3D Printed Engineered Structures for High Performance Direct Air Capture System Contract No. FE0032260

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Carbon Management Review Meeting

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Project Team and Objectives

Project Duration

- **Start Date = September, 2023**
- **End Date = September, 2026**

Budget

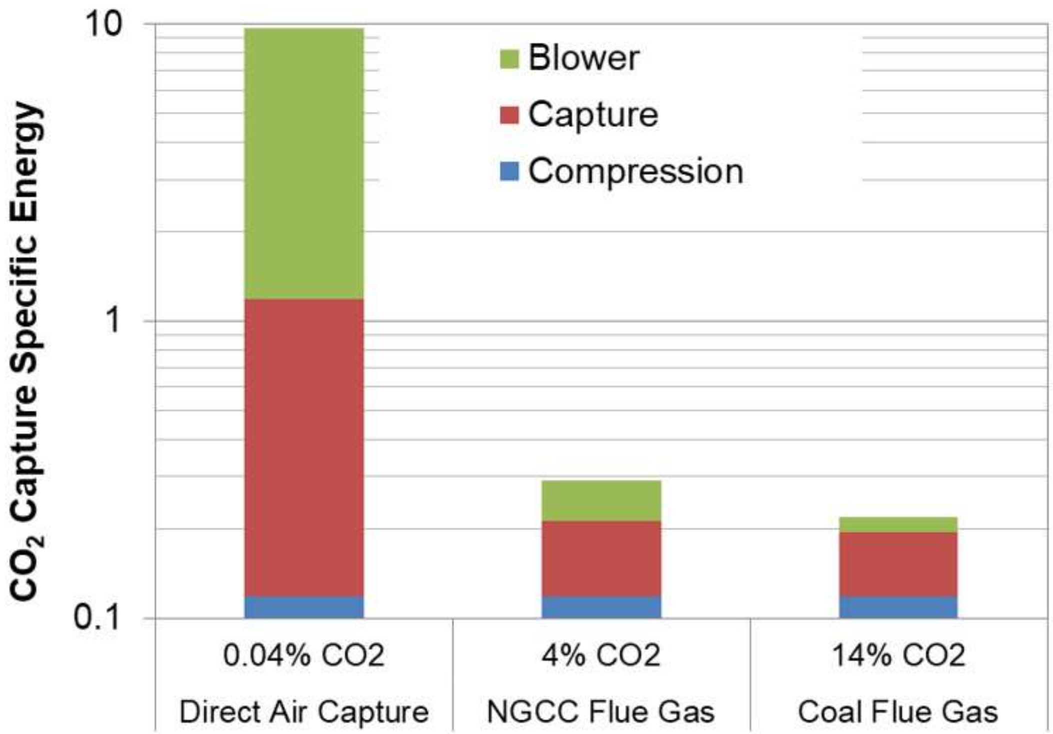
- **Project Cost = $3,749,956**
- **DOE Share = $2,999,956**
- **TDA & partners = $750,000**

- To design and construct an engineered sorbent structure for capturing CO_2 from ambient air via a rapid temperature swing adsorption (RTSA)
- The unit cell will be a 3D printed monolith with integrated heating, that will provide:
  - Low pressure drop
  - Enhanced heat transfer for rapid cycling of the sorbent to ensure high CO_2 productivity in the TSA cycle (i.e., kg CO_2 removed per kg sorbent per unit time)

BP	Period	Main Activity
1	Year 1	Preparation of Small Test Articles
		Optimization of Paste Properties
		Screening Tests
2	Year 2	Preparation of Larger Test Articles
		Large scale Evaluations
		Long-term Cycling
3	Year 3	Module Design
		Techno-economic Assessment
		Life Cycle Analysis

Introduction

- **The sorbent-based Direct Air Capture systems have to address two key challenges that stems from the low concentration (400-500 ppm) of CO_2 in the air:**
  - **The need to circulate large volumes of air**
  - **A rapid cycle sequence that reduces that increases the CO_2 productivity (ton CO_2 removed per ton sorbent per hr)**



