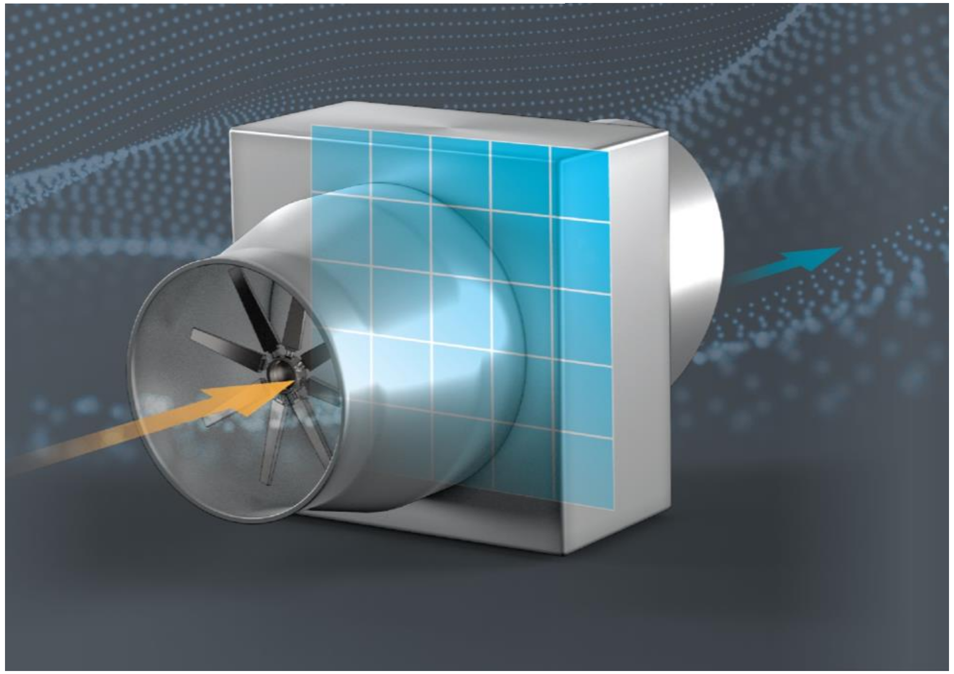
Design, Fabrication, and testing of Direct Air Capture Sorbent modules to increase understanding of trade-offs in pressure drop and capture efficiency



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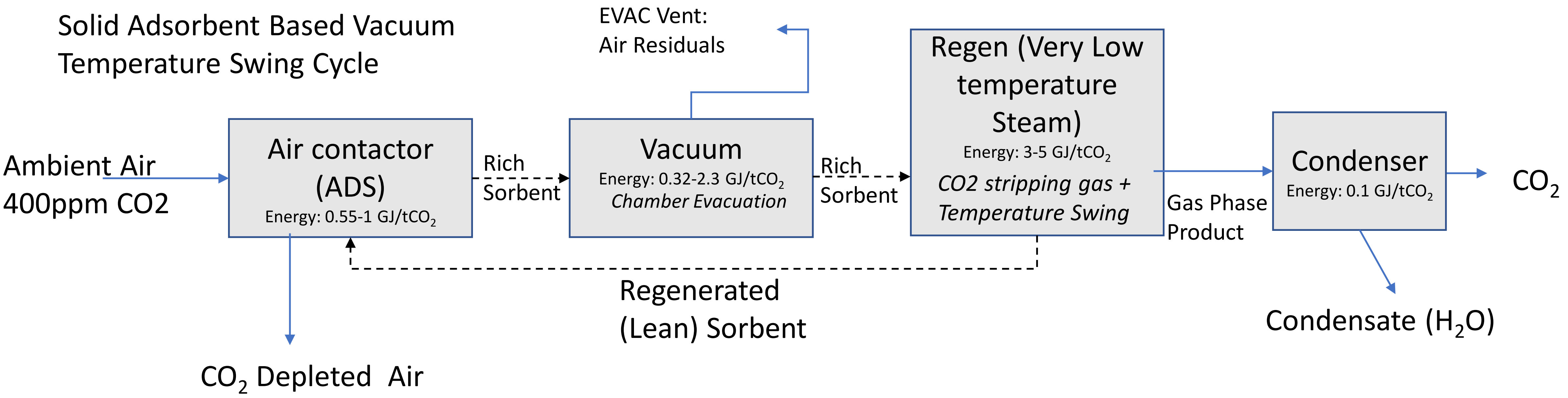
Agenda

- Background
- Experimental Setup and operational cycle
- Module Design and fabrication
- Test Matrix and Target Metrics
- Operational Testing and outcomes of 2 different configurations
- Moving Forward

Background

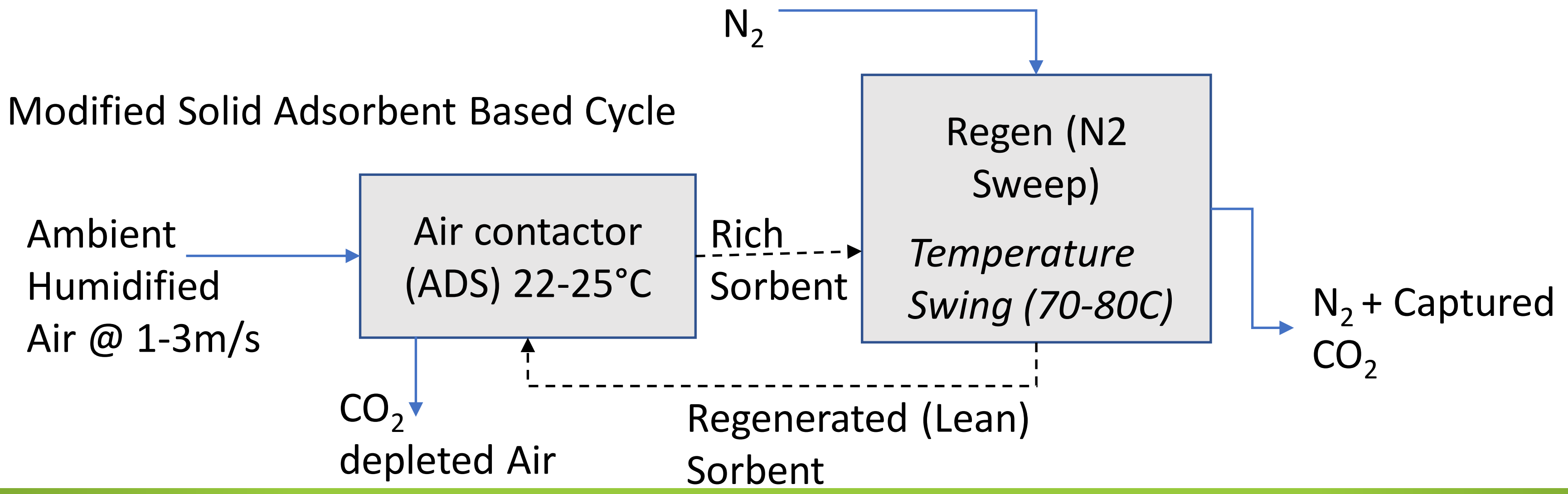
- Direct Air Capture using sorbent materials



