CO2 Direct Air Capture by Ion-Exchange Sorbent and Low-Grade Heat: Advanced Sorbent, Energy, and Performance

a Collaborative Effort of:
Advanced Cooling Technologies, **Lehigh University**, and **Jeevan Technology**

Robin Pham | July 12, 2024

Envisioned Full-Scale System

PROGRAM DETAILS

Contract #: DE-SC0022940

Start Date:	Aug. 28, 2023
Final Report:	Aug. 27, 2025
End Date:	Aug. 27, 2025
Budget:	$1,649,927
ACT:	$889,927
Lehigh:	$710,000
TABA:	$50,000

Technical Monitor/COR

Erika Coffey
Project Manager
CO_2 Removal & Conversion Team
U.S. DOE-NETL

Personnel

Josh Charles (PI), Robin Pham, Elizabeth Seber, Megan Gettle, Arup SenGupta*, Carlos Romero*

Objectives:

Demonstrate and scale a DAC technology based on an **ion-exchange CO_2-selective resin** regenerated using **low-grade heat or electricity**.

Program Goals:

- Develop key components of the DAC system.
- Design and fabricate a sub-scale testbed.
- Demonstrate operation of individual components.
- Refine the Phase I full-scale DAC system model.
- Complete a detailed TEA and LCA.
- Establish relationships with key market players.

BACKGROUND

SYSTEM

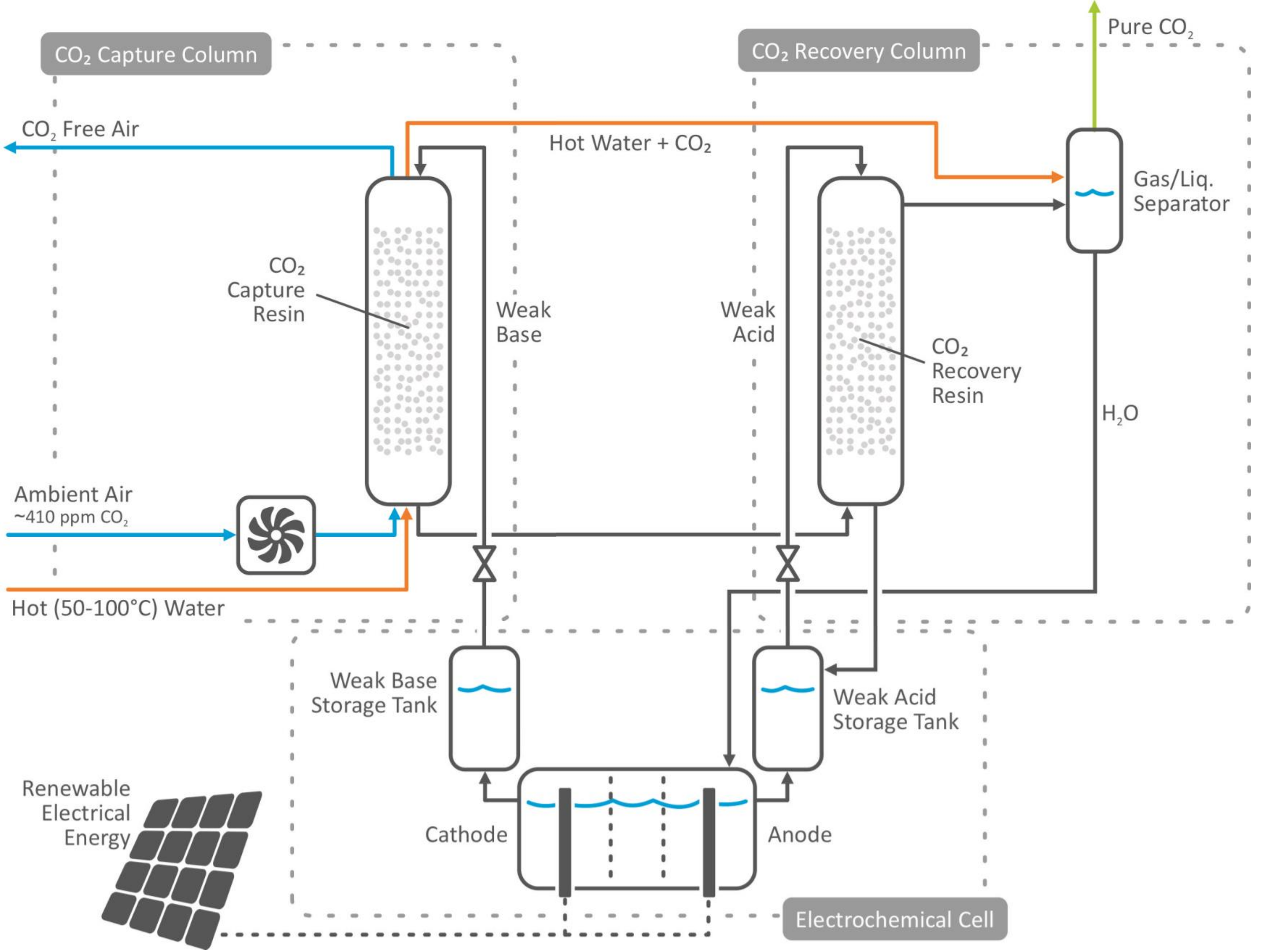
CO2 is captured via **fluidized bed**

Heat is delivered **highly efficiently** with **hot liquid water**

Low-grade heat from industrial processes can be repurposed **(50°C to 100°C operation)**

Liquid-gas sequestration allows for **highly pure CO2 recovery** without vacuum infrastructures

CO2 can be recovered with electricity via **acid-base ion exchange**



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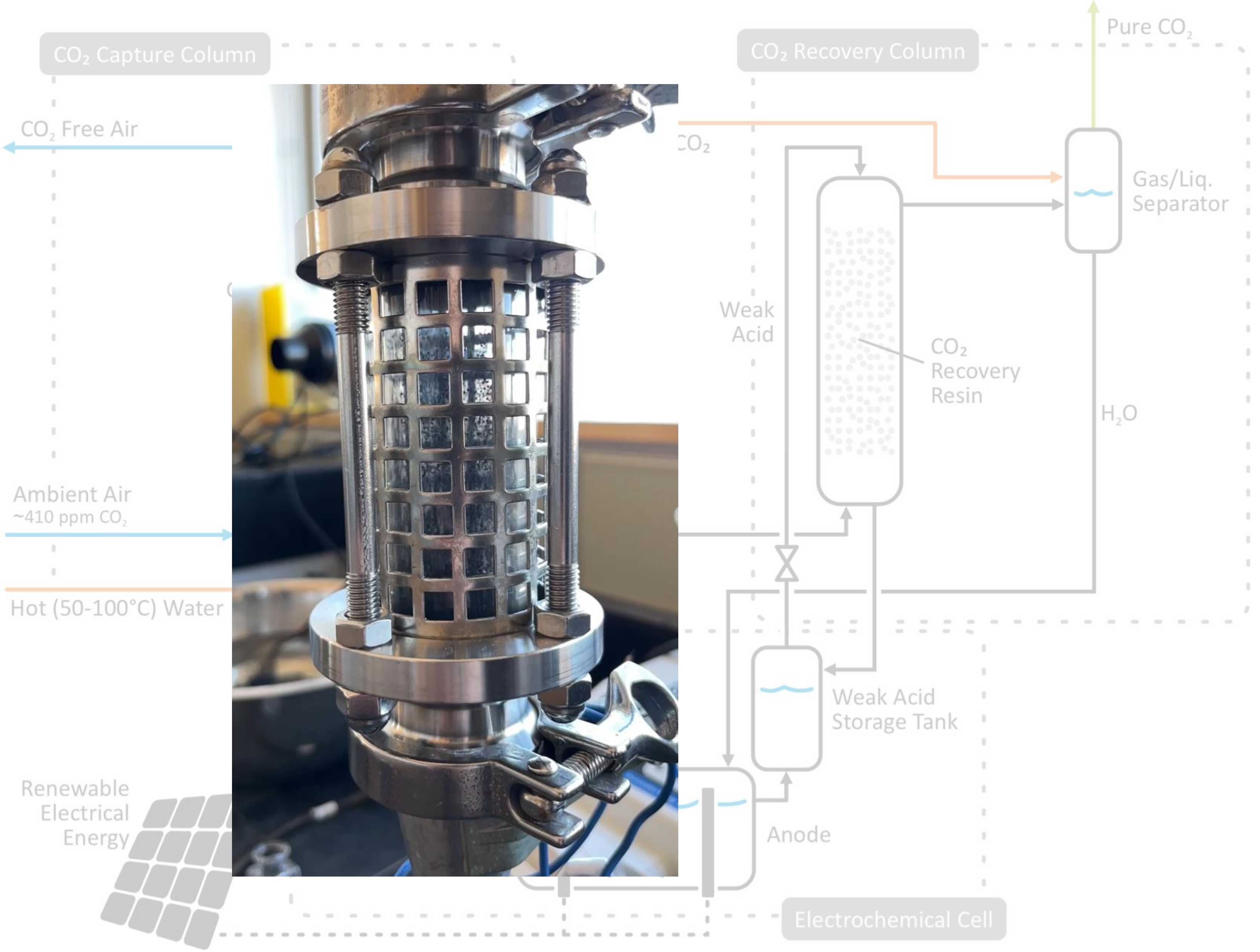


