SUSTEON
Reimagining the carbon ecosystem

Dual Function Materials for Direct Air Capture of CO_2

DOE SBIR Grant: DE-SC0020795

Presented by
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Federal Project Manager
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www.susteoninc.com

Project Overview

DOE SBIR Grant: DE SC0020795	Start Date	End Date	Award Amount
Phase I	6/29/2020	3/28/2021	$250,000
Phase II	8/23/2021	8/22/2023	$1,600,000
Phase IIA	**8/28/2023**	**2/27/2025**	**$1,150,000**

Key Susteon Personnel

Jonathan Peters
Sr. Process Engineer

Monica Abdallah
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Jian-Ping Shen
Senior Principal Scientist

Raghubir Gupta
CEO/Co-Founder

Partners

sasol

Columbia University in the City of New York

AngloAmerican

Corning

NGK Insulators, Ltd.

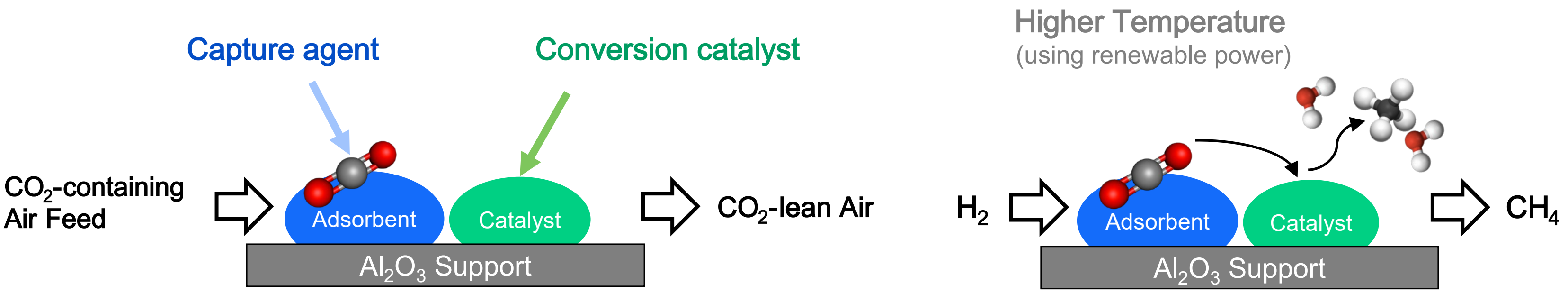
TotalEnergies

Reactive Carbon Capture Platform: Dual Function Materials

Dual function materials (DFMs) are sorbent-catalyst combinations that can capture CO_2 from a point source or DAC and directly convert it into a value-added product.

Step 1 — **CO_2 Capture**

Step 2 — **Hydrogenation with Renewable H_2**



The DFM process is a **Power-to-X platform** for converting renewable power into methane that is compatible with the current pipeline infrastructure.

The DAC-DFM Process for Reactive Capture

Objective: Lower the cost of DAC through development of advanced dual-functional materials (DFM) and production of renewable natural gas (RNG) from CO_2

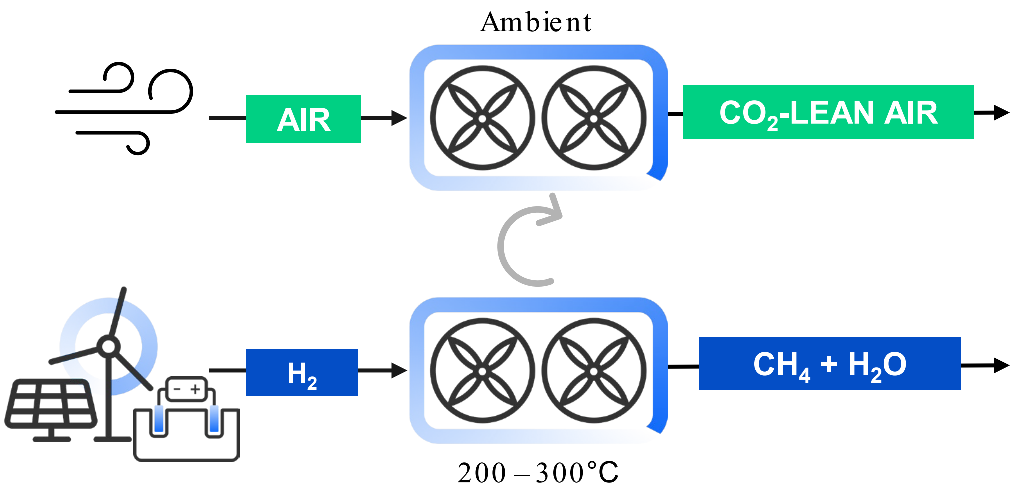
<u>**Two Step Process Cycle**</u>

Step 1: Adsorb CO_2 from air onto DFM at ambient conditions

Step 2: Add renewable H_2 and heat to regenerate the sorbent to directly produce methane

Overall Reaction

$$CO_2 + 4H_2 = CH_4 + 2H_2O$$



This is a Power-to-Gas technology using atmospheric CO_2.

