

High-Permeance Membranes for CO₂ Capture from Industrial Steel Production



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Project Overview



- **Project:** Point Source Capture Technology
- **Funding Source:** NETL Point Source Capture Multiyear Research Plan (MYRP)
- **Project Objective:** developing a scalable thin-film composite (TFC) membrane for industrial carbon capture that has a CO_2 permeance $>3,000$ gas permeance unit (GPU) and CO_2/N_2 selectivity of >25 . All the membrane support, gutter layer, and selective material will be optimized for scalability and performance stability (or non-aging property).
- **Project Participants:**



United States Steel

Carnegie Mellon University

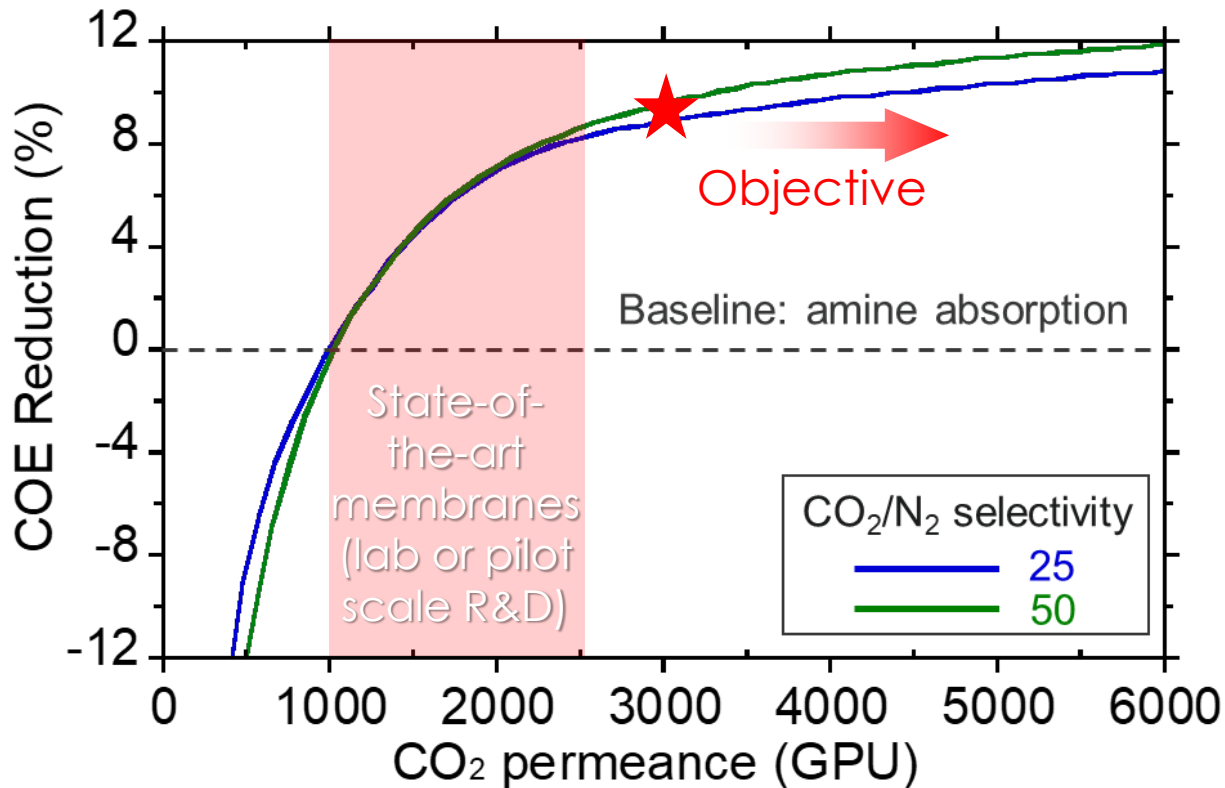


CCSI²
Carbon Capture Simulation for Industry Impact

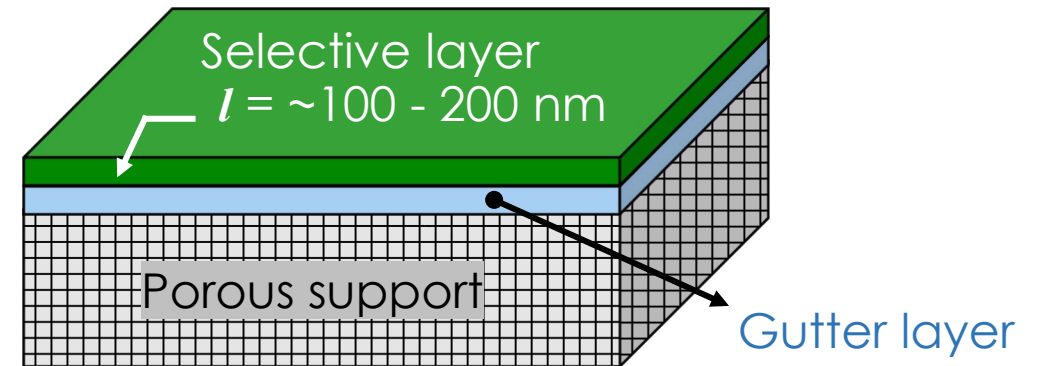


Importance of High-Permeance Membranes

Higher permeance leads to lower capture cost because fewer membrane areas are required.



