A Combined Water and CO_2 Direct Air Capture System

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Project Overview

- DOE FOA 2188 Award
  – *A Combined Atmospheric Water Extraction and CO2 Direct Air Capture System*
- Initial funding – \$3.2M (DOE share - \$2.485M, cost share - \$672K)
- Project Duration – 10/1/2020 – 03/31/2024
- Project Extension granted until 12/31/2024
  Additional budget of \$300,000 (DOE share - \$195K, cost share - \$105K)
- Team
  - Awardee: IWVC
  - Subawardees: PNNL, Barr Engineering
  - Additional Participants: SoCalGas, Univ. North Texas
- Project Objective – build 30 ton-CO_2/year pilot facility; 1000 L/d H_2O capture

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BP Task and Subtask Breakdown

- All Budget Periods
    - Subtask 1.1 – Project Management
    - Subtask 1.2 – Technology Maturation Plan
- Budget Period 1 - HDAC Unit Detailed Design ✓
    - Task 2.0 – HDAC Unit Detailed Design
        - Process Modeling, Equipment Sizing, System Layout, Detailed Design, Update cost estimate
- Budget Period 2 - HDAC Unit Fabrication ✓
    - Task 3.0 – HDAC Unit Fabrication
        - Subtask 3.1 – DAC/Desiccant Bed Fabrication
        - Subtask 3.2 – Water Vapor Vacuum Pump
        - Subtask 3.3 – Condenser
        - Subtask 3.4 – Balance of Plant Assembly and Testing
        - Subtask 3.5 – Host Site Planning and Test Plan Dev.
- Budget Period 3 - Field Performance Test, Data Analysis & Reporting
    - Task 4.0 – Field Site Setup and Performance Testing ✓
        - Phase 1: Operational performance checks and shakedown testing ✓
        - Phase 2: Short duration parametric testing ✓
        - Phase 3: Long-term testing
    - Task 5.0 – Data Analysis and Reporting
    - Task 6.0 – Materials and Process Development

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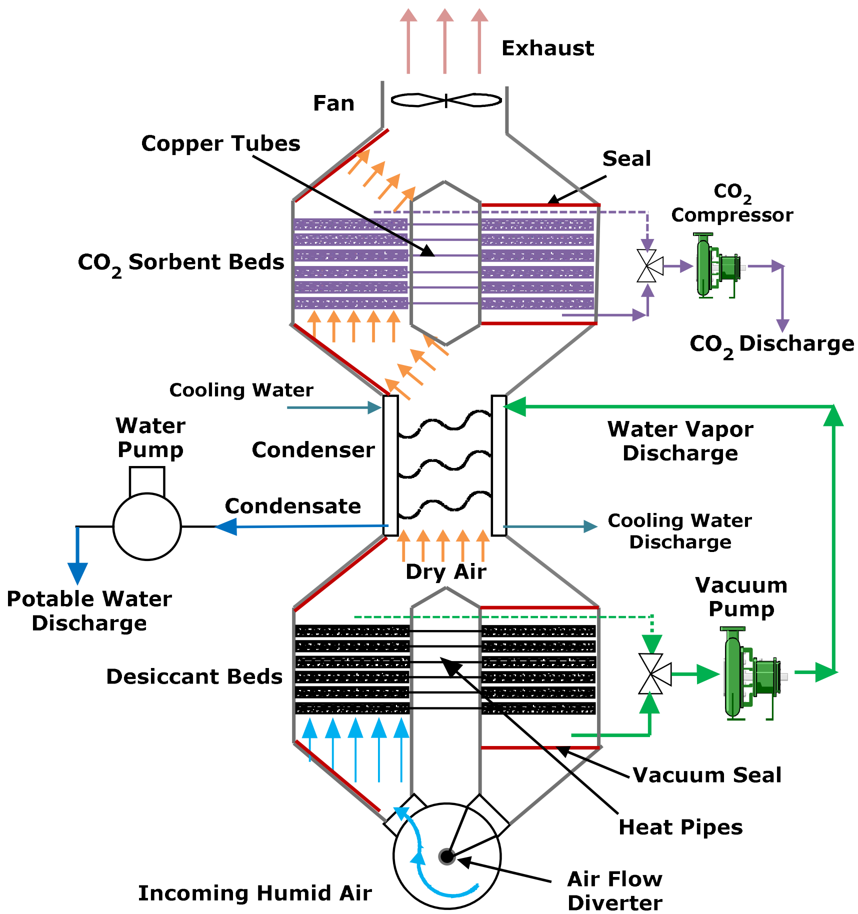
Project and Technology Background

