Demonstration of direct air capture (DAC) of CO_2 with building air handling equipment

FWP-FEAA156

Kai Li

PI: Kashif Nawaz, nawazk@ornl.gov

Oak Ridge National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management Project Review Meeting

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Program Overview

Timeline:

Start date: December 2020

Planned end date: December 2022

Key Milestones

1. Preliminary feasibility analysis (December 2021)
2. Demonstration of scalable system (December 2022)

Budget:

DOE: $1,400,000

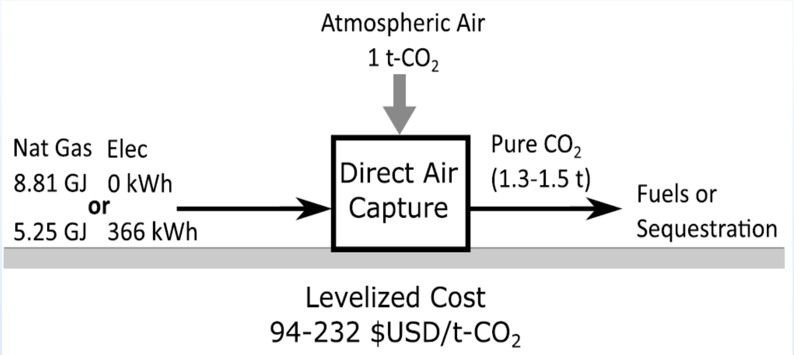
OAK RIDGE National Laboratory

Building Technologies and Research Integration Center (BTRIC)

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

Technology Background



Levelized costs of $94 to $232 per ton CO_2 from the atmosphere (2018)

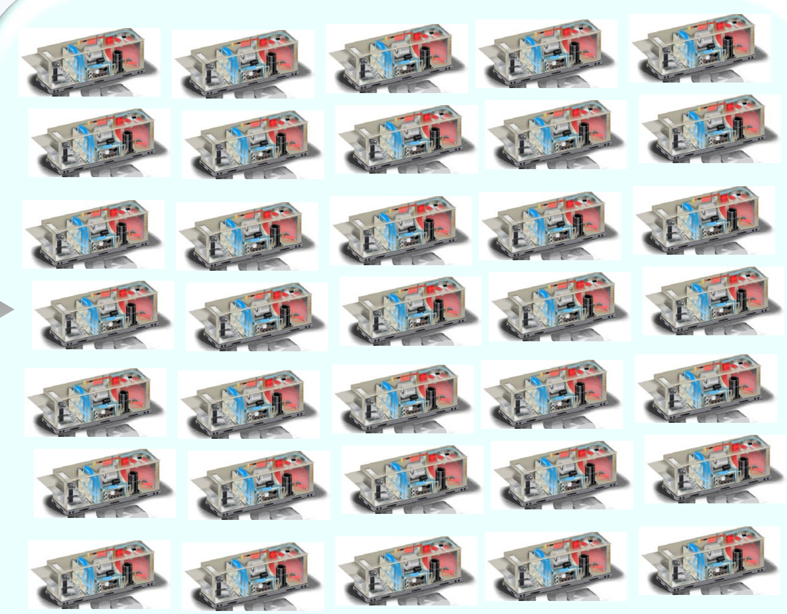
- Centralized DAC is an expensive technology
  - Logistics support (infrastructure)
  - Air movers (blowers)
  - Regeneration (heat, mechanical energy)
- There are over 120 Million buildings across the US
- Air handling infrastructure can enable a distributed DAC

[1] Keith, D.W., et al., Joule, 2018.

Technology Background

Centralized

Distributed



- Develop a highly modular and scalable technology for CO_2 capture
- Distributed deployment with minimal cost (capital and operation)
  - Deployment issues (integration, control, etc.)
  - Compatible materials development

Technical Approach

Materials development and characterization

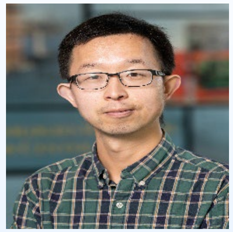
Air handler design analysis and modification

