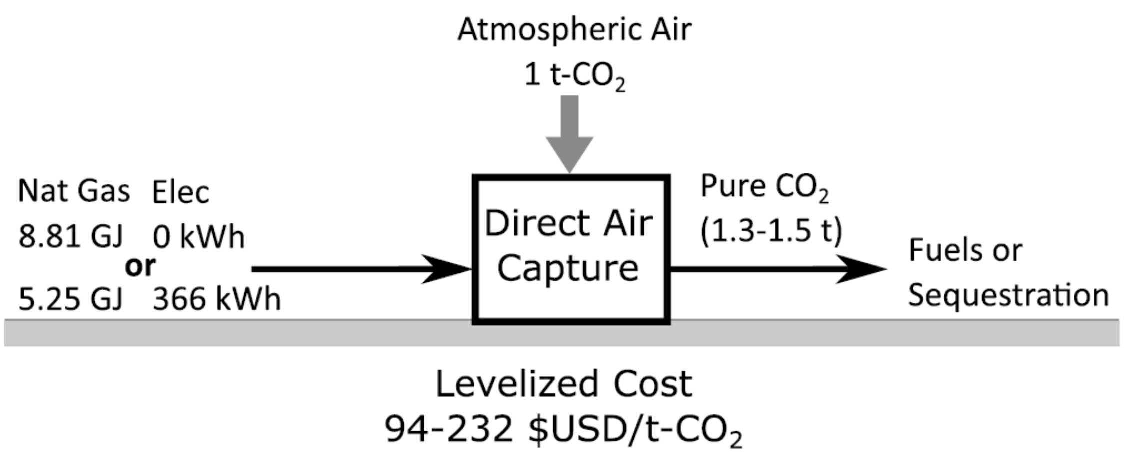
Demonstration of Regeneration Process and System Integration with a Greenhouse Enrichment for Direct Air Capture of CO2 with Building Air Handling Equipment (FWP-FEAA433)

Kashif Nawaz (nawazk@ornl.gov)

Motivation

- Direct Air Capture (DAC) is a critical framework for decarbonizing the energy sector
- Higher capital and operational costs are major barriers for the implementation
- An extensive amount of energy associated with the regeneration process

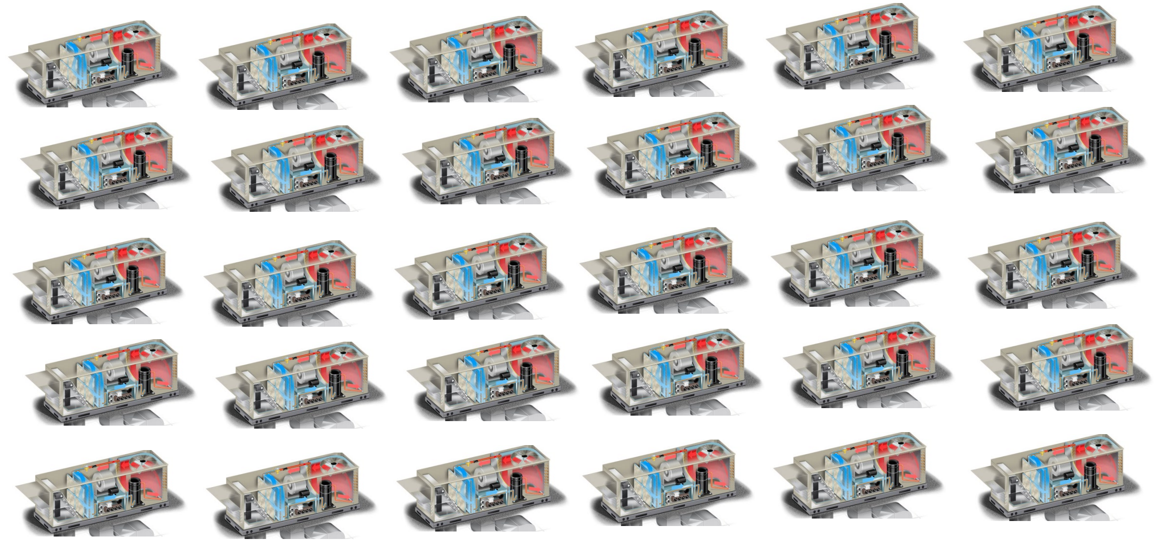
How do we **overcome barriers** associated with higher cost and extensive regeneration energy?



Keith, D.W., et al., *Joule*, 2018.

Motivation

- There are over 120M buildings (residential ~114M, commercial ~6M)
- Existing building equipment moves large amounts of air (blowers and fans)
- Large amount of low-grade heat provide an opportunity for onsite utilization