Technology Background

Isothermal Water Vapor and CO2 Capture (IWVC)



- HDAC – H_2O *and* CO_2 from ambient air stream in single system
- Two-train System – Train 1: adsorption; Train 2: desorption
  - Atmospheric water extraction (AWE)
    - Capture heat from exothermic adsorption; exchange between trains
    - Vacuum swing regeneration
  - Pressure swing DAC section
  - Both use custom contactor design, maximize heat and mass transfer
- CO_2 Sorbent – solid phase MOF
- DAC Heat Source – no external heat required
- Water Consumption – no water consumption
- Primary Consumable – electricity for fans, vacuum pump, compression

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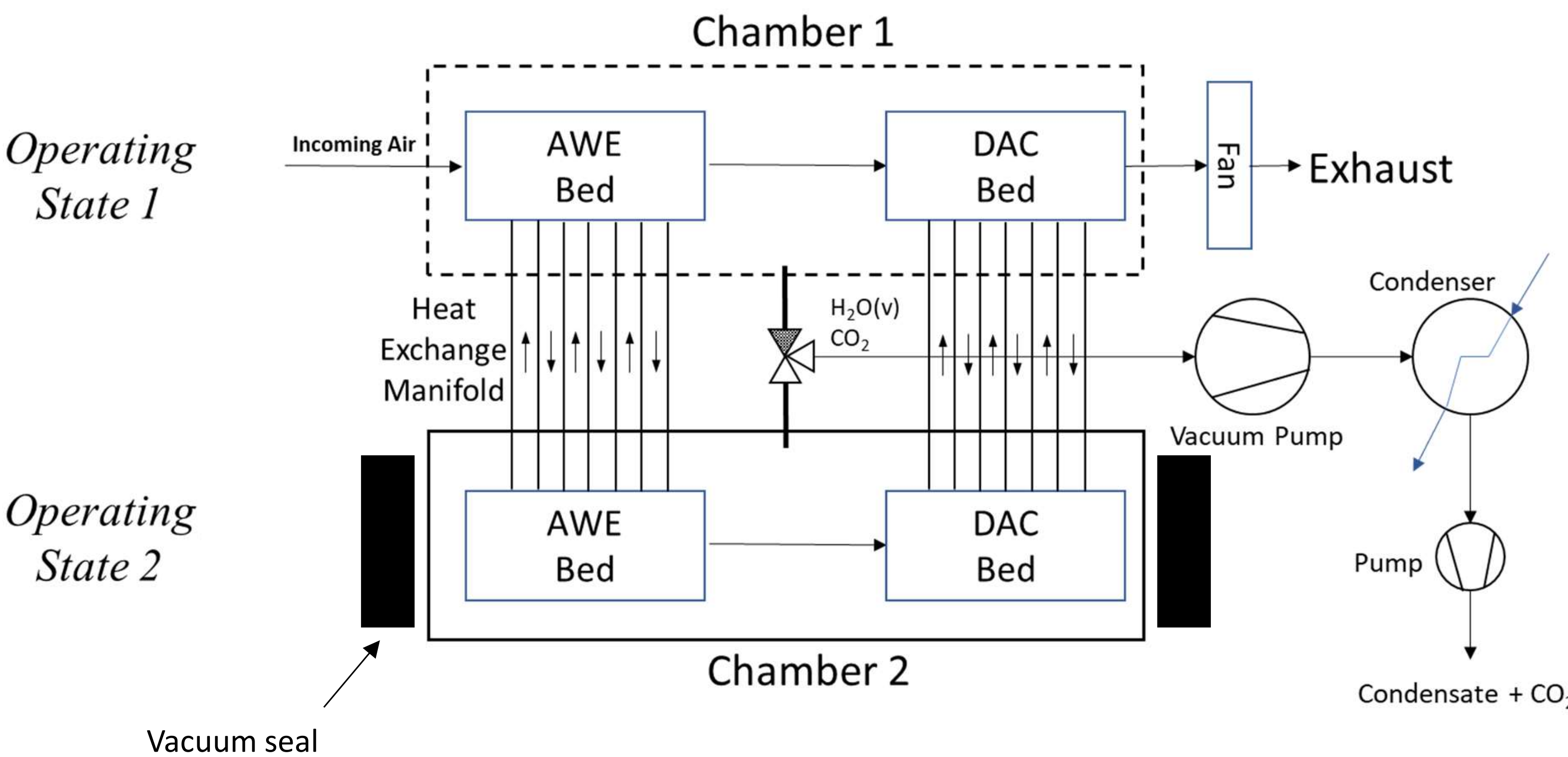
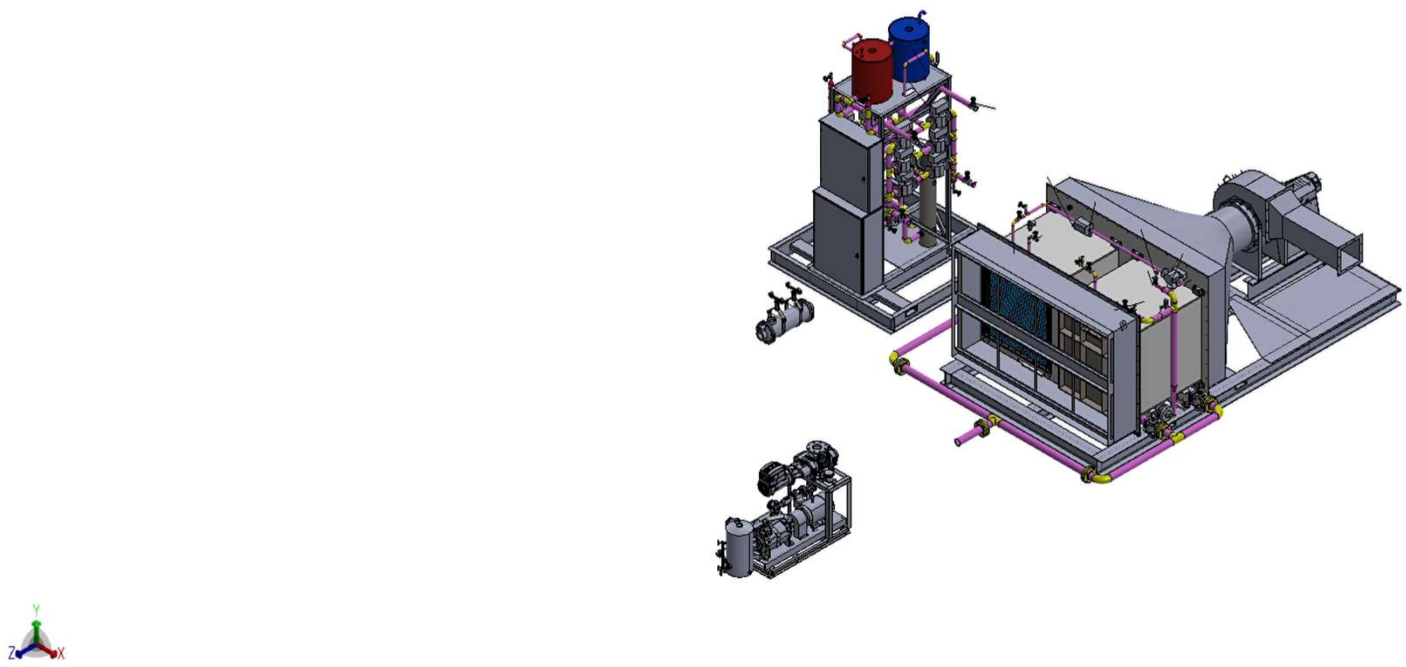
BP1: HDAC Unit Detailed Design - completed