Note: A fixed pressure drop is assumed in all contactors

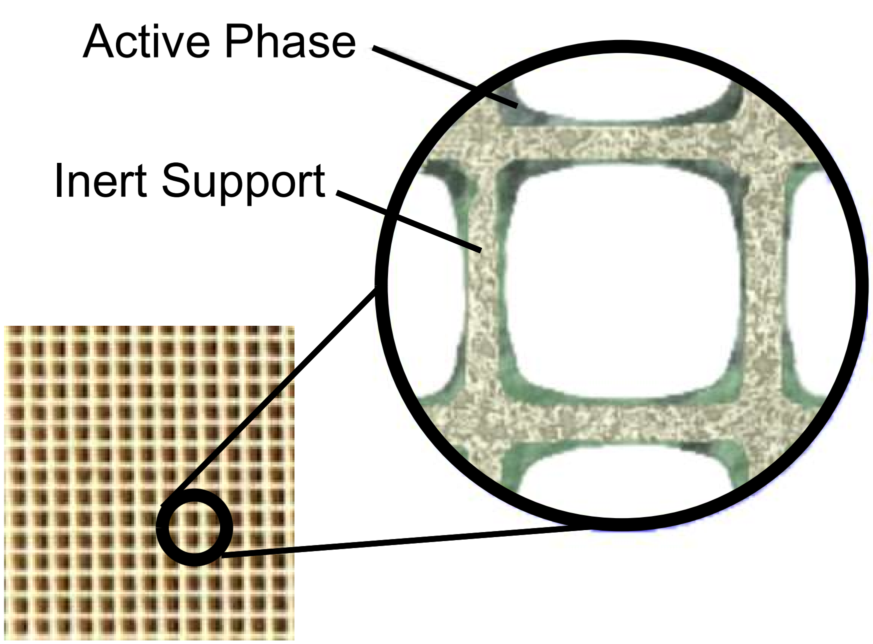
- **A cost-effective gas-solid contactor must achieve a low pressure drop**
- **An effective heat integration/management system is needed to ensure a rapid cycle to reduce the sorbent inventory**

Approach

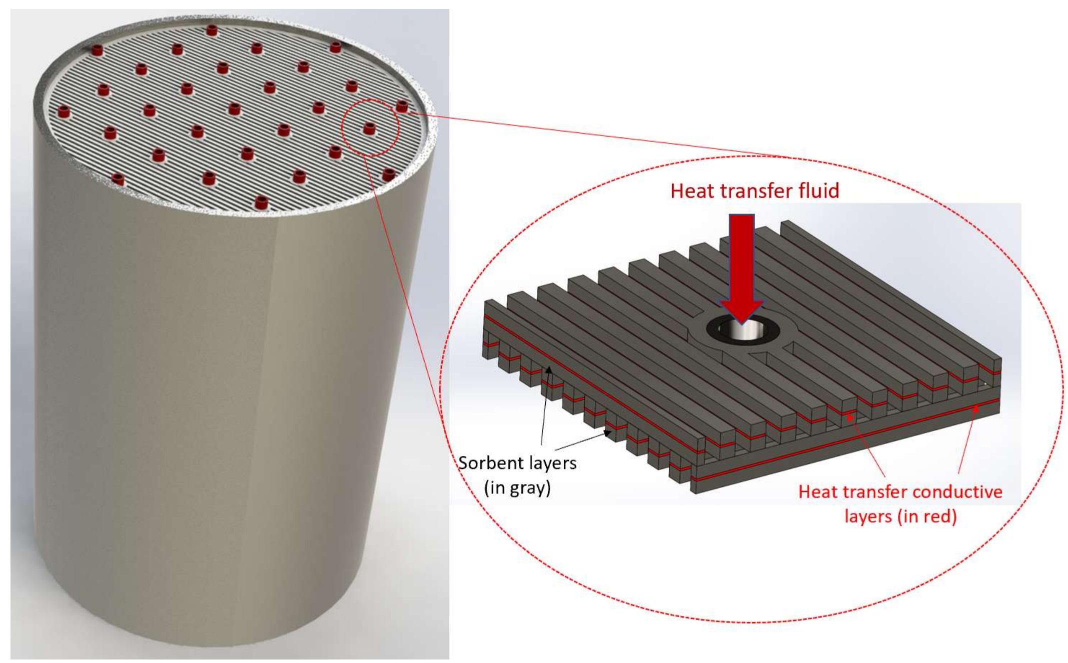
- **A new gas-solid contactor will be designed based on 3D printed monoliths where the entire monolith will be made out of reactive phase**