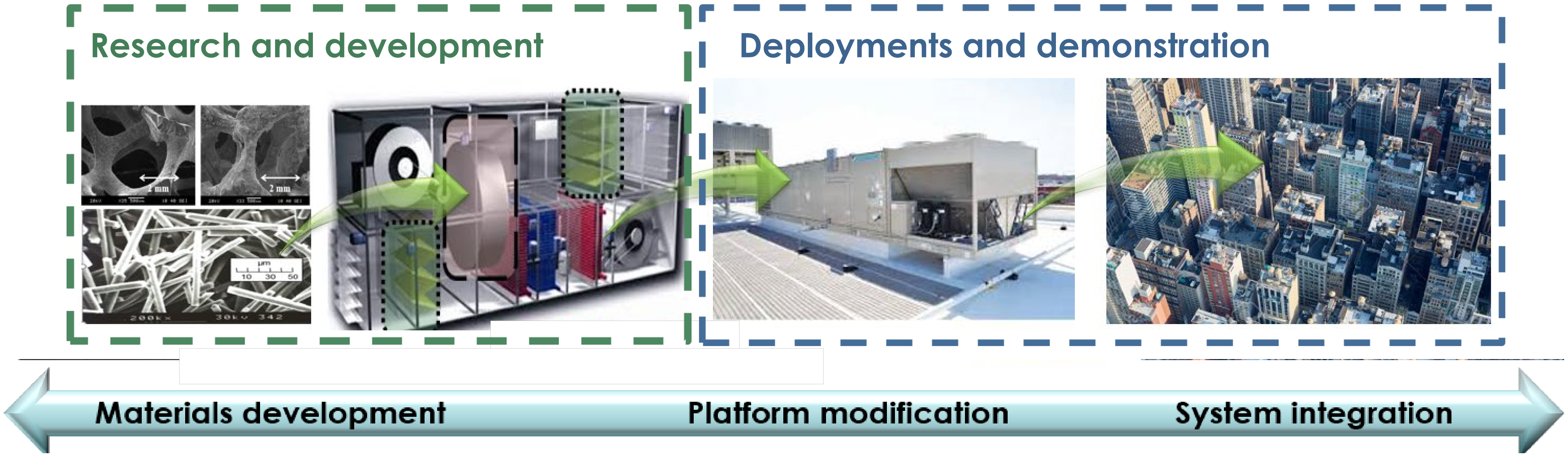


A multifunctional approach combining DAC to air conditioning/thermal management can provide a potential solution: Distributed Direct Air Capture (DAC)

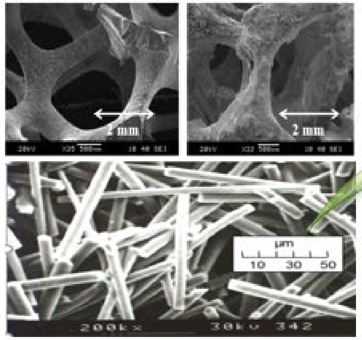
OAK RIDGE National Laboratory

Technical approach

- Highly modular and scalable technology
- Distributed deployment with minimal cost (capital and operation)
- Deployment issues (integration, control, etc.)
- Compatible materials development



Technical approach



Materials Development — Platform Modification — System integration — Distributed Network

Materials development and characterization

Air handler design analysis and modification

Process Control & Integration

Program Overview (Phase 1)

Timeline:

Start date: December 2020

End date: April 2023

Key Milestones

1. Preliminary feasibility analysis (December 2021)
2. Demonstration of scalable system (April 2023)

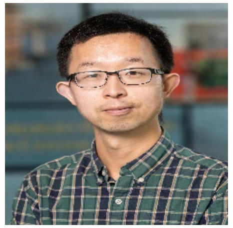
Project Objectives:

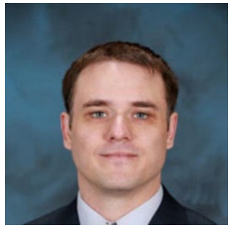
- Preliminary assessment of HVAC systems to accommodate DAC
- Development of appropriate materials and system design
- Demonstration of direct air capture using existing building equipment
- Quantification of the techno-economic impact