Process Control & Integration

Team and Facilities

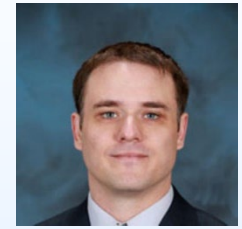

Kashif Nawaz


Brian Fricke


Kai Li


Keju An


Steve Kowalski


Jamieson Brechtl


Cheng-Min Yang


Yarom Polsky


Xin Sun


Tugba Turnaoglu


Michelle Kidder

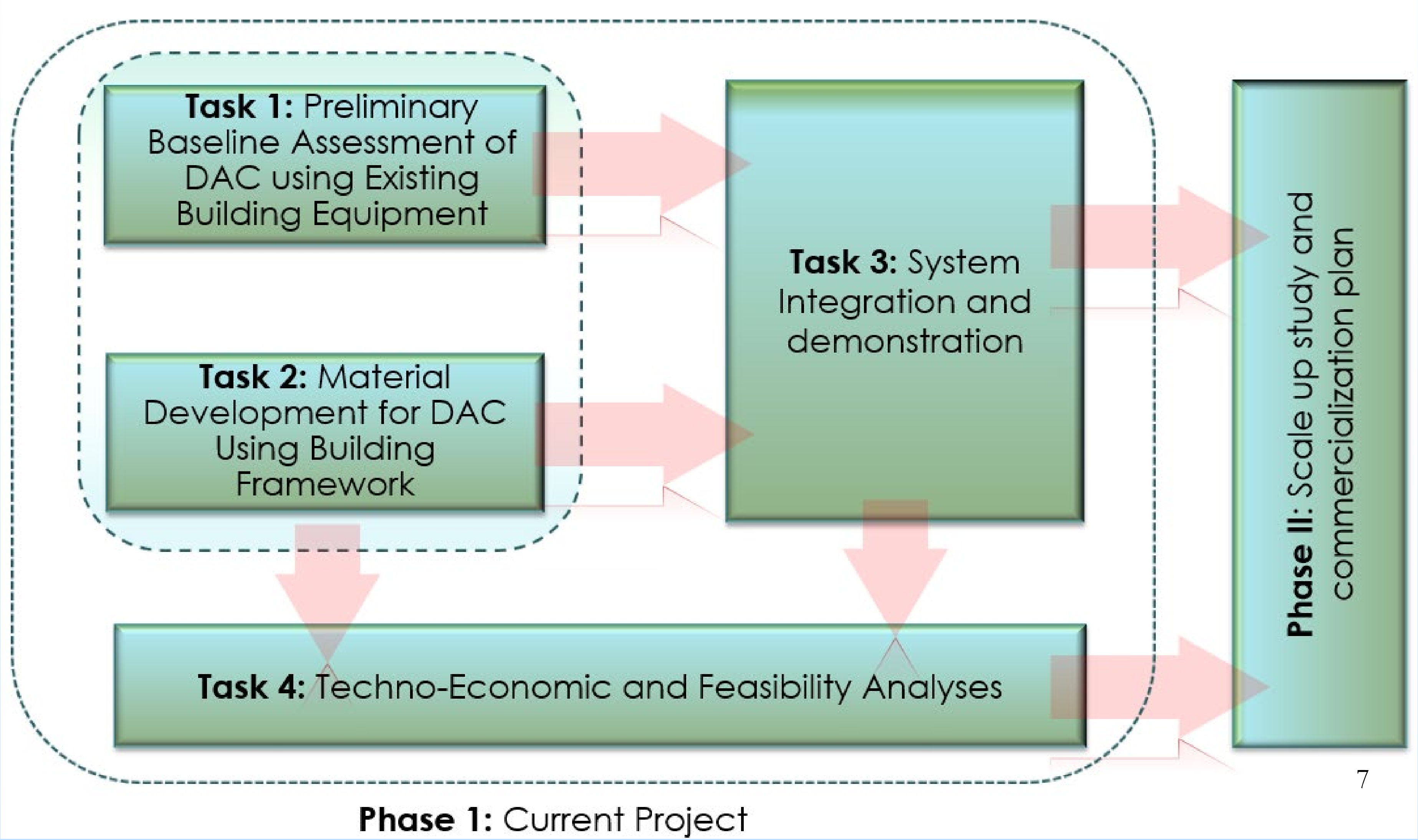

Josh Thompson


Chris Janke


Costas Tsouris

- Building equipment design and demonstration
- Materials development and characterization
- Process control and optimization
- Heat and mass transfer/ process intensification

Project Overview



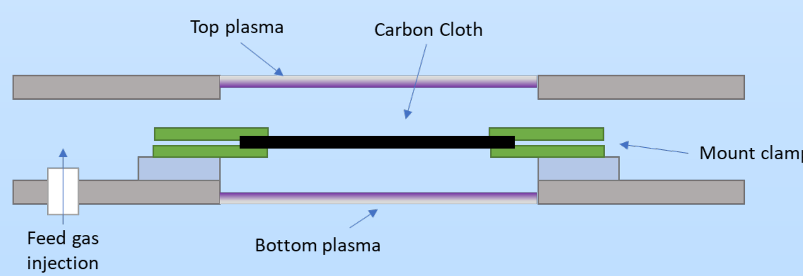
Materials Development

- Different sorbent materials were developed
- PAN-TETA, actived carbon fiber, and cellulose acetate-SiO_2-PEI were down selected for further evaluation and deployment
- PAN-TETA
  - Polyacrylonitrile (PAN) reacts with triethylenetetramine under mild condition
  - Scaled up (20 L) the process for large quantity production

Materials	Composition	Parameters	Surface modification
PE/PLA Fiber	PE/PLA 70/30 Blend	20 µm in diameter, 1988 denier	E-beam grafting
PE/PET Filter sheet	PE/PET 50/50 blend	2.1 mm thickness	E-beam grafting
PAN	PAN	-	Amine grafting
ACF 1000	Activated carbon fiber	Surface area: 950 m^2/g Pore volume: 0.8-1.2 mL/g Pore diameter: 17-20 A Fiber diameter: 16-23 µm	Plasma treatment then grafting or impregnation
SiO_2-CA-PEI fiber	PEI modified fiber	530 (±5) µm in diameter, Surface area: 11.2 m^2/g_{SiO2} Pore volume: 0.1 cm^3/g_{SiO2}	N/A

- Activated carbon fiber (ACF)
  - ACF was treated by plasma and then functionalized with amine
  - Scaling up the reaction to 20 L

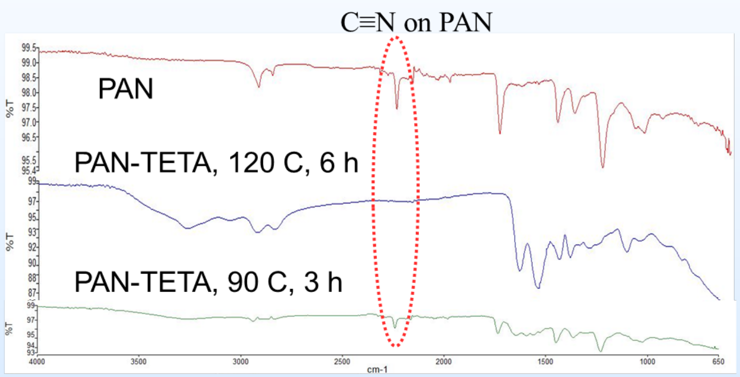
Scale up: 20L reactor



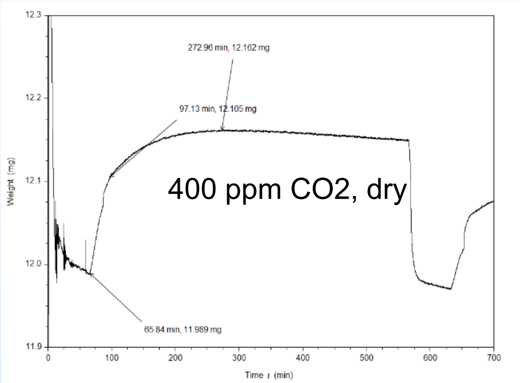
Plasma treatment process

Materials Characterization

- PAN-TETA
  - FT-IR confirmed the PAN was fully functionalized with TETA
  - CO_2 absorption capacity was confirmed using TGA, 0.33 mmol/g

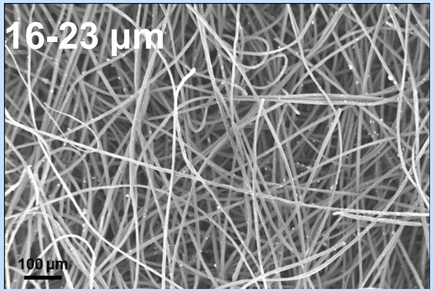


FT-IR

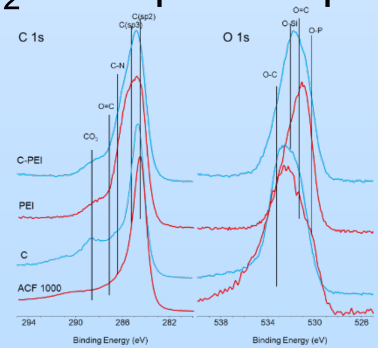


Thermogravimetric Analysis (TGA)

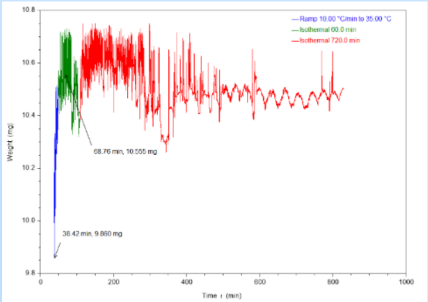
- Activated carbon fiber
  - SEM show the diameter of the fiber is ca 16-23 µm
  - XPS results confirmed the introduction of the functional group
  - TGA confirmed the CO_2 absorption capacity of 1.6 mmol/g



