Energy-Efficient Direct Air Capture System for High-Purity CO_2 Separation

DE-FE0032128

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National Energy Technology Laboratory
Carbon Management Project Review Meeting
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Project Overview

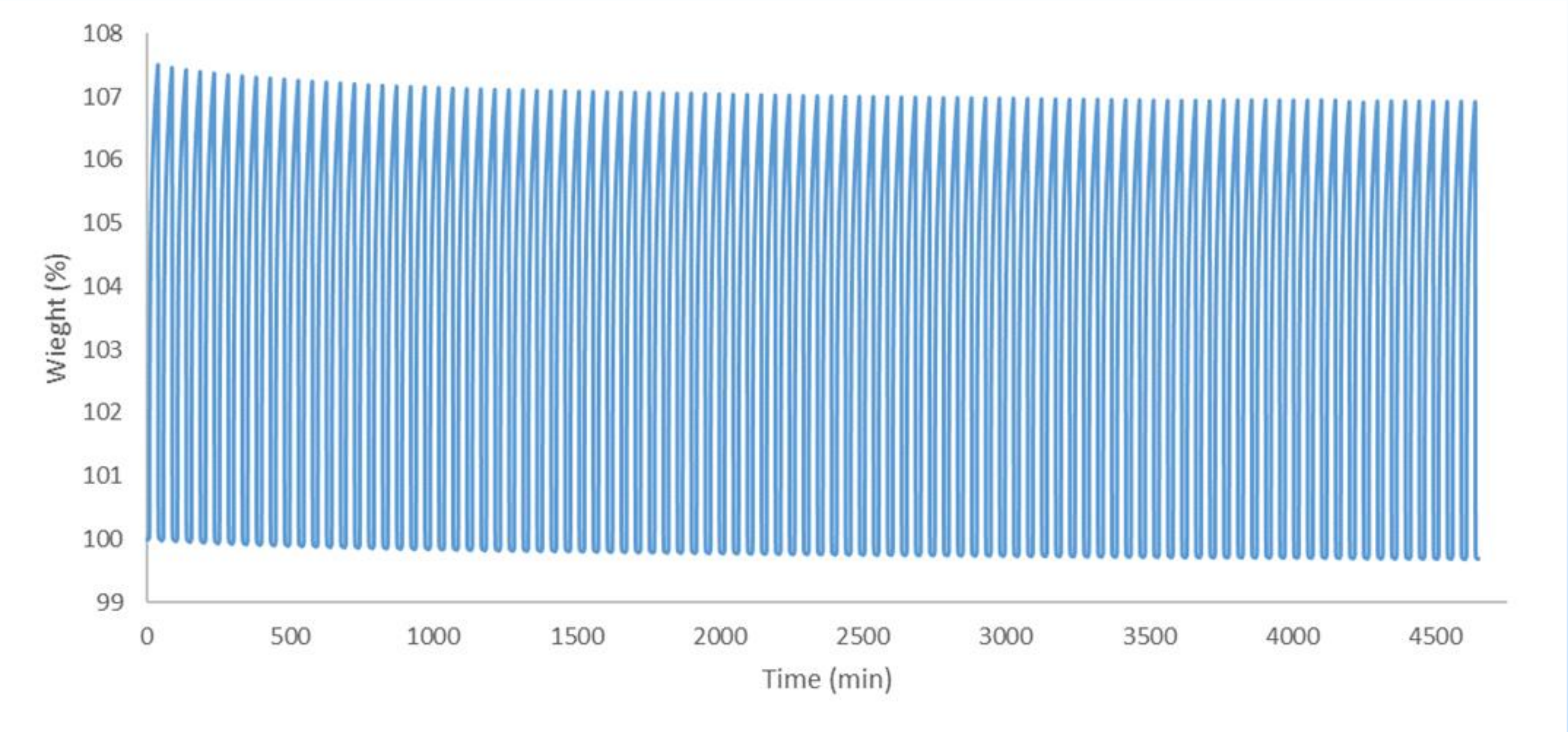
1) Funding: DOE share $1,499,999 and cost share $393,650

2) Overall Project Performance Dates: 10/1/2021 – 9/30/2023 (NCE has been requested)

3) Overall Project Objectives: demonstrate the Recipient's DAC sorbent technology to capture CO_2 from ambient air and separate it at high purity.

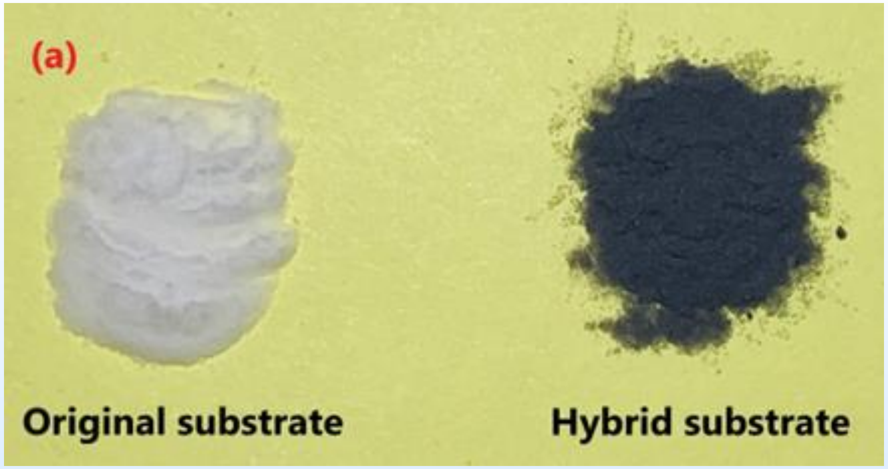
4) Project Participants: University of Cincinnati (UC), BASF, Daeyoung, Trimeric

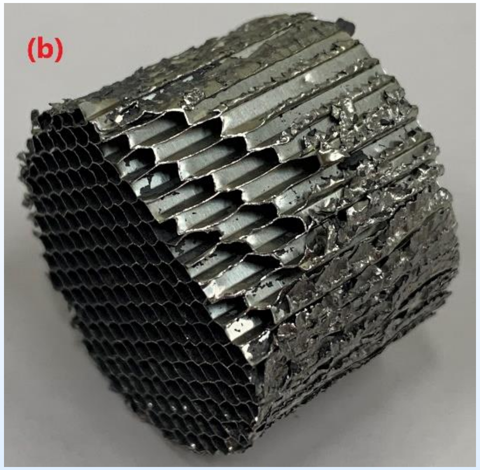
Technology Background



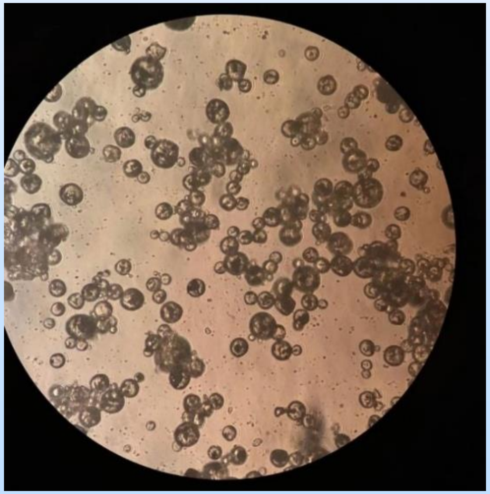
Modified PEI/silica sorbents under 400 ppm CO_2 in dry air at 25 °C for adsorption and desorption with N_2 over **100 cycles** at 110 °C for desorption

