Transformational Membranes for Pre-combustion Carbon Capture

DE-FE0031635

PI: Dr. Winston Ho
Co-PI: Dr. Yang Han
William G. Lowrie Department of Chemical & Biomolecular Engineering
Department of Materials Science and Engineering
The Ohio State University

Carbon Management and Natural Gas & Oil Research Project Review Meeting
NETL, Pittsburgh, PA, August 16, 2021

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 coal-derived syngas**
  - **95% CO_2 purity**
  - **>99% H_2 recovery**
  - **COE 30% less than Baseline approaches**

Funding and Performance Dates

- **Total Budget: 10/01/2018 – 09/30/2021**
  DOE: $799,988; OSU: $199,998 (20% cost share)

  - **BP1: 10/01/2018 – 03/31/2020**
    DOE: $386,694; OSU: $96,674

  - **BP2: 04/01/2020 – 09/30/2021**
    DOE: $413,294; OSU: $103,324

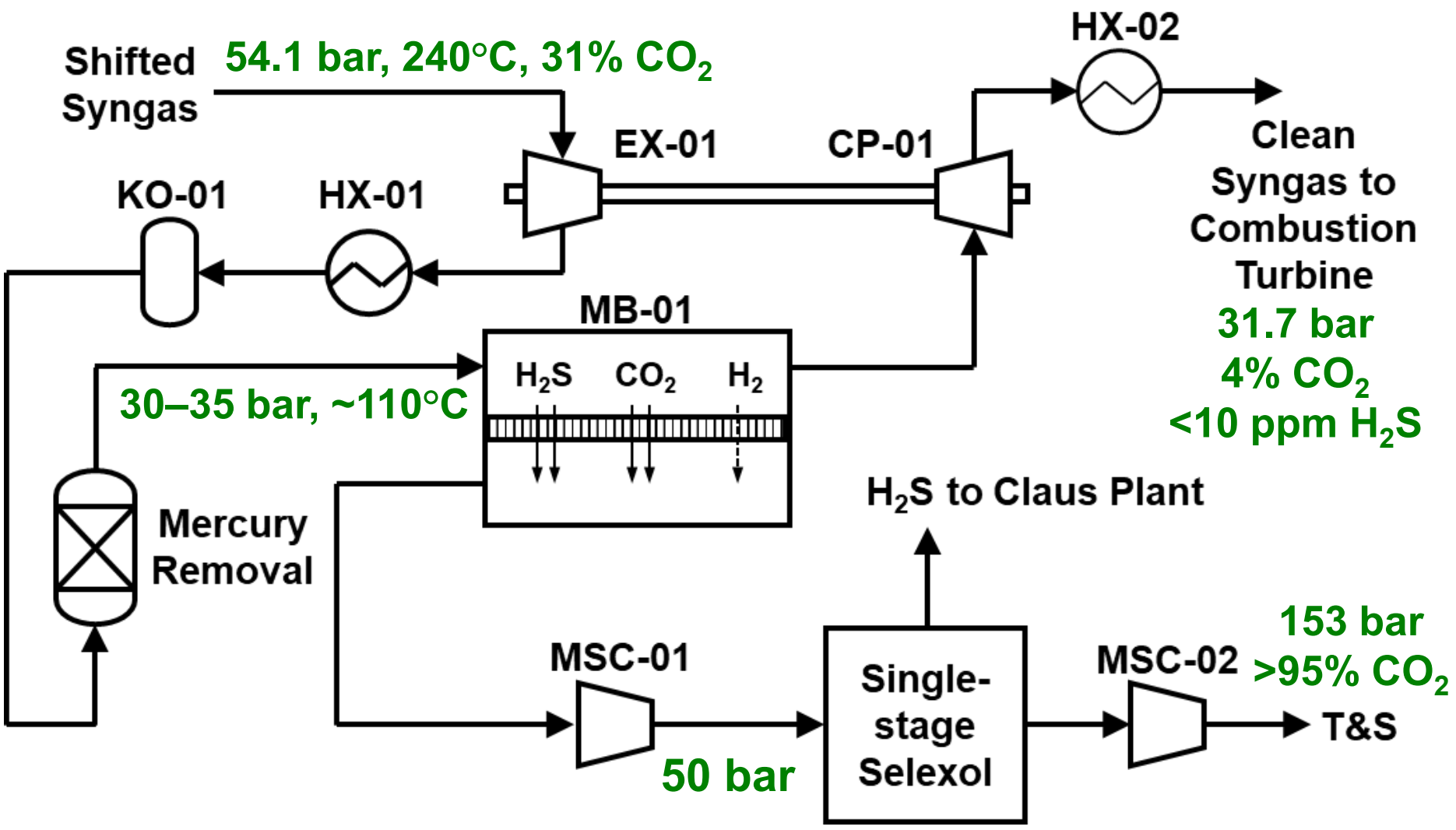
2-Budget Period Project

- **BP1: 10/01/2018 – 03/31/2020**
  - Laboratory-scale membrane synthesis, characterization and transport performance studies
  - High-level preliminary techno-economic analysis

- **BP2: 04/01/2020 – 09/30/2021**
  - Laboratory-scale membrane synthesis, characterization and transport performance studies to continue
  - Fabrication, characterization and transport performance studies of scale-up membrane (14″ wide by 20′ long)
  - Fabrication, performance and stability testing of spiral-wound membrane modules
  - Update techno-economic analysis performed in BP 1