Useful features:

- **Low pressure drop due to the presence of open flow channels**
- **High active material loading (high volumetric capacity)**
- **Integrated heaters & conductive paste allows rapid heating using electricity**
- **The intimate contact between the hot surface and the sorbent material increases the heat transfer rates and ensures rapid heating**



Conventional Monoliths



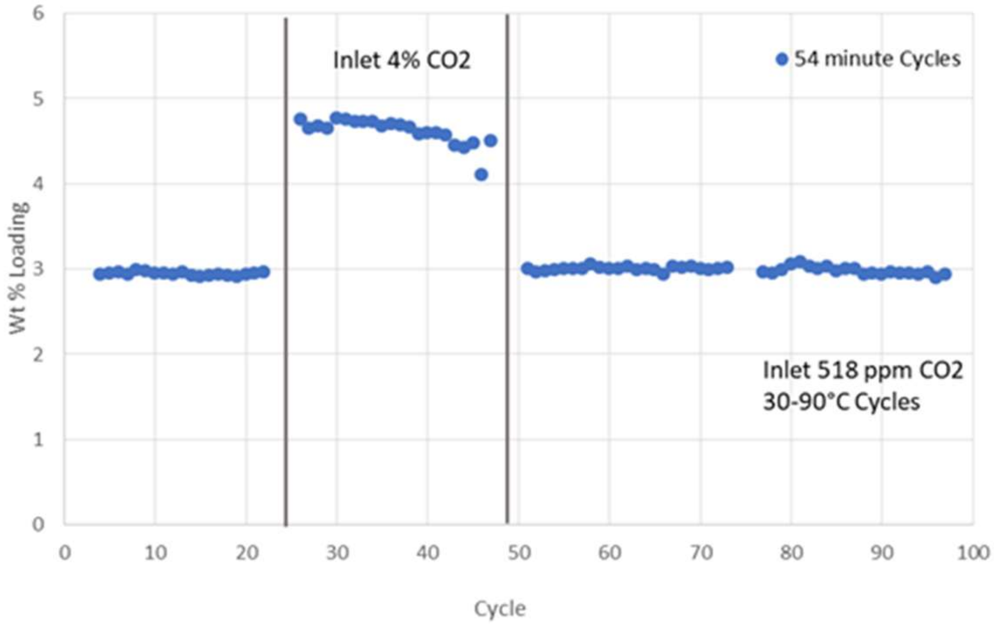
TDA's Monolith

TDA's Sorbent for DAC

- **TDA has been developing a new polymer sorbent for DAC and life support applications (DE-SC-00020846, 80NSSC18C0135, N00178-18-C-8009)**
  - **Sorbent has very high CO_2 uptake in dilute gas streams (e.g., 400 ppm CO_2 in air; 2,500 ppm spacecraft cabin; up to 5,000 ppm in submarines)**
  - **The sorbent maintains its stability at high temperatures (up to 150°C)**
- **The sorbent has been prepared in the form of pellets, laminates and 3D printed monoliths; in this project it will be applied as a coating onto metal structures**

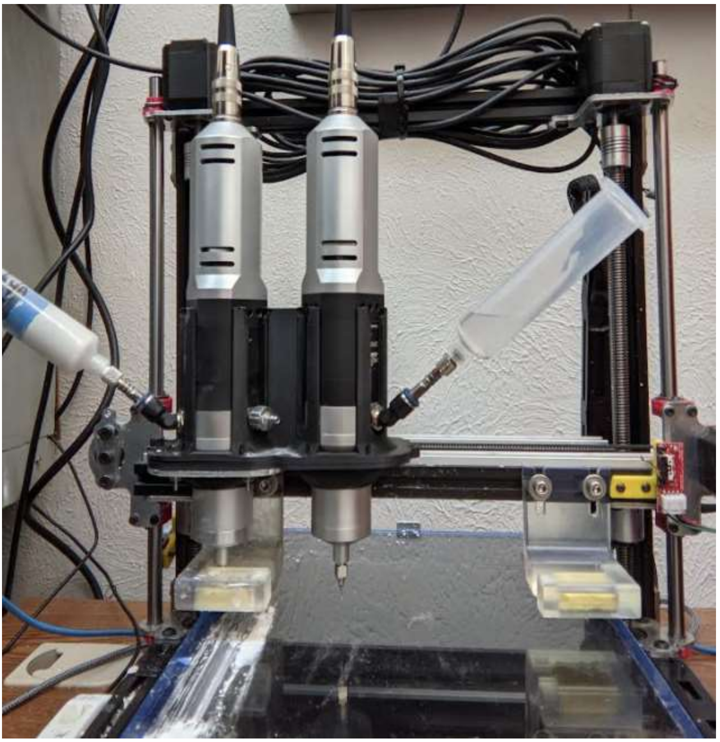
Various forms of polymer sorbent: (left) pellets (middle) laminate and (right) 3D printed monolith