Thin-Film Composite (TFC) Membranes



Selective layer: CO₂/N₂ separation

Gutter layer: preventing pore penetration

Porous support: mechanical reinforcement

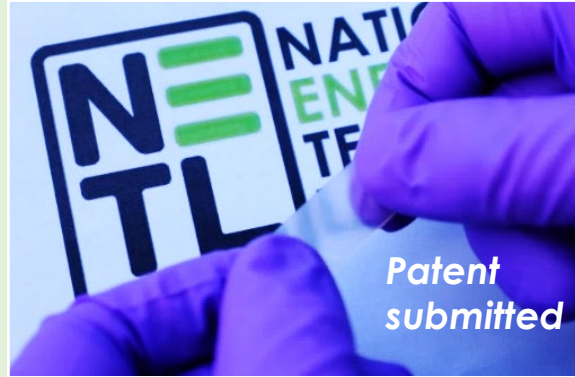
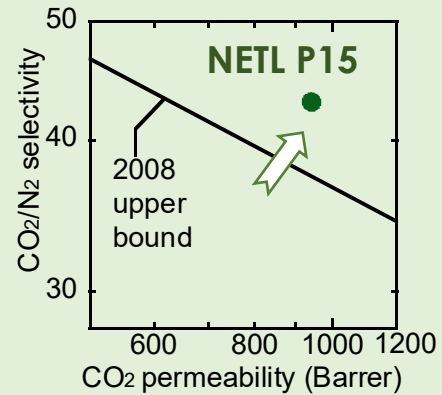
Alex Zoelle et al., [Performance and Cost Sensitivities for Post-Combustion Membrane Systems](#), 2018 NETL CO₂ Capture Technology Project Review Meeting

COE: cost of electricity

Membrane Development Activities at NETL:

Prior Accomplishments

1. Selective layer material innovation

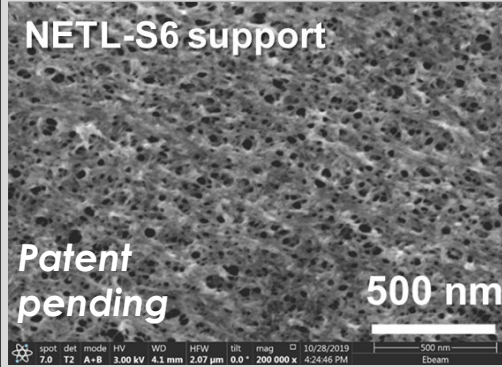


2. Membrane support development

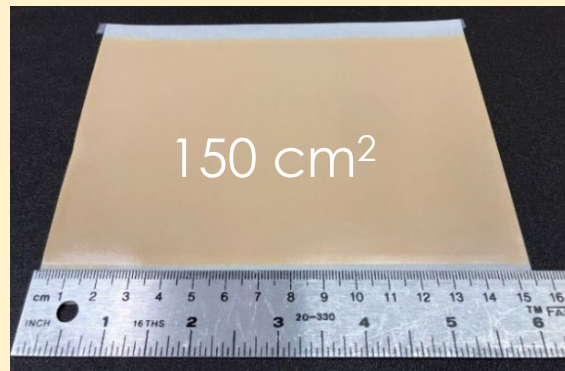
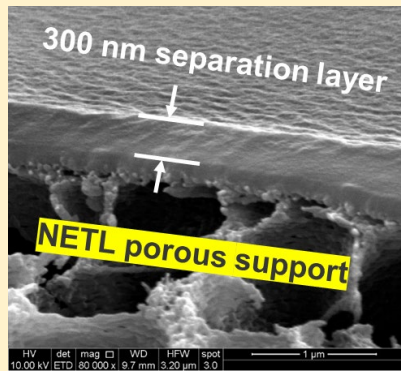
NETL-S6 support

Patent pending

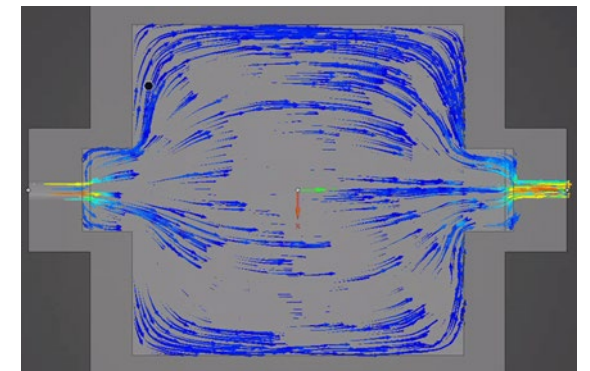
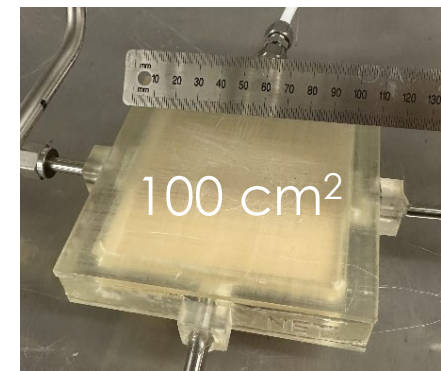
500 nm



