2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Commercial Space Cooling and Direct Air Capture System with Waste Heat Utilization

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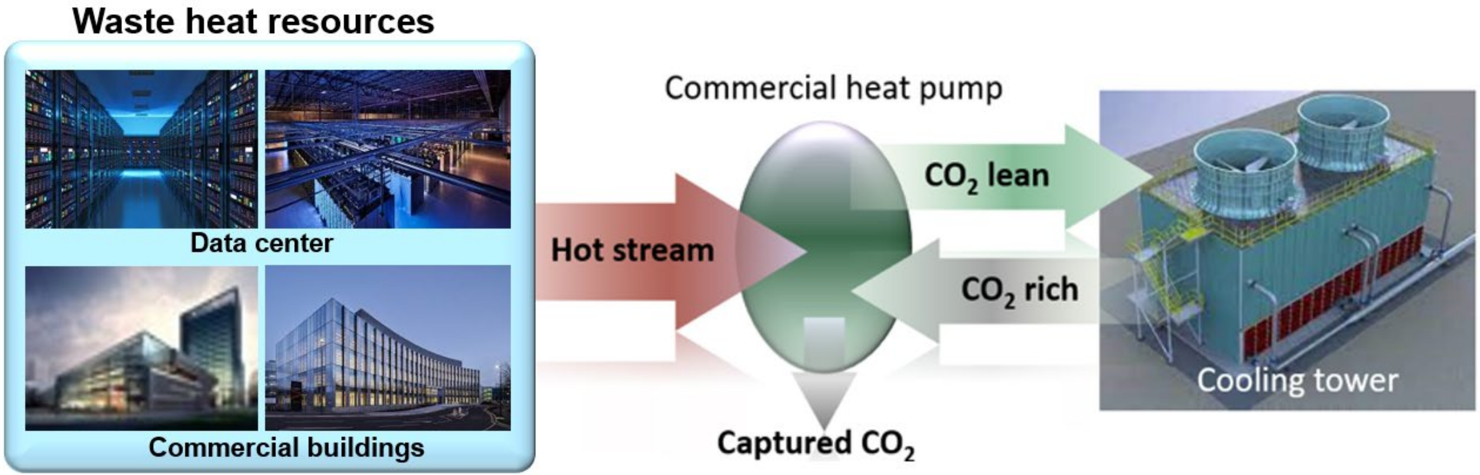

Oak Ridge National Laboratory
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WBS: 03.02.02.76

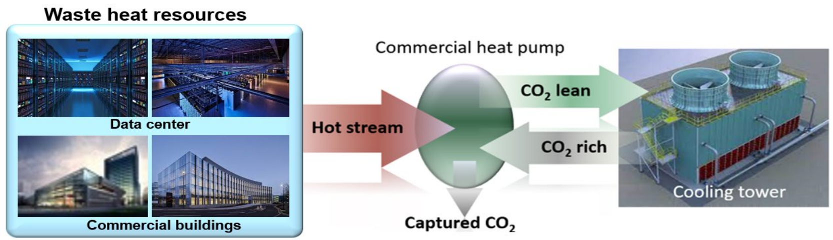
Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

Objective: Design, develop, and demonstrate a framework of onsite utilization of low-grade waste heat from commercial buildings for regeneration of direct air capture of CO_2

Outcome: Demonstration of direct air capture with cooling tower platform and onsite regeneration

Impact: Led to 50% reduction in direct and indirect emissions from the commercial building sector, ensuring a reduction of at least 30 MT of CO_2 emissions



BALTIMORE AIRCOIL COMPANY
BLUE by nature - GREEN at heart

University of Pittsburgh

Southern Company

TEAM AND PARTNERS

Oak Ridge National Laboratory:
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STATS

Performance Period: FY24, DOE budget: $1,750k

Milestone 1: Establishment of CRADA partnership

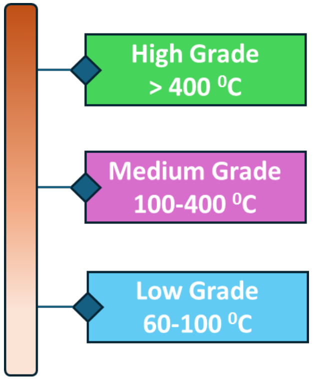
Milestone 2: Characterization of waste heat and upgradation feasibility analysis

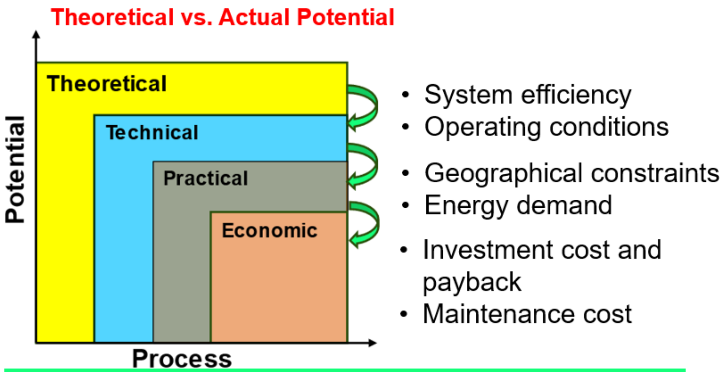
Milestone 3: Lab-scale evaluation of an integrated regenerated approach (30 kW)

