Future of DAC

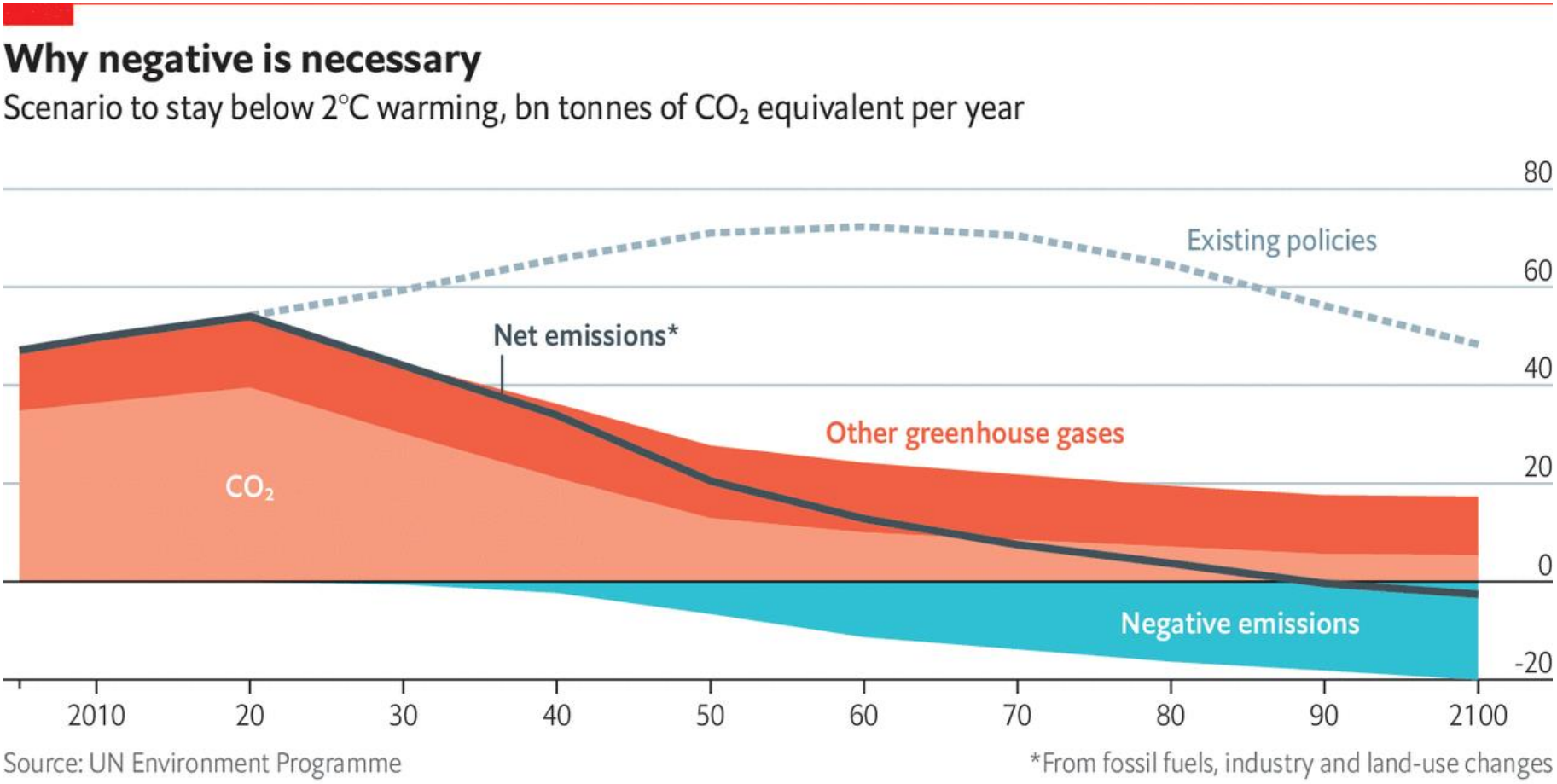
Dr. Katherine Hornbostel

University of Pittsburgh

ARPA-E HDVAC Workshop
Atlanta, GA, Feb 28-Mar 1, 2023

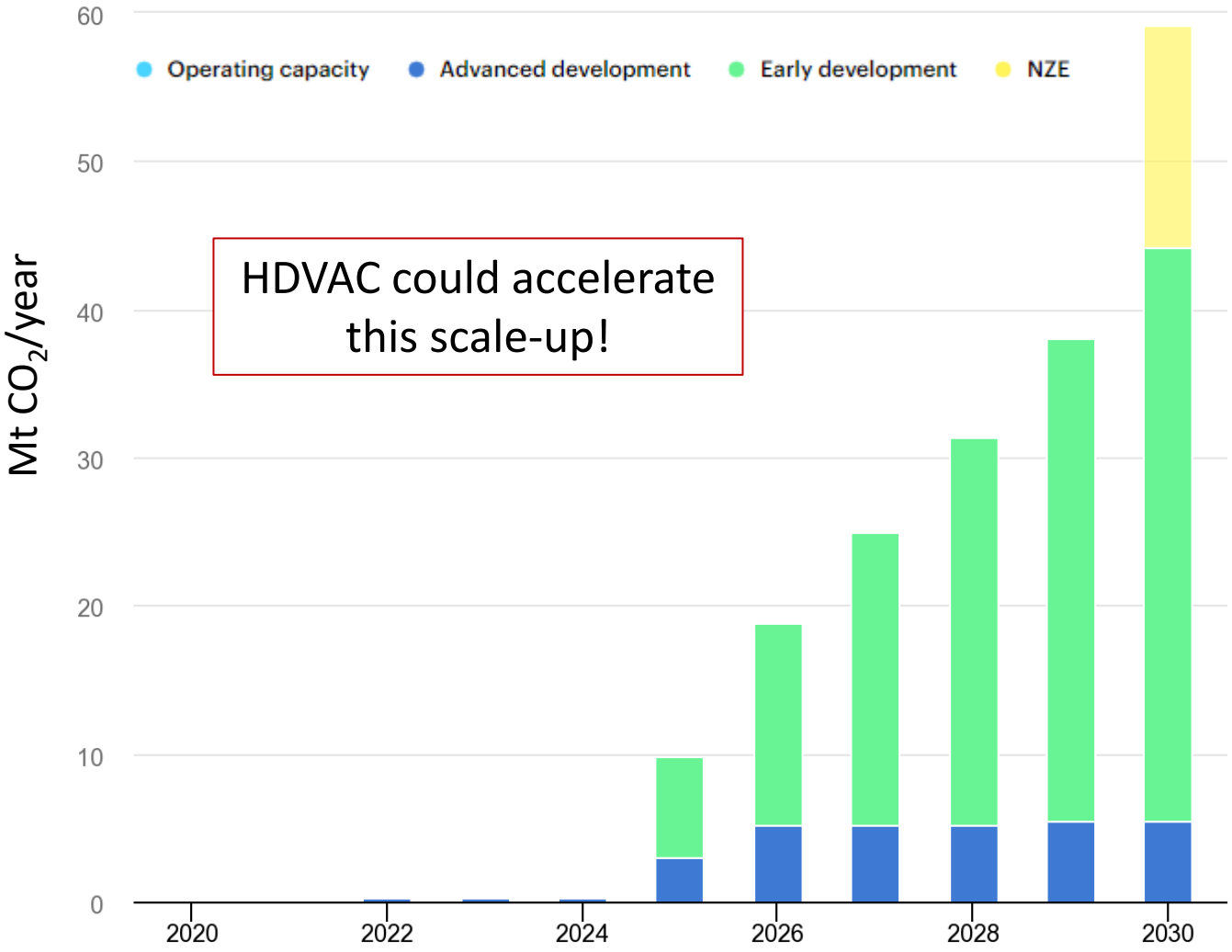
What is Direct Air Capture (DAC) & why should we do it?

Direct Air Capture (DAC) = removing CO_2 from the air to reuse or store



Where is DAC today & where is it headed?

Currently only **18** DAC plants operating worldwide, capturing < 0.01 Mt CO_2/year



https://www.iea.org/reports/direct-air-capture

DAC is hot right now in the US!