Two chamber design integrating both AWE and DAC sections



BP2: HDAC Unit Fabrication - completed

Module and BOP engineering and construction has been completed.



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BP3: HDAC Unit Operation - ongoing

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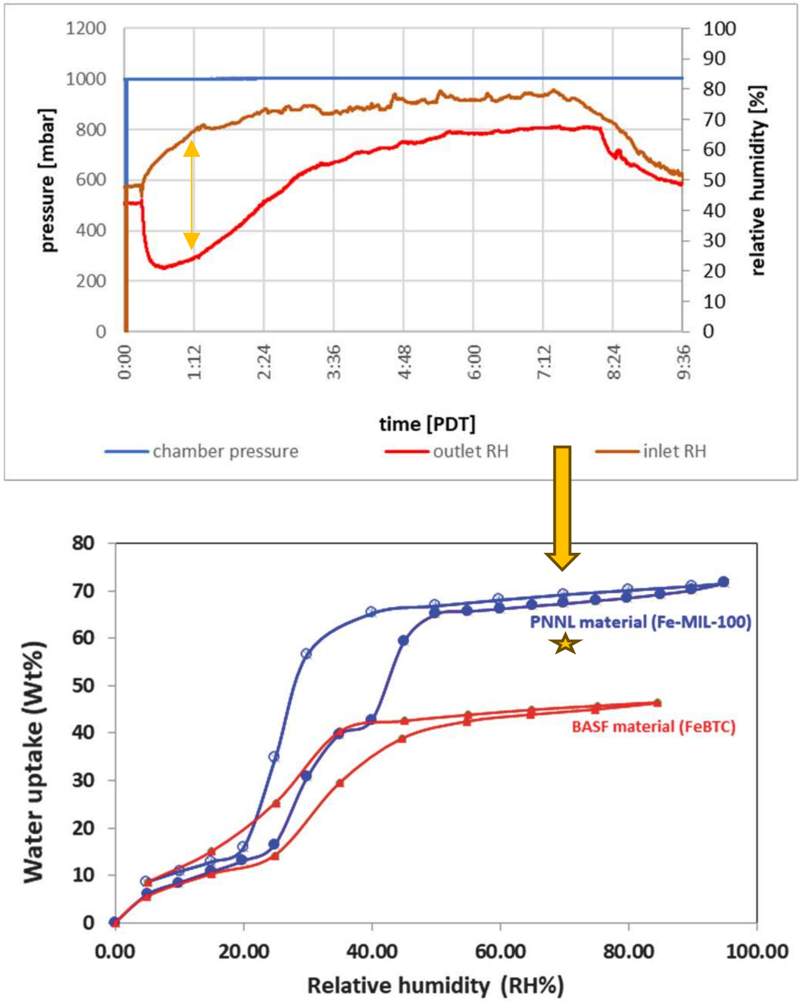
Test Results

Initial results

- AWE chamber initially loaded with non-commercial custom designed radiators coated with dessicant MOF
- AWE captures 4.5 liters (56wt%) of water over adsorption cycle at 70% inlet RH
- Uptake amount is very close to laboratory results from PNNL

AWE radiators coated with dessicant MOF



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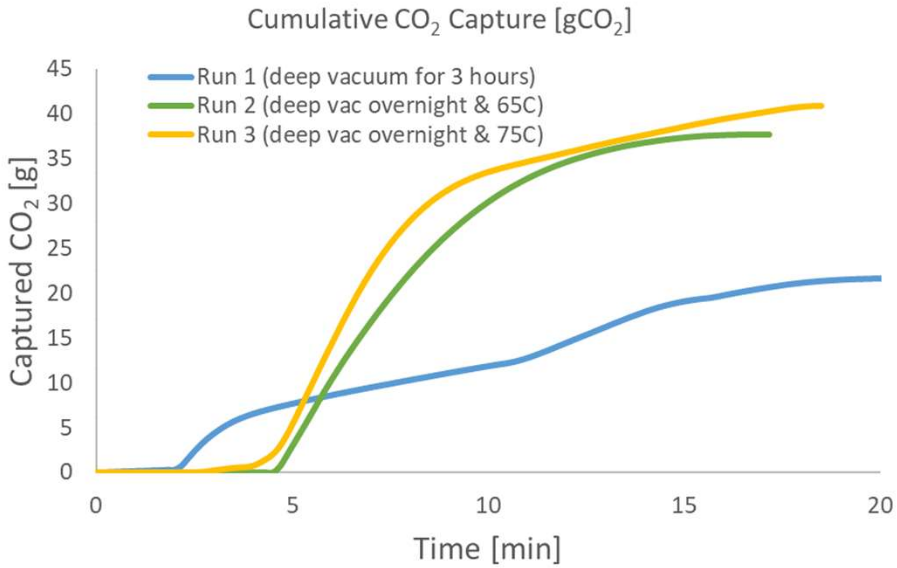
Initial results

Radiators coated with P/TSA MOF

- Custom designed radiators coated with P/TSA MOF were loaded on the DAC side.
- MOF does not desorb CO_2 in significant amounts at pressure generated by liquid ring vacuum pump (25-30 mbar).
- Measurable amounts of CO_2 uptake only after very low pressure (<10 mbar) and elevated temperature desorption.