Technology Background

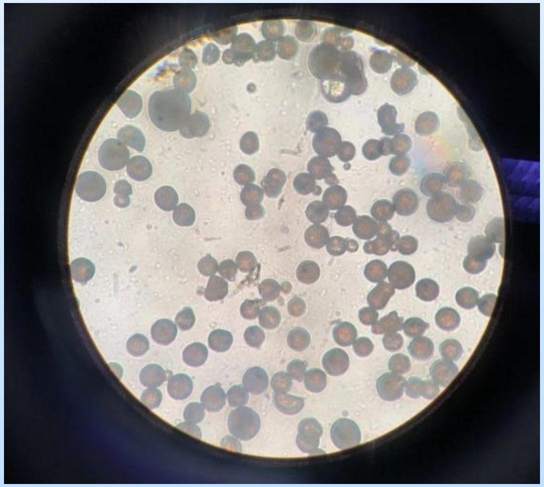




(c) Original silica substrate

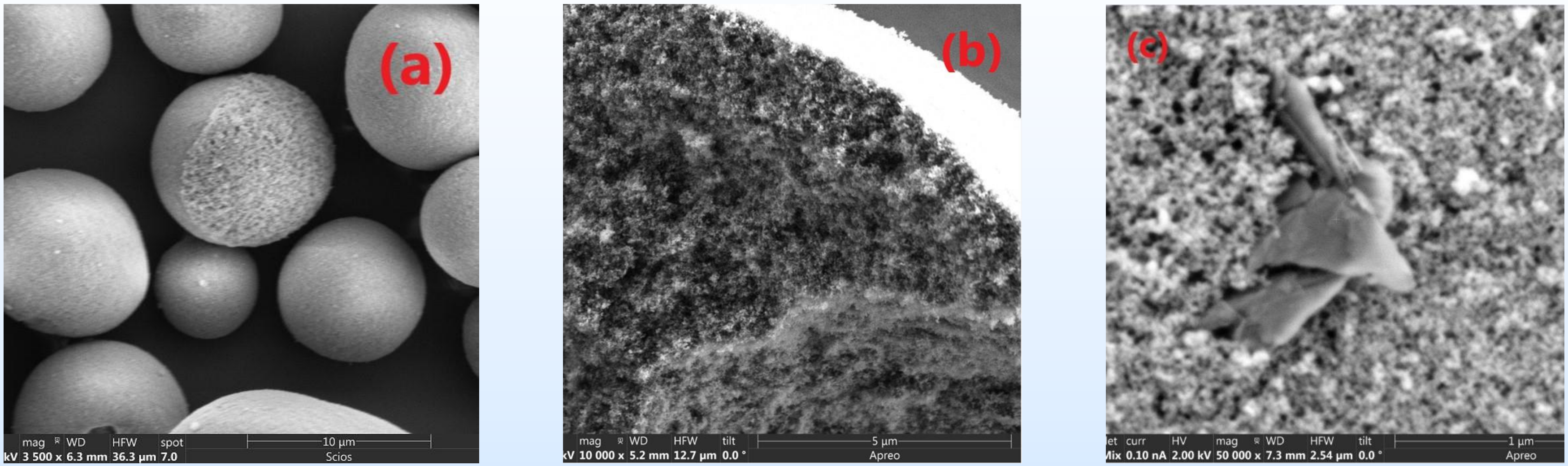


(d) hybrid silica substrate



(e) Modified PEI impregnated onto hybrid substrate

Technology Background



SEM images of synthesized (a) spherical substrate, (b) cross-sectional substrate pores, and (c) hybrid sorbent substrate surface pores.

Surface area (~350 m^2/g), pore volume (~1.8 cm^3/g), and average pore diameter (~20 nm)

Technology Background

- Sorbent with resistance to oxidative and thermal degradations
- Hybrid substrate for better thermal properties
- Passive air contactor without energy requirement during capture
- High throughput of air flow with minimum pressure drop through sorbent-washcoated monolith in air contactor
- Increased selectivity toward CO_2 over water vapor

Technical Approach/Project Scope

- Task 2: CFD and Adsorption Kinetics (UC)
  - ✓ Air flow model through monolith in passive air contactor
  - ✓ Determine CO_2 adsorption kinetics

- Task 3: Manufacture CO_2 sorbent (UC)
  - ✓ Manufacture CO_2 sorbent
  - ✓ Evaluate long-term lab-scale performance

- Task 4: Manufacture sorbent-washcoated monolith structure (UC, BASF, Daeyoung C&E)
  - ✓ Develop sorbent-washcoated monolith
  - ✓ Determine cell size and length

- Task 6: Evaluate performances of sorbent-washcoated monolith in air contactor system (UC)
  - ✓ Measure temperature, humidity, velocity, and CO_2 concentration
  - ✓ Evaluate performance

Technical Approach/Project Scope

Major milestones

Task	Milestone Title & Description	Planned Completion Date
3	Manufacture of 10 kg of CO_2 sorbent	PSD+6 months
4	Manufacture of two sorbent-washcoated monolith prototypes	PSD+8 months
6	CO_2 capture efficiency, energy requirements, and overall volumetric CO_2 productivity	PSD+22 months