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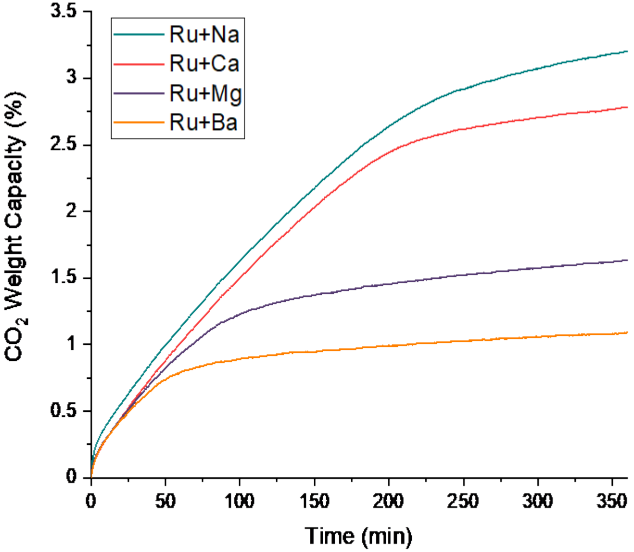
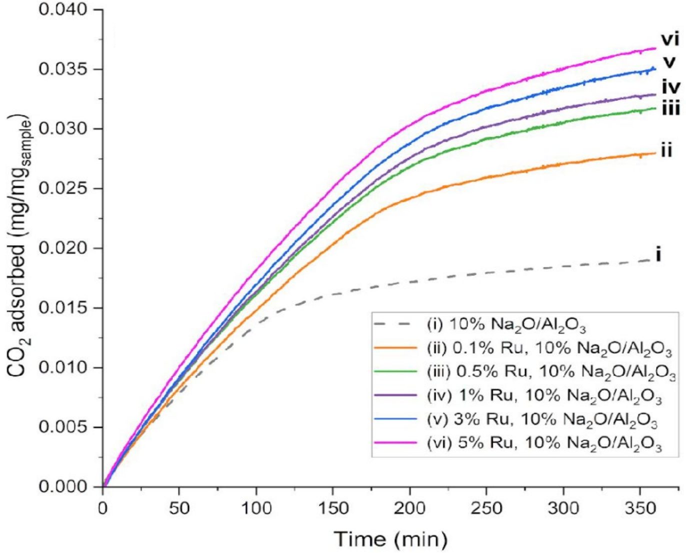
Phase I Achievements: DFM Formulation Ru + Na sorbent

1% Ru, 10% Na_2O/Al_2O_3 (green) shows the **highest** CO_2 capture capacity (~3 wt.%).

Additional insight: Ru enhances CO_2 capture capacity of sorbent (solid v. dotted lines).



Thermal gravimetric analysis: Adsorption @ 25°C on 1% Ru, 10% sorbent/Al_2O_3 granules with 375 ppm CO_2/air

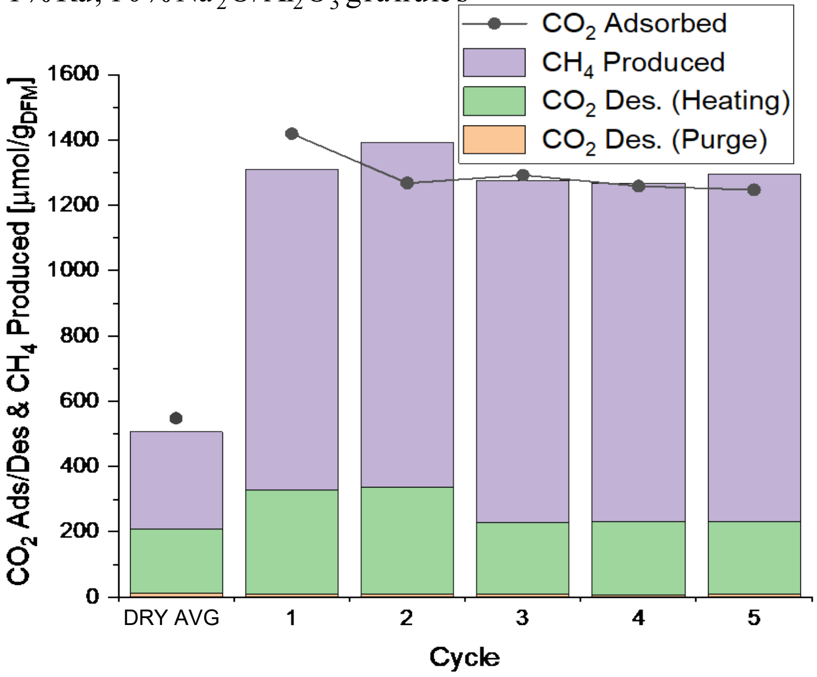


Jeong-Potter, et al. Industrial & Engineering Chemistry Research. 2022. DOI:10.1021/acs.iecr.2c00364
Jeong-Potter, et al. Applied Catalysis B: Environmental. 2022. DOI:10.1016/j.apcatb.2021.120990

Phase I Achievements: DFM Formulation Ru + Na sorbent

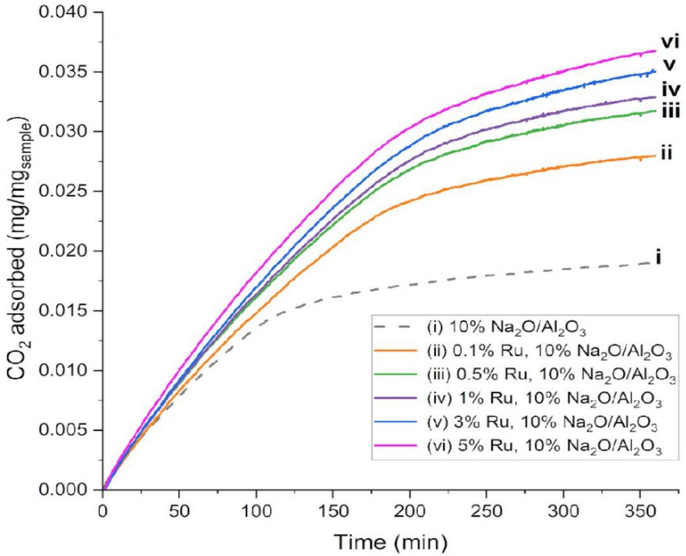
Concept Feasibility in Lab-Scale Reactor

1% Ru, 10% Na_2O/Al_2O_3 granules



Avg. CO_2 Captured	Avg. CH_4 Produced
1300 $\mu mol/g_{DFM}$	1040 $\mu mol/g_{DFM}$

Additional insight: Ru enhances CO_2 capture capacity of sorbent (solid v. dotted lines).