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

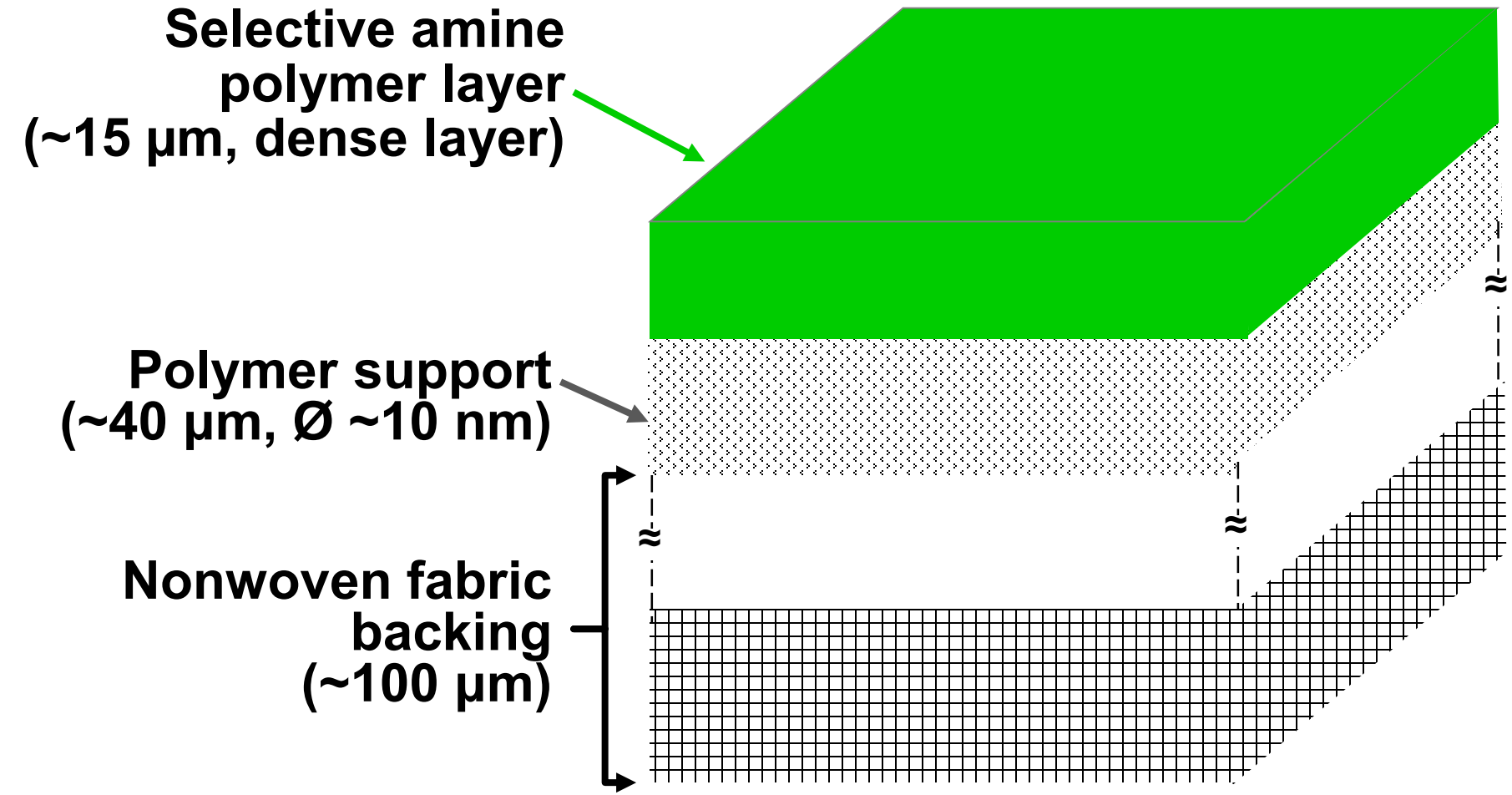
Technical Background: Proposed Process