SEM

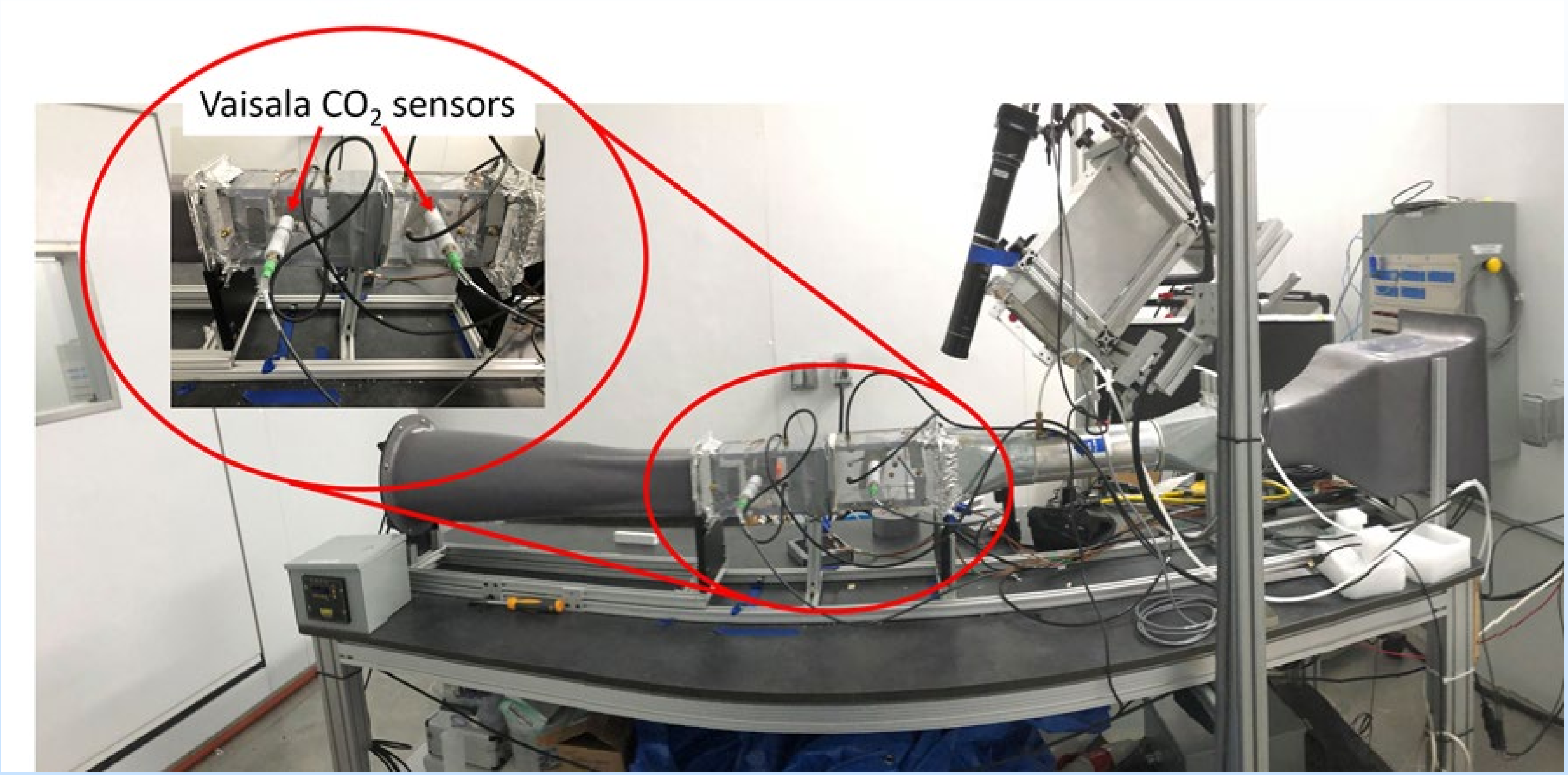


XPS



TGA

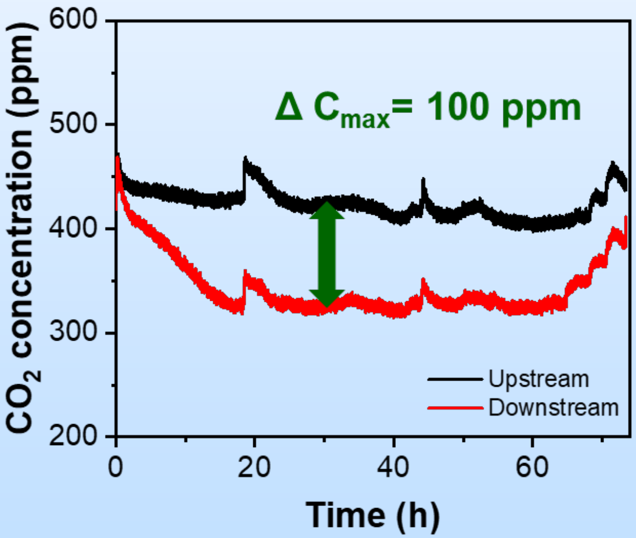
Performance Evaluation



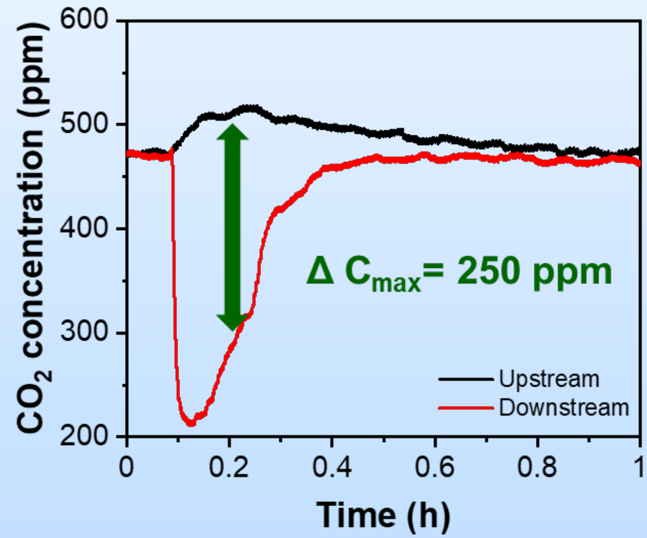
- A comprehensive test facility with a series of instrumentation
- Test setup to simulate any weather conditions- all climate zones in US and beyond
- One of its kind facility to test any DAC technology (at-scale)

Performance Evaluation

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



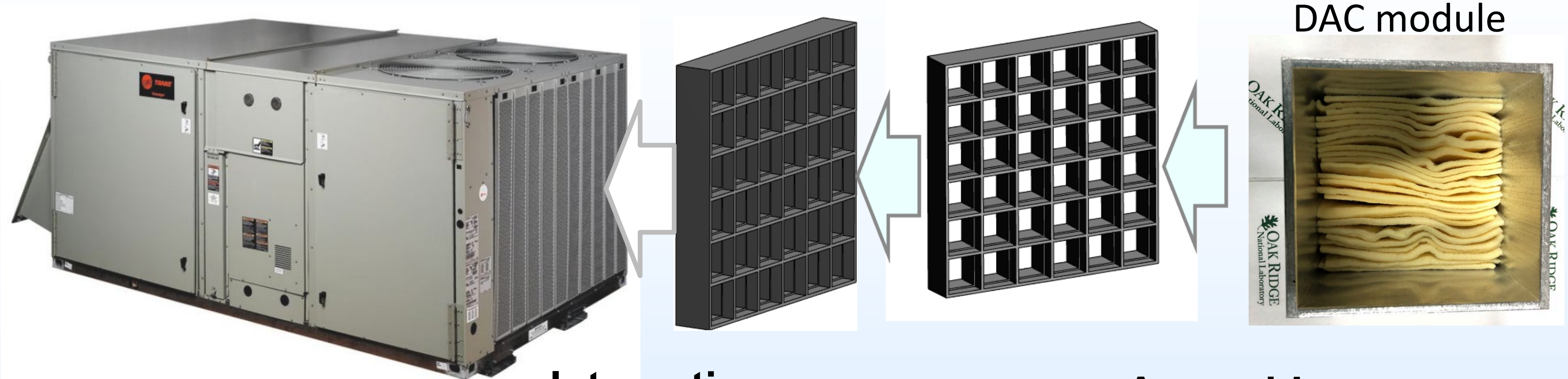
- Cellulose acetate-SiO_2-PEI
- 18.8% weight gain (1 h)
- 72.5 F, 68 RH%
- Material mass: 48.1 g