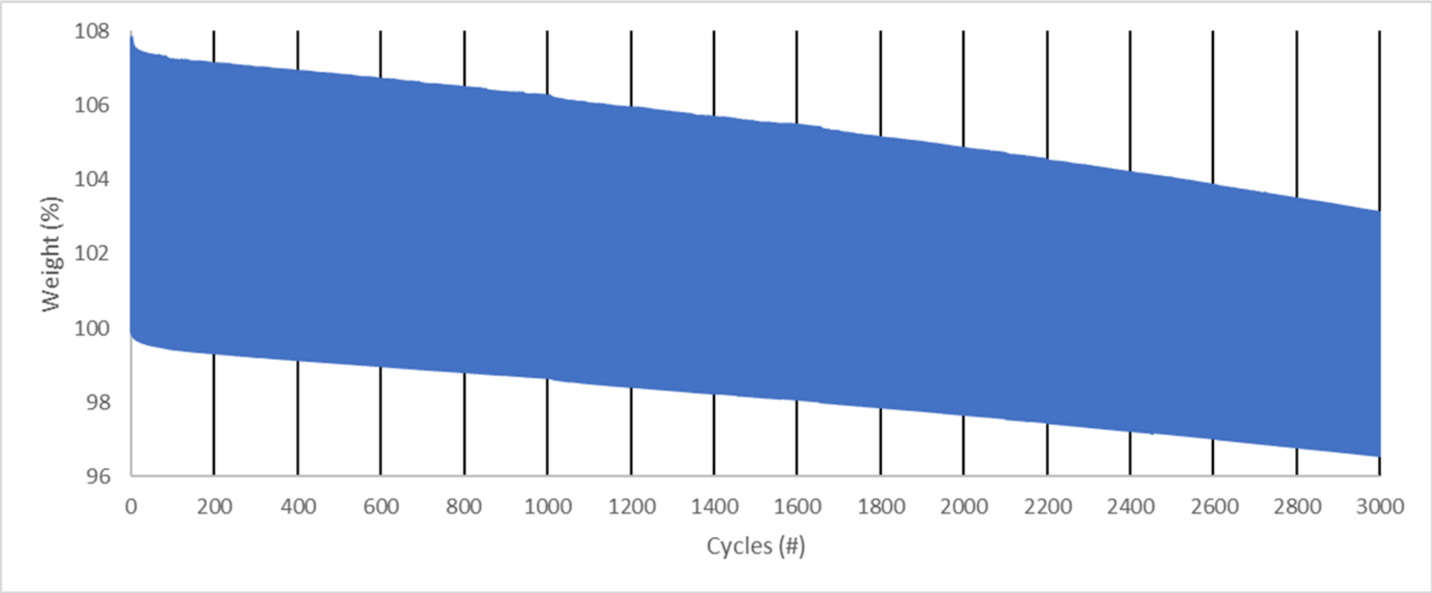
Major Success criteria

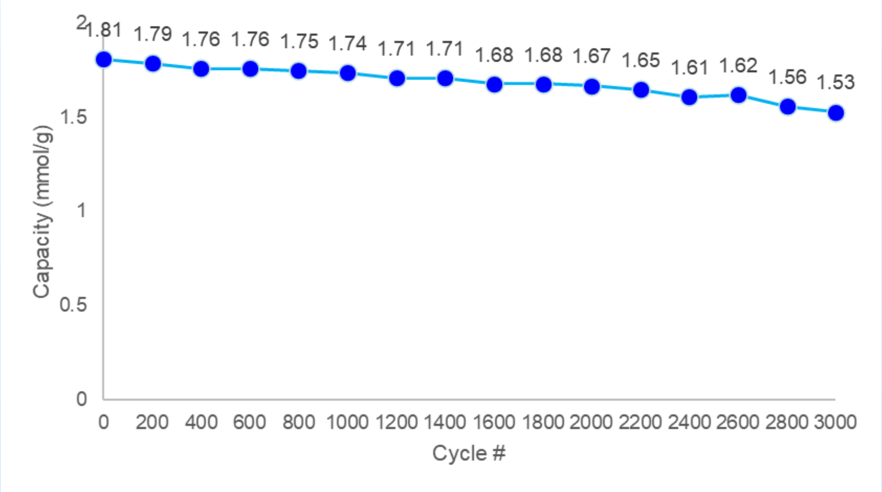
- 70% average CO_2 capture efficiency in passive air contactor with monolith with pressure drop of <200 Pa
- Overall volumetric productivity of ~2 (gmol CO_2/(hr x V(l))

Project Risks and Mitigation Strategies

- Low performance of sorbent-washcoated monolith: BASF and Daeyoung will attempt many different coating formulations
- Low DAC system performance: parametric testing will be carried out to investigate the effects of parameter (i.e., operating conditions, materials, etc.)

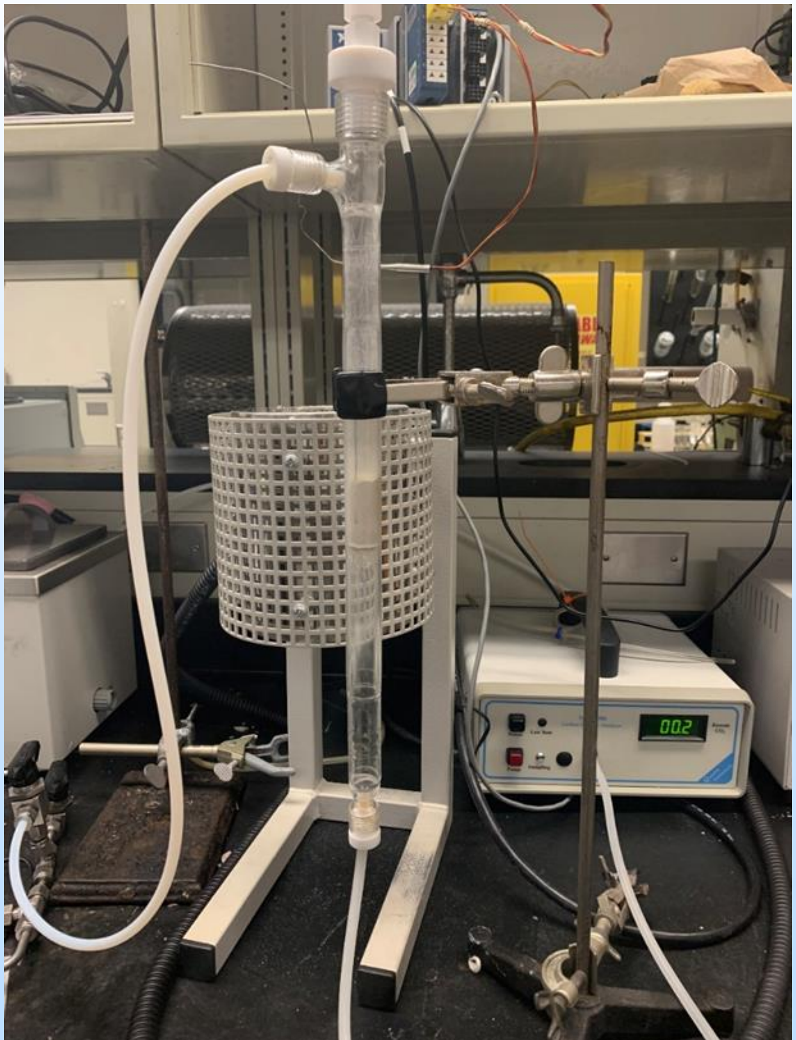
Performance of Powdered Sorbent in TGA

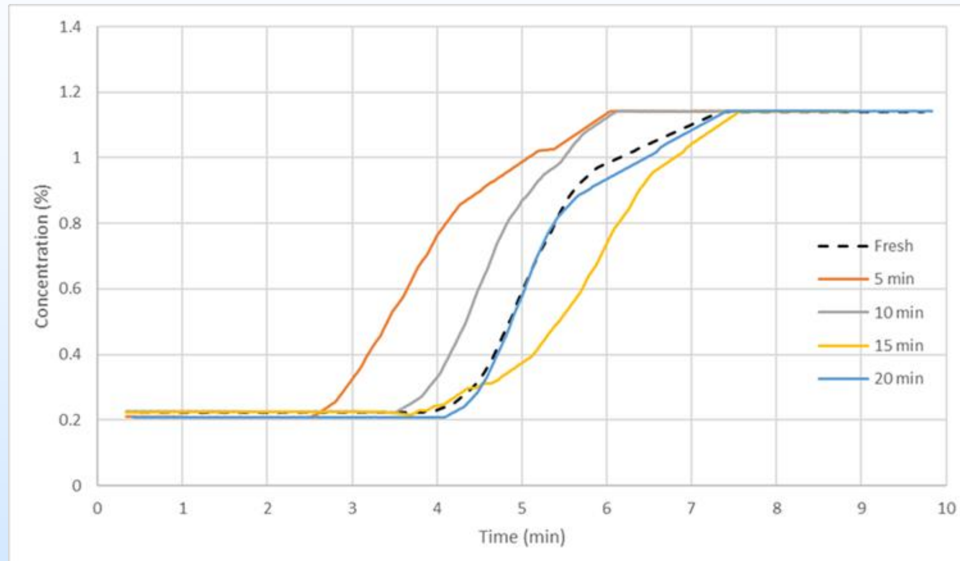




- Adsorption under 400 ppm CO_2 in dry air at 30°C and desorption under N_2 at 100 °C for desorption using powdered sorbent.
- <~20% loss in capacity over 3,000 cycles