High Temperature Stability

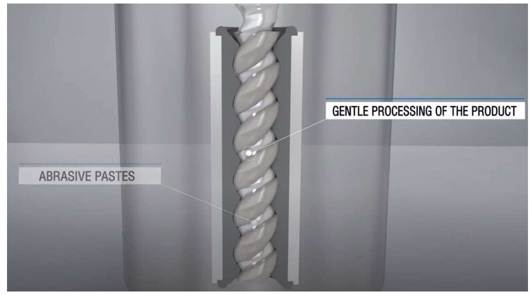


- **High stability under TSA/VTSA cycling**
- **No release of by-products at temperatures up to 150°C**
- **High working capacity**
  - **Up to ~3% wt. CO_2 uptake at 60°C swing**
- **Stable operation for ~800 cycles under DAC conditions (over 10,000 cycles has been demonstrated for the Navy application)**

3D Printing Setup

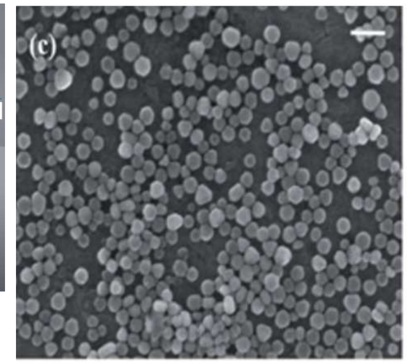


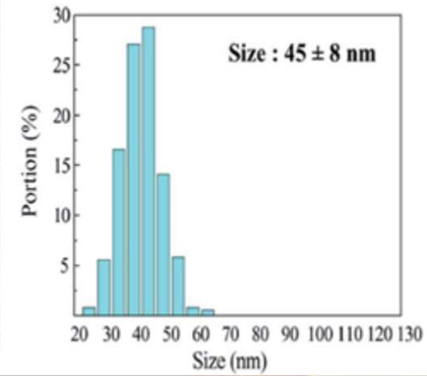
Double-headed 3D printer