Milestone 4: Field demonstration of 100 kW or higher capacity

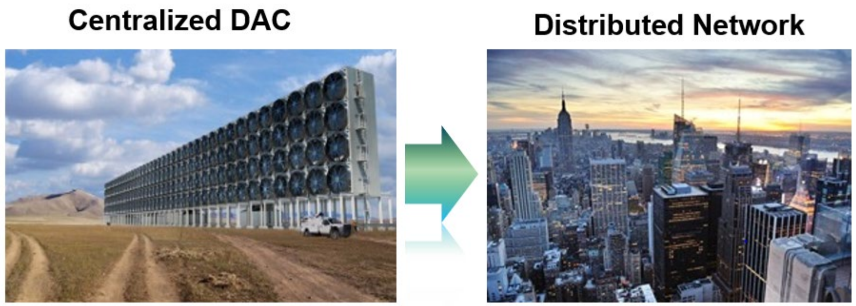
Problem

- Extensive amount of energy is released as "waste heat" from buildings
- Direct air capture (DAC) has been noted as a major initiative for decarbonization
- Dedicated DAC systems have extensive capital and operational costs
- >250,000 cooling towers have been installed in the US
- Existing building infrastructures like cooling towers can enable a distributed DAC





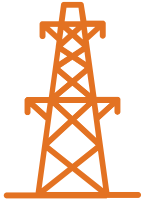
Theoretical Potential = Mass Flow Rate × Enthalpy



Alignment and Impact

- The project will lead to at least a 50% reduction in direct and indirect emissions from the commercial building sector, ensuring a reduction of at least 30 MT of CO_2 emissions
- The DAC system enabled by the proposed framework will result in at least a 40% reduction in capital and operational costs, compared with the costs of dedicated DAC frameworks
- The project directly supports the DOE Building Technologies Office's Energy, Emissions, and Equity (E3) Initiative
- Based on preliminary estimates, the proposed framework for waste heat recovery will ensure at least 20% utilization of waste heat that would otherwise be rejected into ambient air