OAK RIDGE National Laboratory


Kashif Nawaz


Brian Fricke


Kai Li


Jamieson Brechtl


Steve Kowalski


Cheng-Min Yang


Keju An


Tugba Turnaoglu

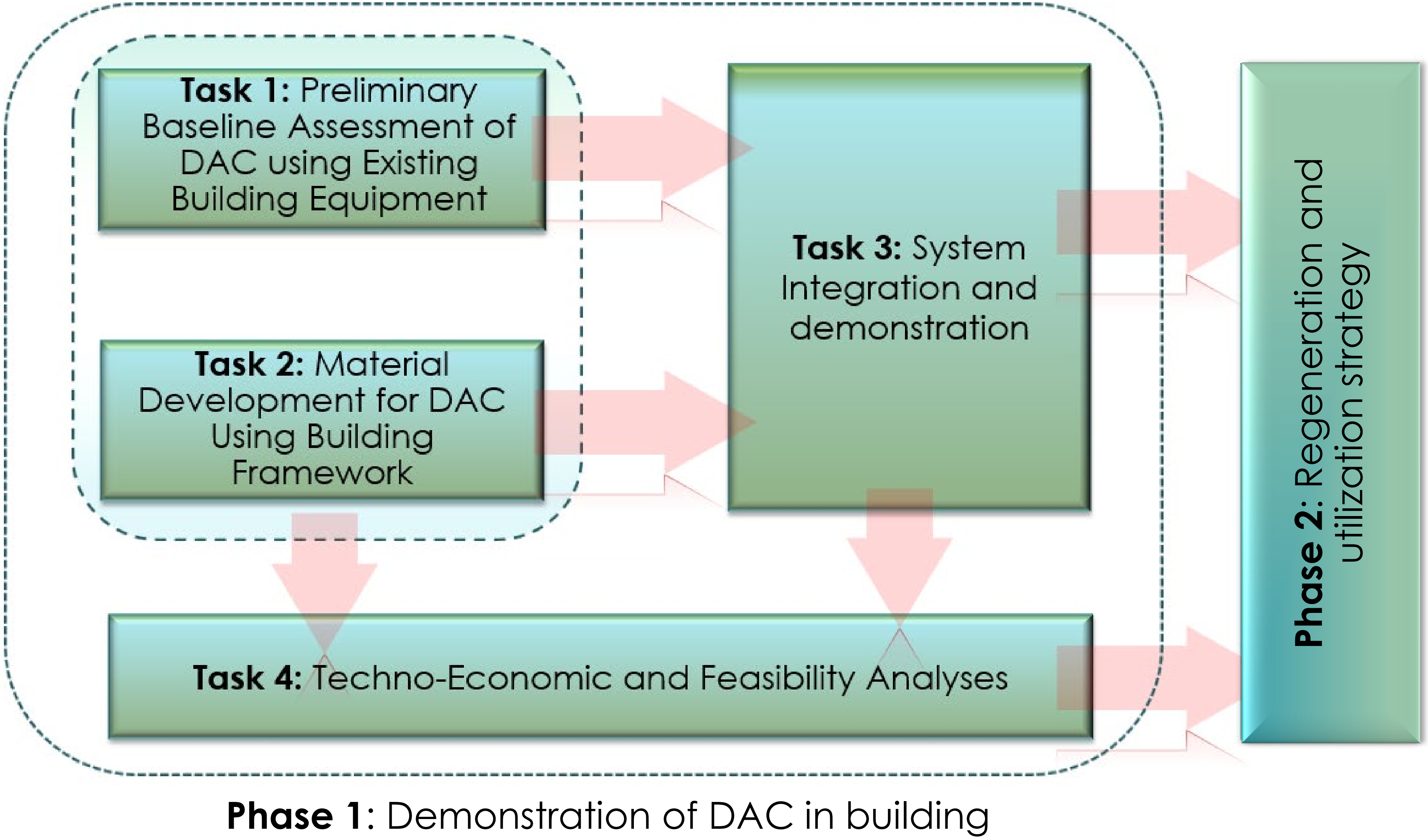

Michelle Kidder


Josh Thompson

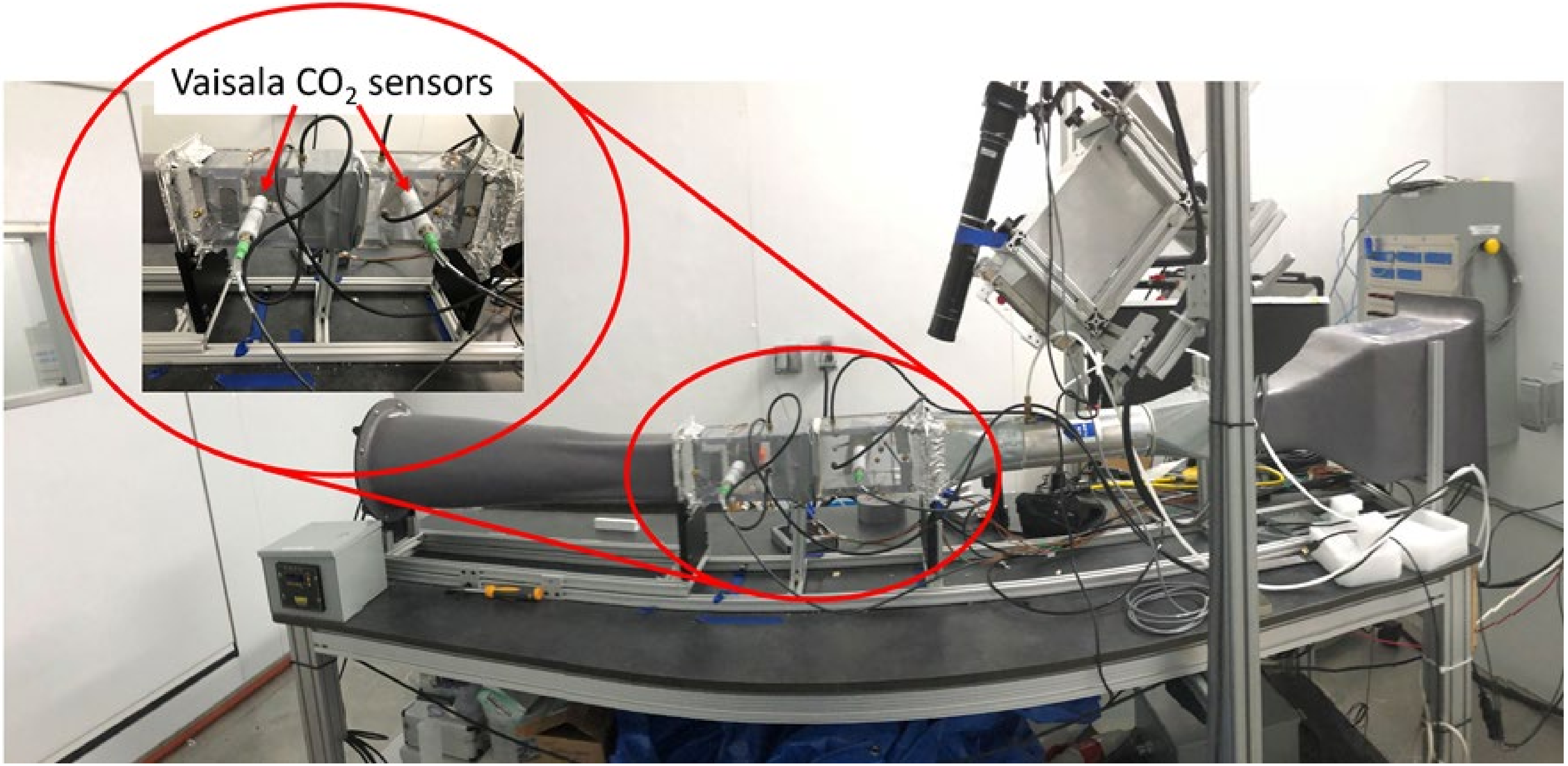

Chris Janke


Costas Tsouris

Project Overview



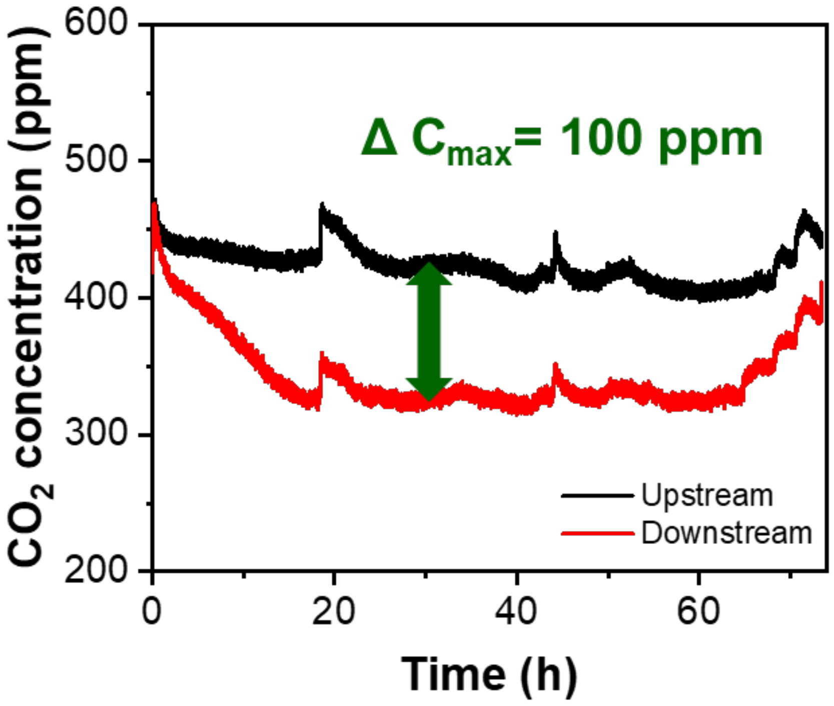
Performance Evaluation: Setup



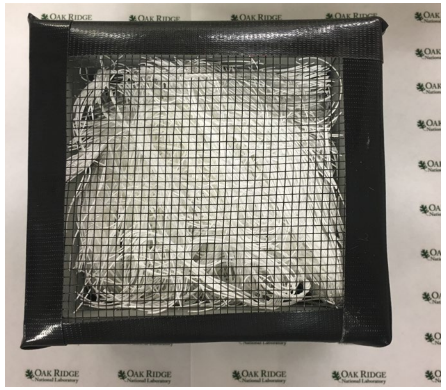
- A comprehensive test facility with a series of instrumentation