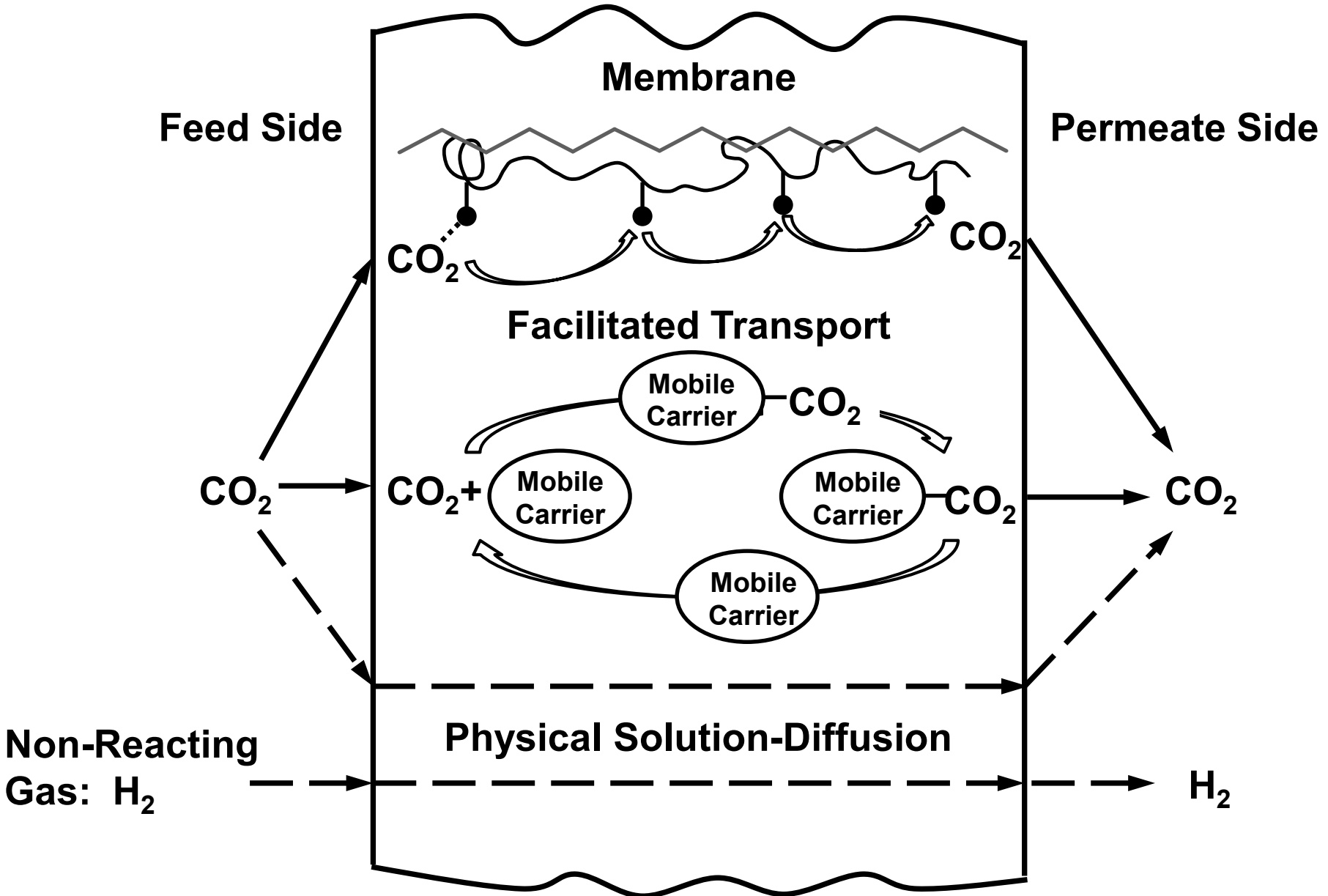
- **Proposed membrane process does not require significant syngas cooling (compared to competition)**