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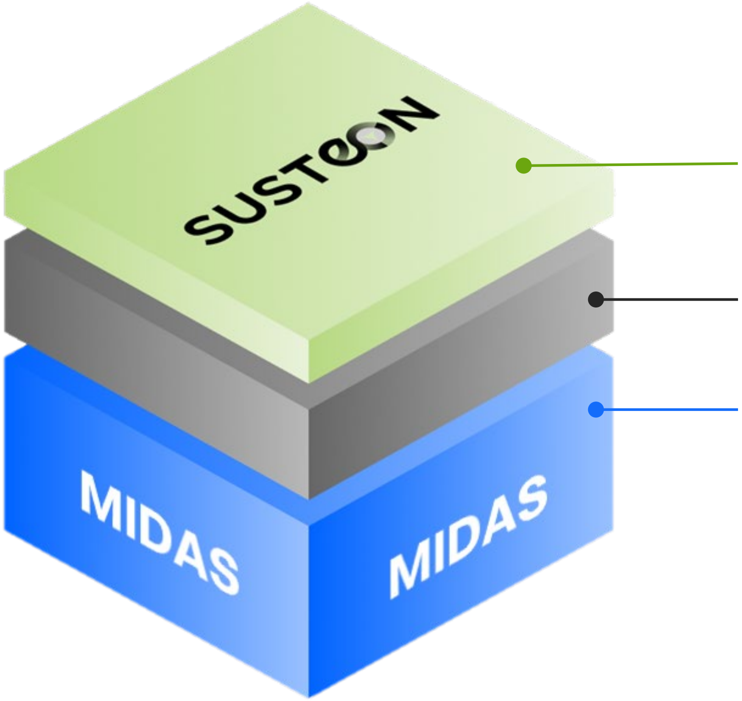
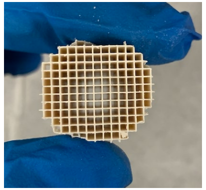
Phase II: Electrification via Structured Material Assembly (SMA)

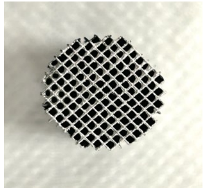


Our SMA integrates the heating layer, sorbent, catalyst, support and monolith substrate. **Key advantages:**

- ✓ **Increases productivity** by enabling fast CO_2 adsorption and fast conversion
- ✓ **Lowers the energy utilization** by reducing pressure drop during adsorption and energy losses during methanation
- ✓ **Rapidly heats** between adsorption and conversion
- ✓ **Powered by low -carbon electricity** for maximum conversion efficiency



Before washcoating

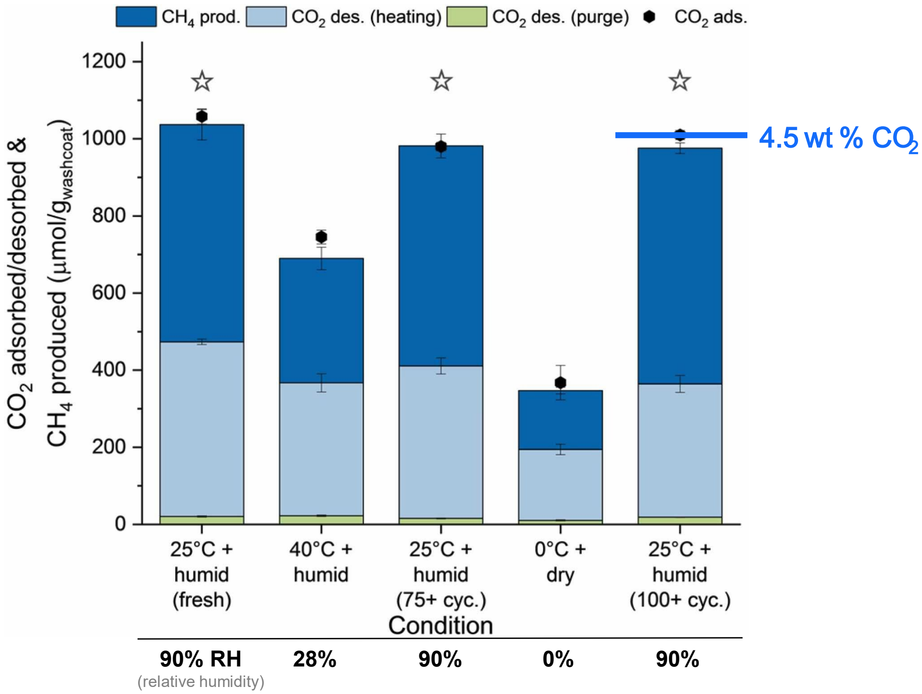


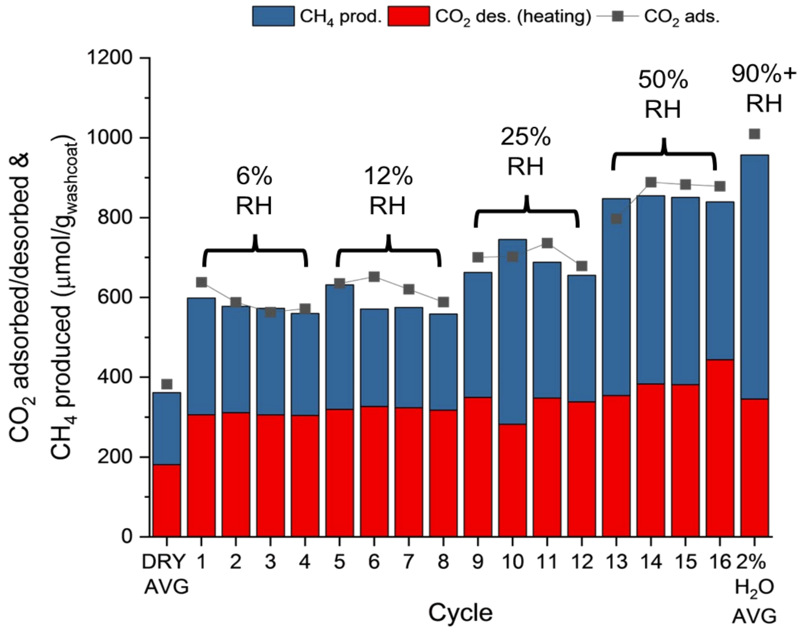
After washcoating

Phase II: DFM Monolith Showed Long-Term Stability >100 Cycles

CO_2 capacity **returns to 4.5 wt.%** after exposed to extreme climate conditions over 100+ cycles.