- Test setup to simulate any weather conditions- all climate zones in US and beyond
- One of its kind facility to test any DAC technology (at-scale, 4 " × 4 ")

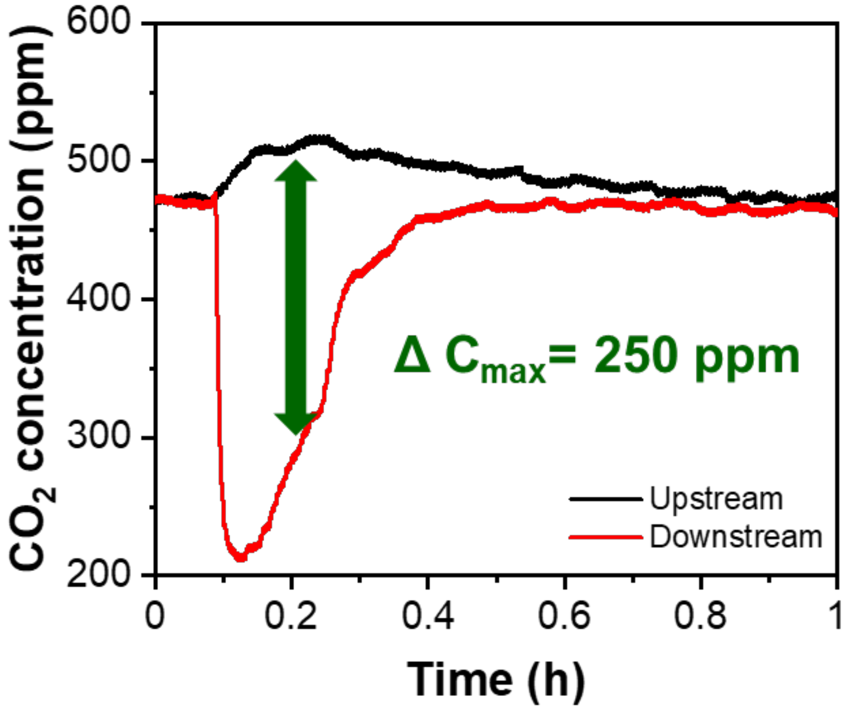
Performance Evaluation: Material comparison

- PAN-TETA
- 25 sheets
- 37.7% weight gain (72 h)
- 72.5 F, 68 RH%
- Material mass: 157.3 g



- Cellulose acetate-SiO2-PEI
- 18.8% weight gain (1 h)
- 72.5 F, 68 RH%
- Material mass: 48.1 g

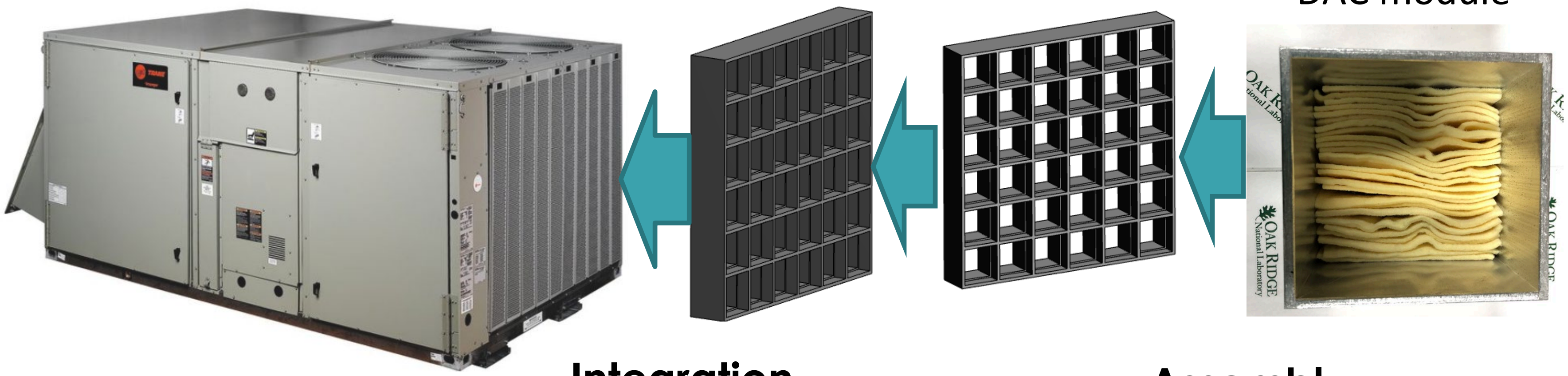




Different materials have different absorption behavior

System Integration (HVAC-DAC)

