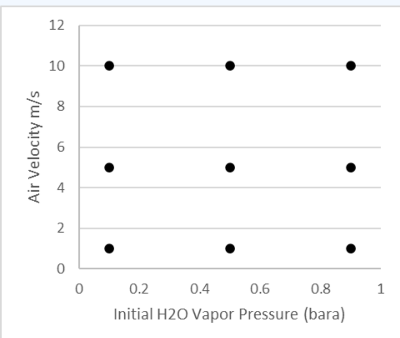
Power requirement sensitive to N2 spec at 98%+ N2

- Monolith cooling proposed to be carried out with N2 instead of with vacuum
- Cooling is necessary to reduce monolith oxidation

What are the tradeoffs with N2 purity, opex, capex, lifetime?

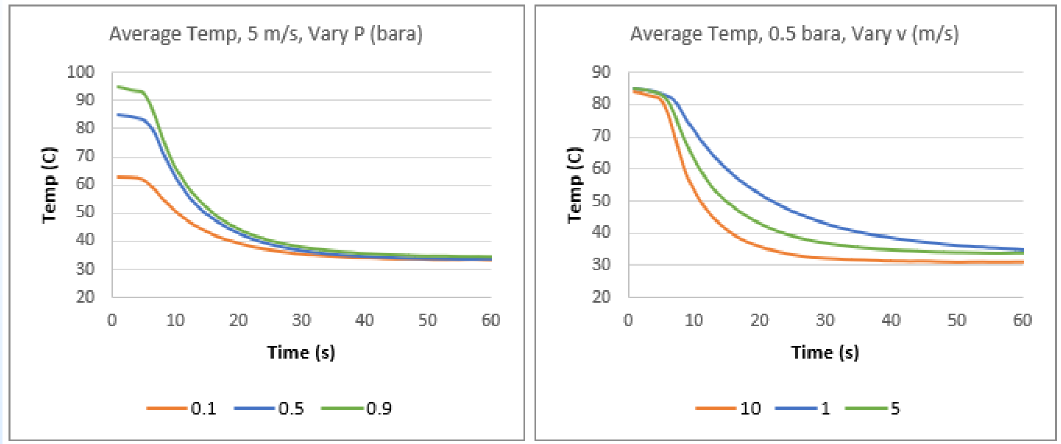
Process Development: Cooling

Experimental matrix on SPP for convective cooling profiles:

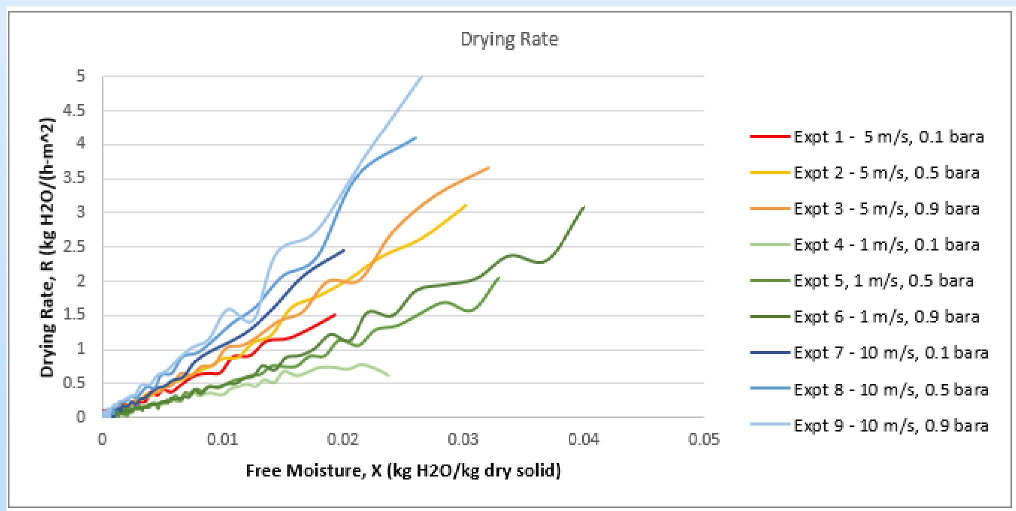


GT SPP

Cooling is rapid, dominated by evaporation, likely limited by external flowrate in these experiments