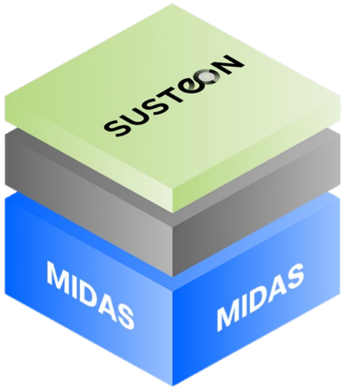
CO_2 capture is **enhanced** with higher moisture content in the feed





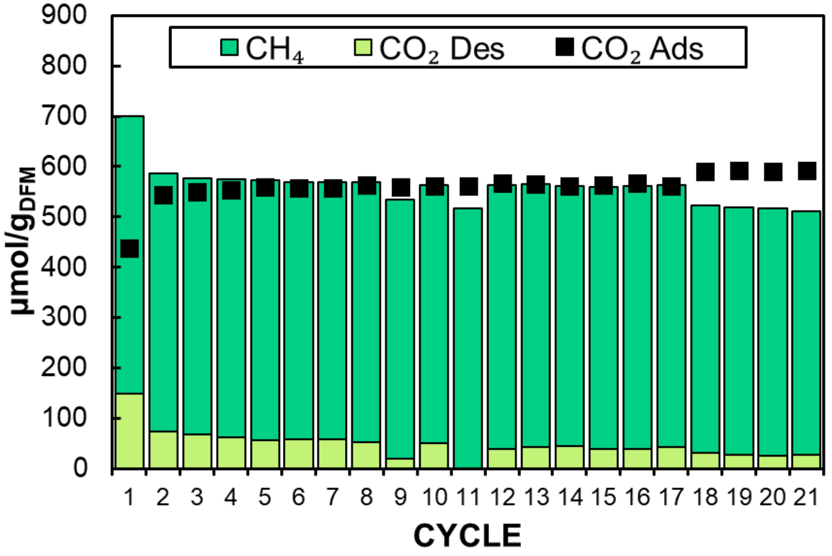
Abdallah, et al. Applied Catalysis B: Environmental. 2023. DOI:10.1016/j.apcatb.2023.123105

Phase II: Demonstrated Joule Heated DFM Cycles



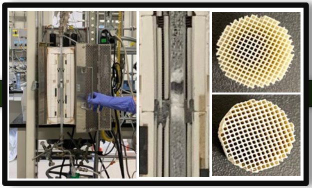
Reliable, cyclic CO_2 conversion is achieved using the DFM SMA with Joule heating layer

Additional screening tests showed over 70% conversion of CO_2 to CH_4 during 300+ hours of continuous testing



State of Technology & Objectives of Phase IIA

Phase I — Laboratory Testing



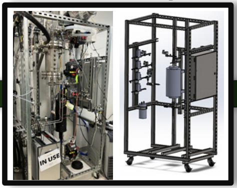
0.5 g CO_2/day
TRL - 2

2020 - 2021

✓COMPLETED

Phase II — Development of DFM washcoated monolith

Bench Component Testing



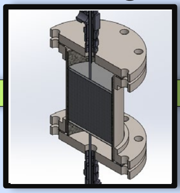
300 g CO_2/day
TRL - 4

2021 - 2023

✓ COMPLETED

Phase IIA — DFM with cyclic direct electric heated methanation

Integrated Bench Testing



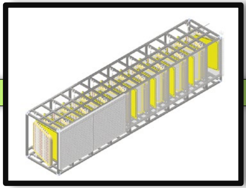
0.3 - 1 kg CO_2/day
TRL - 5

2023 – 2025

ONGOING

Technology package ready for commercial investment

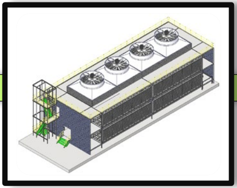
Pilot Demonstration



50 kg CO_2/day
TRL - 7

Fully integrated DAC-DFM unit demonstrated for continuous RNG production

Demonstration Plant



1 t. CO_2/day
TRL-8/9

2025 & beyond

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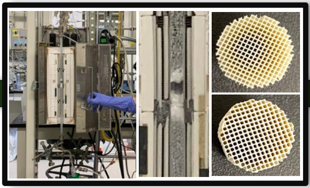
State of Technology & Objectives of Phase IIA

Phase I

Laboratory Testing



0.5 g CO_2/day
TRL - 2

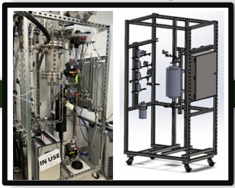
2020 - 2021

✓COMPLETED

Phase II

Development of DFM washcoated monolith

Bench Component Testing



300 g CO_2/day
TRL - 4

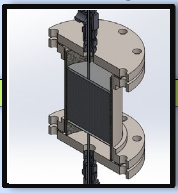
2021 - 2023

✓ COMPLETED

Phase IIA

DFM with cyclic direct electric heated methanation

Integrated Bench Testing



0.3 - 1 kg CO_2/day
TRL - 5

2023 – 2025

ONGOING

1. **De-risk** technology scale up through long-term bench testing under representative conditions
2. Use bench data **to develop high - level process design** for 50 kg/day pilot system
3. Perform **TEA** and **LCA**
4. Develop **commercialization plan** for next scale development and deployment