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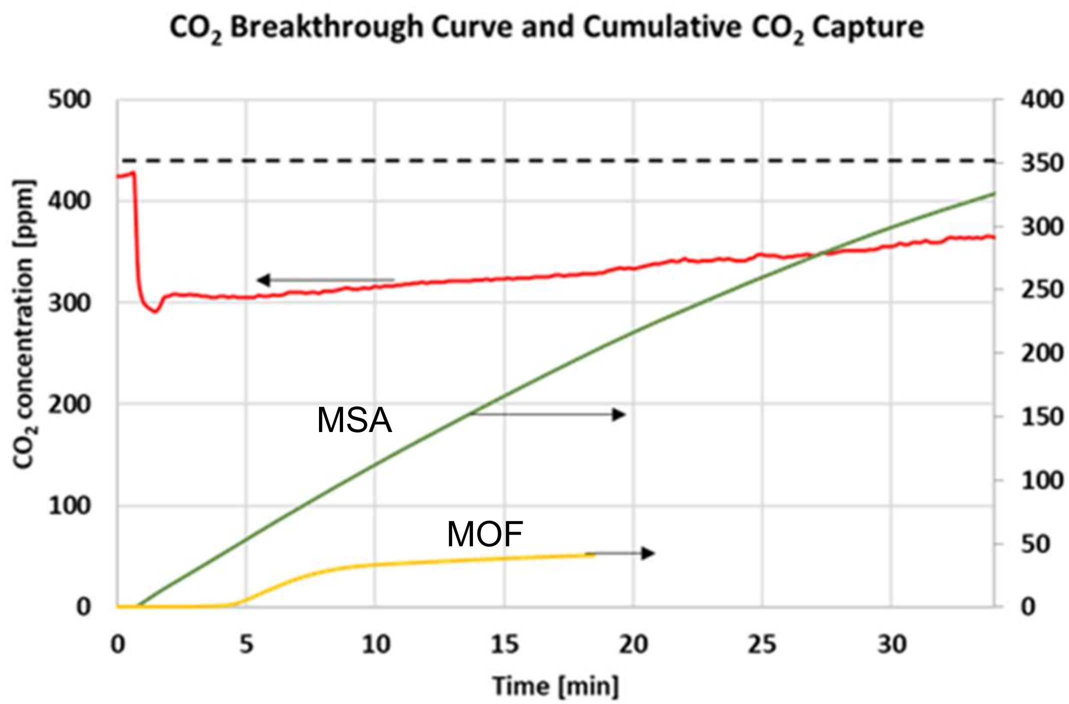
First results with moisture swing adsorbent (MSA)



Due to limitations of P/TSA sorbent, DAC sorbent was replaced with Avnos-built packed beds containing moisture swing adsorbents (MSA)

- First attempt: ~300 grams CO_2 captured in 30 minute adsorption cycle (1.0 mmol/g working capacity)
- CO_2 uptake amount (green curve) is 6X higher than best result with MOF (yellow curve)

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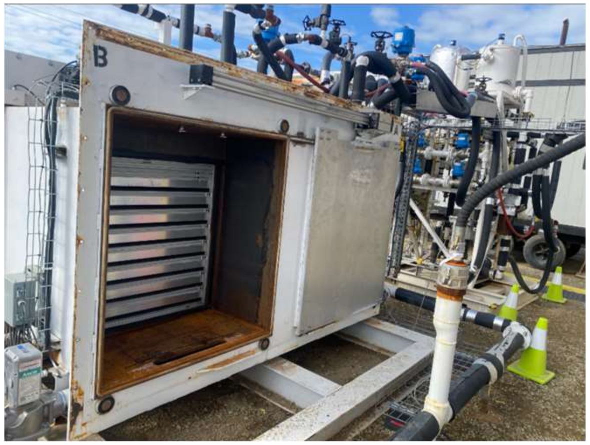
Commercial radiators coated with AWE adsorbent

