Enabling 10 mol/kg swing capacity via heat integrated sub-ambient pressure swing adsorption

Ryan P. Lively
Principal Investigator

Yoshiaki Kawajiri, Matthew J. Realff, David S. Sholl, Krista S. Walton
Co-Principal Investigators
Georgia Institute of Technology
School of Chemical & Biomolecular Engineering
Atlanta, GA 30332

DOE-NETL CO_2 Capture Technology Project review Meeting
Thursday, August 24th , 2017

inmondo tech

Georgia Tech School of Chemical & Biomolecular Engineering

Key Idea:

***Combine*:**

(i) Sub-ambient gas processing and energy recovery with

(ii) ultra-porous metal-organic frameworks and

(iii) space- and energy-efficient fiber sorbent contactors

to yield a game-changing process strategy

Project scope—Re-thinking general assumptions about post-combustion CO_2 capture

ExxonMobil Research and Engineering

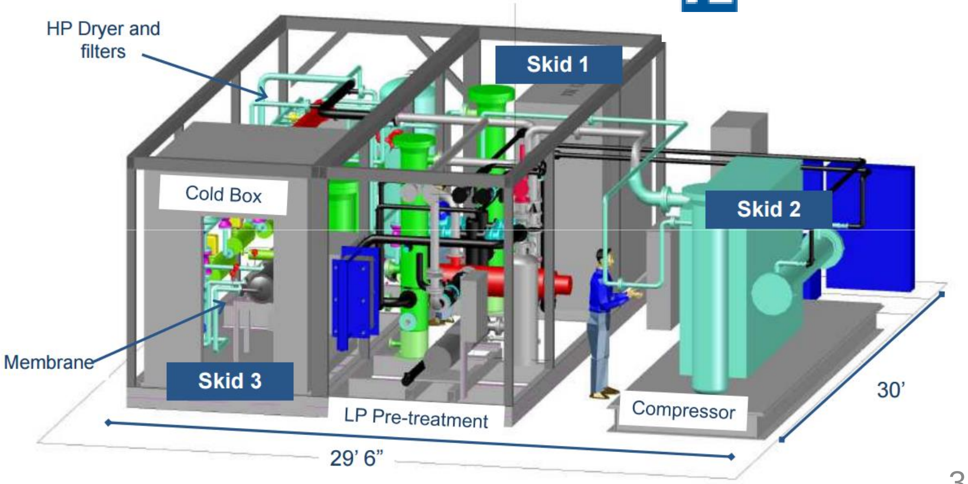
QuestAir Pure Innovations

- Rapid pressure swing adsorption is more straightforward than rapid temperature swing adsorption (the former has been commercialized)
- Immense pore volume and surface area of MOFs are advantageous at sub-ambient conditions and moderate CO_2 partial pressures (~1-2 bar)
- Sub-ambient conditions increase adsorption selectivity and working capacity—even without adsorbent structural changes
- Weaknesses of MOFs addressed through contactor (hollow fiber sorbents) and through process strategy

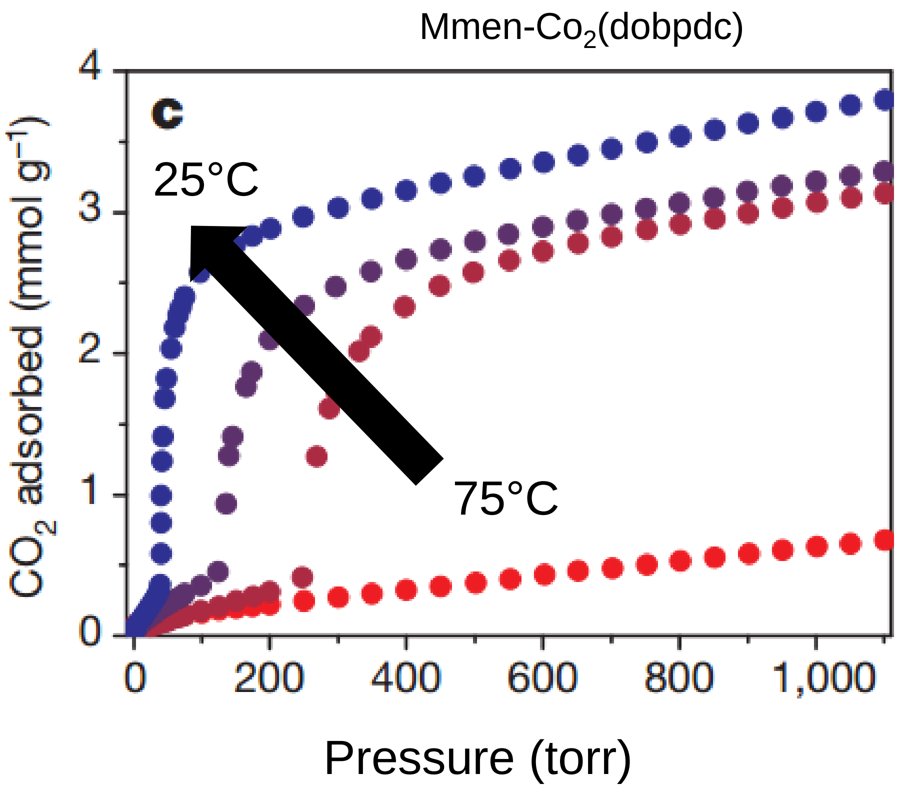
RCPSA

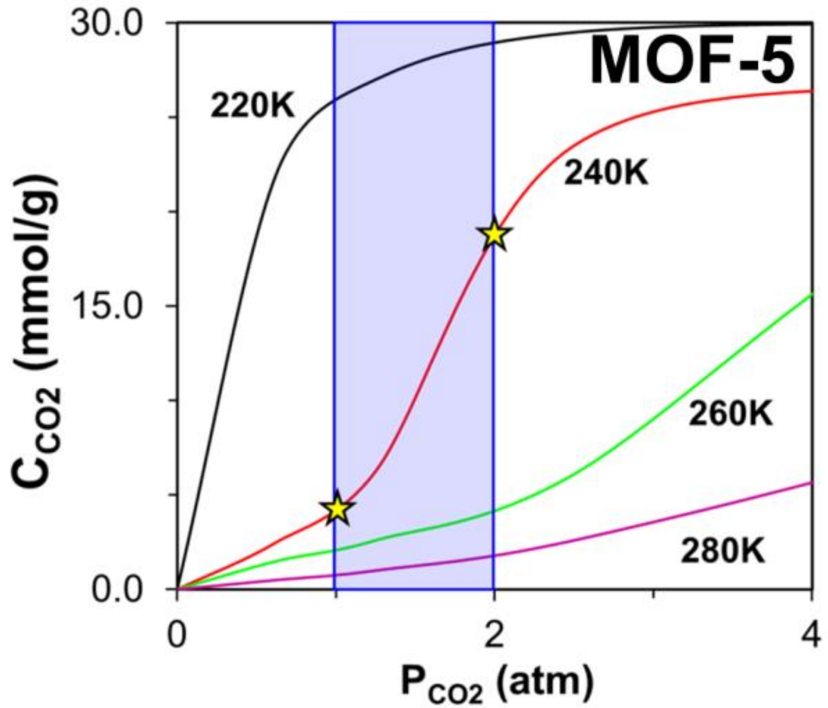
Sub-ambient membrane system

AIR LIQUIDE



Background: Metal-organic frameworks—State-of-the-art

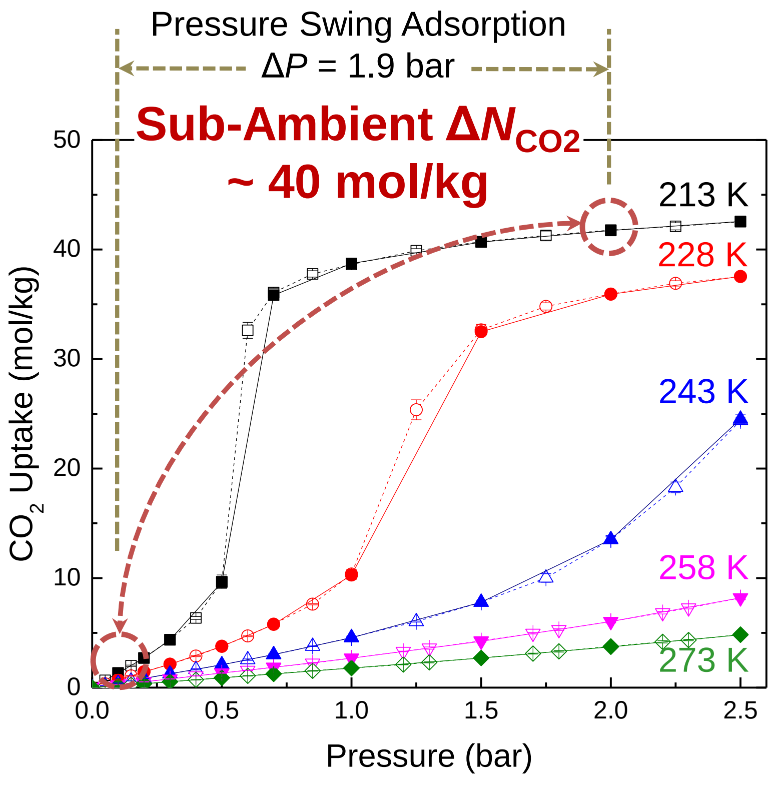


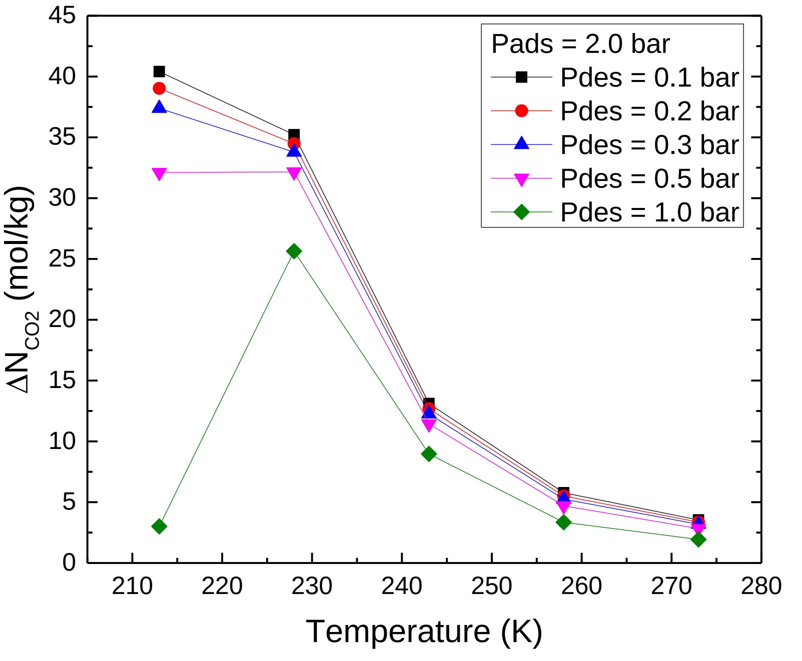


[1] TM McDonald, JR Long et al., *Nature*, 2015, 519, 303-308

[2] JM Simmons, T Yildirim et al., *Energ. Env. Sci.*, 2011, 4(6), 2177-2185

A wide variety of MOFs can hit >10 mol/kg swing capacities at sub-ambient conditions