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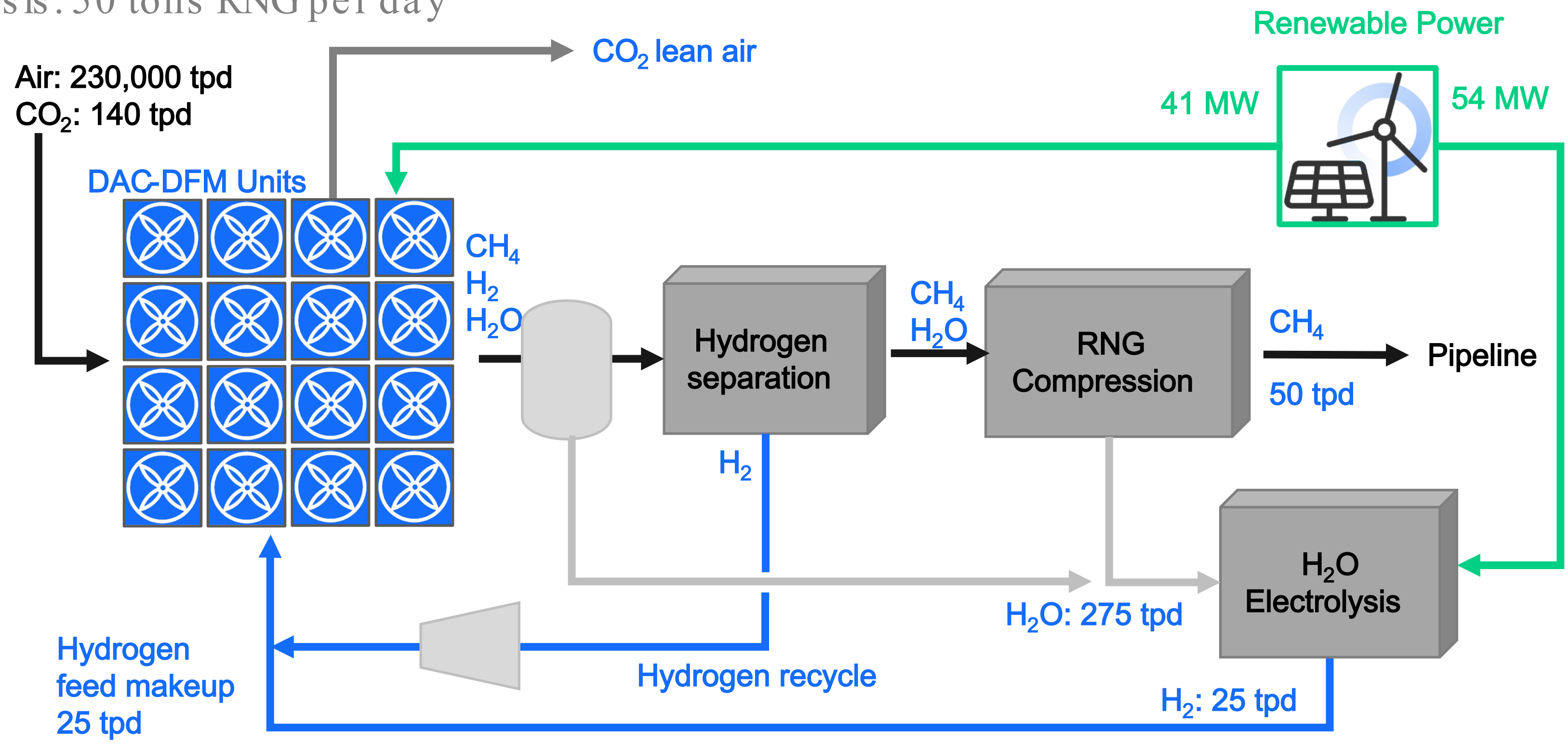
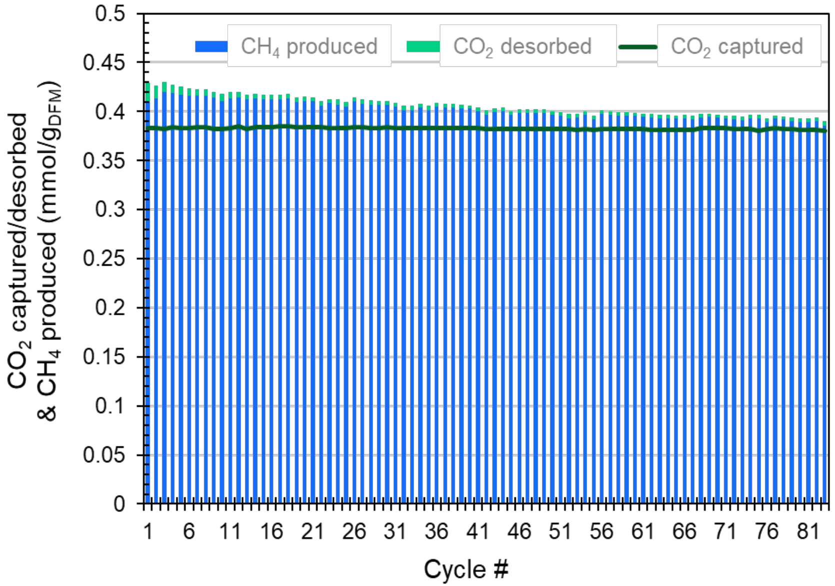
Conceptual Process Design