- Infrastructure Investments and Jobs Act (2021) included several provisions to support DAC commercialization
  1. Expansion of CO_2 transport & storage through loans, permits, etc.
  2. FEED grants & grants for four DAC hubs
  3. DAC technology prize competition

- DOE's Carbon Negative Earthshot program (2021) aims to remove gigatons of CO_2 by 2050 at < \$100/ton CO_2

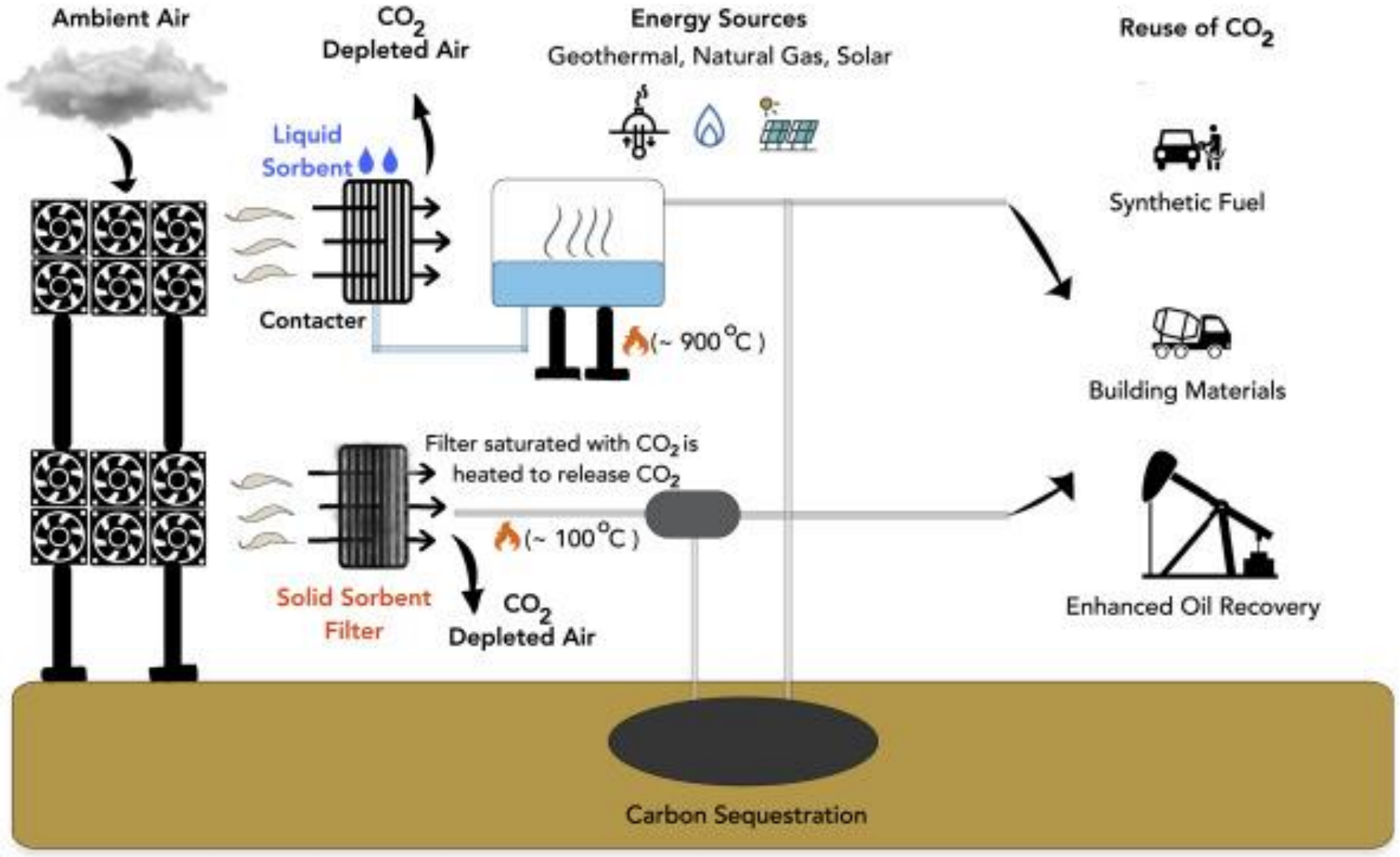
- 45Q tax credits expanded in 2022 to include DAC:
  - \$130/ton CO_2 if reused
  - \$180/ton CO_2 if stored