[1] J Park, RP Lively, DS Sholl, *J. Mater. Chem. A.* 2017, 5, 12258-12265

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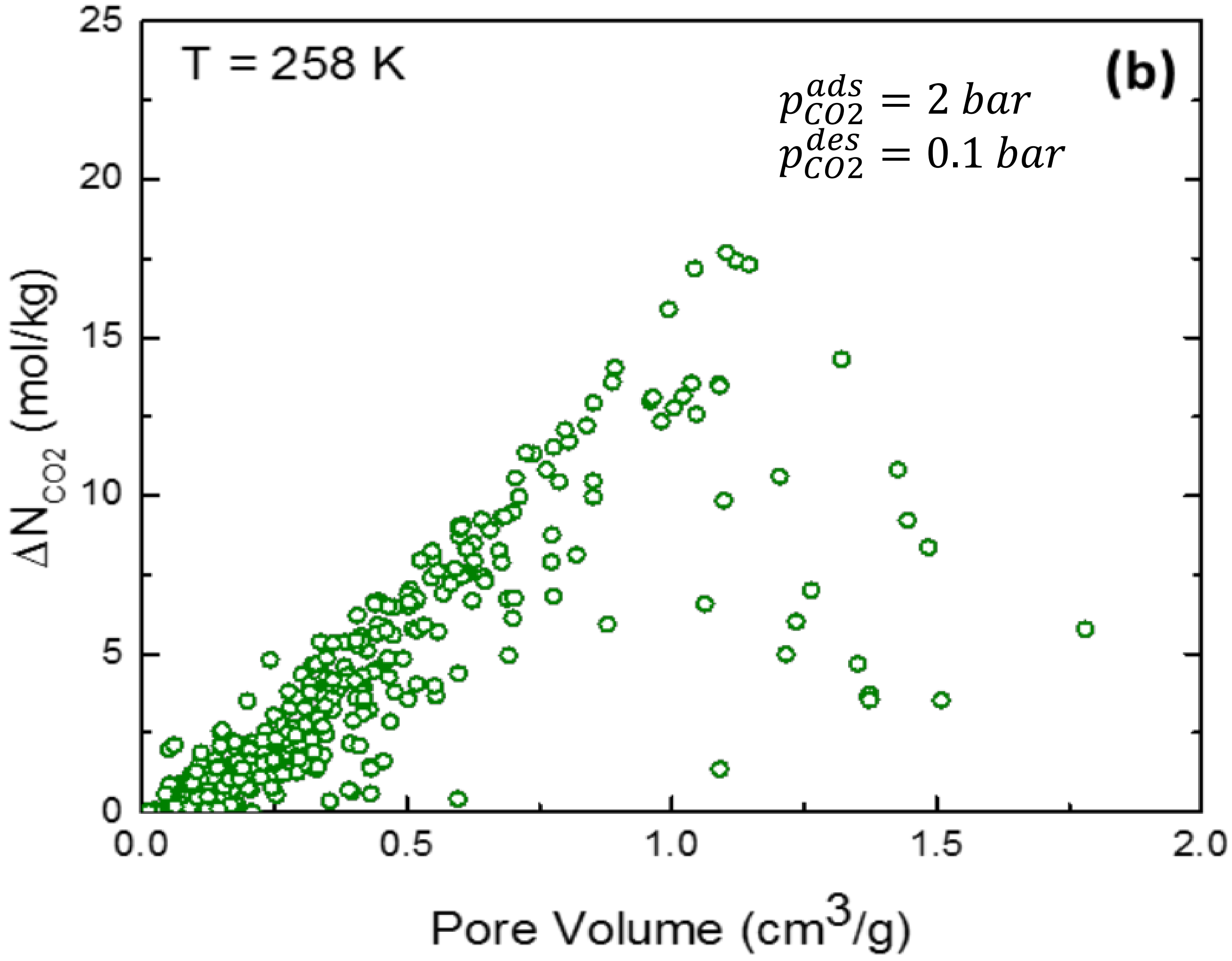

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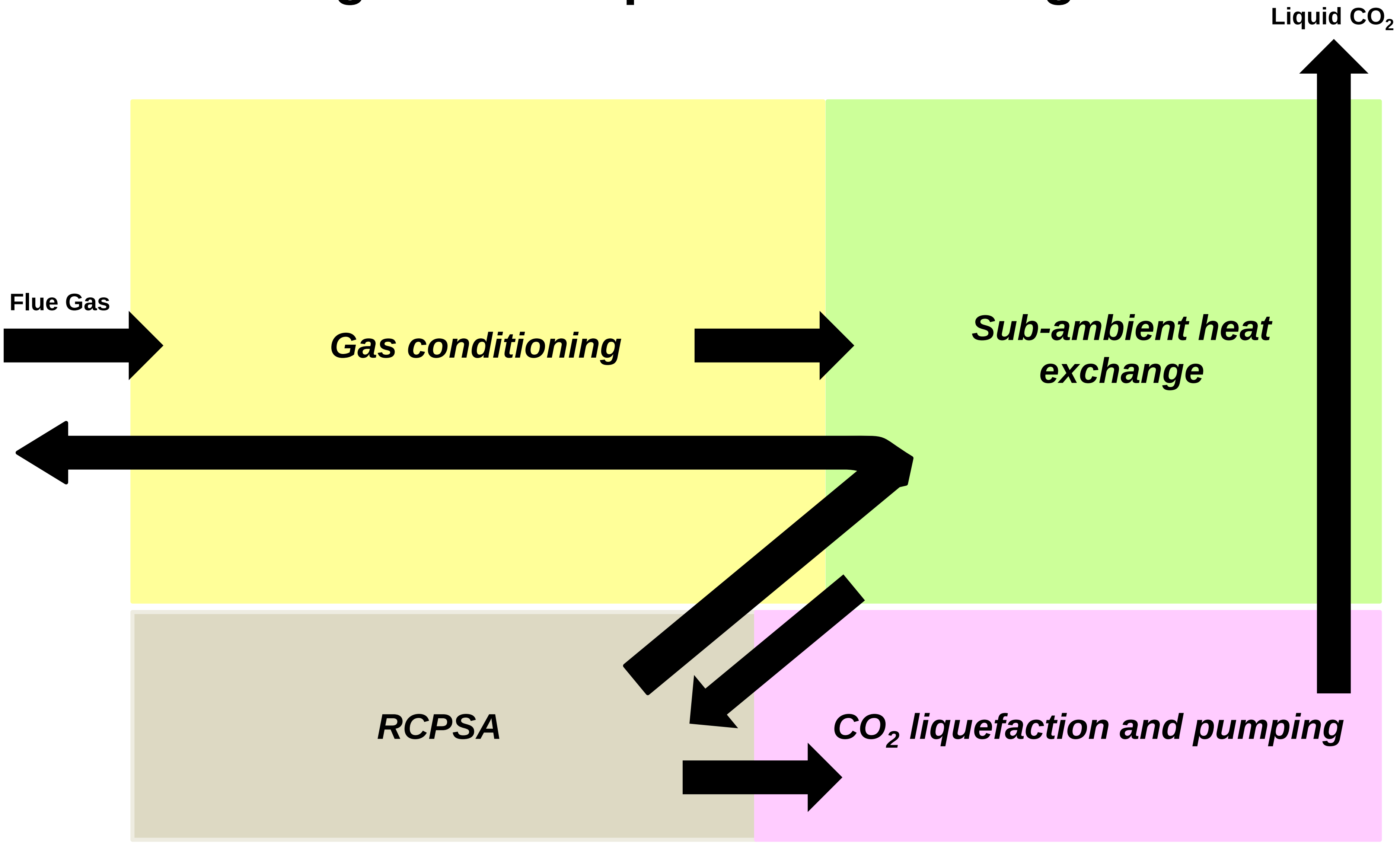
2^{nd} generation process flow diagram



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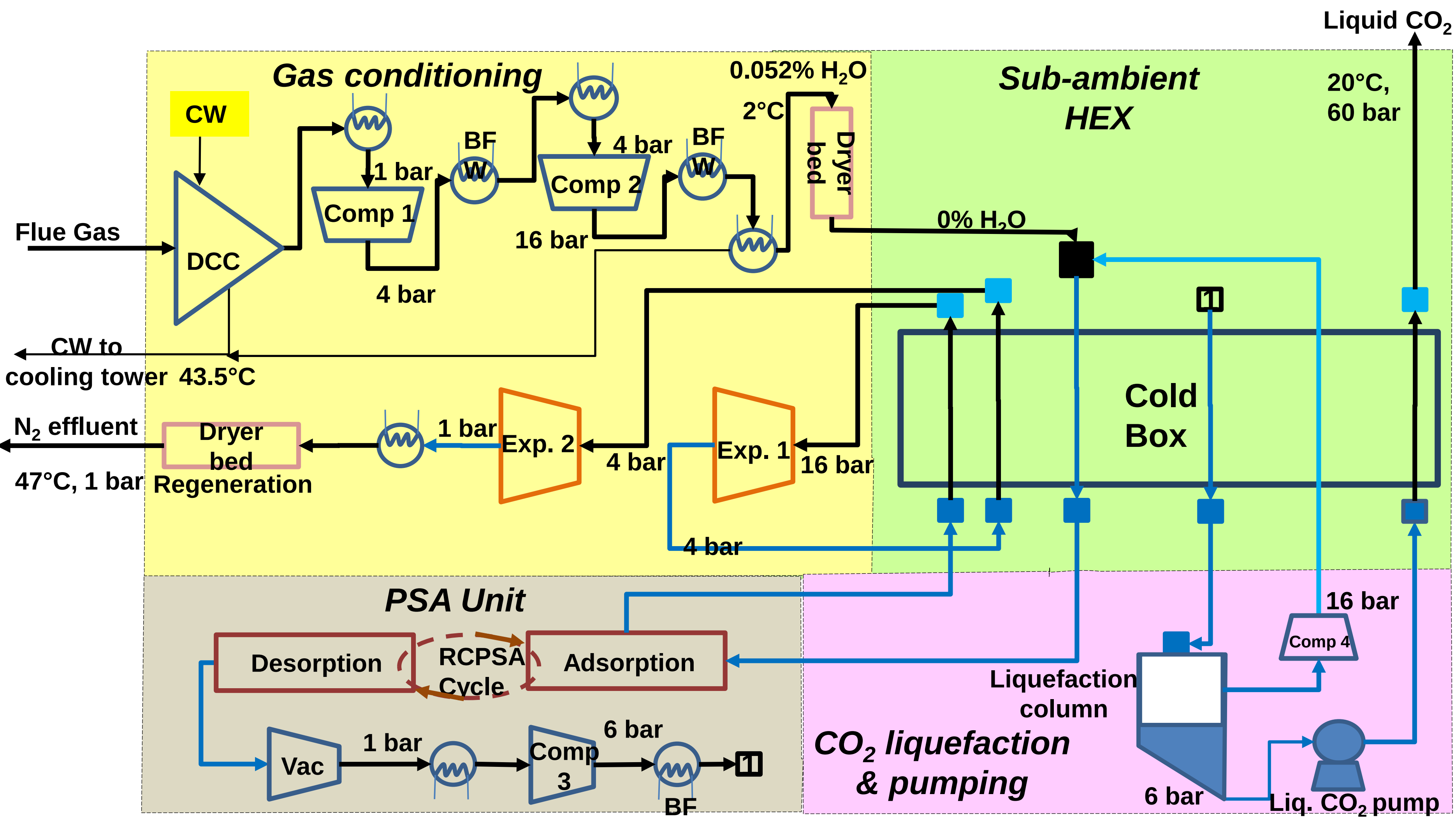
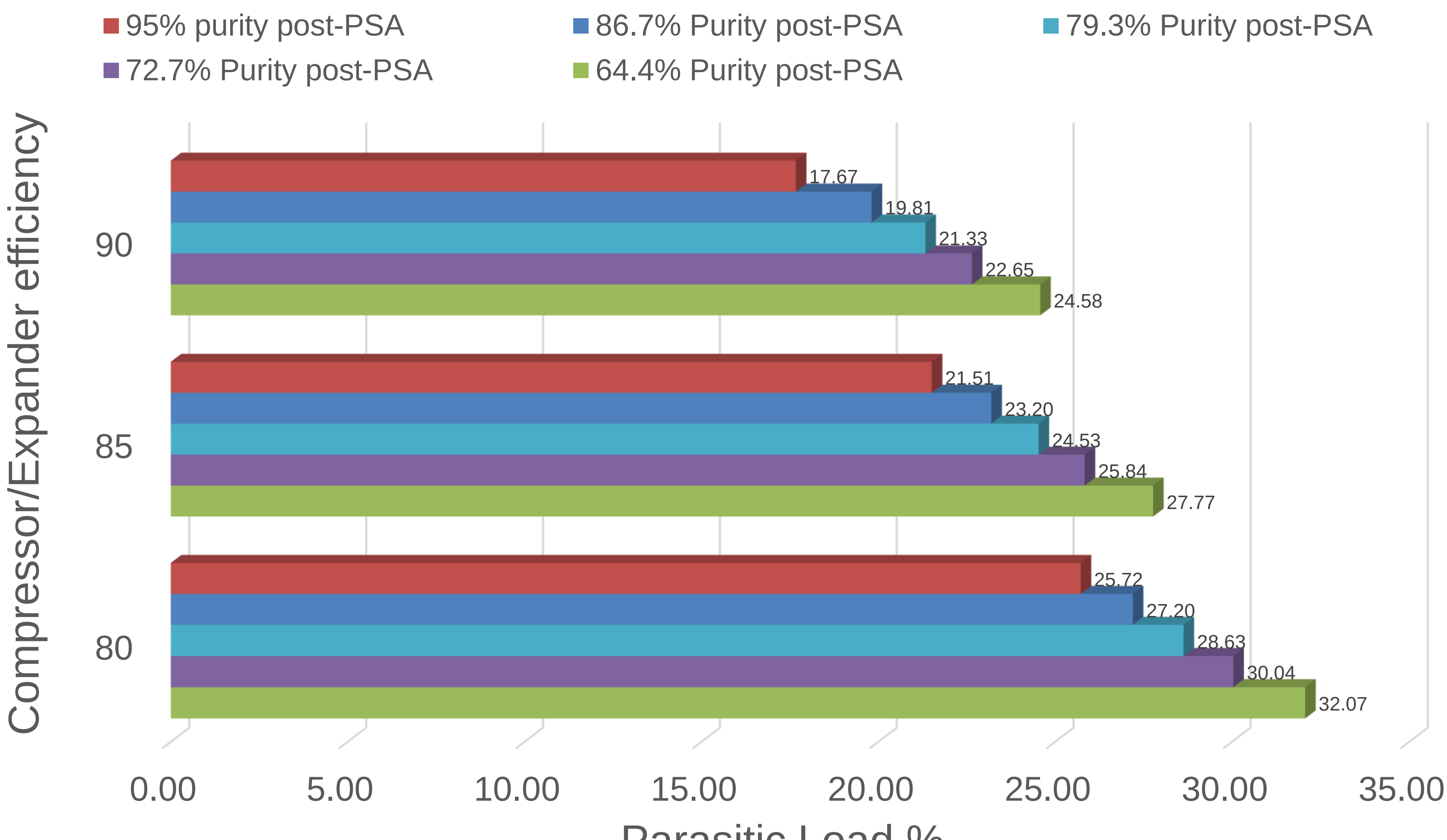


