A New Direct Air Capture System Operating on Low Grade Heat Generated from Geothermal Plants
Contract No. DE-SC022687

Gökhan Alptekin, PhD
Freya Kugler, PE
Autumn Zemlicka
Sarah DeVoss
Ewa Muteba
Ambalavanan Jayaraman, PhD

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TDA Research Inc. · Wheat Ridge, CO 80033 · www.tda.com

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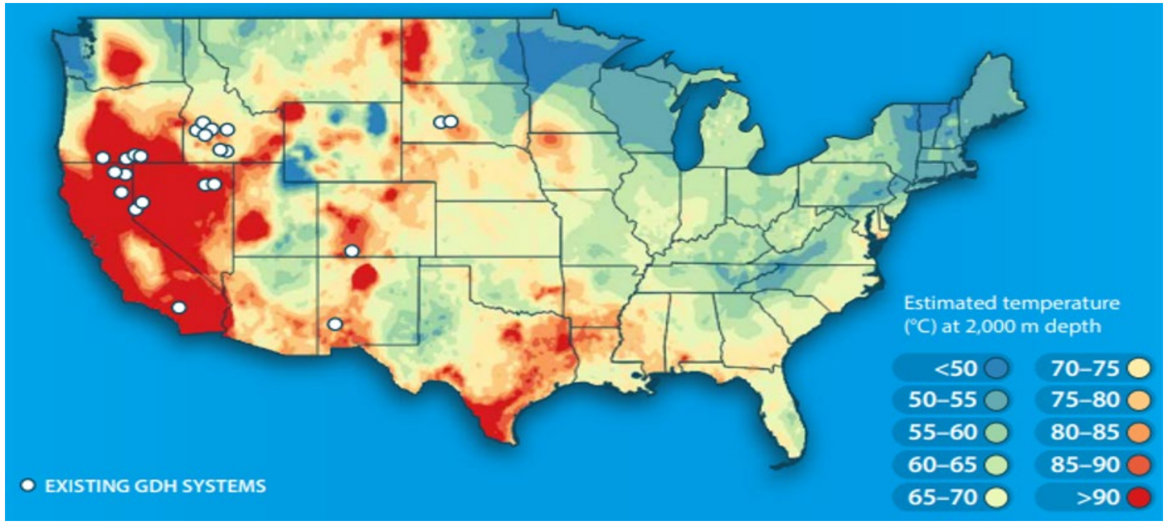
Project Objectives and Team

- **Project Duration**
  - **Start Date = September, 2023**
  - **End Date = September, 2025**
- **Budget**
  - **Project Budget = $1,000,000**

- Develop/demonstrate the efficacy of integrating a thermally driven DAC process using waste heat from geothermal power plants
  - Evaluate integration options of the DAC system with the overall geothermal process
- Phase II
  - Optimize the sorbent for the geothermal power cycle
  - Proof-of-concept experiments to demonstrate the technical viability at the bench-scale
  - Carry out long duration cycles (min 1000)
  - Reactor design supported by Computational Fluid Dynamics and thermal Finite Element Analysis
  - Design, fabrication, demonstration of a prototype system for proof-of-concept evaluations
  - High fidelity techno-economic analysis

Introduction

- DAC is challenging due the low CO_2 concentration in air (< 500 ppm)
  - Low driving force requires a high energy input compared to stationary carbon capture systems
  - Dilute CO_2 concentration in the air also requires large volumes of air recirculation to capture reasonable amounts of CO_2
- Integration with geothermal power plants presents opportunities to address these challenges
  - 87-90% of the source heat is wasted
  - 2/3rd of US geothermal power are in arid locations; air-cooling is the primary heat rejection method



Location of existing geothermal systems overlaying estimated temperature at 2,000 m depth Source: Mullane (2016)


Air-cooled geothermal plants: 330 MW plant in Sarulla, Indonesia (left) and 27 MW plant Tungsten Mountain, Nevada (right Source: Ormat Technologies

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Process Schematic

Integration of DAC sorbent into Air Cooled Condenser

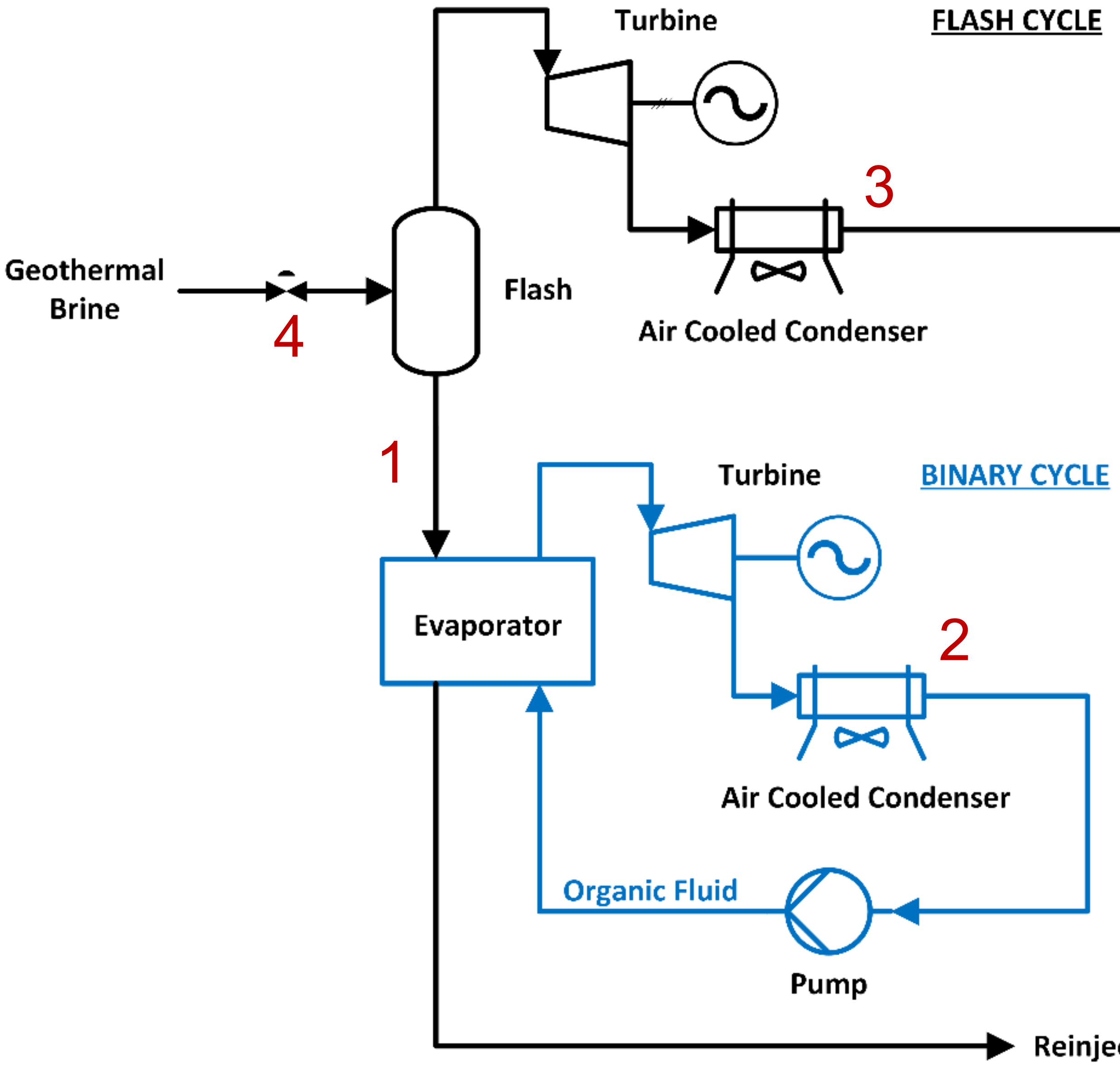
- Geothermal plants reject heat, which can be used to drive the sorbent regeneration
- If temperature of these processes match, there may be savings due to reduced energy intake for DAC

