Highly Permeable Thin-Film Composite Membranes of Rubbery Polymer Blends for CO_2 Capture

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Membrane R&D: Victor Kusuma, Thien (James) Tran, Fangming Xiang

NETL Research & Innovation Center (RIC)

2023 FECM/NETL Carbon Management Research Project Review Meeting
Point Source Carbon Capture — Capture from Power Generation (Lab/Bench)

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Disclaimer

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Project Overview

- **Project:** High-Permeance Blended Rubbery Membranes
- **Project Period**: 04/01/2021 – 03/31/2026
- **Funding Source**: NETL-RIC Field Work Proposals: Transformational Carbon Capture (2021)
  Point Source Capture Technology (2022-2026)
- **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*. Both the *membrane support* and *selective material* will be optimized for scalability, thermal and chemical stability, and non-aging properties.**
- **Project Participants:**

NATIONAL ENERGY TECHNOLOGY LABORATORY

INL Idaho National Laboratory

NATIONAL CARBON CAPTURE CENTER

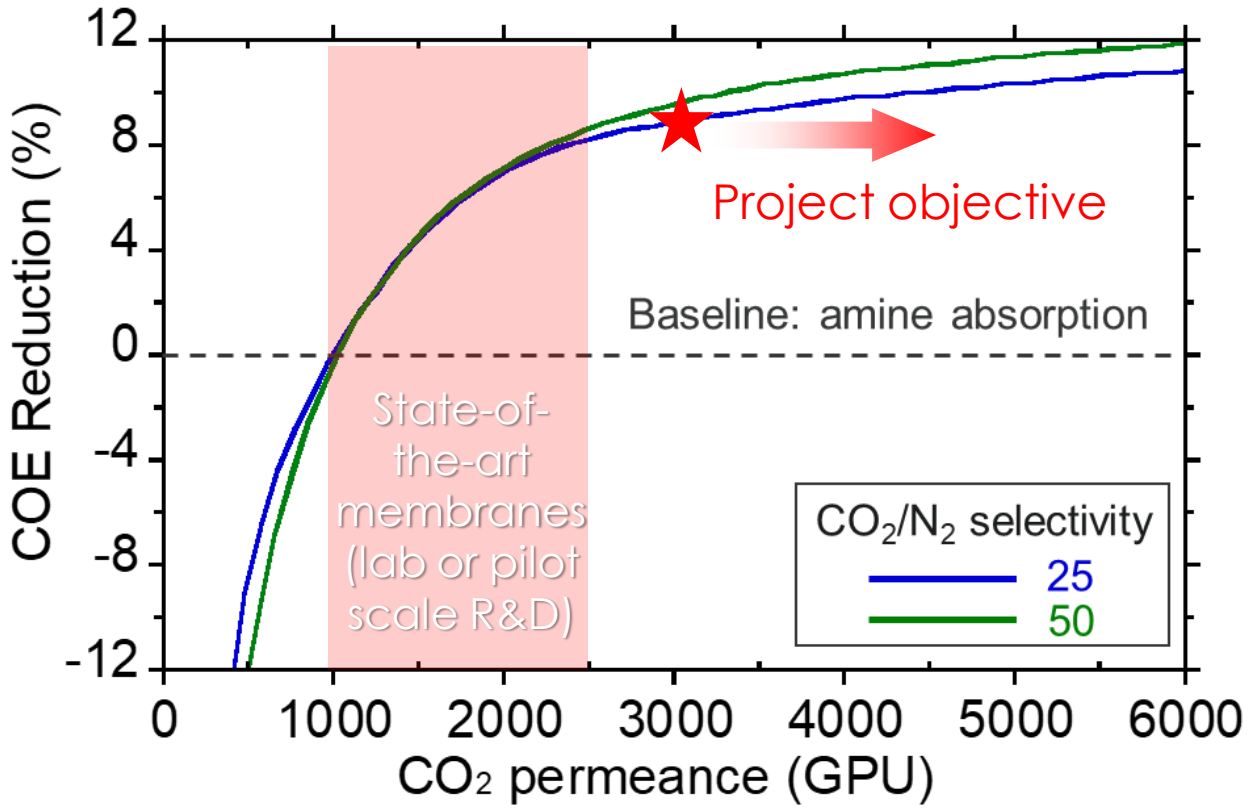
United States Steel

Carnegie Mellon University

CCSI² Carbon Capture Simulation for Industry Impact

THE UNIVERSITY OF TOLEDO

Background: Importance of High-Permeance Membranes



COE: cost of electricity

- Coal flue gas decarbonization: membrane vs. amine absorption
- Two-stage membrane process with air sweep, designed by Membrane Technology and Research (MTR)
- 95% CO_2 purity at a high CO_2 recovery (capture rate) of 90%

For coal flue gas decarbonization, an increase in CO_2 permeance is more important than a further increase in CO_2/N_2 selectivity when the selectivity is above 25.

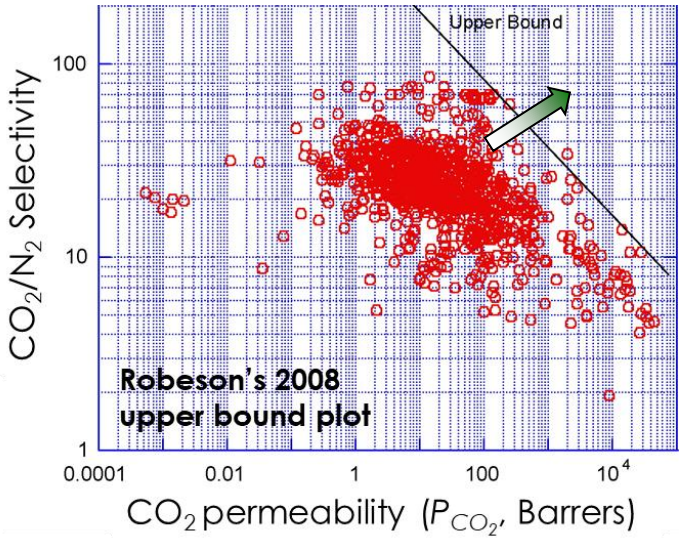
Alex Zoelle *et al.*, *Performance and Cost Sensitivities for Post-Combustion Membrane Systems*, 2018 NETL CO_2 Capture Technology Project Review Meeting

