Novel Transformational Membranes and Process for CO_2 Capture from Flue Gas

DE-FE0031731

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Carbon Management Project Review Meeting
NETL, Pittsburgh, PA, August 18, 2022

Outline

- Project Overview
- Technical Background
- Accomplishments
- Summary/Outlook

Project Objective

- **Develop a cost-effective design and fabrication process for a novel transformational membrane and its membrane modules that capture CO_2 from flue gas**
  - **95% CO_2 Purity**
  - **60–90% CO_2 Recovery**

Funding and Performance Dates

- **Total Budget: 07/01/2019–03/31/2023**
  DOE: $2,999,988; OSU: $740,000; GTI: $10,000
  (20% cost share)

  - **BP1: 07/01/2019–12/31/2020**
    DOE: $1,395,100; OSU: $348,778

  - **BP2: 01/01/2021–03/31/2023**
    DOE: $1,604,888; OSU: $391,222; GTI: $10,000

Technical Background: Thin-Film Composite (TFC) Membrane Structure: 3 Layers

Efficient and Scalable Membrane for Low Cost

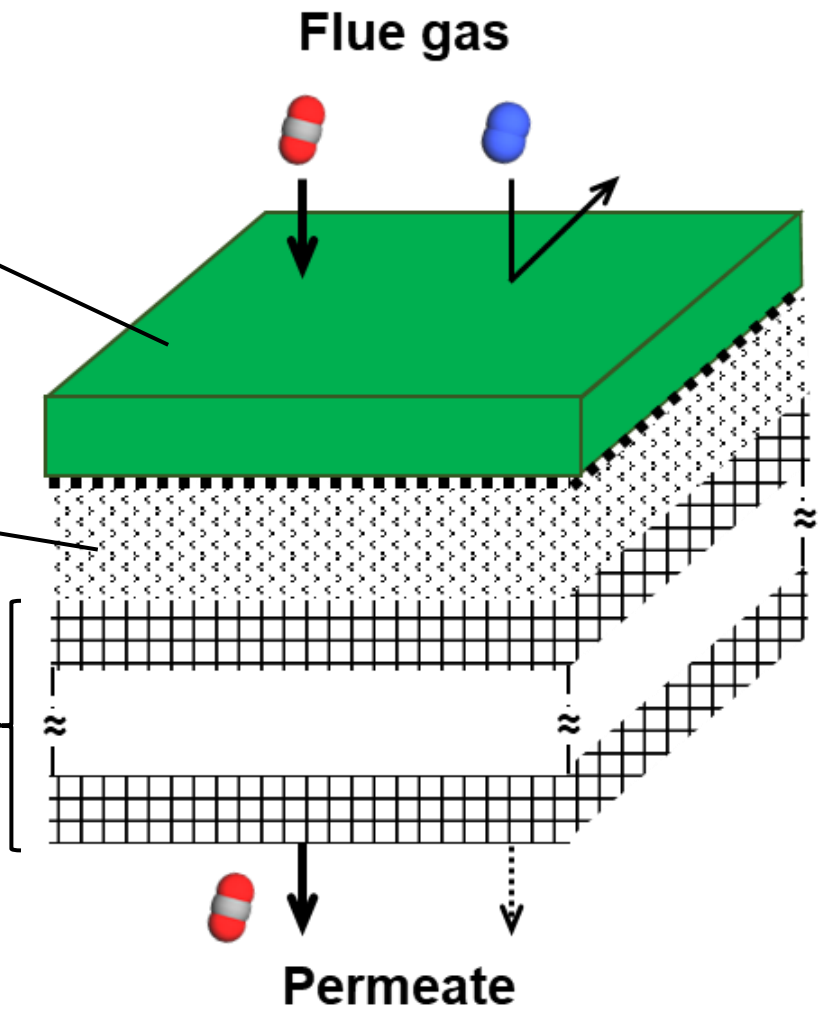
Highly selective amine polymer layer (170 nm, dense layer)

>140 CO_2/N_2 selectivity

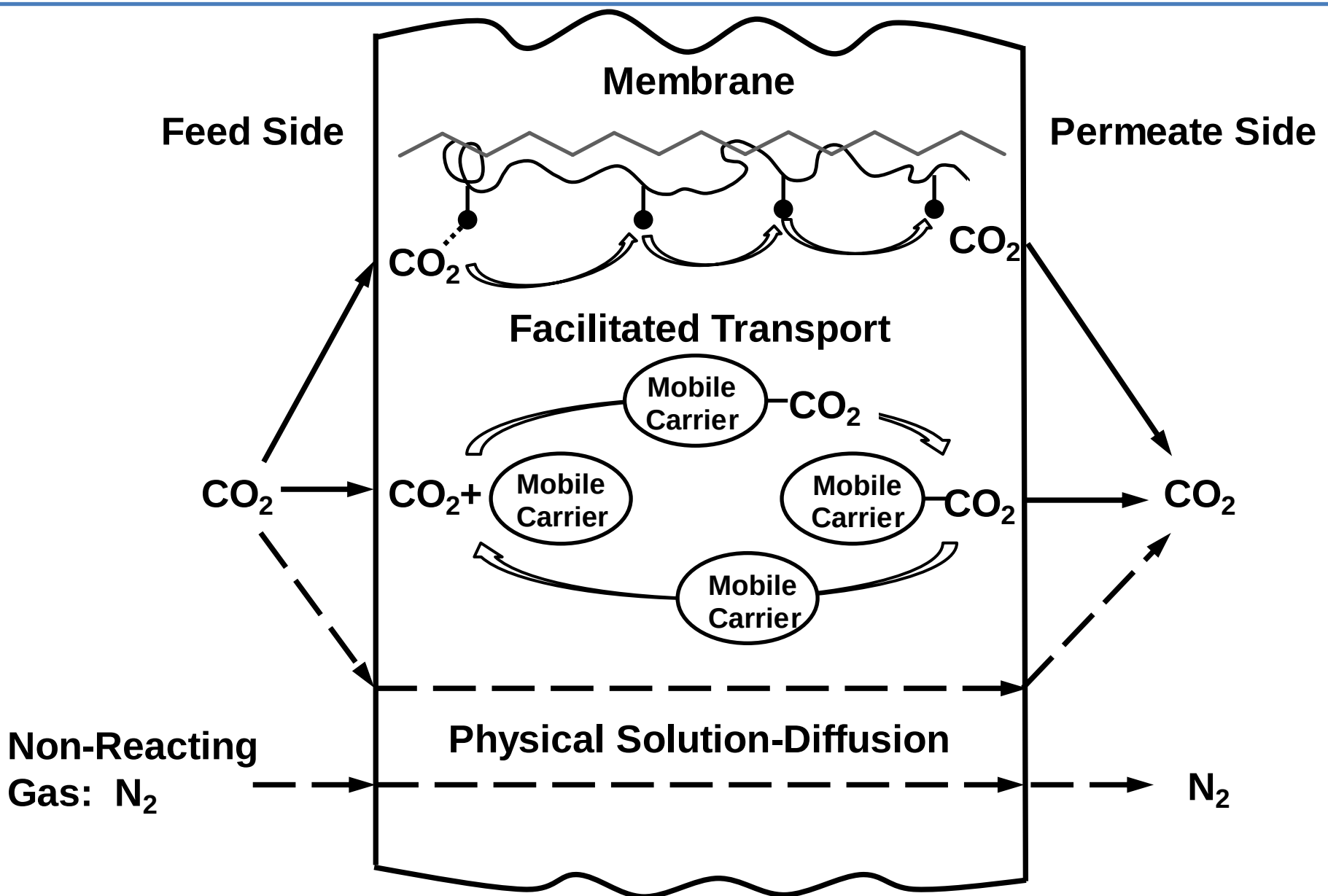
Ultra-permeable polymer support (~20 µm, Ø ~30 nm)

>300,000 GPU CO_2 permeance

Nonwoven fabric backing (~100 µm)



Amine-Based Facilitated Transport Membrane for High Performance



Technical Approach

- **BP1: 07/01/2019–12/31/2020**
  - Computation-aided material design
  - Lab-scale membrane synthesis, characterization and transport performance studies
  - Design of integrated membrane skid
  - High-level techno-economic analysis

- **BP2: 01/01/2021–03/31/2023**
  - Laboratory-scale membrane synthesis to continue
  - Fabrication and characterization of scale-up membrane (21″ wide)
  - Fabrication and evaluation of spiral-wound membrane modules (8″ diameter, 22″ length)
  - Fabrication and field test of integrated membrane skid
  - Update techno-economic analysis by Gas Technology Inst.