Waste Heat Availability

- Heat of condensation of working fluids
- Hot brine and Flash bottoms

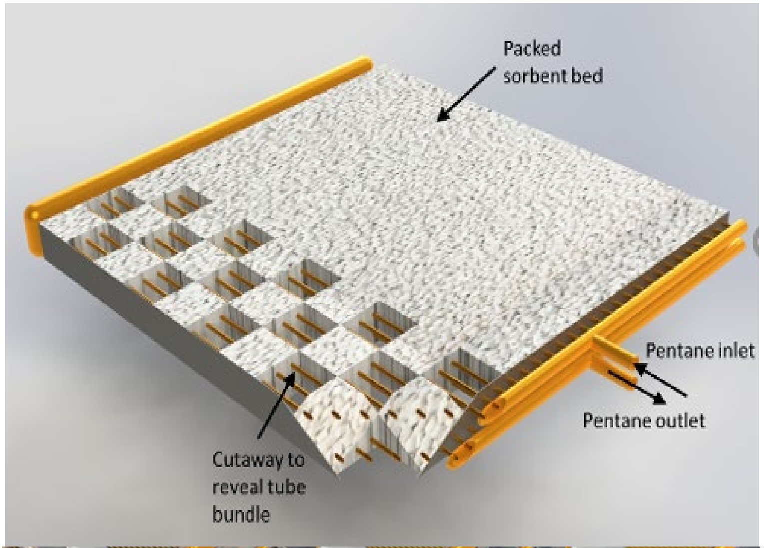
Four Integration Potential Points:

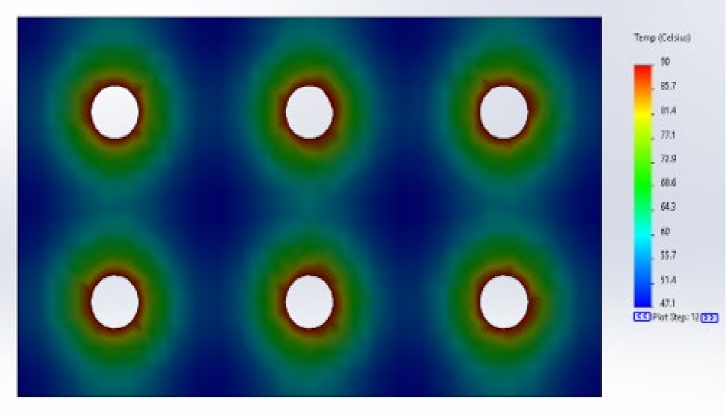
1. Flash bottoms
2. Hybrid Steam + ORC HP condenser
3. Air cooled condenser
4. Brine slip stream (up to 110-120°C)



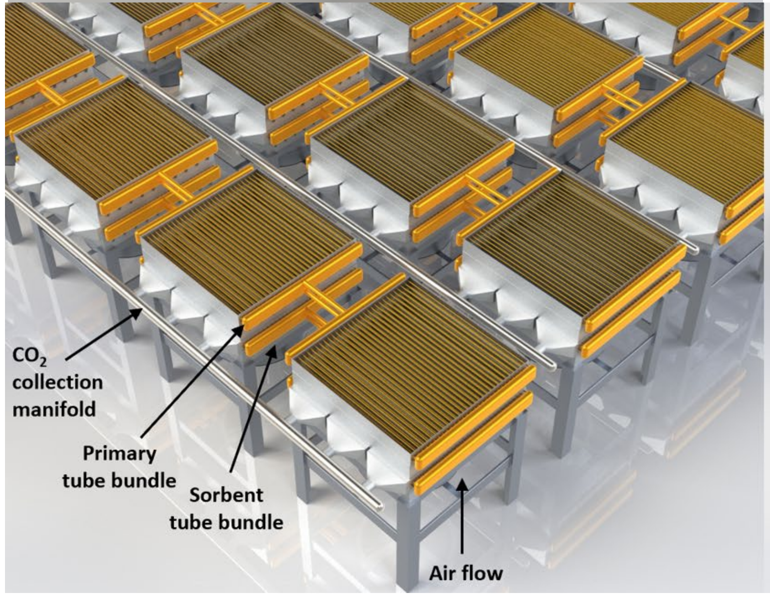
Conceptual Cell and Plant Design

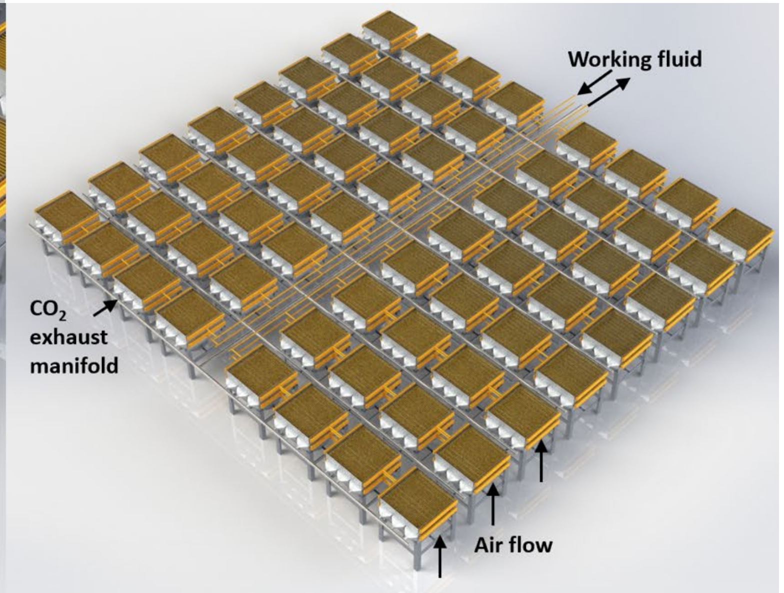
Unit Cell Design





Plant Design





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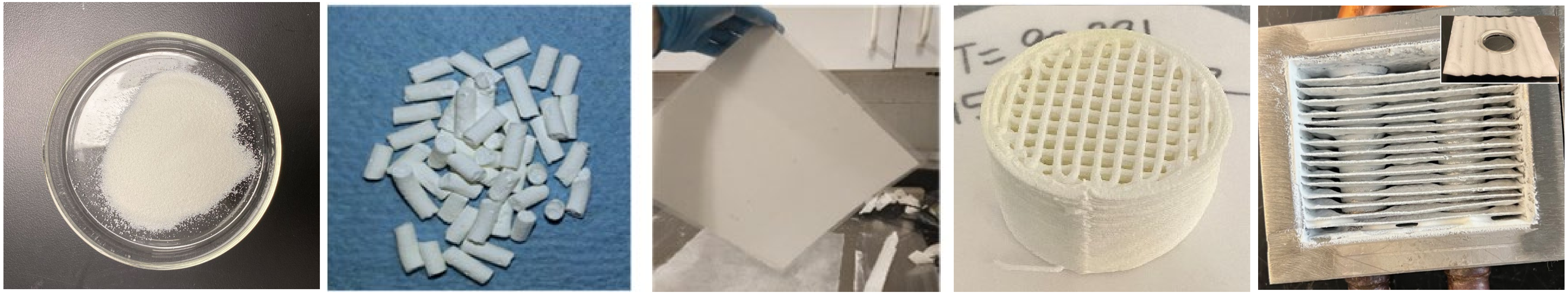
TDA's Sorbent for DAC

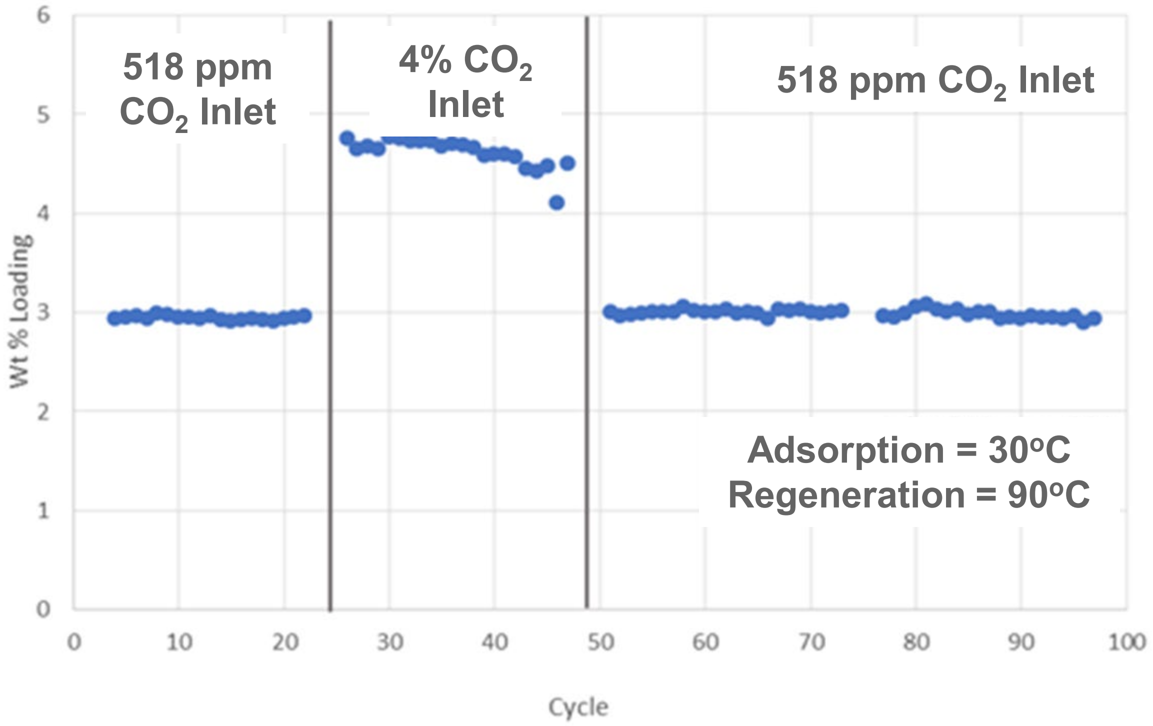
- **TDA has been developing a new polymer sorbent for DAC and life support applications (DE-SC-00020846, 80NSSC18C0135, N00178-18-C-8009)**
  - **Sorbent has very high CO_2 uptake in dilute gas streams (e.g., 400 ppm CO_2 in air; 2,500 ppm spacecraft cabin; up to 5,000 ppm in submarines)**
  - **The sorbent maintains its stability at high temperatures**
- **The sorbent can be prepared in the form of pellets, laminates and 3D printed monoliths; in this project it will be applied as a 3D printed monolith**