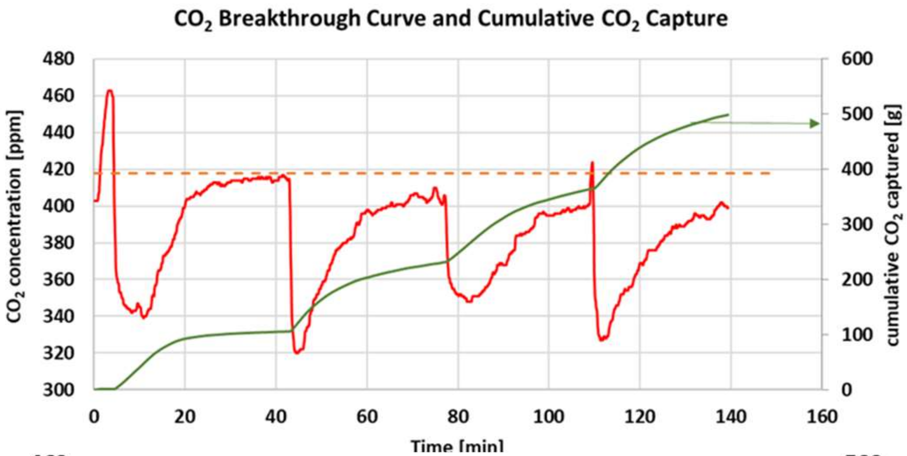


9 radiators installed per chamber

- AWE radiators replaced with commercial micro-channel heat exchangers.
- High uniformity of fins results in uniform sorbent coatings.
- Overall AWE working capacity similar to before but significant improvement in kinetics.

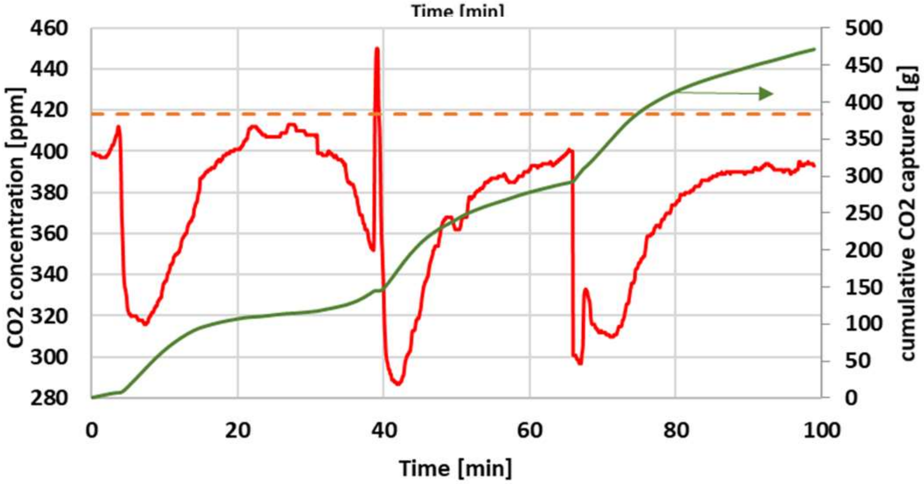
Cyclic performance with new AWE and MSA contactors

Different process conditions were explored, primarily including variations in desorption pressure, temperature and duration.



Baseline Low Pressure Process

- CO_2 capture rate: 0.25 kg/h
- Water capture rate: 2 kg/h
- H_2O:CO_2 ratio = 8



Elevated Pressure Process:

- CO_2 capture rate: 0.3 kg/h
- Water capture rate: 0.3-0.7 kg/h
- H_2O: CO_2 ratio = 1-2

- Elevated pressure cycle allows for reduction in water production rate with similar CO_2 production rate.
- Uniformity of new AWE contactors results in 4X higher water production rates than before.

Automated pilot plant operation

- Automation implemented end of June and cycles optimized in July.
- All cycle parameters (e.g. number of cycles, pressures, temperatures etc.) can be modified.
- July 25: First overnight automated run.
- 30 cycles completed back-to-back (21 hours of total run time).
- Since July 25, pilot plant has been running in automated mode.