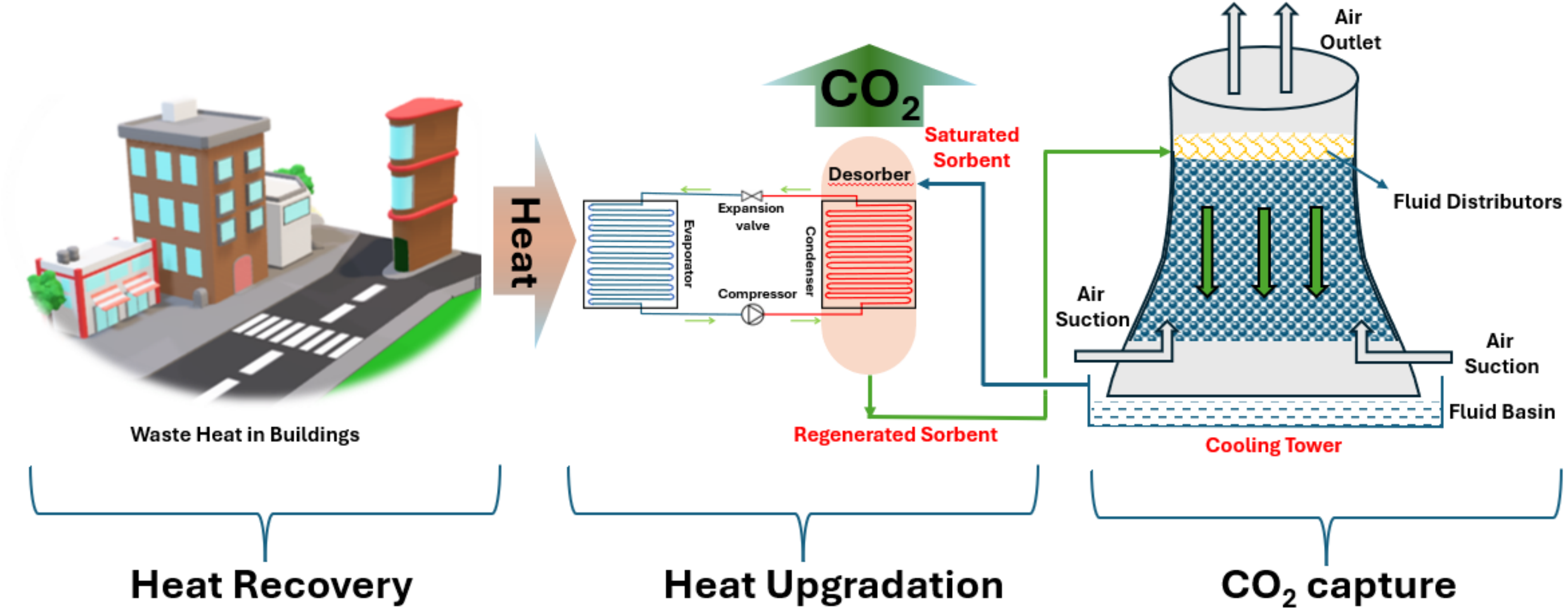
GHG emissions reductions



Power system decarbonization

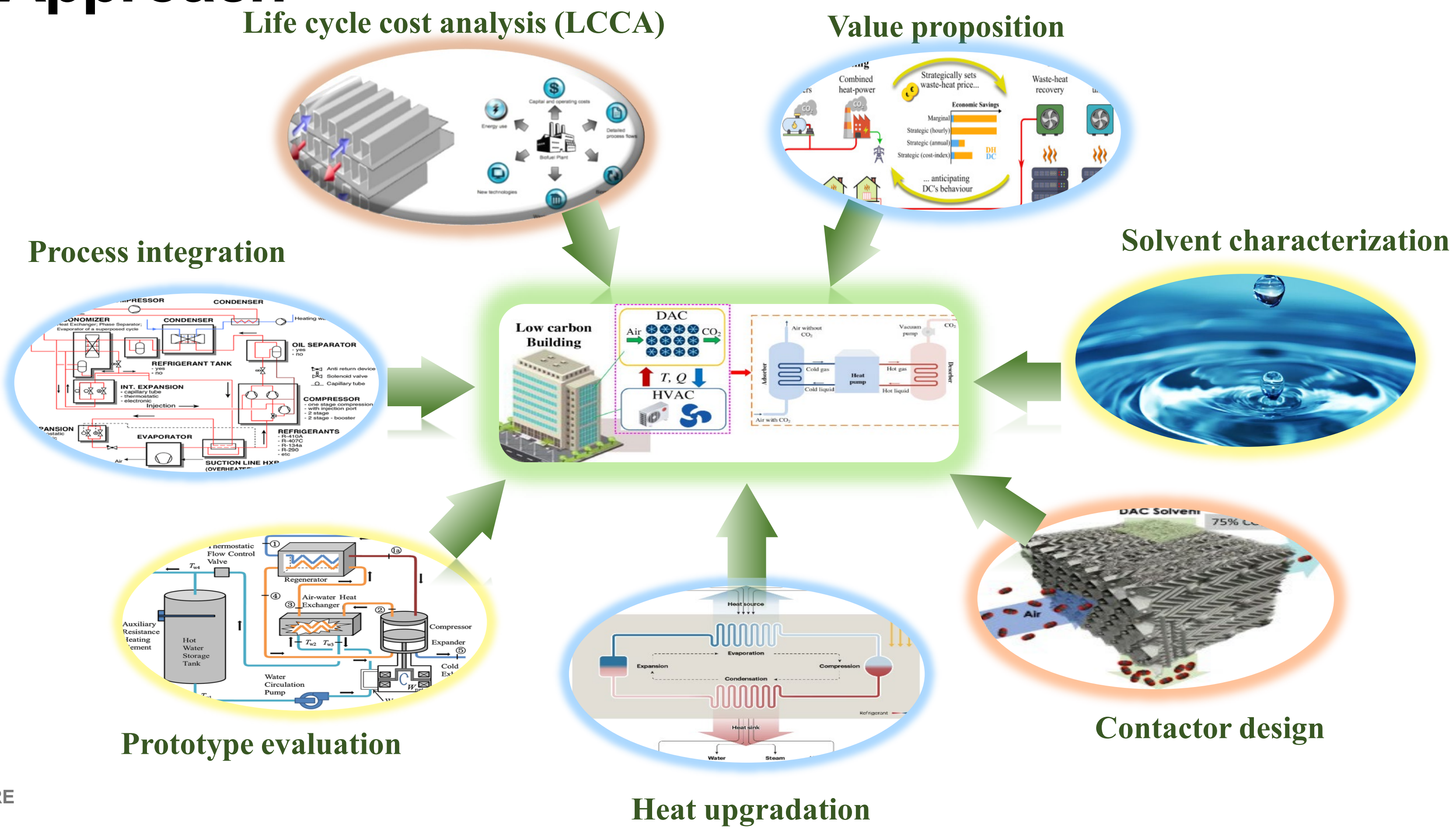
Energy justice

Approach



Heat
Evaporator
Expansion valve
Compressor
Condenser
Desorber
CO_2
Saturated Sorbent
Regenerated Sorbent
Air Outlet
Fluid Distributors
Air Suction
Air Suction
Fluid Basin
Cooling Tower
Waste Heat in Buildings
Heat Recovery
Heat Upgradation
CO_2 capture

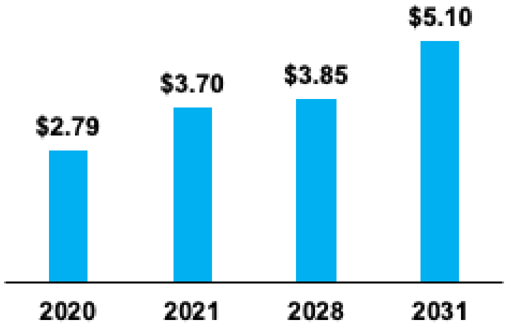
Approach

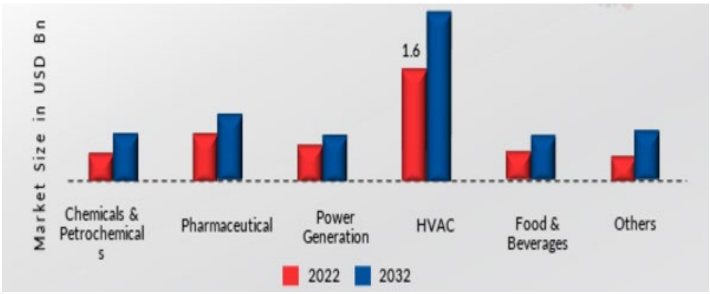

Life cycle cost analysis (LCCA)
Value proposition
Process integration
Solvent characterization
Low carbon Building
DAC
HVAC
Prototype evaluation
Heat upgradation
Contactor design

