Assembly, Integration, and Initial Testing of the Carbon Dioxide Removal System at the Space Analog for the Moon & Mars

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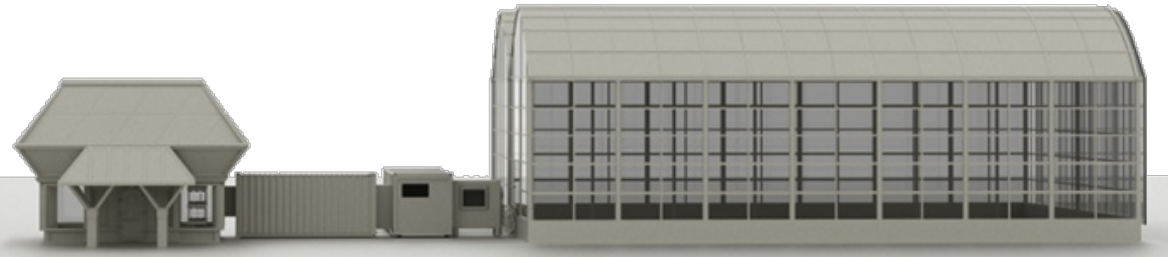
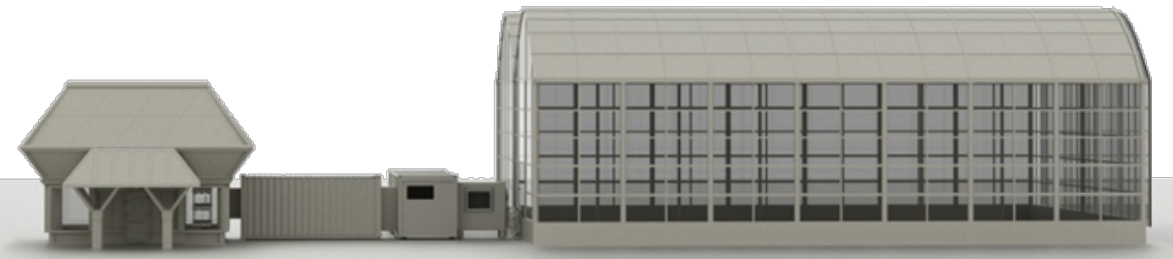
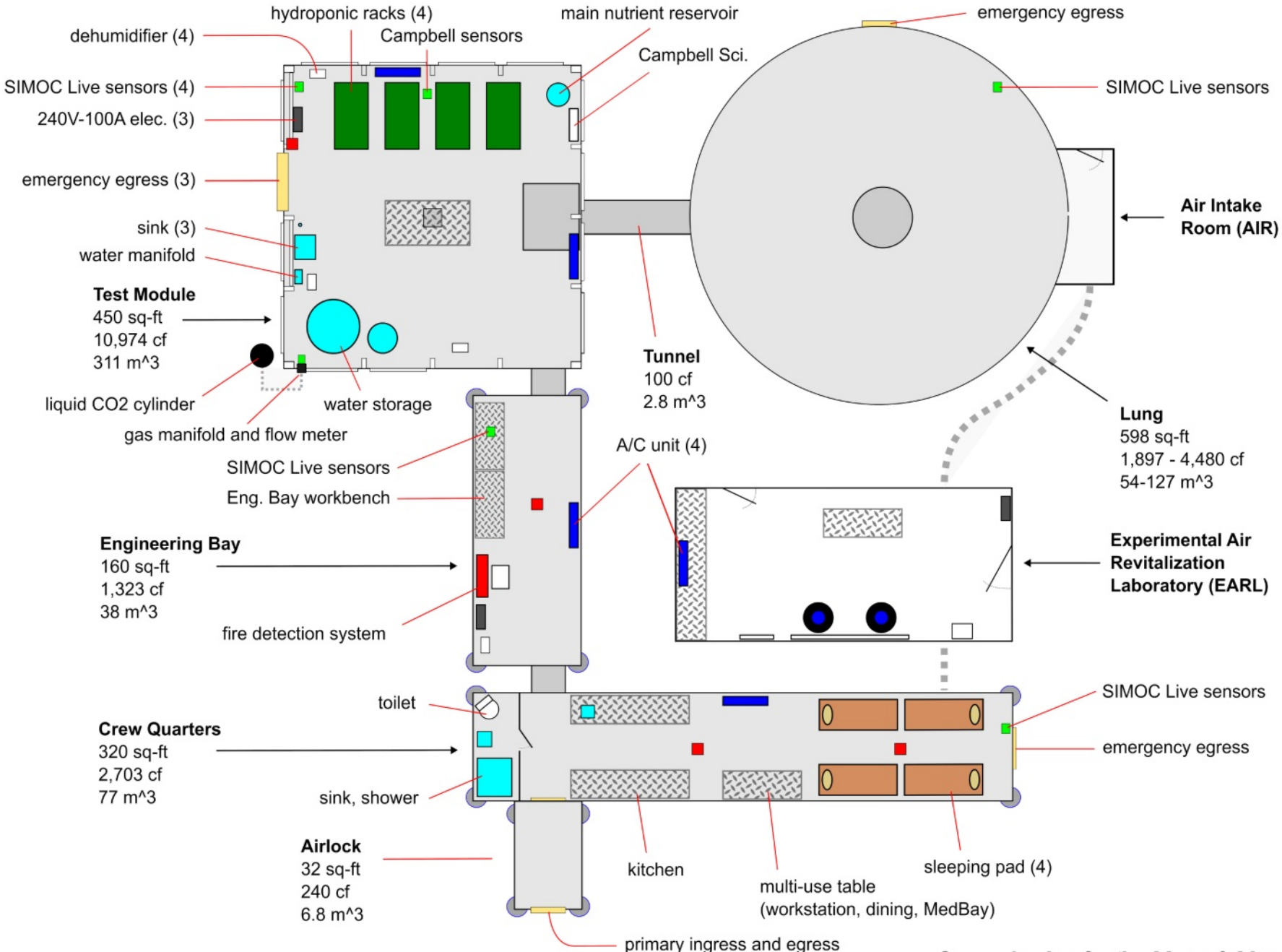
by Griffin Hentzen, Kai Staats, James Knox, Alyssa Ackerman, Jeffrey Buskirk, and Brendan Phoebe



SAM Overview

- SAM: Space Analog for Moon & Mars
  - Hermetically sealed, pressurized (~0.05 psi over ambient) habitat research center located at the University of Arizona, Biosphere 2 campus
  - Modules
    - Variable volume pressure regulation module (“Lung”)
    - Controlled Environment (“Test Module”) with hydroponics for bioregeneration
    - Engineering Bay
    - Crew Quarters
    - Functional airlock
  - Primary research objectives
    - Studies in food cultivar bioregenereation and physicochemical air revitalization
    - Model validation with the SIMOC Live air quality monitor
    - Support of visiting “analog” teams