3. Scalable thin-film coating



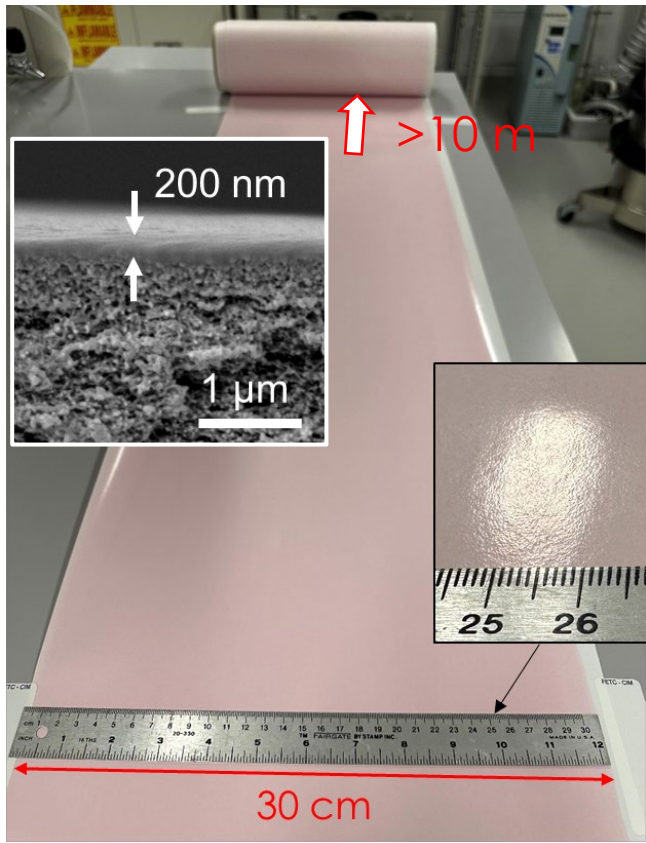
4. Module design, 3D printing and testing



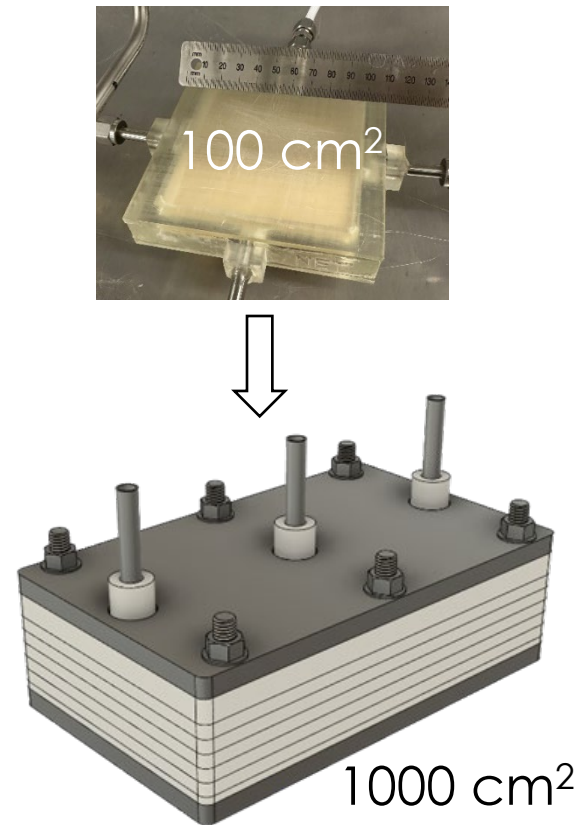
Membrane Development Activities at NETL:

2023-2024 Accomplishments

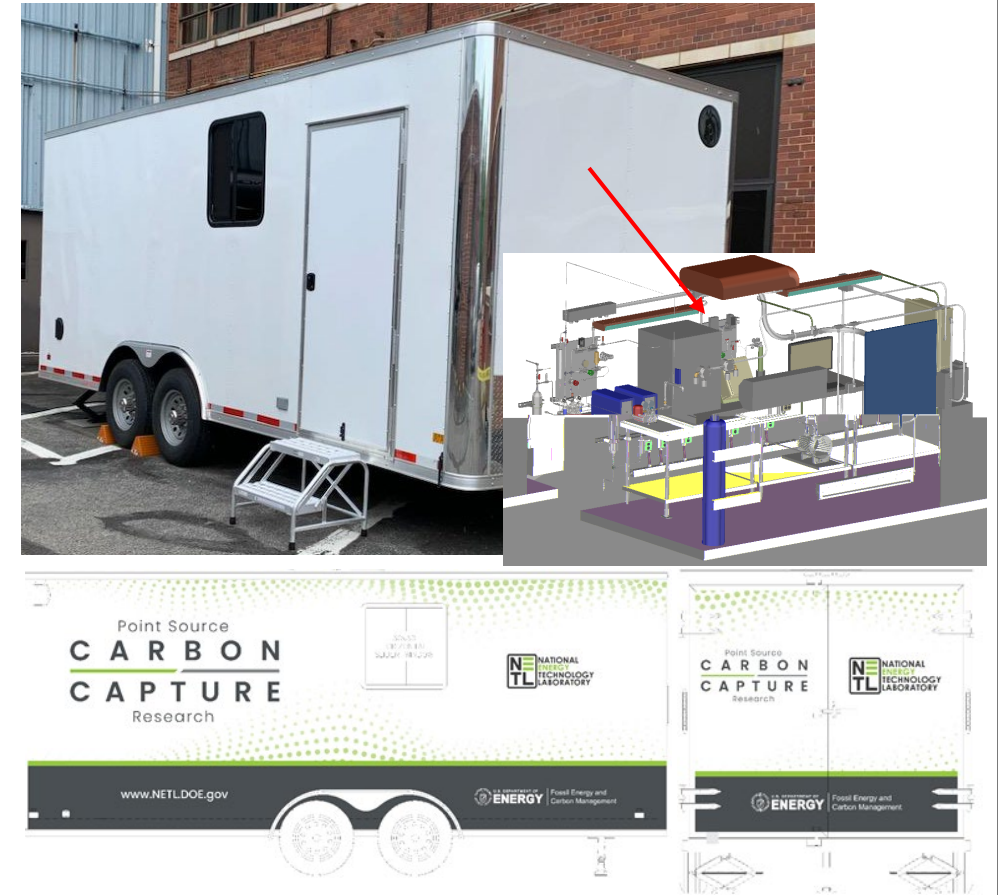
Roll-to-Roll TFC Fabrication



3D-Printed Module Scaleup & Testing

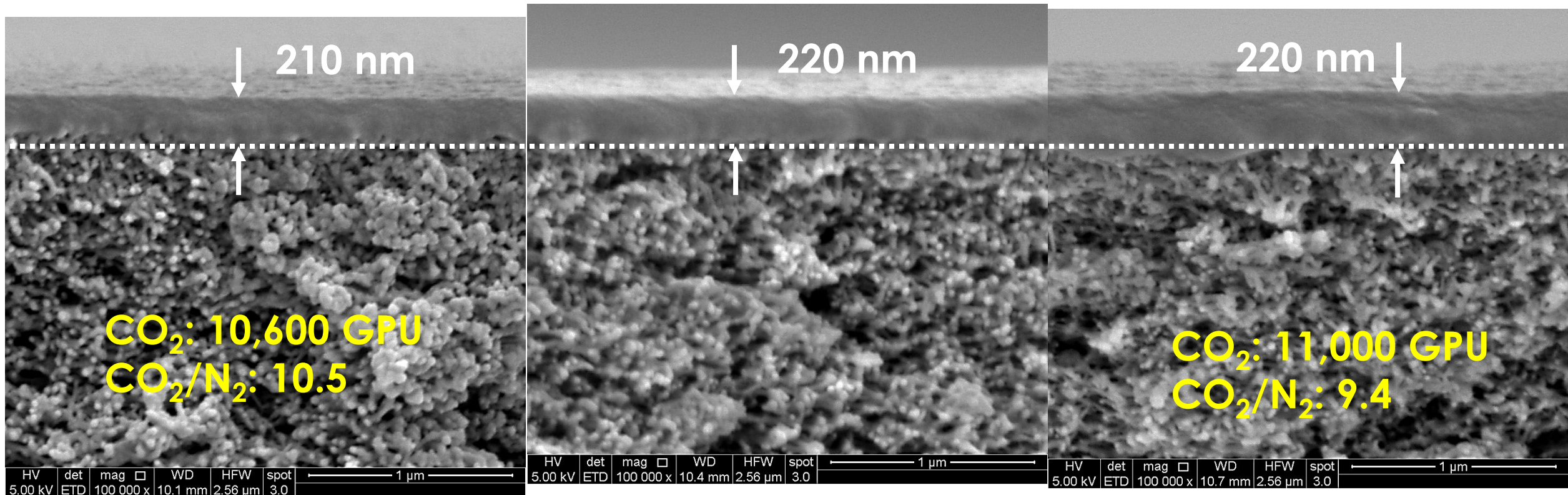


NETL Mobile Membrane Test Skid



Uniform Coating Thickness in the Roll-to-Roll (R2R) Process

3 samplers out of a 12m long thin-film coating; 100k magnifications under SEM

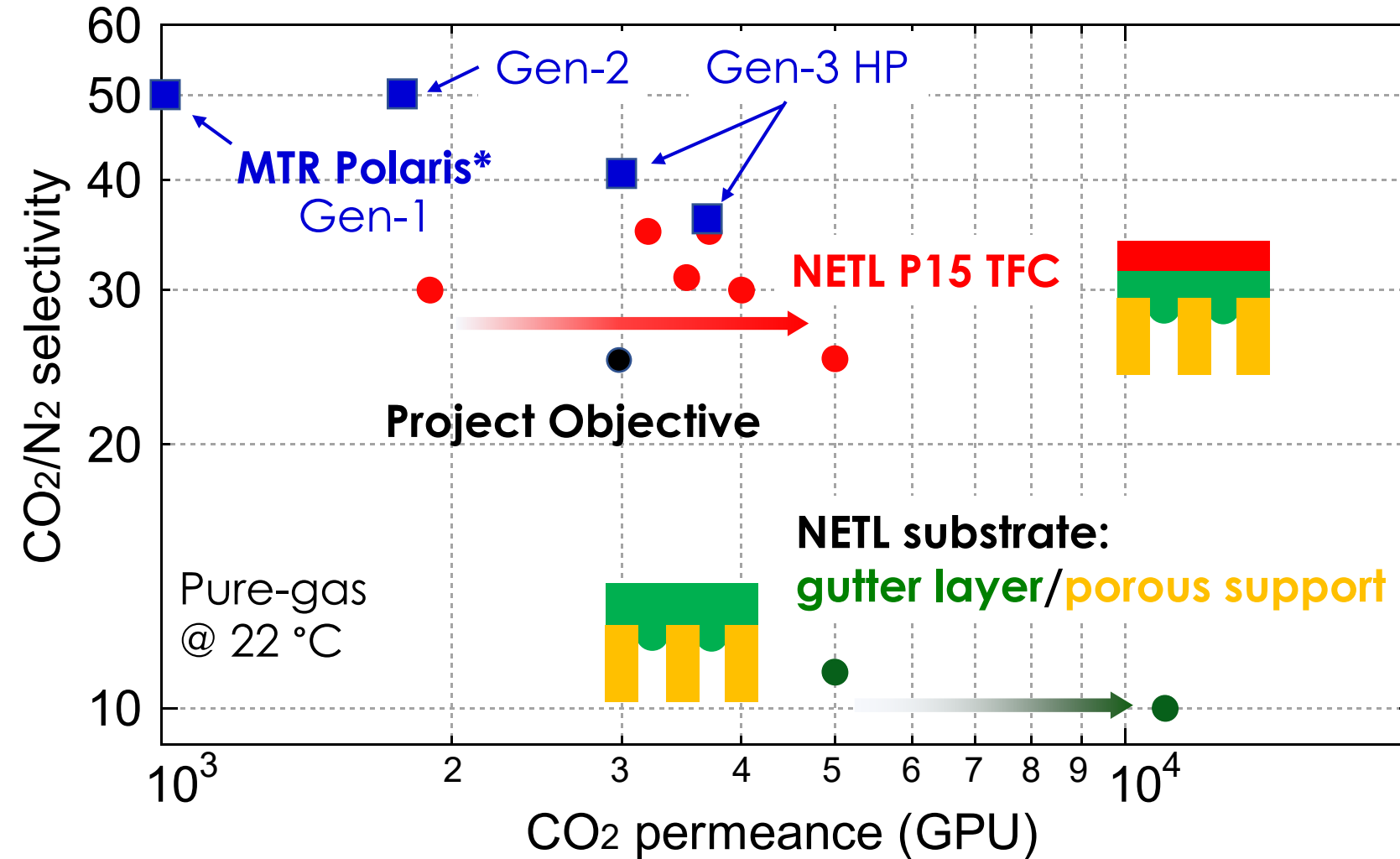


@1st meter

@6th meter

@12th meter

Membrane Separation Performance Benchmark



- NETL results are based on scalable R2R coating.
- Increasing gutter layer permeance leads to the improvement of TFC performance.
- NETL's 11,000 GPU substrate is the key to our high-permeance TFCs.

NETL Gutter Layer Membrane Exceeds Other Reports in Terms of Combined Performance and Scalability

	NETL	MTR-conventional	MTR-isoporous	Tianjin U, China	U. Melbourne, Australia
CO ₂ permeance(GPU) @ test temp (°C)	11,000 @ 22C	6,000 @ 30C	11,800 @ 30C	10,000 @ 25C	14,000 @ 35C
CO ₂ /N ₂ selectivity	10	n/a	n/a	10	9.0
G-layer thickness (nm)	~200	90	120	125	~50
Coating method	R2R	R2R	R2R	R2R	Spin coating
Porous support	polymer w/ good solvent resistance	An engineering polymer	Isoporous block copolymer (costly & weak solvent resistance)	Polysulfone (weak solvent resistance)	Polyacrylonitrile
Solvent resistance	Good	n/a	Weak	Weak	Good
Comments on scalability	Easy to scale up at low material cost	Demonstrated at MTR's Polaris membranes	Hard to scale up due to the difficulties in forming isoporous supports at scale	Scalable but needs special machinery for dip coating of wet supports	Not scalable due to the coating method used
Reference	This work	MTR's DE-FE0031596 Project Close Out Meeting, May 31, 2024		Sep. Purif. Technol. 239 (2020) 116580	Chem. Eng. J. 462 (2023) 142087

Scaleup Fabrication of Plate-and-Frame Membrane Modules for the U. S. Steel Field Test