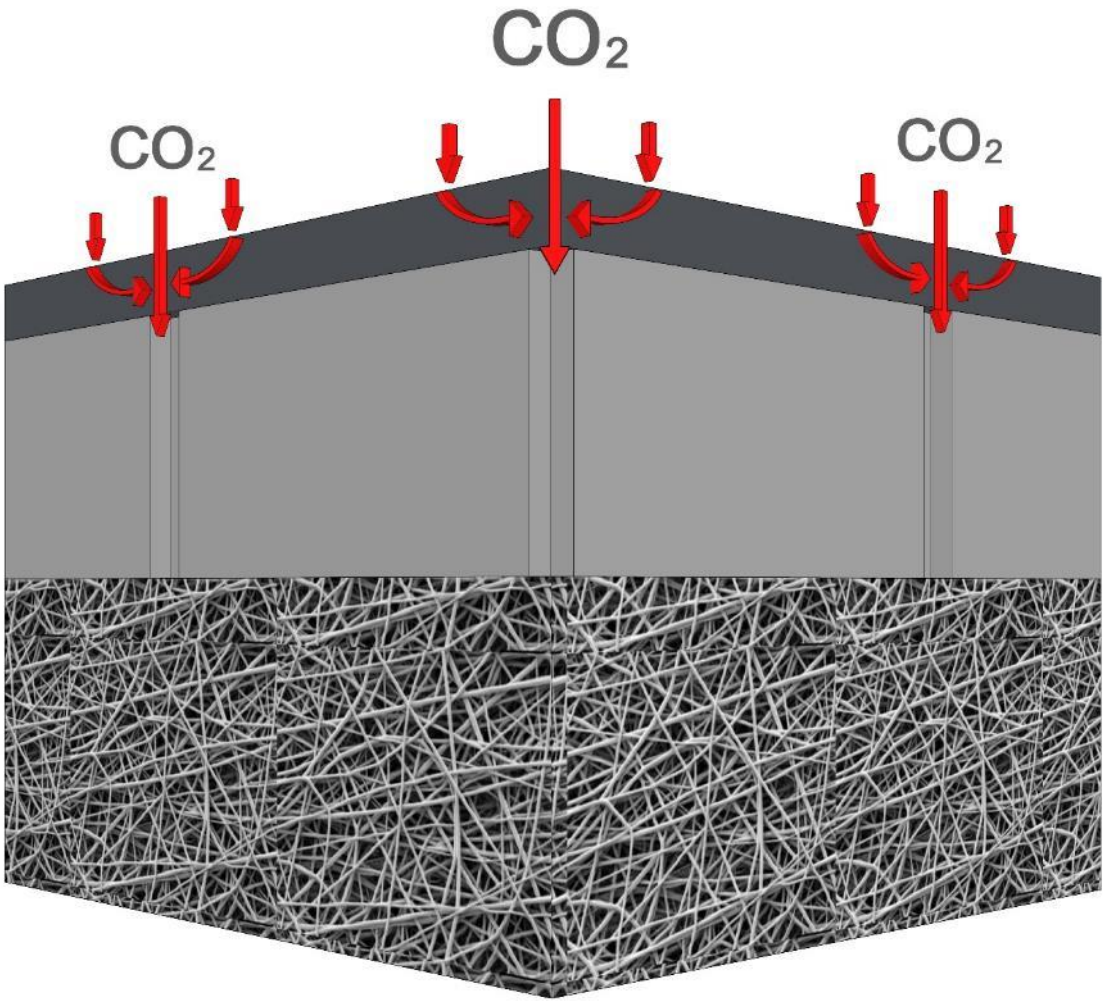
- **Integrated program with fundamental studies, applied research, synthesis, characterization and transport studies, and high-level techno-economic analysis**

Improved Polymer Support

Dense selective layer
(Lateral diffusion)

Porous substrate layer
(Knudsen diffusion)

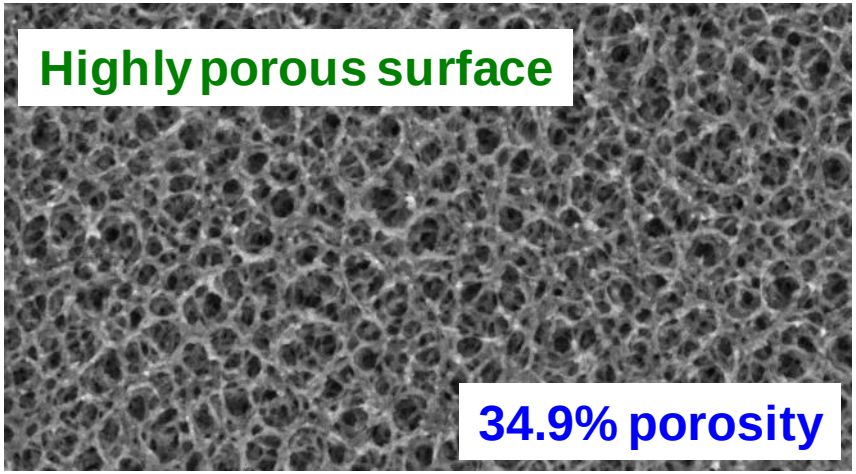
Nonwoven fabric backing
(Viscous flow)

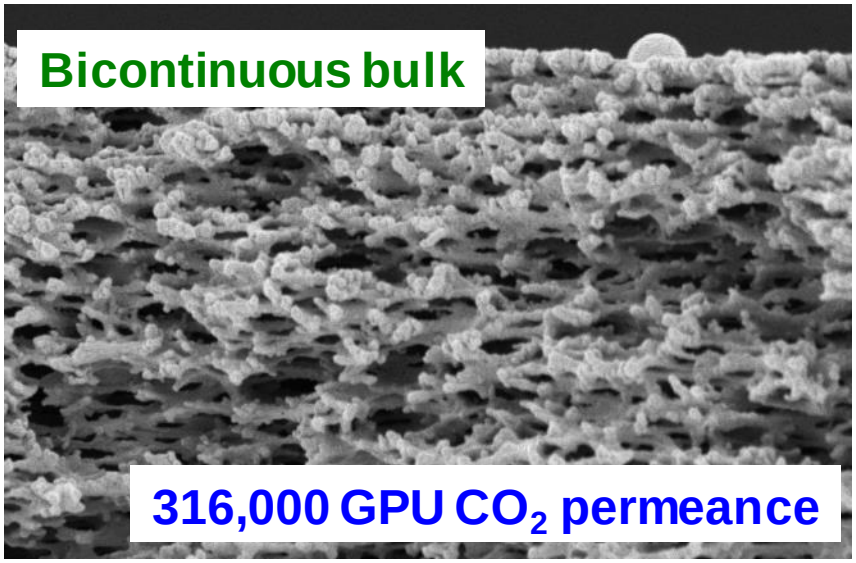


- **Substrate morphology has significant effect on CO_2 transport performance of composite membrane**