DAC companies are developing bigger facilities

Rendering of Climeworks' Mammoth facility under construction in Iceland

https://climeworks.com/roadmap/mammoth

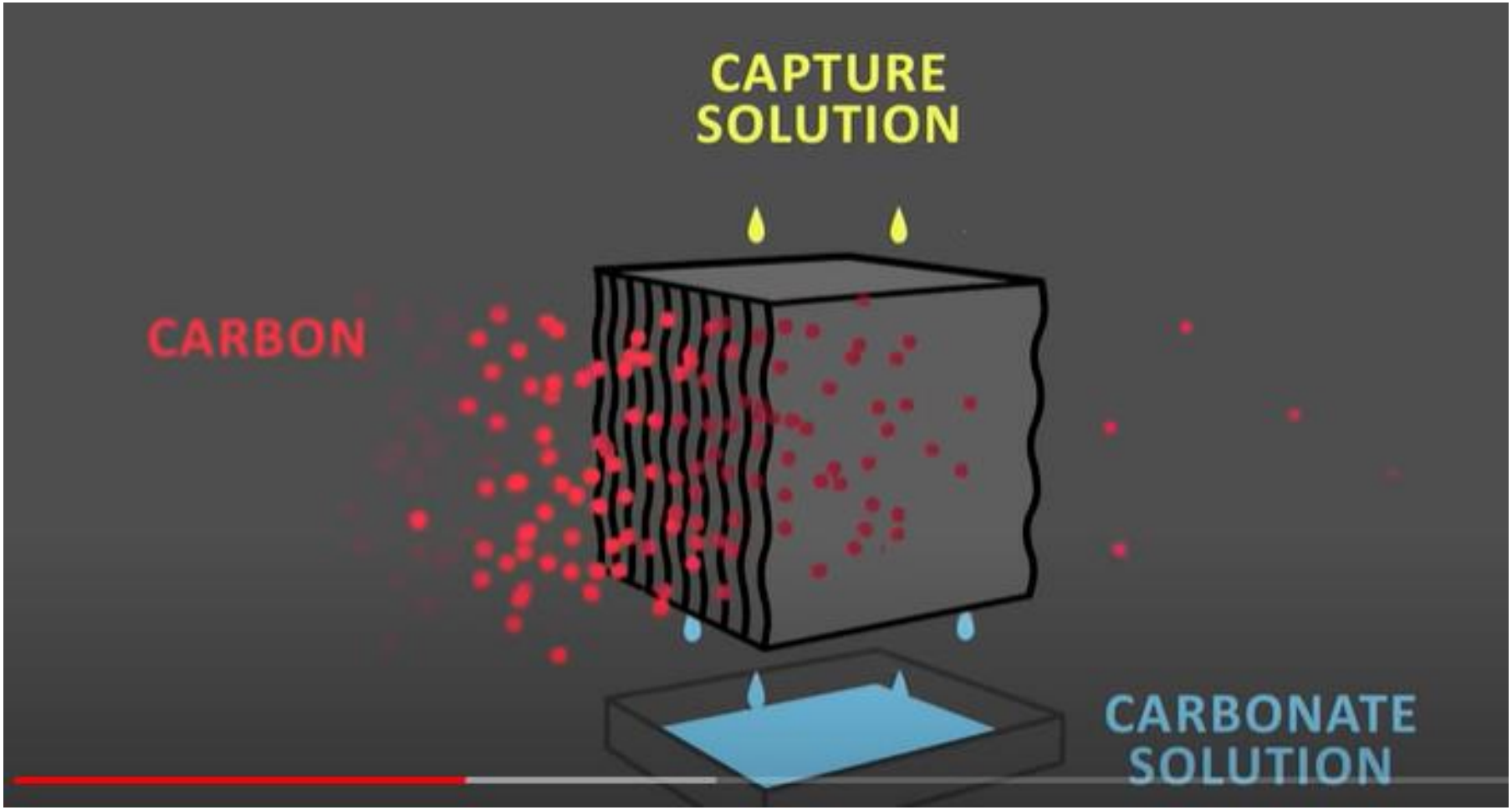
How is DAC typically done?