- Different Materials has different absorption behavior

System Integration (HVAC-DAC)

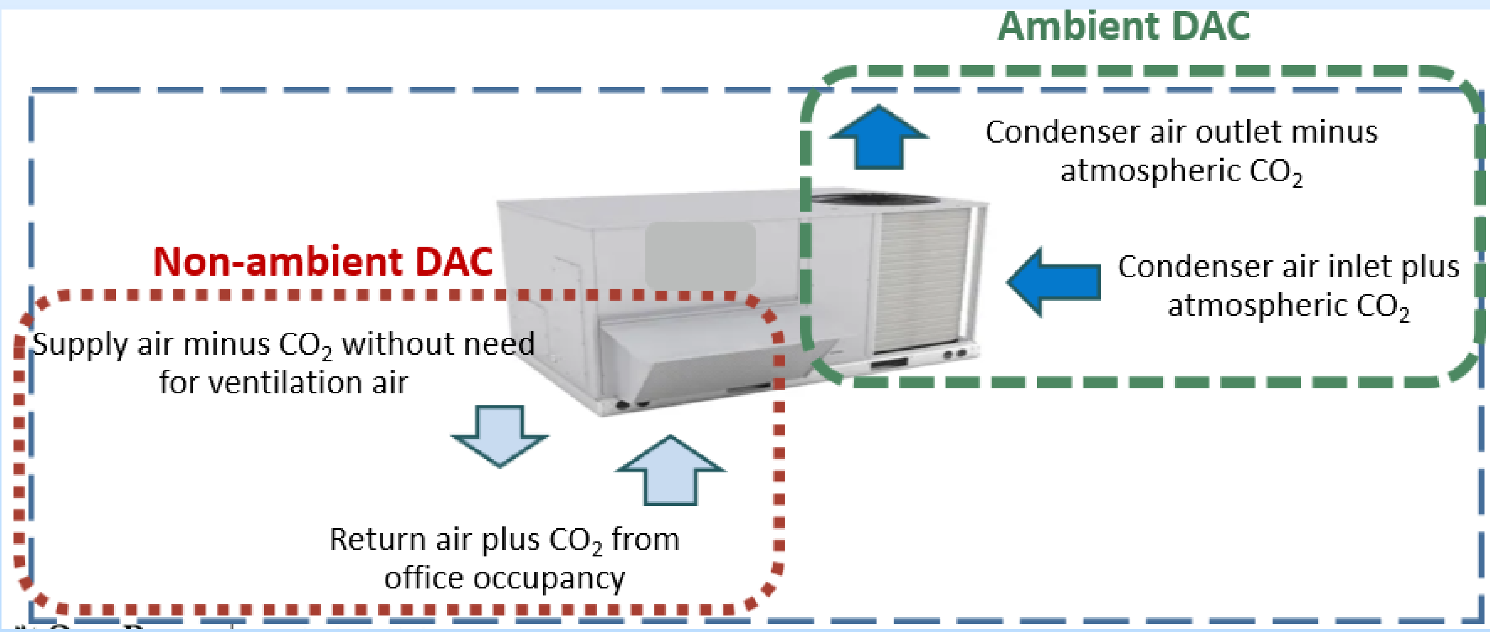
DAC module



Integration

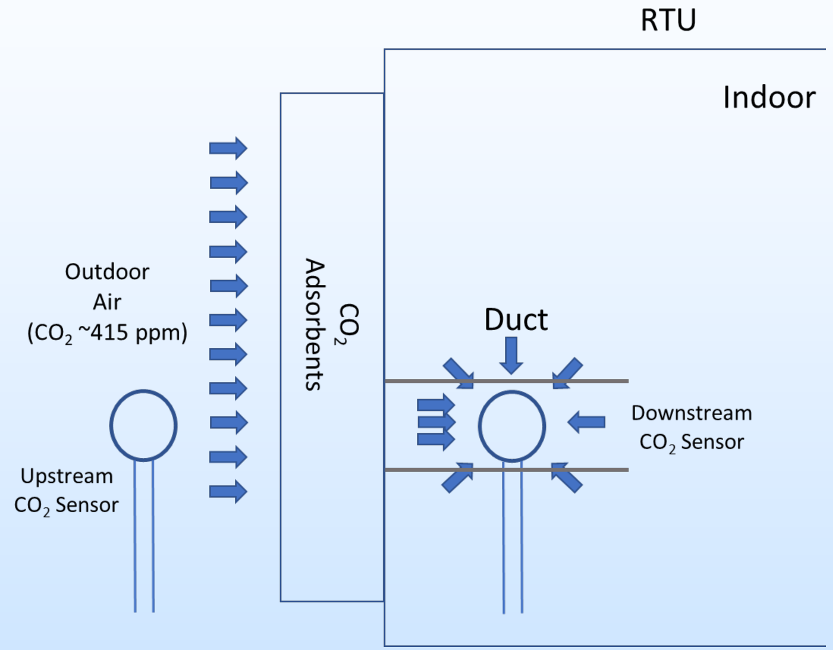
Assembly

DAC framework



Scaled-up Analysis

Deployment strategy



Sensors' deployment (CO_2, moisture, temperature)

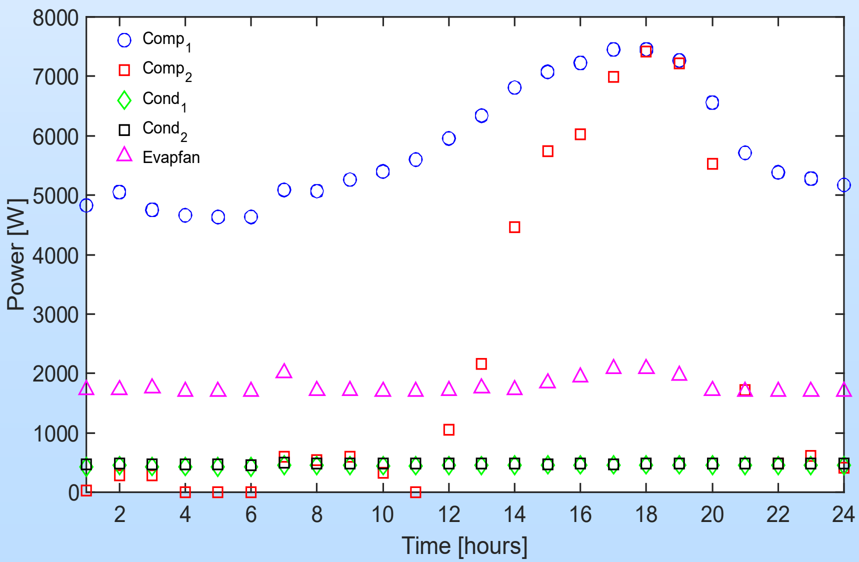
- Transient measurements of change in CO_2 concentration
- Change in the mass of module over an extended operation
- TGA-MS analysis to establish the CO_2 adsorption