Selective Amine Polymer Layer / Polymer Support

Simplicity of Membrane for Low Cost



Amine Polymer Layer Contains Mobile and Fixed Carriers: Facilitated Transport



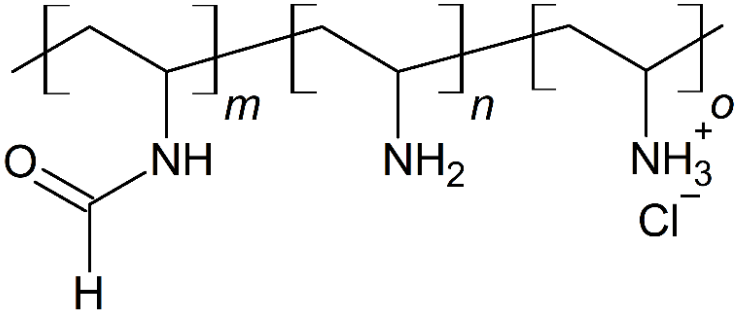
Facilitated Transport vs. Solution-Diffusion Mechanism

- **CO_2 Facilitated Transport Flux: Very High**
  - **CO_2-amine reaction enhances CO_2 flux**

- **H_2 Flux: Very Low**
  - **H_2 does not react with amine**
  - **H_2 transport follows conventional physical solution-diffusion mechanism, which is very slow**