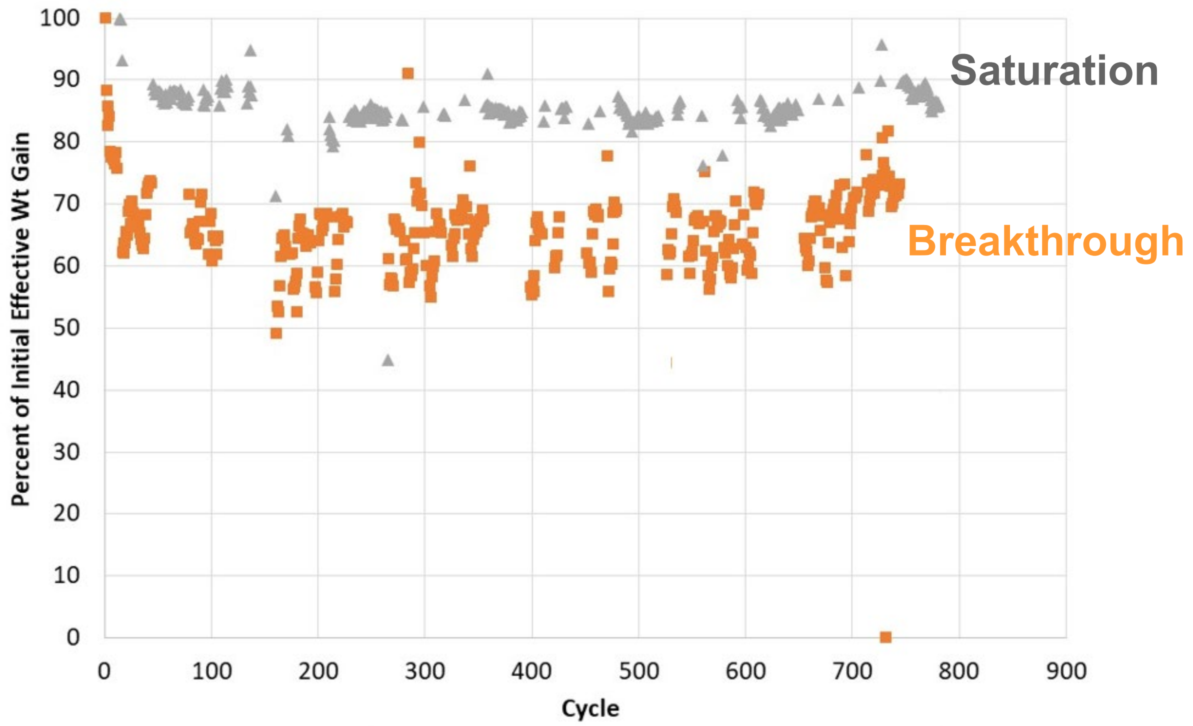


(a) *(b)* *(c)* *(d)* *(e)*

Various forms of polymer sorbent: (a) powder (b) pellets (c) single laminate layer (d) 3D printed monolith (e) applied as a coating on HEX surfaces

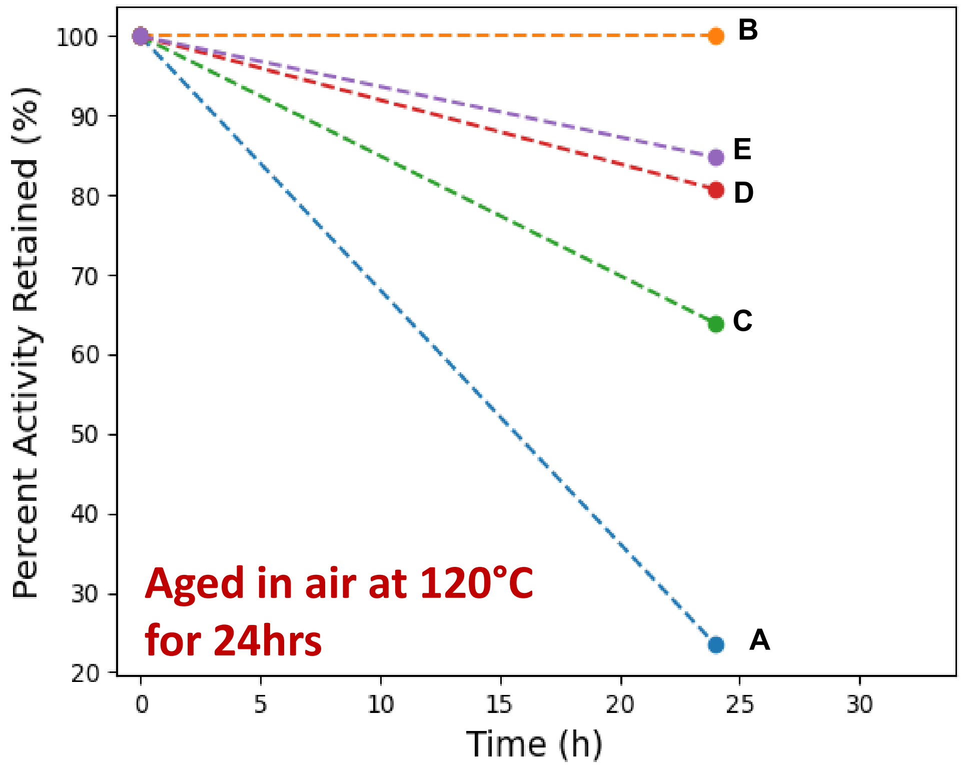
Temperature & Cyclic Stability

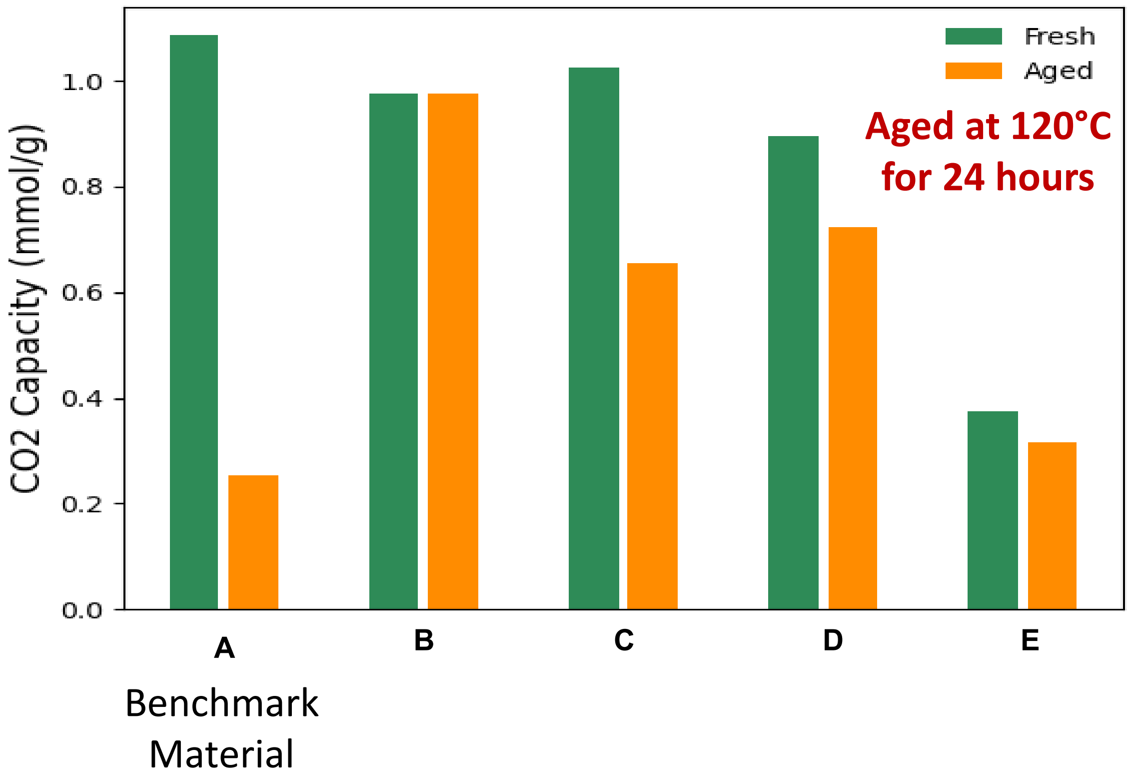




- High stability under TSA/VTSA cycling
- High working capacity
    - ~3% wt. CO_2 uptake at a 60°C swing
- Stable operation for ~800 cycles under DAC conditions (over 10,000 cycles has been demonstrated for the Navy application)