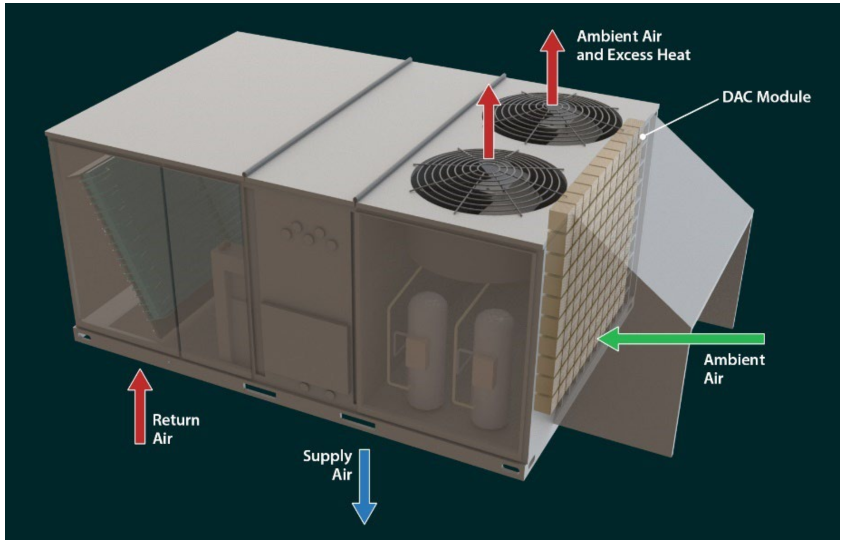
DAC module

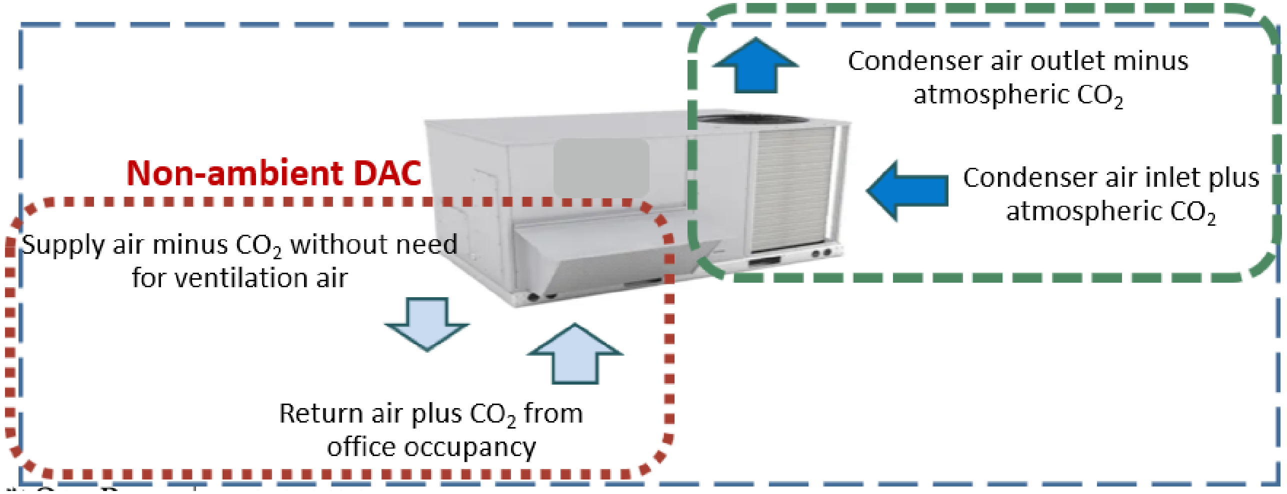


Integration

Assembly

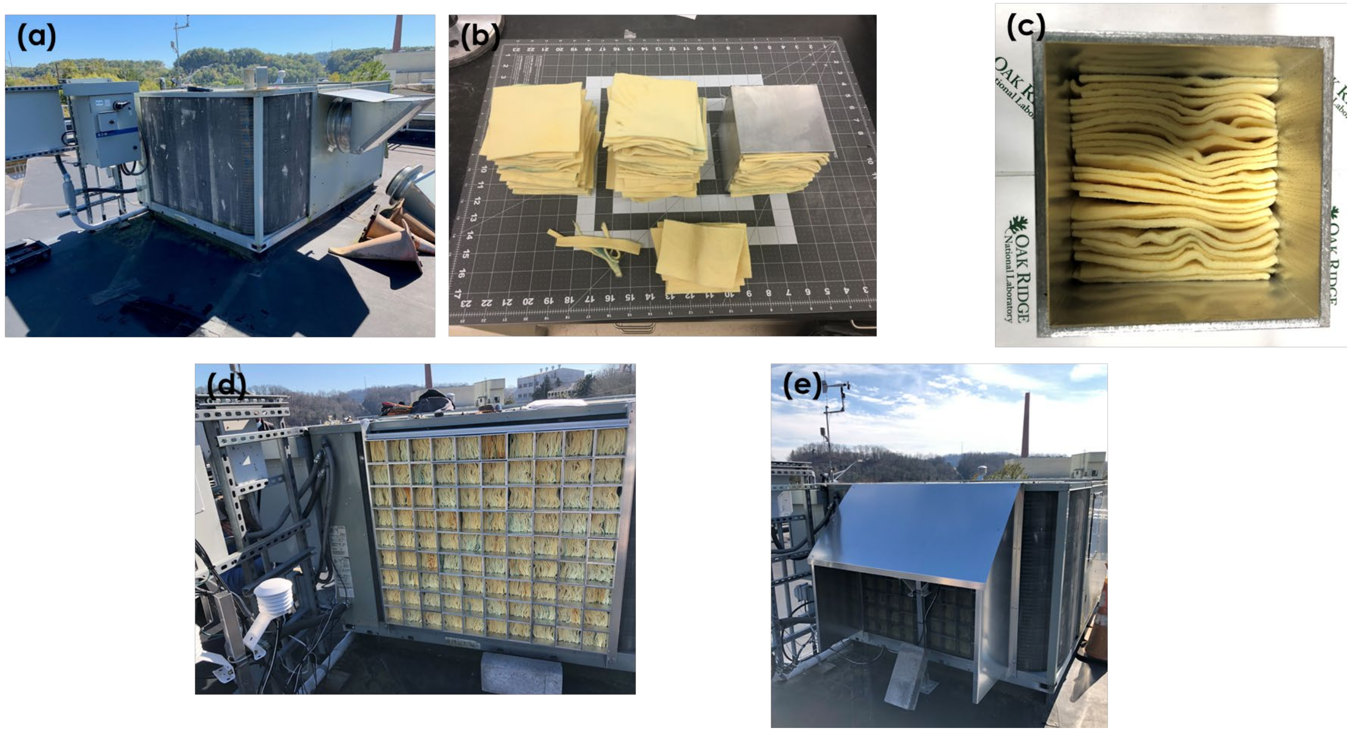
DAC framework



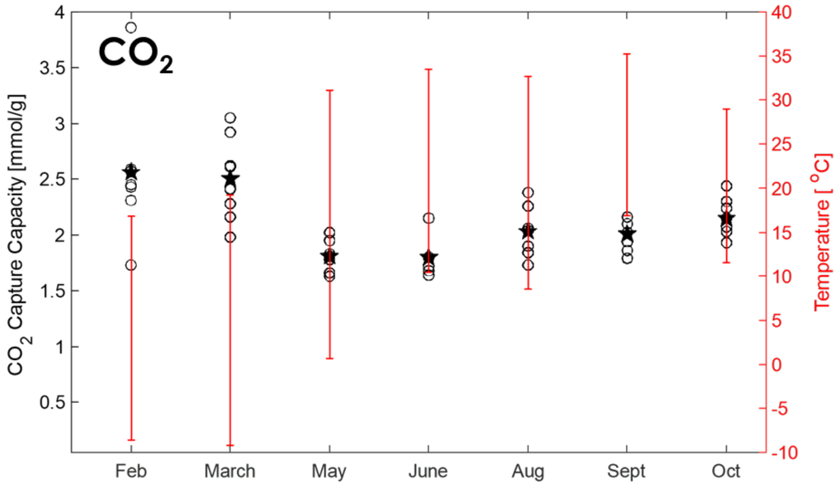