Background: Achieving High Permeance via Selective Material Optimization and TFC Fabrication

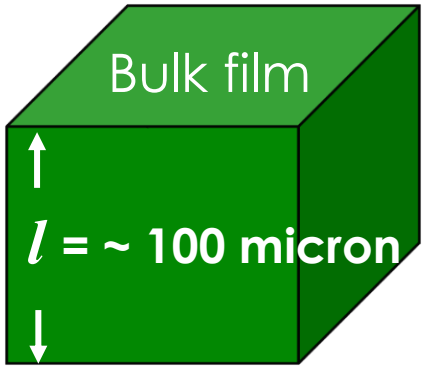
$$\uparrow \textbf{Permeance} = \frac{Permeability\ (P)\ of\ selective\ material \uparrow}{thickness\ of\ selective\ layer \downarrow}$$

1. Selective material optimization

Permeability/selectivity tradeoff

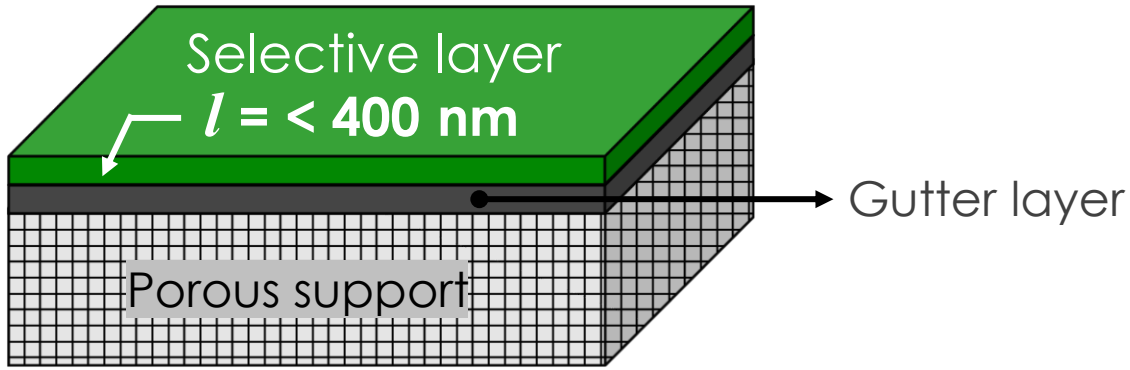


Robeson, *J. Membr. Sci.* 320 (2008) 390



Thickness reduction

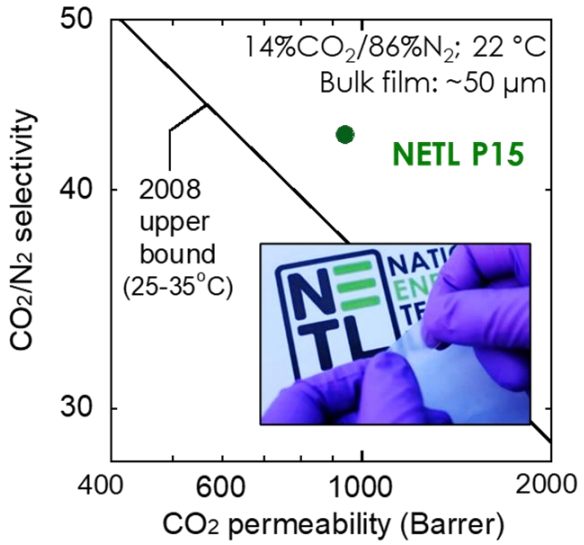
2. TFC membrane fabrication

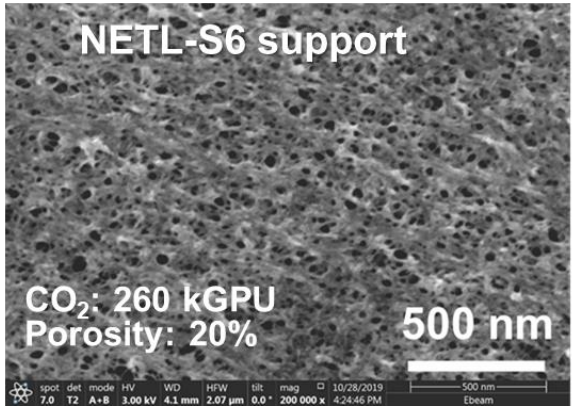


Selective layer (< <1 um): CO_2/N_2 separation
Gutter layer (< 500 nm): preventing pore penetration and smoothening porous support
Porous support (> 20 μm): mechanical reinforcement

Prior Efforts (2019-2022): Successful Bench-Scale Fabrication

High-performance materials





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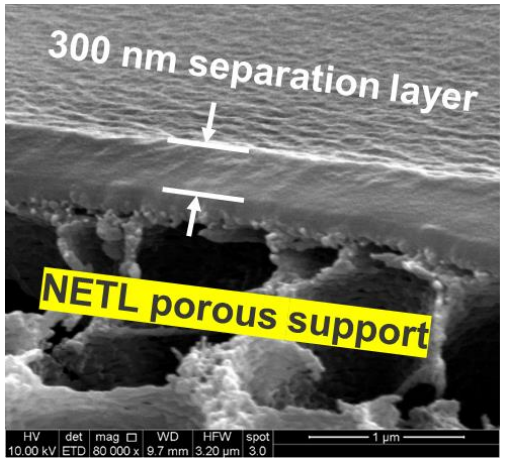
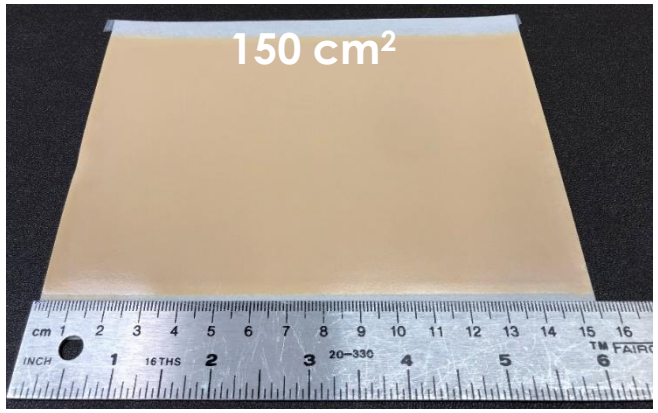
Suitable coating technique