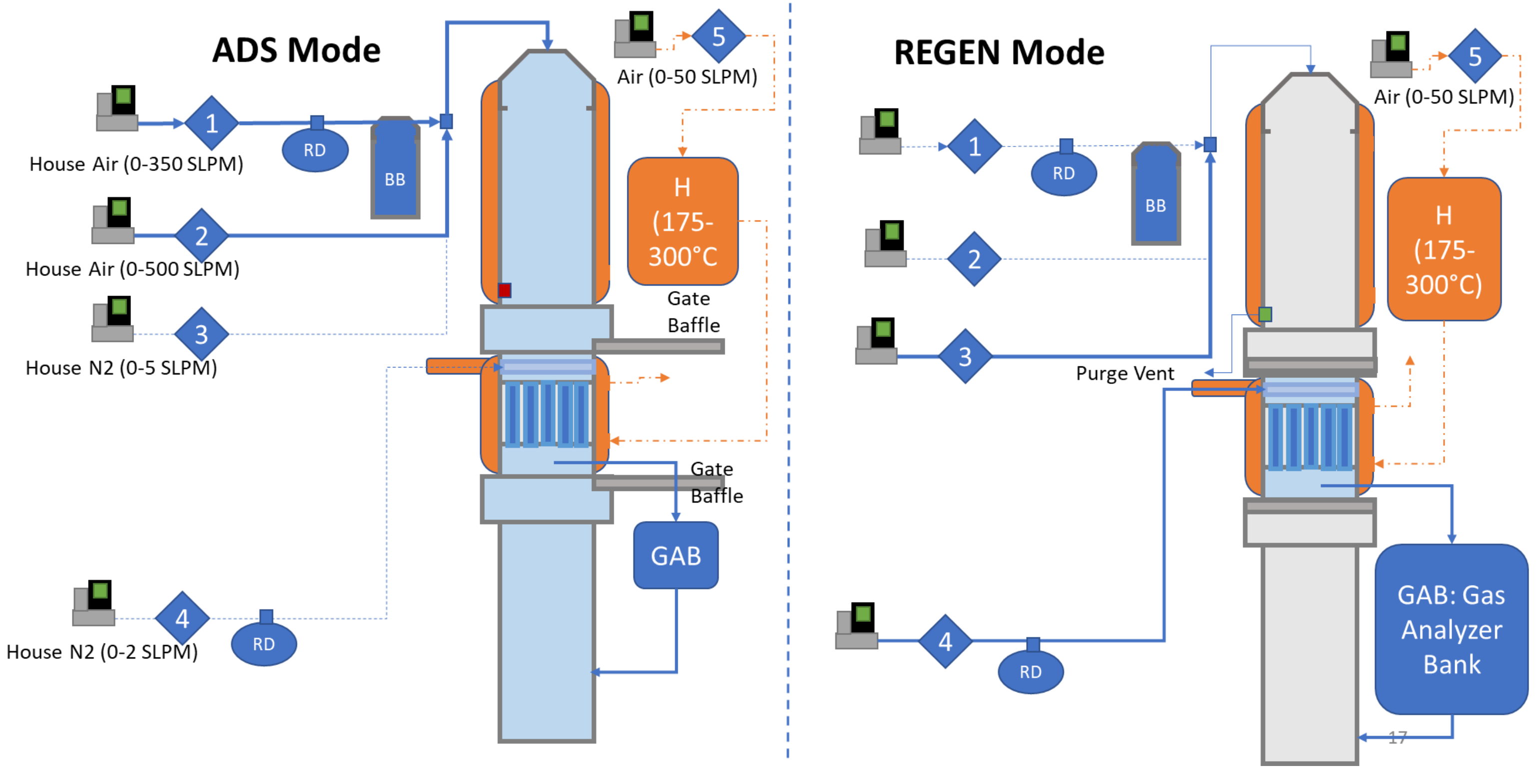
- NETL has been developing PIM based sorbent materials that could within this type of cycle
  - A. K. Sekizkardes, V. A. Kusuma, J. T. Culp, P. Muldoon, J. Hoffman, J. A. Steckel and D. Hopkinson, "Single polymer sorbent fibers for high performance and rapid direct air capture," Journal of Materials Chemistry A: Materials for Energy and Sustainability, vol. 11, no. 22, pp. 11670-11674, 2023.

Objectives

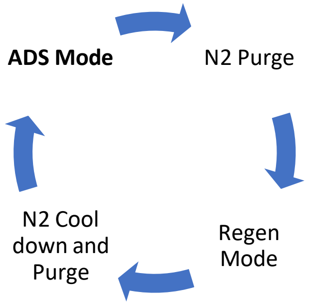
- Develop scalable modular formfactors for Direct Air Capture of Atmospheric CO2 based around NETLs patented sorbent technology, Wet Spun PIM-Tris(2-aminoethyl)amine (TAEA).
- Enable the sorbent material to be shaped and arranged into a specific form factor for practical implementation into flow contactor setups.
- Establish trade offs in pressure drop and capture effectiveness with a basic Adsorption and inert sweep/Temperature swing cycle.