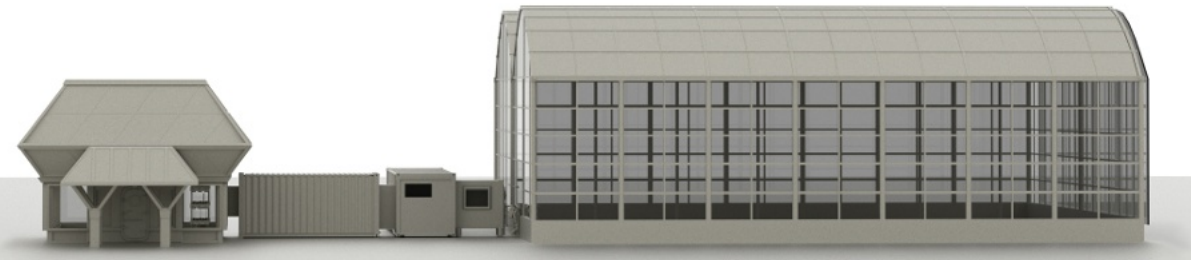


Space Analog for the Moon & Mars


N1987B

Review of the prior, ICES 2025 paper

- Developed a mathematical model of the SAM habitat.
- Uses data from four prior, 4-person, 6-days missions at SAM.
- Took into account the general location of crew members while in SAM.
- Air circulation and ventilation to maintain desired CO_2 levels.
- Assumed constant temperature, perfect mixing, and ventilation at 24 SCFM.
- Predicted CO_2 scrubber efficiency as matching ISS 4BCO_2.
- Using the model, tested four ways in which to manage the air flow.

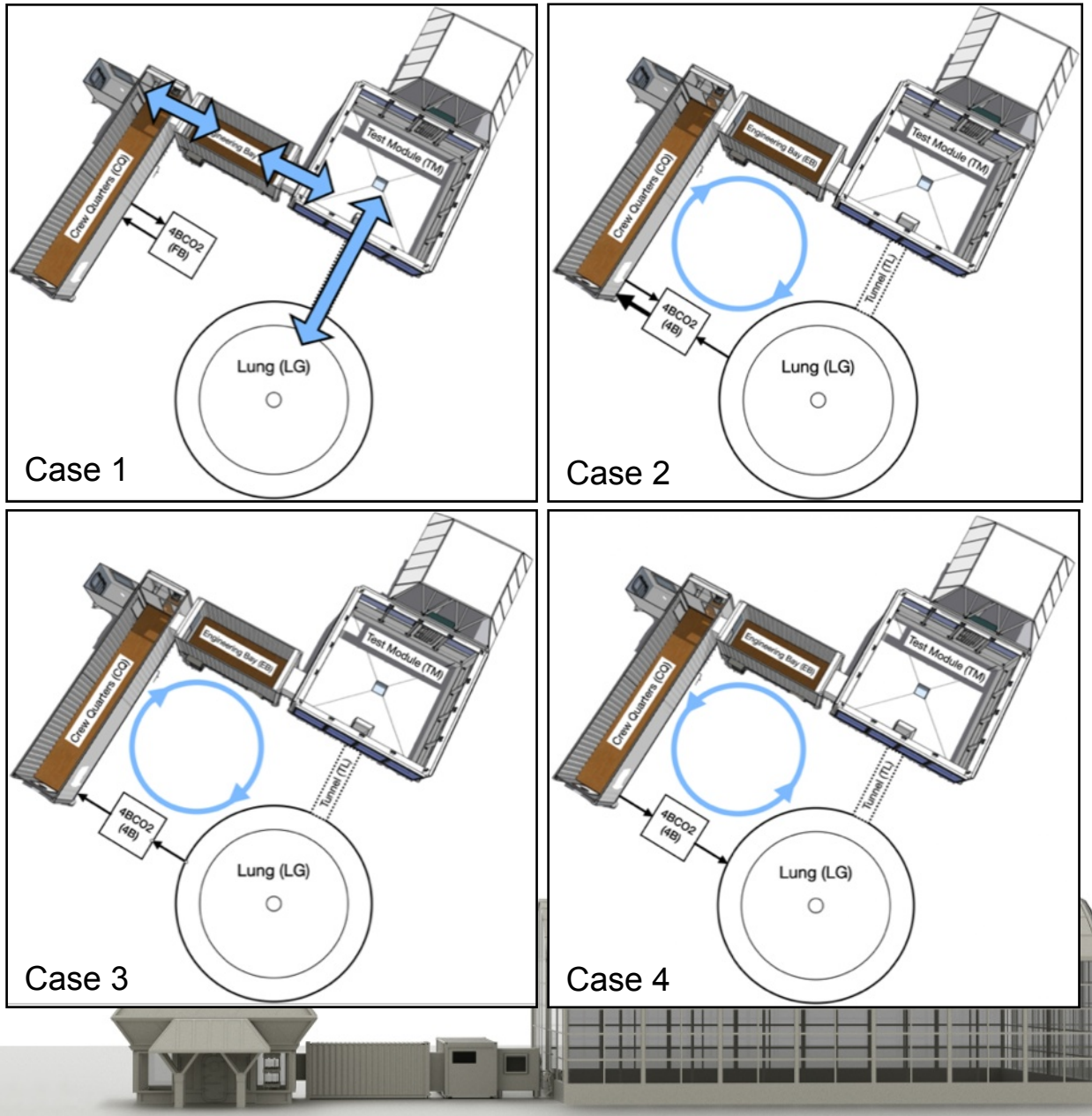


Analysis Cases

Summary of Conditions for Analysis Cases			
	IMV Mode	IMV Direction	Scrubber Interface
Case 1	Interchange	N/A	Same Inlet/Outlet
Case 2	Racetrack	Clockwise	Same Inlet/Outlet
Case 3	Racetrack	Clockwise	Different In/Out
Case 4	Racetrack	Counter-Clockwise	Different In/Out

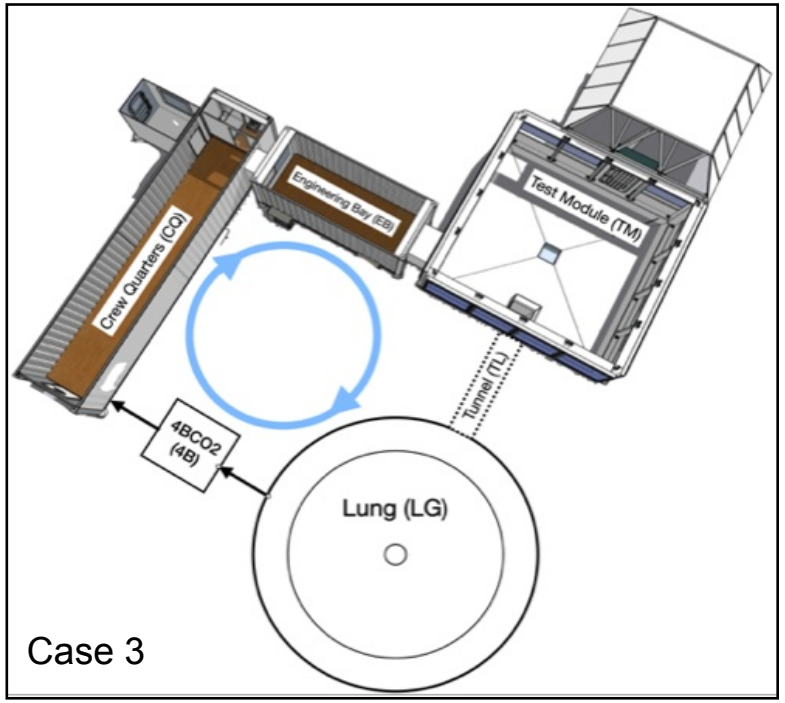
Assumptions/inputs

- Uniform IMV flow rate of 24 SCFM
- Scrubber flow rate of 24 SCFM
- No leakage out of modules (most conservative case)
- Crew metabolic and sleep rates set at average Human System Integration Requirements (HSIR) rates
- Crew locations/activities set by Imagination-1 mission
- CO_2 scrubber performance set by $4BCO_2$ on ISS