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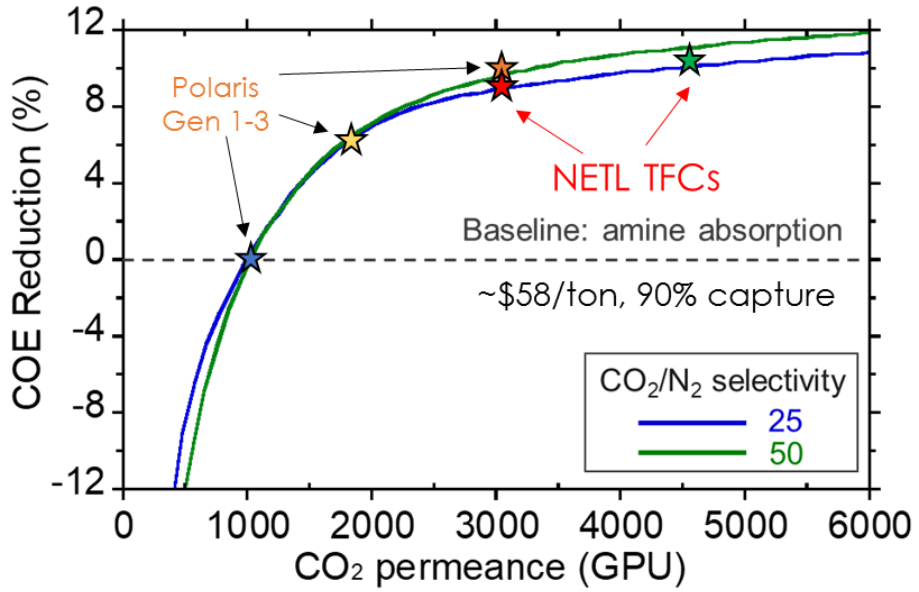
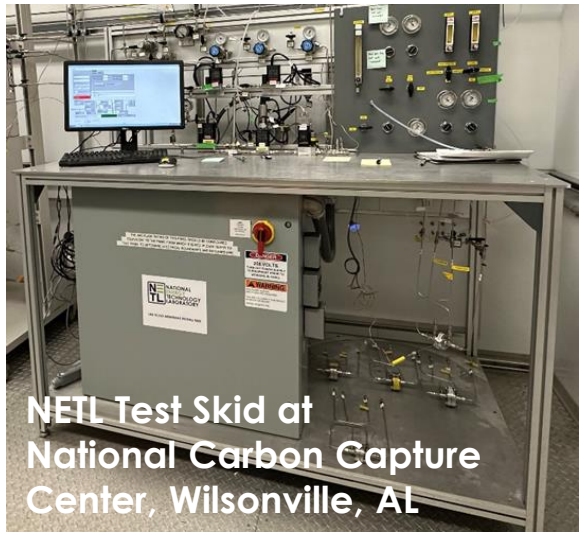


Lower-cost CO_2 capture vs. amine absorption

1. Alex Zoelle *et al.*, *Performance and Cost Sensitivities for Post-Combustion Membrane Systems*, 2018 NETL CO_2 Capture Technology Project Review Meeting
2. MTR Polaris membrane performance: Project FE0031591 Technology Sheet, https://netl.doe.gov/project-information?p=FE0031591

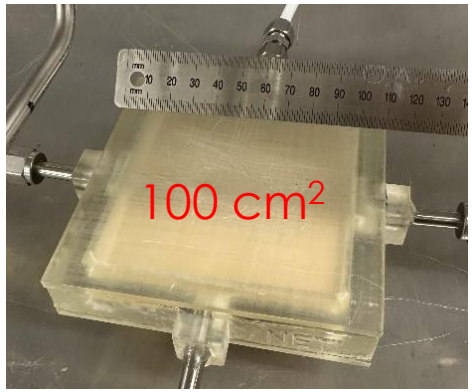
Highlights of 2022-2023 Accomplishments

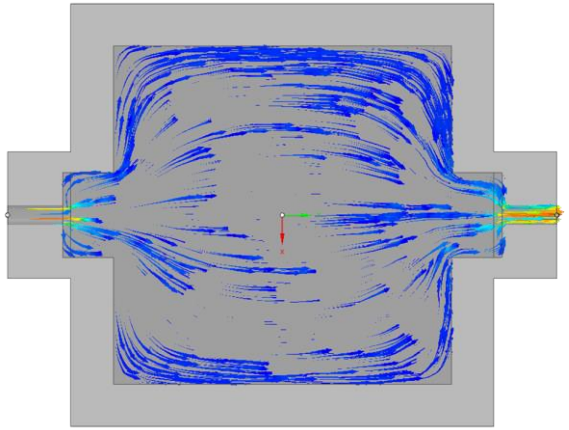
Field Test @ NCCC



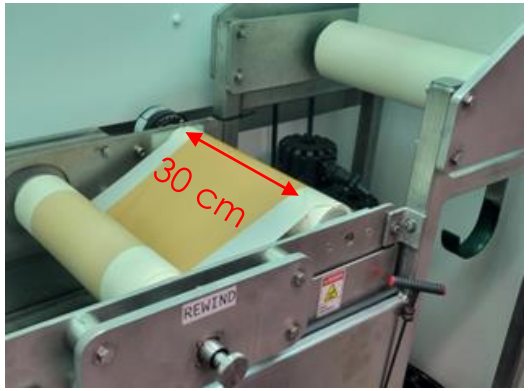
- Oct. 2022 - current
- 6 membranes tested
- >5,000 hours run time

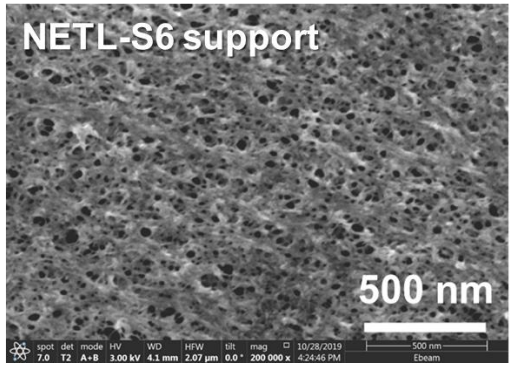
Membrane module design, 3D printing, and optimization