PILOT SCALE

Operating condition:

- Room temperature ~25°C
- Common humidity ~50% RH

Dimensions:

- Footprint ~3.25 m2
- Height ~2 m

Capacity:

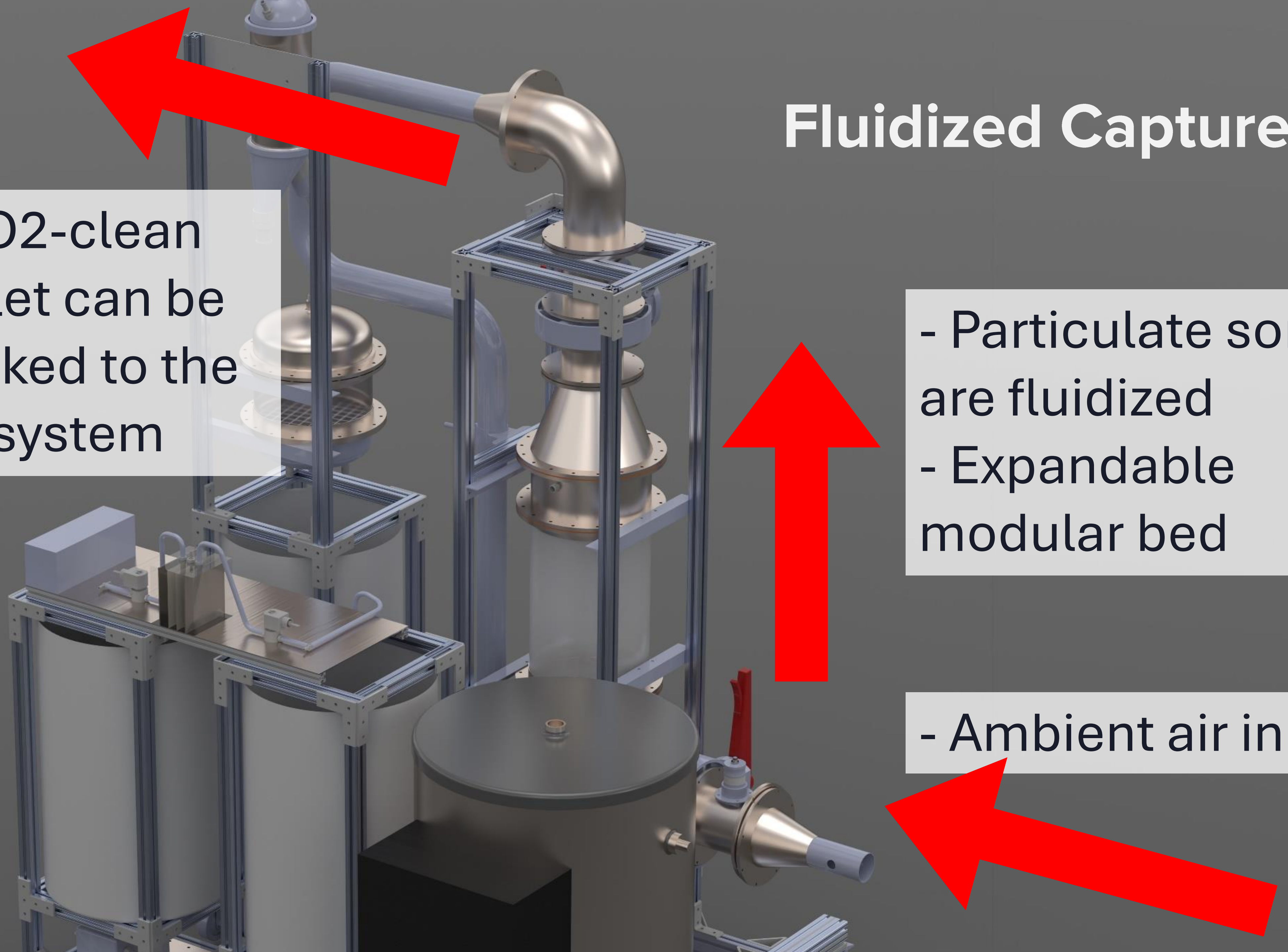
- ~15-20 kg of sorbents
- ~80 mol CO2 at full capture
- ~27 mol CO2 per 2-hour cycle (~5 tonnes per year)