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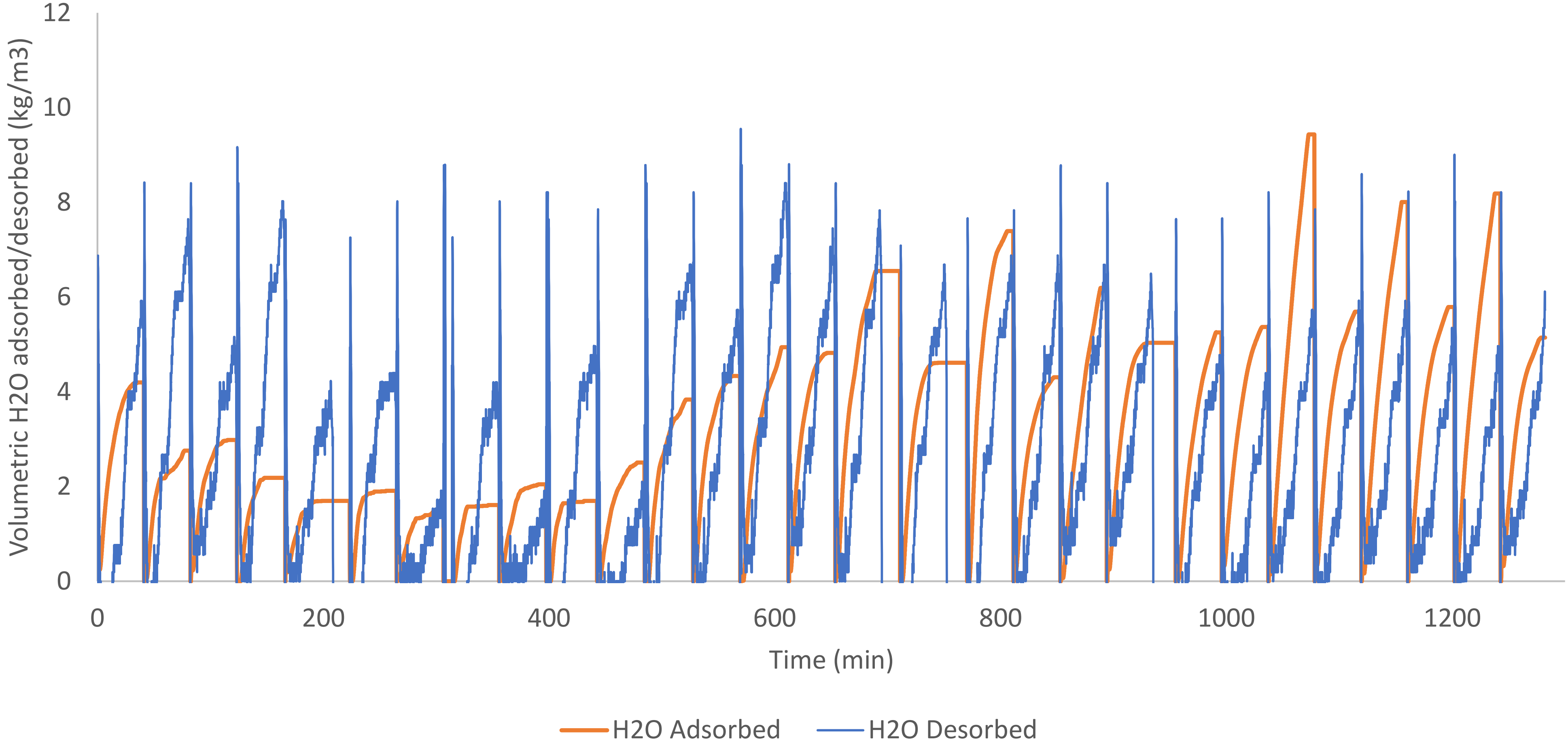
Consistent H_2O production rate over 30 cycles



- More water desorbed during initial cycles since AWE is saturated after being exposed to humid air overnight.
- Mass balance closure achieved after ~10 cycles (steady state operation).
- Average water production rate (9 kg/m^3/h) is within expected range.