Progress

Market analysis

- The global cooling towers market was valued at $2.79B in 2020
- The market is expected to reach value of US$5.1B by the end of 2031
- It is estimated to grow at CAGR of 3.4%–4.5% from 2020 to 2031
- Power generation and HVAC have the largest market share
- Key market players
  - Baltimore Aircoil Company Inc., Brentwood Industries Inc., Babcock & Wilcox Enterprises Inc., Johnson Controls, and others





Source-Market research future

Progress

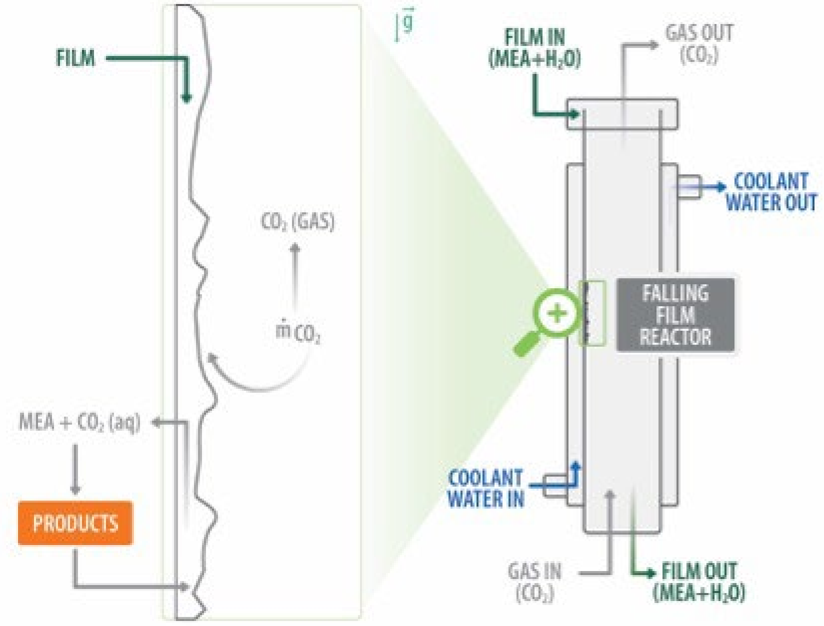
Computational Fluid Dynamics Model

Several physical processes are taking place in a carbon capture contactor
Challenge: Modeling the complex dynamic of the fluid-gas interface is extremely computationally expensive

Turbulent flow and solvent-gas interactions (shear stripping, heat transfer)

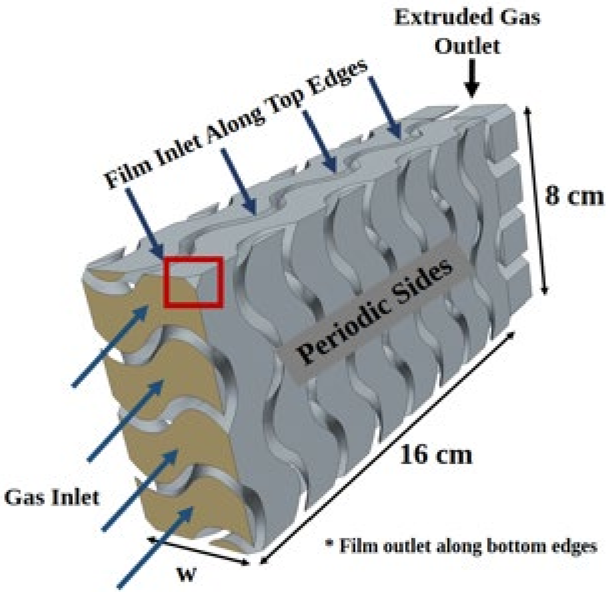
Solubility: Mass transfer of CO_2 from gas phase to liquid phase

Homogeneous reactions: CO_2 reacts with solvent to produce products

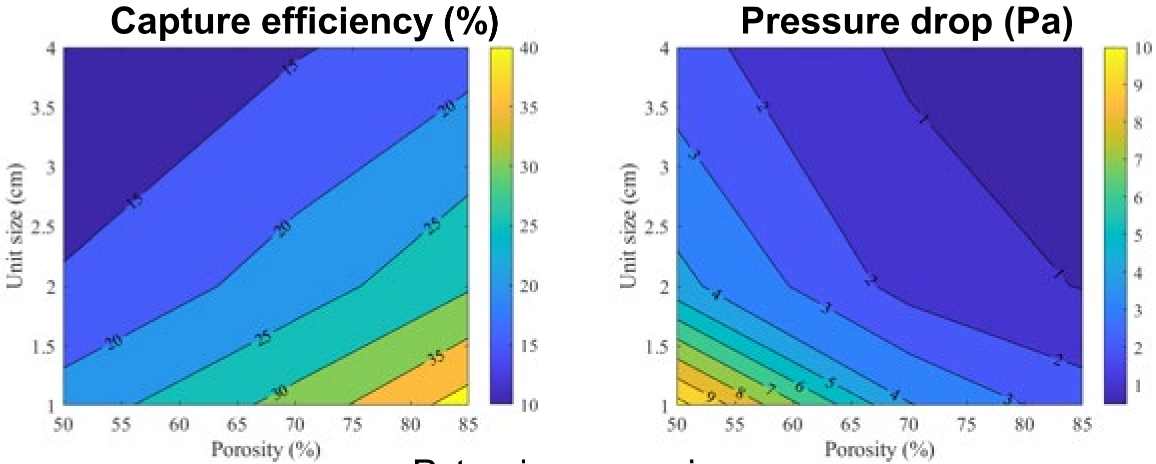


Progress

CFD Modeling on TPMS Contactor



- Porosity and cell size parametric study is conducted for both MEA and potassium sarcosine
- Small unit cell with high porosity offers maximum efficiency with small pressure drop