A scale-up effort from lab-scale system

DE-SC0022940

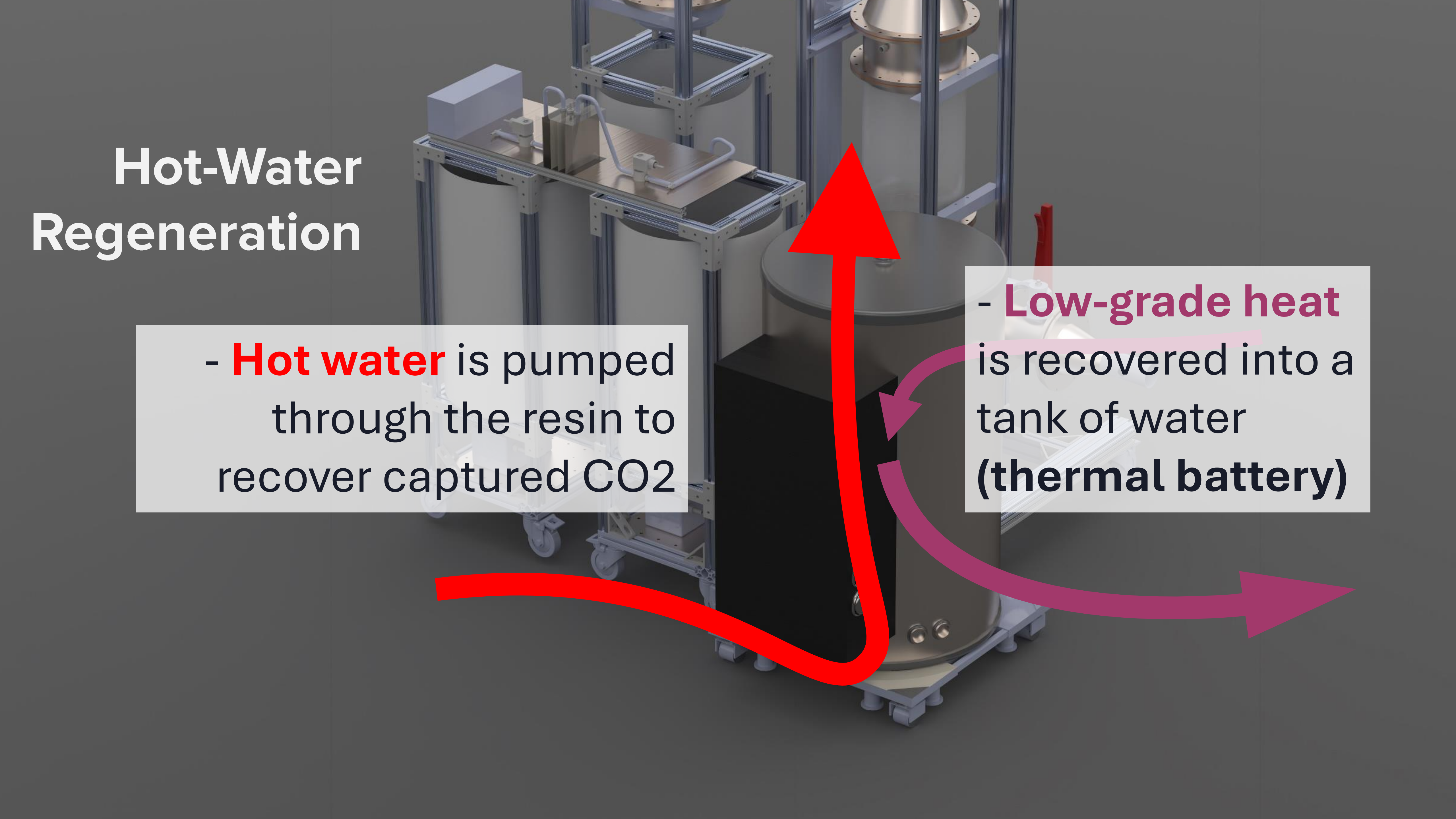
Fluidized Capture Bed

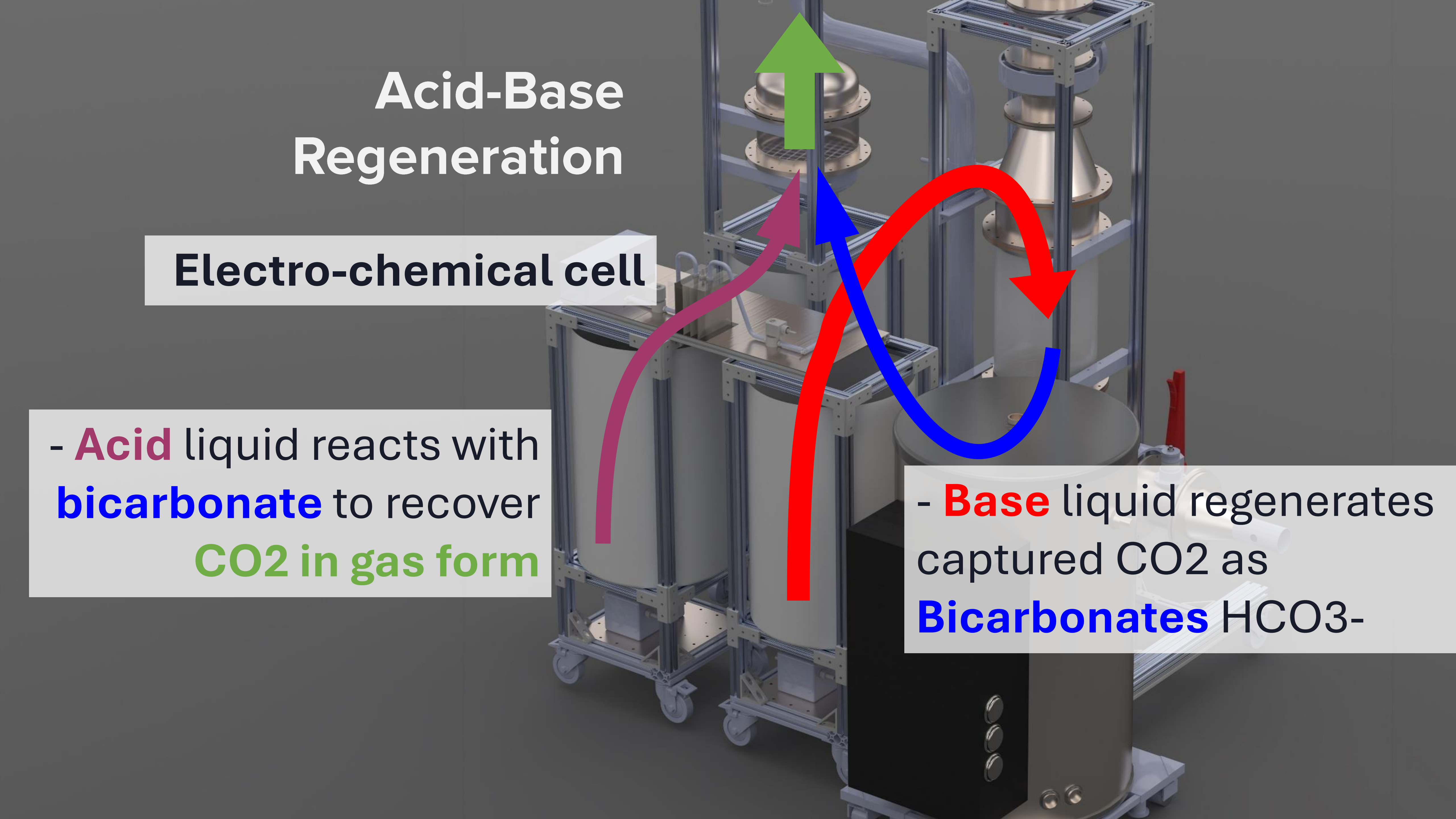
- CO2-clean outlet can be hooked to the AC system