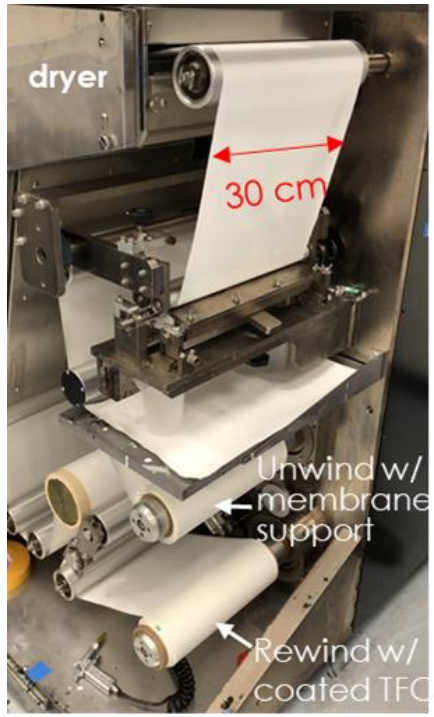


Roll-to-roll scale-up of membrane support

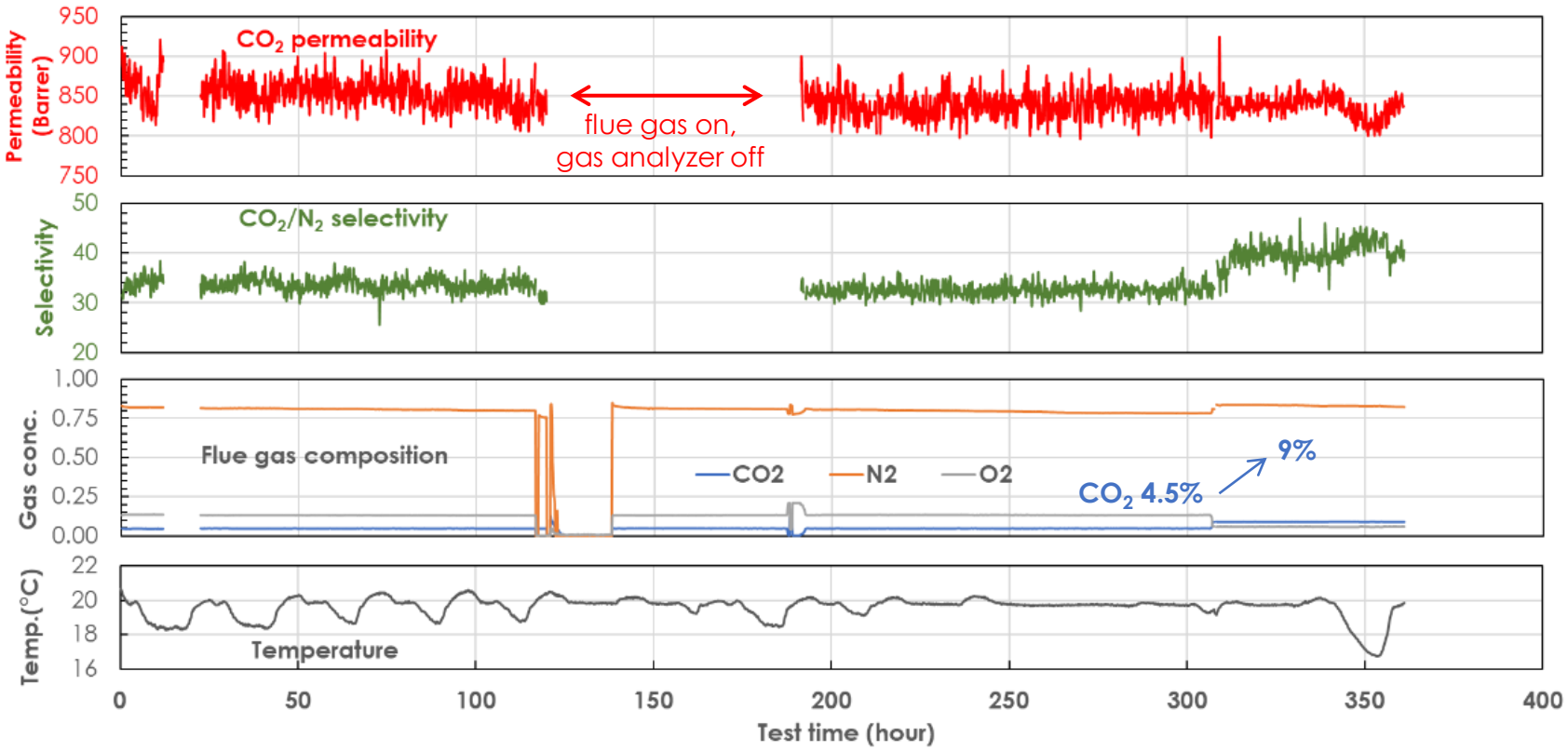




Installation and shakedown of a roll-to-roll thin-film membrane coater

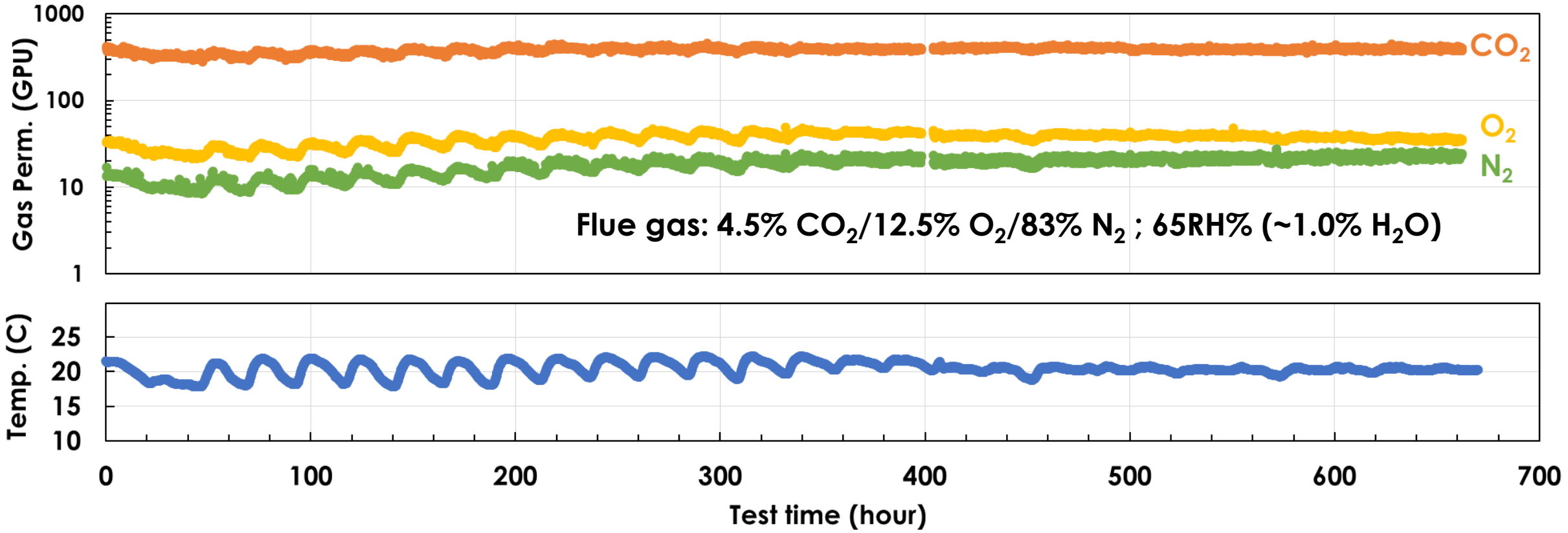


NETL Rubbery Polymer Blend Bulk Films Demonstrating Long-Term Stability in Flue Gas at NCCC



360-hour field test of a **50 µm** P15 film at NCCC in **natural gas flue gas** with varying CO_2 concentrations of 4.5–9 mol.% at ~20 °C