Preliminary technoeconomic analysis

Parasitic load (NETL Base Case 550 MW power plant)



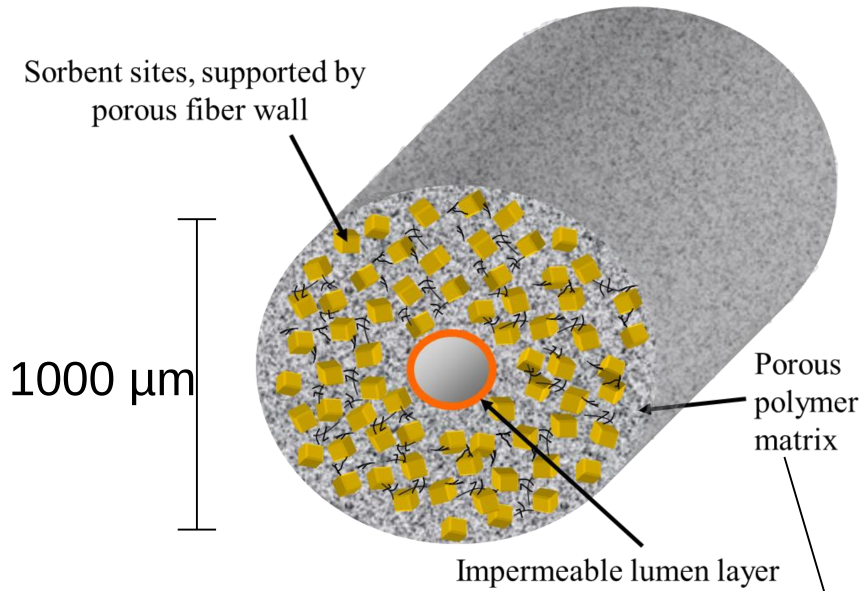
✔ Task 14 (process flow sheet optimization)

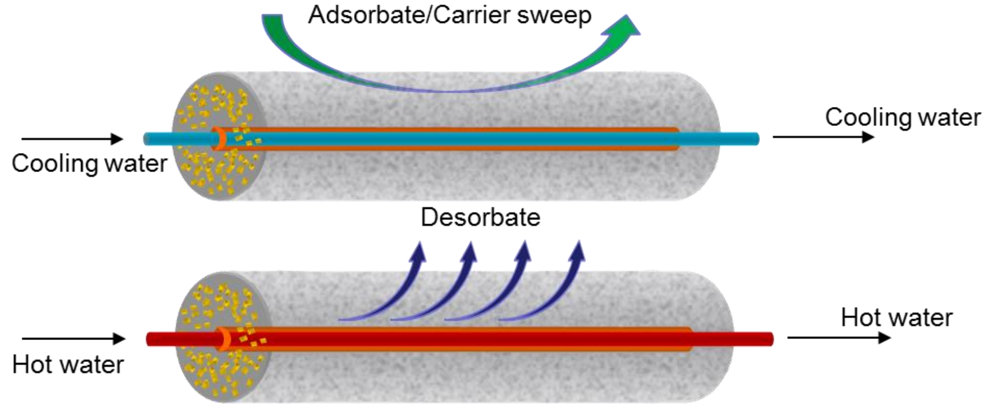
Preliminary technoeconomic analysis

Equipment	Cost (MM$)
compressors & expanders	74
HX	38
PSA	38
DCC & cooling tower	2
Liquid CO_2 pump	< 0.1
silica bed	< 0.1
Total	**~155**

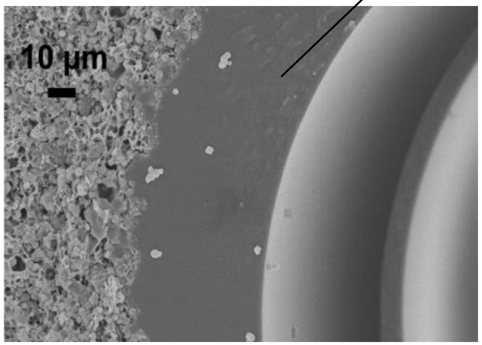
✓ Task 14 (process flow sheet optimization)

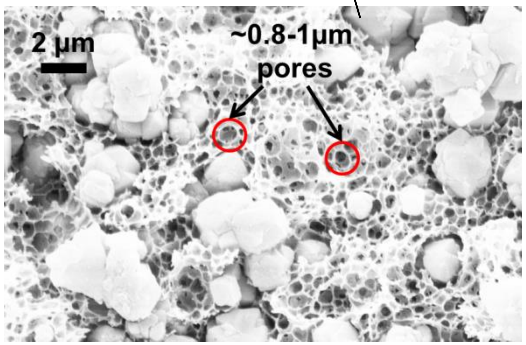
Background: Hollow fiber sorbents, a mass producible structured sorbent inspired by hollow fiber membrane spinning