- Particulate sorbent are fluidized
- Expandable modular bed

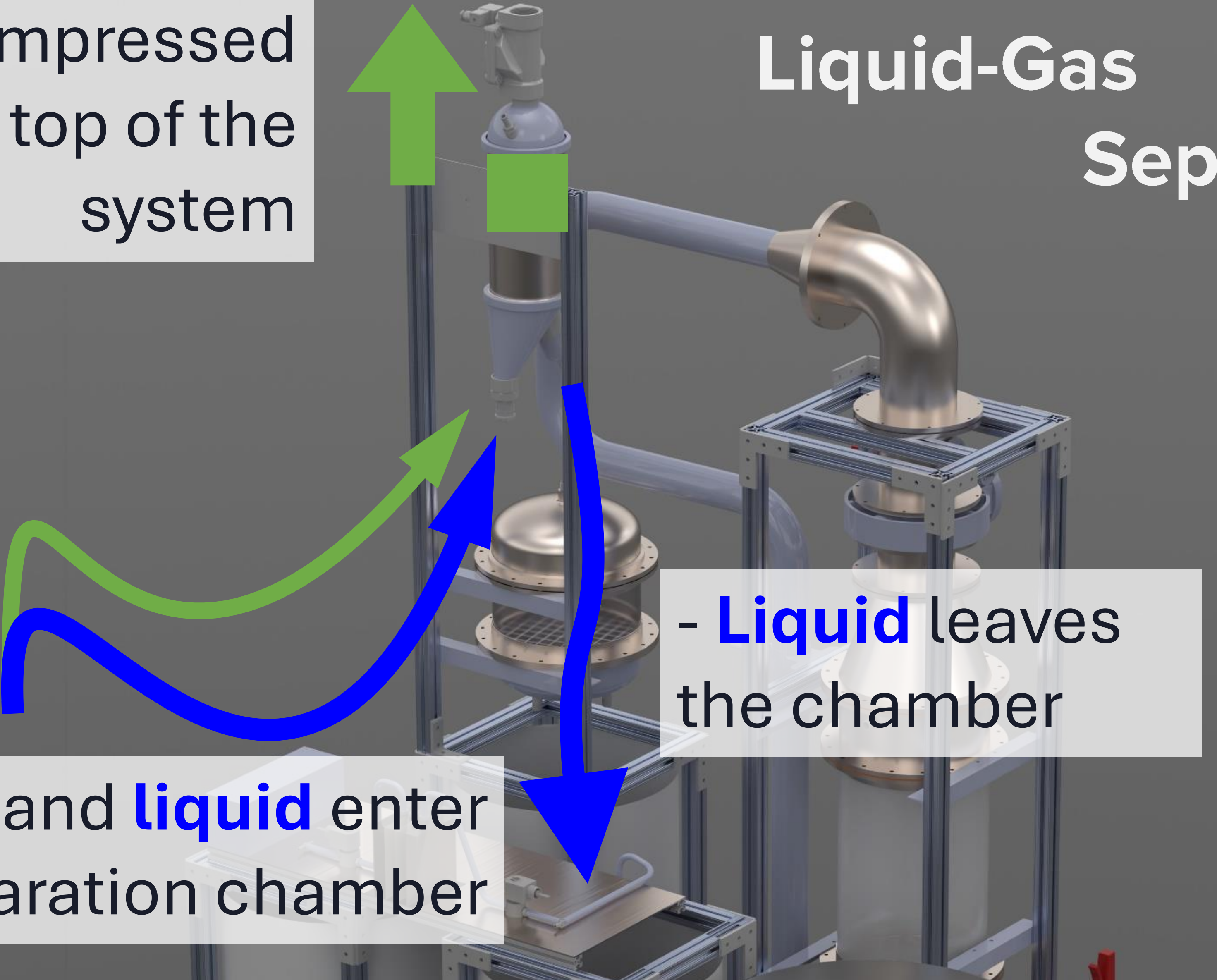
- Ambient air inlet


Hot-Water Regeneration
- Hot water is pumped through the resin to recover captured CO2
- Low-grade heat is recovered into a tank of water (thermal battery)


Acid-Base
Regeneration
Electro-chemical cell
- Acid liquid reacts with
bicarbonate to recover
CO2 in gas form
- Base liquid regenerates
captured CO2 as
Bicarbonates HCO3-