Test Method and Current Rig setup



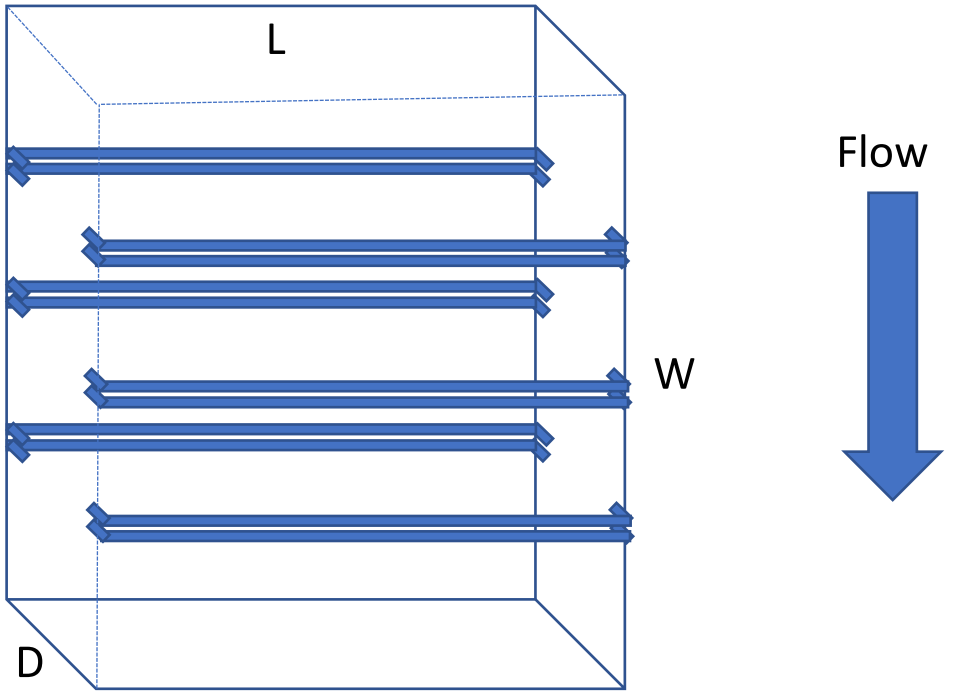
- Each testing day starts with a Regen Cycle to ensure the sorbent is free of CO_2.
- Cycle Progression

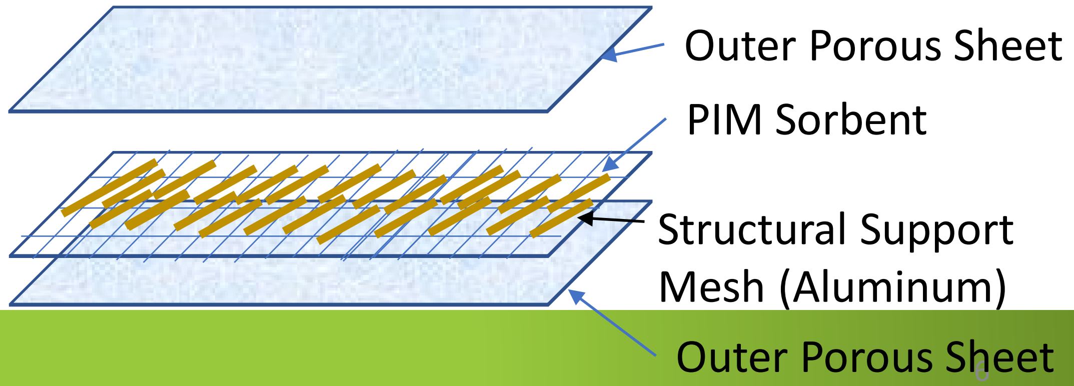


Test Condition									Flows [SLPM]				
44%RH 1m/s									MFC 1	MFC 2	MFC 3	MFC 4	MFC 5
Step	**t (min)**	**Method Segment**	**Gate Baffles**	**Vent Valve**	**Rig Valve**	**N2 Cooling Valve**	**H Setpoint [°C]**	**RH [%]**	**ADS Humid Air**	**ADS Dry Air**	**Purge N2**	**Regen N2**	**Heater Air**
1	20	Initial Heat up	In	Open	Shut	Open	340	0	0	0	1	0.5	40
2	12	Ramp ~20C/min to regeneration zone (>60C)	In	Open	Shut	Open	340	0	0	0	1	0.5	35
3	60	Regeneration Zone @ 65-85 C for 60 min	In	Open	Shut	Open	285	0	0	0	1	0.5	28
4	12	Ramp ~20C/min to 25C (Using Cooling N_2)	Out	Open	Shut	Open	240	0	0	0	175	0.5	5
5	-	Isothermal at 25C for 10 minutes	Out	Open	Shut	Open	240	0	0	0	175	0.5	5
6	0.5	Switch to ADS Mode	Out	Shut	Open	Shut	300	44	250	30	0.1	0.5	5
7	10	Isothermal for **TX** (TOS) minutes	Out	Shut	Open	Shut	300	44	250	30	0.1	0.5	5
8	10	ADS Post N2 Purge (Isothermal for 10 minutes)	Out	Open	Shut	Open	340	0	0	0	175	0.5	35
9		Repeat from step 2 for regen of material											