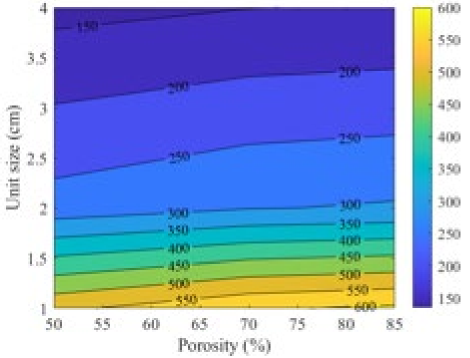


Potassium sarcosine

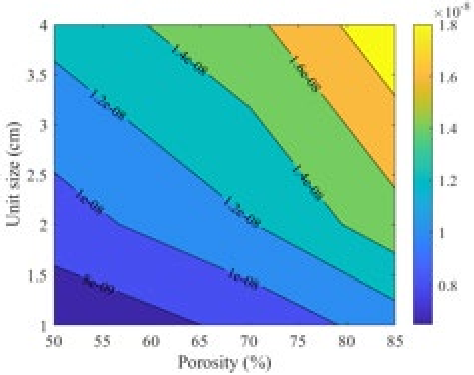
Progress

CFD Modeling on TPMS Contactor

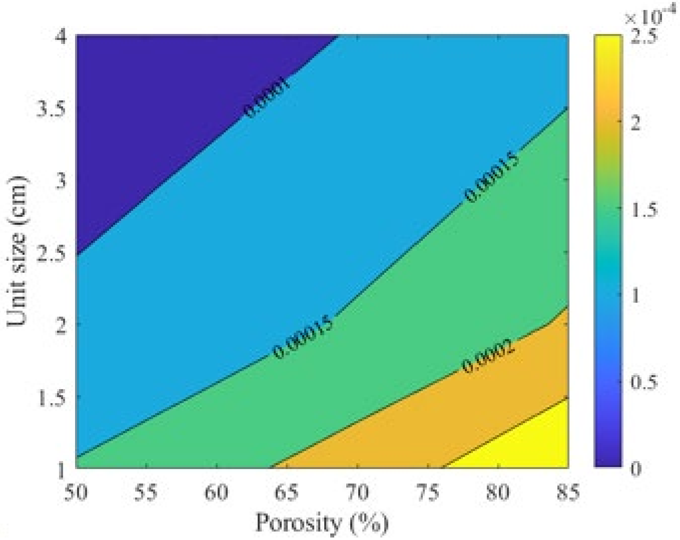
TPMS specific surface area (m^2/m^3)



Interfacial mass transfer rate $(\frac{kmol}{m^2 s})$



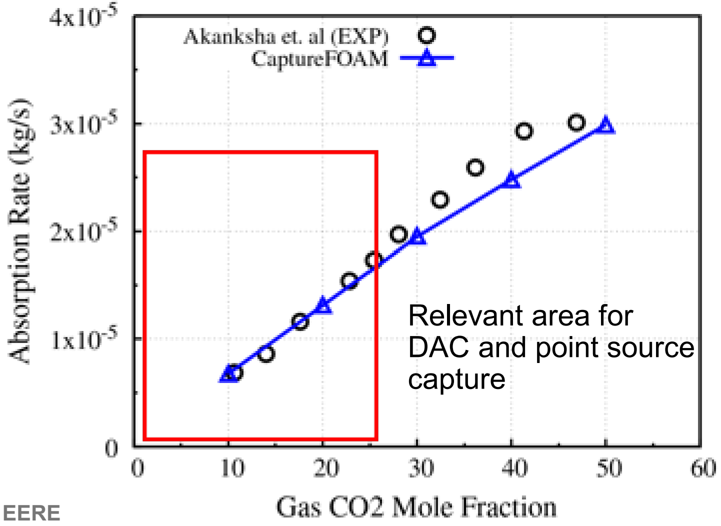
- Both TPMS surface area and interfacial mass transfer increase with increasing porosity
- TPMS surface area varies by around 4× over the tested range of parameters, thus governing the efficiency behavior



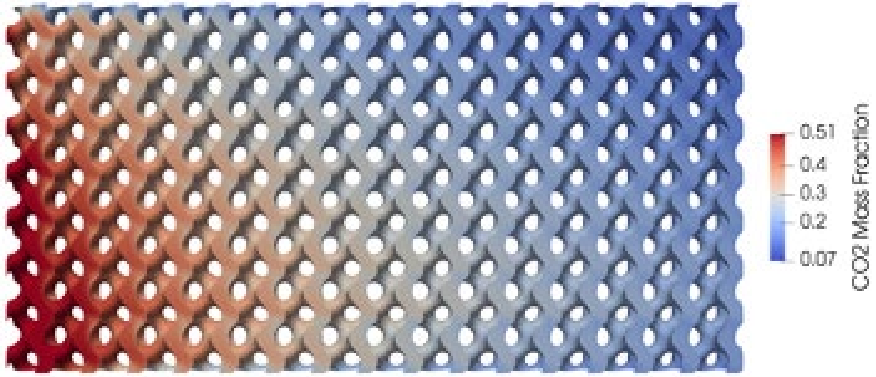
Progress New Model for Carbon Capture

- DAC model implementation in OpenFOAM will allow larger-scale simulations
- New mass transfer model CaptureFOAM was developed and validated