Liquid-Gas Separation

- Pure CO_2 gas is compressed at the top of the system



- Liquid leaves the chamber
- Gas and liquid enter separation chamber

Hybrid Approach to Sorbent

Common Amine-Based Sorbent

Our Team's Sorbent, DeCarbonHIX : Hydroxide-Coated Amine

RESULTS and LESSONS LEARNED:
1st Year

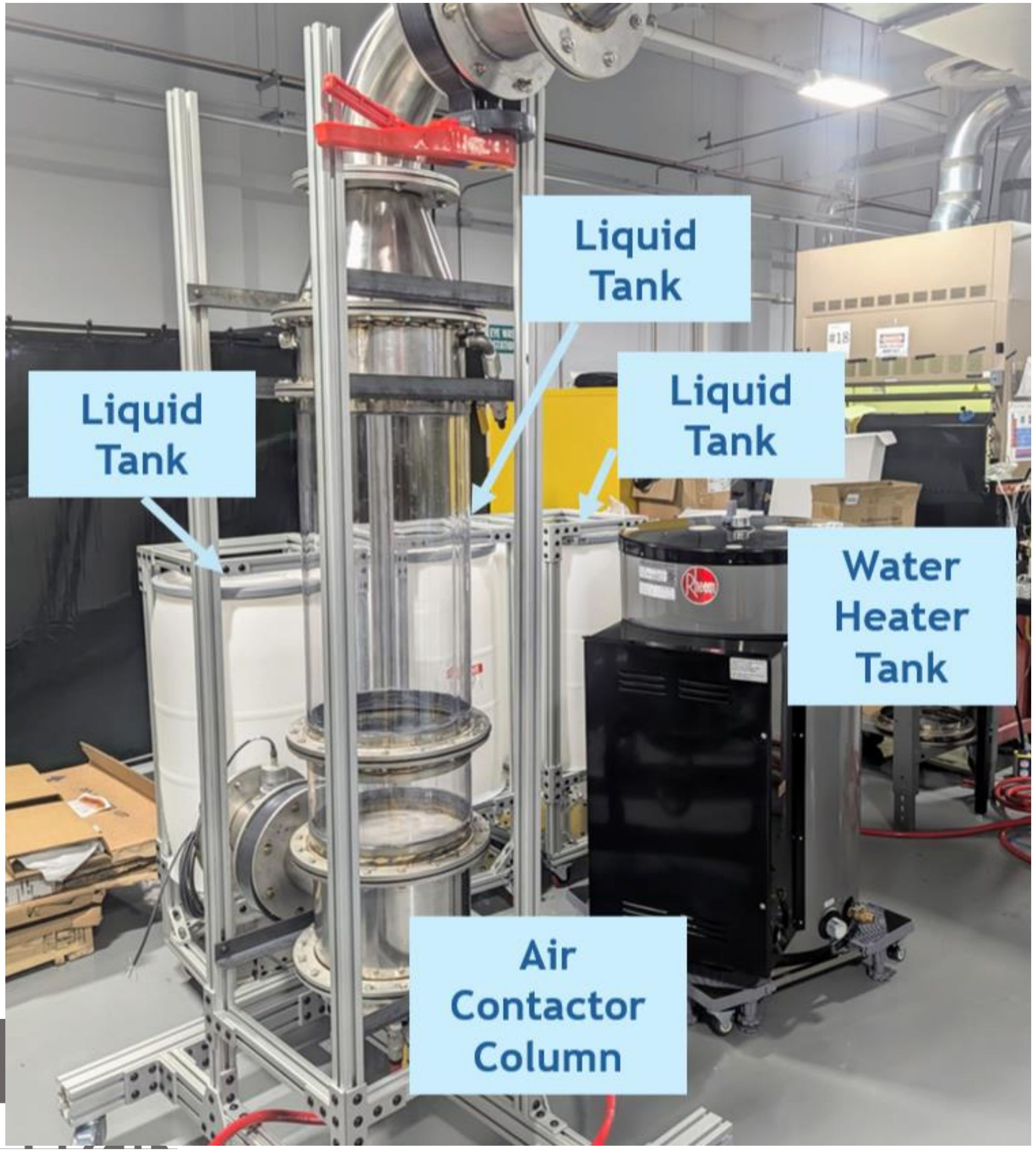
Pilot System Fabrication

Completed the Testbed Design

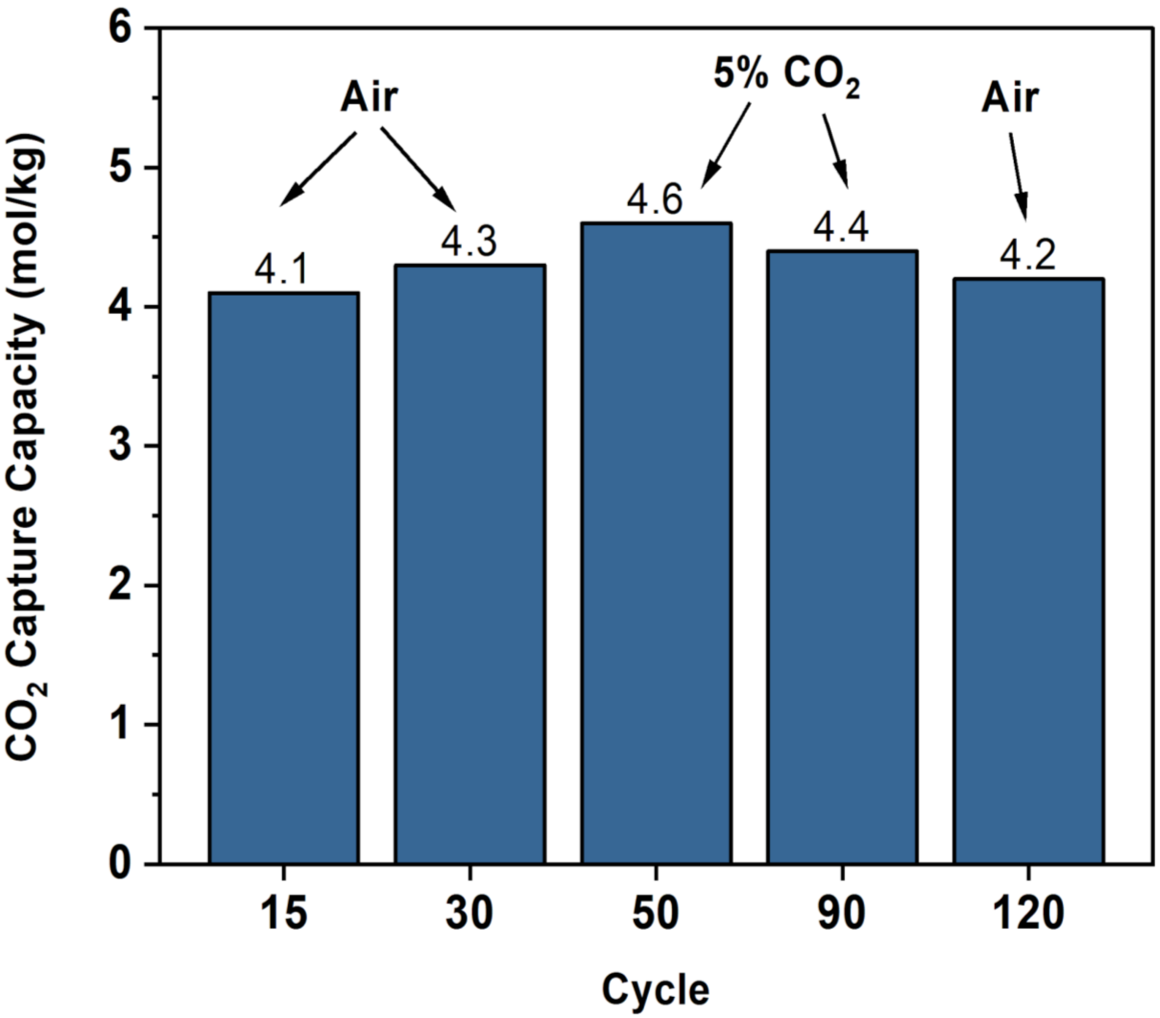
- The 1st year was spent in building up the pilot scale system and testing individual components.

Air-contactor column filled with liquid

Zoomed-in view at the 100-micron mesh and supporting grid



Sorbent Life Cycle Testing



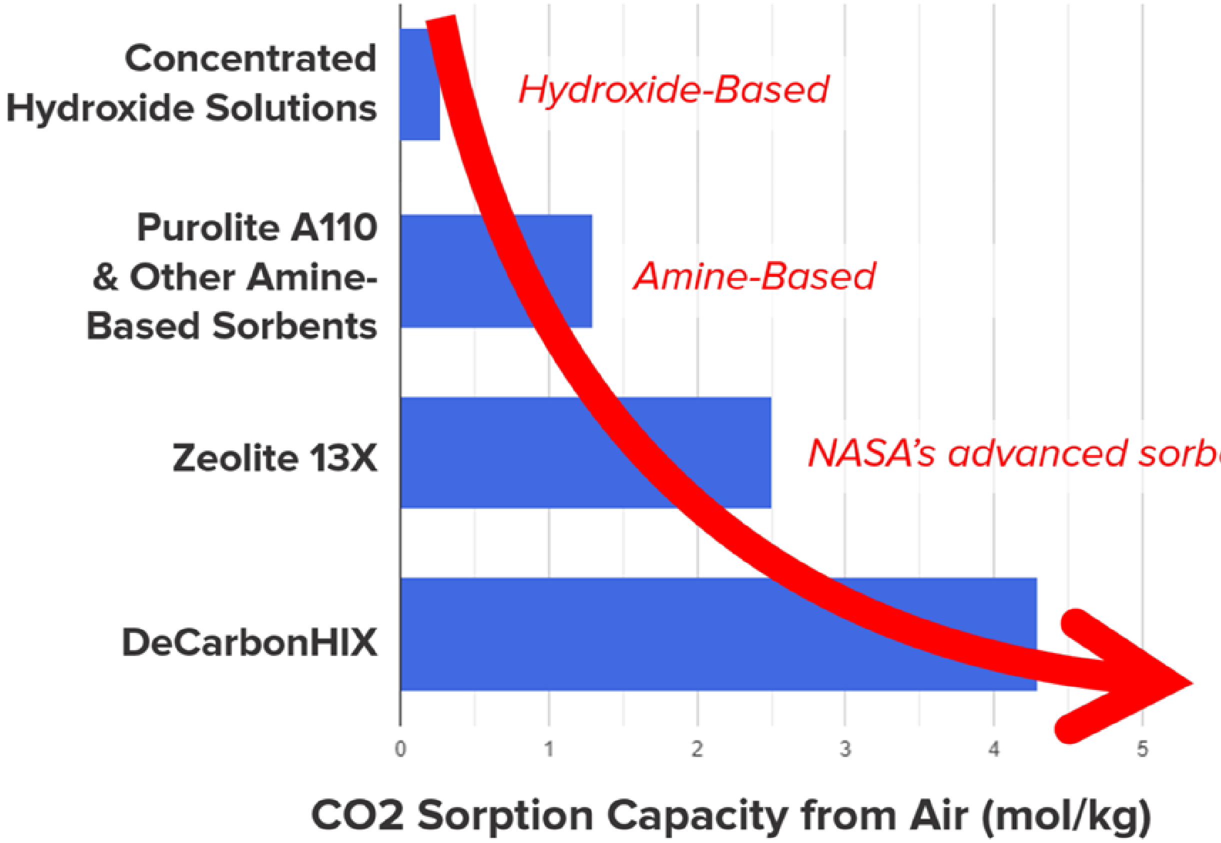
Highly Stable through Many Cycles

- Tested through more than 150 cycles with 80 C hot water regeneration
- In terms of Direct Air Capture – that means stable projected operation of CO2 capture plant through 3 months of full saturated capturing!