https://doi.org/10.1016/j.isci.2022.103990

Example of liquid solvent DAC: Carbon Engineering

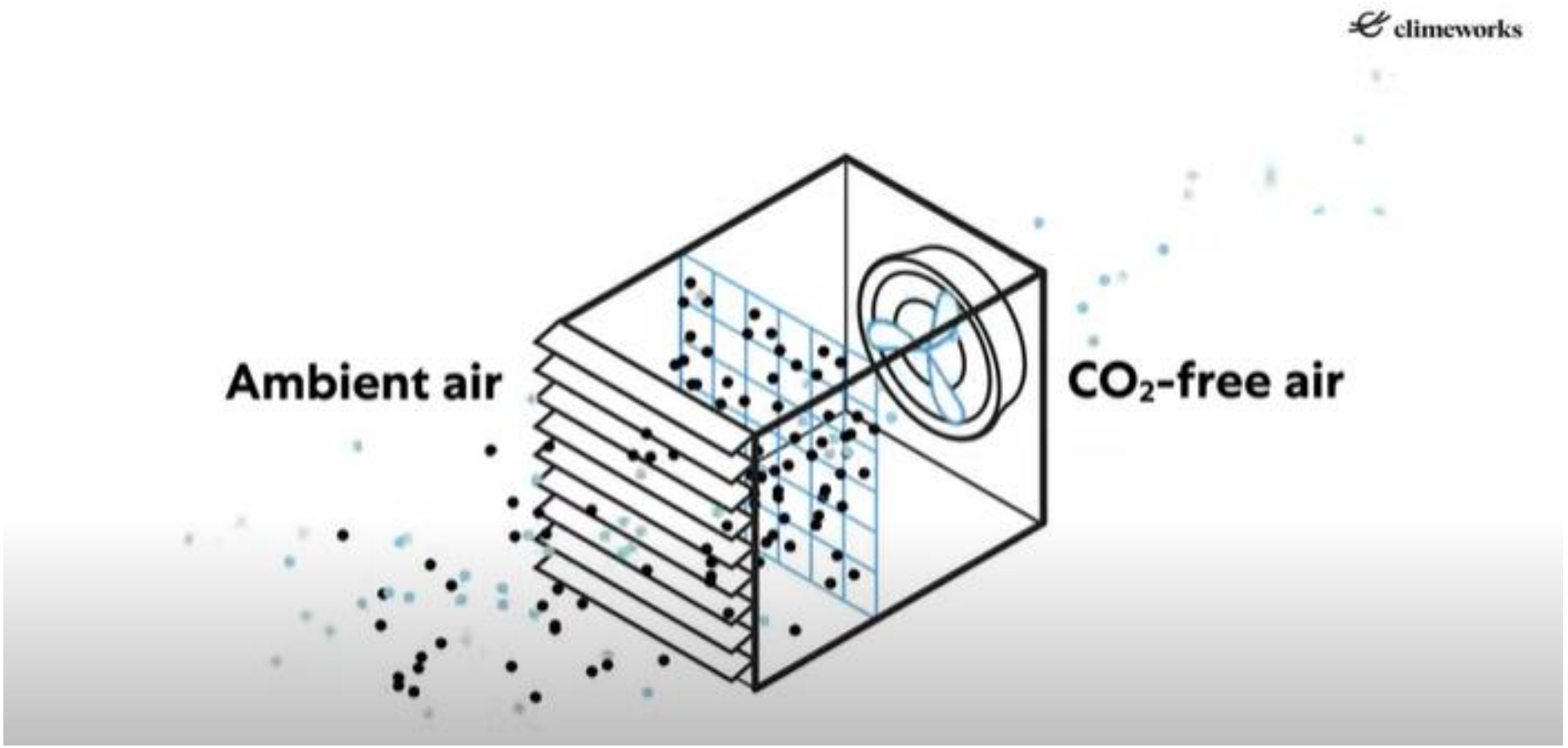
Not very practical for HDVAC because 1) huge footprint, and 2) high temperature



https://youtu.be/mG9FZ9zqOdo

Example of solid sorbent DAC: Climeworks

More practical for HDVAC because 1) more modular, and 2) lower temperature



https://youtu.be/1rAR7PSLUHY

Solid sorbent DAC 101

- Estimated cost: \$205-\$233/ton CO_2
- Typical sorbent lifespan: 6 months-1 year
- Typical cycle time: 15 minutes-1 hour
- Typical desorption process: temperature swing using steam at 90-100°C