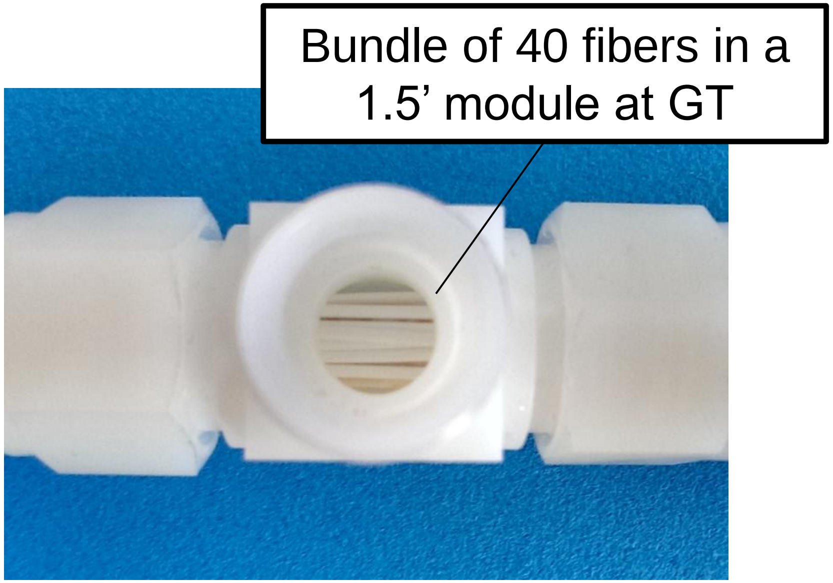




Ideal temperature swing adsorption

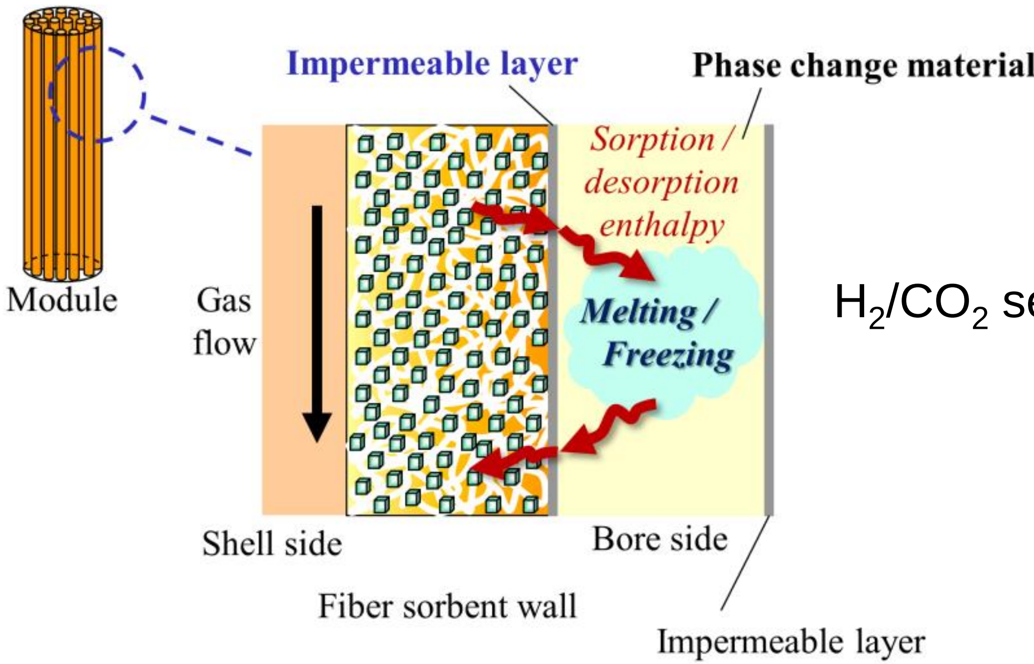




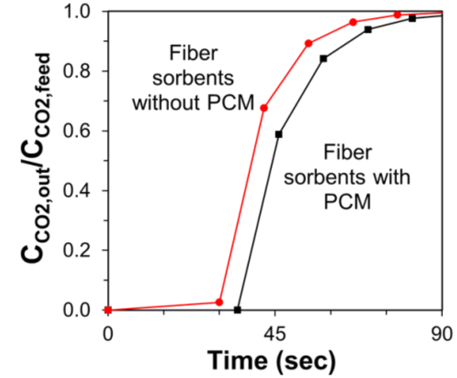


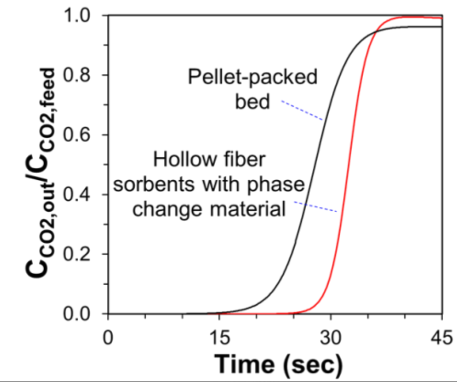
[1] RP Lively, WJ Koros et al., *Ind. Eng. Chem. Res.*, 2009, 48(15), 7314-7324

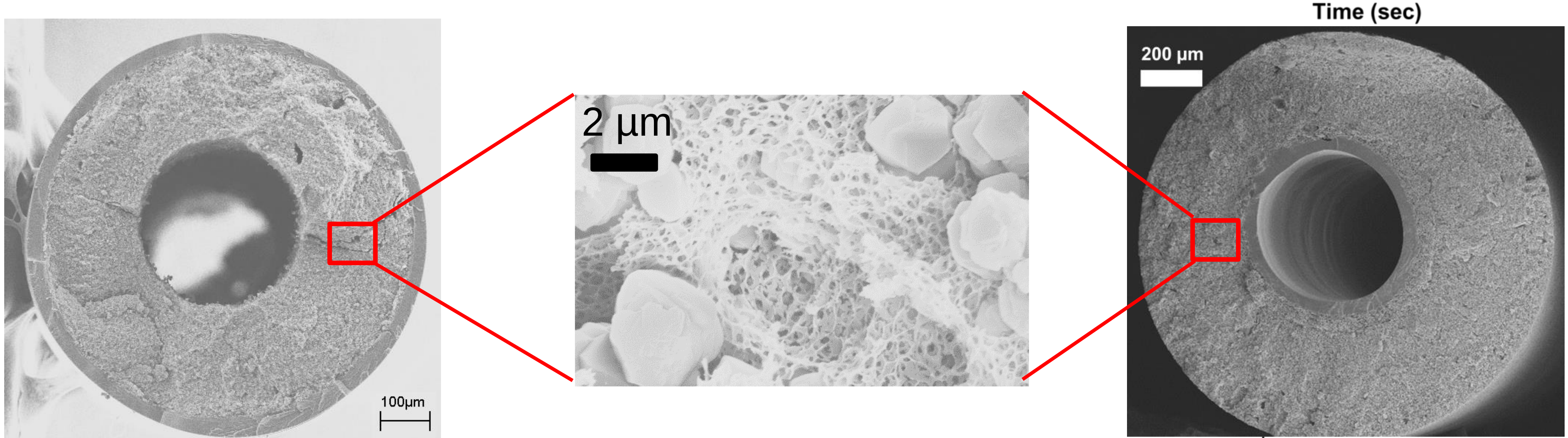
Background: Fiber sorbents for PSA applications



H_2/CO_2 separations

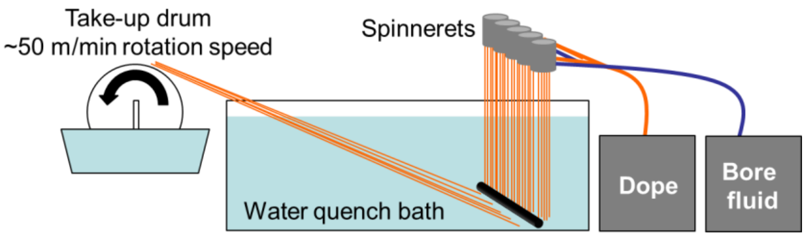






[1] RP Lively, WJ Koros et al., *Int. J. Hydrogen Energ.*, 2012, 37(20), 15227-15240

Post-synthesis formation of MOFs in fiber sorbents



Load metal oxide fibers into adsorption module

Task 7 (synthesize MOFs and spin fibers)

[1] BR Pimentel, RP Lively et al., *Ind. Eng. Chem. Res.* **2017**, 56(17), 5070-5077

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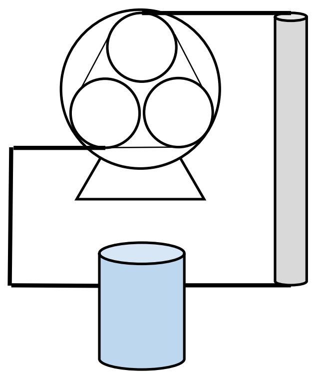

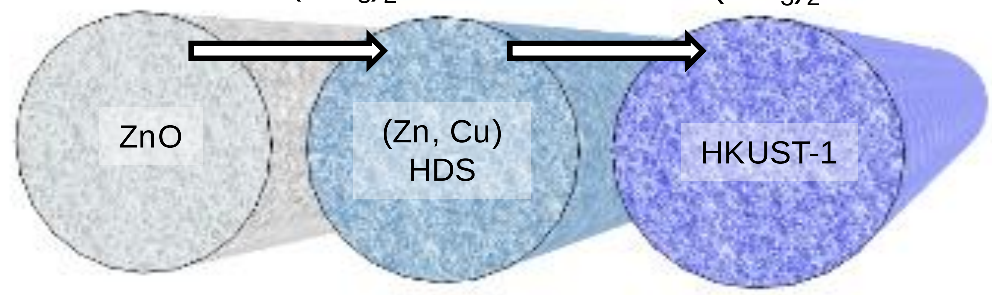

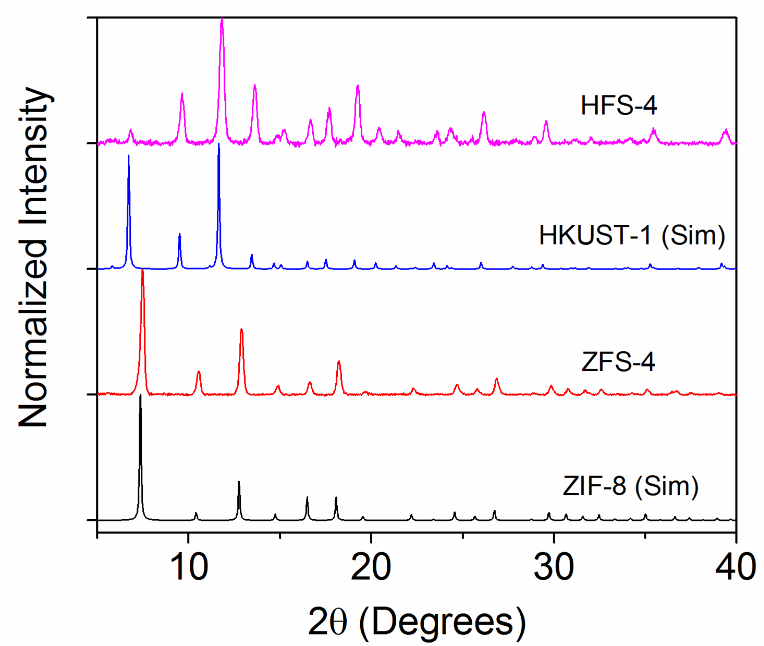

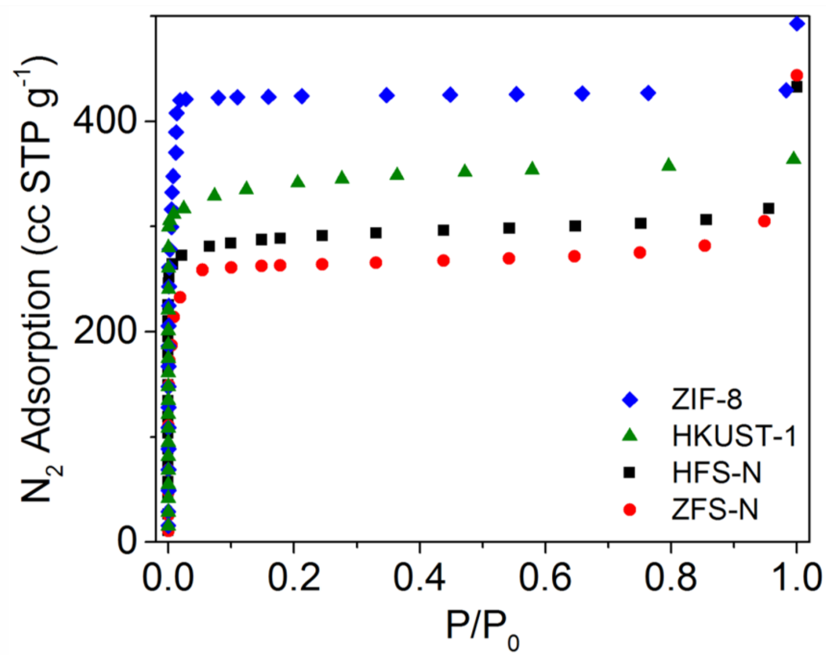

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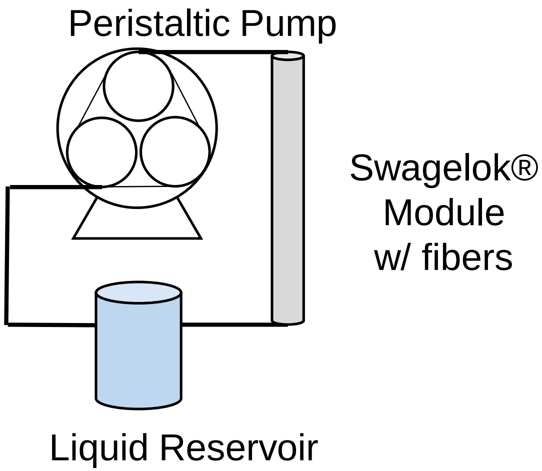