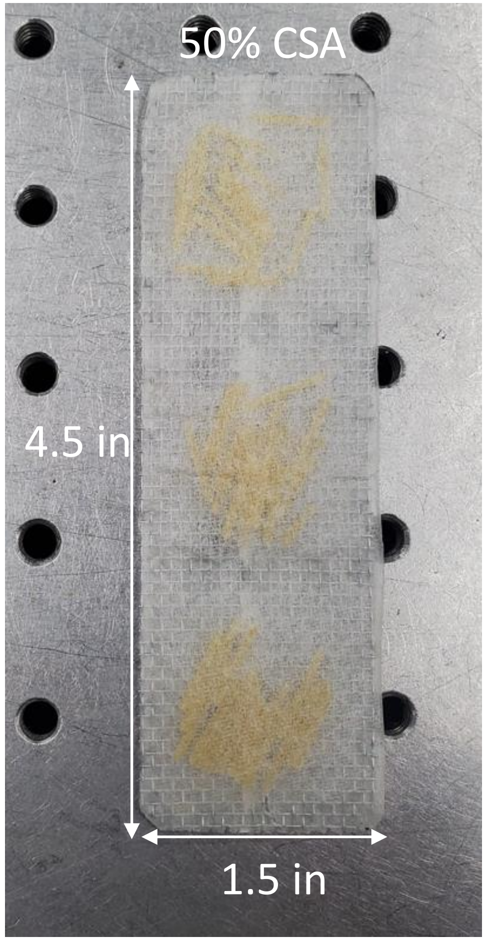
Cartridge Module Design and Fabrication

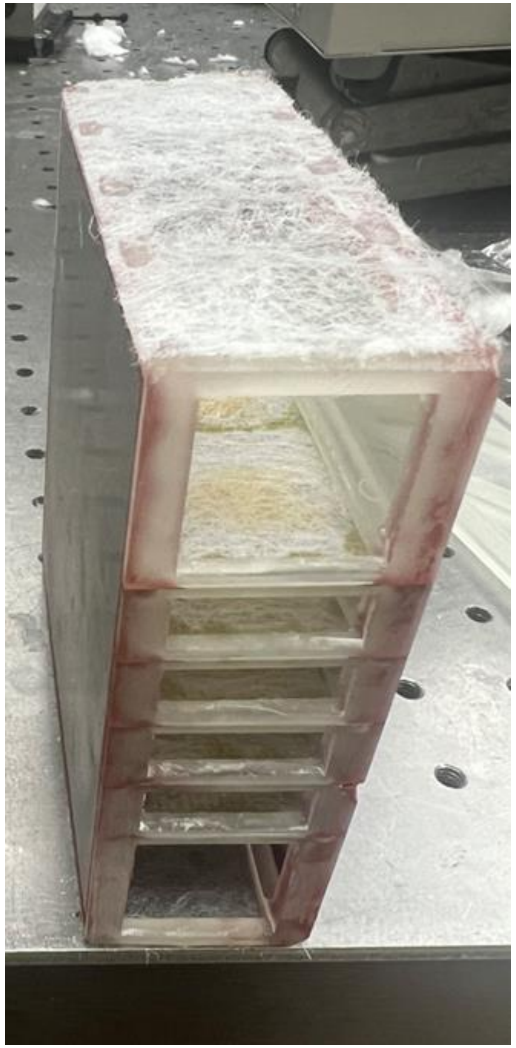
- Cartridge Module
  - 3d printed Support framework
    - Support framework: L = W = ~4.5 in, D = ~1.6 in
    - 1/8in Aluminum Plates (For Heat Transfer) on the sides of the cartridge
  - Sorbent Elements
    - Layered Straight wet spun Fiber separated by Low resistance porous support sheets supported by an aluminum support mesh
    - Elements consist of 3 quilted packets
    - Elements compress into support framework





Cross flow Cartridge Module setup

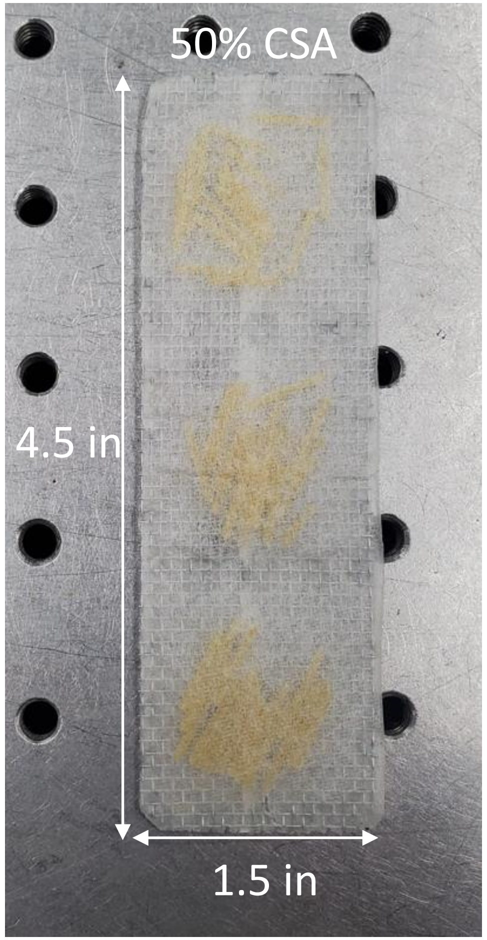




Element #	1	2	3	4	5
Packet 1	0.0747	0.0746	0.0748	0.0743	0.0748
Packet 2	0.0746	0.0748	0.075	0.0748	0.0749
Packet 3	0.0752	0.0749	0.0746	0.0751	0.074
Per Element (g)	0.2245	0.2243	0.2244	0.2242	0.2237
Total (g)	1.1211				

- Each Element consists of three "Quilted" Packets
  - Aim for similar loading between packets and elements
- FF1bH consists of 5 elements
  - 2nd generation cartridge module design compresses the 5 elements to the hot zone area for better consistent heating during regen

Parallel Flow Cartridge Module setup



Element #	1	2	3	4	5
Packet 1	0.0742	0.0744	0.074	0.0742	0.0741
Packet 2	0.0744	0.0748	0.0748	0.0745	0.0755
Packet 3	0.0745	0.0748	0.0742	0.0746	0.0745
Per Element (g)	0.2231	0.224	0.223	0.2233	0.2241
Total (g)	1.1175				