Validation against falling film tube experiment



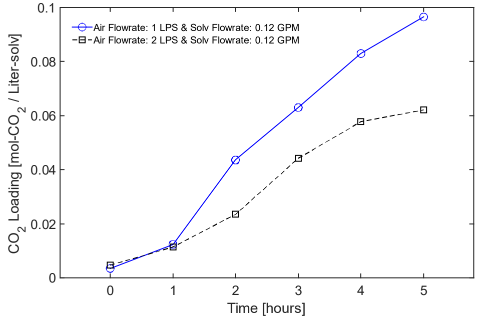
Model tested for gyroid geometries

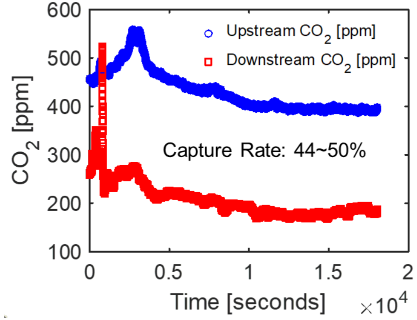


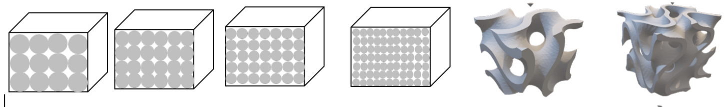
Progress

Contactor Evaluation

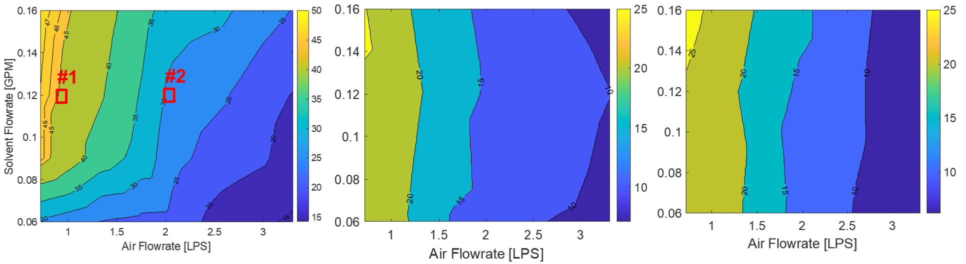
- Design and tested various contactor configuration
- Develop various prototypes
- Optimize parameters based on specific design and configuration







	Packed Bed #1	Packed Bed #2	Packed Bed #3	Packed Bed #4	Gyroid	Fischer Kosh
Particle size/ Unit cell size	0.375 inch	0.3125 inch	0.25 inch	0.156 inch	0.4 inch	0.4 inch
Voidage	0.4	0.363	0.375	0.375	0.7	
Total Number of balls/unit cells	1615	2981	5706	13002	1052	751
Specific Surface Area [m²/m³]	375	457	578	904	579	
Actual Surface Area [m²]	0.48	0.58	0.74	1.15	0.74	

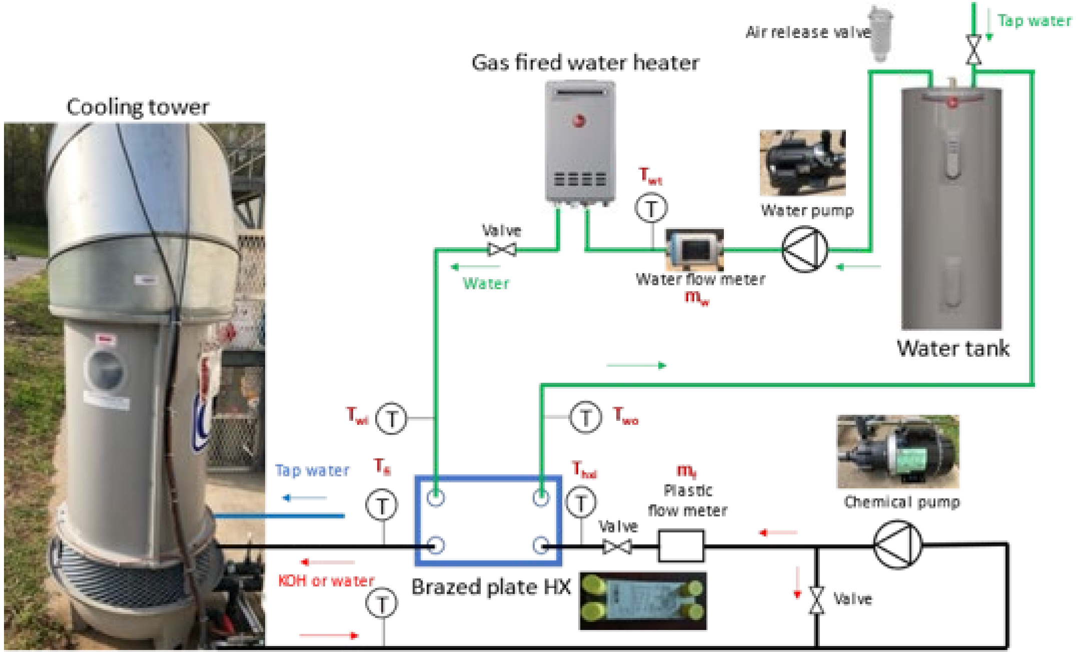


Contour plots showing removal rate based on flow rates for various contactor designs

An, et al., AIChE J., 2024, e18429.