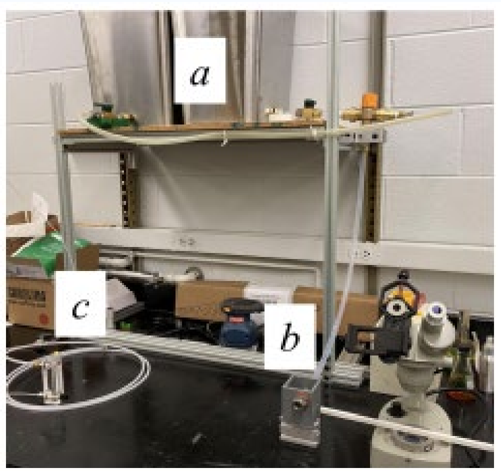
Average monolith surface temperatures during cooling



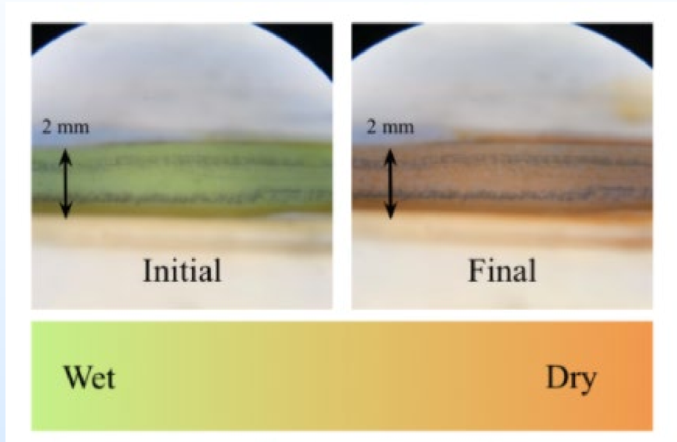
Drying rate as a function of free moisture content

Process Development: Cooling

Single channel experiments



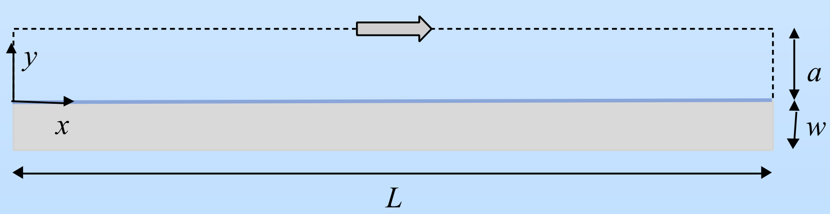
Apparatus for validation experiments at Georgia Tech



Dye based indication method of tracking of monolith wetness during drying experiments

Project Goal: Develop single channel monolith evaporative cooling model, combine with oxidation rate law to evaluate cost and lifetime implications of process basis ranges

Single channel model



$$\partial_t T = \alpha_w \nabla^2 T,$$ Solid Wall

$$\partial_t T = \alpha_l \partial_y{}^2 T,$$ Liquid Layer

$$\partial_t T + \mathbf{u} \cdot \nabla T = \alpha_g \nabla^2 T,$$ Gas

Plans for future testing/development/ commercialization

Project Scope:

- Develop and demonstrate prototype cDAC process
- Evaluate TEA/LCA and scale potential

Future Project Scope:

- Refine mechanical/process/equipment selections based on technology improvements
- Scale up designs and build at larger scale, possibly for commercial application

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

Learnings generated during project are general and extend beyond scope of project