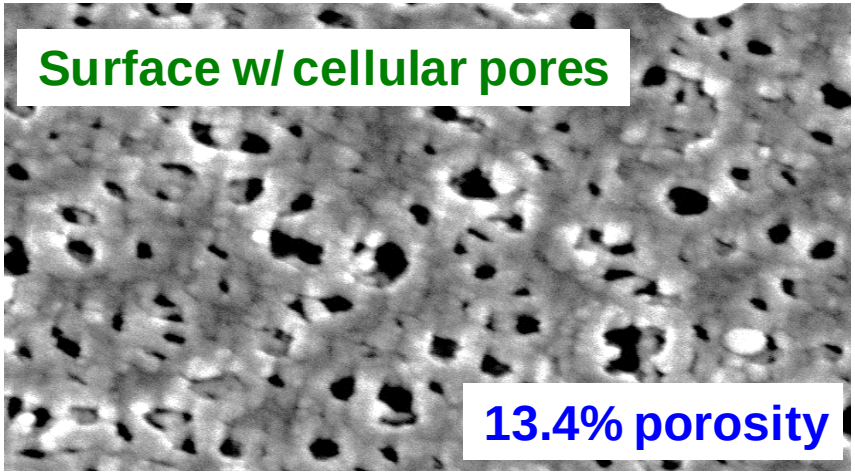
Improved vs. Benchmark Supports

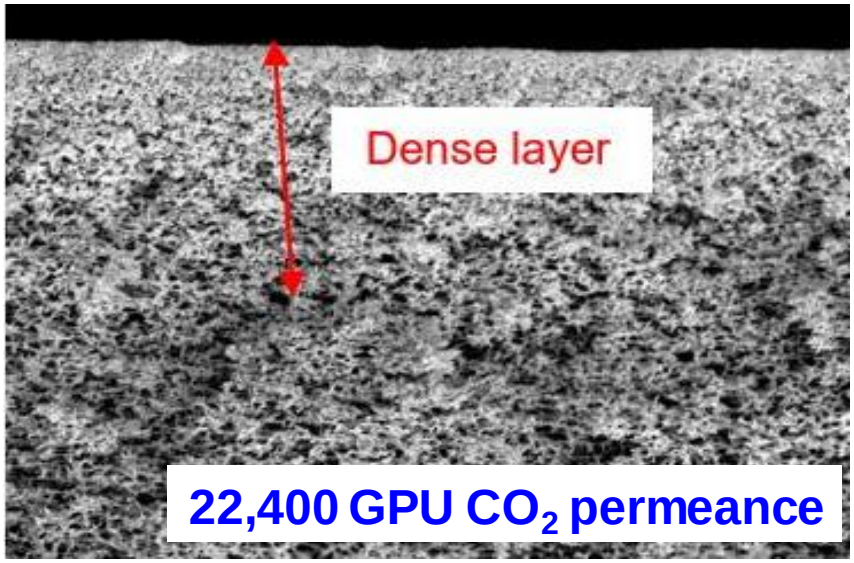
Improved



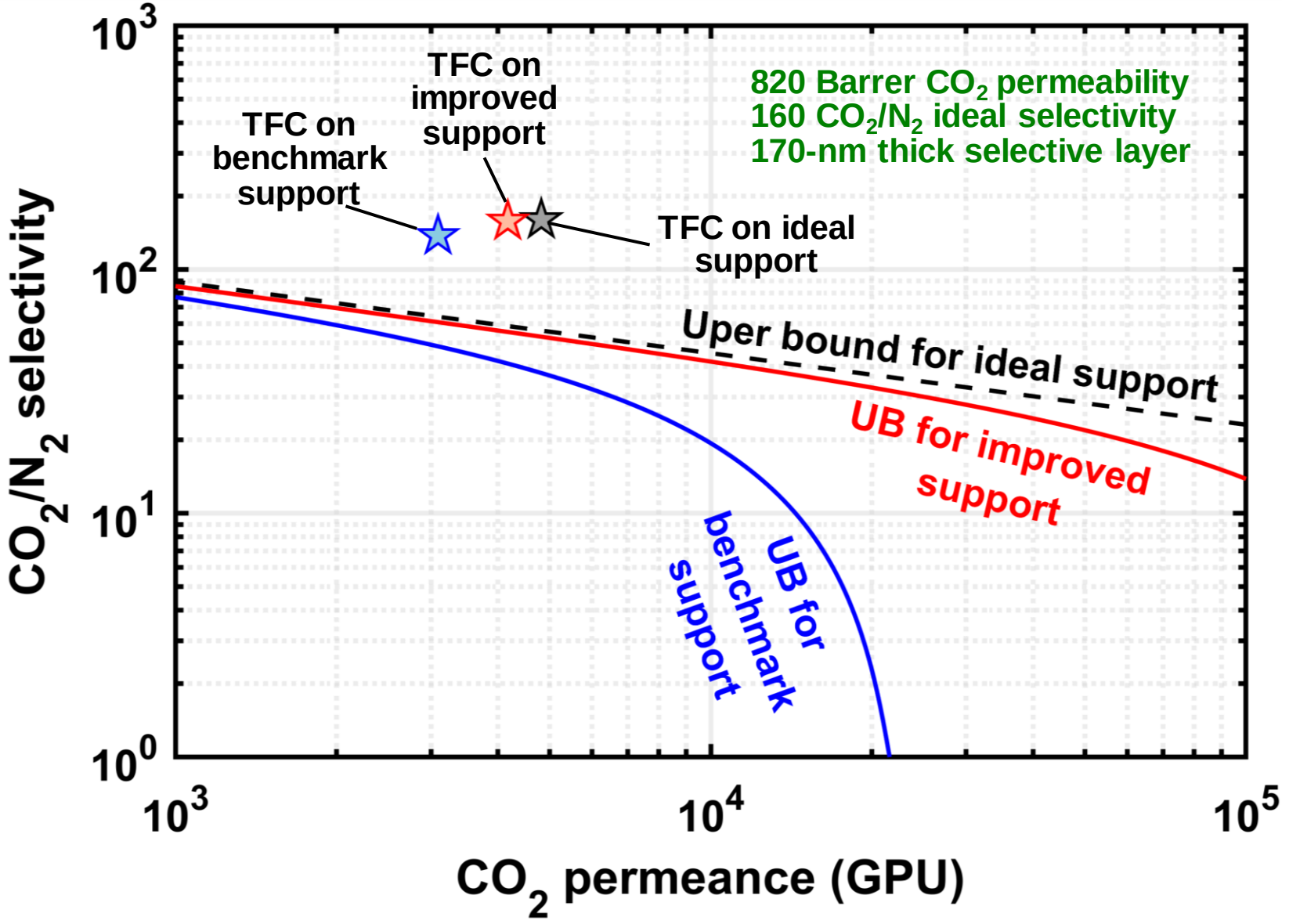


Benchmark

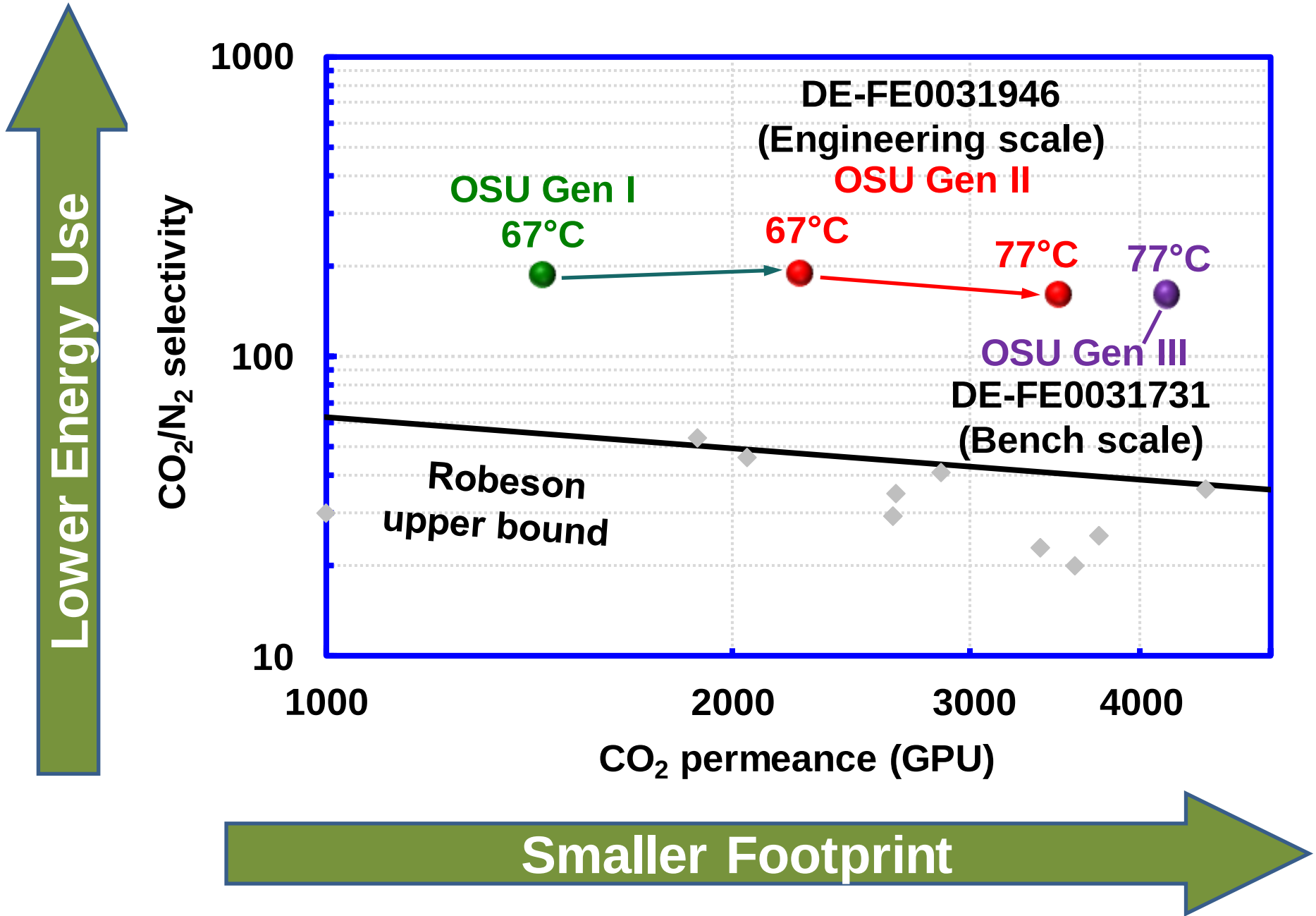




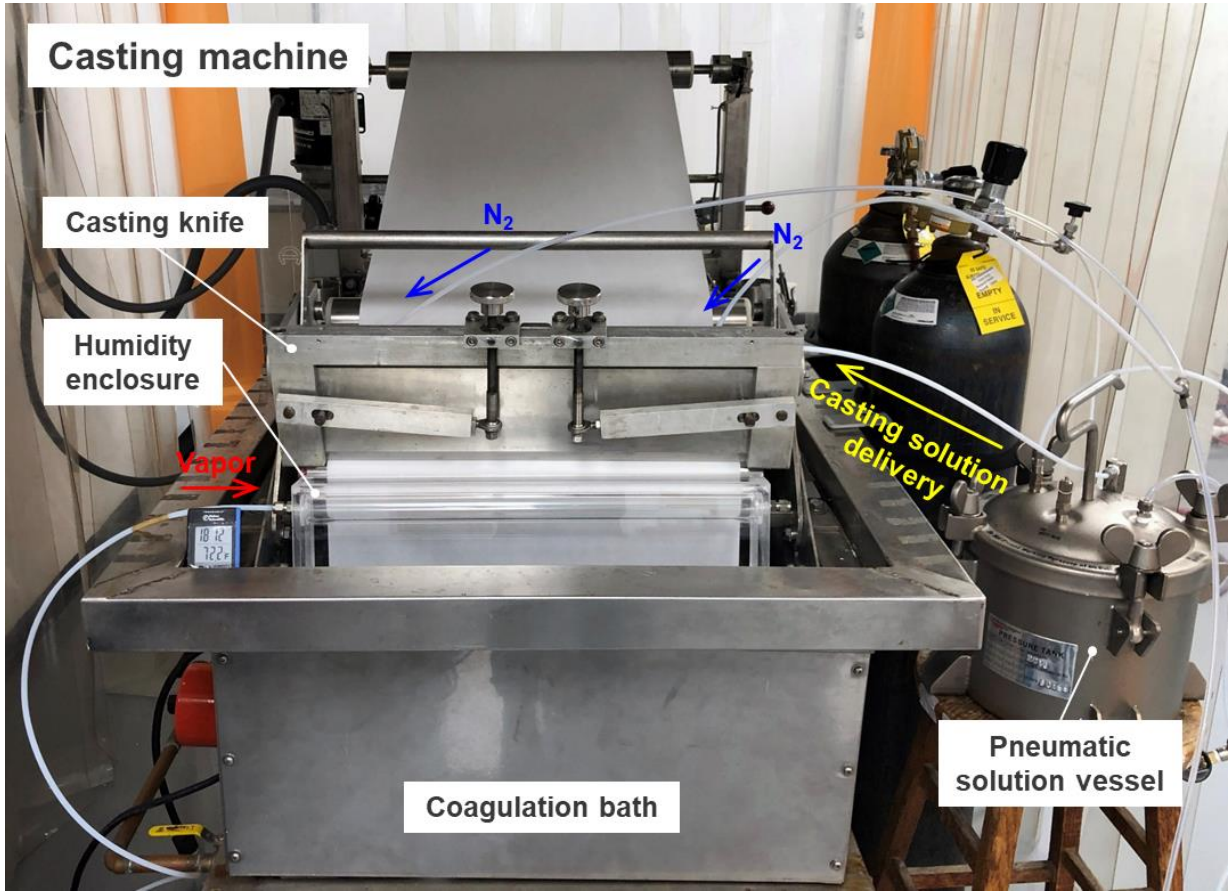
Better TFC Membranes by Improved Polymer Supports