Performance of Powdered Sorbent in Fixed-bed Reactor

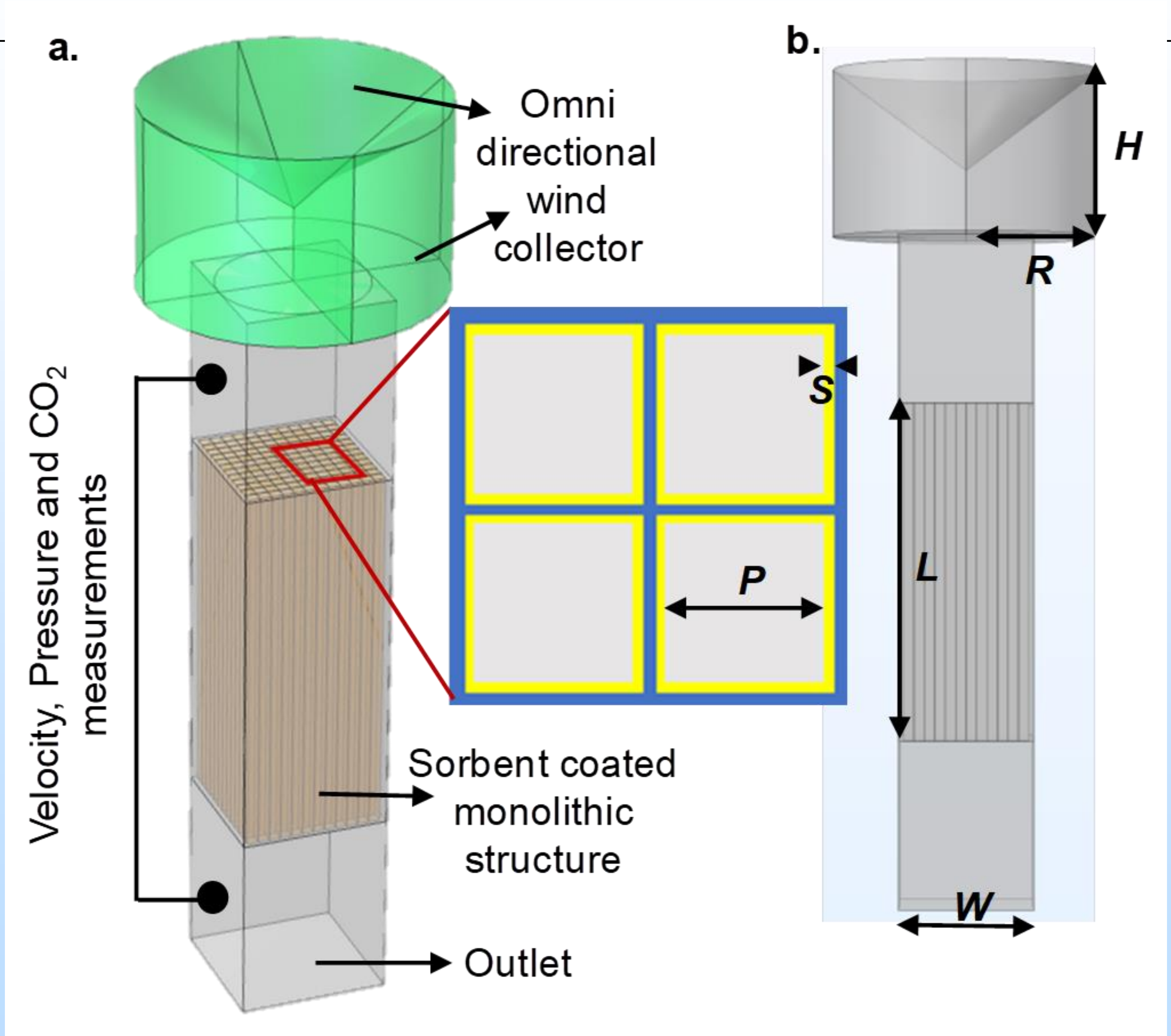




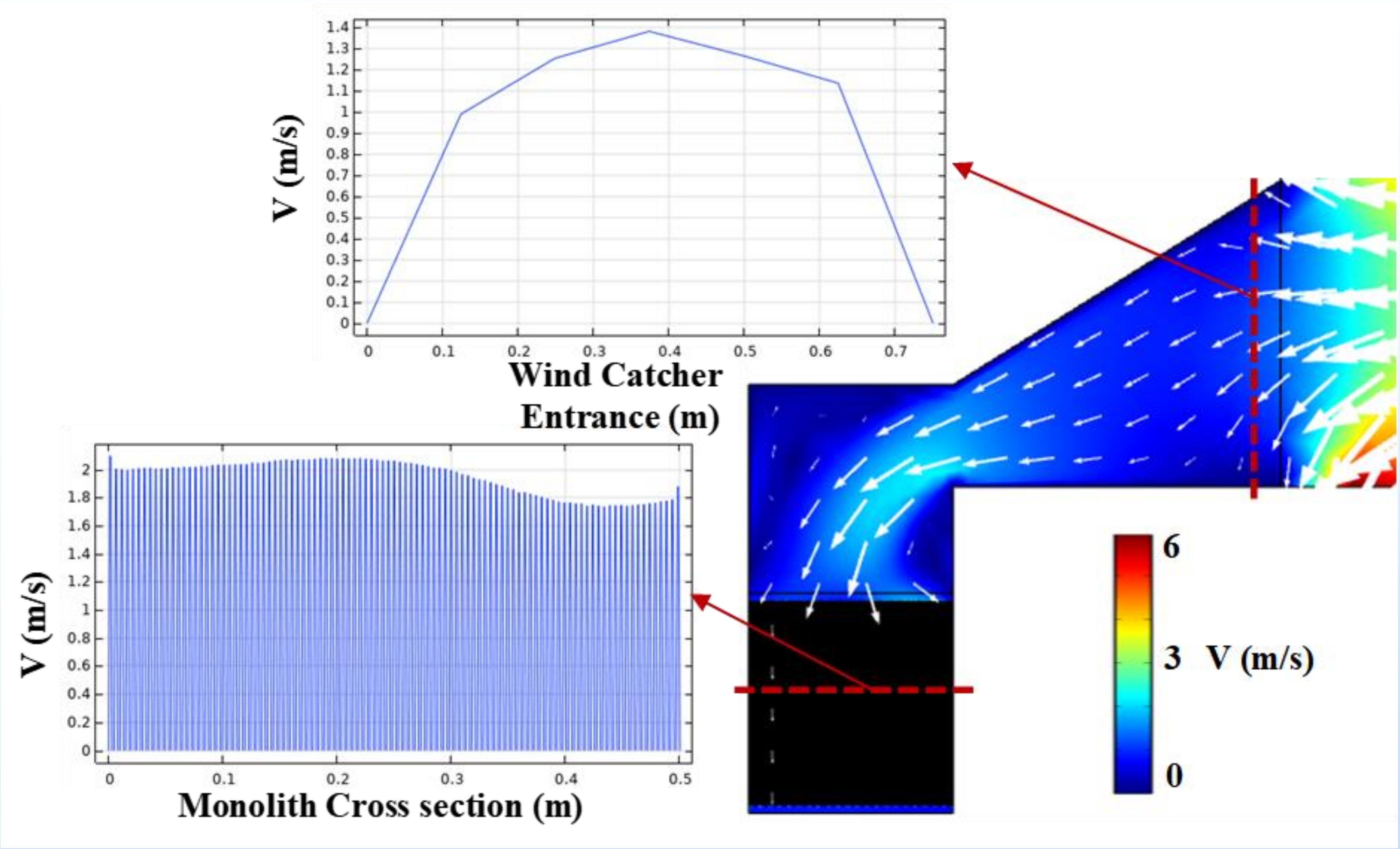
Adsorption capacity using 1% CO_2 in N_2 after desorption at -70 kPa and 110 °C

(1) Fresh: 1.80 mmol/g;
(2) 5 min vacuum: 1.07 mmol/g;
(3) 10 min vacuum: 1.33 mmol/g;
(4) 15 min: 1.72 mmol/g;
(5) 20 min: 1.77 mmol/g.