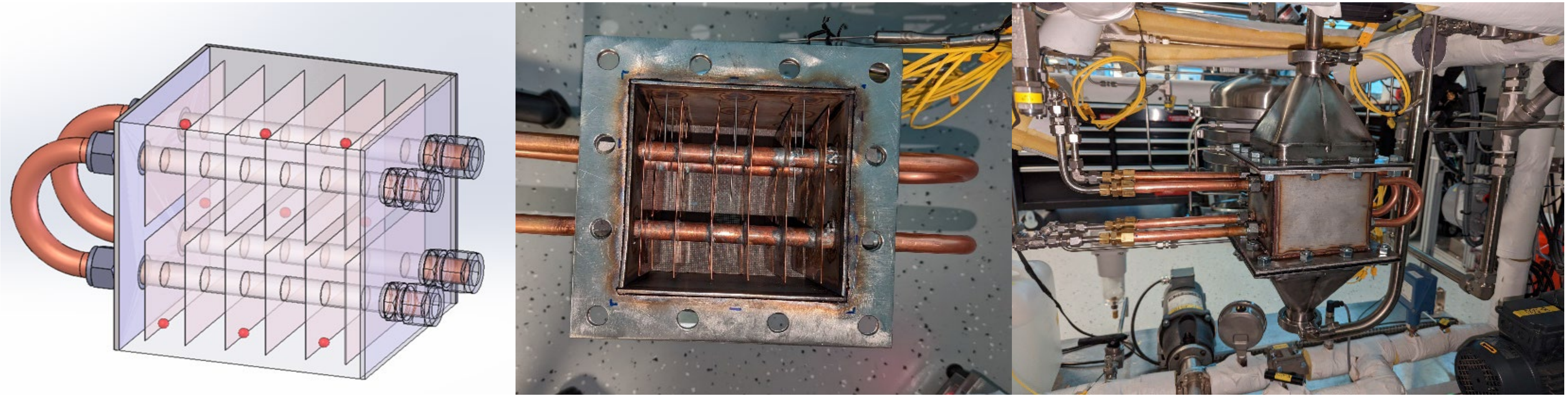
High Temperature Oxidative Stability





- **TDA identified several formulations that can provide high temperature oxidative stability**
- **An aggressive test method is developed to accelerate aging effects in air for 24 h at 120°C under dry conditions**
- **CO_2 uptake performance is tested before and after the aging test in a 5 min concentration swing cycle at 60°C**

Reactor Design and CFD Analysis



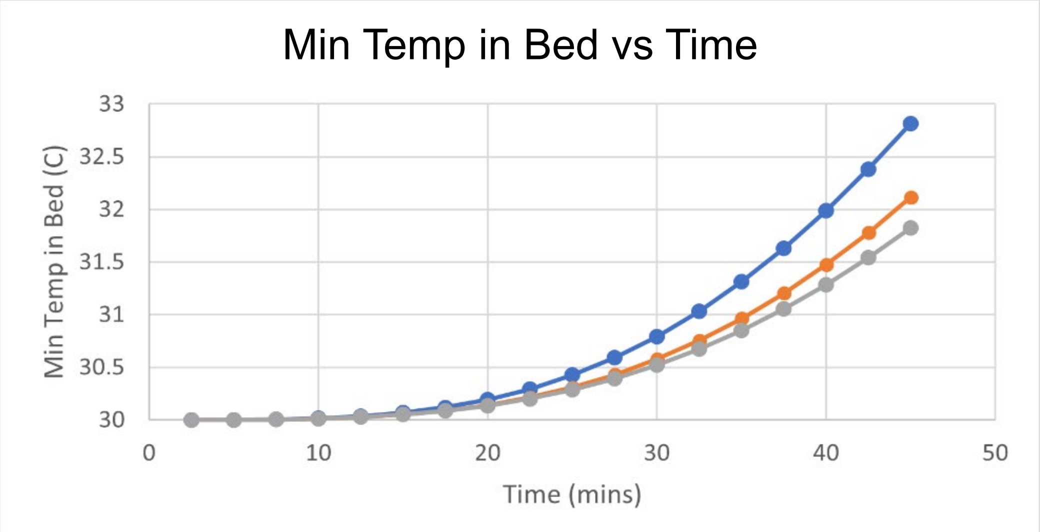
Gen 1 Cube Unit Cell Design for Scale up (3.5 L sorbent, 6 x 6 x 6 inches)

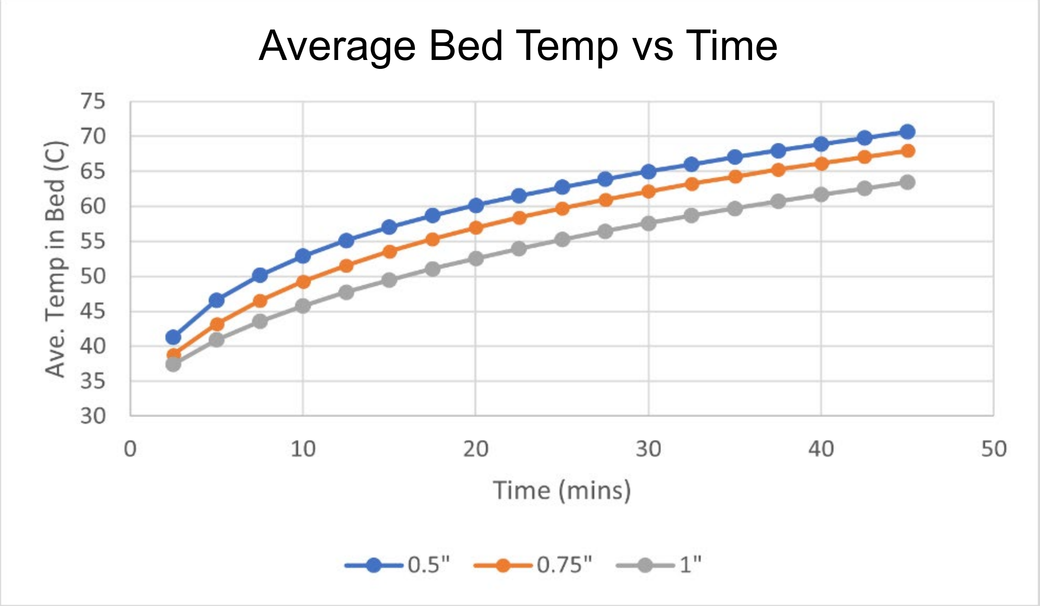
<u>Critical Performance Metrics</u>	Heating time, Temperature distribution/uniformity, Pressure drop, Volume increase per module (bed dimensions), Capture efficiency, Overall cost
<u>Critical Design Variables</u>	Fin spacing, Fin material, Fin height, Bed depth, HT fluid flow rate, Tube diameter – set by flow rate through tubes, Heat loss