Developed Membrane Outperforms Others

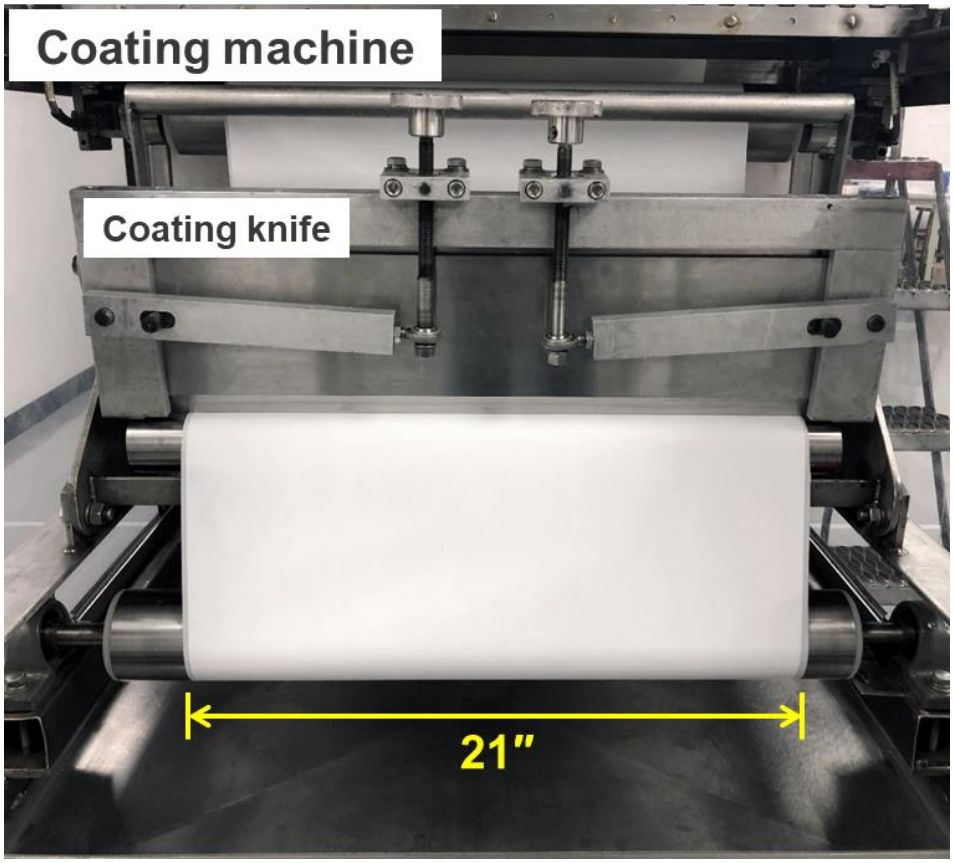


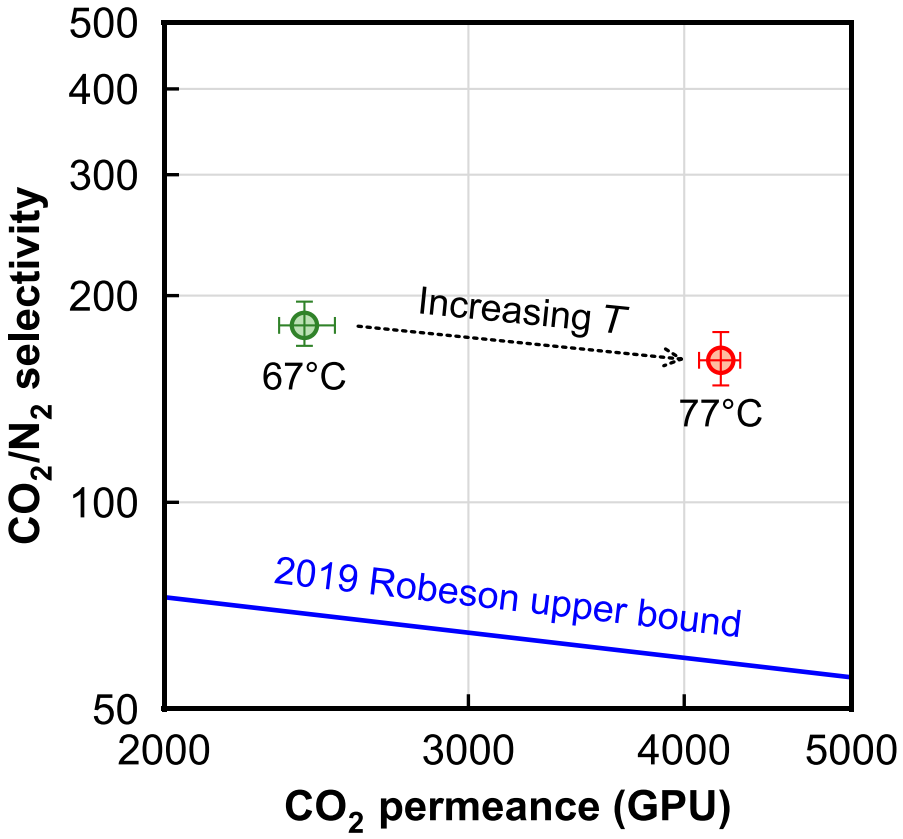
21″-Wide Continuous Roll-to-Roll Support Casting Demonstrated



- Vapor-induced phase separation process demonstrated
- 1,300 ft in length per casting run

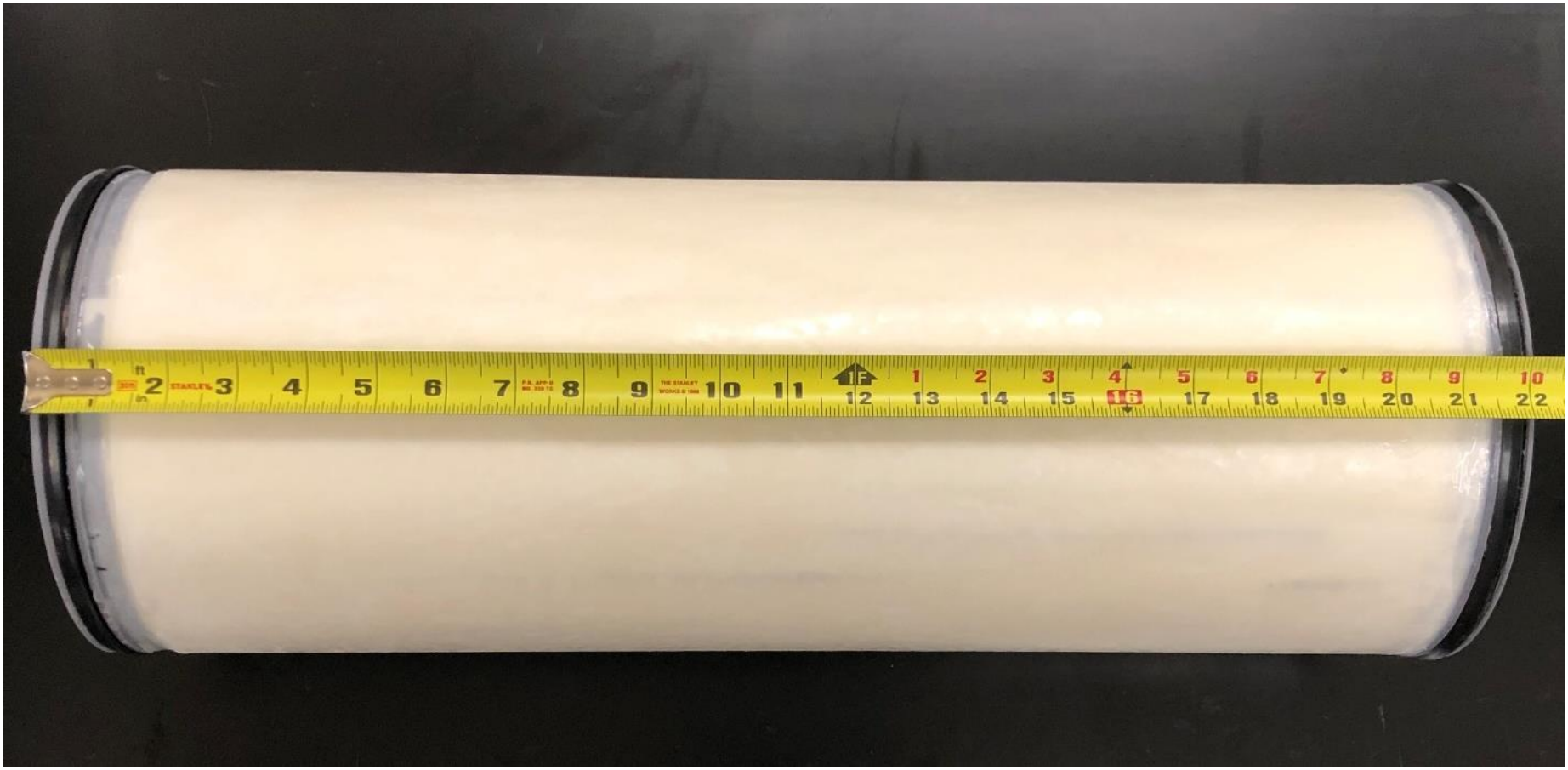
Prototype Gen III Membrane Fabricated by Roll-to-Roll Coating





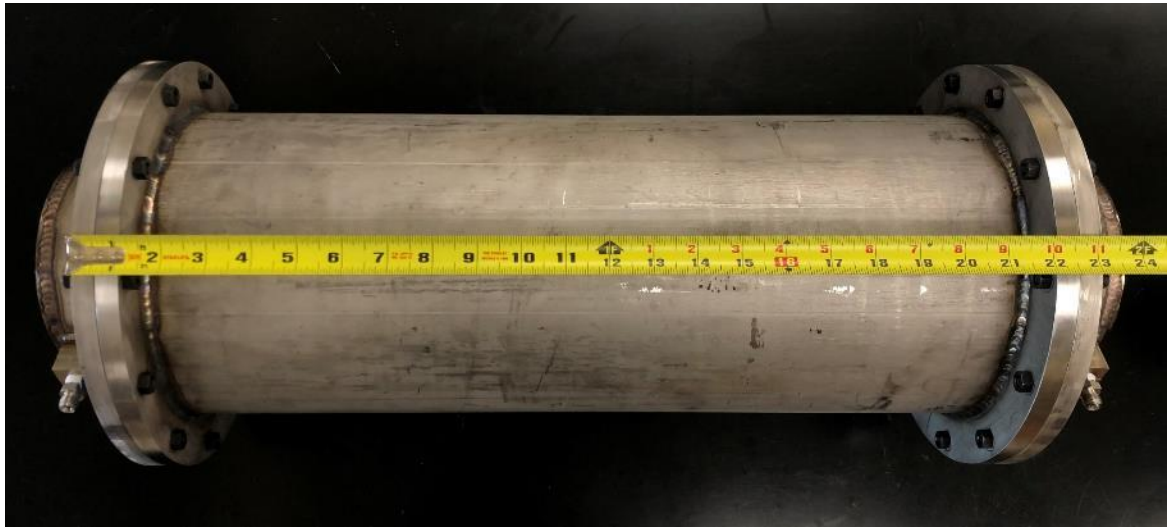
- **Thin selective layer coated on fabricated polymer support**
- **~4,200 GPU and CO_2/N_2 selectivity of ~160 at 77°C**