Mendel 2.0

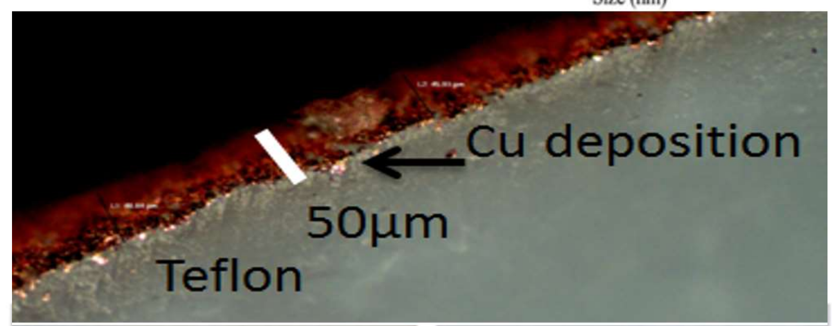


Vipro Extruder
Progressive Cavity Pump

4” x 8” monoliths



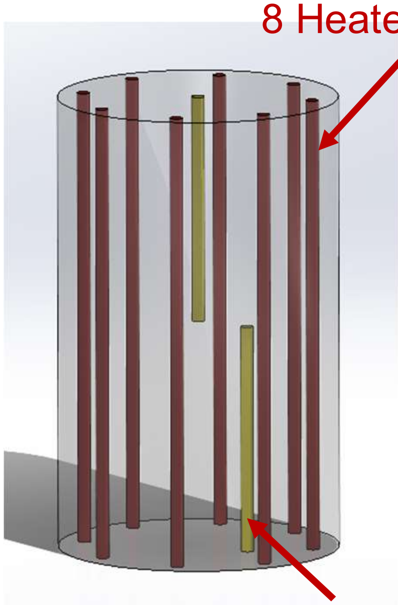


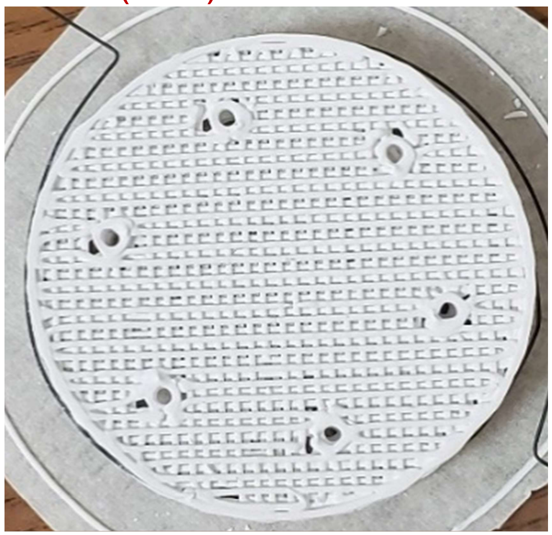


3D printed ceramic articles with
conductive layer

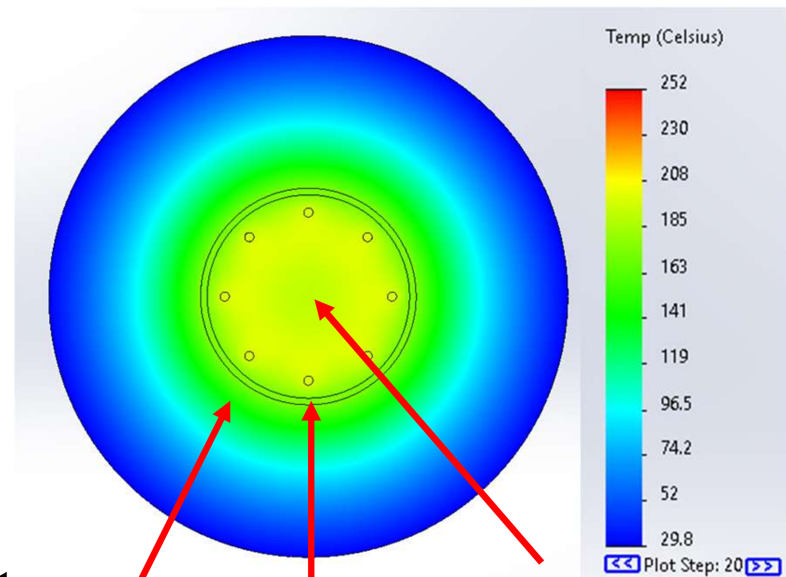
- **An open source 3D printer is modified and fitted with a double printing head that allows printing of ceramic monoliths with added conductive layers**
- **Use off-the-shelf & proprietary conductive inks**