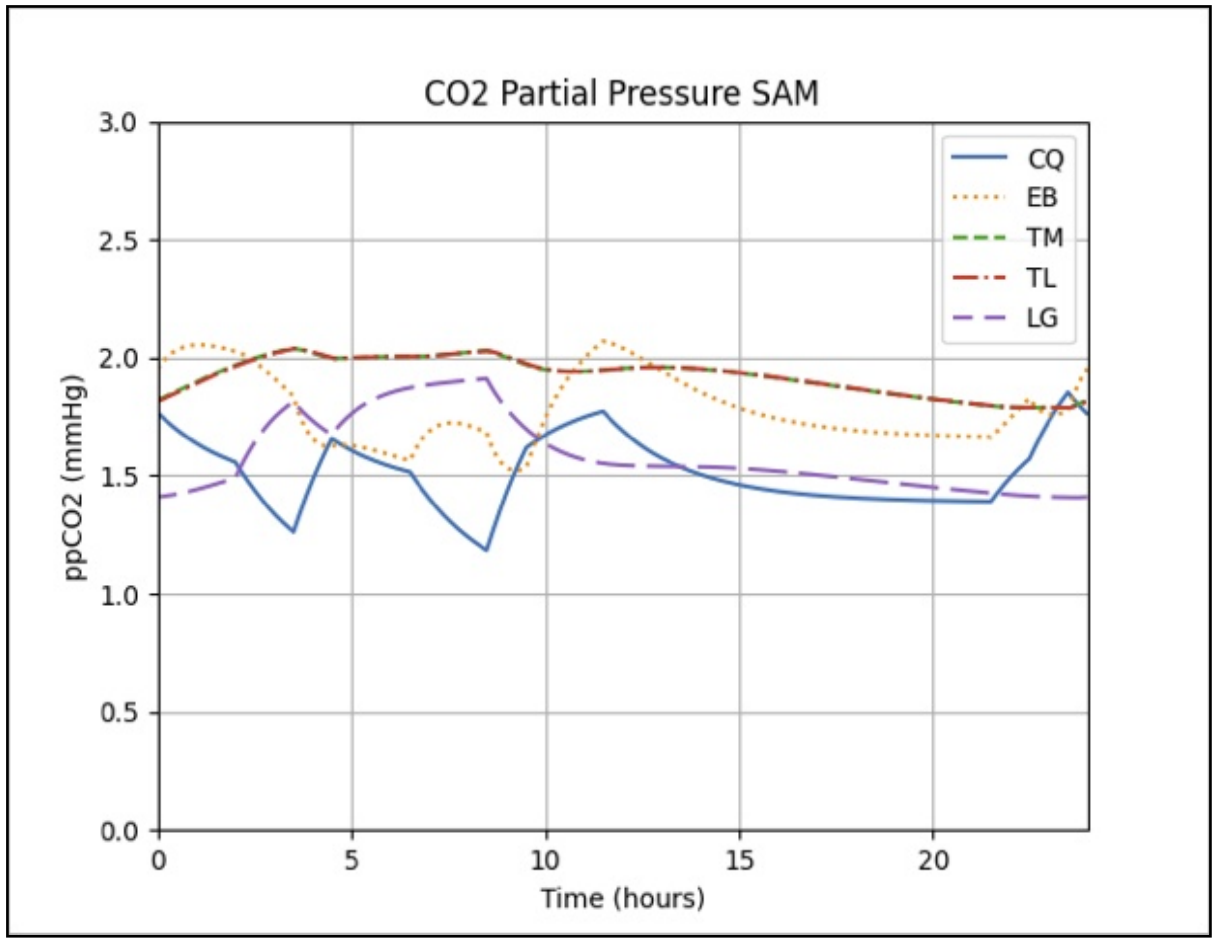


Analysis Case 3

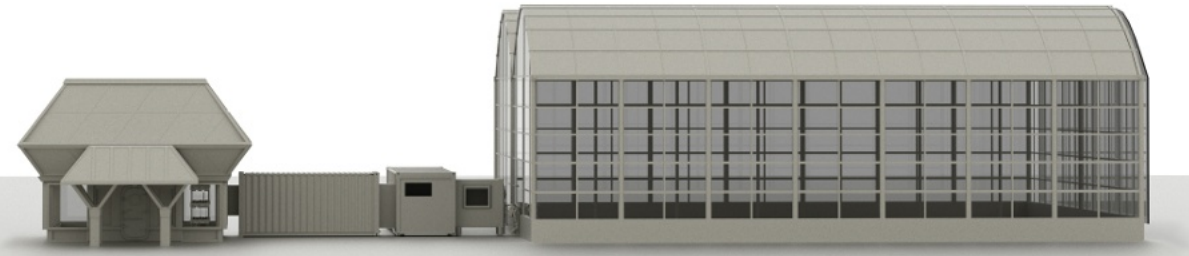
IMV Mode	IMV Direction	Scrubber Interface
Racetrack	Clockwise	Different In/Out