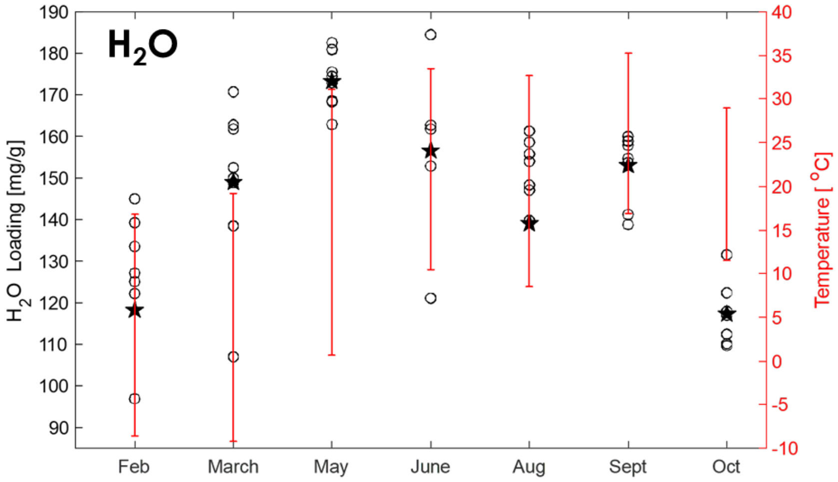
US 20230125924A1, Multi-functional equipment for direct decarbonization with improved indoor air quality

Deployment Case 1: Ambient DAC @ Rooftop Unit (RTU)