Scaled-up Analysis

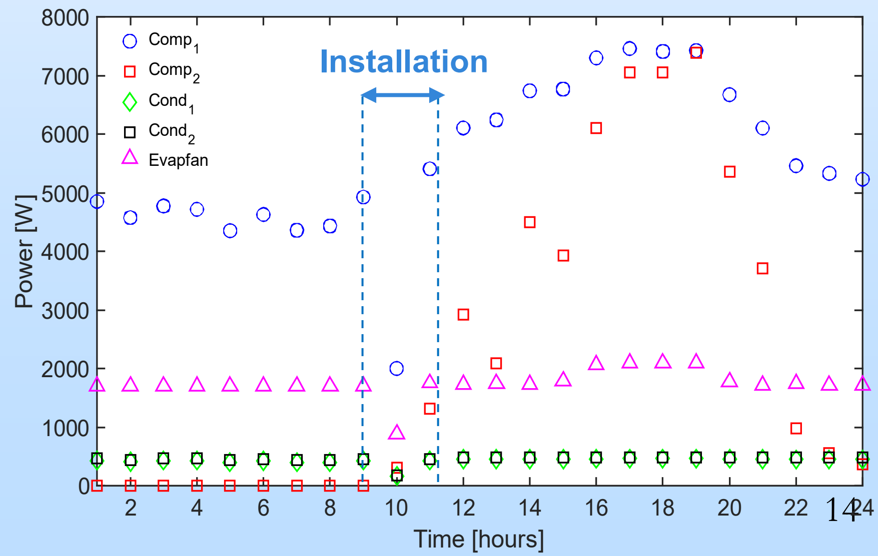
	Weather			Week 1	Week 2	Week 3	Week 4
	Average	Minimum	Maximum				
February	42 ºF, 65%RH	34ºF	52ºF				
March	50ºF, 68%RH	41ºF	62ºF				
April	59ºF, 68%RH	49ºF	71ºF				
May	67ºF, 70%RH	57ºF	78ºF				
June	65ºF, 70%RH	74ºF	85ºF				