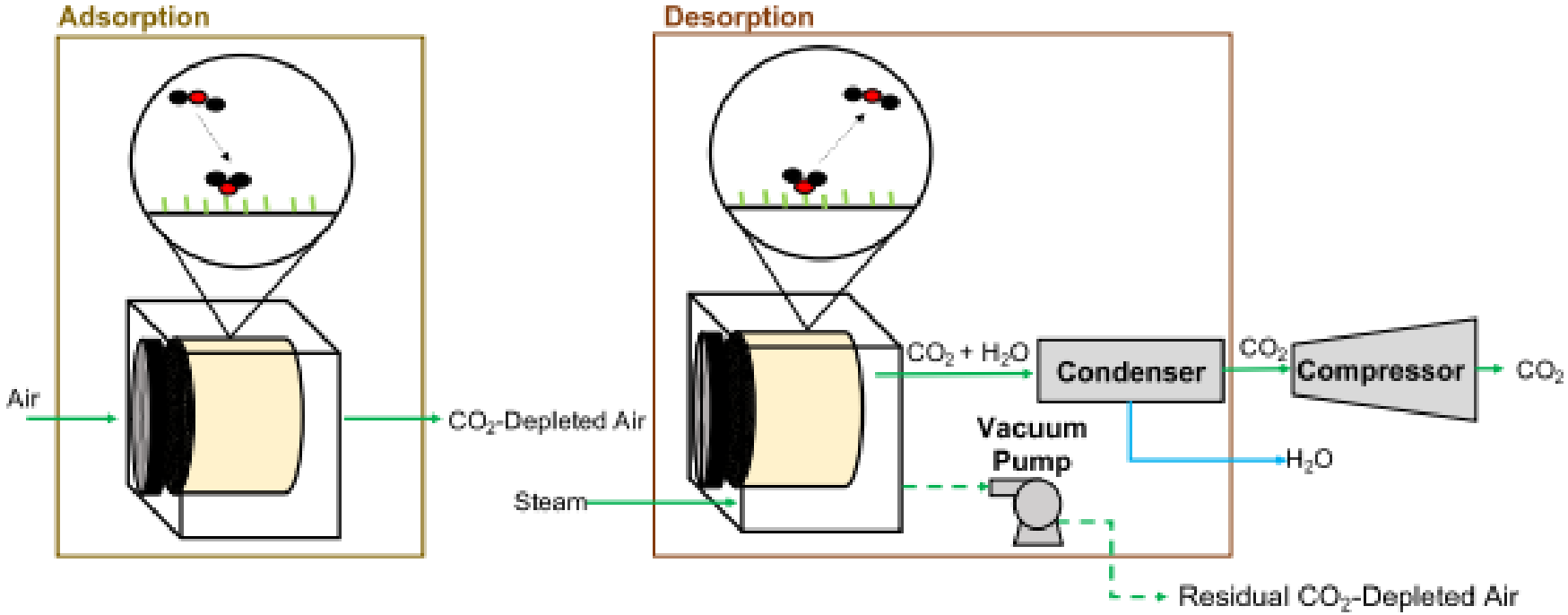


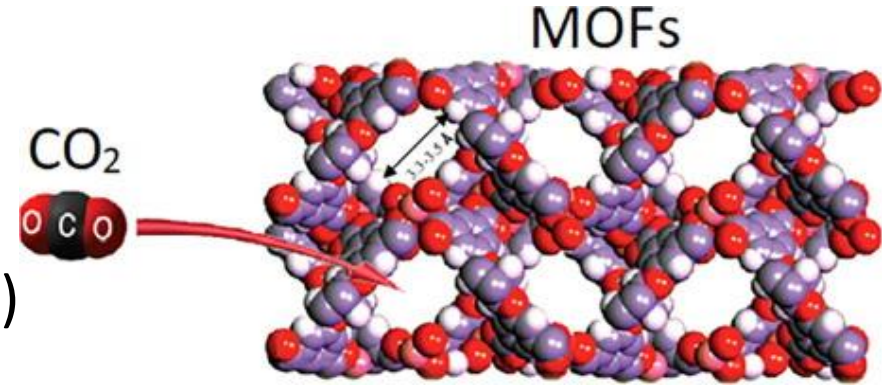
Figure 2. Representative process flow diagram for solid sorbent DAC. The adsorption and desorption processes for the solid sorbent process are performed in batch, with each composed of multiple process steps. Here, green lines represent gaseous flows and blue lines liquid flows. The dashed green line from the contactor to the vacuum pump represents the initial phase of desorption where residual air is removed from the contactor to prevent dilution of the produced CO_2 after evolution from the sorbent.

https://iopscience.iop.org/article/10.1088/2516-1083/abf1ce/pdf

DAC solid sorbent design & challenges

Common DAC sorbent types:

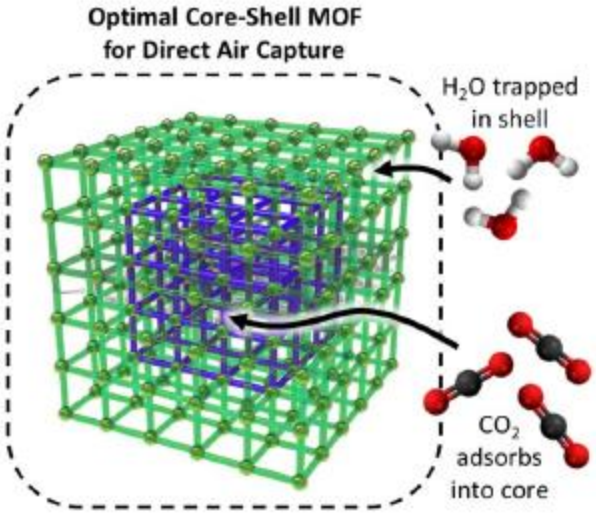
- Amine-functionalized sorbents
- Metal-organic-frameworks (MOFs)
- Zeolites (e.g. Zeolite 13X)



https://www.sciencedirect.com/science/article/abs/pii/S004896971935082X

Traits of a good DAC sorbent:

- Stability in presence of other gases
- High CO_2 capacity & selectivity
- High surface area per unit volume
- Long lifespan & high durability