Prototype Spiral-Wound (SW) Membrane Element Fabricated



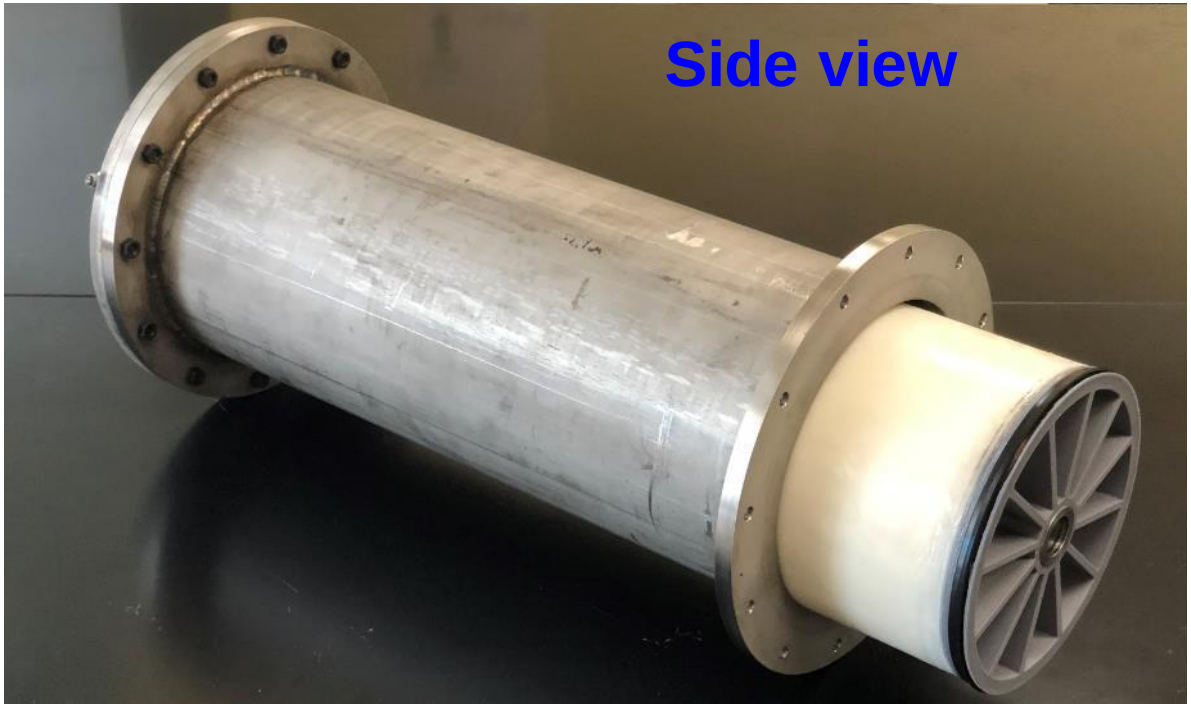
- 8″-diameter SW element fabricated using scale-up membrane
- Element contained 41 membrane leaves for 35 m^2 area