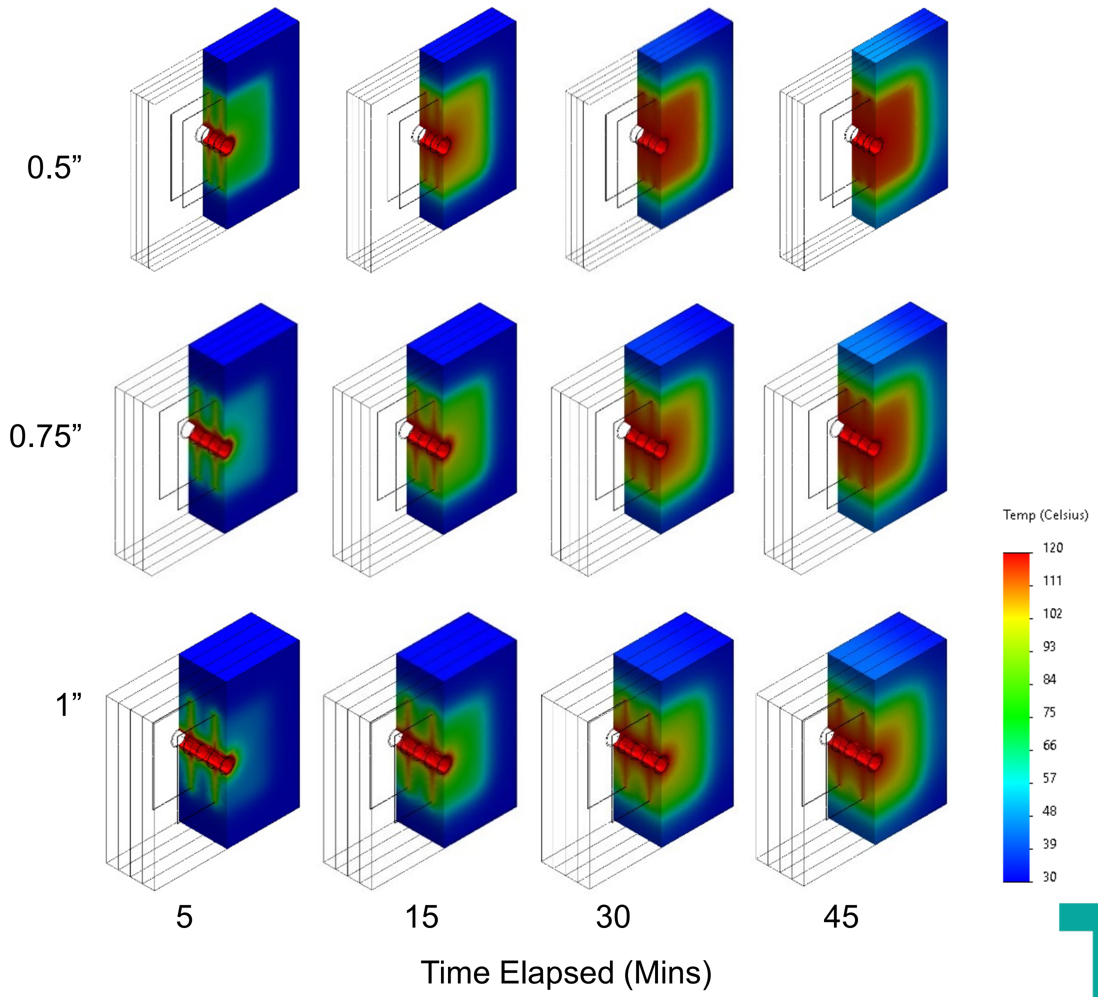
Task 5. Reactor Design and CFD Analysis

Effect of Fin Spacing

HX Fluid Temp = 120 ^{o}C
Material: Copper
Fin Height: 1.25”







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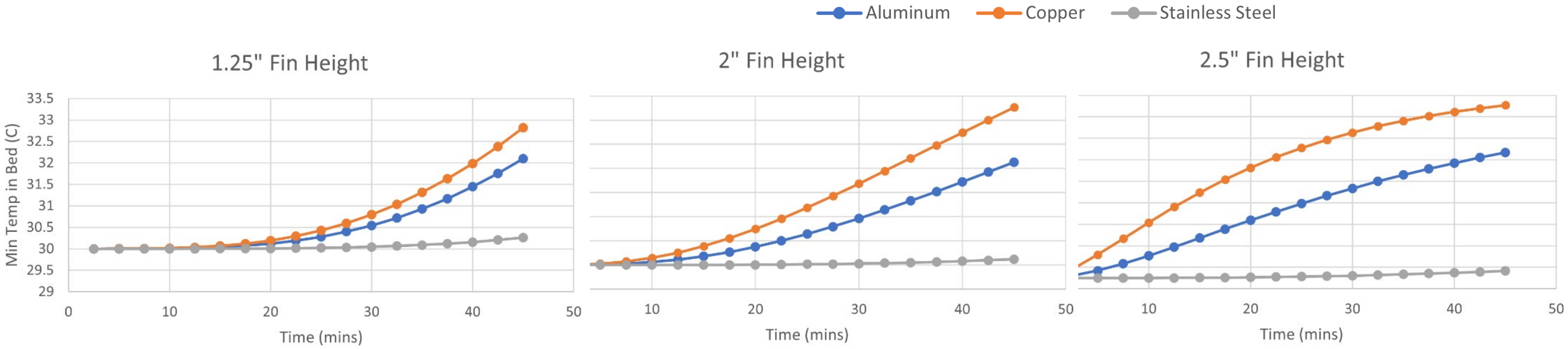
Reactor Design and CFD Analysis

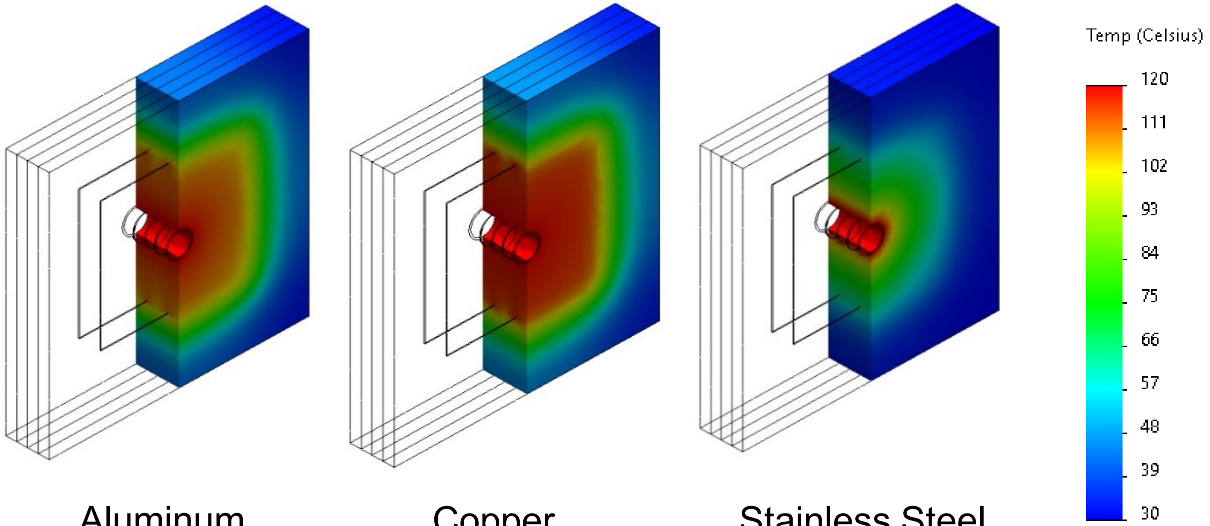
Effect of Fin Material



HX Fluid Temp = 120 ^{o}C

Fin Height: 1.25”
Fin Spacing: 0.5”