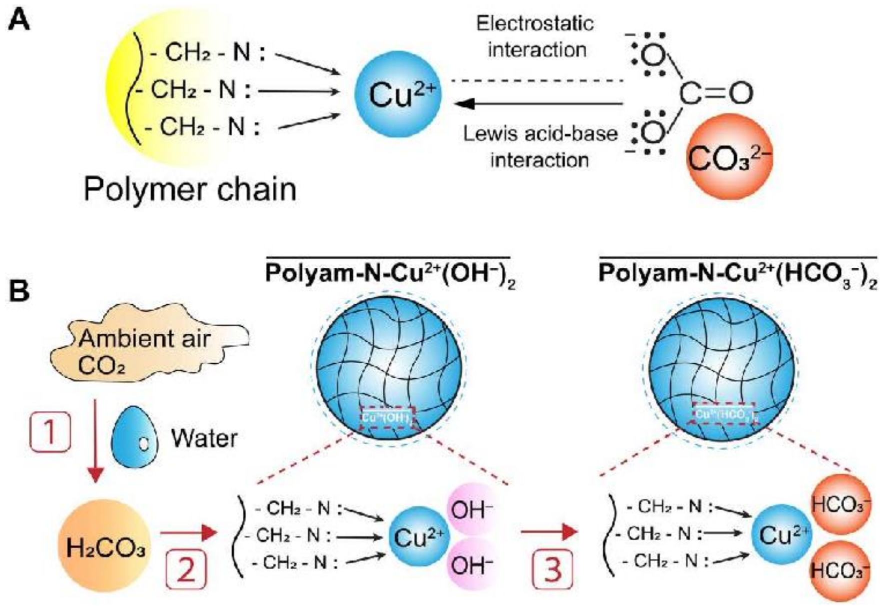
Strengths

- Hydroxide coating protecting the amine
- A stable amine can capture much more
- Mechanically stable sorbent allows for fluidization

Sorbent Life Cycle Testing



A novel approach: Hydroxide-Loaded Amines



A Holistic System Model

Economics of Carbon Management

- Cost in Energy
- Cost in Time
- Cost in Space, Size, and Footprint

Capture Phase

Energy Cost

$$W = \Delta P \cdot \Delta V$$

- Is a product of Pressure Drop (P) and Total Air Volume moved (V)

With Fluidization:

- Pressure Drop is reduced by **50% to 70%**

- Total Air Volume movement is reduced by **60 to 85%**

- Compounding to more than **80% of energy saving**

Capture Phase

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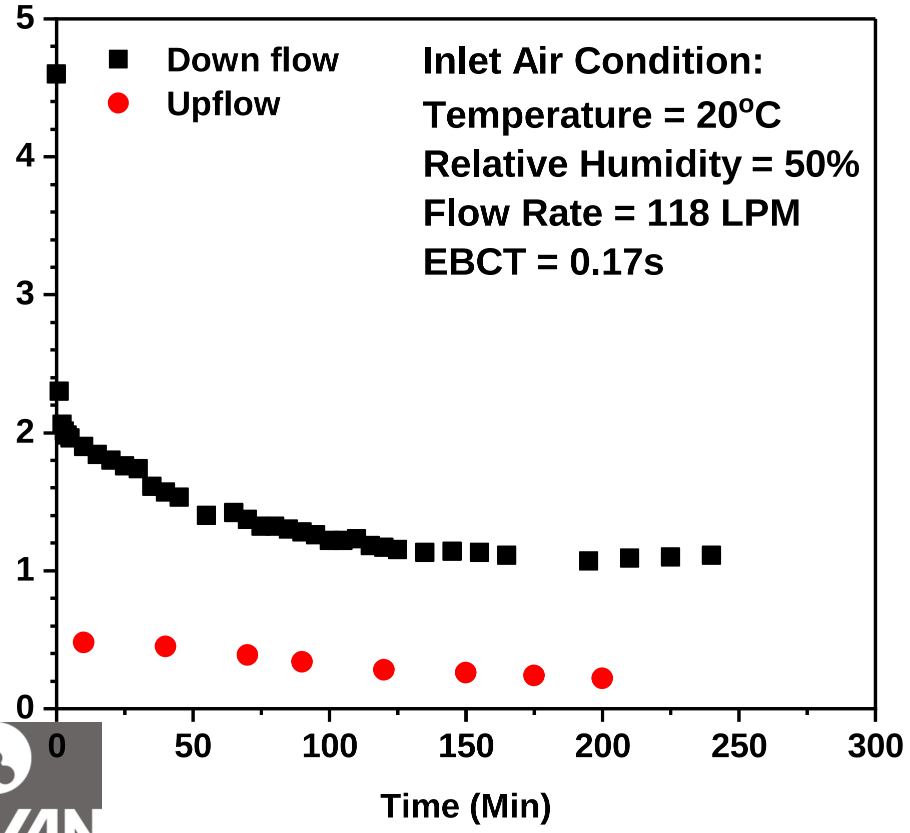

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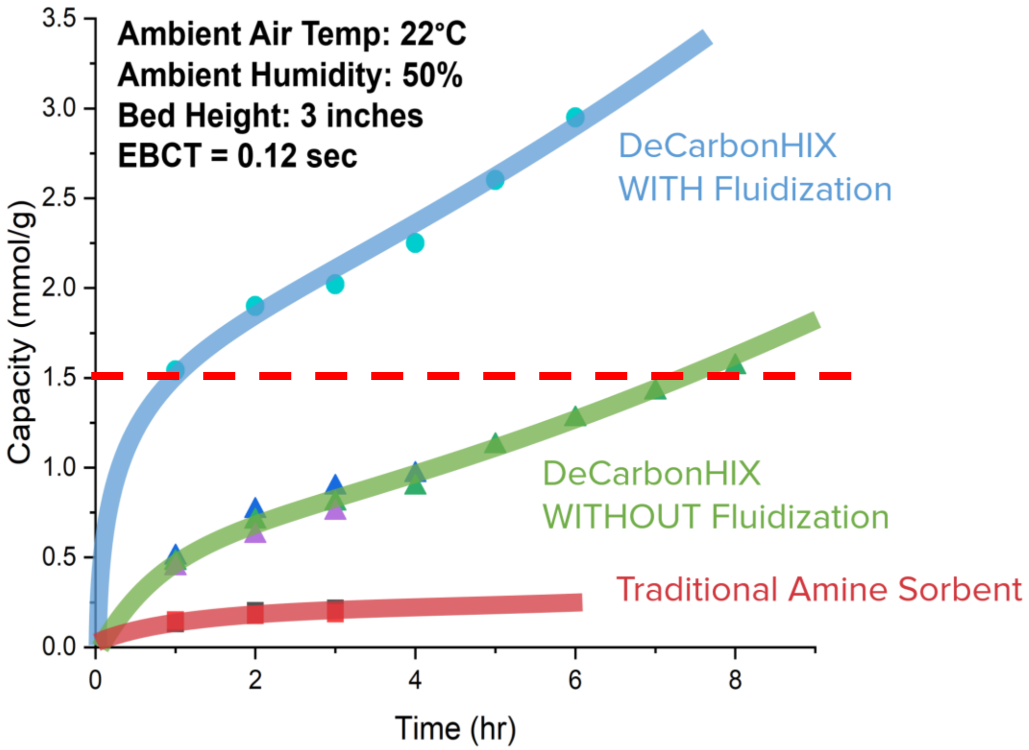
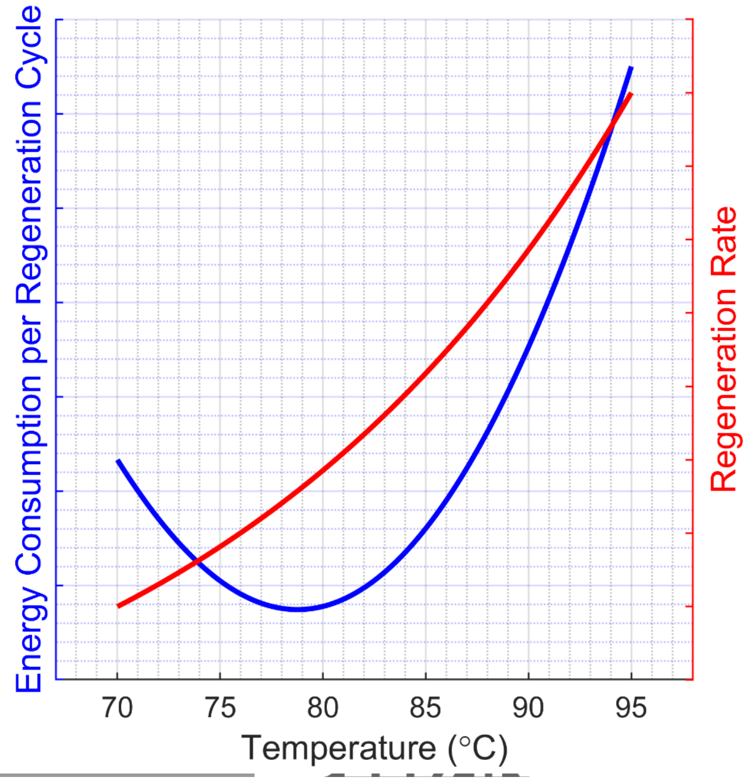