NETL Rubbery Polymer Blend Thin-Films Demonstrating Long-Term Stability in Flue Gas at NCCC

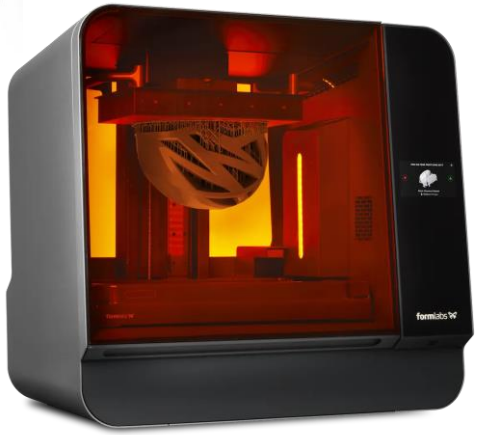


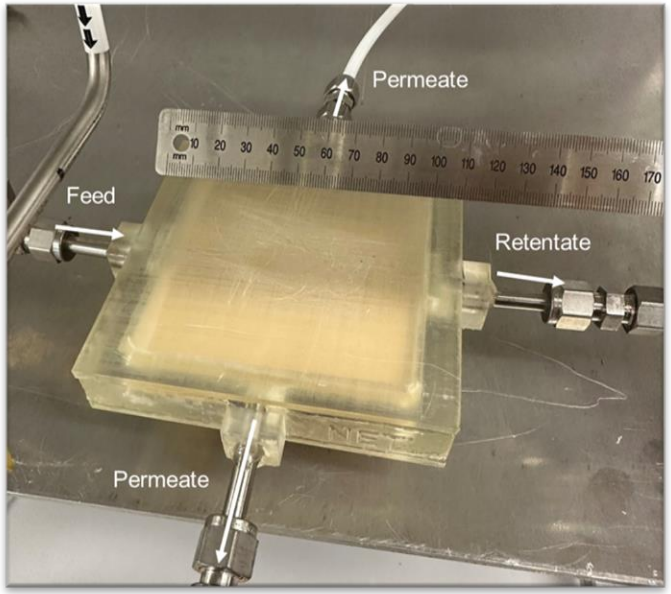
670-hour (4-week) field test of a **submicron** P15 thin-film composite at NCCC in **natural gas flue gas** with a CO_2 concentration of 4.5 mol.% at ~20 °C

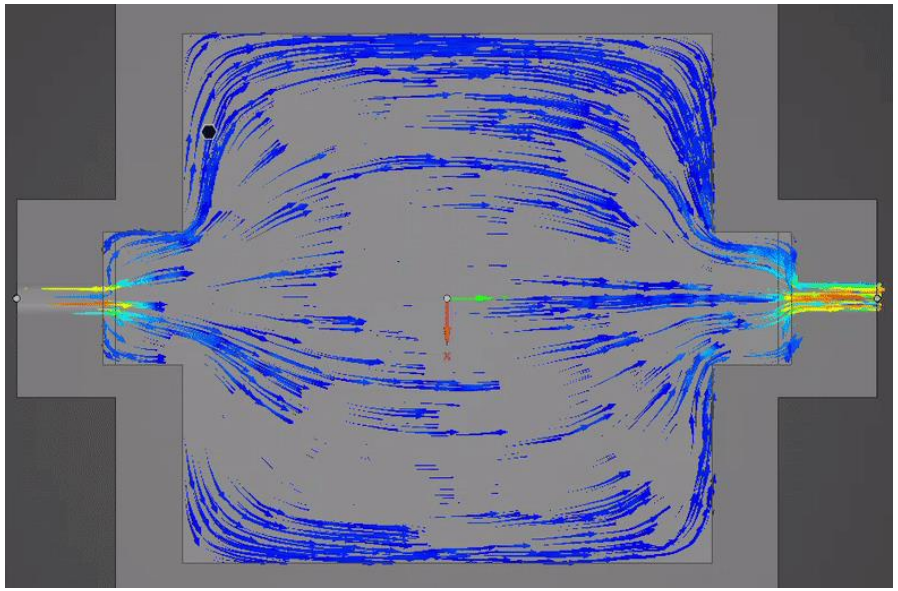
Design, CFD Simulation, and 3D Printing of Plate-and-Frame Membrane Modules