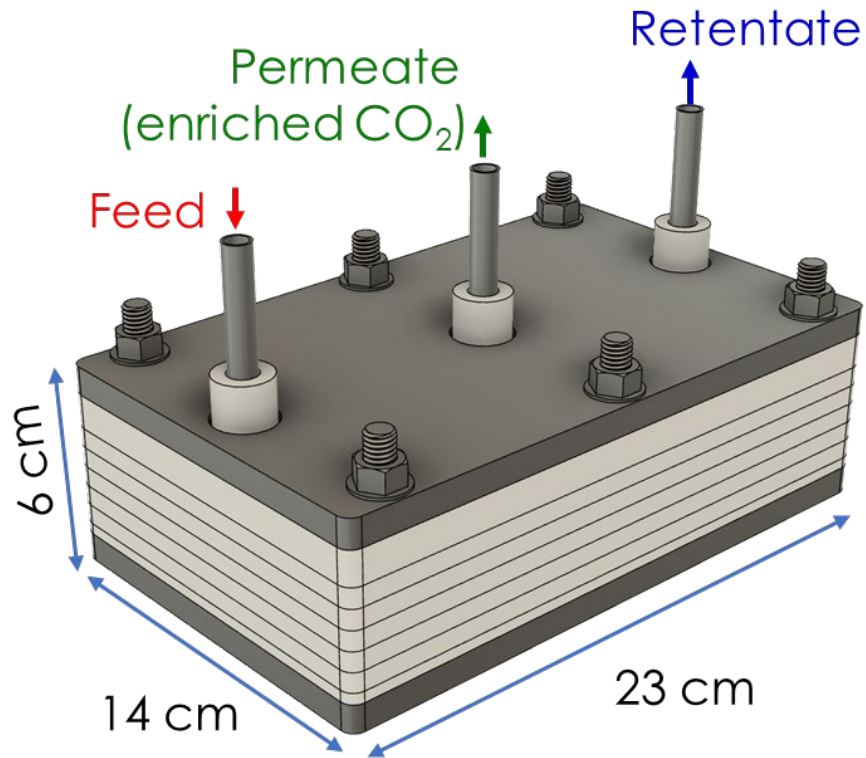
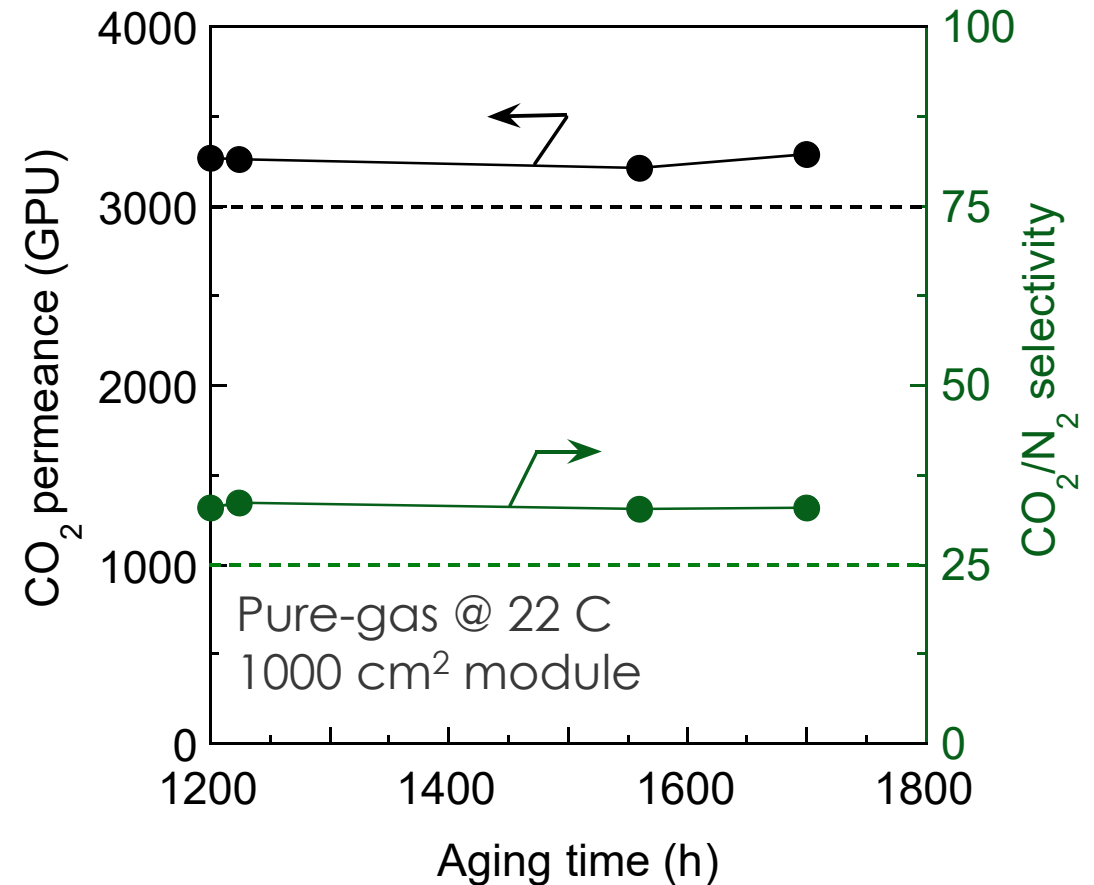
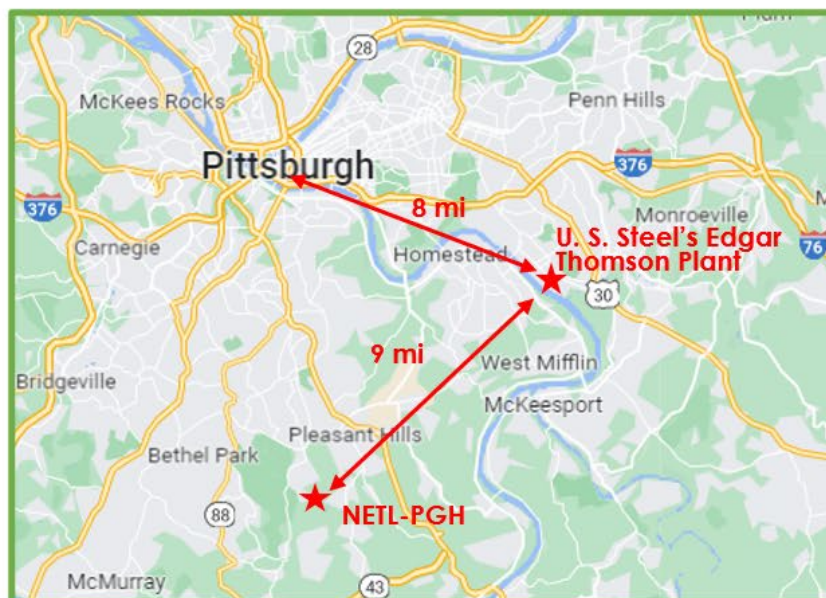
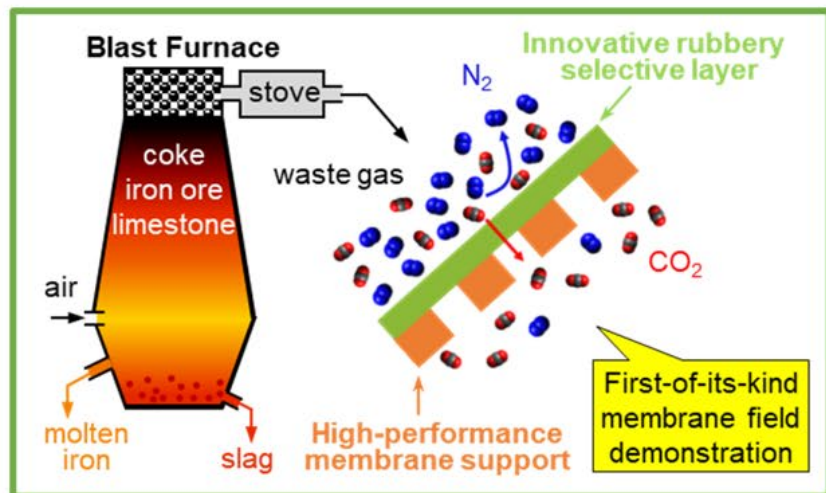