Case 3 Airflow



Case 3 Module CO_2 Simulation



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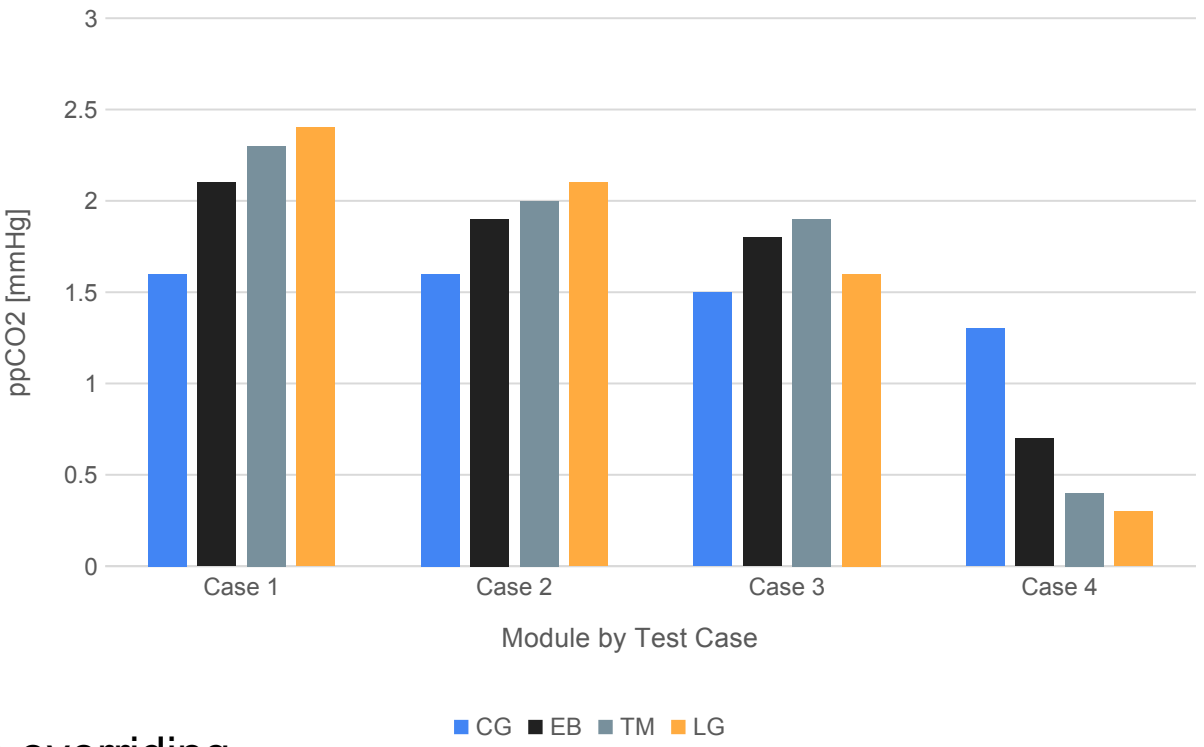
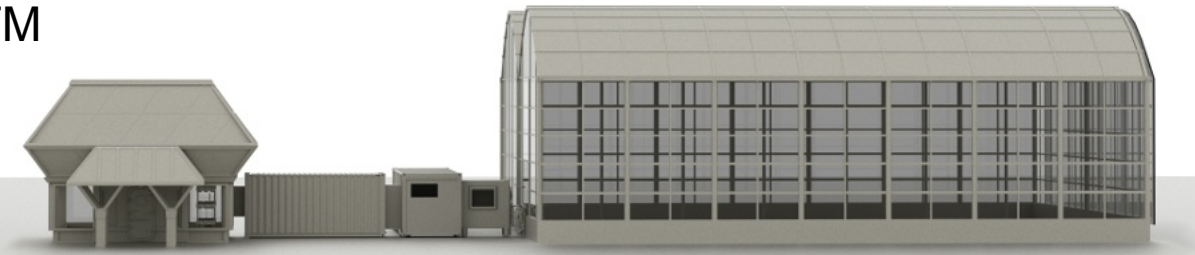


Key Conclusions

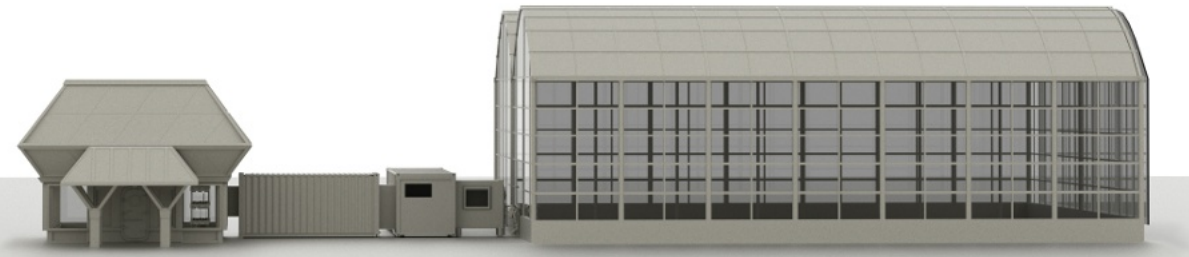
- Case 1 results in highest CO_2 levels
- Case 4 results in lowest CO_2 levels
- All cases remain in acceptable CO_2 range
- Case 3 selected as design configuration due to overriding design criteria:
  - CW airflow prevents humidity from TM into CQ
  - CW airflow provides CO_2 to plants in TM



Completed since the prior, 2025 paper

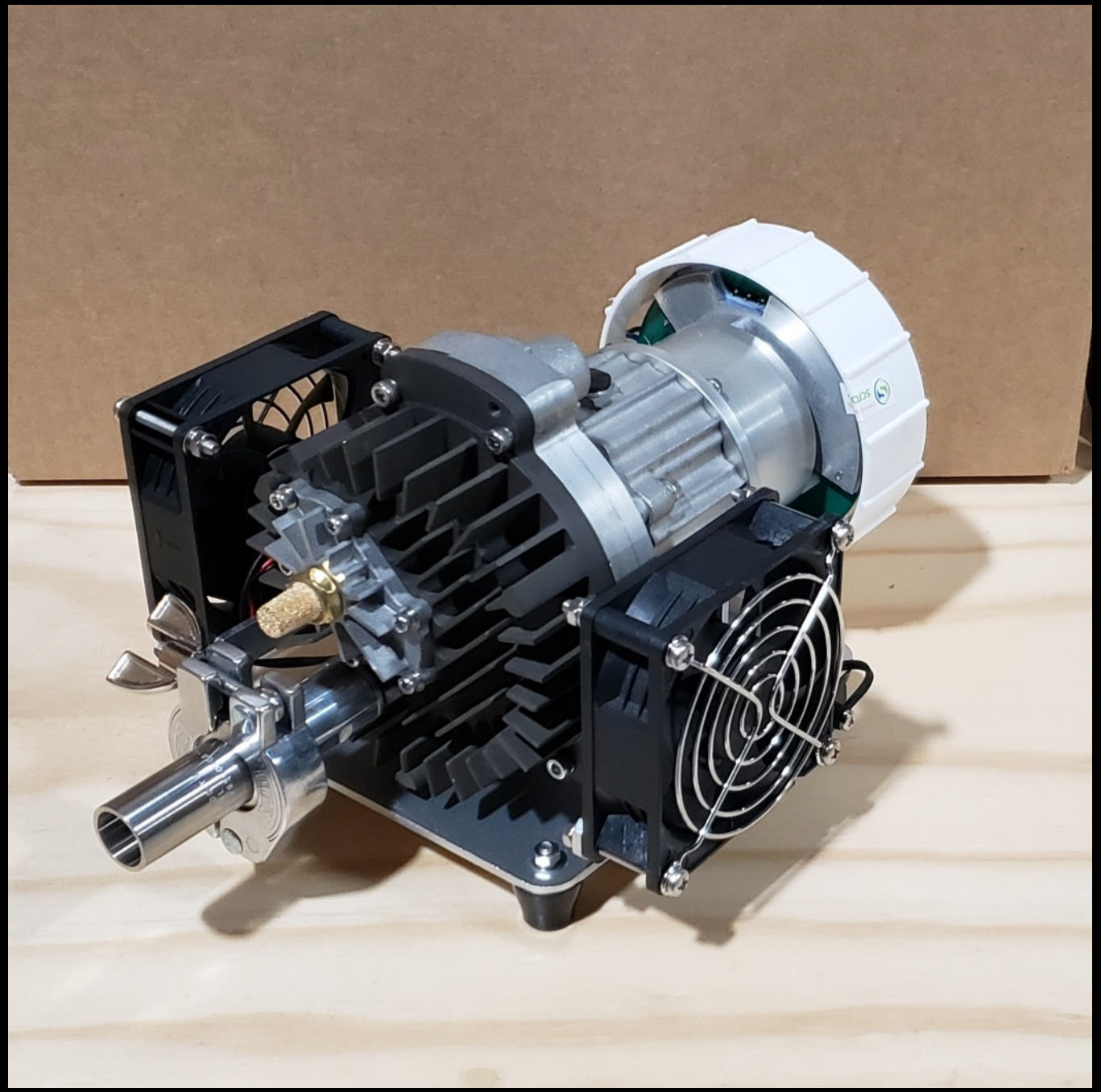
- Constructed the new Experimental Air Revitalization Laboratory (EARL)
  - An open air, separate structure from SAM
  - Includes internal power distribution, dedicated (oversized) room cooling, and a scrubber coolant loop