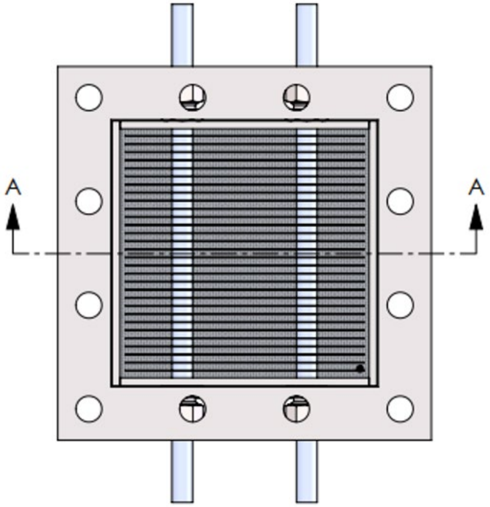
Time elapsed: 45 mins

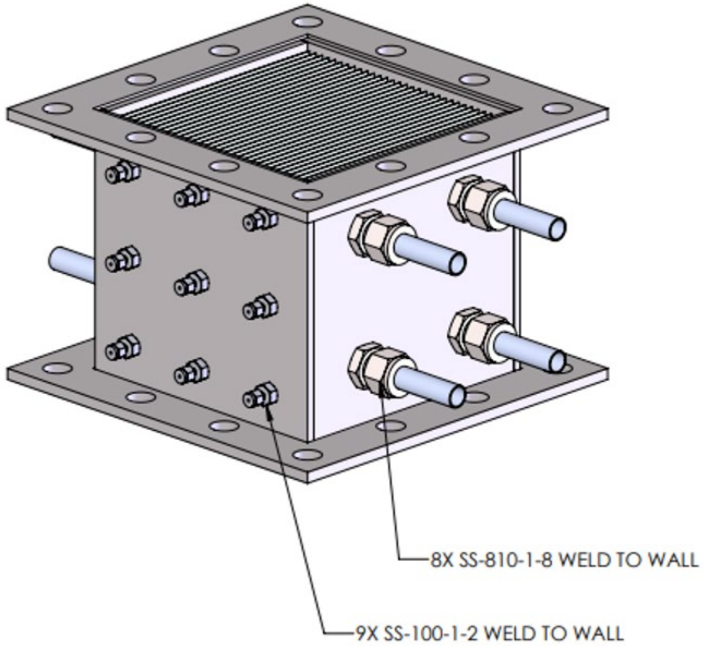


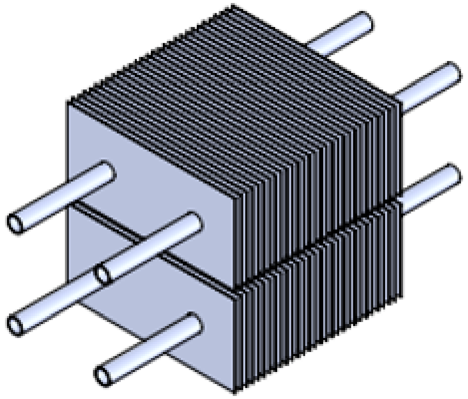
Aluminum Copper Stainless Steel

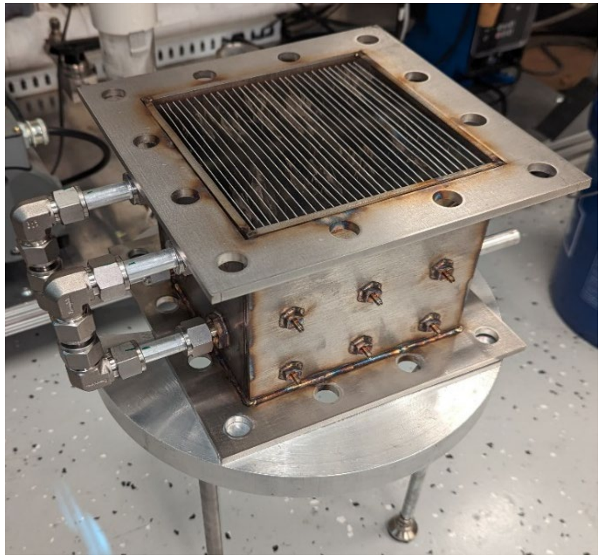
Reactor Test Cell Design – Gen 2

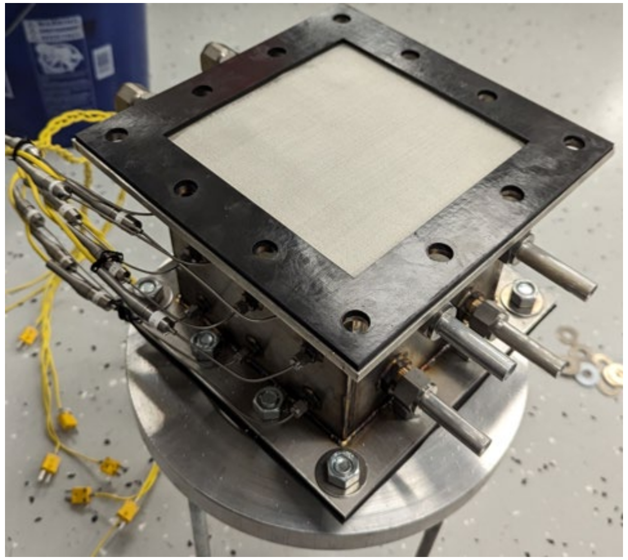
- Aluminum construction optimized for fast heat transfer
- Tighter fin spacing



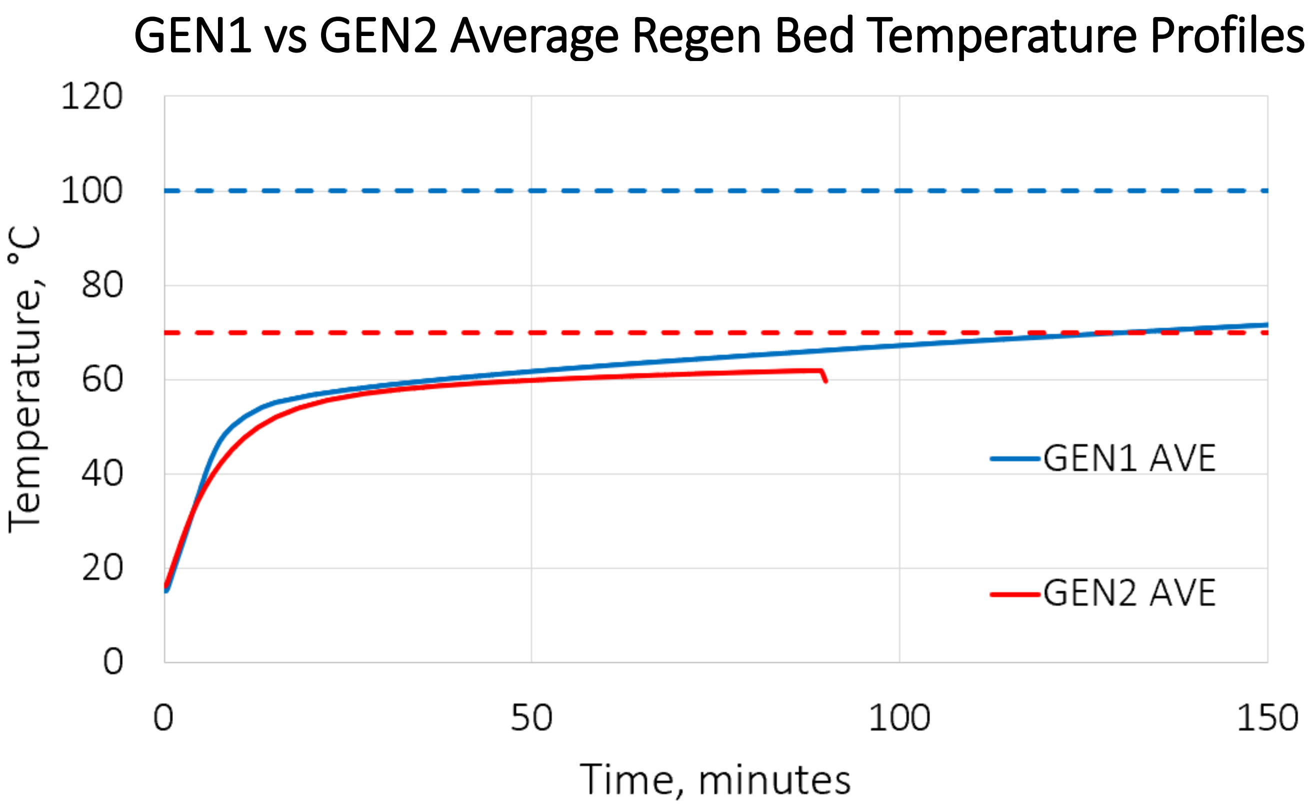


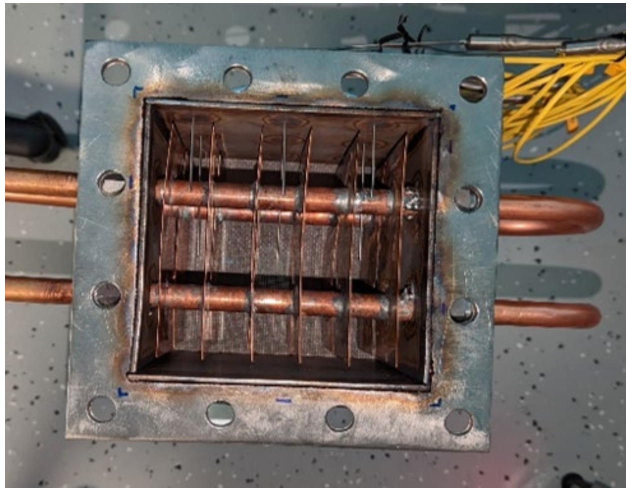


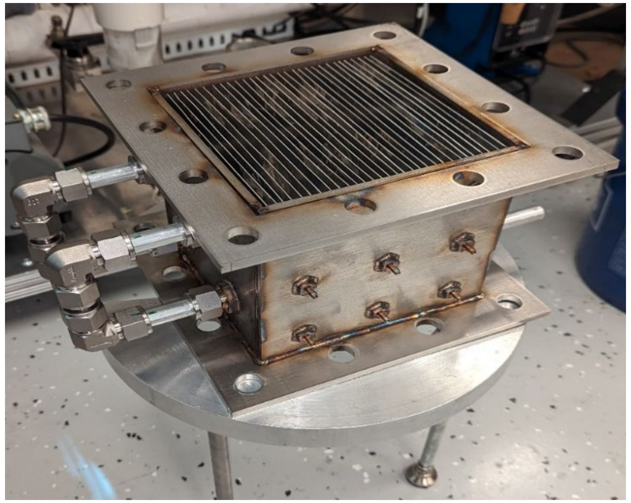




Heat Transfer Improvements







- Approach temperature for the Gen 2 design is < 10 °C compared to ~40^{o}C for the Gen 1