Regeneration Phase

Energy Cost Linked to Time

$$Q = h\,A \cdot \left(T_{\text{regen}} - T_{\text{ambient}}\right) \cdot t$$

- Is the product of temperature difference $(T_{\text{regen}} - T_{\text{ambient}})$ and the time required for the process (t)



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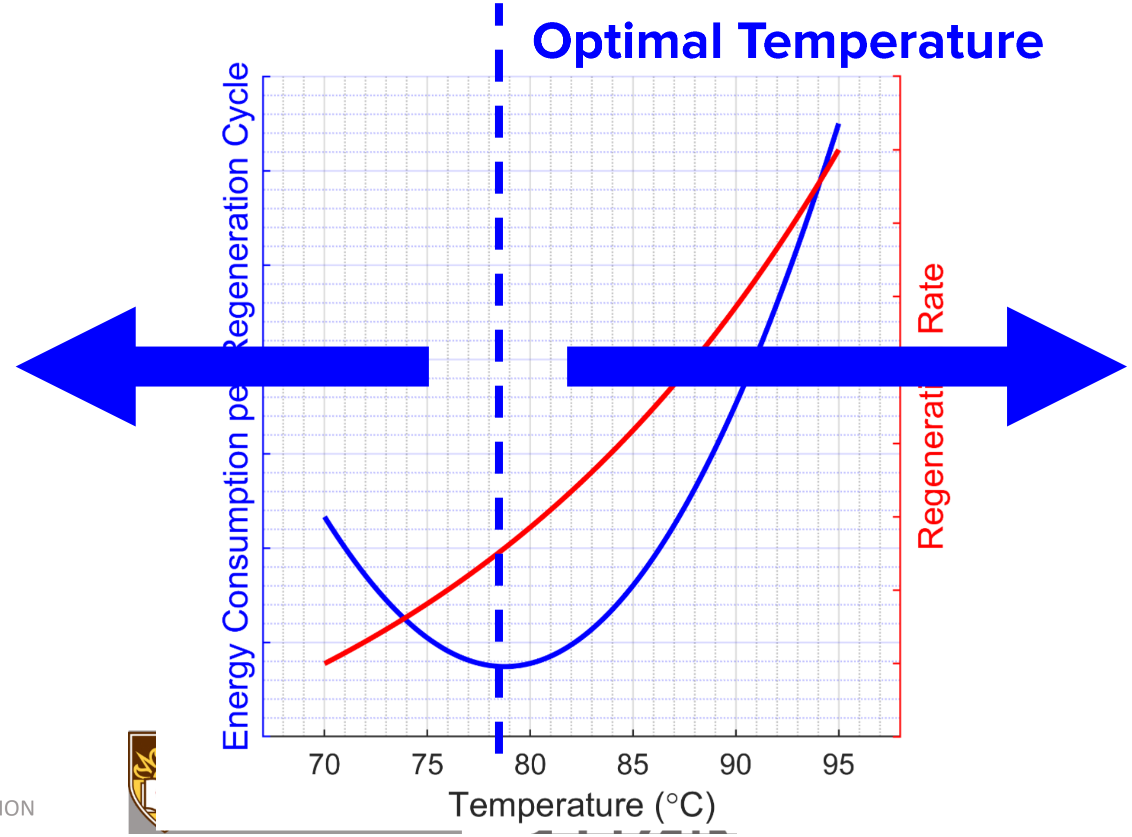
Process Takes too Long

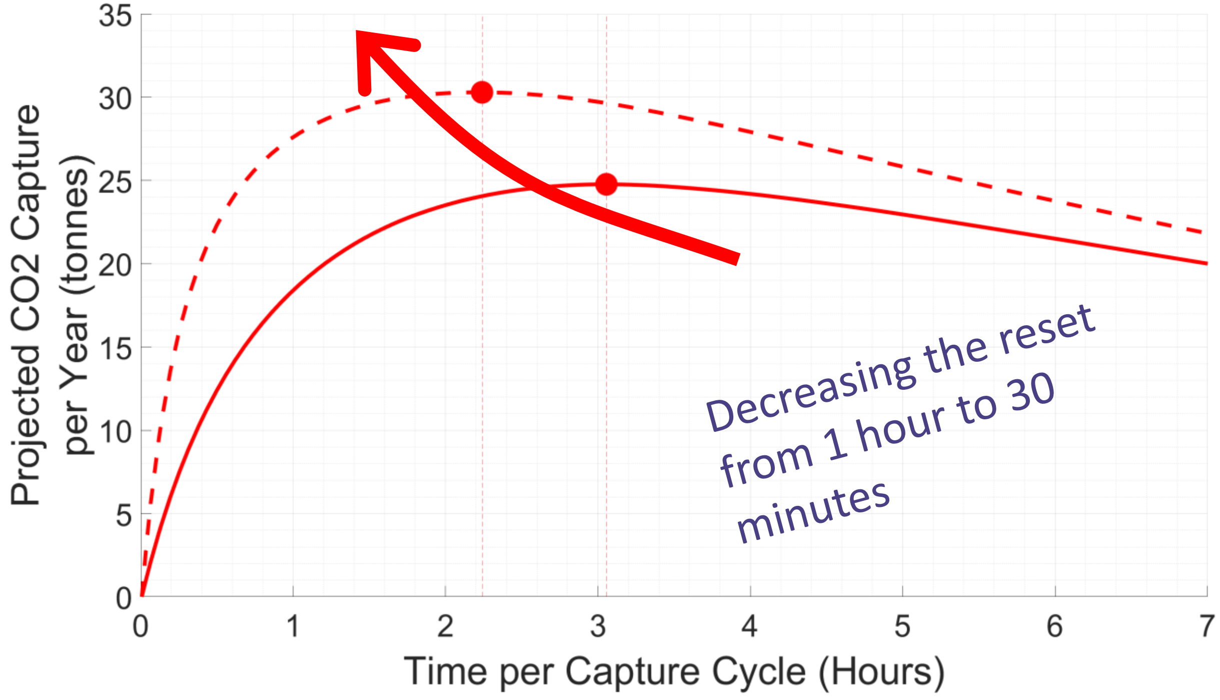


Energy Loss to Ambient too High

Total Cycle

Time Cost

- The shorter the cycle time is, the more high-kinetics of early-stage fluidization we can exploit.
- Problem: process overheads