Unit running time Percent: ~ 74%

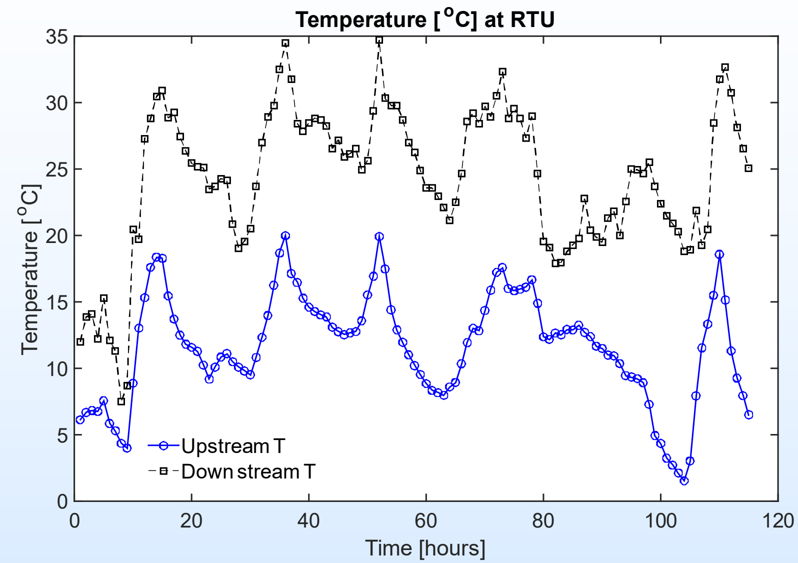
Without module: 6/13/22

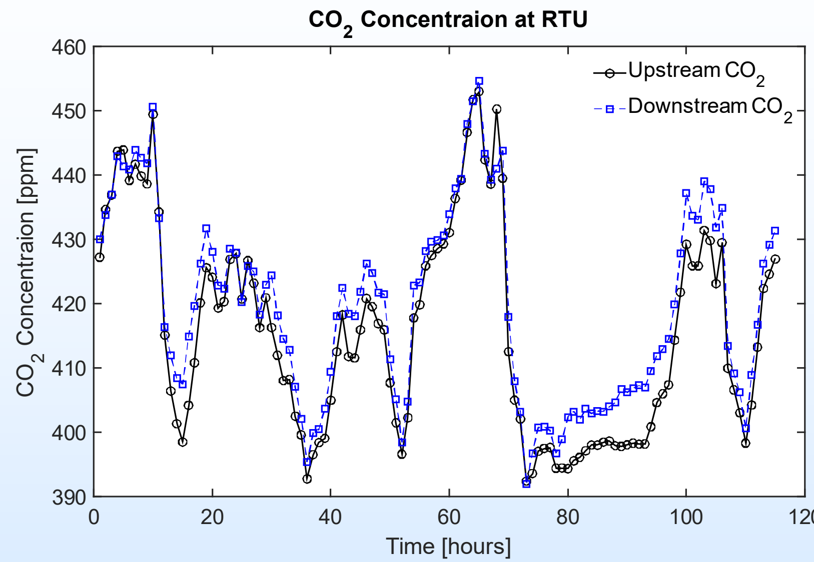


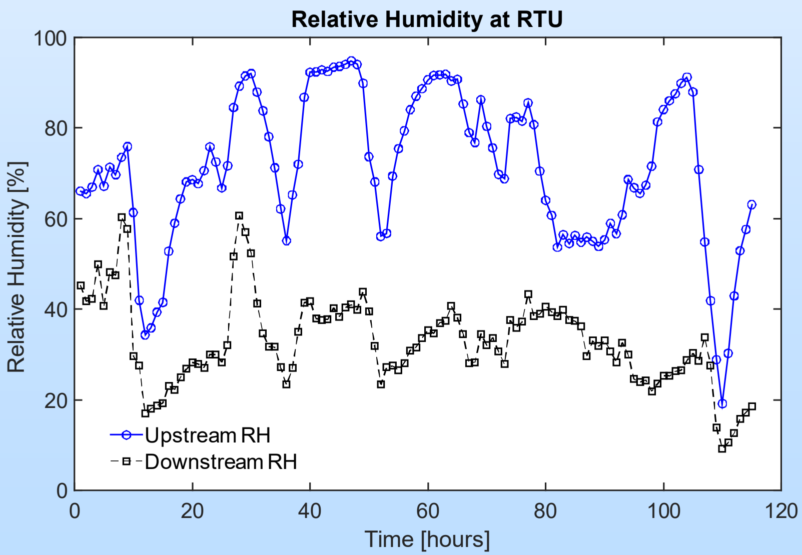
With module: 6/14/22

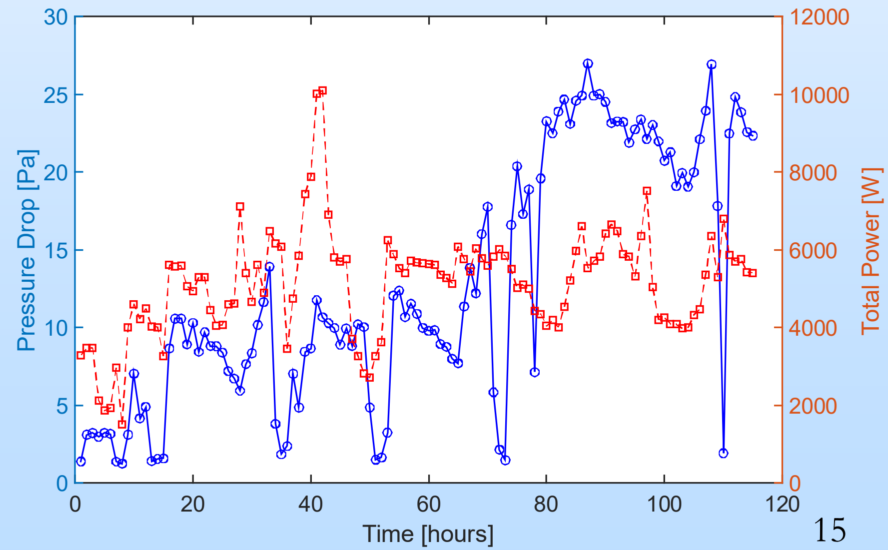


Scaled-up Analysis





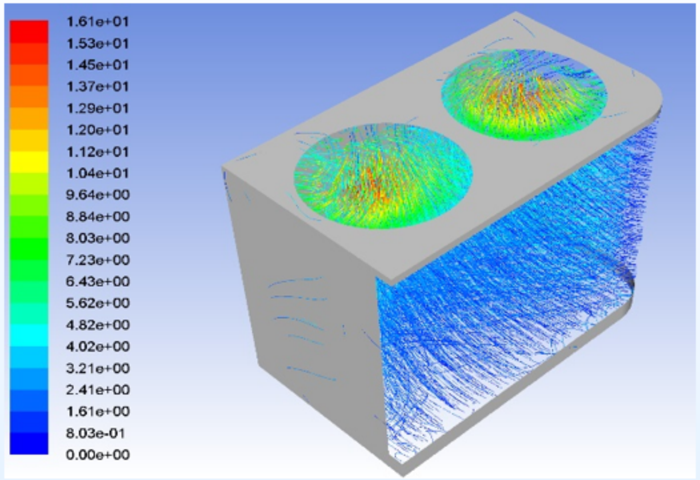




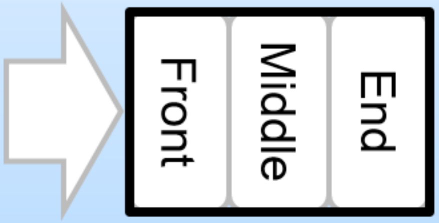
Test Period: 3/15/22 to 3/21/22

Scaled-up Analysis

		Columns									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	1	64	8	27	9	14	6	56	55	29	34
	2	25	38	26	48	47	50	40	35	24	46
	3	17	12	44	37	42	60	53	2	31	77
	4	3	7	49	41	54	32	11	67	4	90
Rows	**5**	1	36	61	63	10	66	51	80	78	76
	6	79	88	86	28	43	16	83	33	23	15
	7	58	74	13	19	75	68	85	87	52	5
	8	73	82	30	57	81	39	65	20	62	89
	9	72	22	84	59	45	71	69	70	18	21

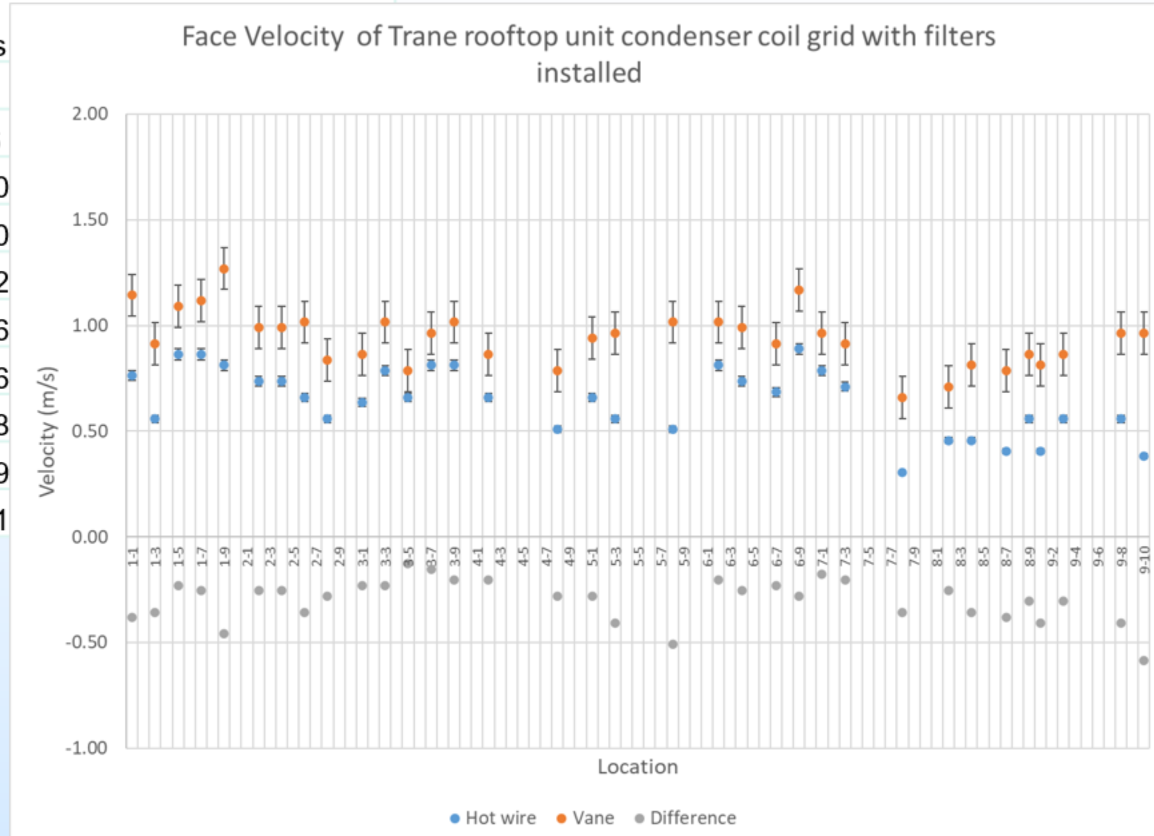


- Location of the materials within the module is important
- Location of individual module is important as well
- A facility to test multiple materials for performance comparison



Scaled-up Analysis

		Columns					
		1	2	3	4	5	
	1	64	8	27	9	14	6
	2	25	38	26	48	47	50
	3	17	12	44	37	42	60
	4	3	7	49	41	54	32
Rows	**5**	1	36	61	63	10	66
	6	79	88	86	28	43	16
	7	58	74	13	19	75	68
	8	73	82	30	57	81	39
	9	72	22	84	59	45	71