Progress Prototype Development

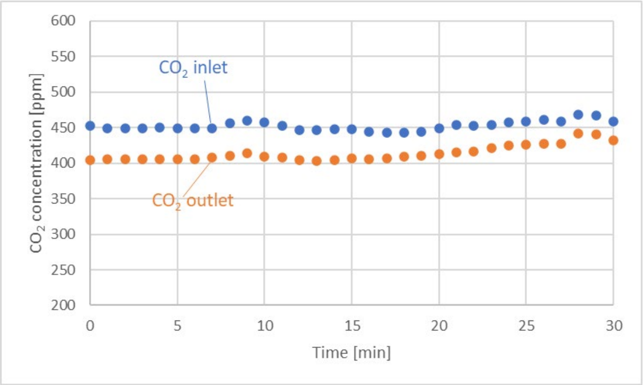
- Developed a process model and identified various components for sustainable operation
- Building prototype cooling tower facility
- Developed framework for baseline analysis
- Scaling up the cooling tower and building a regeneration device
- Acquired equipment and developed instrumentation



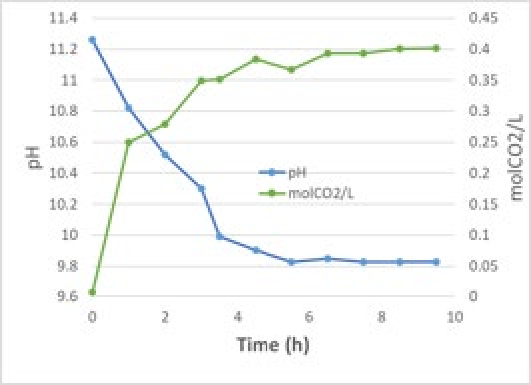
Progress

Carbon Capture Performance

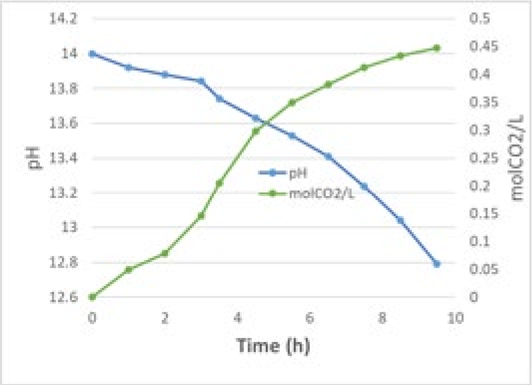
- Both solvents demonstrated capability to capture CO_2 from air using cooling tower
- ~50 ppm CO_2 difference was observed from upstream and downstream
- pH reduces with increase of CO_2 loading
- K-sarcosine has faster reaction kinetics than KOH and can capture 1 kg every 6 h