Heater Integration

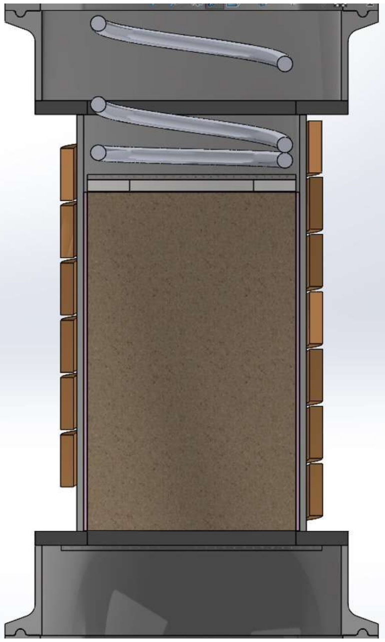


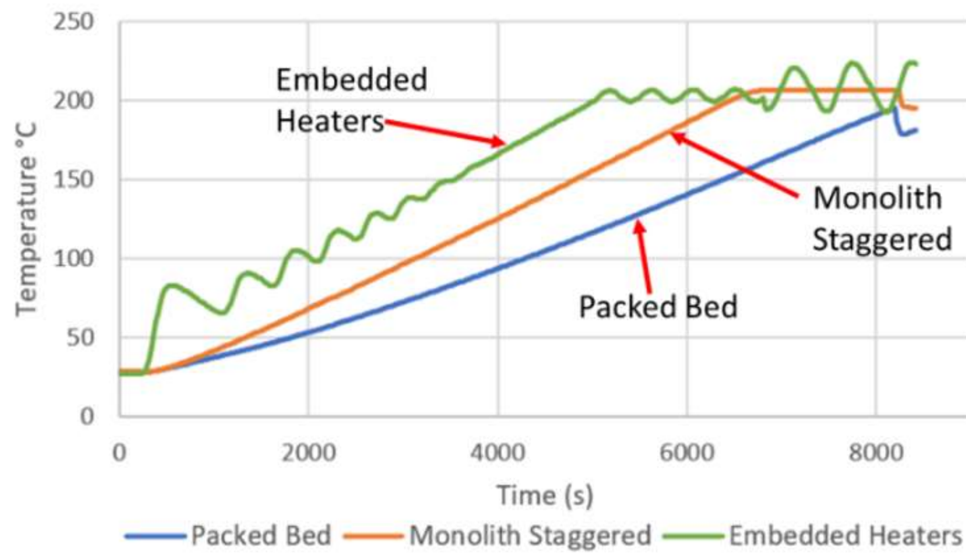


- **Used simulations to optimize heater positions**
- **Heater holes were 3D printed into the structure**
- **Embedded nichrome wire into heater holes and potted with conductive ink/binder mixture for better heat transfer to the sorbent**