Basis: 50 tons RNG per day

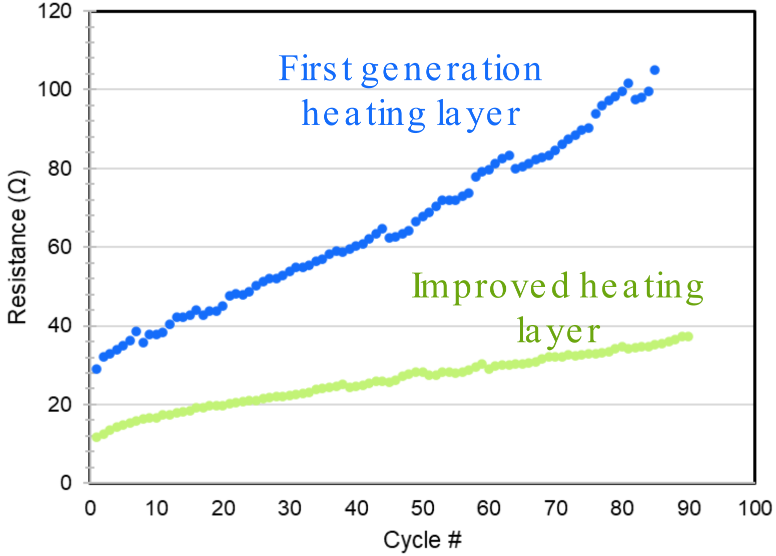


Stable DFM Integrated with Improved Resistive Carbon

>90% conversion to CH_4 achieved using electrical heating platform (SMA)



Stability of heating layer resistance is improved with the new carbon synthesis method.



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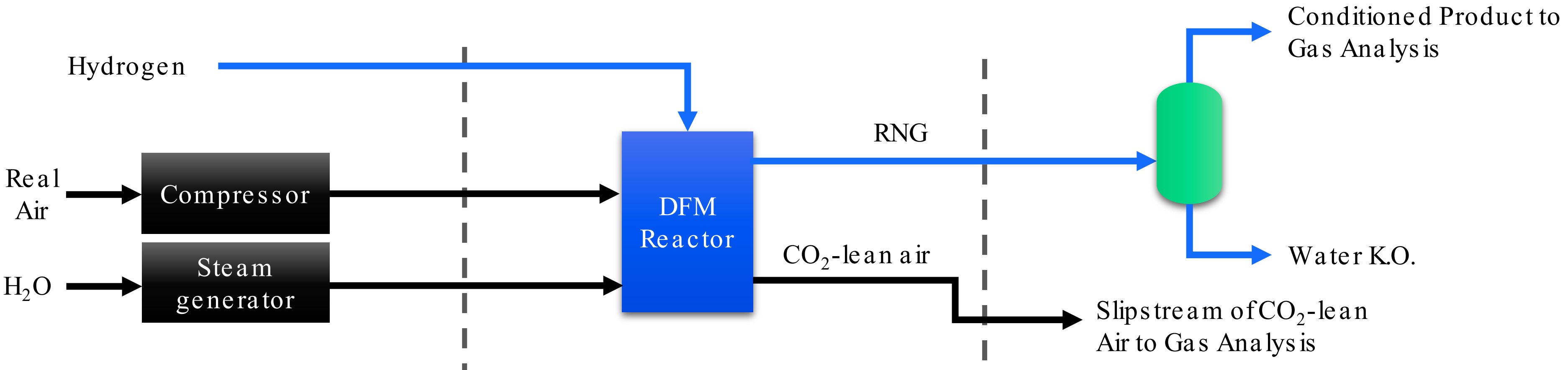
Bench Unit Overview & Key Components



Inlet Gas Manifold

Gas supply
Mass flow controllers
Valves
Steam generator

DFM Reactor

Reactor Vessel
DFM Monolith
SCR Heaters
Pressure and Temperature Transmitters

Product Gas Conditioning & Analysis

Water knockout
Valves
Product gas analysis

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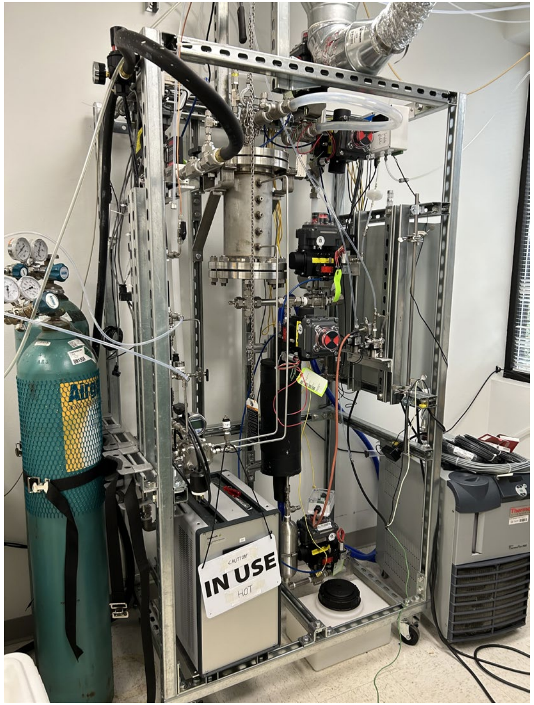
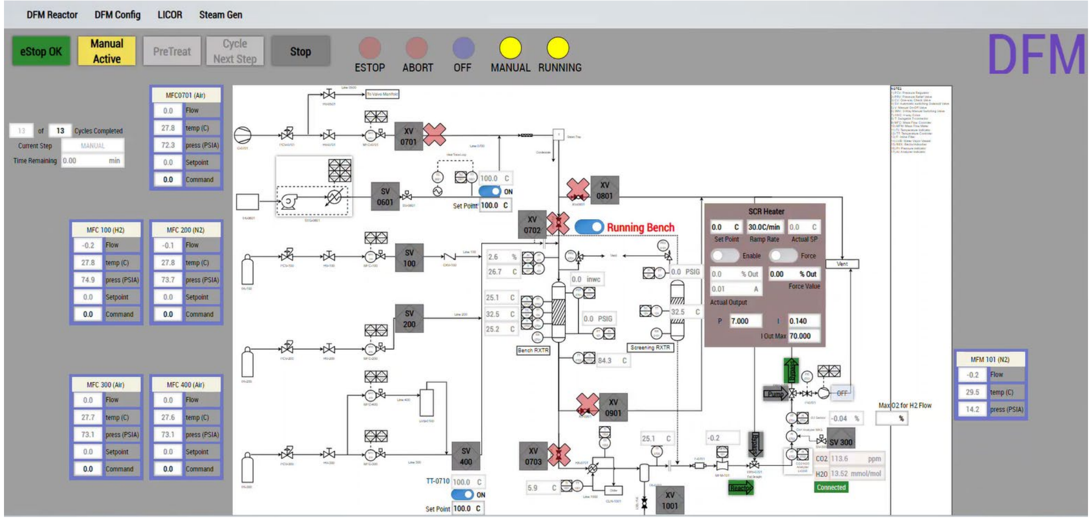
Bench DFM Unit is Fully Commissioned