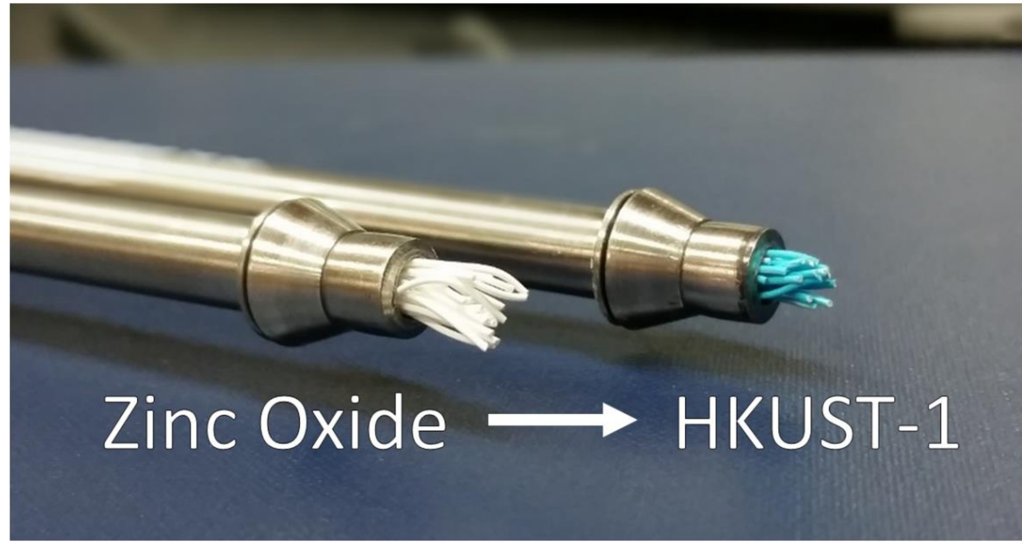

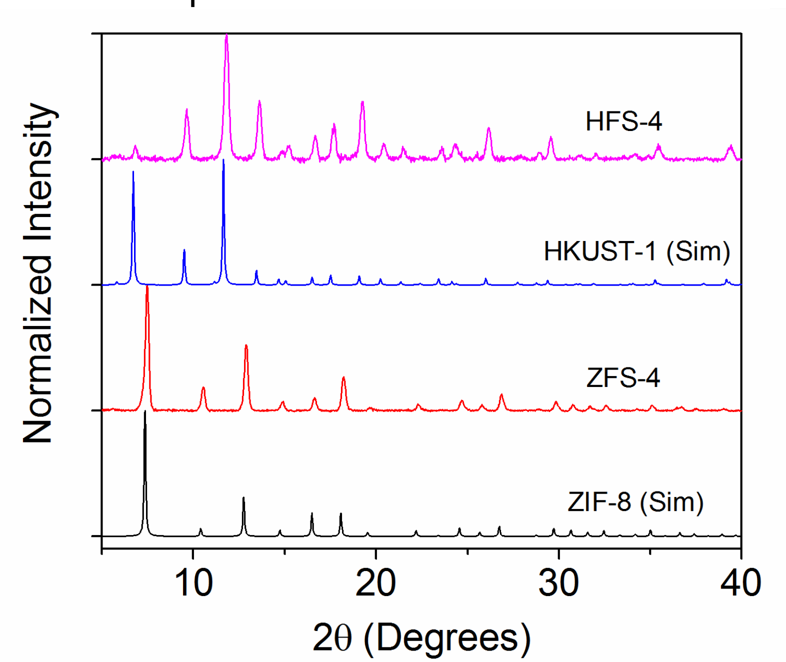

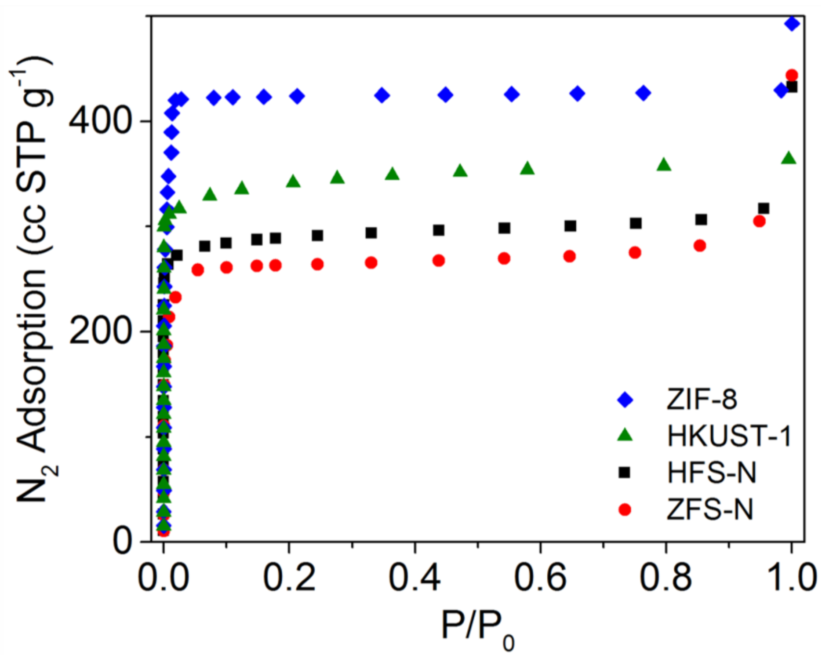

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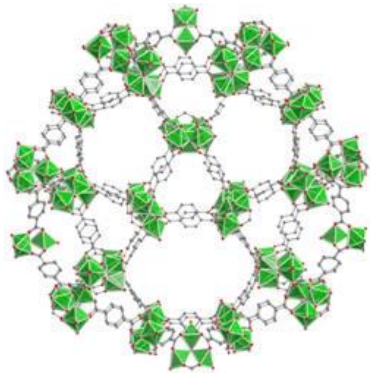
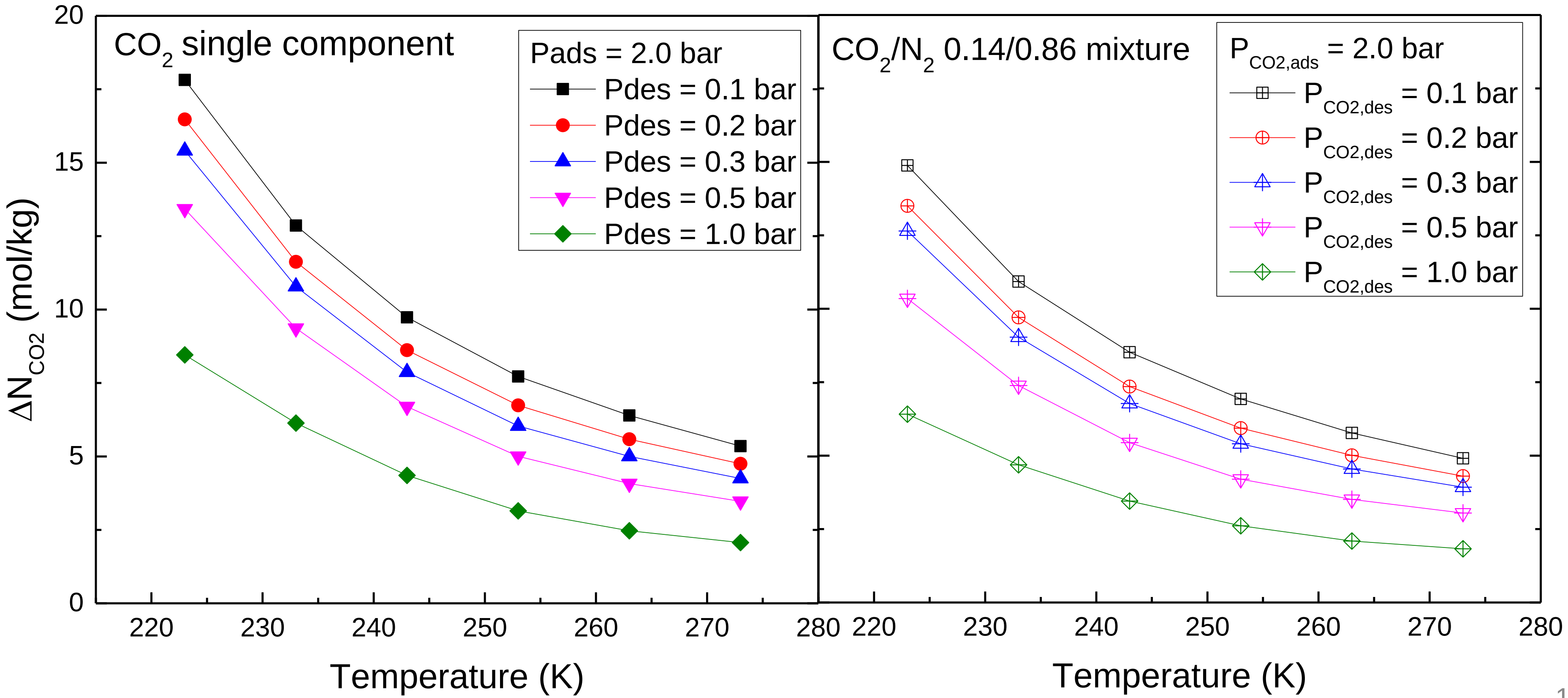
MIL-101(Cr) emerged as a promising candidate



Low cost ligands (benzene dicarboxylate)
Relatively low cost metal centers (chromium nitrate)
Scale-up is straight forward (70% yield on large batches)
Water stable



[1] J Park, RP Lively, DS Sholl, *J. Mater. Chem. A.* 2017, 5, 12258-12265
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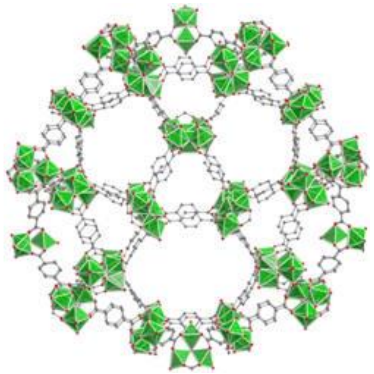

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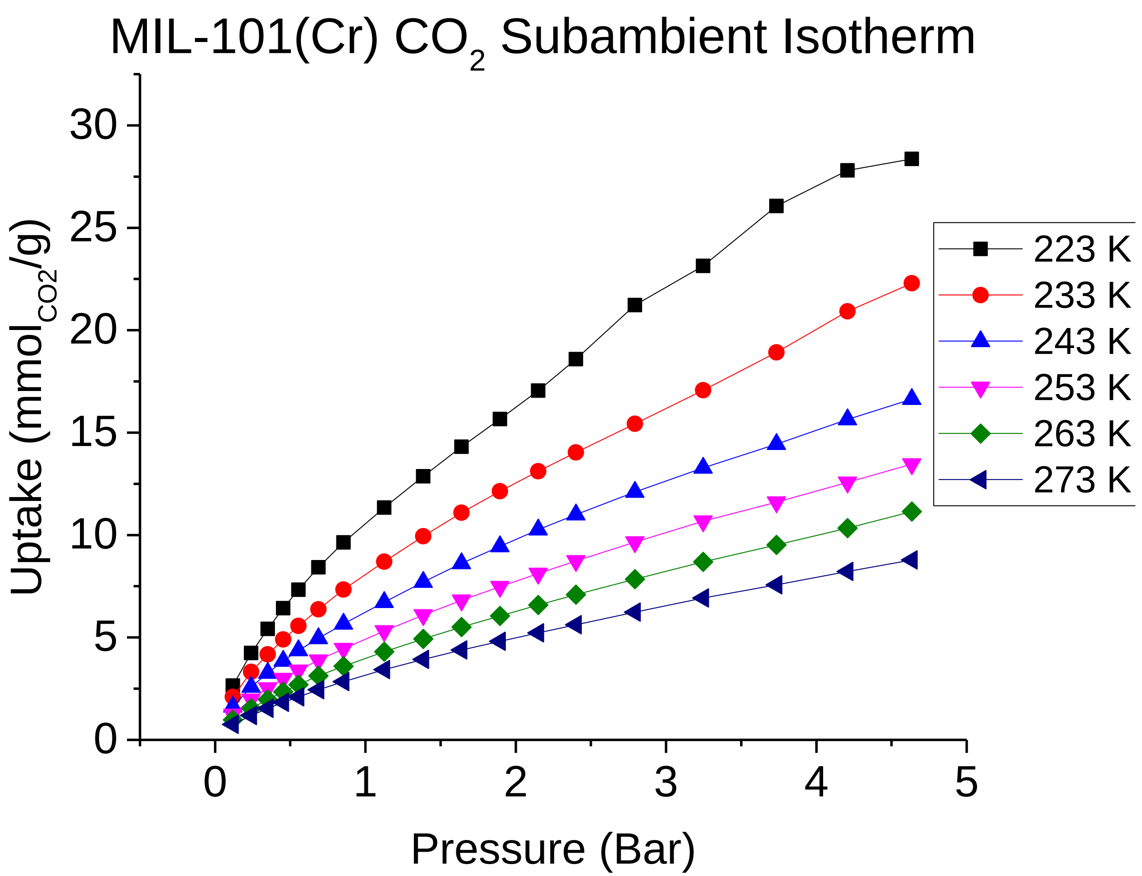