FormLabs 3+
14.5 × 14.5 × 18.5 cm

FormLabs 3L
33.5 × 20 × 30 cm





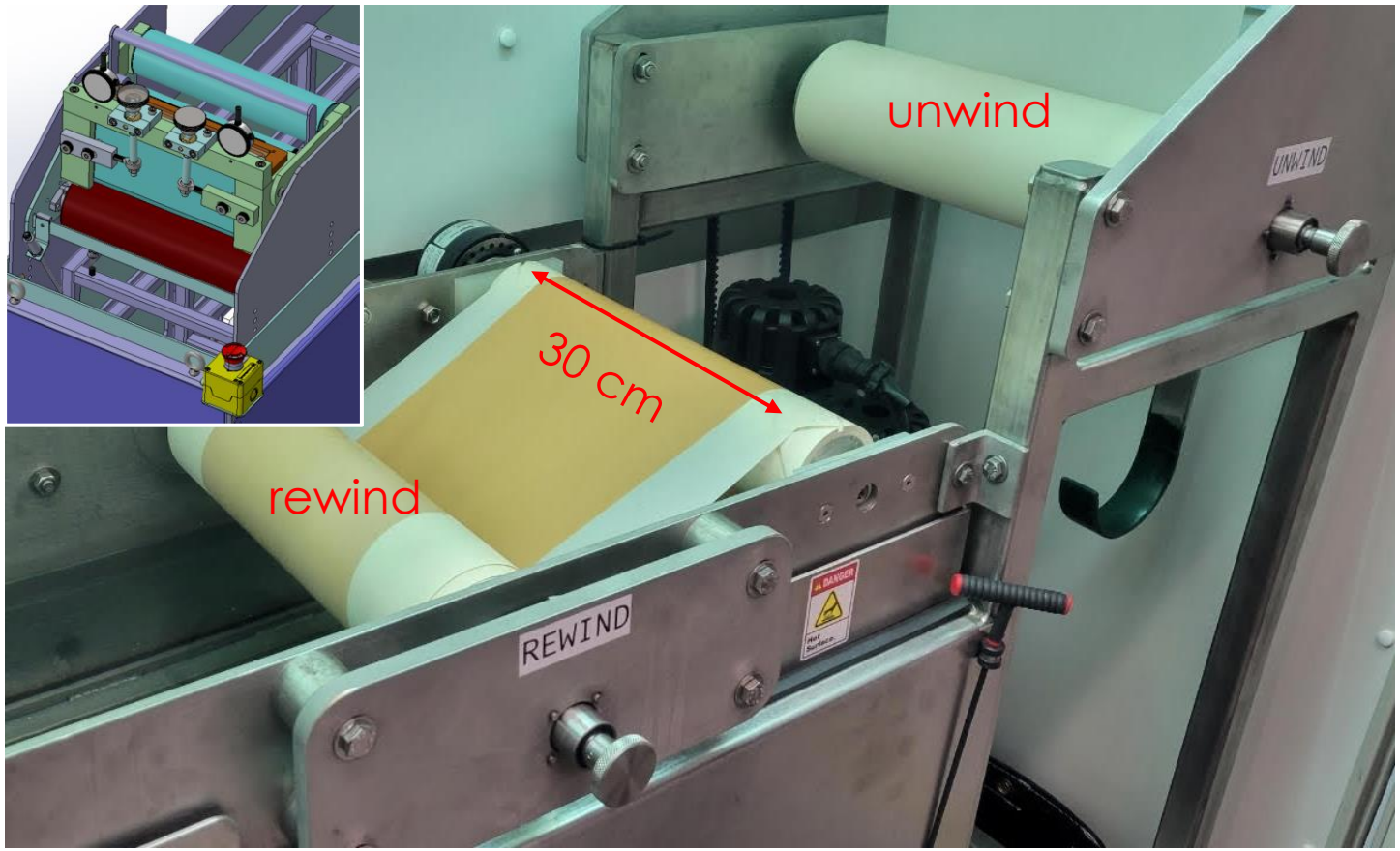


- Good gas tightness resulting from stereolithography (SLA) printing with resin
- High XYZ resolutions: 25 µm

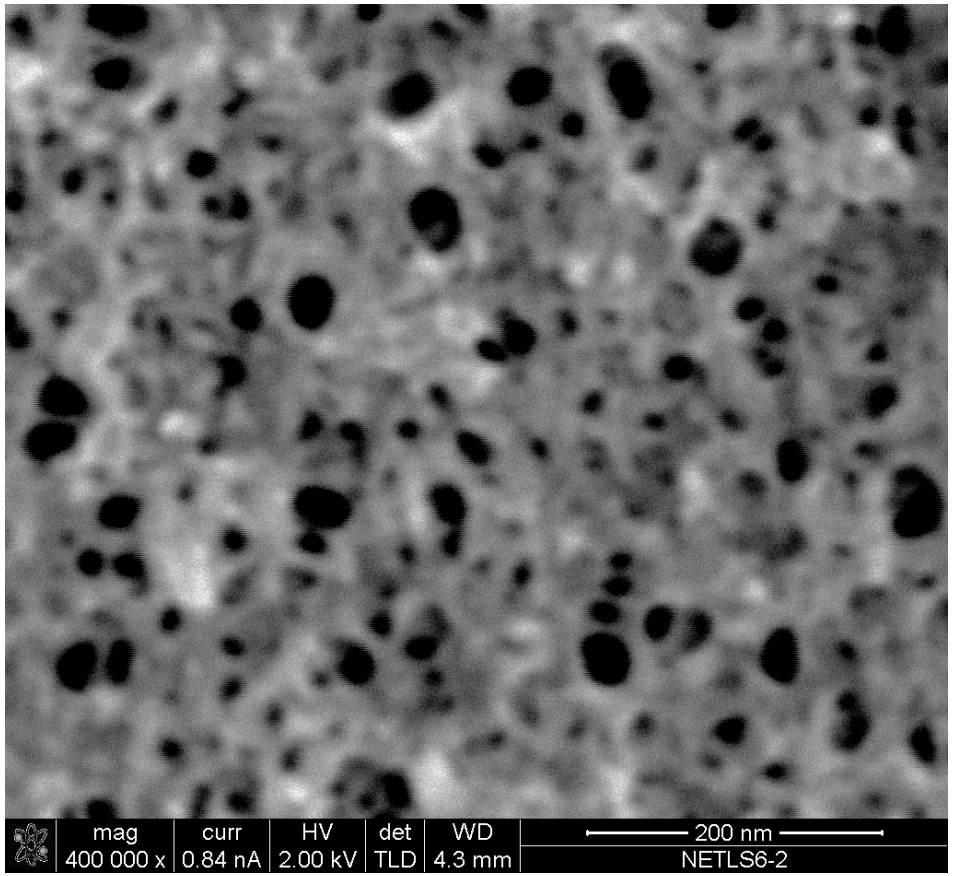
A 3D-printed 100 cm^2 module prototype being tested in a permeation system