SW Membrane Element in Housing



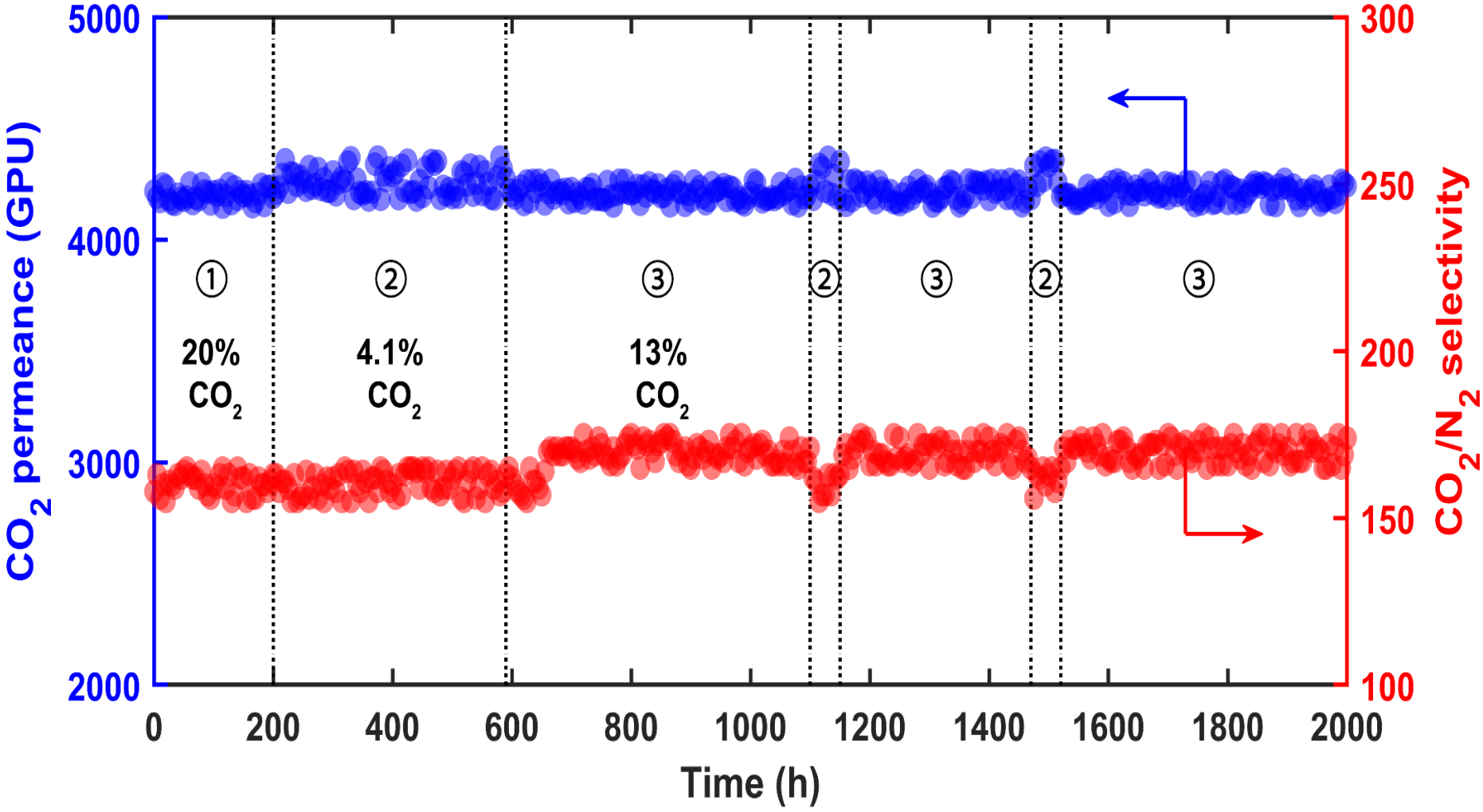
End view

Side view



- ⌀8″ SW element fitted tightly into SS module housing

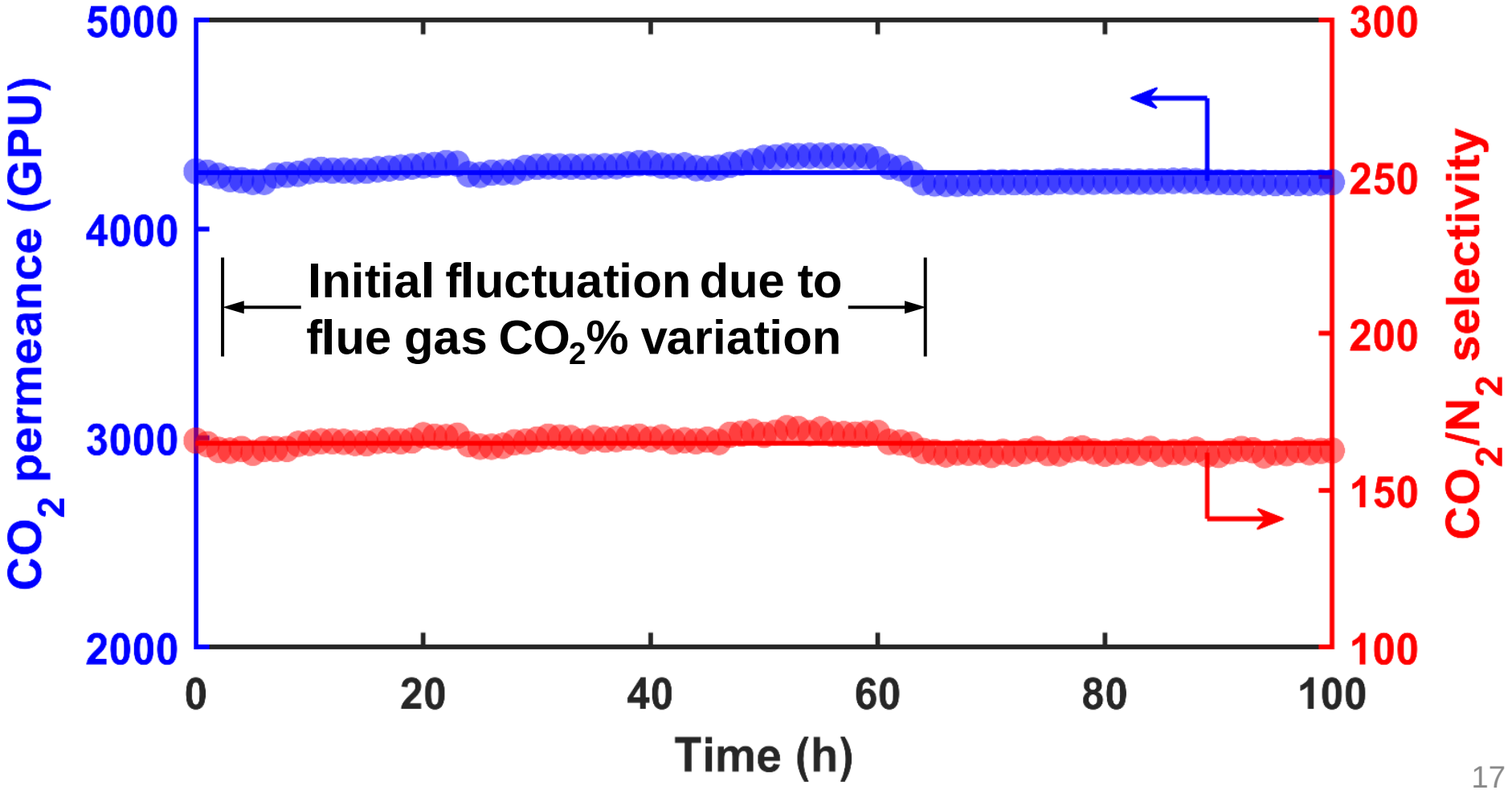
Module Tests with Simulated Flue Gases



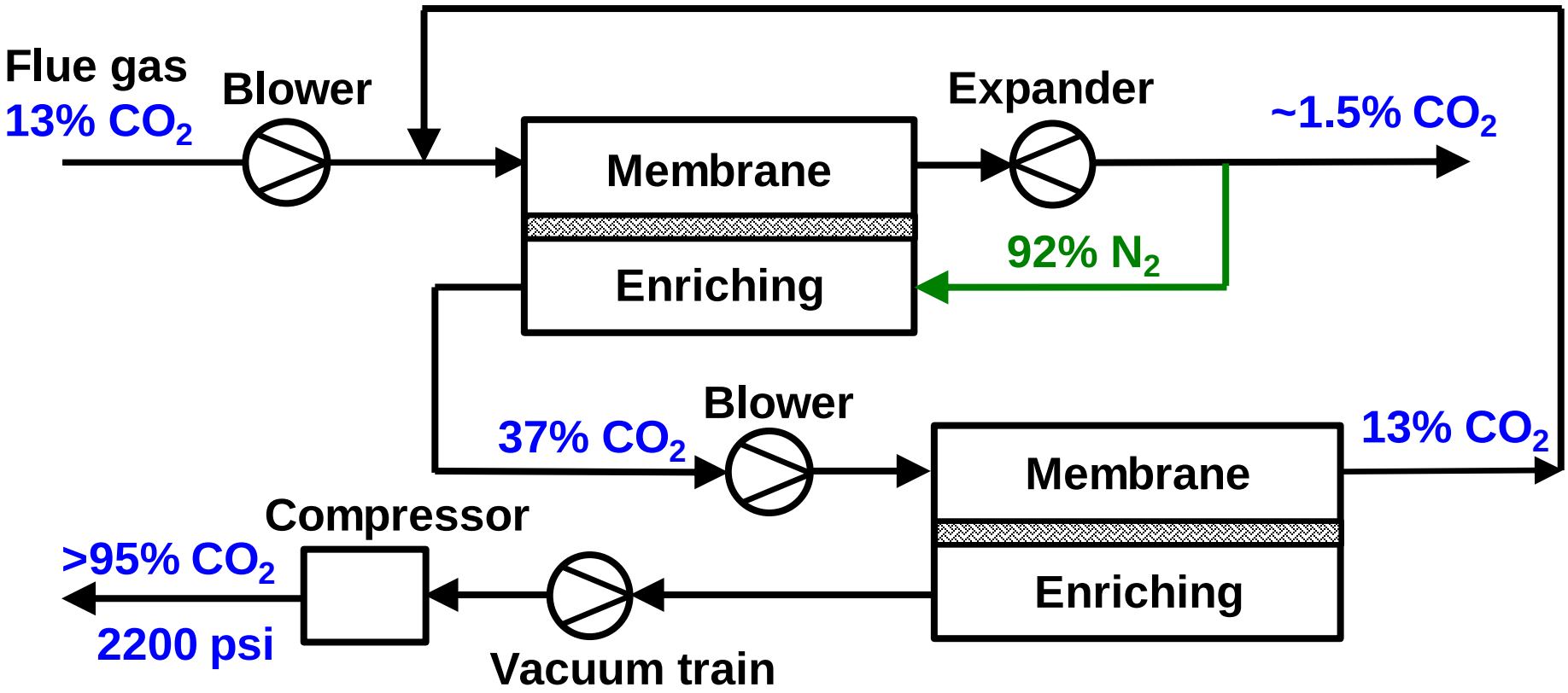
① = Simulated flue gas (20% CO_2);
② = Simulated NGCC flue gas (4.1% CO_2);
③ = Simulated coal flue gas (13% CO_2)