Passive Air Contactor

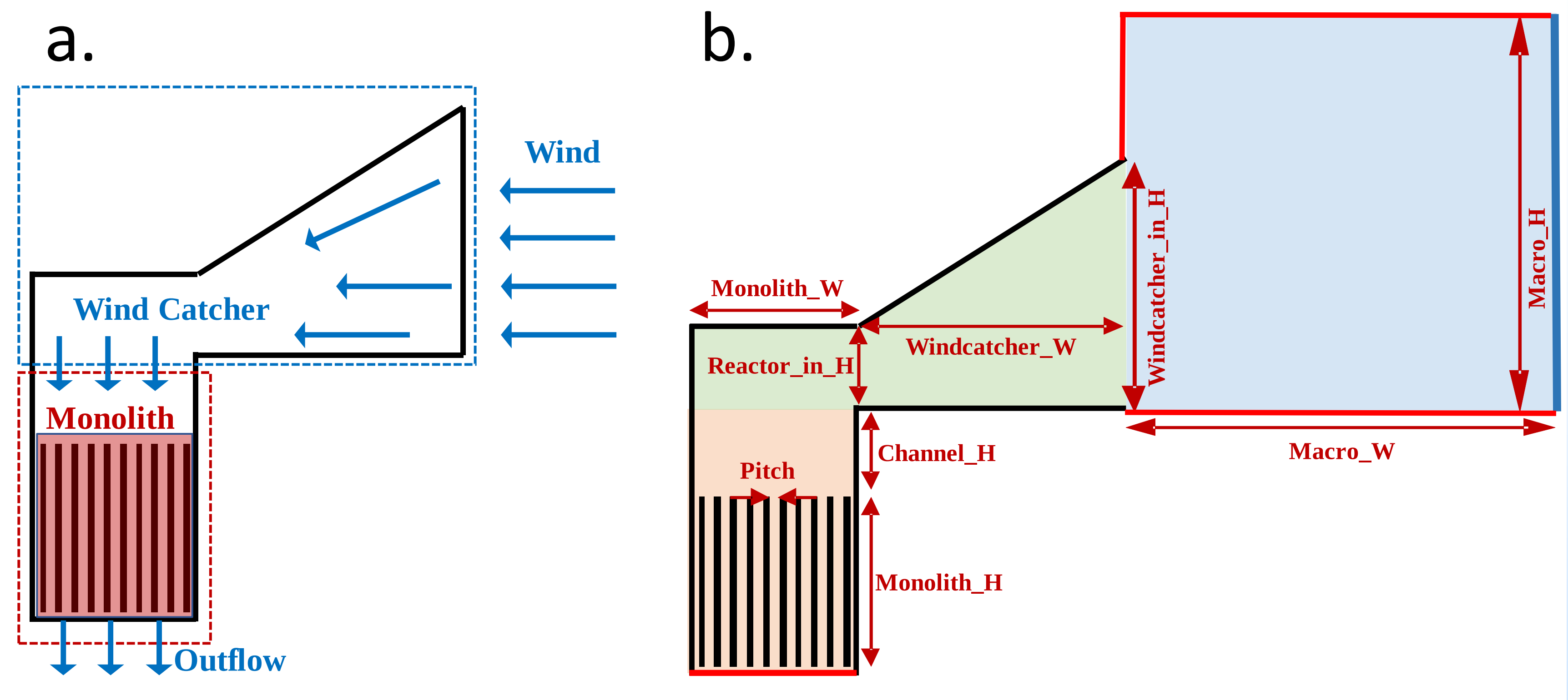


CFD for Passive Air Contactor



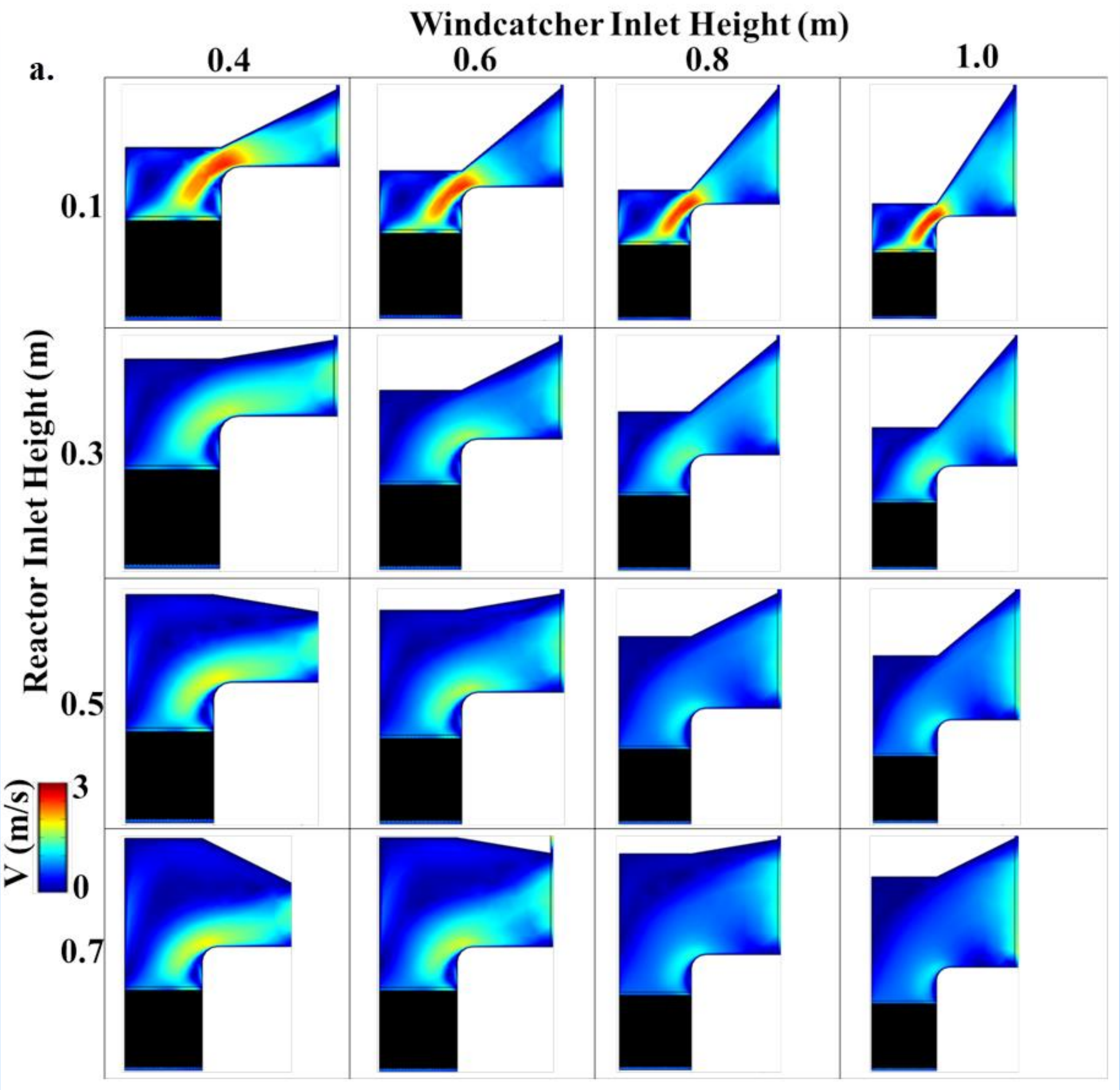
Wind speed: 5 m/s; pitch: 2 mm; linear velocity: ~2 m/s at middle height; Re: ~270