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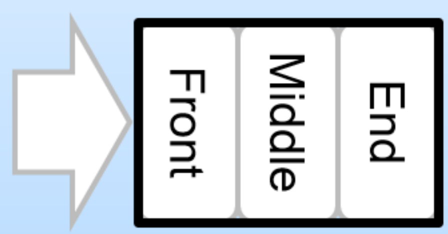

Scaled-up Analysis

Test	Reason for selection	Velocity measurement (m/s)	CO_2 absorption capacity (mmol/g)	Water uptake (mg/g)	Mass before (g)	Mass after (g)	Mass change
Module 1	Medium speed	0.66	**1.74**	132.3	92.2	130.0	41%
Module 14	High speed	0.86	**2.43**	134.7	91.2	131.3	44%
Module 21	Low speed	0.38	**3.86**	115.0	79.5	109.5	38%
Module 29	High speed	0.81	**2.31**	133.1	68.1	97	42%
Module 42	Medium speed	0.66	**2.57**	116.0	83.6	107.3	43%
Module 64	High speed	0.76	**2.59**	116.5	70.7	102.4	45%
Module 28 front	High speed, selected for gradient samples	0.74	**2.93**	137.8	85.9	121.9	42%
Module 28 middle			**2.45**	116.2			
Module 28 end			**2.45**	119.1			

- Location of the materials within the module is important
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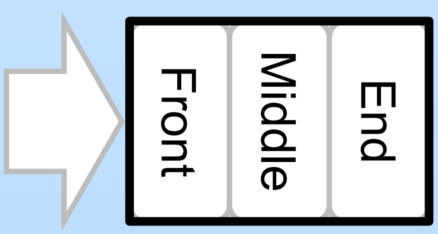
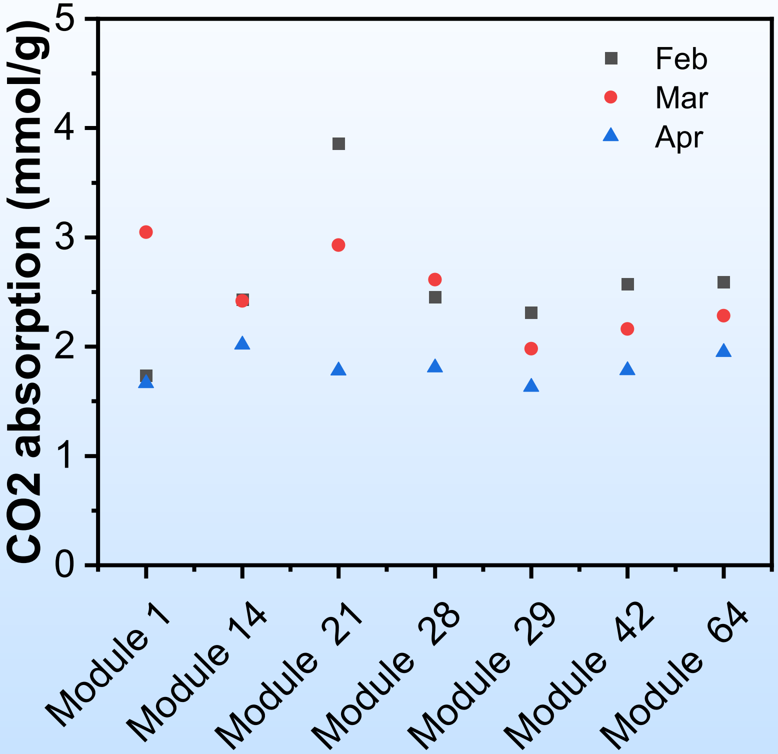
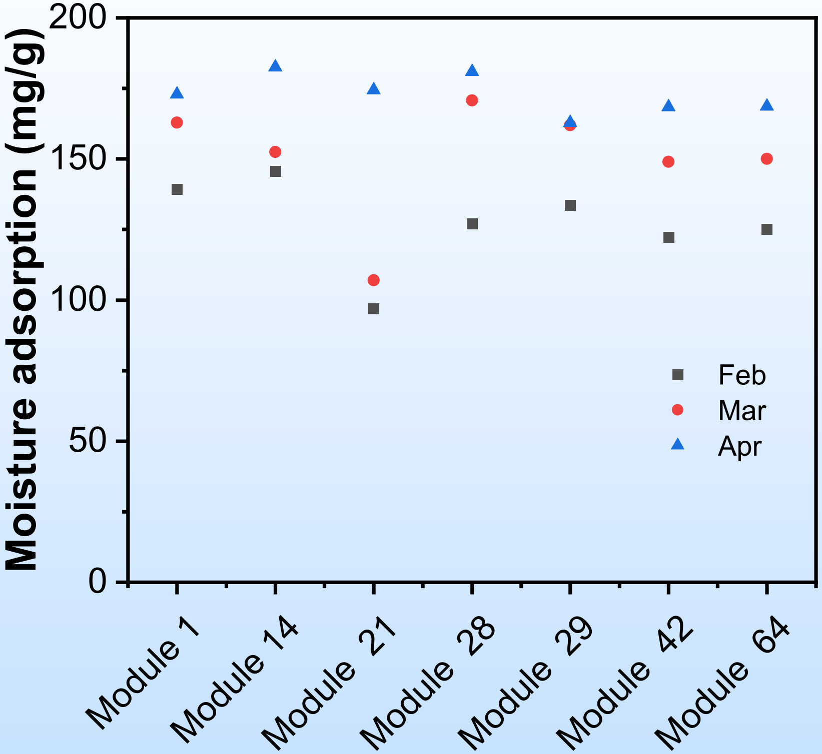


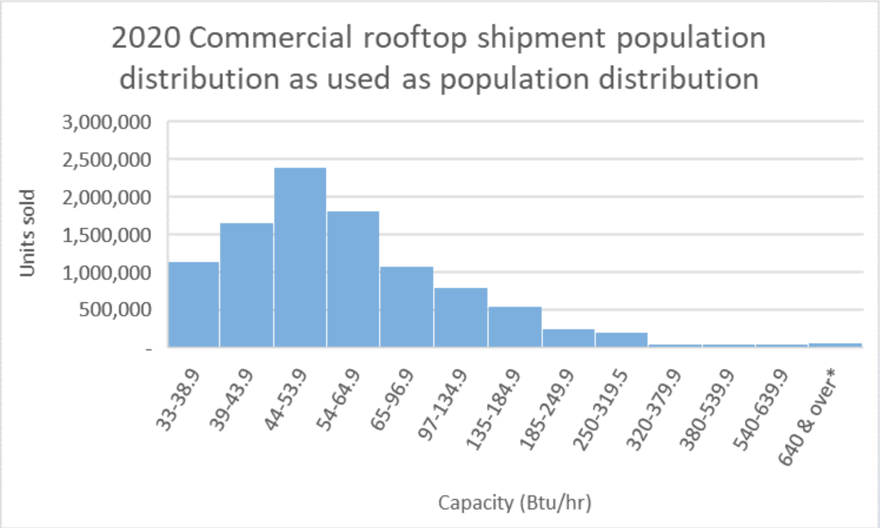
Scaled-up Analysis





- Materials maintain the absorption capacity, around 2-2.5 mmol/g
- The capture devices show long team stability
- Materials adsorb moisture from air, 125-175 mg/g