Good Module Stability Demo with Ohio Coal Flue Gas at U. of Kentucky

Sponsored by Ohio Dept. of Development in a Separate Project

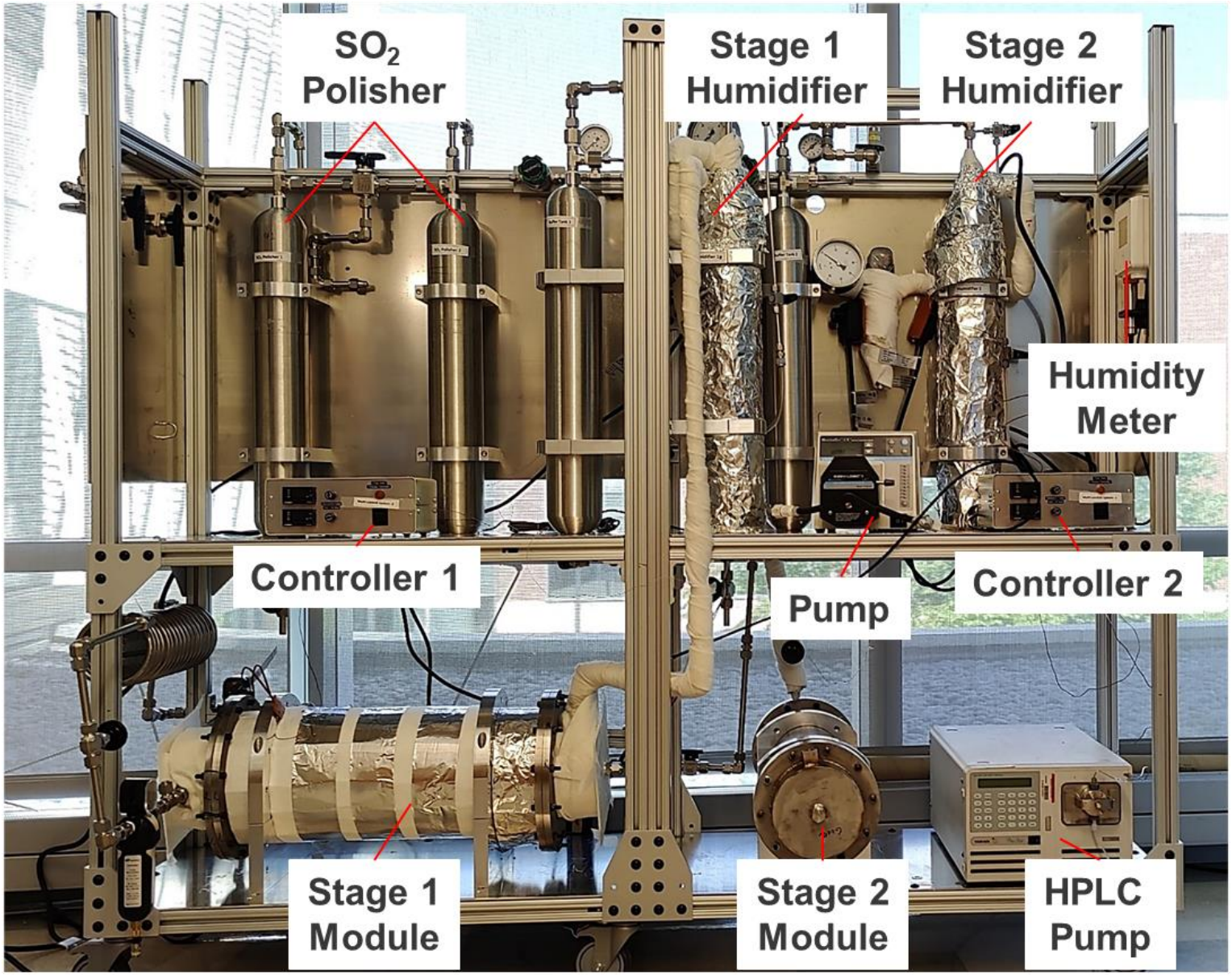


The Proposed Process for 90% Capture



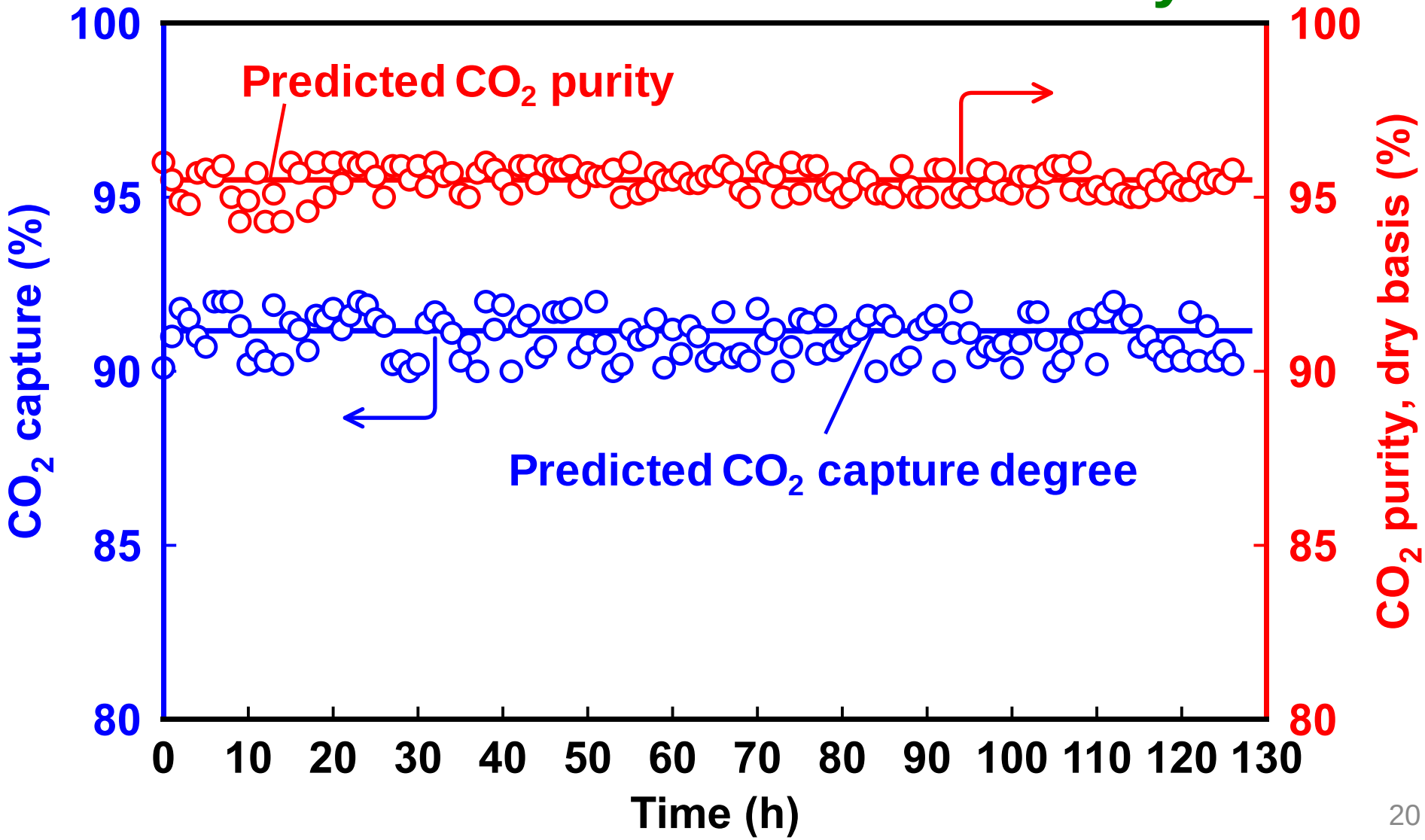
- Partial retentate recycle enables efficient separation
- Proposed membrane process does not require flue gas cooling and cryogenic distillation

Integrated Bench Skid Constructed



90+% CO_2 Capture and 95+% Purity Demonstrated with Simulated Flue Gas

Bench Skid with 1.33 tonne/day



Summary/Outlook

- **Achieved milestones/success criteria**
  - Support CO_2 permeance = 23,000–3,0000 GPU (~316,000)
  - Membrane CO_2 permeance = 3,800–4,000 GPU (~4,200)
  - CO_2/N_2 selectivity = 140–200 (~160)
  - Scale-up membranes fabricated (21″ wide)
  - Prototype SW modules fabricated (Ø8″ x 22″ & 35 m^2)
  - Integrated skid constructed (90% capture & 95% purity)

- **Remaining tasks**
  - Thorough skid testing with simulated flue gas at OSU
  - 500-h skid stability with actual flue gas at NCCC
  - Final TEA by GTI
  - Environmental Health and Safety (EH&S) assessment

Acknowledgments

- **Krista Hill, Andy Aurelio, and José Figueroa, DOE/NETL**
  - **Great efforts and strong inputs**
- **Kunlei Liu & his Team, U. of Kentucky**
  - **Model testing using Ohio coal**

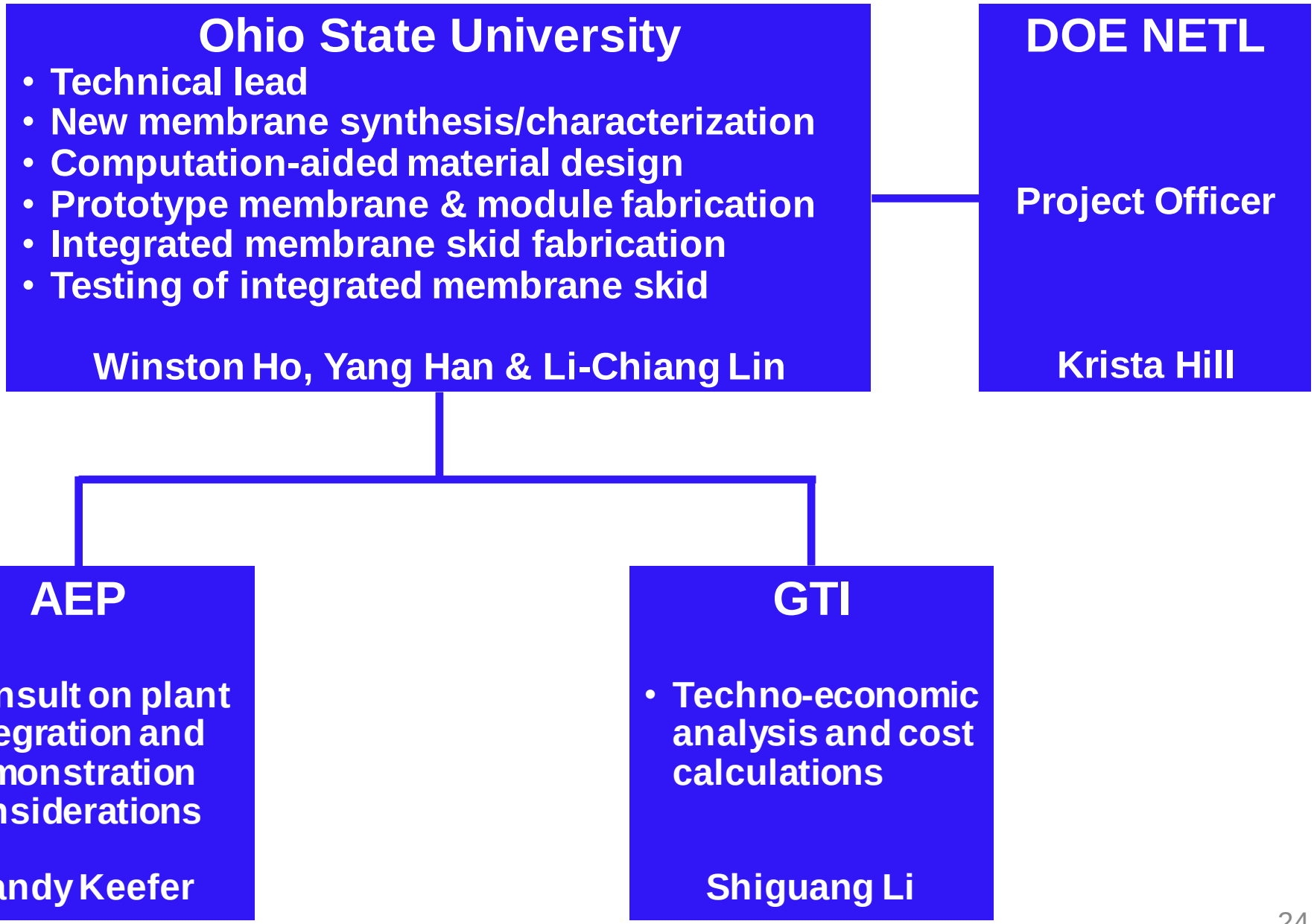
Financial Support

DOE/NETL: DE-FE0031731

Appendix

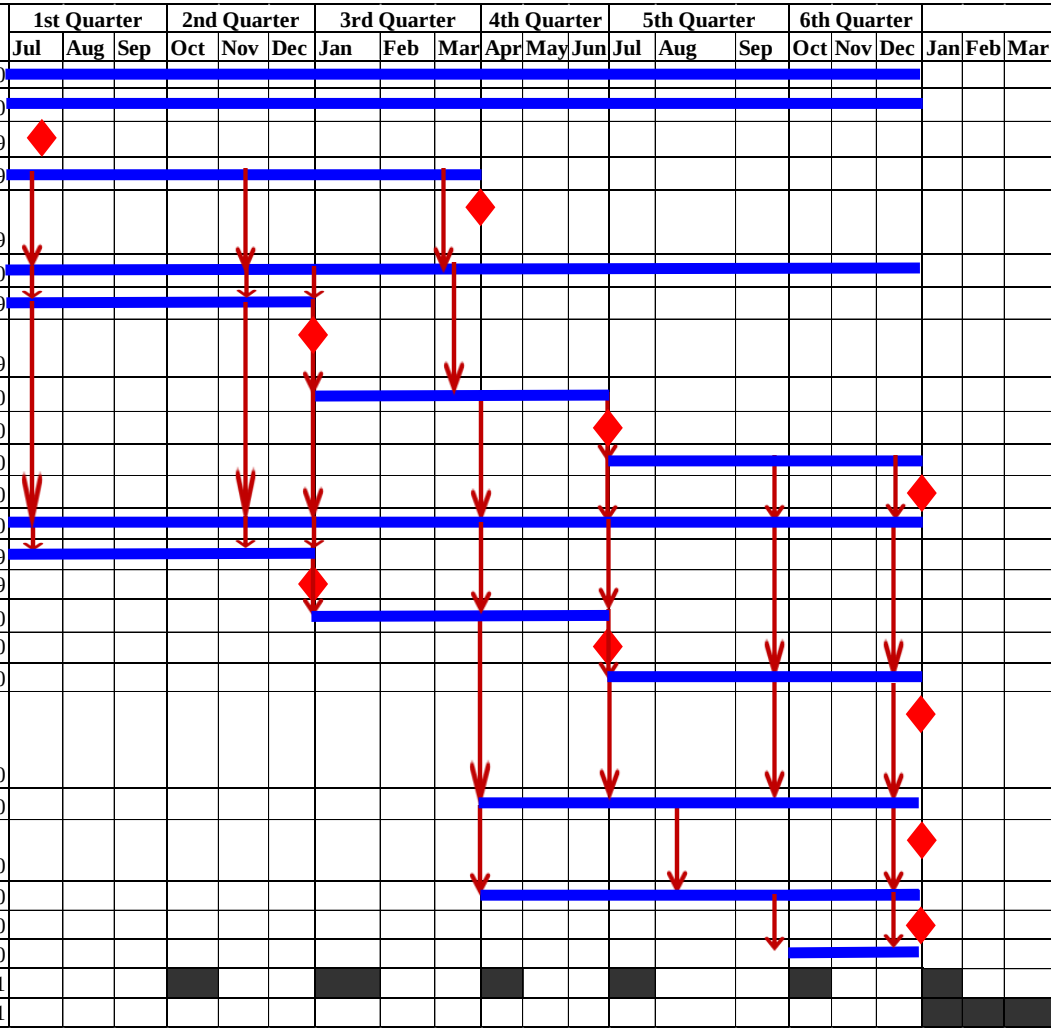
- **Project Organization**
- **Gantt Chart**