Illustration of a **1,000 cm²** membrane module for the U. S. Steel test: simple to increase membrane area by adding more stackings.

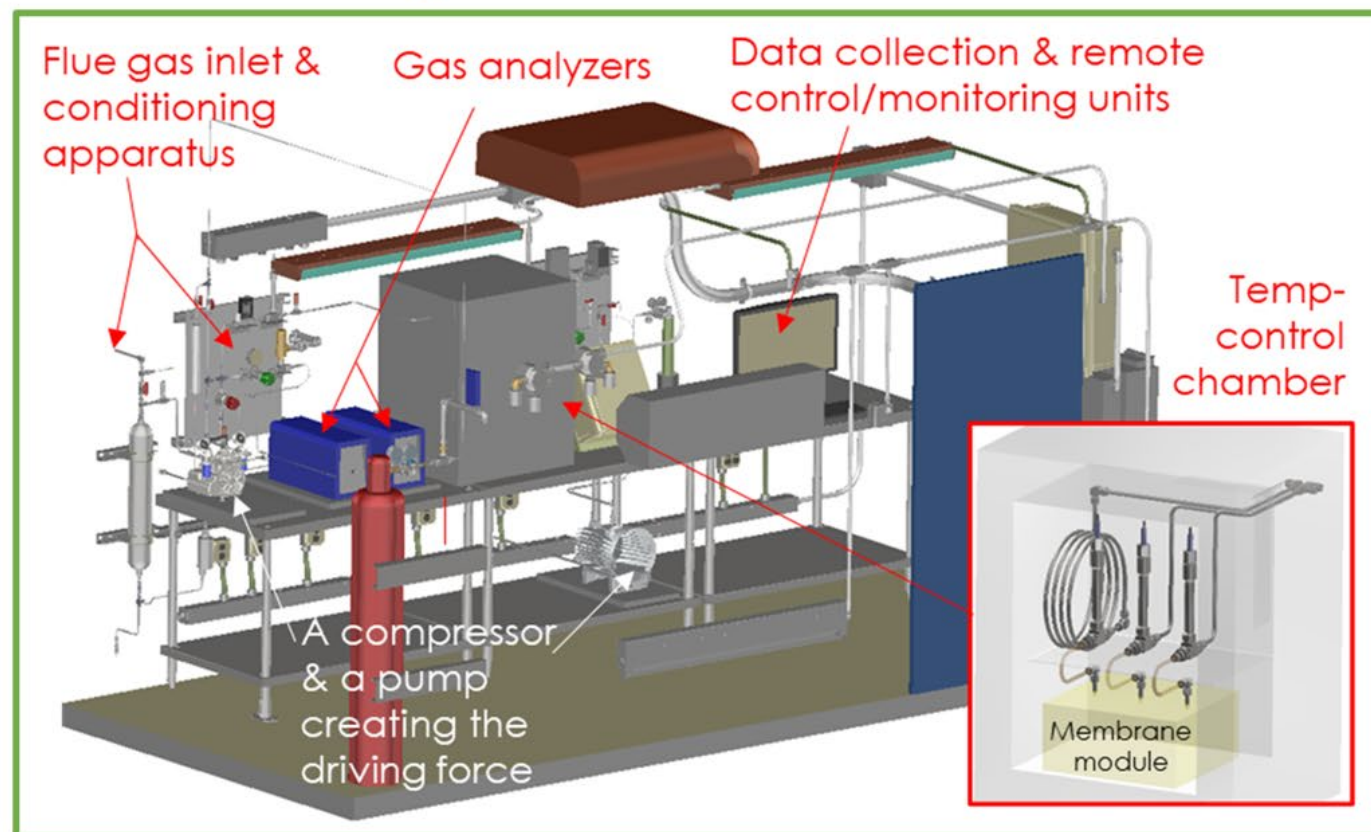


Membranes were stored for 50 days (1200 h) before being assembled into a module for testing.