Rapid Heating of the Monolith



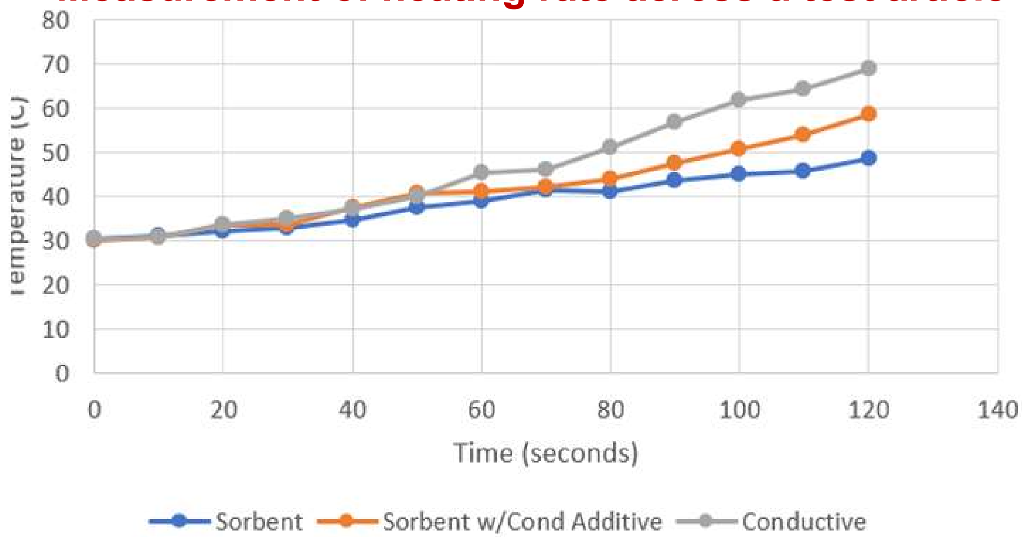


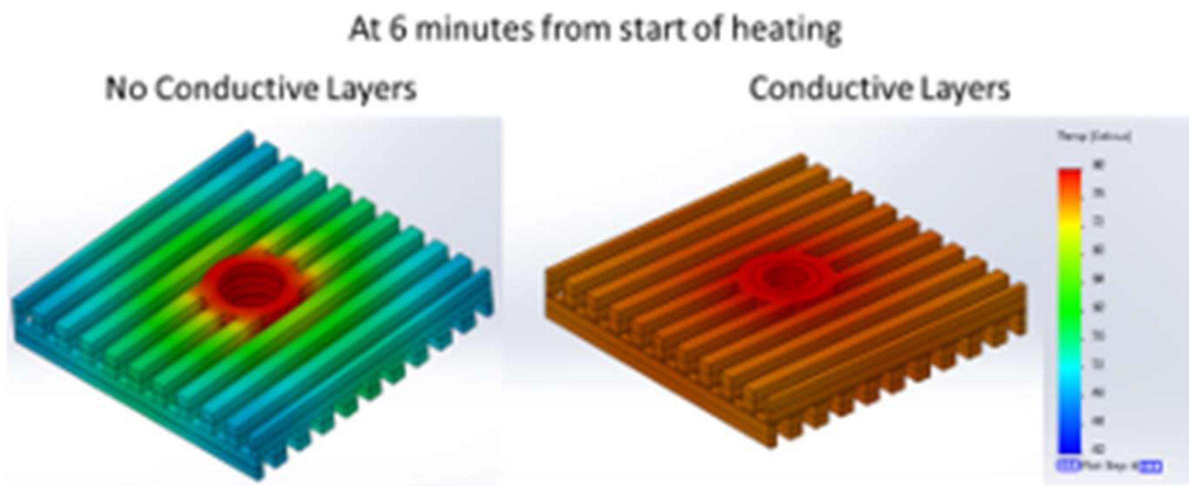
- **Structure embedded heater tests were successful**
  - **Time to reach 200°C is reduced with the embedded heater design**
  - **Structured sorbent had better heat transfer characteristics compared to a packed bed**

Further Improvement in Heat Transfer

- **Preliminary CFD results show that the conductive layer significantly enhances the heat transfer across the monolith**

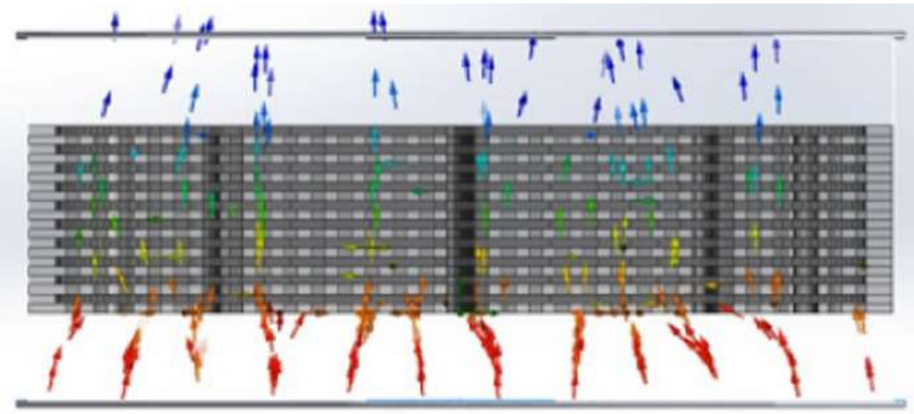
Measurement of heating rate across a test article