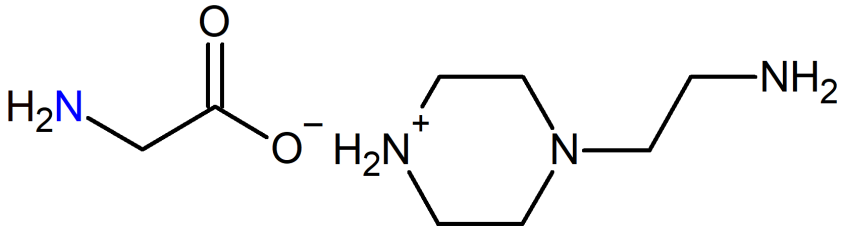
Amine-Containing Carriers

- **Fixed-Site Carrier**

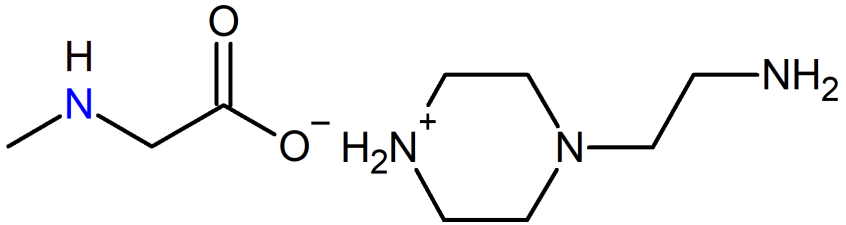


PNVF-*co*-VAm

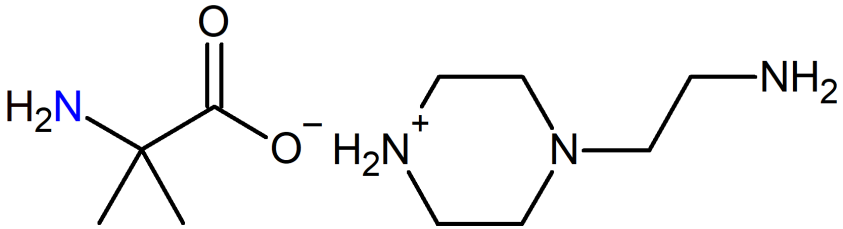
- **Mobile Carriers**



PZEA-Gly



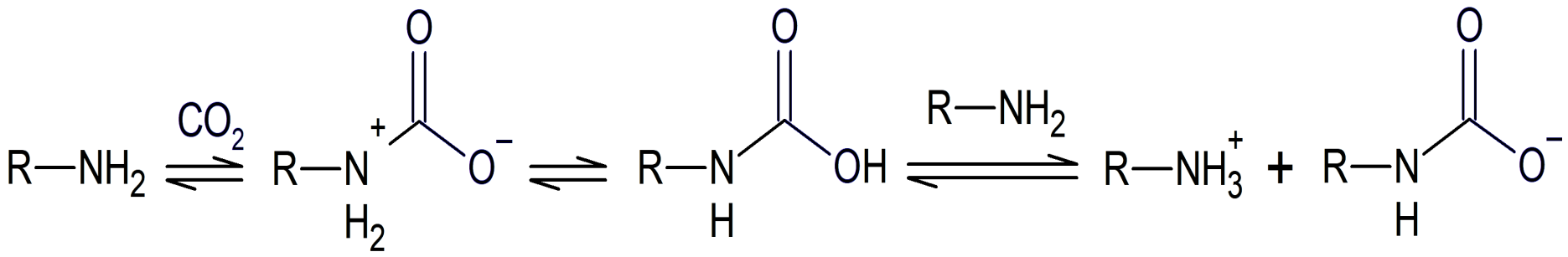
PZEA-Sar



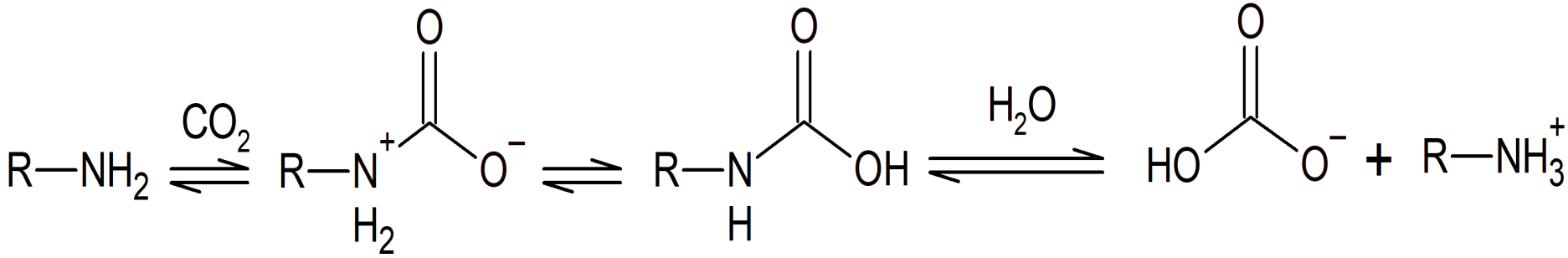
PZEA-AIBA