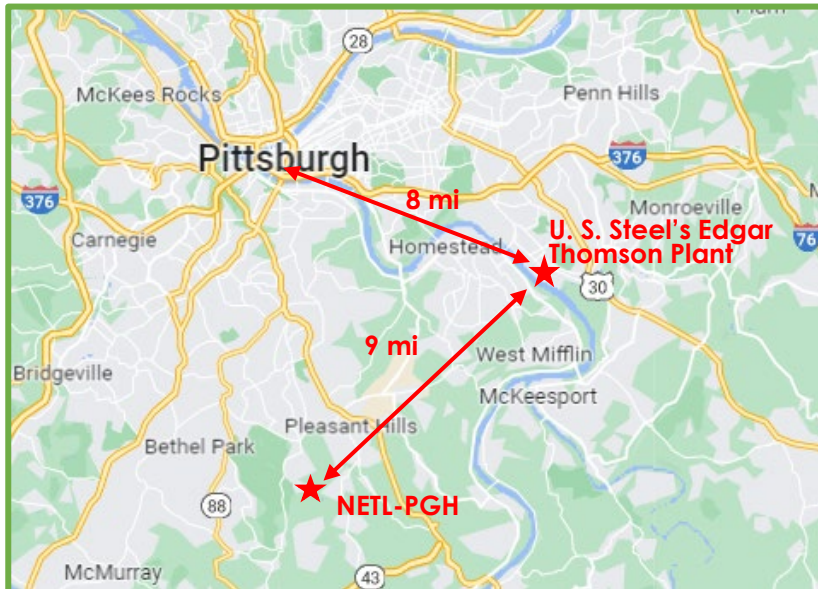
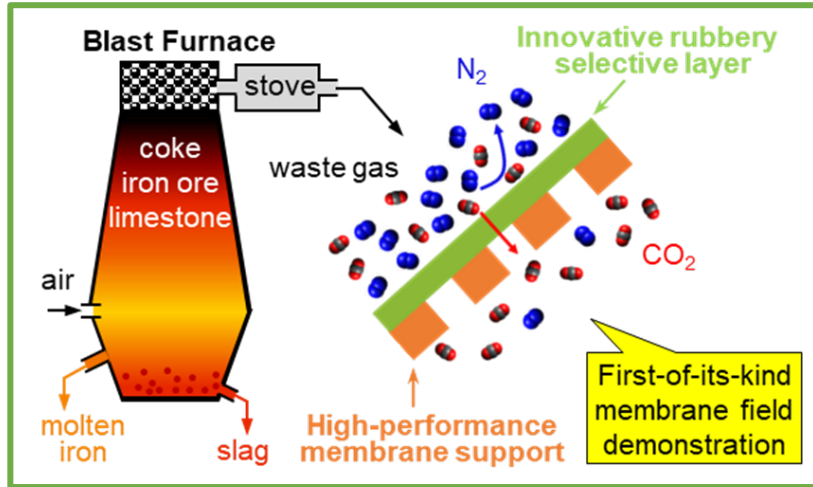
Preparations for the Field Demonstration in 2025



Collaborate with U. S. Steel for field test using blast furnace waste gas (>20% CO₂) at U. S. Steel's Edgar Thomson Plant, Braddock, PA.



Preparations for the Field Demonstration in 2025

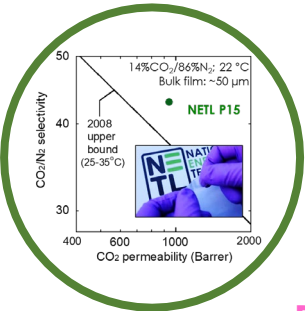


Collaborate with U. S. Steel for field test using blast furnace waste gas (>20% CO₂) at U. S. Steel's Edgar Thomson Plant, Braddock, PA.



Summary: NETL High-Permeance TFC Membranes' Pathway to Scale-Up and Field Demonstrations

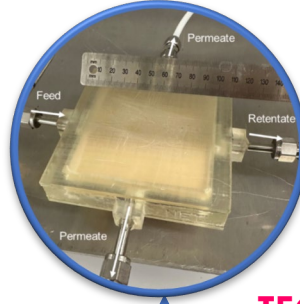
NETL P15 selective material synthesis and optimization



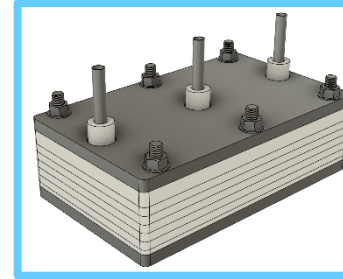
NETL S6 support scale-up via roll-to-roll



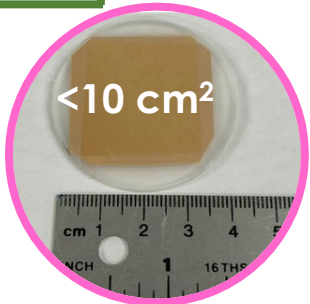
3D-printed bench-scale membrane module



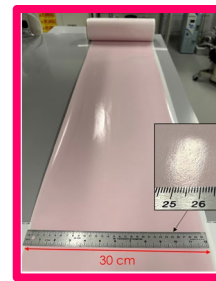
3D-printed multi-stacking membrane module



Bench-scale TFC fabrication



TFC scale-up via roll-to-roll



Field test at the U. S. Steel's Edgar Thomson Plant

1. Complete long-term field test at U. S. Steel's Edgar Thomson Plant
2. Perform systems and economic analysis by CCSI²

2021

2022

2023

2024

2025

2026

Acknowledgments



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Michael Ciocco
John O'Connor

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Glenn Lipscomb(UToledo)

CMU: CFD Simulation

Grigorios Panagakos
Cheick Dosso
Hector Alejandro Pedrozo

U. S. Steel: Field Test Host Site

Brenda Petrilena
Neil Pergar

INL: Material Synthesis

John Klaehn
Josh McNally

NCCC: Field Test Host Site

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Robert Lambrecht
John Carroll
John Cagle
Wayne Isbell

DOE Program Managers

Dan Hancu
Ronald Munson
Tim Fout



U. S. Steel



CCSI²
Carbon Capture Simulation for Industry Impact

Carnegie
Mellon
University



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