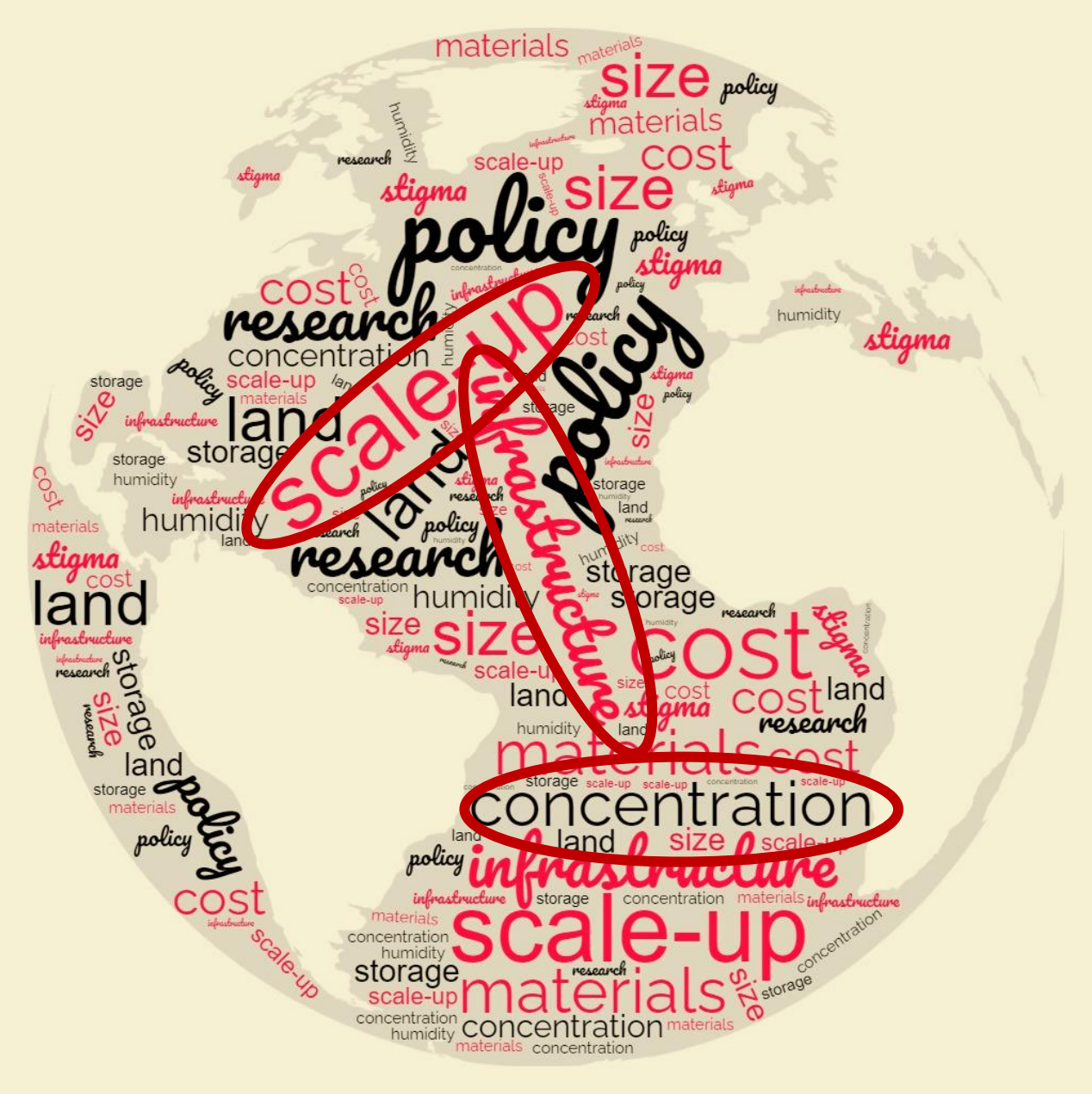
https://doi.org/10.1039/D2NR03177A

Challenges:

- Scaling up sorbent production
- Tuning sorbents to selectively bind CO_2 over other gases

https://iopscience.iop.org/article/10.1088/2516-1083/abf1ce/pdf

What are the challenges facing DAC?



HDVAC addresses many of these!

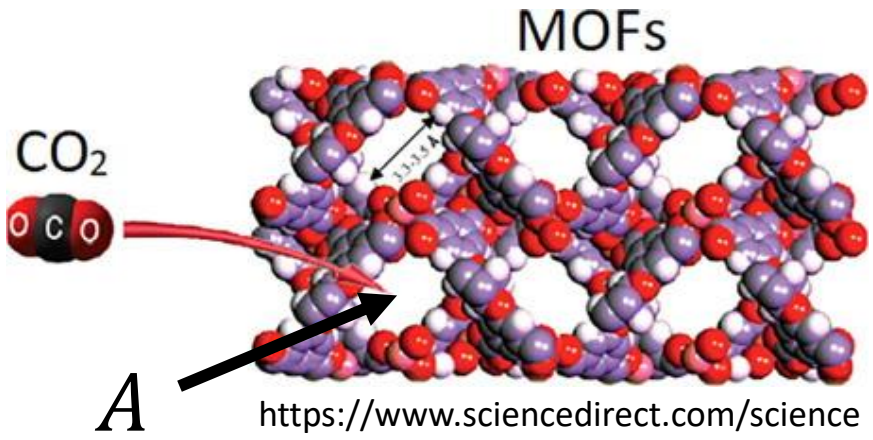
Graphic generated on: https://www.wordclouds.com

How HDVAC helps with concentration…

1) <u>Speeds up adsorption</u>:

$$CO_2 + A \xrightarrow{k_f} ACO_2$$

$$Reaction\ rate = k_f[CO_2][A]$$



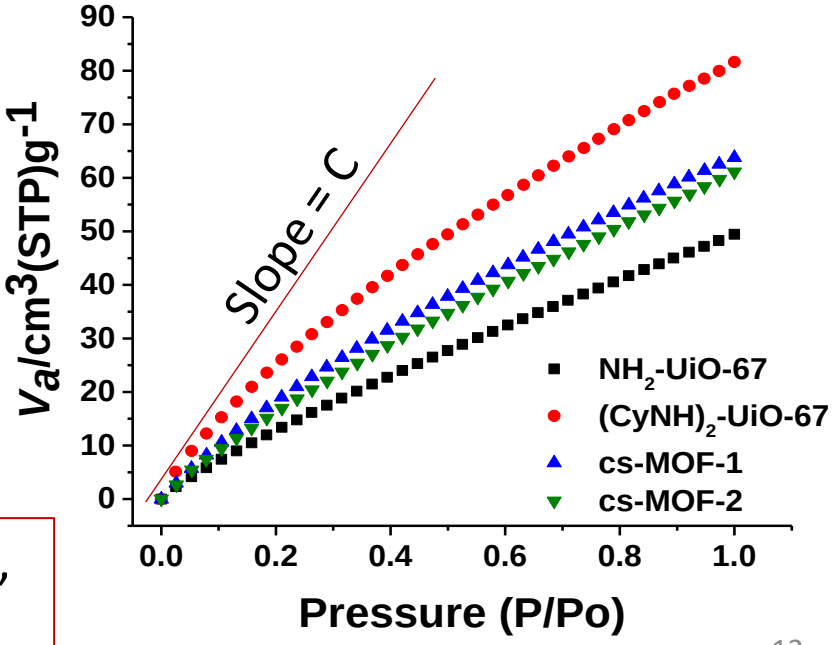
https://www.sciencedirect.com/science/article/abs/pii/S004896971935082X

$[CO_2]$ roughly 2x higher for HDVAC than for DAC, so reaction will be roughly twice as fast!