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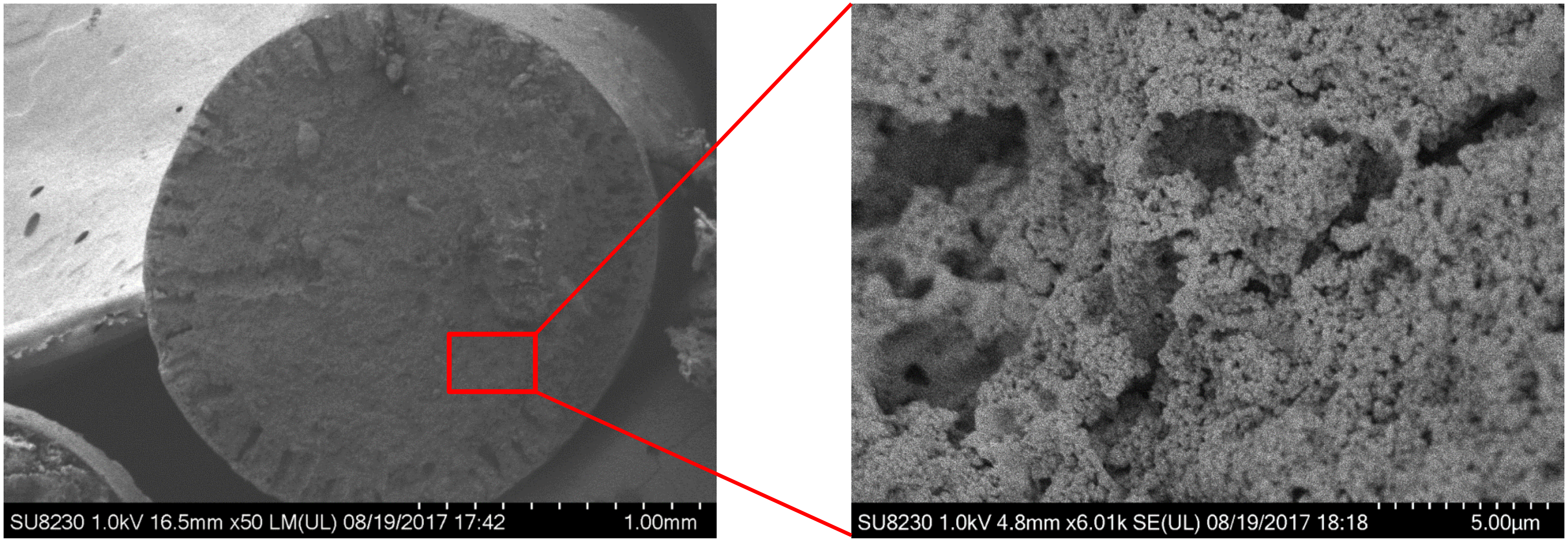
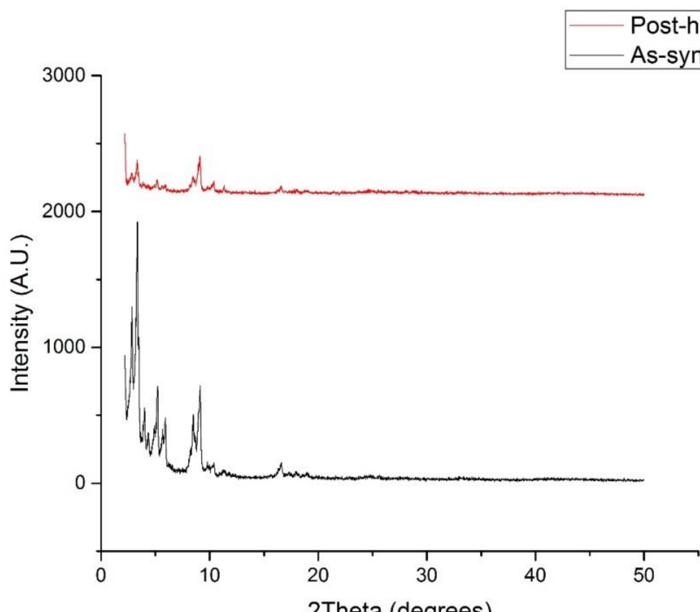
MIL-101(Cr) fiber sorbents





Solvent stability ✓
Water stability ✓

BET Specific Surface Area (m^2/g)	
As-synthesized	2740
Post-humid SO_2	2790

✓ Task 8 (moisture and acid gas stability—also completed for UiO-66)

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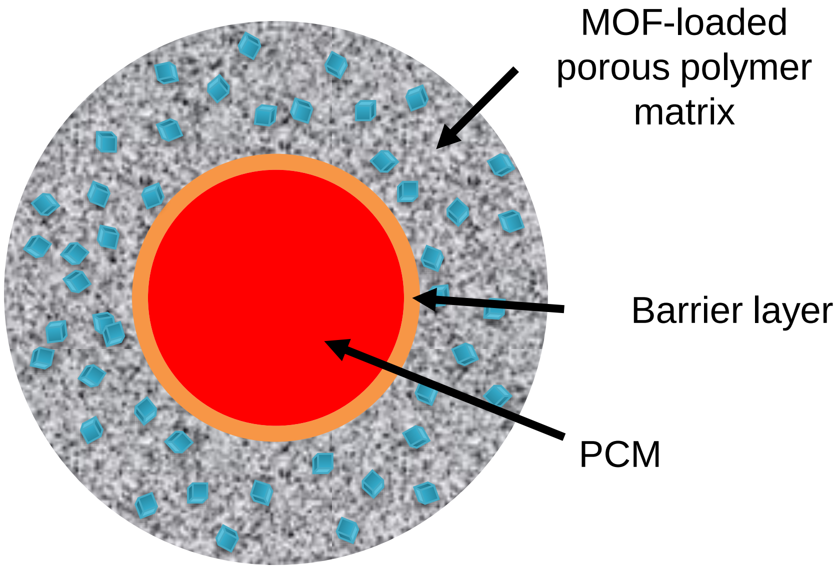
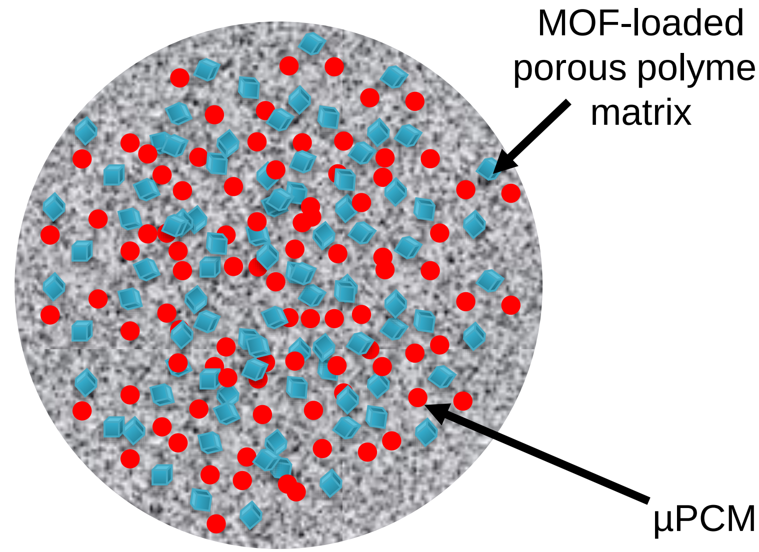
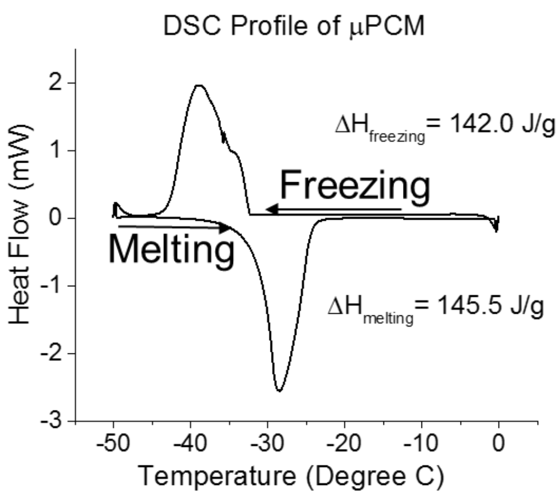
Installing thermal modulation into fiber sorbent contactors