Computational fluid dynamics (CFD) simulation integrated to design modules with optimal flow efficiency

NETL-S6 Membrane Support Scale-Up *via* Roll-to-Roll Process

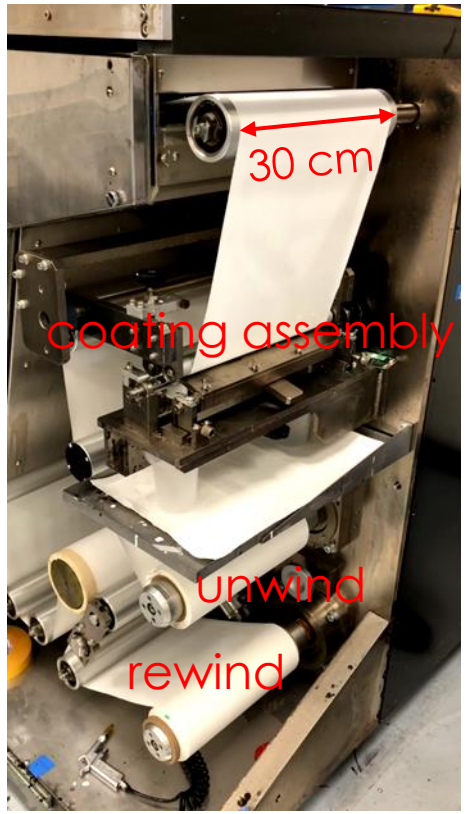


NETL's custom membrane casting machine

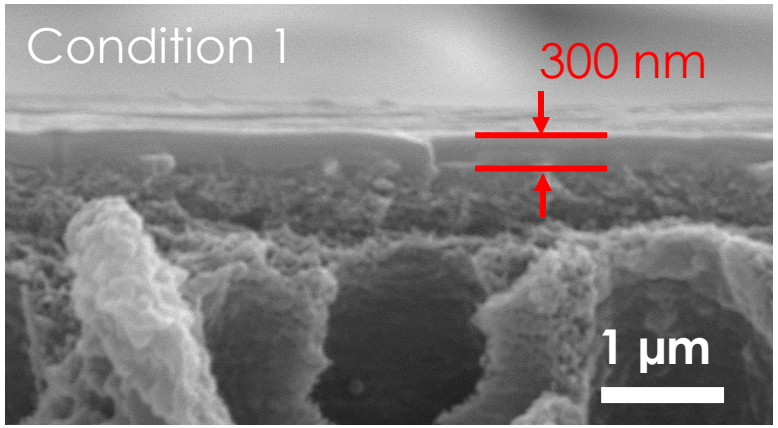


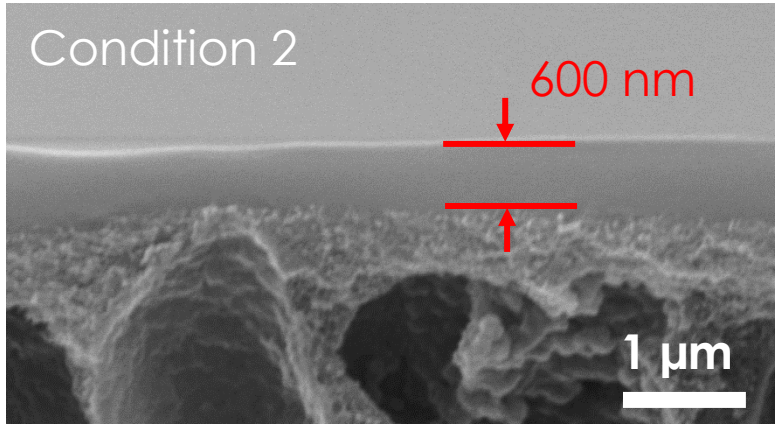
Scaled-up membrane's microporous feature

Progress Update on TFC Scale-Up via Roll-to-Roll Process



Thin-film coating test run at the vendor's site in 03/2022





Roll-to-Roll Thin-Film Coating Machine

- A custom machine ordered in 12/2022 and delivered in 07/2023
- Installation, shakedown, and EHS approval by 12/2023
- Optimized roll-to-roll thin-film coating by 03/2024

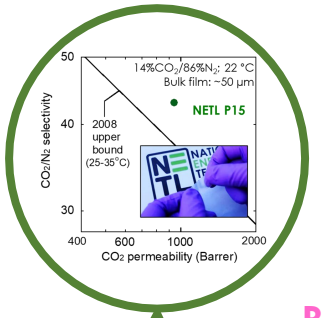
Materials

- P15 polymer scale-up synthesis: 40 g/batch (equiv. 100 m^2 thin films)
- NETL-S6 membrane support rolls

R&D Timeline: Project Progress and Future Work

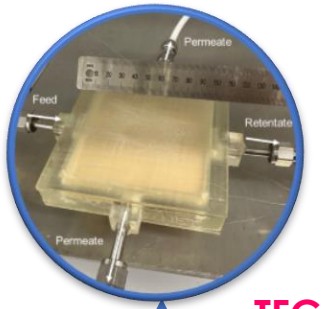
NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL P15 selective material synthesis & optimization