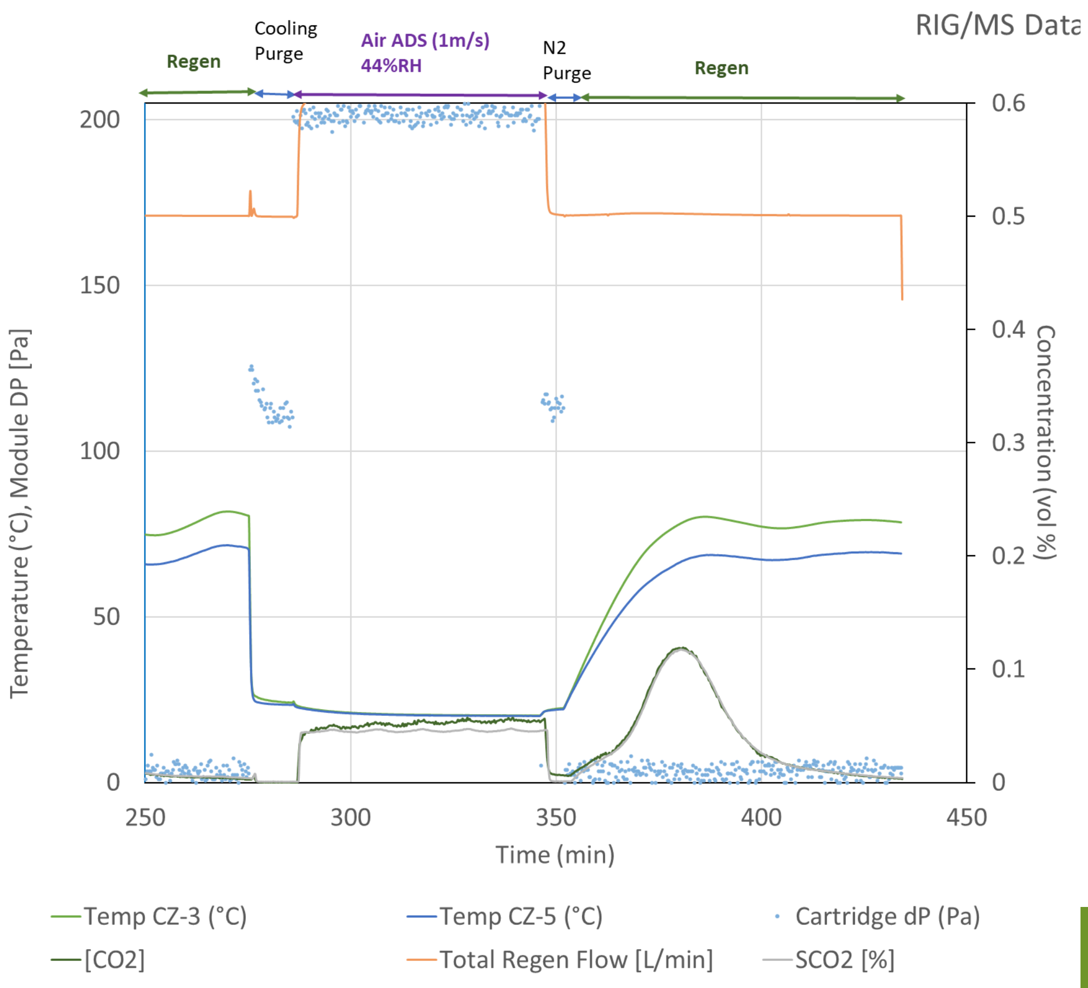
- Each Element consists of three "Quilted" Packets
  - Aim for similar loading between packets and elements
- FF1bP consists of 5 elements evenly spaced in the flow module (~5/8-3/4in gap between elements)
- Top of the element pieces have a teardrop type cross support to minimize flow resistance

Test Matrix: 5 element flow modules

Velocity Test condition	1 m/s		1 m/s		1 m/s	1 m/s	1.5 m/s	3 m/s
Form Factor	5 element Cross Flow				5 element Parallel Flow			
ADS Condition	44% RH	25%RH, ~21°C, ~400ppm CO2			44%RH	25%RH, ~21°C, ~400ppm CO2		
TOS	[min]							
T0	0		0		0	0	0	0
T1	1		1		1	1	1	1
T2	5		5		5	5	5	5
T3	10		10		10	10	10	10
T4	30		30		30	30	30	30
T5	60		60		60	60	60	60
Regen Condition	~75°C, 0.5 SLPM N2, 70 minutes							

Conduct a regen after each TOS condition to build uptake profiles.

T5 (60min ADS 44%RH)



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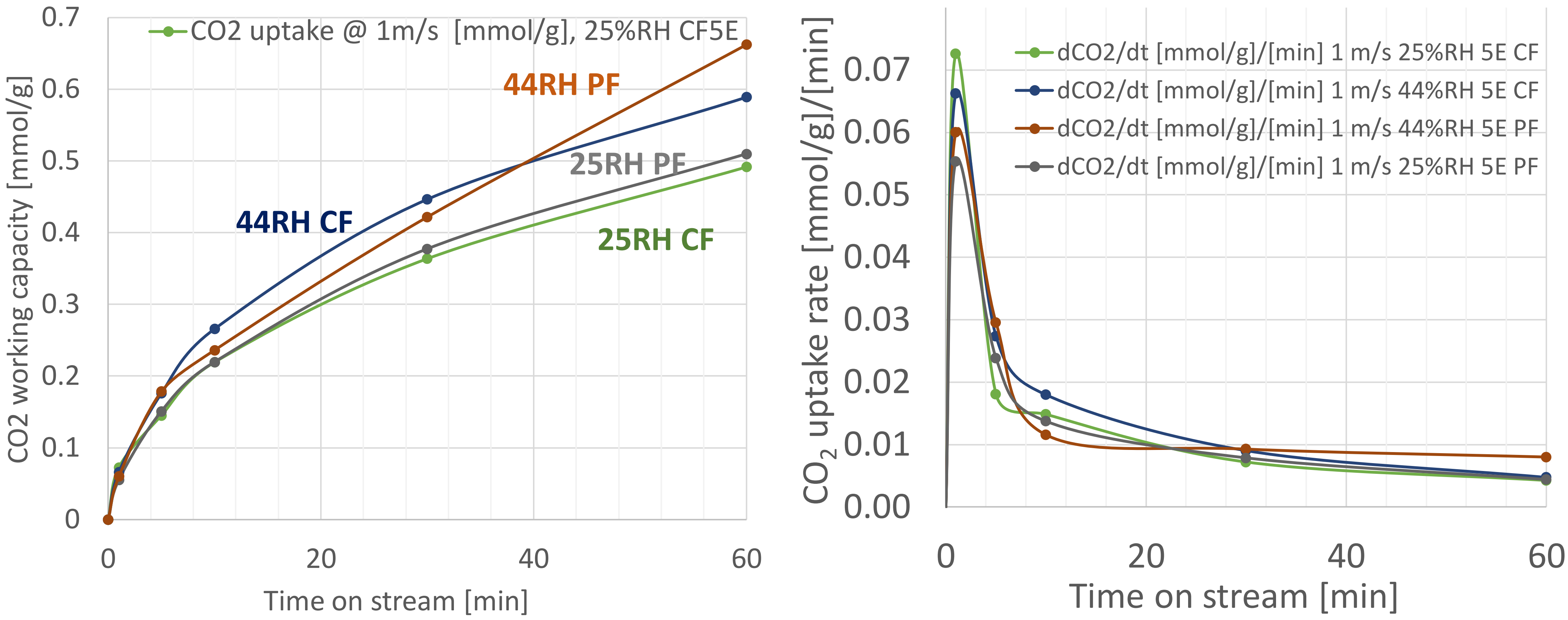
Impact of Air RH in 5 element Parallel flow 25 & 44% RH @ 1m/s (Compared to Cross Flow Orientation)