Reactor HMI displays the current system state, allows manual operation, and monitoring and intervention during automated cycling.



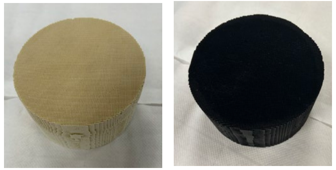


Bench reactor

- Up to 300 g CO_2 captured & converted per day
- Includes Joule heating functionality for cyclic temperature swing
- Concept for pre-commercial scale

Commissioning the Bench Unit with an Unoptimized DFM Brick

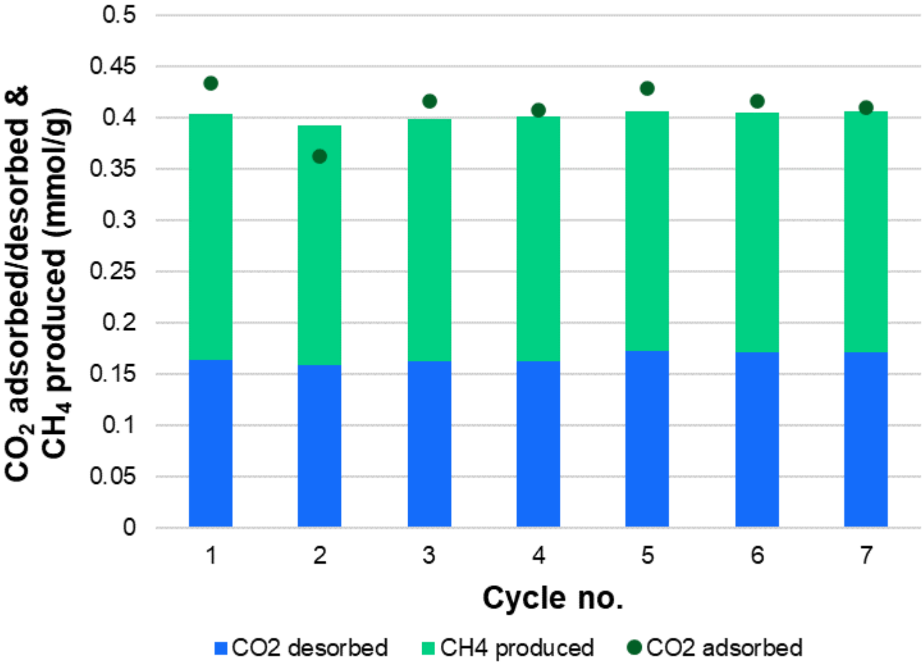
Sample specifications:
5.25” diameter x 2.83” length
0.31 wt.% Ru & 15.15 wt.% Na_2CO_3
1.75 g/in^3 washcoat loading



Uncoated and coated monoliths

Air flow rate [WHSV]	Air	H_2 flow rate [WHSV]	Target heating rate & methanation temperature
100 SLPM [74 hr^{-1}]	Humid (~2% H_2O)	1000 sccm [0.75 hr^{-1}]	30°C/min, 300°C

After successful commissioning, we are optimizing the DFM brick and operating conditions.



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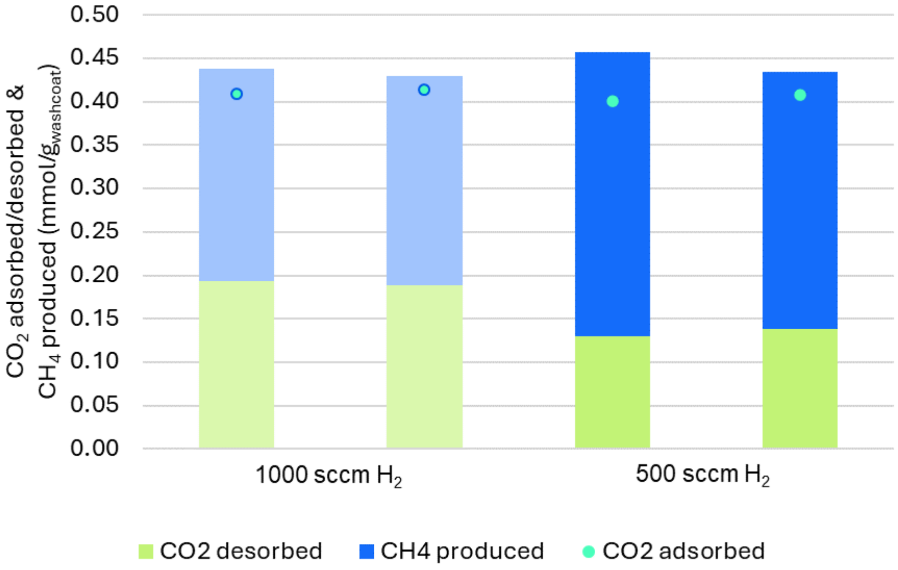
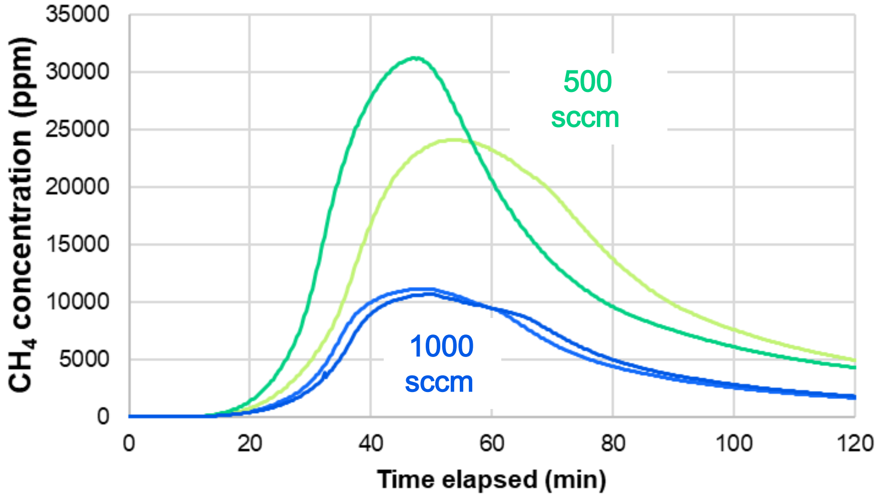
Impact of H_2 Flow Rate on CO_2 Conversion