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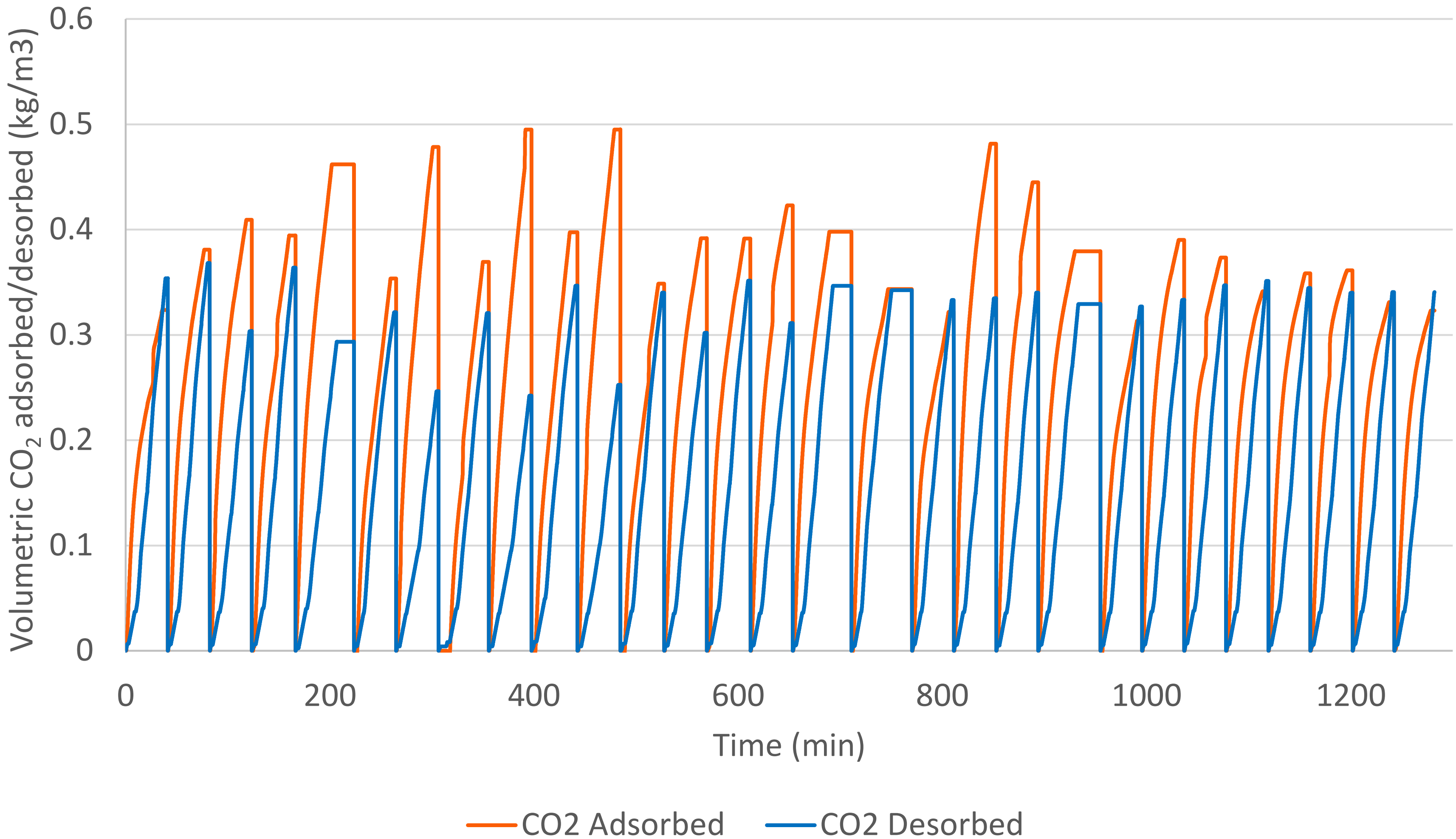
Consistent CO_2 production rate over 30 cycles



Average volumetric CO2 production rate of 0.5 kg/m^3/h is within expected range for packed bed contactor

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Lessons Learned

- **Hybrid Direct Air Capture successfully demonstrated!**
- AWE and MSA sorbents have working capacities in expected ranges.
- Improvement of the quality of the AWE contactors and cross-sectional uniformity of the water capture resulted in the improvement of water production rates by a factor 4.
- The initial MOF material (P/T swing) did not yield satisfactory results due to limitations on minimum vacuum pressure achievable.
- MSA materials have been operated successfully and provided performance in the range required for commercial implementation.
- Novel AWE and MSA materials will benefit from further development.

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Plans for future testing/development/ commercialization

Project Next Steps:

- Continued long term testing of automated cycles.
- Replace packed beds with structured sorbents.
- Preparation of updated project documents as per project milestone requirements.
- End of project as per 12/31/2024.

15X Scale-up Project:

- Underway with the Office of Naval Research.
- Construction to commence January 2025.

Commercial Scale Projects and Agreements have been secured under the commercial entity: AVNOS

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Acknowledgements

Project Team

Will Kain
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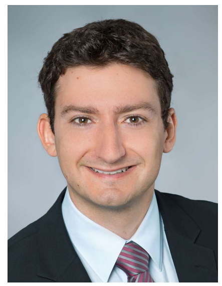
Ben McCool



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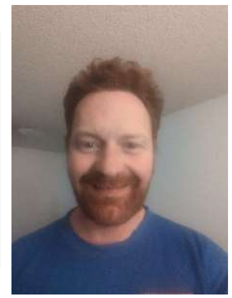

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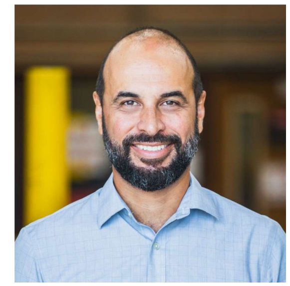

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Appendix

Revised IWVC HDAC PROJECT TIMELINE - GANTT CHART - February 2024