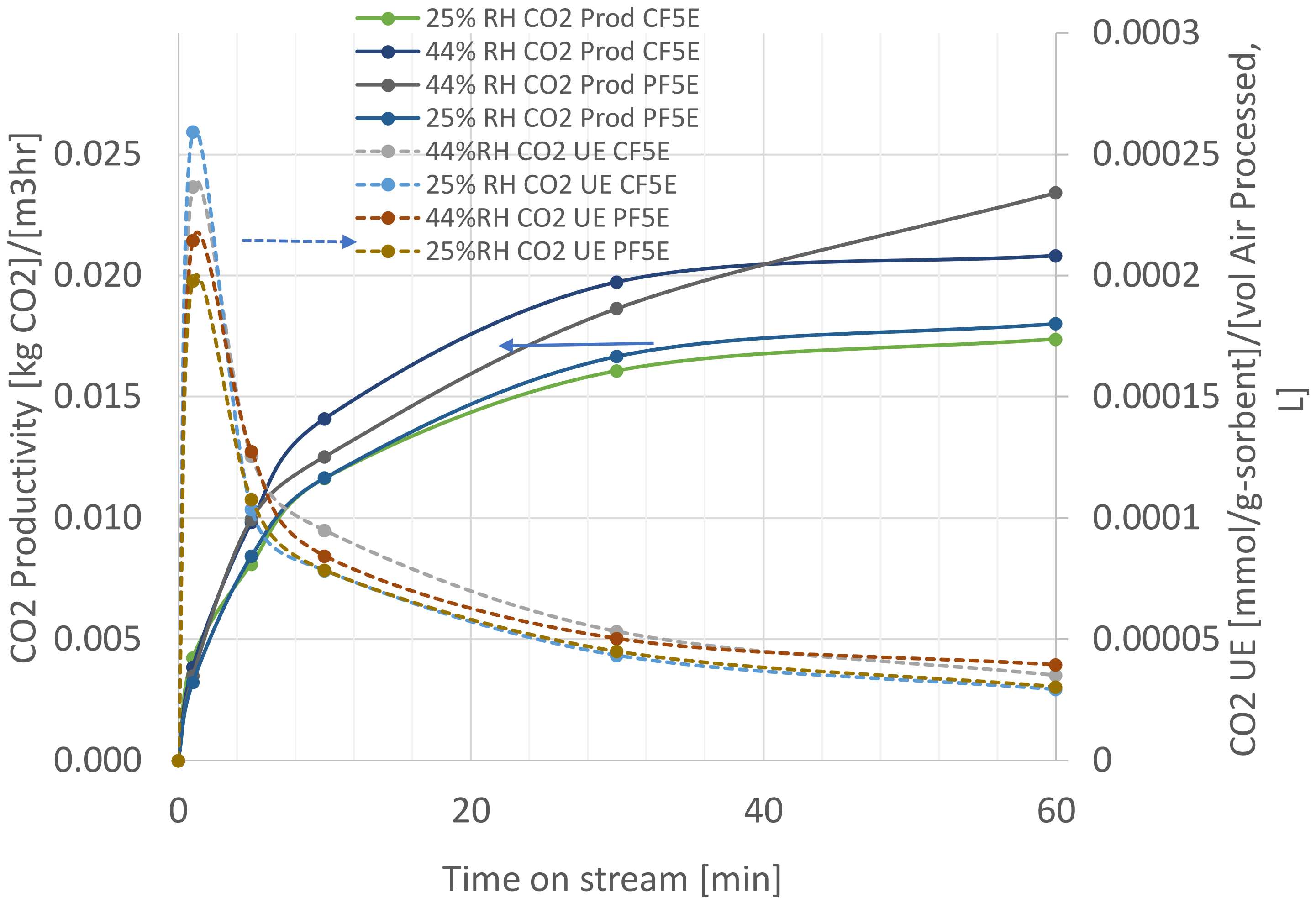
Measured CO_2 Working Capacity and Rate



- Increase in uptake capacity w.r.t. increase in RH. Marginal Impact of module orientation on working capacity.
- Higher uptake rates observed in CF orientation at early TOS due to less passive nature of flow module
- FF1bP ~19Pa DP at 1 m/s where as FF1bH ~200Pa @ 1m/s.

FF1bP: 5 element CF & PF @25 & 44% RH 1m/s

CO_2 Productivity & uptake effectiveness



CO_2 Productivity

- *[kg CO_2/m^3hr]*
- *CO2 Prod (@TOS) = (CO2 uptake @ TOS [kg])/(Module Volume [m^3]*Total Cycle Time[hr])*
- *Module volume = 0.0005 m^3 (~30.4 in^3)*
- *Total Cycle time [hr] = (TOS_{ADS})+ Purge + Regen + Cooling Purge*