K-Sarcosine



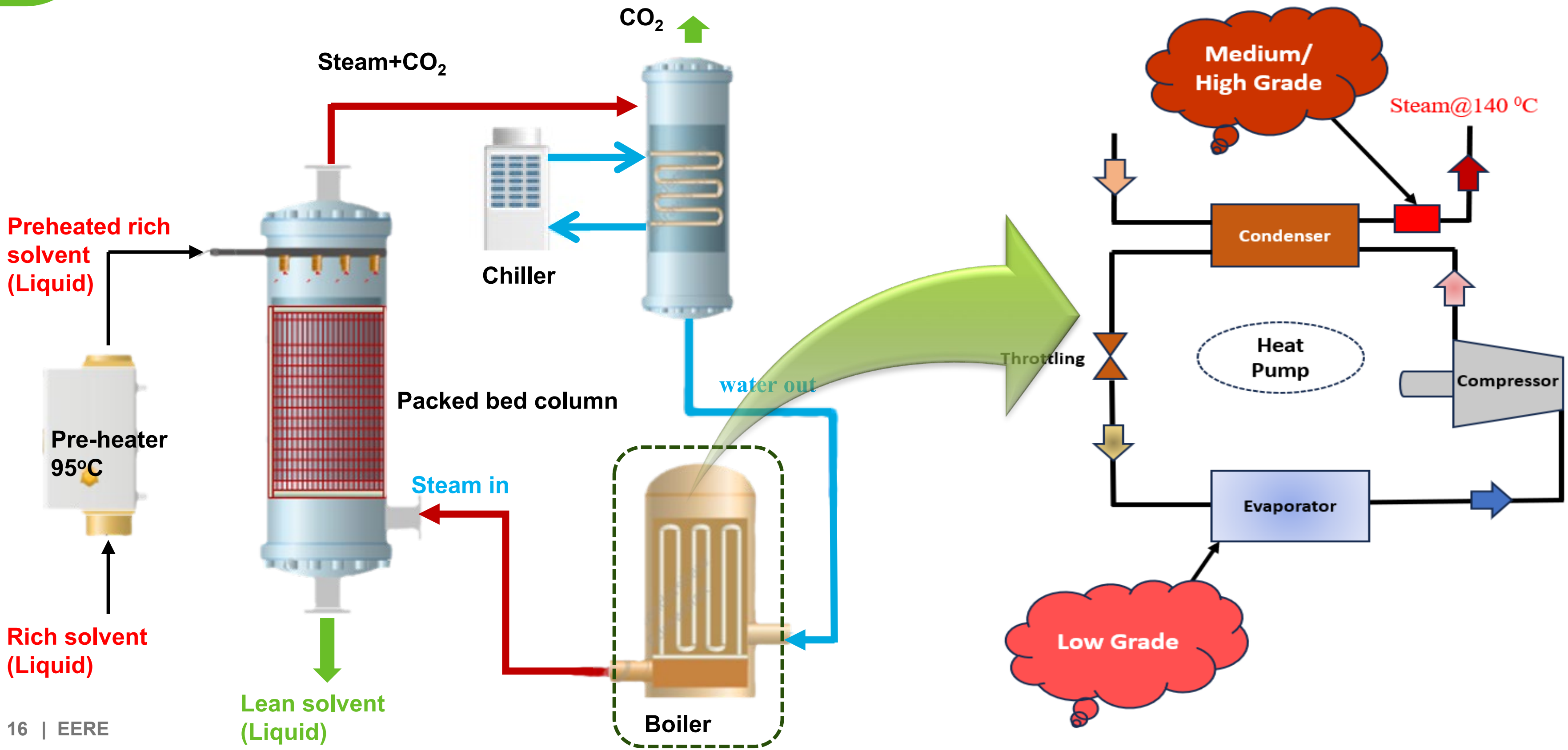
K-Sarcosine



KOH

Progress

Regeneration with Steam



Outcomes

- Presentation
  - “Numerical assessment of triply periodic minimal surface packings for solvent-based carbon capture,” 18th International Conference on Energy Sustainability, ASME 2024
- Publications
  - K. An, K. Li, C. M. Yang, J. Brechtl, D. Stamberga, “Direct air capture with amino acid solvent: Operational optimization using a crossflow air-liquid contactor,” *AIChE J., 2024, e18429.*
  - F. D. F. Chuahy, K. Kincaid and K. Nawaz, “A thin-film modeling approach for analysis of carbon capture sorbent-based devices,” *Carbon Capture Science & Technology, 2023,* 9, 100134.
  - “Numerical assessment of triply-periodic minimal surfaces for direct air capture of carbon dioxide” (in preparation).
  - “Intensified direct air carbon capture through a cooling tower” (in progress).
- Intellectual Property
  - “Intensified carbon capture using building infrastructure,” US20230130721A1.

Thank you

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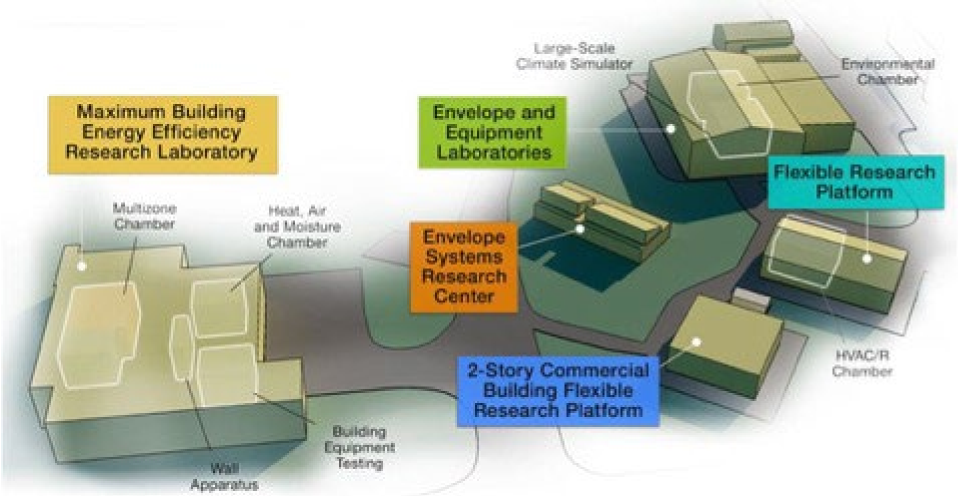


The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

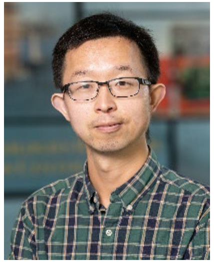
Reference Slides

Project Execution

	FY2024				FY2025				FY2026			
Planned budget	1,000,000				1,000,000				1,000,000			
Spent budget	750,000				750,000							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Evaluation of current procedures and value proposition for existing commercial air conditioning systems, various cooling tower platforms has been completed and their suitability for accommodation of absorbent solutions for direct air capture is established		◆										
Q2 Milestone: An experimental facility has been developed and is operational to analyze performance at prototype scale and a manuscript has been developed focused on numerical evaluation of DAC using absorbent			◆									
Q3 Milestone: Analysis and evaluation of various waste heat resources and associated carbon footprints have been determined, analysis of potential for recovery and upgradation through a heat pump system. The compliance potential of the proposed framework to support the electrification initiative has been established				◆								
Q1 Milestone: The requirements for regeneration process for the absorbent for direct air capture system have been established and requirements for direct use of waste heat as well potential for upgradation have been analyzed					◆							
Current/Future Work												
Q3 Milestone: Based on the process requirements appropriate framework has been developed for system integration, the performance of the overall system has been simulated accounting for various climate zones.							◆					

Team

Kashif Nawaz
Distinguished R&D Staff



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