Demonstration of cDAC remains on target for 2023

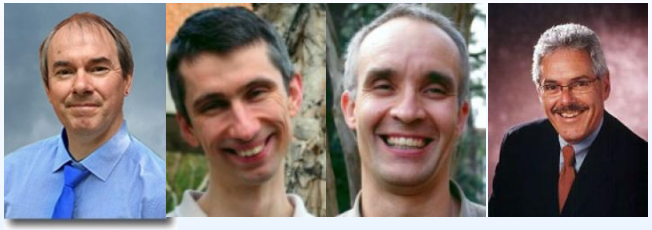
Team

Global Thermostat

Eric Ping – Project Coordinator
Miles Sakwa-Novak – Co-PI
Yanhui Yuan
Zach Foltz

Ron Chance
Jed Pruett
Sarah Wyper
Julian Bouckenooghe

Georgia Institute of Technology



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Ryan Davis
Kylee Harris

VADA
Bud Klepper

Zero Carbon Partners
David Elenowitz

Appendix

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

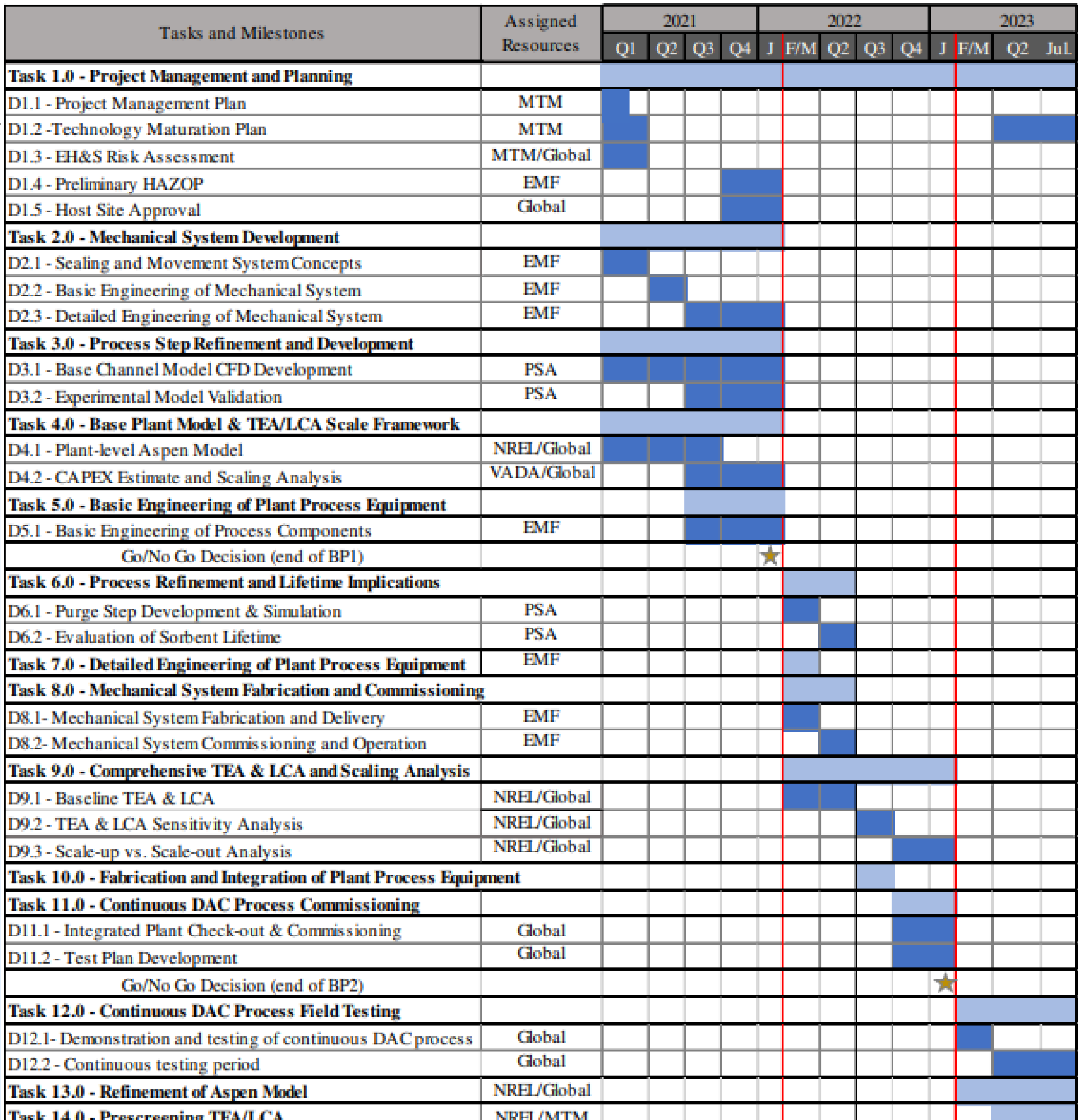
Process Systems and Analysis Team

- 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