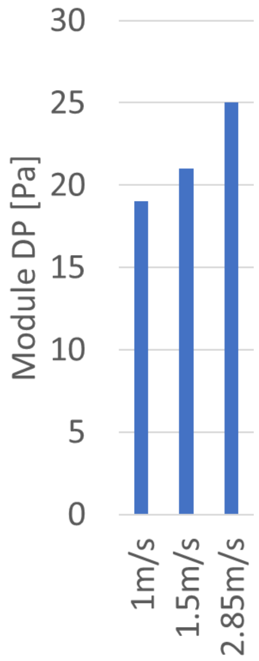
CO_2 uptake effectiveness

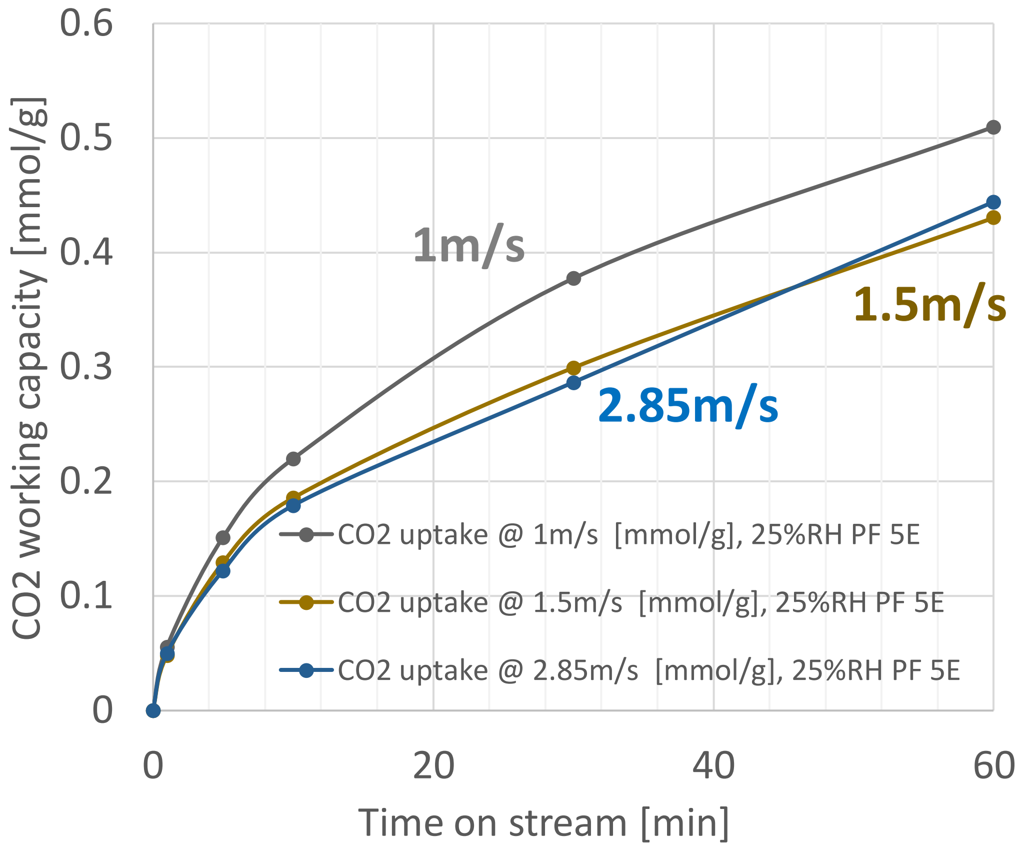
- *[mmol/g-sorbent]/[vol Air Processed, L]*
- *CO2 UE (@TOS) = CO2 uptake [mmol/g sorbent]/ vol Air Processed, L*

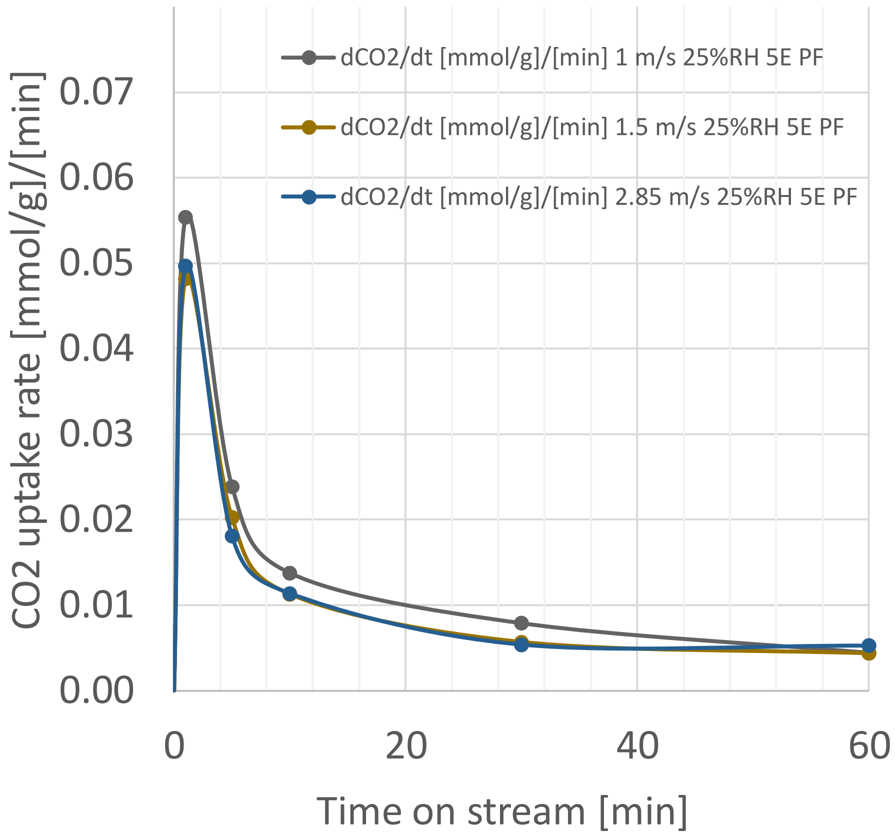
FF1bP: Impact of Air Velocity in 5 element Parallel flow 25% RH @ 1, 1.5 & 2.85m/s

Measured CO_2 Working Capacity and Rate

Module Pressure Drop in ADS mode







- Slight decrease in working capacity w.r.t. increase in Velocity.
- Noted a similar effect with the previous RIG/TGA screening experiments