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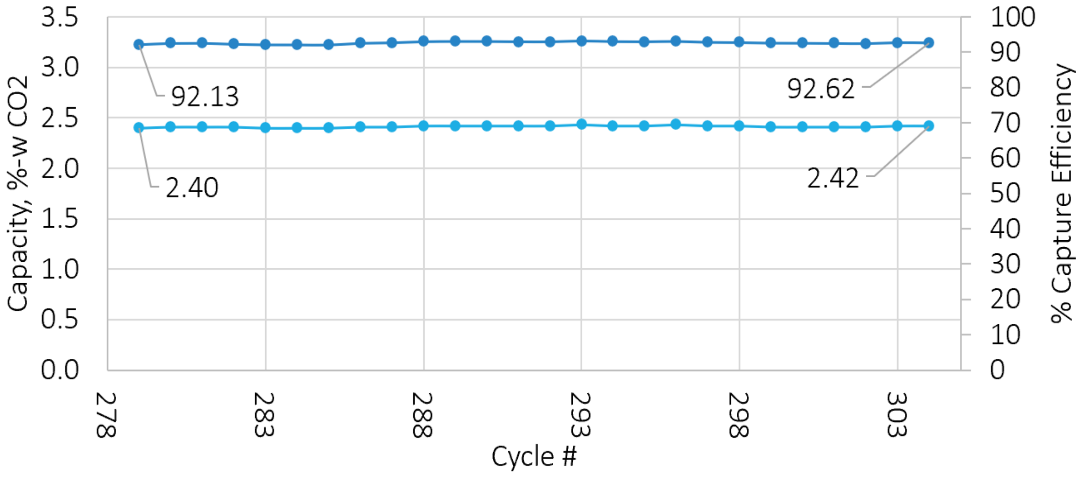
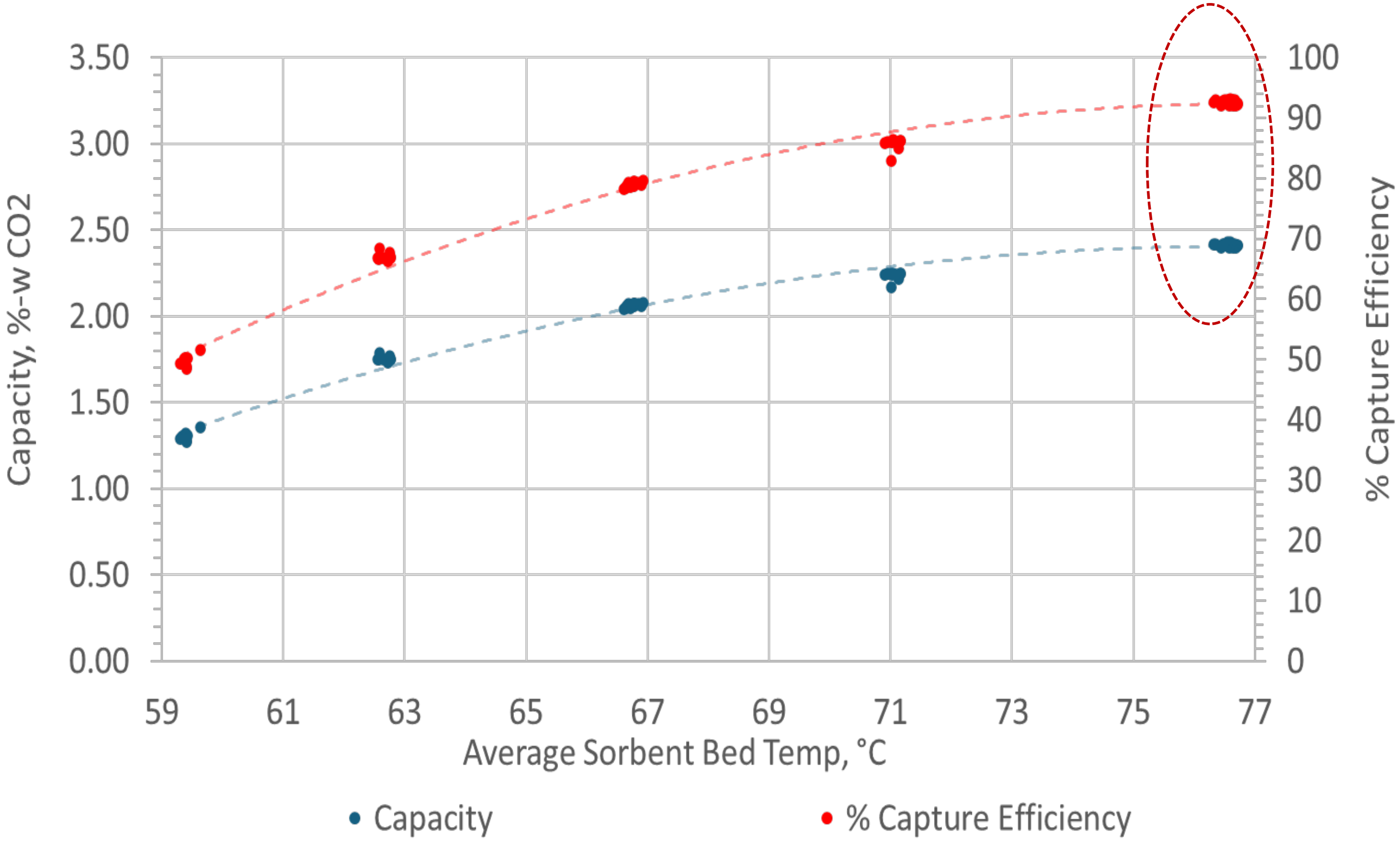
Sorbent Evaluation

Sorbent capacity and capture efficiency as a function of regeneration temperature over 340+ cycles

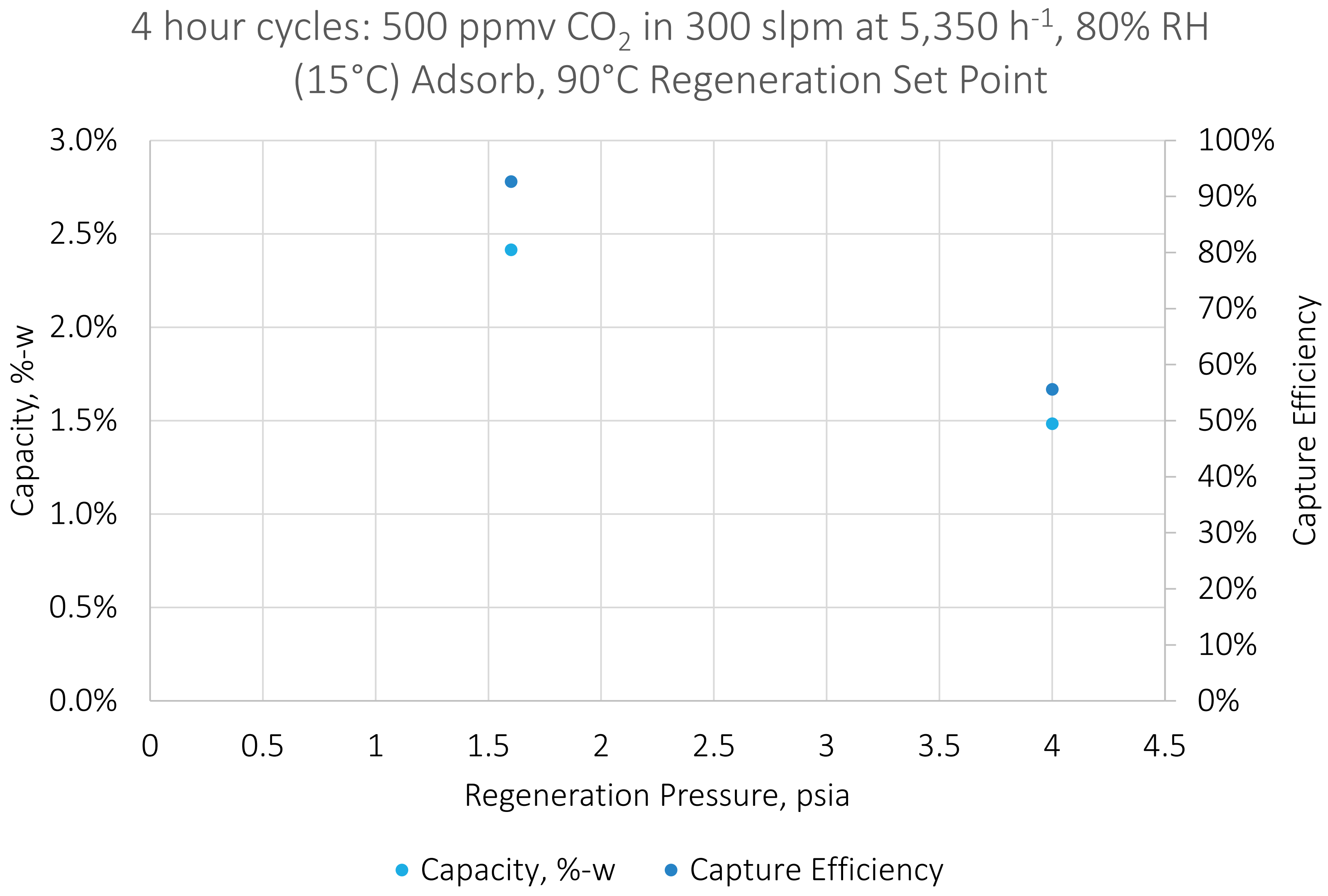
Adsorption - 500 ppmv CO_2, 18°C dew point, 300 slpm (~0.6 kg CO_2 removal/day) at 5,350 h^{-1}