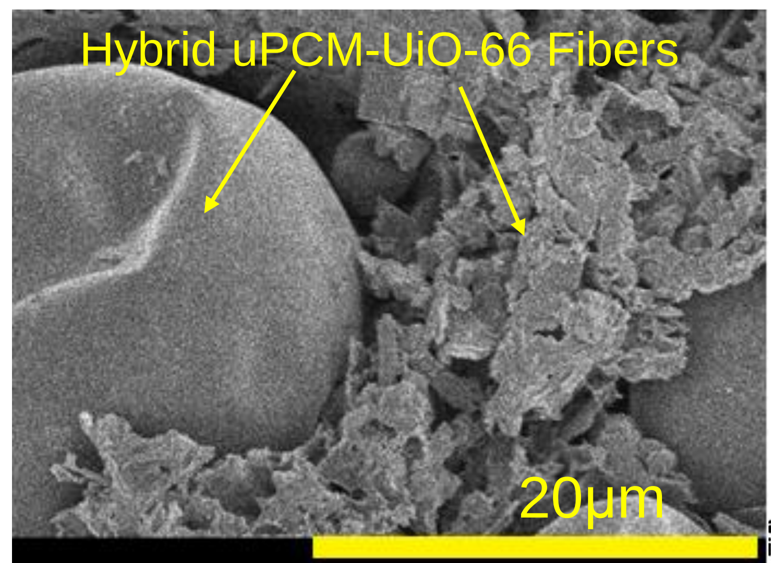


<u>3 steps:</u> spinning, barrier layer installation, PCM installation



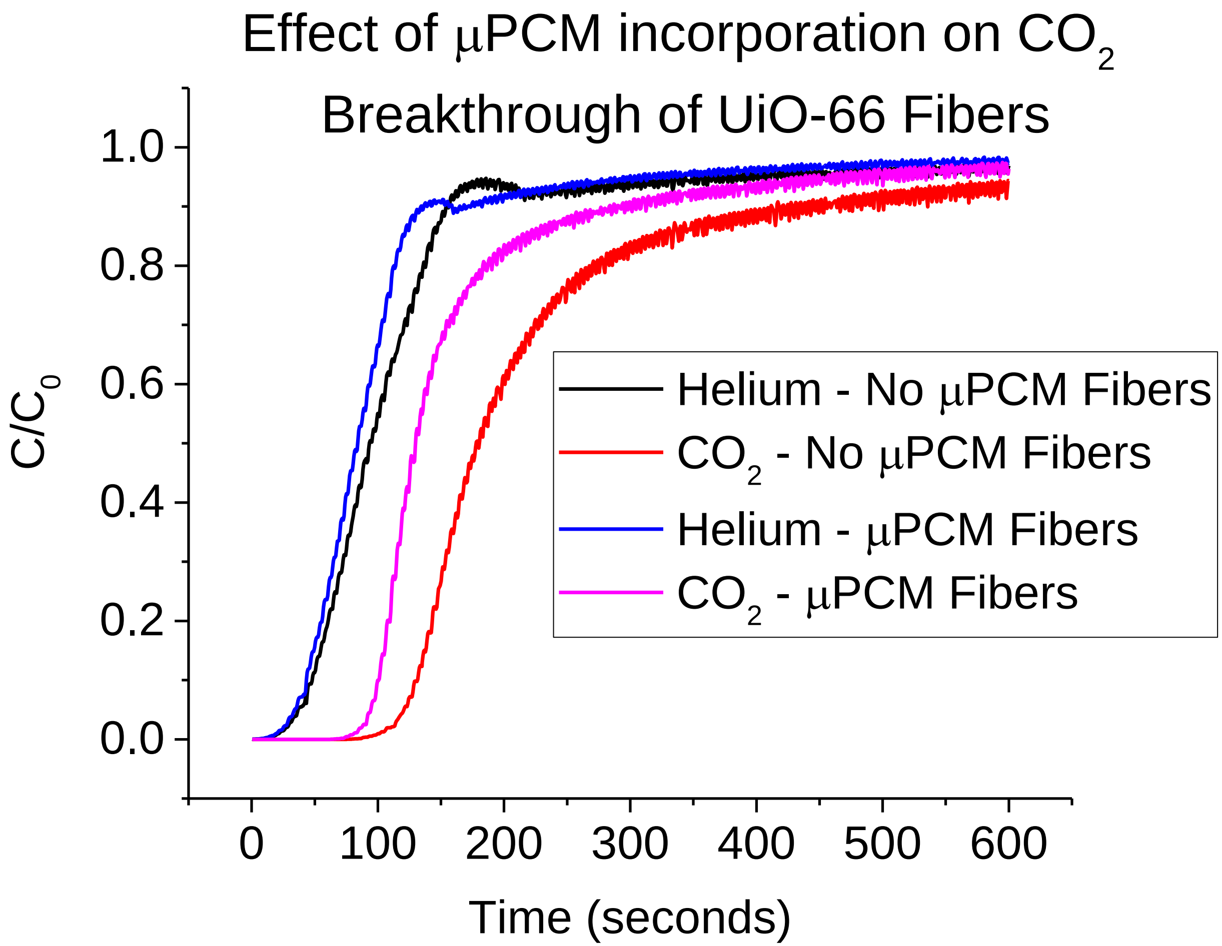
<u>1 step:</u> spinning





✔ Task 11 (integrate PCM into modules)

Performance of thermally modulated MOF fiber sorbents



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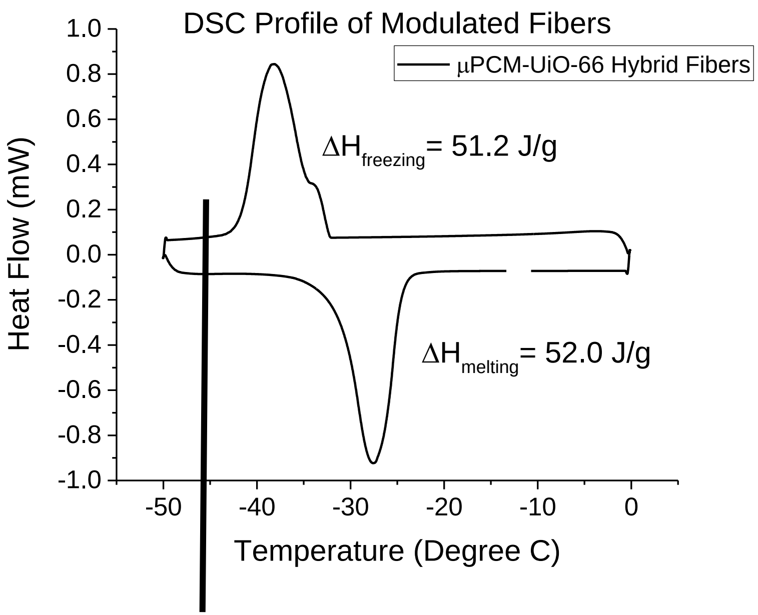
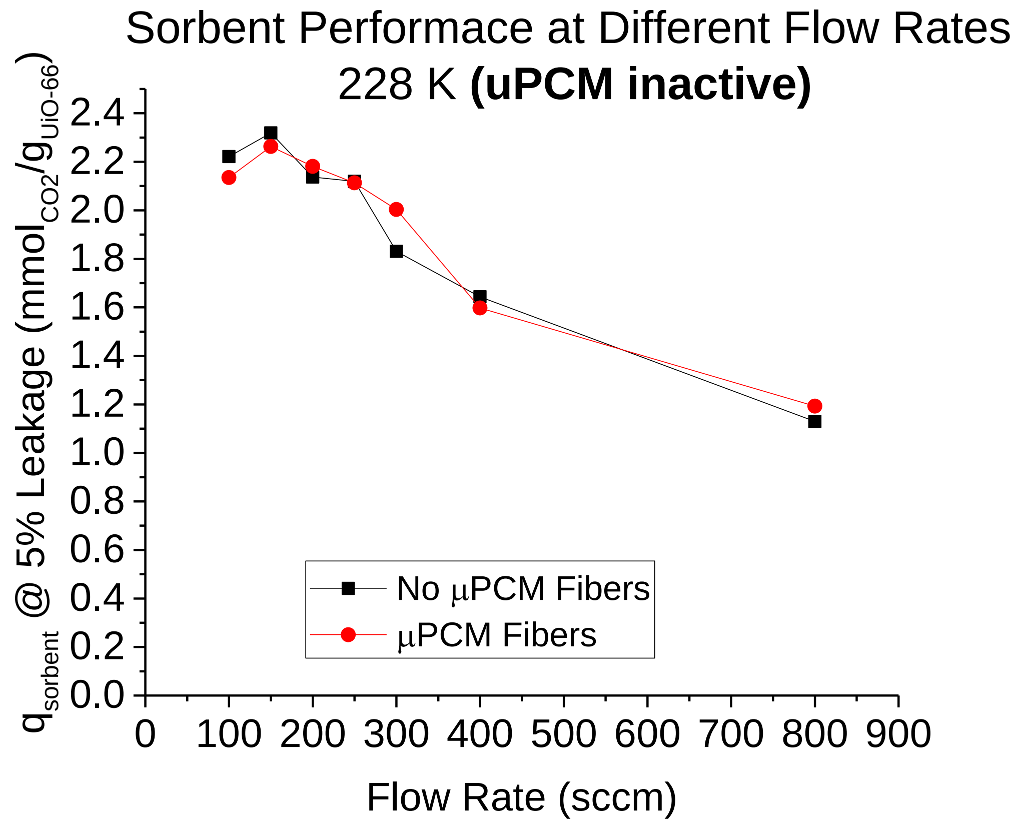
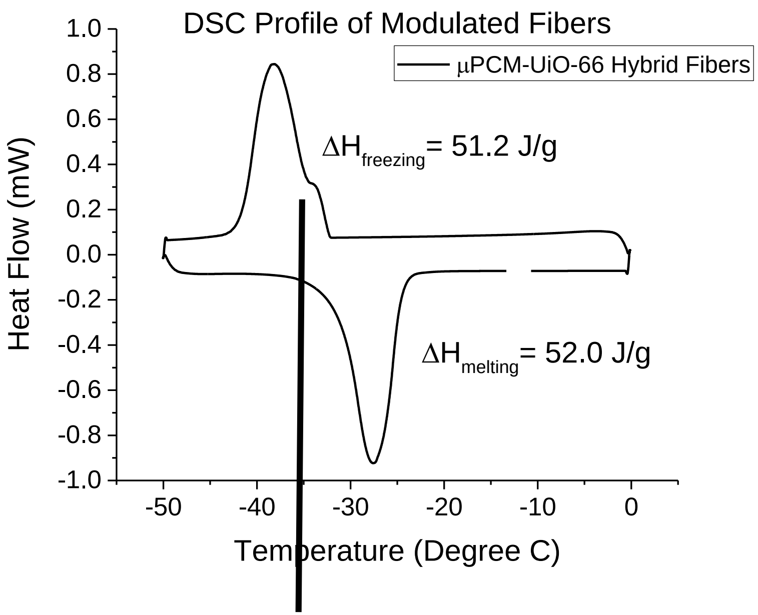


Operating Temperature

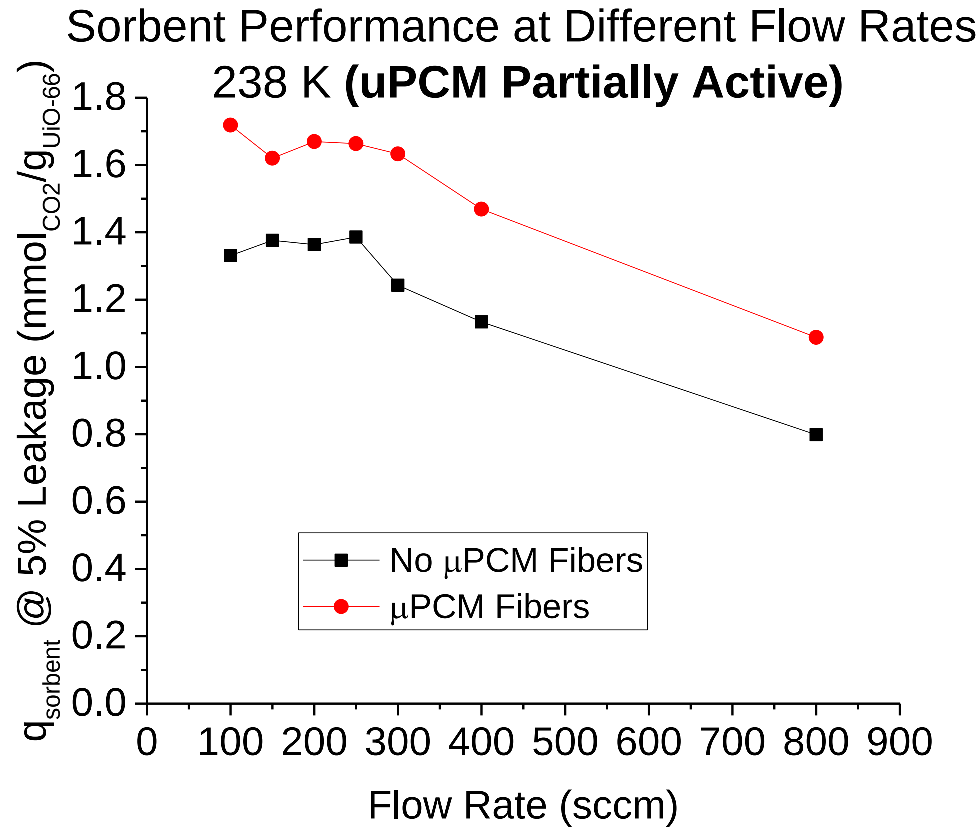


Task 10 (experimental PSA cycles)