CFD for Passive Air Contactor

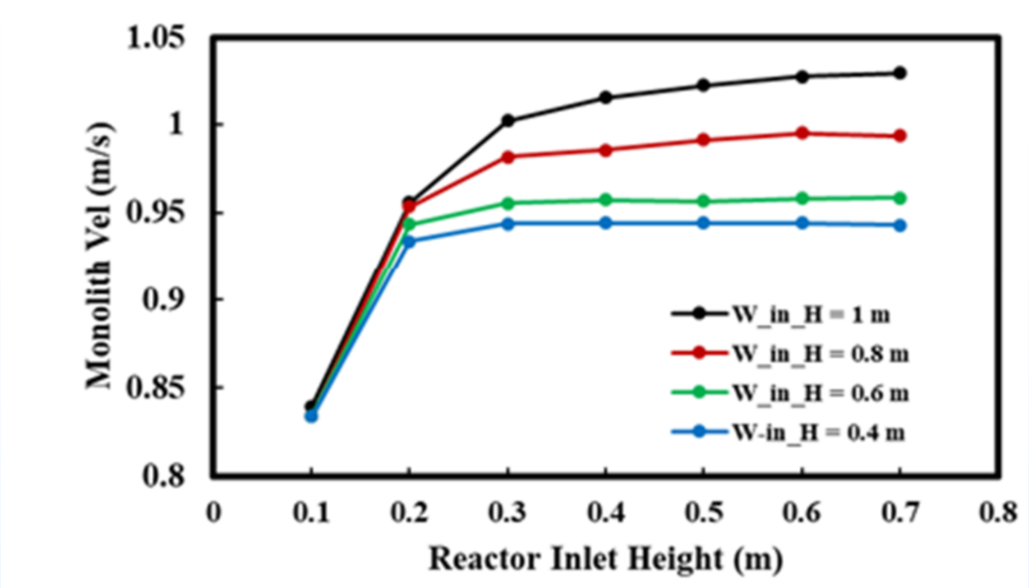


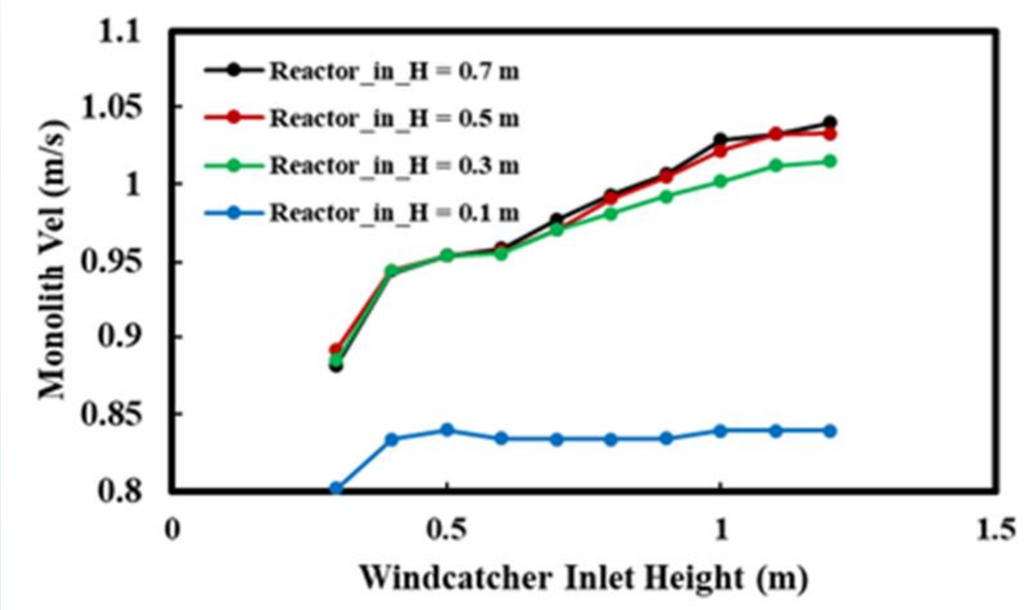
Geometric parameter	Simulated value
Wind velocity	5 m/s
Windcatcher_in_H	Variable
Reactor_in_H	Variable
Windcatcher_W	80 cm
Channel_H	30 cm
Monolith_W	50 cm
Monolith_H	50 cm
Pitch	3 mm