- Built the SAM Carbon Dioxide Removal Assembly (SCDRA - “skee-druh”)
  - Selected the 4BCO_2 architecture as the design foundation
  - Licensed the technology from NASA Marshall
  - Zeolite-based, regenerable system
  - Combination of commodity, off-the-shelf-components; and
  - Custom fabricated chambers and wall-mount rigging

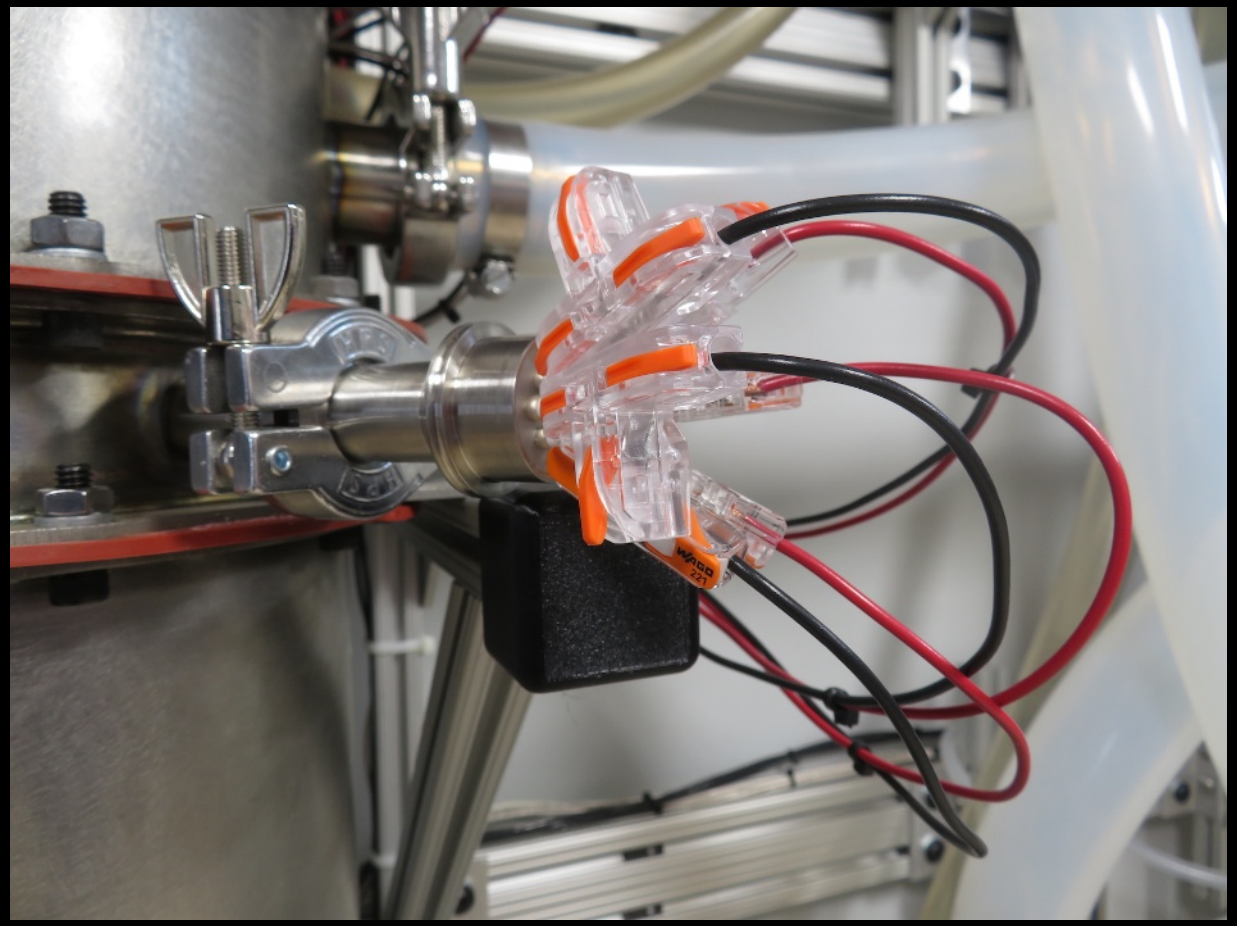



OREMUS
MATERIAL
BridgeKing
Con-Tech

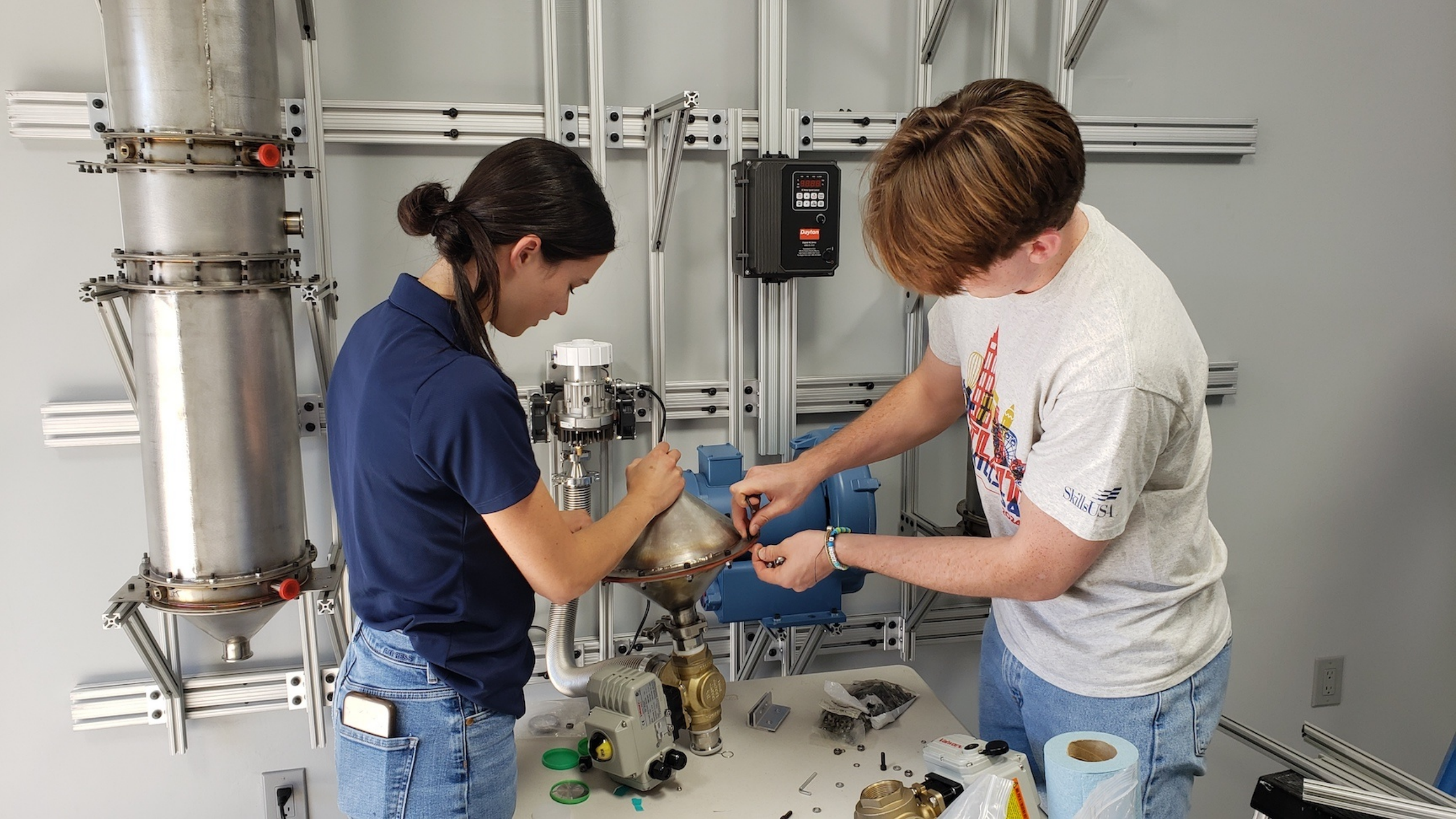

HUSKY
BEHR
1PK



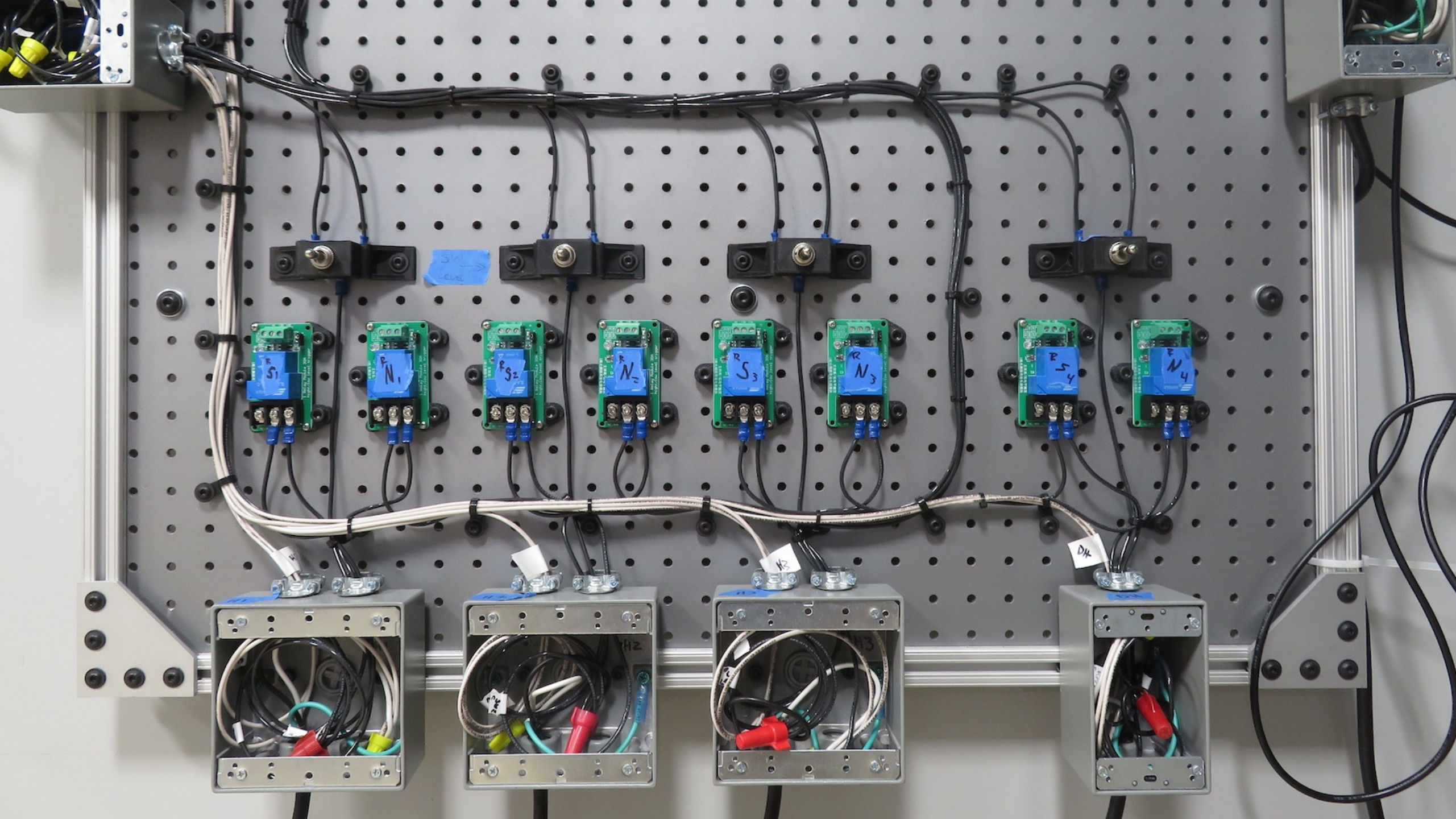

Valworx




AGFRC
DIGITAL SERVO

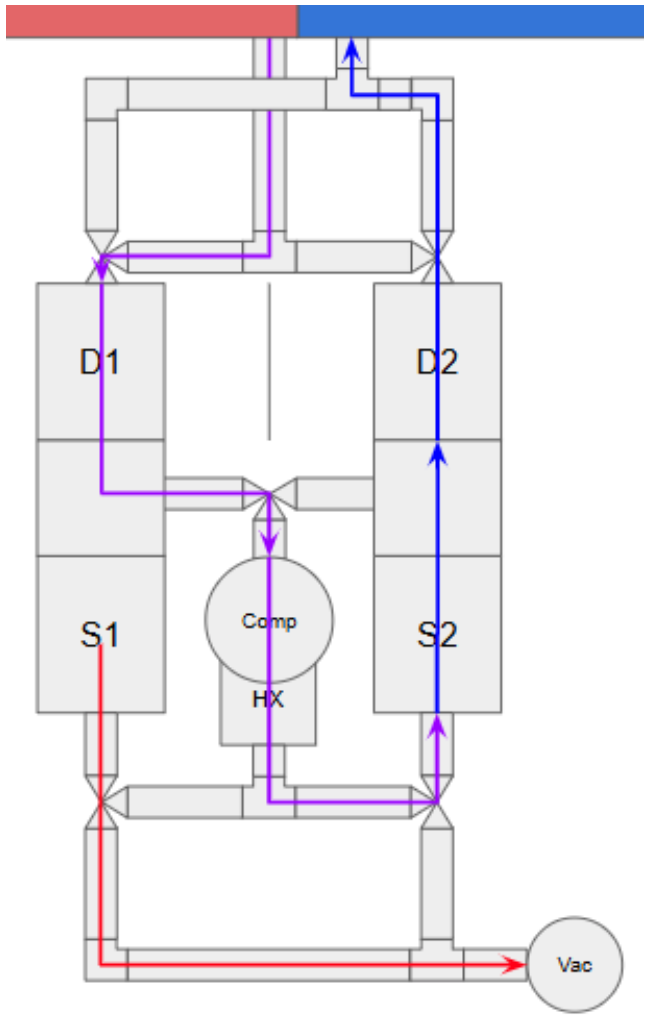

Dayton
SkillsUSA

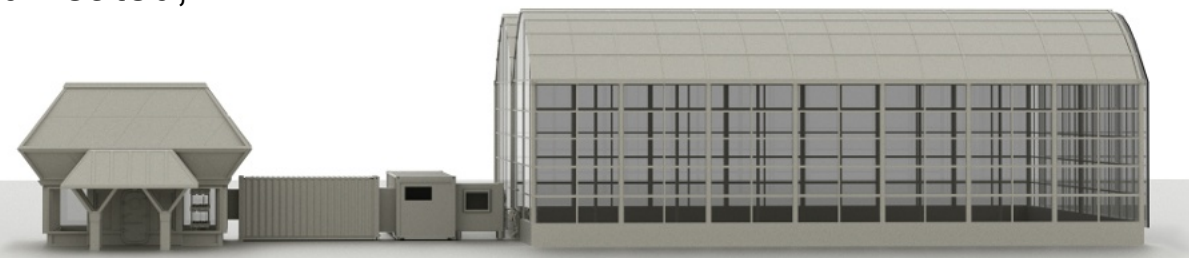

BILT
ICC-ES ESR-2955
THE HOME DEPOT
EVERB
NIRVANA
VOLCOM


R S1
R N1
R S2
R N2
R S3
R N3
R S4
R N4