Deployment strategy

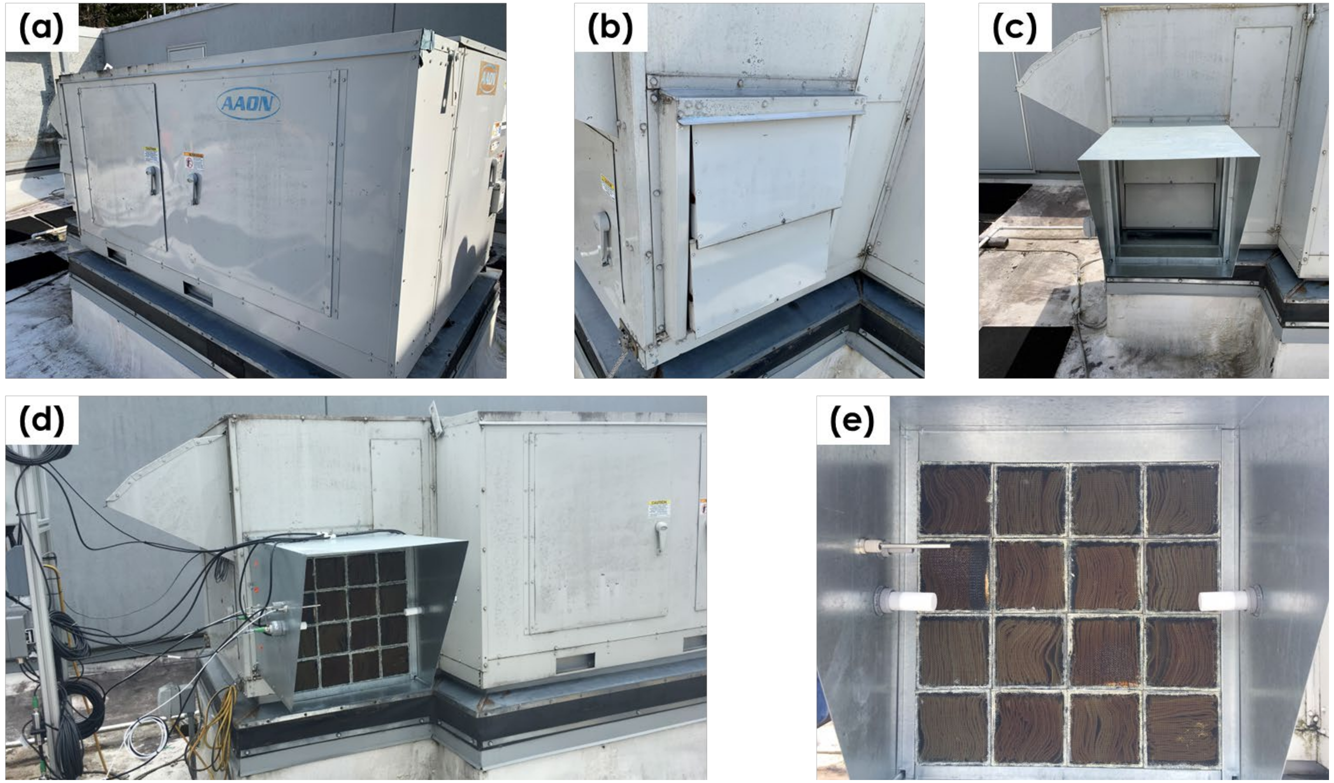




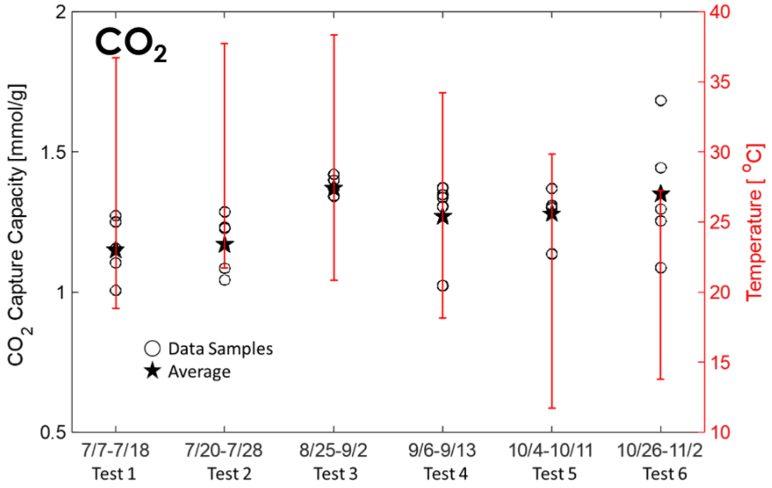
OAK RIDGE National Laboratory

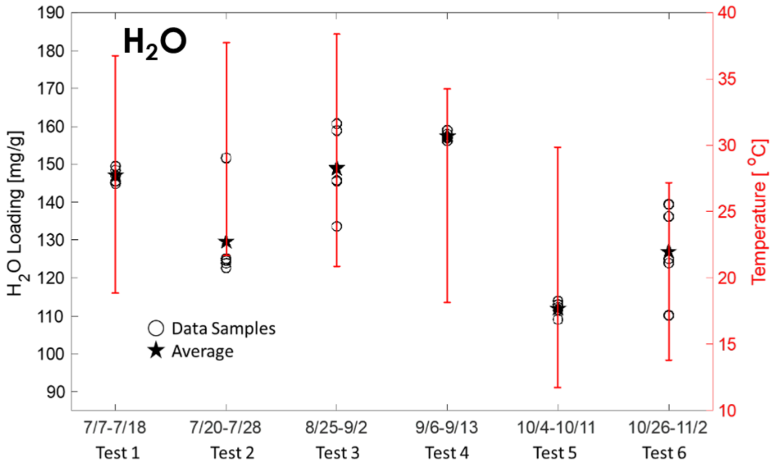
An, K., Nawaz, K., et al., *Environmental Science: Advances*, **2024**

Deployment Case 2: Non-ambient DAC (Makeup Air Unit)



Deployment strategy





Outcomes

Patents

- Multi-functional equipment for direct decarbonization with improved indoor air quality, US 20230125924A1
- Modified plasma treated porous carbon fiber for carbon capture with electrical current desorption, invention disclosure No. 81932771 (**Selected for provisional patent application**)

Journal papers

- Multifunctional Rooftop Unit for Direct Air Capture, Environmental Science: Advances, **2024**, DOI: 10.1039/D4VA00013G
- A Comprehensive Review on Regeneration Strategies for Direct Air Capture Journal of CO2 Utilization 2023, 76, 102587
- Direct air capture using triethylenetetramine functionalized polyacrylonitrile (In progress, Target journal: *Journal of Environmental Chemical Engineering*)
- PEI-grafted plasma treated carbon fiber for direct carbon capture (In progress, Target journal: Chemical Engineering Journal)

Presentations

(1) D-DAC Distributed direct air capture- A new paradigm of DAC technology, Carbon Capture, Utilization and Storage Gordon Research Conference, April 3-8, **2022**, Ventura, CA

(2) Demonstration of direct air capture (DAC) of CO_2 with building air handling equipment, Carbon Management Project Review Meeting, August 15-19, **2022**, Pittsburgh, PA

Program Overview (Phase 2)

Oak Ridge National Laboratory

Timeline:

Start date: March 2024

End date: February 2026

Key Milestones

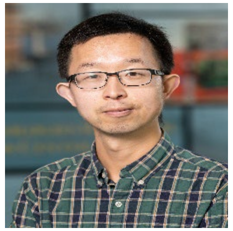
1. Complete the demonstration of the “on-site” regeneration (September 2025)
2. Complete the Techno-Economic Analysis (TEA) and Life Cycle Cost Analysis (LCCA) (February 2026)

Project Objective:

- Assessment of current sorbent regeneration strategies for DAC and their potential in building frameworks.
- Develop and demonstrate sorbent regeneration
- Develop appropriate materials and system design modifications to achieve an optimum regeneration process for DAC.
- Develop integration strategies for greenhouse enrichment using the captured CO2 in buildings.
- Quantify the techno-economic effect of the regeneration process and greenhouse enrichment integration.

Kashif Nawaz

Brian Fricke

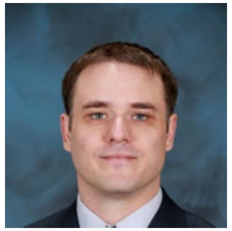


Kai Li

Poori Kashkouli

Steve Kowalski

Cheng-Min Yang



Jamieson Brechtl

Archana G.