CFD for Passive Air Contactor

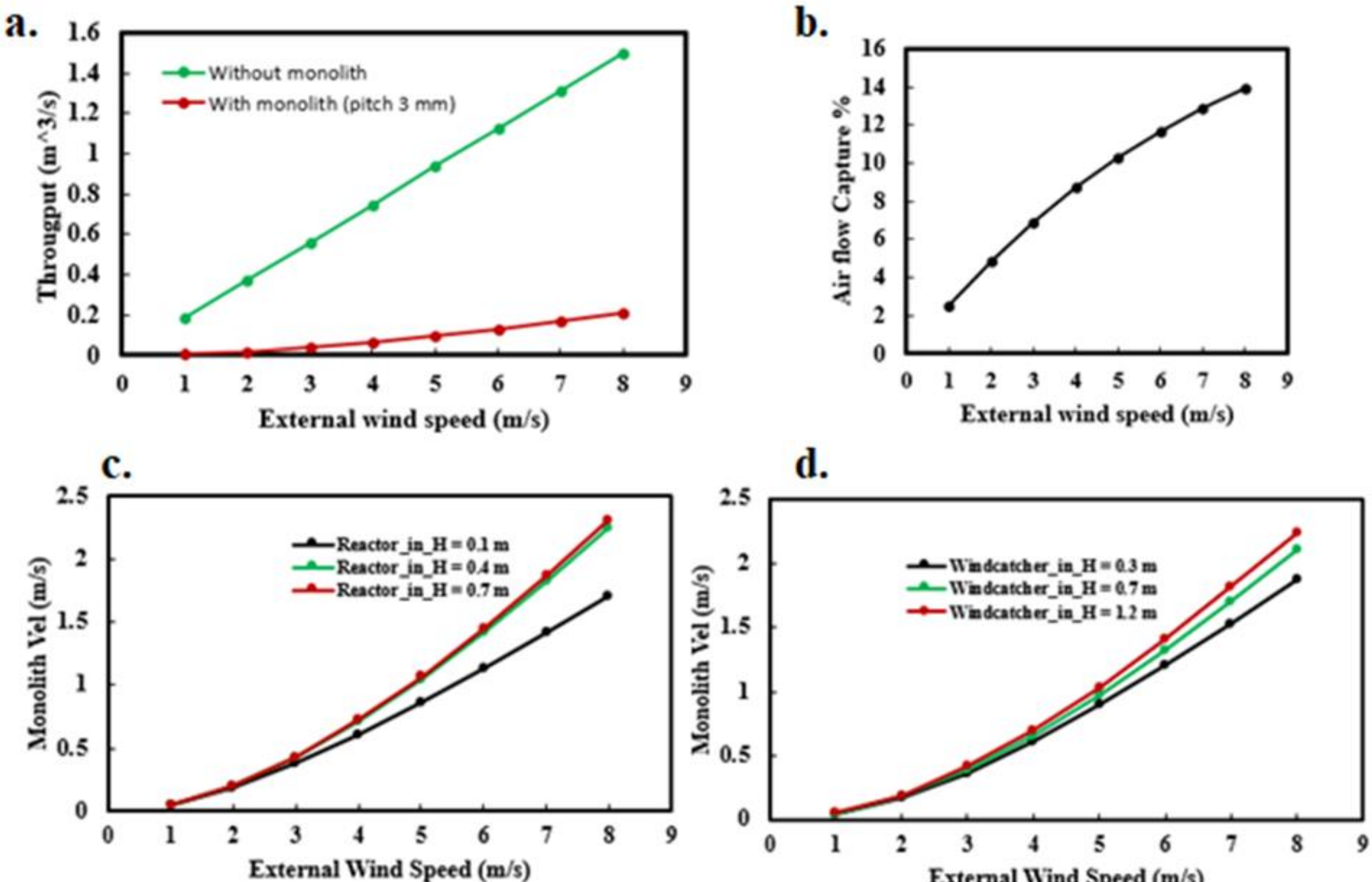


CFD for Passive Air Contactor

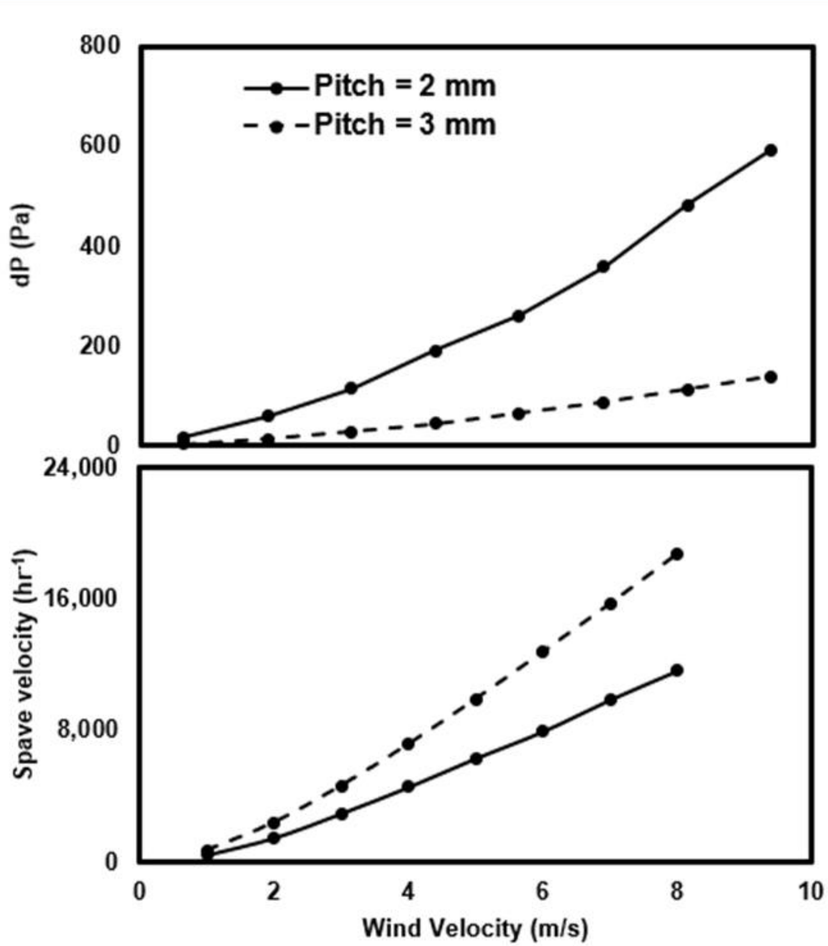


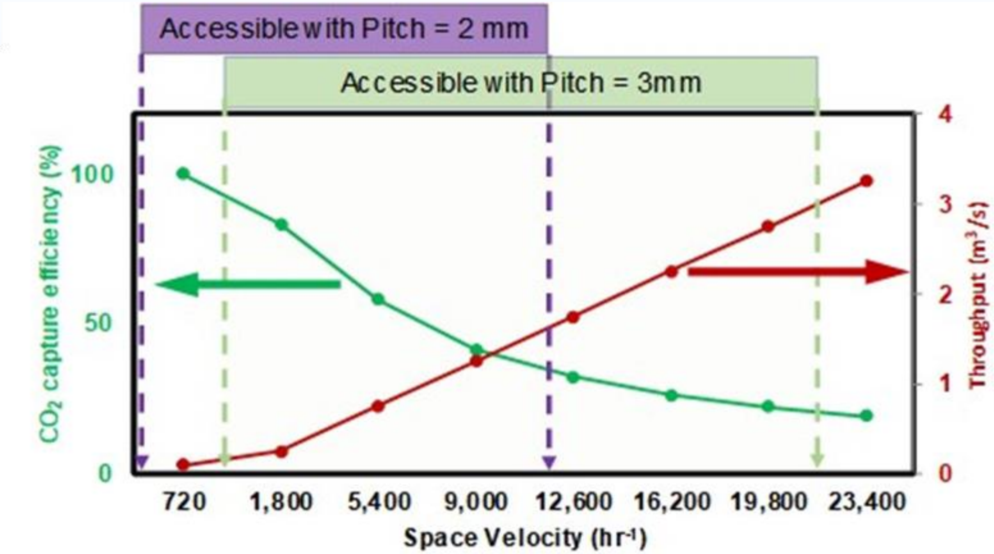


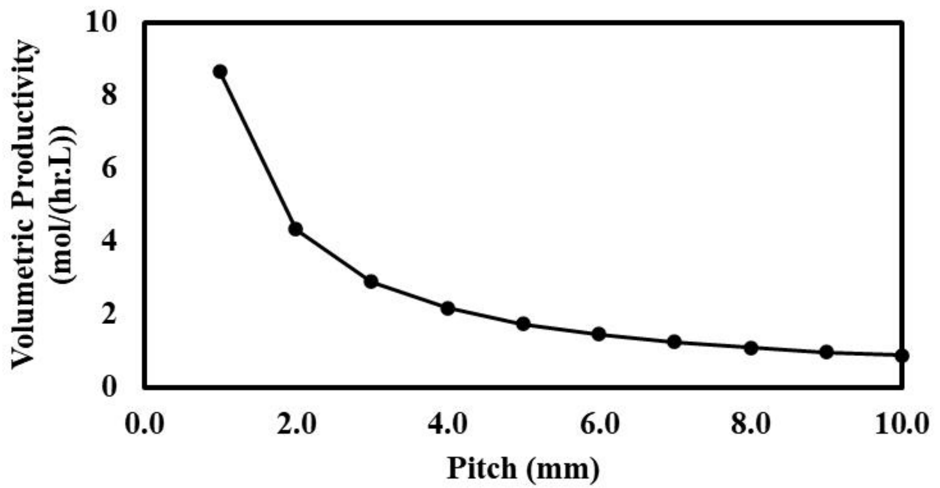
CFD for Passive Air Contactor



Estimated Performances for Sorbent-Washcoated Monolith

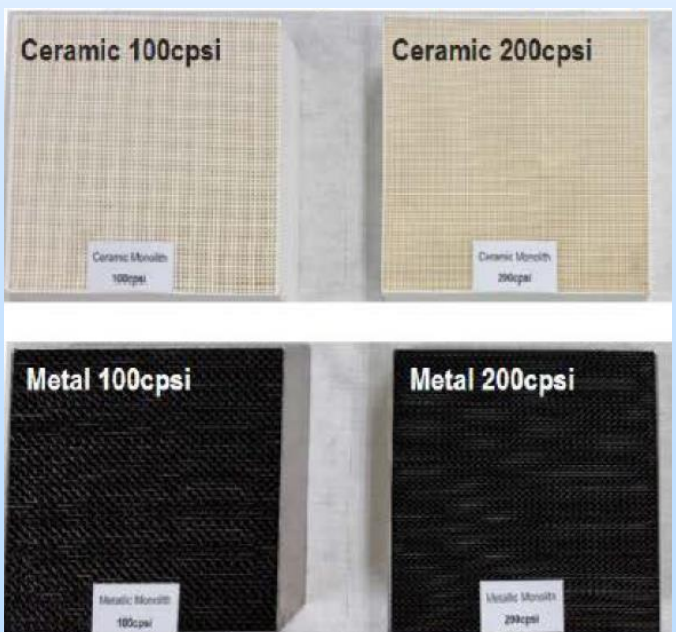


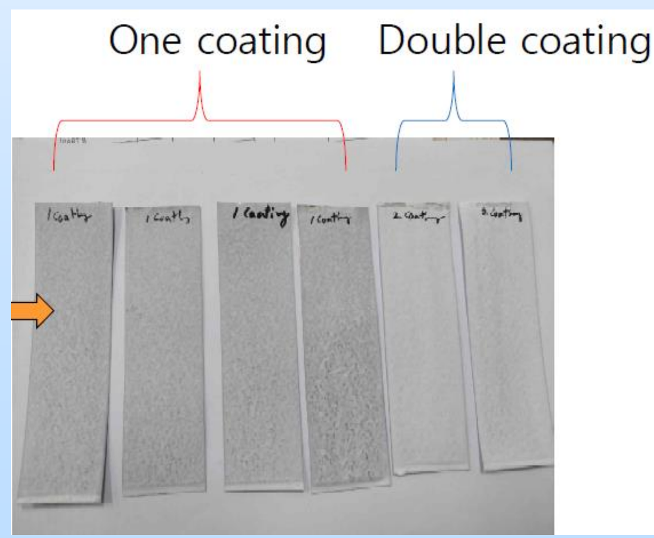




Plans for future testing/development

- Task 2: CFD combined with adsorption kinetics for DAC
- Task 4: Sorbent-washcoated monolith structure
  - ✓ Determine coating formulations
  - ✓ Develop scaled monoliths after testing small monoliths
- Task 6: Performance evaluation of sorbent-washcoated monolith in DAC system to be installed in environmental chamber.





Summary Slide

- Sorbent technology based on modified amine and hybrid substrate
- Collaboration with BASF and Daeyoung on developing sorbent-washcoated monoliths for DAC
- Systematic and rational DAC design using CFD combined with adsorption kinetics
- Performance evaluations of DAC system in terms of wind directions, speeds, temperature, and humidity in environmental chamber

Appendix

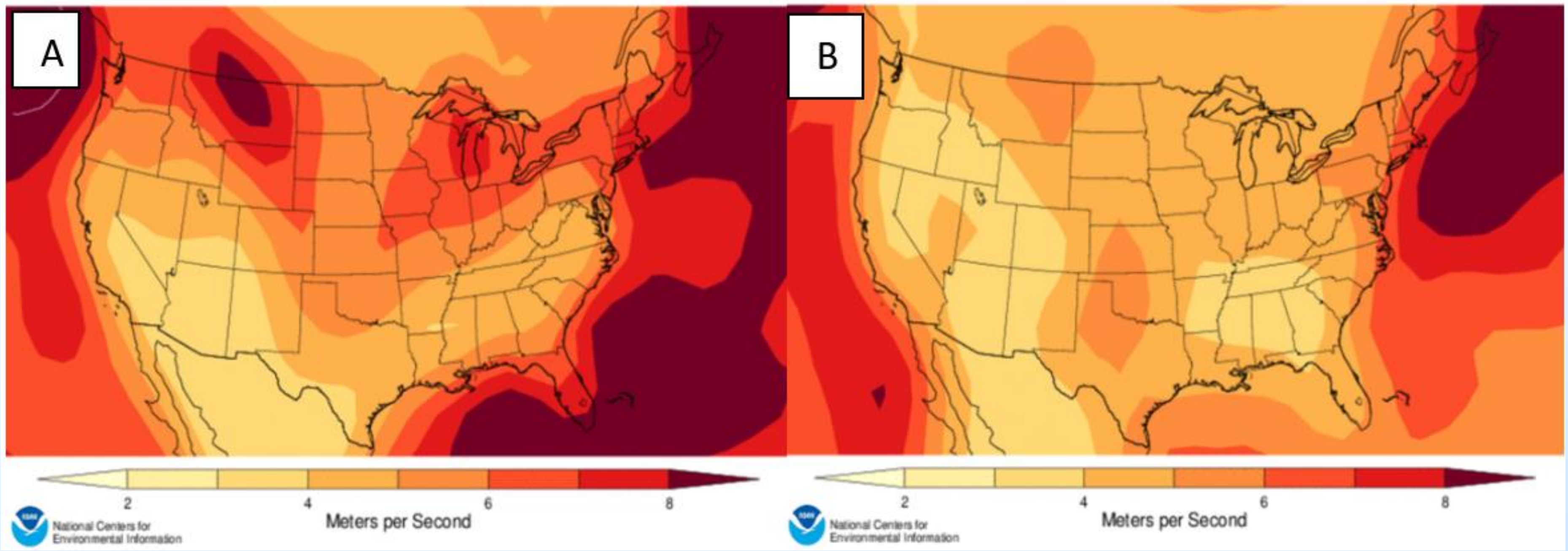
Organization Chart

- University of Cincinnati (UC)
  Project management, Sorbent manufacture and performance, Adsorption/desorption kinetics, Adsorption kinetic modeling, System development
  Joo-Youp Lee (PI)
  - UC
    CFD
    Aashish Priye (Co-PI)
  - BASF
    Monolith structure
    Gregg Sanko (Co-PI)
  - Daeyoung C&E
    Monolith structure
    Myungjin Ga (Co-PI)
  - Trimeric
    TEA/LCA
    Darshan Sachde (Co-PI)

Gantt Chart

		Months from Project Start Date (PSD)																							
Task	**Description**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1.0	**Project Management and Planning**																								