Performance of thermally modulated MOF fiber sorbents



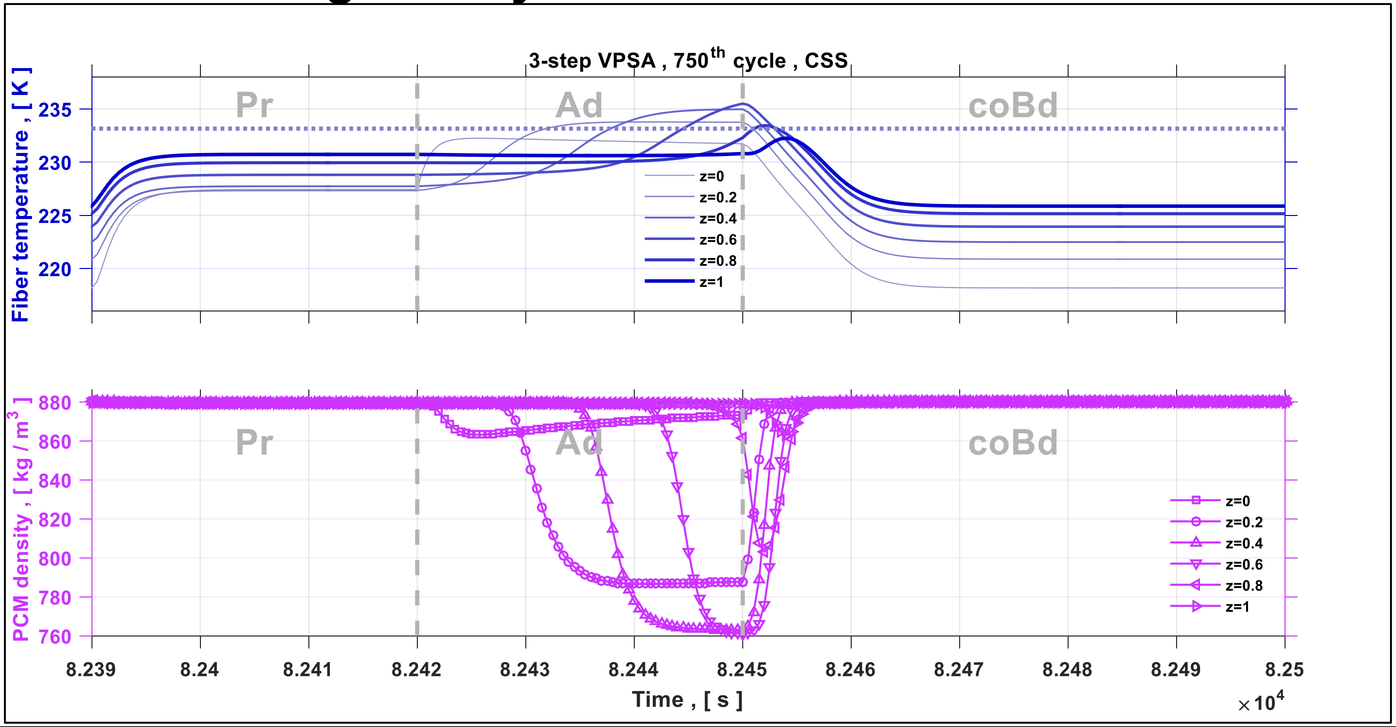
Operating Temperature

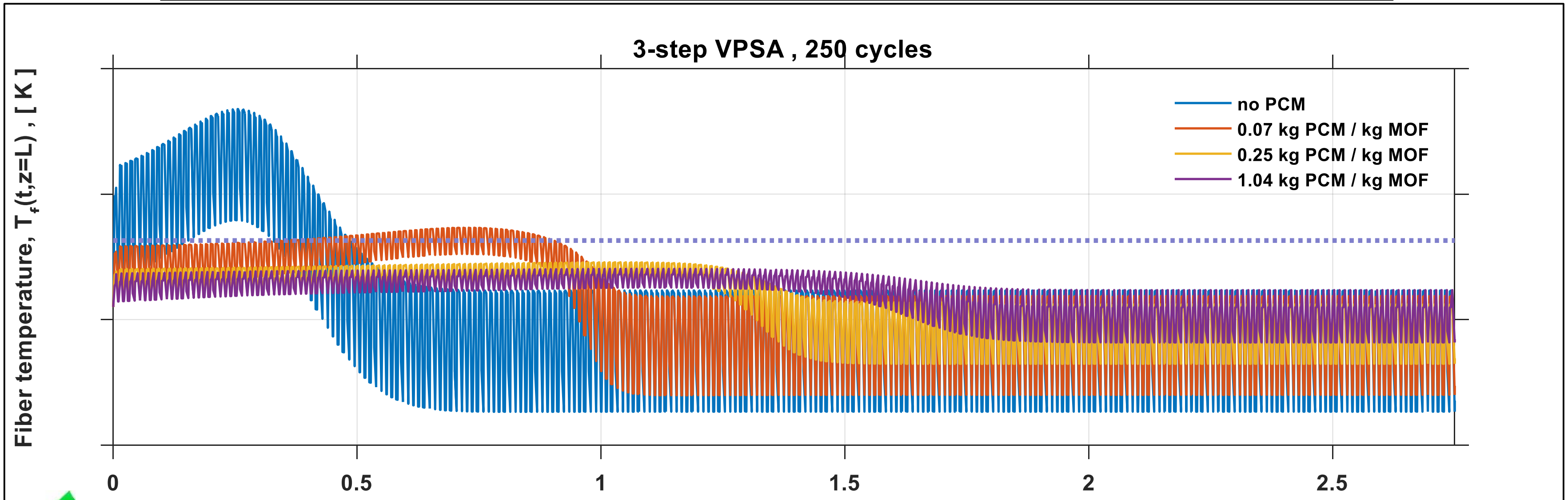


$ (μPCM) << $ (MOF)

Task 10 (experimental PSA cycles)

Cyclic PSA modeling clearly shows the benefit of thermal modulation





✔ Task 12 & 13 (model development)

Process Scope—Key Topics, BP2

Seven major activity areas for BP2:

Task 7.0: Generate >250 g/quarter of UiO-66, sub-ambient sorption isotherms, and simple fiber sorbents**—Complete**

Task 8.0: Moisture and acid gas stability**—Complete**

Task 9.0: Lumen layer synthesis**—Obsolete via micro PCM**

Task 10.0: Cyclic RCPSA using clean gas**—Ongoing, 80% complete**

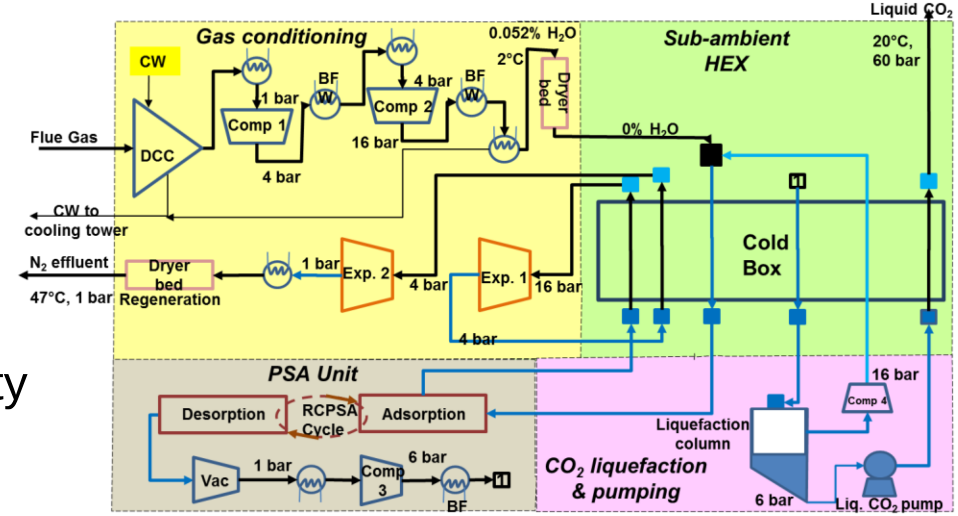
Task 11.0: PCM integration into modules**—Complete**

Task 12.0 & 13.0: Model development**—Complete**

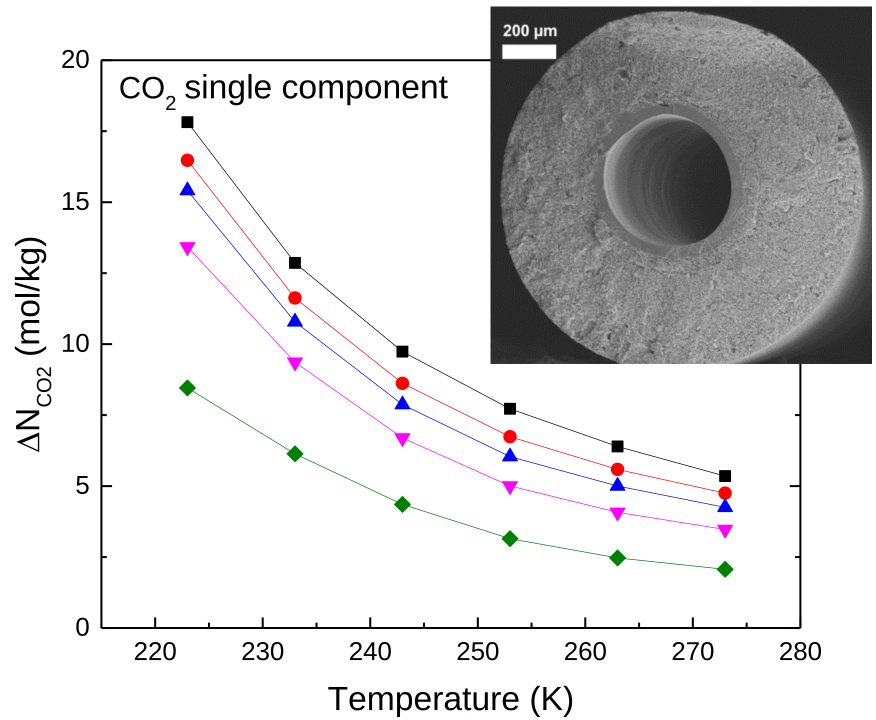
Task 14.0: Flowsheet optimization**—Complete**

Summary

- Novel polymer/MOF sorbent composite hollow fibers will be used in new sub-ambient RPSA process for post-combustion CO_2 capture
  - 50% experimental demonstration
  - 50% prediction, modeling, optimization, and economic feasibility analysis



- Viability of concept is being demonstrated
  - Potential for game-changing swing capacities by utilizing MOFs in sub-ambient conditions
- Georgia Tech and Inmondo Tech are partners on this project
- Annual reports, annual review meetings and conferences presentations and quarterly reports have been used to update DOE on team activities



- DOE contribution: ~\$2.0M
  Georgia Tech contribution: ~\$0.5M