2) <u>Raises sorbent CO_2 capacity</u>:

$$CO_2\ \text{capacity} = \text{C} * P_{CO2}$$

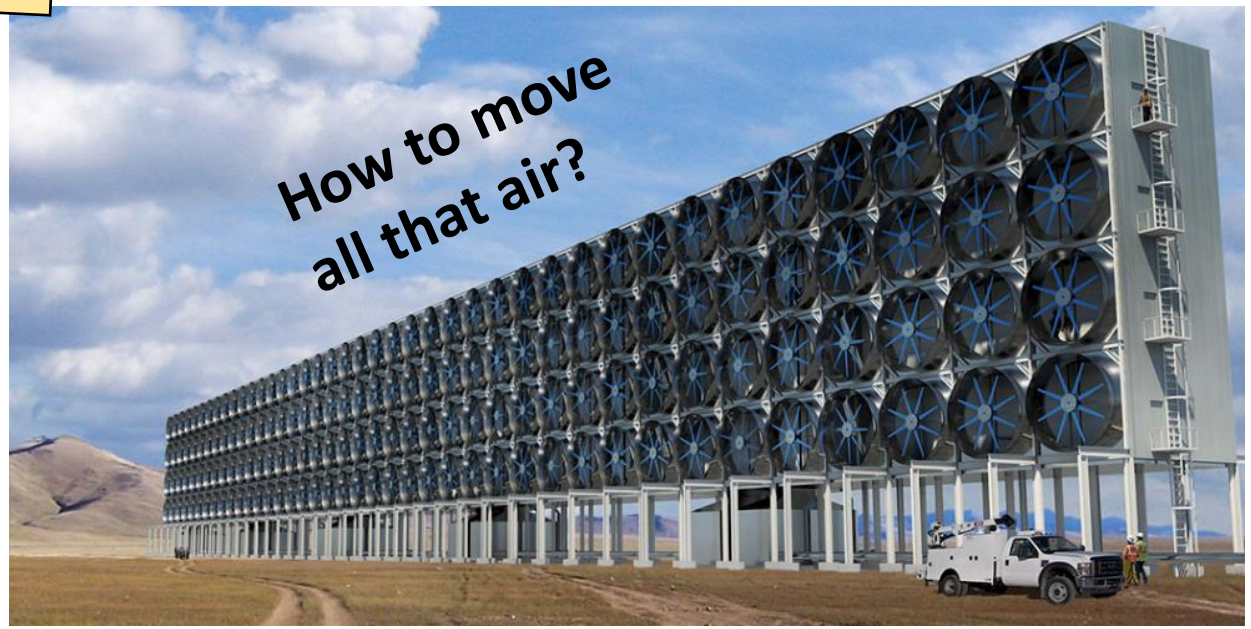
P_{CO2} roughly 2x higher for HDVAC than for DAC, so CO_2 capacity will be roughly twice as large!



How HDVAC helps with infrastructure & scale-up…

Electricity source?

Steam source?



https://www.science.org/content/article/cost-plunges-capturing-carbon-dioxide-air

CO_2 transport & storage?

Challenges & opportunities associated with HDVAC

1. System integration
   - How to hook up to power & waste heat/steam
   - Where to place in HVAC system (near blowers vs. near exhaust? Centralized vs. distributed?)
   - Any potential co-benefits/synergies (e.g. dehumidification, filtering particles or toxic gases)

2. Regeneration
   - How to generate steam? Water source -> dehumidifier?
   - Consider moisture swing & electric-swing sorbents
   - How to cycle between adsorption/regen (timer? Moving bed?)

Challenges & opportunities associated with HDVAC (cont.)

3. CO_2 storage & transport

- How to store (e.g. compressed cylinders on roof?)
- How to transport (e.g. truck picking up cylinders daily or weekly?)

4. Modular, low pressure drop design

- Designs for DAC cartridges that can easily be installed at the building exhaust points
- Minimal pressure drop designs (e.g. monolith contactors) so HVAC system isn't strained by devices

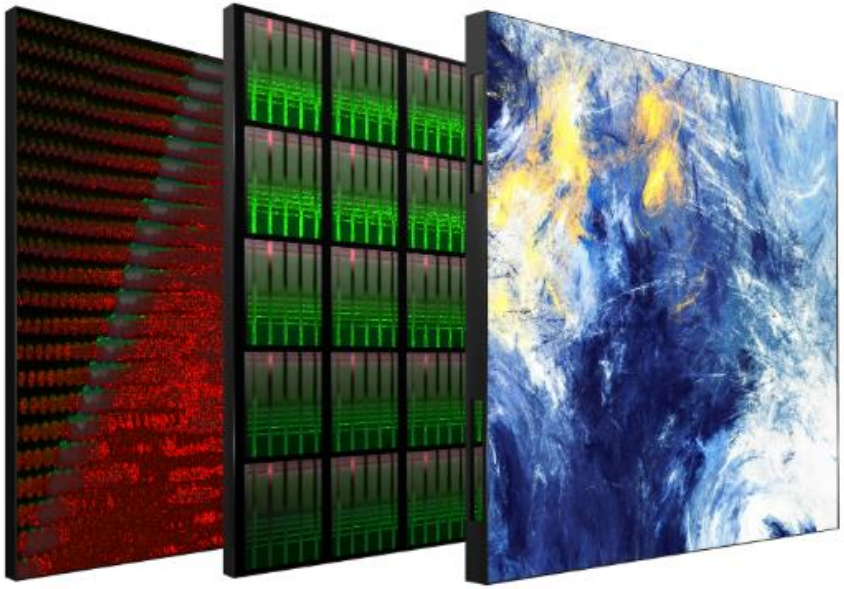
5. Dynamics & controls

- Ramp up/shut down and transitions for HVDAC system
- Quick response to electric grid fluctuations and daily building cycles

Closing inspiration for HDVAC designs…

Artveoli

http://www.artveoli.com/



The core technology is a microfluidic high density photobioreactor that converts CO_2 into Oxygen. There are three essential parts:

- **LED Panel** - *LED Panel that acts like the Sun*
- **Chips Panel** - *Microfluidic Bio-Chips that act like trees using photosynthesis to convert CO_2 to Oxygen*
- **Front Panel Options** - *Front Panel - customizable front cover in digital or printed art*

https://tinyurl.com/26eb5h4p

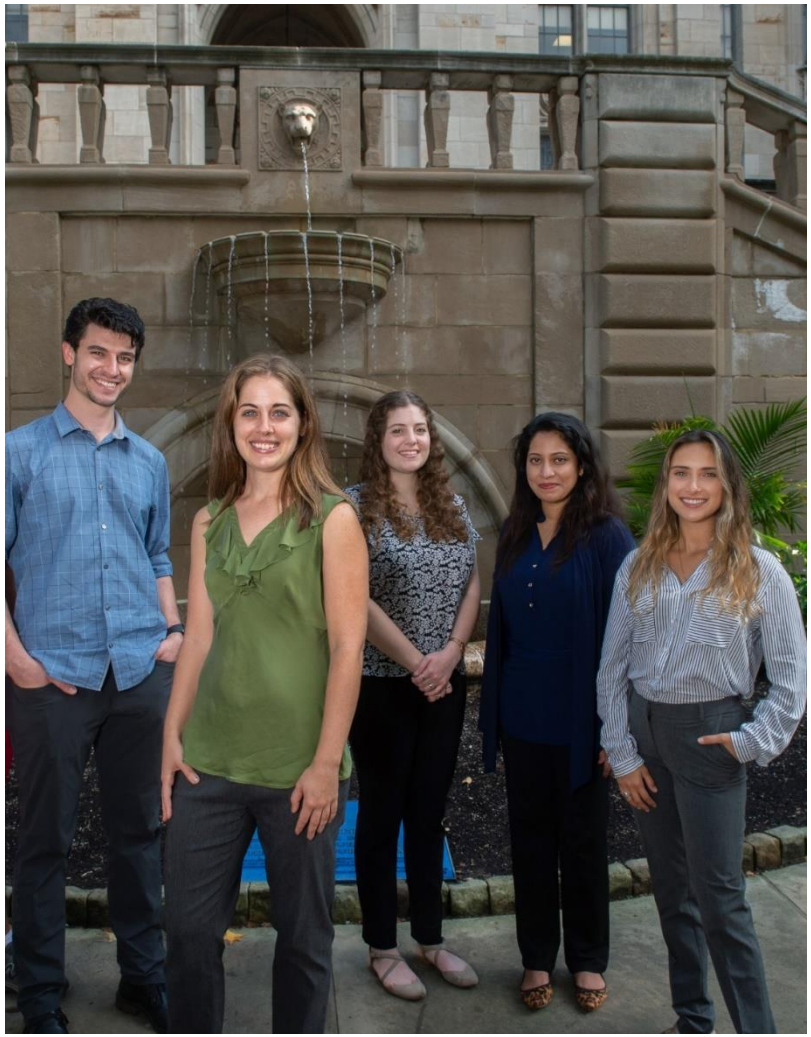
Intl Space Station

Use a bed of zeolites with thermal regeneration to filter CO_2 out of the air

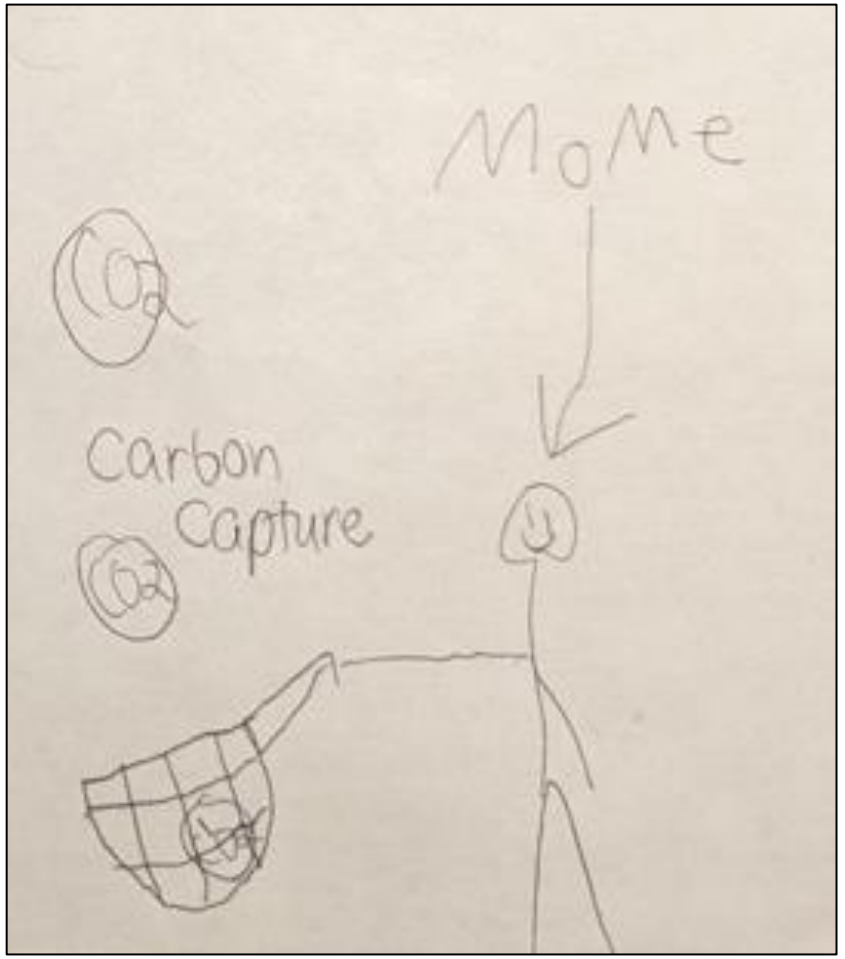
Thanks! Questions?

Hornbostel@pitt.edu

www.hornbostelresearch.com



Me with my four PhD students.



My daughter Evelyn's depiction of what Mommy does for work.