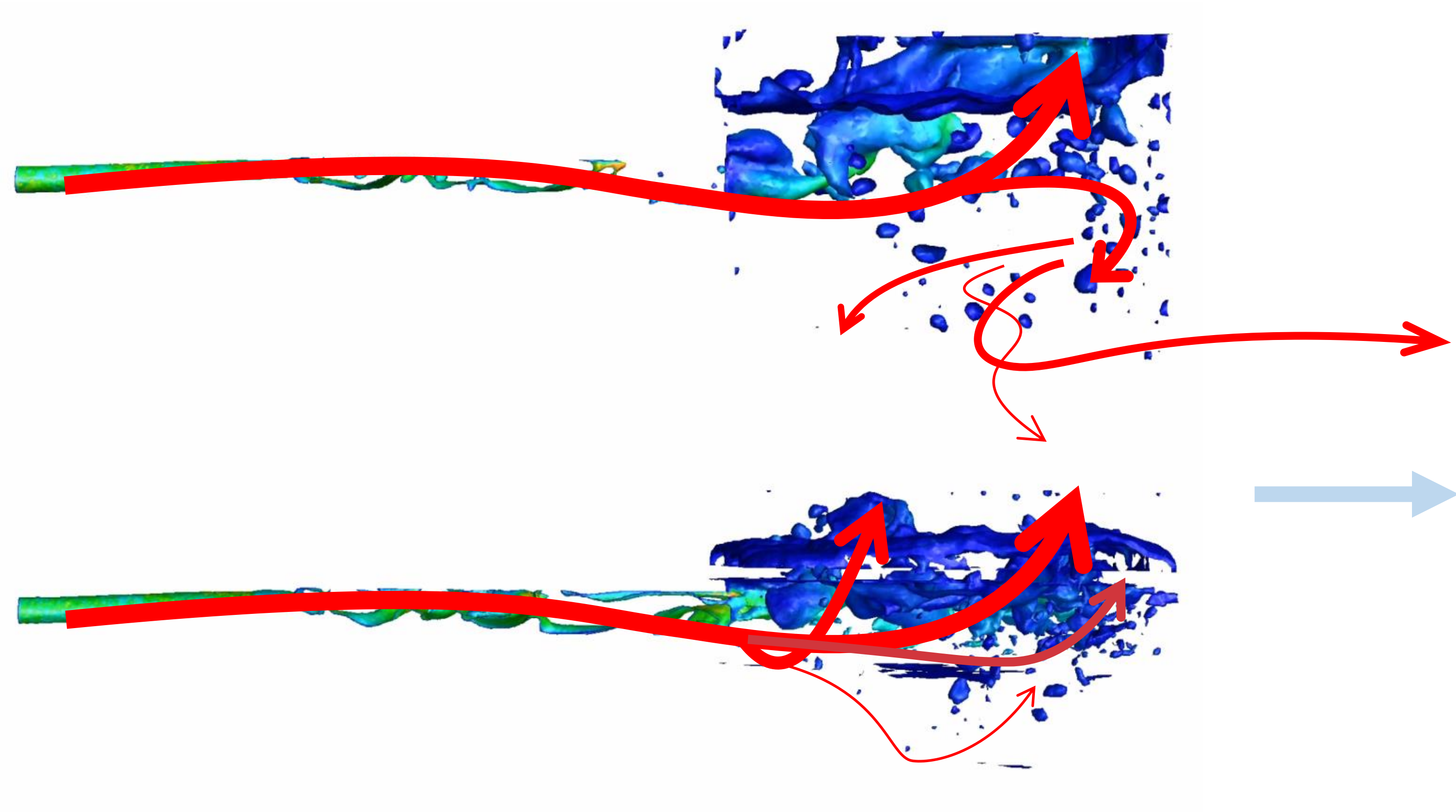
Hypothesized model for 6 pilot systems sharing regeneration facility

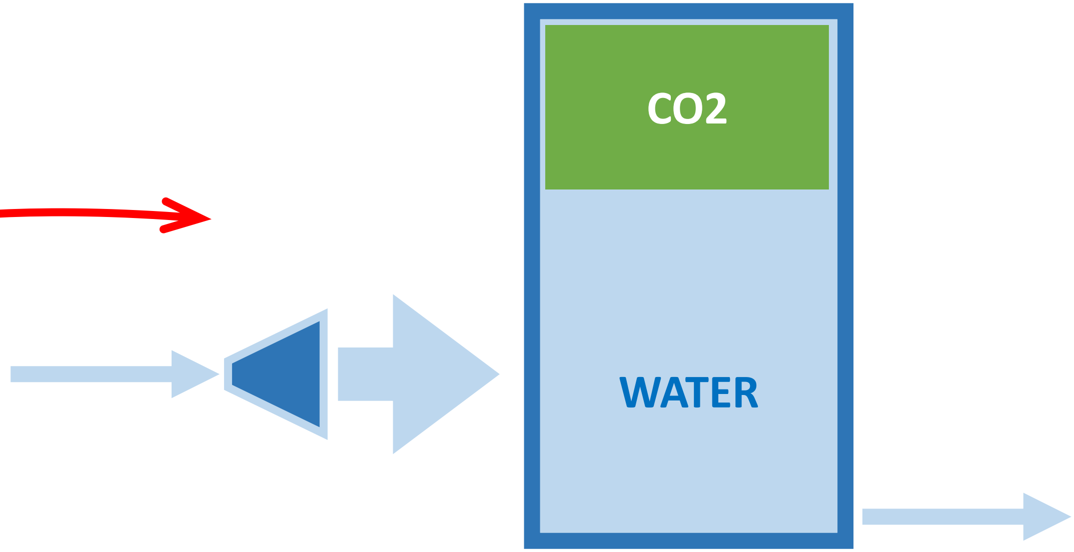
Gas-Liquid Separation

Sizing Cost

- Gas-liquid separation can be done highly efficiently via gravity.
- However, **gravity needs space for the acceleration to take effect**, otherwise the gas would recycle into the system.
- A new technology for compact separation: *Bi-Philic Meshes*

Gas-Liquid Separation





SUMMARY and PLANS:
1st Year

Next Step in the Project

- The focus and strength of our Team is a holistic approach to the DAC, focusing on the ***efficiency of each step*** and ***harmonious interplay of each component***

- Characterize the operational speed and costs and overheads of the built pilot system
- Update the system model
- Generate the new optimal operational point
  - *Prepare for scaling up another magnitude !*

- Ocean-based storage of CO_2 (saving energy and overheads on regeneration phase) – Our presentation on Friday, 8:15 AM, Room 408/409/410 ☺


THANK YOU