Air Flow for 1st Half Cycle

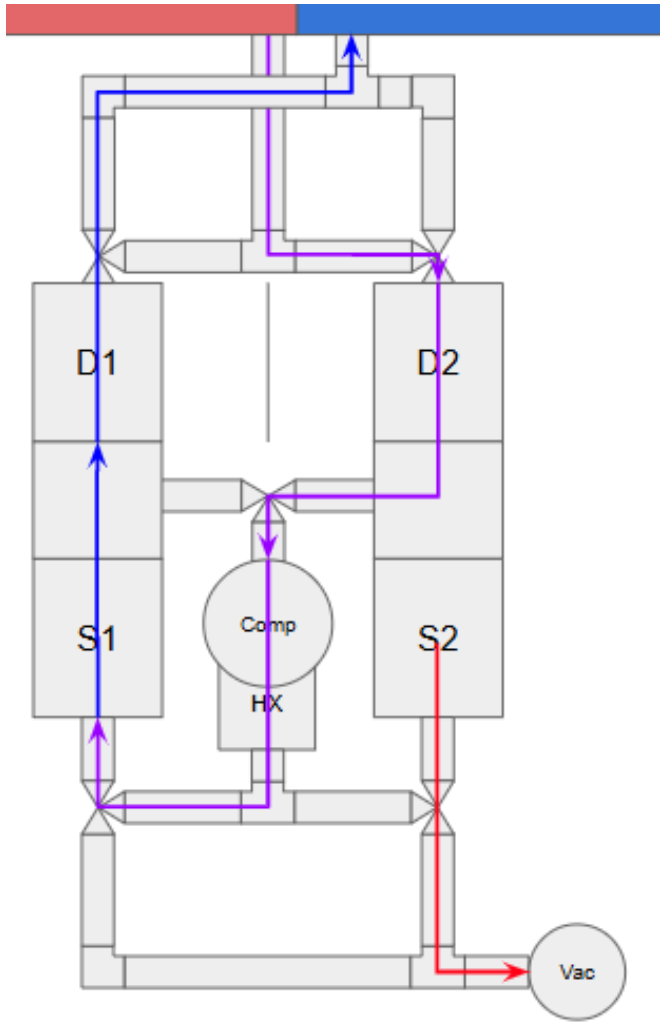
1) Air enters through a previously regenerated desiccant bed D1 where moisture from the air stream is removed.
2) Dehumidified air then enters the blower where it is pressurized.
3) The heat exchanger (HX) removes the heat of adsorption and compression, cooling the air to roughly 10°C (50°F).
4) CO_2 ladened, cool, dry air moves to sorbent bed S2, which is virtually devoid of CO_2 and hot at the beginning of this half cycle.
5) The in-bound air cools S2 such that it can adsorb again, and CO_2 is removed from the air stream.
6) As the start of this half cycle, the out-bound air is hot, and forces the moisture from desiccant bed D2 back into the airstream.