Value Proposition

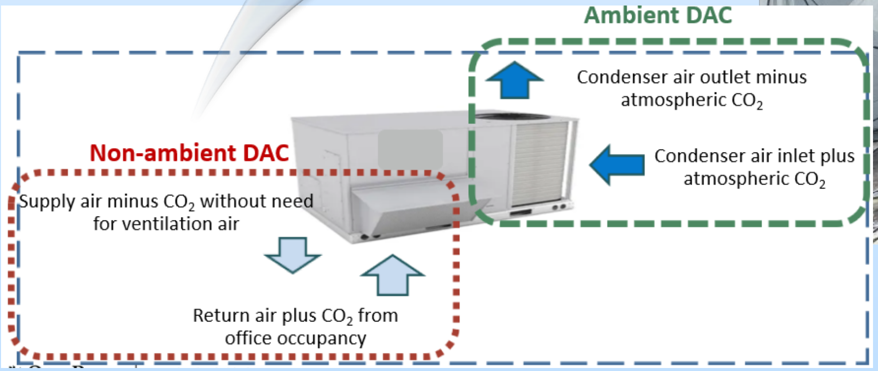


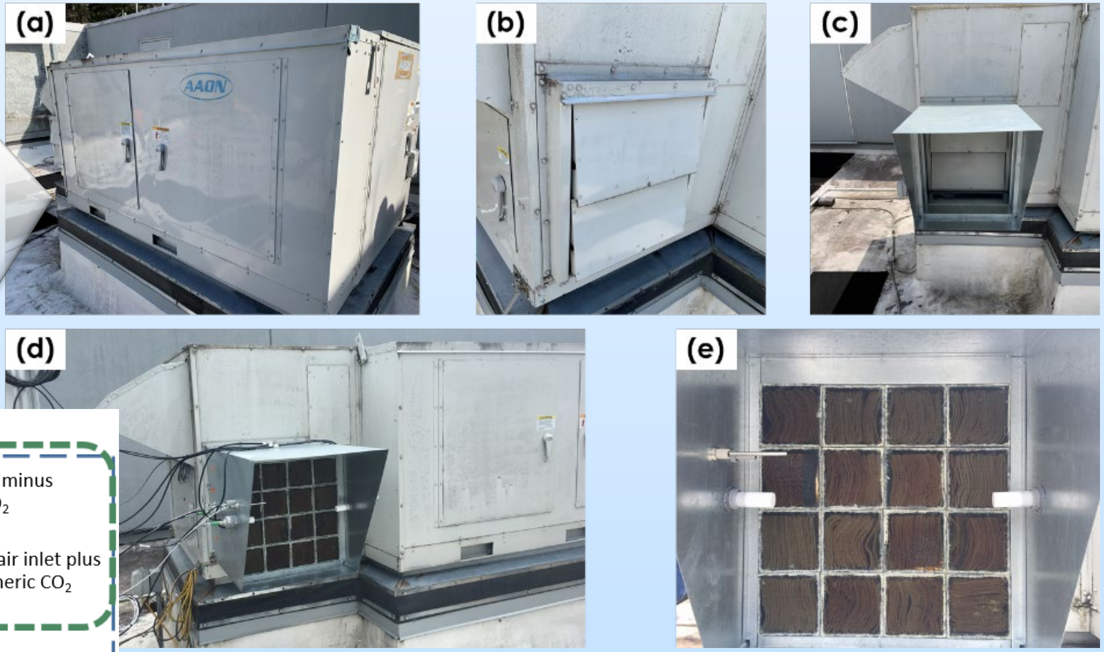
City	Average percent of monthly hours below balance point for year	Average percent of monthly hours below balance point for heating season	Average heating hours (hr)	Average cooling hours (hr)	Average supplementary heat hours during heating season (hr)
Miami, Florida	0.00%	0%	27	600	0
Houston, Texas	0.45%	1%	276	427	3
Phoenix, Arizona	0.03%	0%	256	496	0
Atlanta, Georgia	3%	6%	489	244	29
Los Angles, California	0.00%	0%	249	130	0
Las Vegas, Nevada	0.3%	0%	385	390	1
San Francisco, California	0.00%	0%	611	53	0
Baltimore, Maryland	13%	25%	779	189	196
Albuquerque, New Mexico	7.3%	15%	643	202	94
Seattle, Washington	3%	6%	874	51	52
Chicago, Illinois	25%	49%	886	124	437
Boulder, Colorado	17%	33%	773	119	257
Minneapolis, Minnesota	33%	64%	1060	104	681
Helena, Montana	30%	58%	916	73	533
Duluth, Minnesota	40%	74%	1283	42	945
Fairbanks, Alaska	53%	95%	1639	22	1557

- Number of installed rooftop units (RTU) and associated cooling/heating capacity
- Ambient conditions and type of building is an important information
- Operational time can be established based on feedback from OEMs.

Work in Progress

- Deployment of different configuration of adsorbents (parallel channels vs. packed bed)
- Non-ambient DAC system (higher CO_2 concentration)
- Impact of climate conditions on the performance
- Different adsorbent materials- Going from a small scale to large scale





(a) MAU unit in Maxlab, (b) exhaust outlet of the MAU, (c) MAU with a duct installed outside to the exhaust outlet, and (d, e) MAU with capture device installed.

Publications and Acknowledgements

- Thermodynamic evaluation of direct air capture- Establishing the technical limits
- D-DAC Distributed direct air capture- A new paradigm of DAC technology
- US patent application 63/272,351, "Multi-functional Equipment for Direct Decarbonization with Improved Indoor Air Quality (IAQ)."

Lynn Brickett (Fossil Energy and Carbon Management)

Support staff at Buildings Technologies Research and Integration Center (BTRIC)

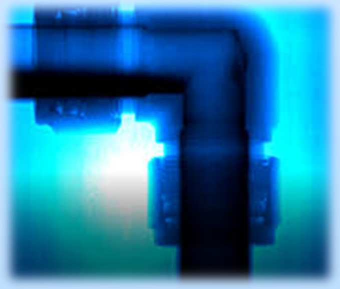
Facilities and infrastructure

Materials characterization

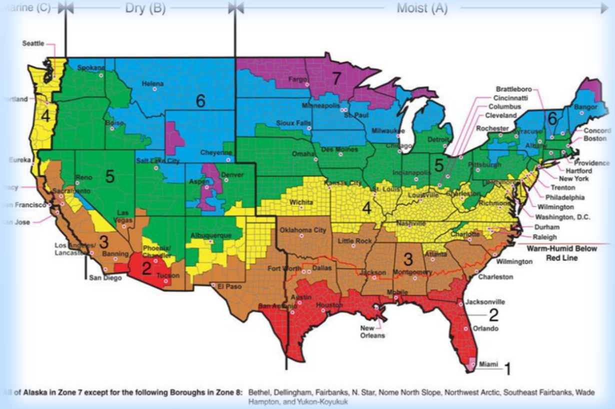
Contactor performance evaluation

Additive manufacturing

Advanced computation



Advanced visualization



National climate data

DAC performance in various climate zones
(temperature, relative humidity, CO_2 concentration)