Michelle Kidder

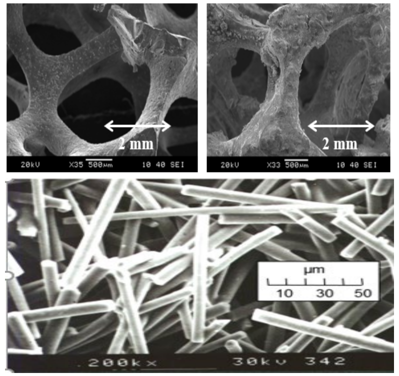
Chris Janke

Costas Tsouris

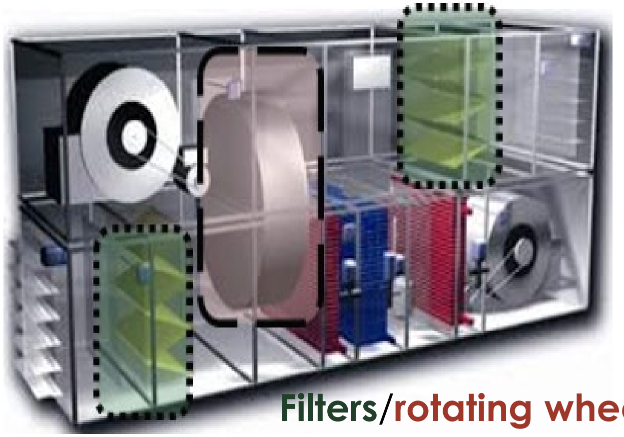
Frederic Vautard

Technical Approach

Materials development



Platform modification for regeneration

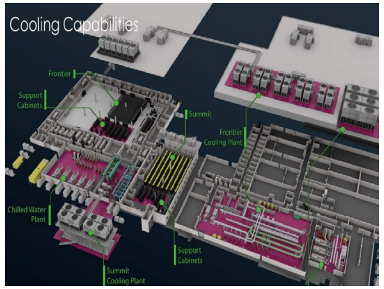


Filters/rotating wheels

System Integration

Greenhouse Enrichment

Building Equipment



ORNL Leadership Computational Facilitates

On-site Regeneration

- **Temperature swing**
  - **Joule heating**
  - **Steam**
  - **Microwave**
  - **Magnetic induction**
- **Moisture swing**
- **Pressure swing**
- **Electrochemistry**

Temperature and moisture swing are most used for solid DAC among various regeneration methods for DAC materials

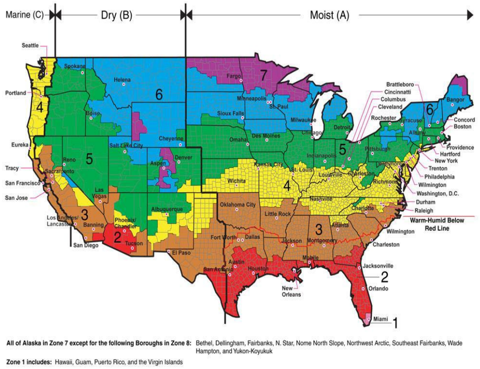
An et al., A comprehensive review on regeneration strategies for direct air capture, Journal of CO2 Utilization, 76, October 2023, 102587

On-site Utilization

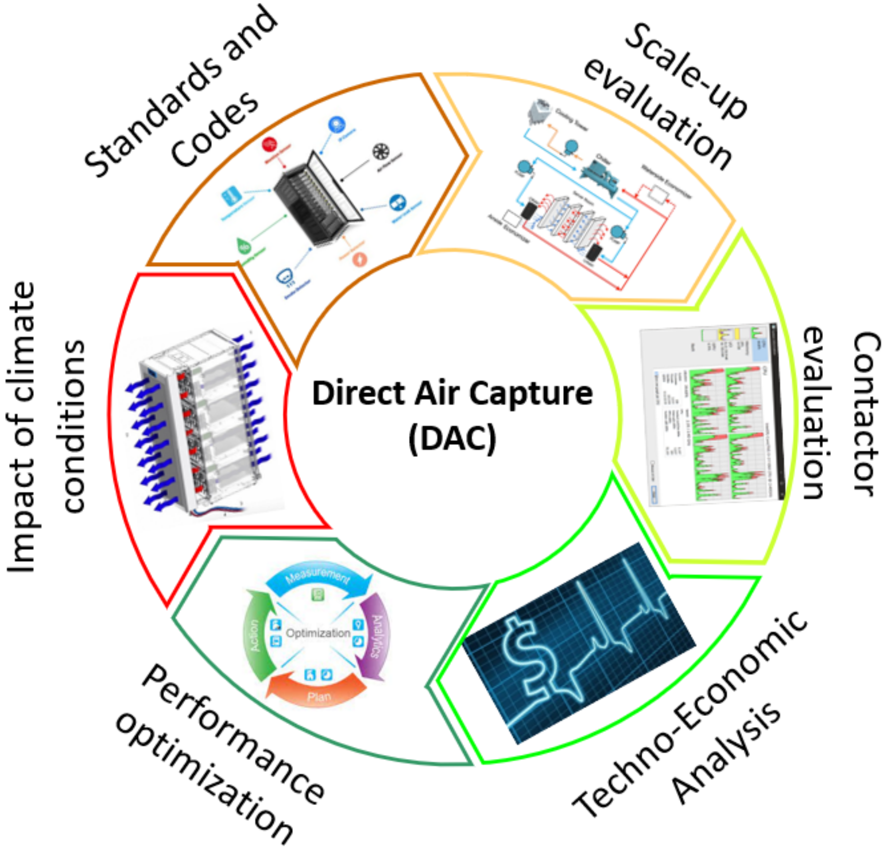
CO2 enrichment to 1000 ppm can almost double the yield!

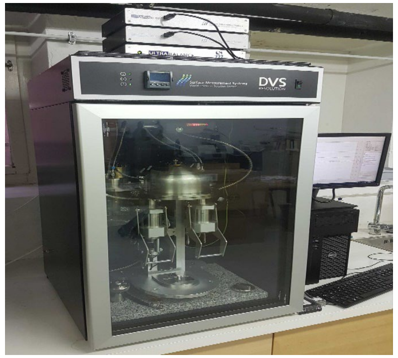
Development of Capabilities and Facilities

DAC in various
climate zones



National
climate data





Materials
characterization

Contactor
performance
evaluation

The developments have resulted in one-of-a-kind facilities. ORNL can test any DAC technology at scale under any climate condition

OAK RIDGE
National Laboratory

Acknowledgement

- Fossil Energy and Carbon Management Office (Andy Jones, Erika Bittner)
- NETL (Akhil Satesh)
- ORNL (Edgar Lara-Curzio, Michelle Kidder)
- ORNL staff

Thanks!

Kashif Nawaz
nawazk@ornl.gov