7) The air then leaves the system carrying the same total moisture as was input to the system over the previous half-cycle, but minimal CO_2.
8) Sorbent bed S1, loaded with CO_2, is isolated, exposed to vacuum (space on ISS; vacuum pump at SAM), and heated;
9) This desorbs the CO_2 through the exhaust line.

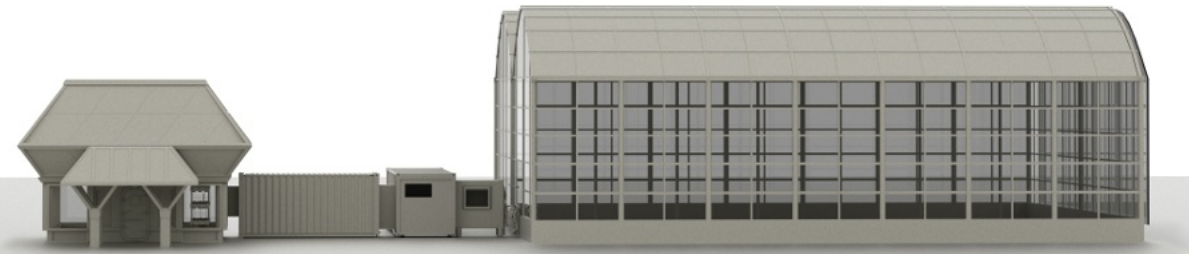




Air Flow for 2nd Half Cycle

1) The cycle then flips and each bed assumes the opposite role.
2) Airflow enters the freshly desorbed desiccant bed D2 and continues into the freshly desorbed sorbent bed S1.
3) Continues through the now-loaded desiccant bed D1, causing it to release its moisture; while
4) The loaded sorbent bed S2 is isolated and the CO_2 is desorbed to vacuum, and through the exhaust line.