Project Organization and Roles

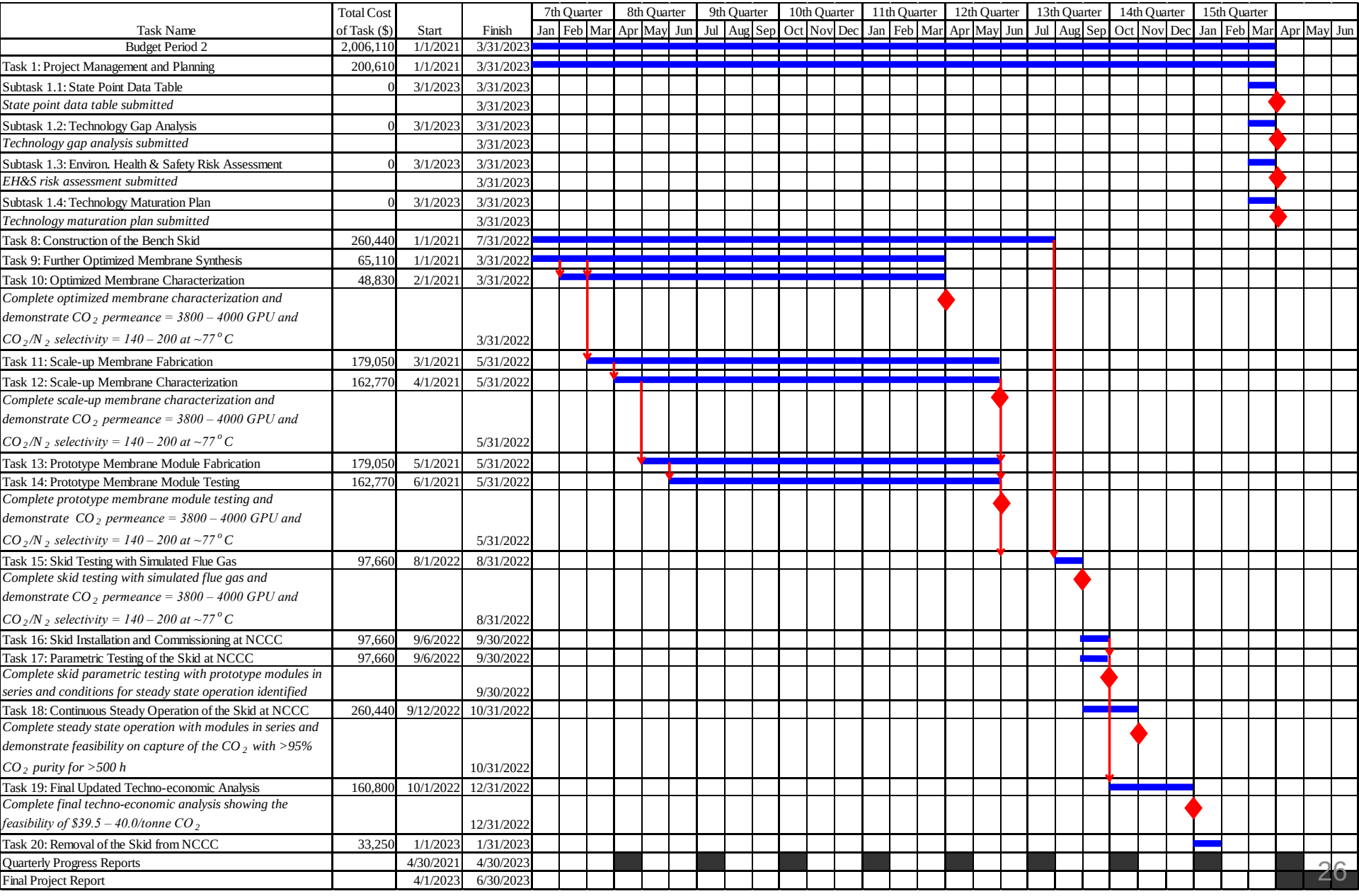


Gantt Chart

Task Name	Total Cost of Task ($)	Start	Finish
Budget Period 1	1,743,878	7/1/2019	12/31/2020
Task 1: Project Management and Planning	174,388	7/1/2019	12/31/2020
Updated PMP submitted			7/30/2019
Task 2: Synthesis of Improved Polymer Support	227,610	7/1/2019	3/31/2019
Complete polymer support synthesis and demonstrate CO_2 permeance of the support = 23000 – 30000 GPU at ~77°C			3/31/2019
Task 3: Optimized Synthesis of Transformational Membrane	455,222	7/1/2019	12/31/2020
Subtask 3.1: Investigation of CO_2 Carrier Structures	151,742	7/1/2019	12/31/2019
Complete density functional theory calculations to identify the structures for synthesis			12/31/2019
Subtask 3.2: Incorporation of Nano-fillers	151,740	1/1/2020	6/30/2020
Nano-fillers incorporated in the membrane			6/30/2020
Subtask 3.3: Synthesis of Higher MW Polyamine	151,740	7/1/2020	12/31/2020
Complete synthesis of 3 – 5 million MW polyamine			12/31/2020
Task 4: Membrane Characterization	455,222	7/1/2019	12/31/2020
Subtask 4.1: Morphology of Membranes	151,742	7/1/2019	12/31/2019
Obtain SEMs showing membrane morphologies			12/31/2019
Subtask 4.2: Transport Properties	151,740	1/1/2020	6/30/2020
Determine CO_2 permeance and CO_2/N_2 selectivity			6/30/2020
Subtask 4.3: Membrane Stability	151,740	7/1/2020	12/31/2020
Complete membrane stability testing and demonstrate CO_2 permeance = 3000 – 3800 GPU and CO_2/N_2 selectivity = 80 – 140 at ~77°C			12/31/2020
Task 5: Preliminary Techno-economic Analysis	158,886	4/1/2020	12/31/2020
Complete preliminary techno-economic analysis showing the feasibility of $40.0 – 41.5/tonne CO_2 for 90% recovery			12/31/2020
Task 6: Design of an Integrated Skid	227,610	4/1/2020	12/31/2020
Complete the design of the integrated skid			12/31/2020
Task 7: NCCC Site Preparation	44,940	10/1/2020	12/31/2020
Quarterly Progress Reports		10/1/2019	1/30/2021
Budget Period 1 Annual Report		1/1/2021	3/30/2021



Gantt Chart



Task Name	Total Cost of Task ($)	Start	Finish
Budget Period 2	2,006,110	1/1/2021	3/31/2023
Task 1: Project Management and Planning	200,610	1/1/2021	3/31/2023
Subtask 1.1: State Point Data Table	0	3/1/2023	3/31/2023
State point data table submitted			3/31/2023
Subtask 1.2: Technology Gap Analysis	0	3/1/2023	3/31/2023
Technology gap analysis submitted			3/31/2023
Subtask 1.3: Environ. Health & Safety Risk Assessment	0	3/1/2023	3/31/2023
EH&S risk assessment submitted			3/31/2023
Subtask 1.4: Technology Maturation Plan	0	3/1/2023	3/31/2023
Technology maturation plan submitted			3/31/2023
Task 8: Construction of the Bench Skid	260,440	1/1/2021	7/31/2022
Task 9: Further Optimized Membrane Synthesis	65,110	1/1/2021	3/31/2022
Task 10: Optimized Membrane Characterization	48,830	2/1/2021	3/31/2022
Complete optimized membrane characterization and demonstrate CO_2 permeance = 3800 – 4000 GPU and CO_2/N_2 selectivity = 140 – 200 at ~77 °C			3/31/2022
Task 11: Scale-up Membrane Fabrication	179,050	3/1/2021	5/31/2022
Task 12: Scale-up Membrane Characterization	162,770	4/1/2021	5/31/2022
Complete scale-up membrane characterization and demonstrate CO_2 permeance = 3800 – 4000 GPU and CO_2/N_2 selectivity = 140 – 200 at ~77 °C			5/31/2022
Task 13: Prototype Membrane Module Fabrication	179,050	5/1/2021	5/31/2022
Task 14: Prototype Membrane Module Testing	162,770	6/1/2021	5/31/2022
Complete prototype membrane module testing and demonstrate CO_2 permeance = 3800 – 4000 GPU and CO_2/N_2 selectivity = 140 – 200 at ~77 °C			5/31/2022
Task 15: Skid Testing with Simulated Flue Gas	97,660	8/1/2022	8/31/2022
Complete skid testing with simulated flue gas and demonstrate CO_2 permeance = 3800 – 4000 GPU and CO_2/N_2 selectivity = 140 – 200 at ~77 °C			8/31/2022
Task 16: Skid Installation and Commissioning at NCCC	97,660	9/6/2022	9/30/2022
Task 17: Parametric Testing of the Skid at NCCC	97,660	9/6/2022	9/30/2022
Complete skid parametric testing with prototype modules in series and conditions for steady state operation identified			9/30/2022
Task 18: Continuous Steady Operation of the Skid at NCCC	260,440	9/12/2022	10/31/2022
Complete steady state operation with modules in series and demonstrate feasibility on capture of the CO_2 with >95% CO_2 purity for >500 h			10/31/2022
Task 19: Final Updated Techno-economic Analysis	160,800	10/1/2022	12/31/2022
Complete final techno-economic analysis showing the feasibility of $39.5 – 40.0/tonne CO_2			12/31/2022
Task 20: Removal of the Skid from NCCC	33,250	1/1/2023	1/31/2023
Quarterly Progress Reports		4/30/2021	4/30/2023
Final Project Report		4/1/2023	6/30/2023