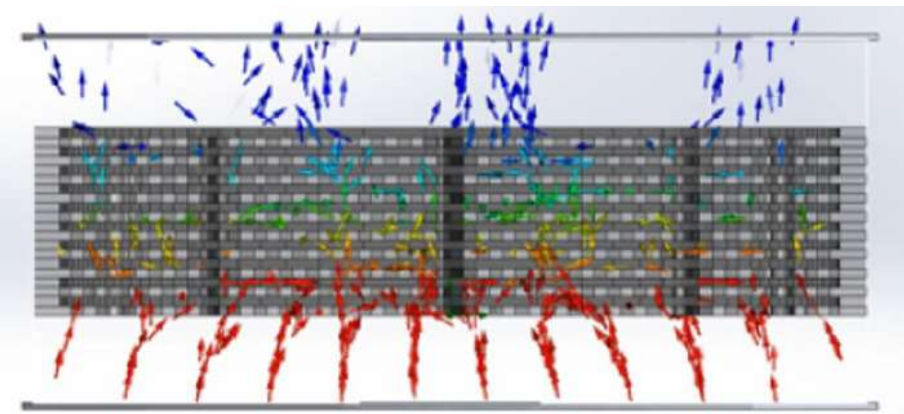


Benefits of the Monolith

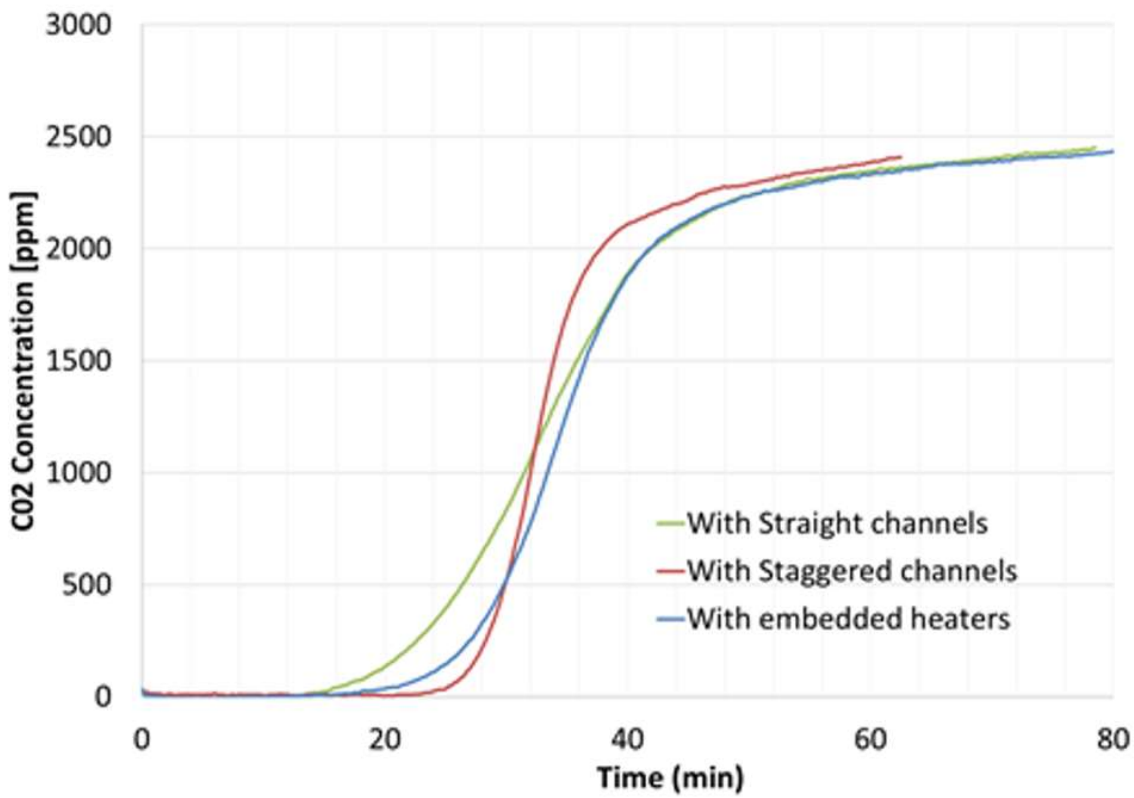
Straight Channel Configuration



Advanced Channel Configuration



T= 35°C, 2,500 ppm CO_2 in air



- **Advanced channel configurations could allow better flow distribution that results in higher capture efficiency**

Project Tasks

Task 1. Project Management

Budget Period 1

Task 2. Preparation of Sorbent Material
Task 3. Preparation of Structured Sorbents
Task 4. Evaluation of Test Articles
Task 5. Design of the Sorbent Module
Task 6. Initial Techno-Economic Analysis

Budget Period 2

Task 7. Preparation of Larger 3D Structures
Task 8. Fabrication of the Test Unit
Task 9. Multiple Cycle Testing
Task 10. Process Simulation/Optimization

Budget Period 3

Task 11. Installation of Test Unit
Task 12. Evaluation at Structured Sorbent
Task 13. Process Simulation/Sensitivity Analysis
Task 14. Final TEA
Task 15. EH&S, TGA and TMP

TDA RESEARCH