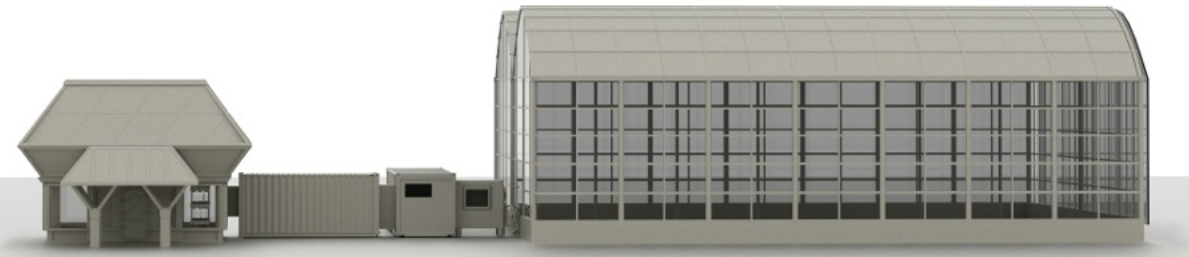


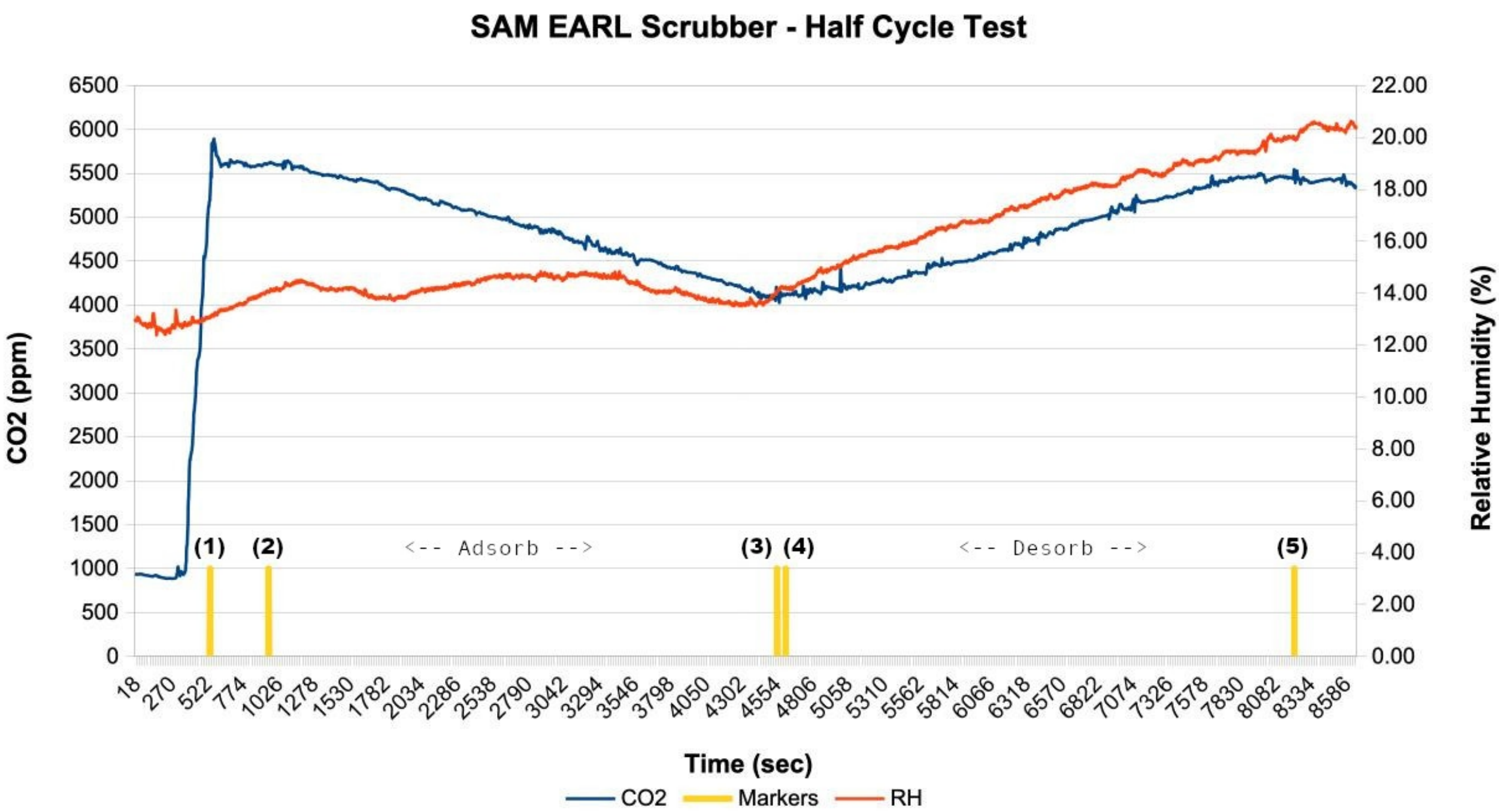
Half Cycle Test Procedure

1) Sealed front door to EARL to minimize air exchange. Rear door remained operable.
2) Set fan to circulate CO_2 upon injection from external canister.
3) Raised the CO_2 level to 5000 ppm.
4) Ran 30 minutes baseline for CO_2 loss. *
5) Ran #3-4 again, with human inside to account for additional CO_2. **
6) Injected CO_2 to 5000 ppm.
7) Ran adsorb half-cycle.
8) Ran desorb half-cycle.

* SIMOC Live captured CO_2, relative humidity, and temperature.

** 2-way radios were used to monitor levels, coordinate CO_2 injection, cycle start and stop.



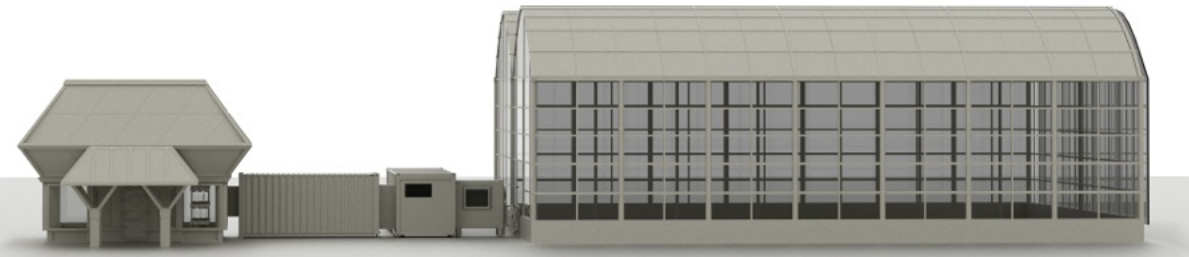

SAM EARL Scrubber - Half Cycle Test
CO2 (ppm)
Relative Humidity (%)
Time (sec)
(1)
(2)
(3)
(4)
(5)
<-- Adsorb -->
<-- Desorb -->
CO2
Markers
RH

Half Cycle Test results

Adsorb			Desorb		
Initial CO_2	Final CO_2	Adsorption Rate	Initial CO_2	Final CO_2	Desorption Rate
5610 ppm	4150 ppm	1406 ppm/hr	4121 ppm	5493 ppm	1426 ppm/hr

CO_2 Removal Rate Summary				
	Ppm CO_2 / hr	Mol CO_2 / (mol air * hr)	kg CO_2 / hr	kg CO_2 / day
Adsorb	1406	0.001406	0.167	4.01
Desorb	1426	0.001426	0.170	4.08

- Operated at 5000 ppm CO_2
- Target removal rate was 4.5 kg/day
- Actual removal rate was 4.01 kg/day
- Reasons for shortfall:
  - Incomplete desorb of desiccant bed
  - Incomplete desorb of sorbent bed
  - Lower flow rate than nominal (designed for 25 cfm; run at 22.3)



Thank You!

Questions?

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