1.1	Project Management Plan																								
1.2	Technology Maturation Plan																								
2.0	**CFD and CO_2 Adsorption Kinetics**																								
2.1	CFD Model through Monolith in Air Contactor																								
2.2	CO_2 Adsorption Kinetics																								
2.3	CFD Model Combined with CO_2 Adsorption Kinetics																								
3.0	**Sorbent Manufacture and Long-term Evaluation**																								
3.1	Manufacture of CO_2 Sorbent																								
3.2	Long-term Lab-scale Evaluation																								
4.0	**Sorbent-washcoated Monolith Structure**																								
4.1	Development of Sorbent-washcoated Monolith																								
4.2	Determination of Cell Size and Length																								
5.0	**DAC System**																								
5.1	Design of DAC System										★														
5.2	Fabrication of DAC System																								
5.3	Start-up of DAC System\																								
6.0	**Performance Evaluation of DAC System**																								
6.1	Measurements of Temperature, Humidity, Speed, and CO_2 Concentration																								
6.2	Performance Evaluations																								
7.0	**TEA and LCA**																								
7.1	Development of Technical Cost Modeling (TCM)																								
7.2	Development of Life Cycle Inventory (LCI)																								
7.3	TEA/LCA Assessment of Scale-up DAC Technology																								
7.4	Final State-Point Data Table																								

Average Wind Speeds in Continental U.S.



Monthly average wind speed data for the month of (A) November 2020 and (B) May 2020 across the U.S. Accessed from the U.S. Wind Climatology database on National Centers for Environmental Information (NOAA) retried on June 29, 2021.