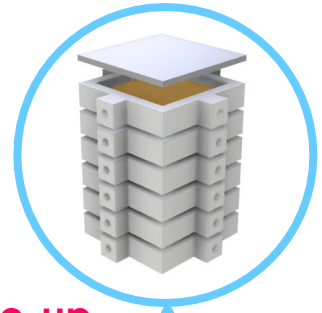


NETL S6 support scale-up via roll-to-roll

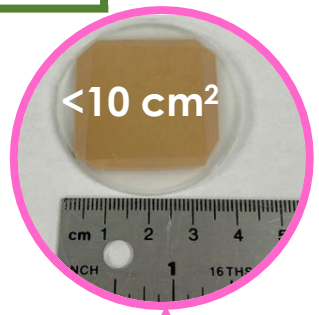
3D printed bench-scale membrane module

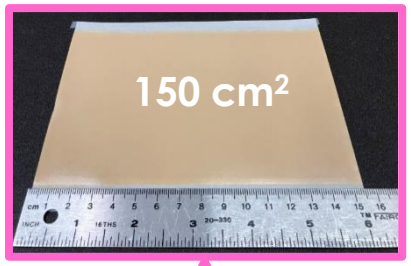


3D printed multi-stacking membrane module

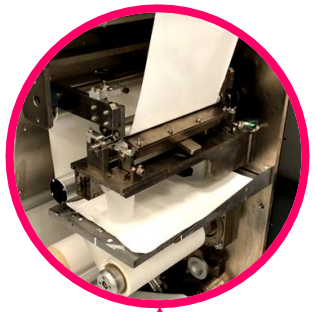


Bench scale TFC fabrication





TFC scale-up via roll-to-roll

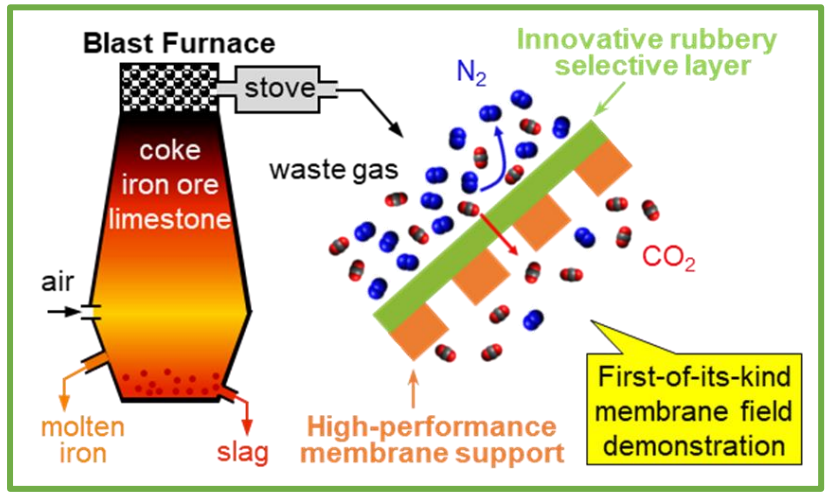


1. Complete long-term field test at U. S. Steel's Edgar Thomson Plant
2. Perform systems and economic analysis by CCSI²

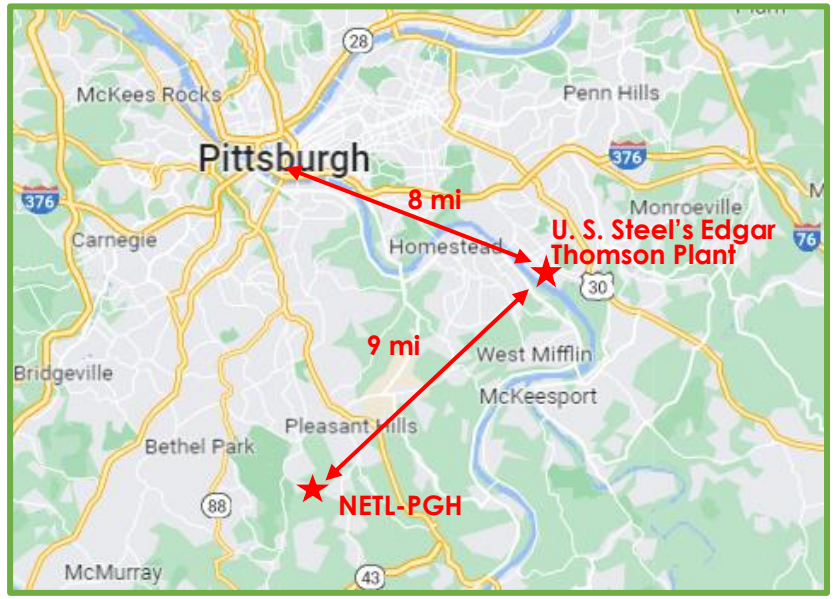
Initiate field test at a commercial steel mill (U. S. Steel's Edgar Thomson Plant)

2021 2022 2023 2024 2025 2026

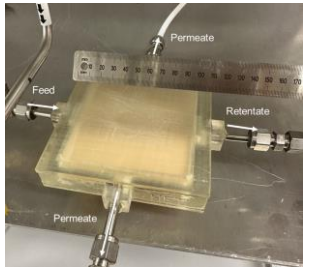
Field Demonstration Preparations in 2024-2025

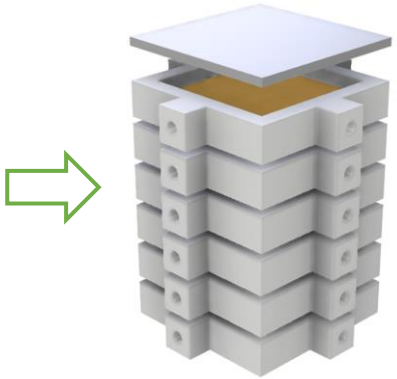


Collaborate with U. S. Steel for field test using blast furnace waste gas (>20% CO_2) at U. S. Steel's Edgar Thomson Plant, Braddock, PA



Design and construction of membrane testing skid





Module fabrication and lab testing

Acknowledgments

NETL Membrane R&D

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U. S. Steel: Field Test Host Site

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INL: Material Synthesis

John Klaehn
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NCCC: Field Test Host Site

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