Regeneration - 1.4 psi



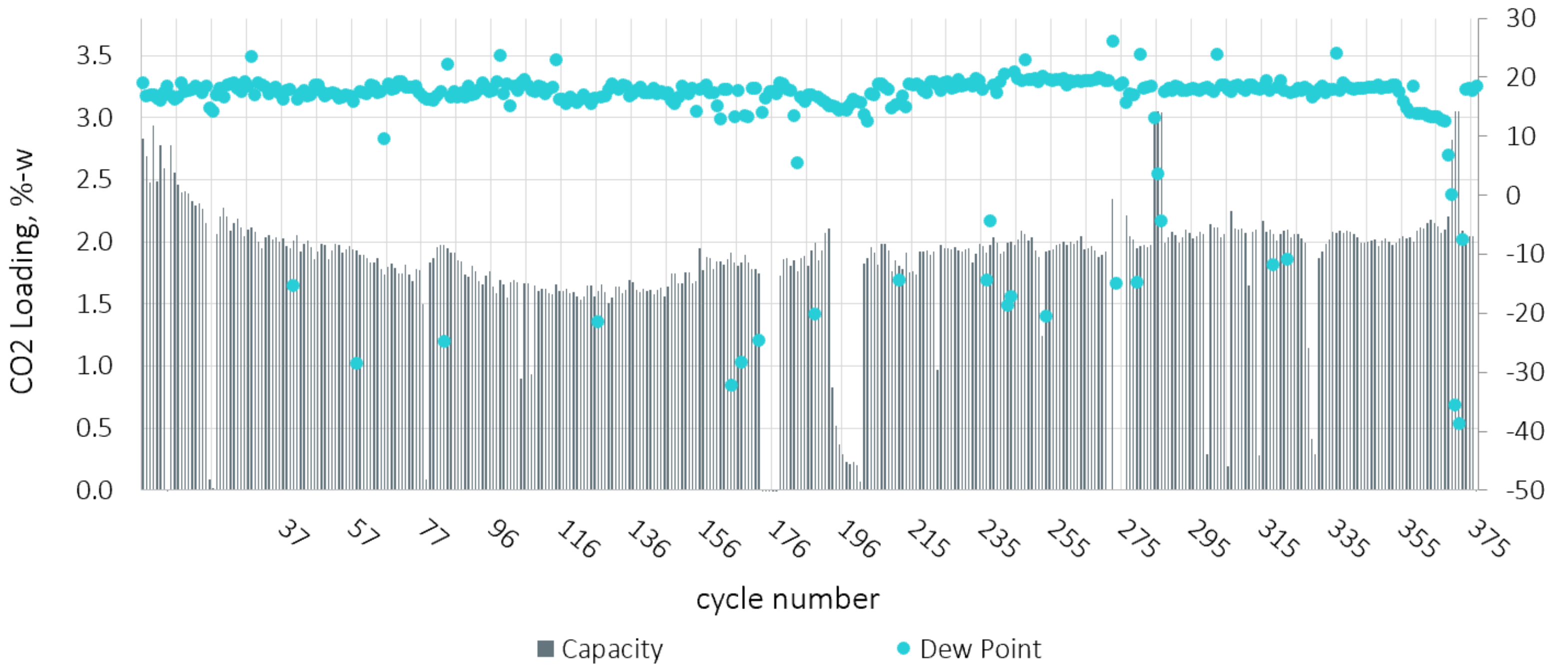


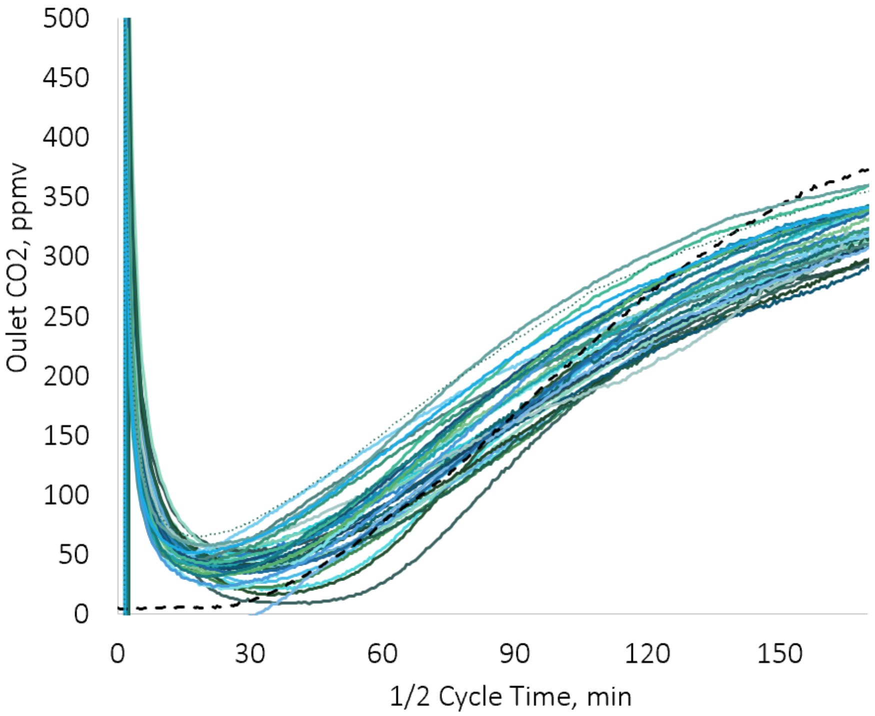
Effect of Regeneration Pressure



Multiple Cycle Tests

- Stability testing in axial flow configuration
- Adsorption - 1.35 slpm, 500 ppm inlet CO_2, 13.5 psia, 20°C adsorb, 18°C dew point
- Regeneration - 100°C desorb, 8 psia





US Geothermal Plant Operators

STEAM CYCLES

- Calpine Corp
  - 725 MW, 15 plants CA
- CalEnergy / BHP Renewables
  - 345 MW Imperial Valley
- Coso
  - 272 MW Flash Steam
- PacificCorp
  - 11 MW Blundell UT

BINARY CYCLES

- Ormat
  - 3,200 MW
- Terra-Gen Power
  - 80 MW, NV
- Cyrc Energy
  - 152 MW, NM, NV, UT
- Open Mountain Energy
  - 4 MW, NV
- Enel Green Power (ITA)
  - 100 MW, NV

Engineering Analysis / System Design Basis

Case Study 1 – Binary Cycle

- Neal Hot Springs, Oregon (3 units, 8.2 MW each)
- Built by US Geothermal; owned/operated by Ormat
- Brine input 0.82 kg/h at 138°C and 99.2 psia
- 80.26 MWth source, 10.16% cycle efficiency
- Cooling fan power 721 kW

- Large 30' fans reduce capital cost by ~89% in blades, shaft bearings/belts, motors, cables, and starters
- *Larger fans reduce air recirculation – key for DAC*

Case Study 2 – Simple/Flash Cycle

- Tasman Pulp Kawerau Field, Reykjavik Energy
- Existing single flash or dry steam plants
- Brine temperature ~150°C
- Integrate air cooled condenser air with waste heat from saturated liquid

Design Basis:

- Adsorb at 15°C at 50% RH, 80% capture efficiency
- Regen at 100-120°C and 4+ psia vacuum with 100% CO2 no purge

Summary:

- Saturated liquid contains enough thermal energy to capture 67 MT CO_2 per year

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NETL Project Manager
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