FF1bP: 5 element Cross flow 25% RH @ 1, 1.5 & 2.85m/s

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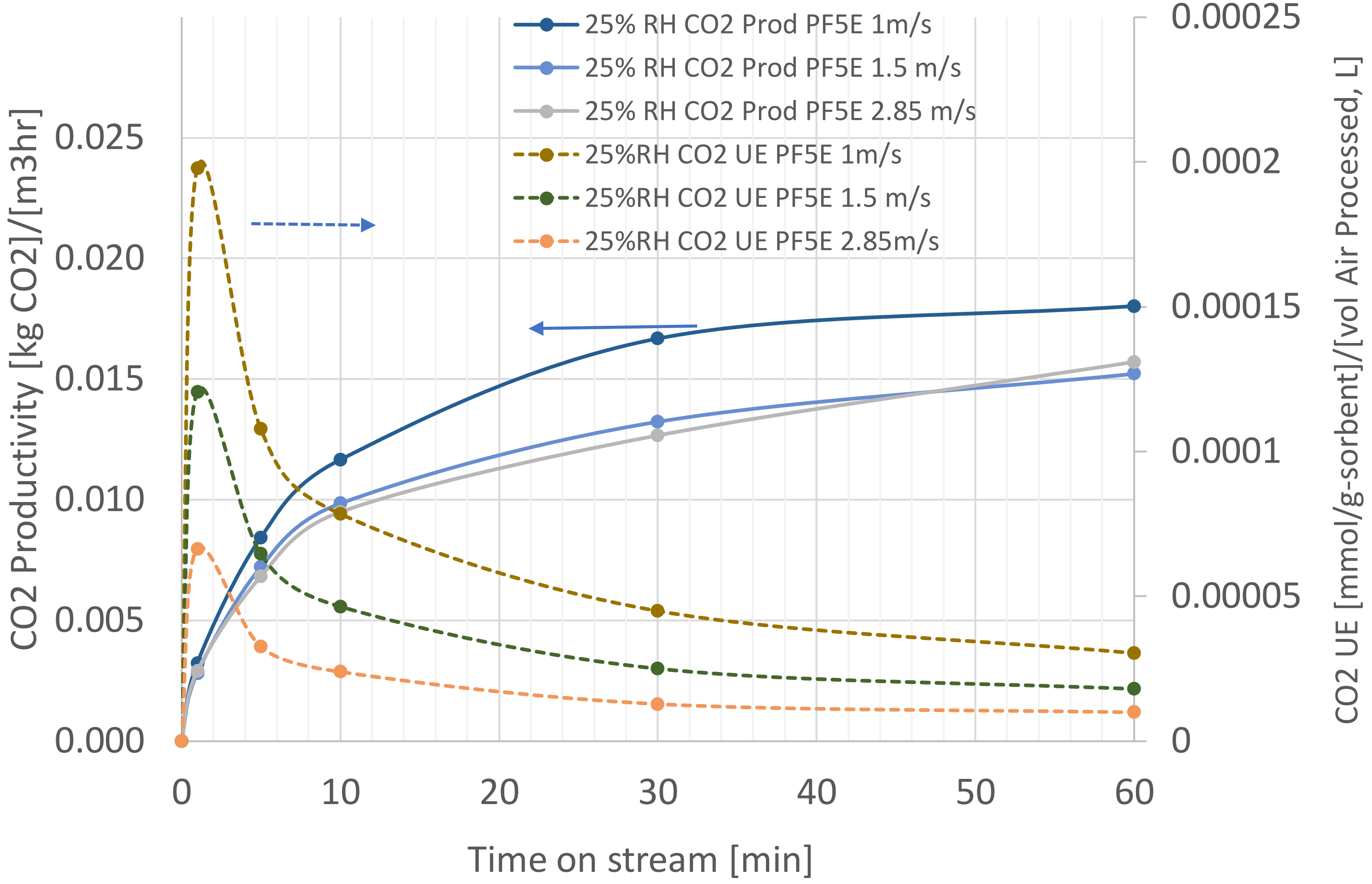
CO_2 Productivity & uptake effectiveness



CO_2 Productivity

- *[kg CO_2/m^3hr]*
- *CO2 Prod (@TOS) = (CO2 uptake @ TOS [kg])/(Module Volume [m^3]*Total Cycle Time[hr])*
- *Module volume = 0.0005 m^3 (~30.4 in^3)*
- *Total Cycle time [hr] = (TOS_{ADS})+ Purge + Regen + Cooling Purge*

CO_2 uptake effectiveness

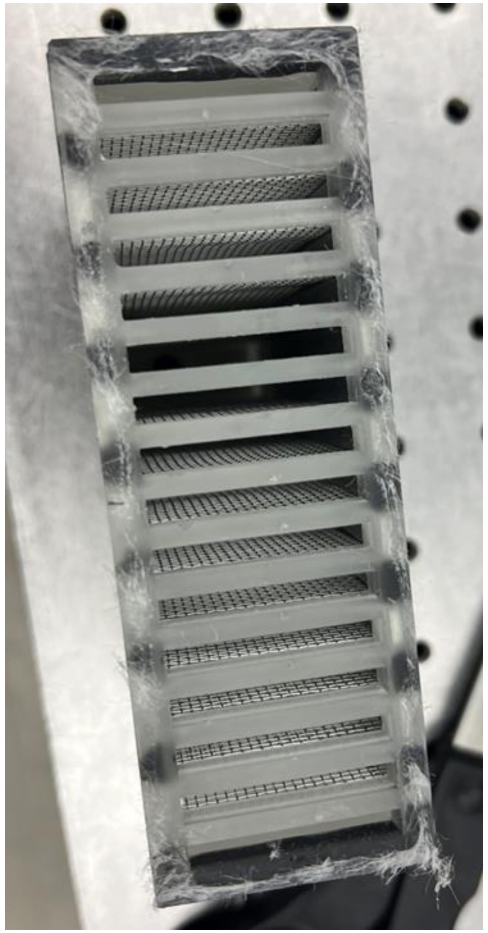
- *[mmol/g-sorbent]/[vol Air Processed, L]*
- *CO2 UE (@TOS) = CO2 uptake [mmol/g sorbent]/ vol Air Processed, L*

Summary and Moving forward

- Enable the sorbent material to be shaped and arranged into a specific form factor for practical implementation into our flow contactor/regen setup.
- RH shows a positive impact on CO2 working capacity and uptake rate
- Flow orientation does not have a large impact on working capacity at longer TOS.
  - Reduced Pressure drop with equivalent ultimate working capacities

Moving Forward: Increasing Sorbent Loading Density in the Flow contactor

- Completed the initial design and shakedown a mock 15 element parallel flow module.
  - DP ~50-60Pa @2.85 m/s
  - Tentatively plan to test the 15 element module under the same conditions at the 5 element for direct comparison



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Questions?

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