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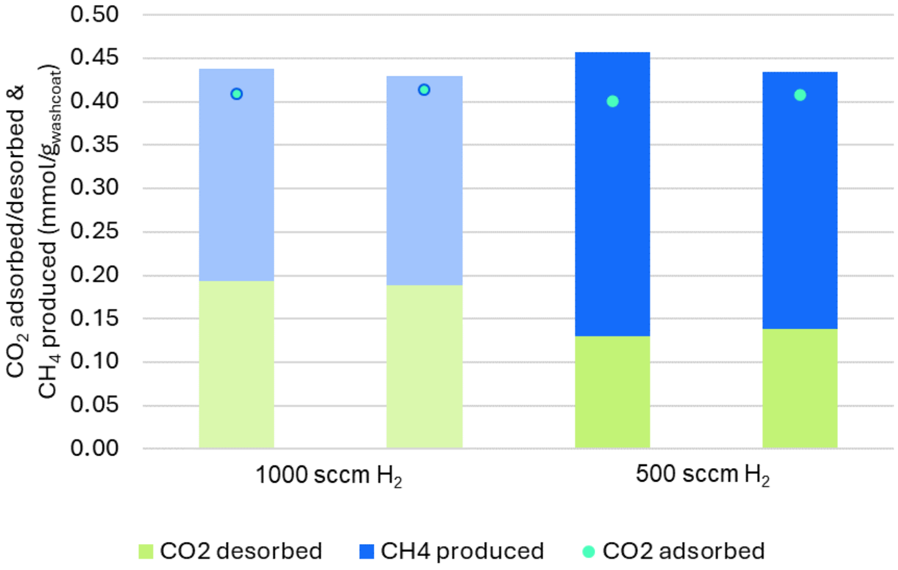
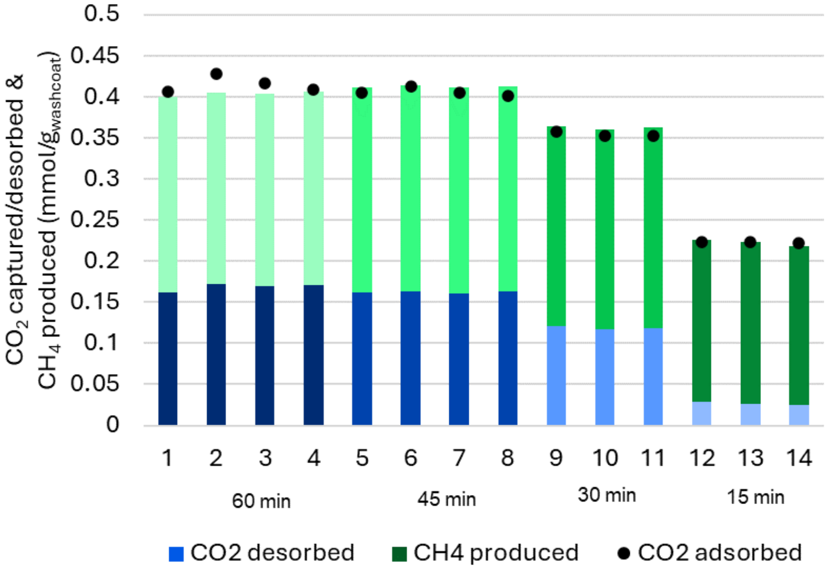
Impact of H_2 Flow Rate on CO_2 Conversion



Conversion further improves by shortening the duration of capture step



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Lessons Learned

1. CO_2 can be captured and converted into methane in a single reactor.
2. Electric heating was successfully demonstrated to provide the heat for temperature swing and methanation light-off.
3. Process design developed for a commercial embodiment.
4. Robust DFM compositions successfully coated on a commercial monolith.
5. Mechanical design for long-term operation is being developed.
6. Low-cost, carbon-free hydrogen is critical for commercial viability of this technology.
7. Methane produced from the process can be designated as renewable natural gas (RNG), and incentives such as LCFS and 45Q credits will promote its early adoption.

Budget Period 2: Planned Work

1. Conduct long-term bench-scale testing
   - Parametric testing to optimize operating conditions and productivity
2. Refine and validate the current process model
3. Develop a process design and technology package
4. Perform techno-economic assessment (TEA) and life cycle analysis (LCA)
5. Develop Business/Commercialization plan

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