CO_2–Amine Chemistry

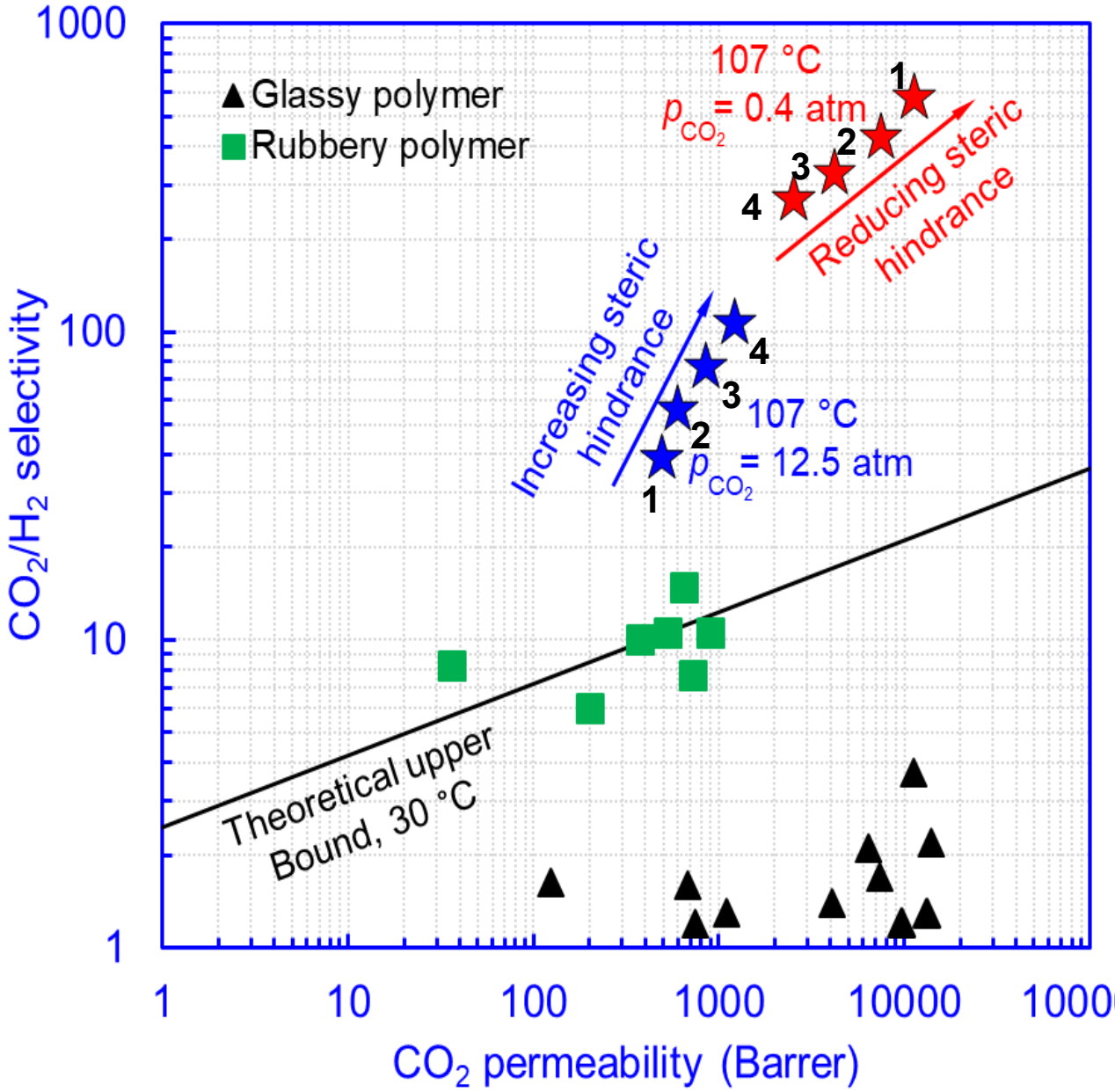
- **Unhindered Amine – Carbamate Pathway**

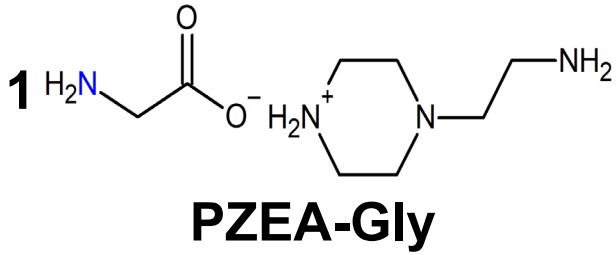


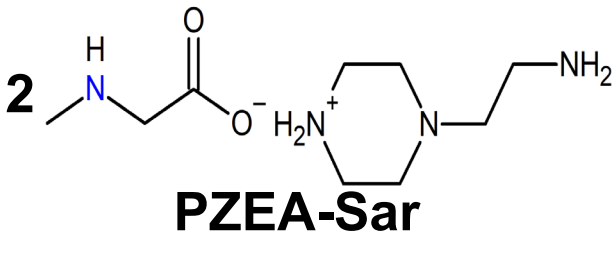
- **Hindered Amine – Bicarbonate Pathway**

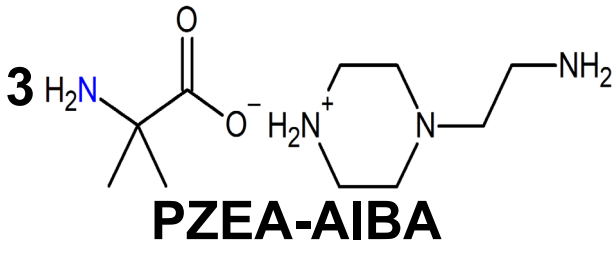


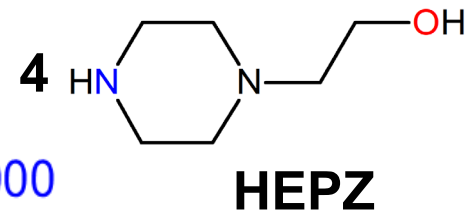
CO_2/H_2 Separation Properties





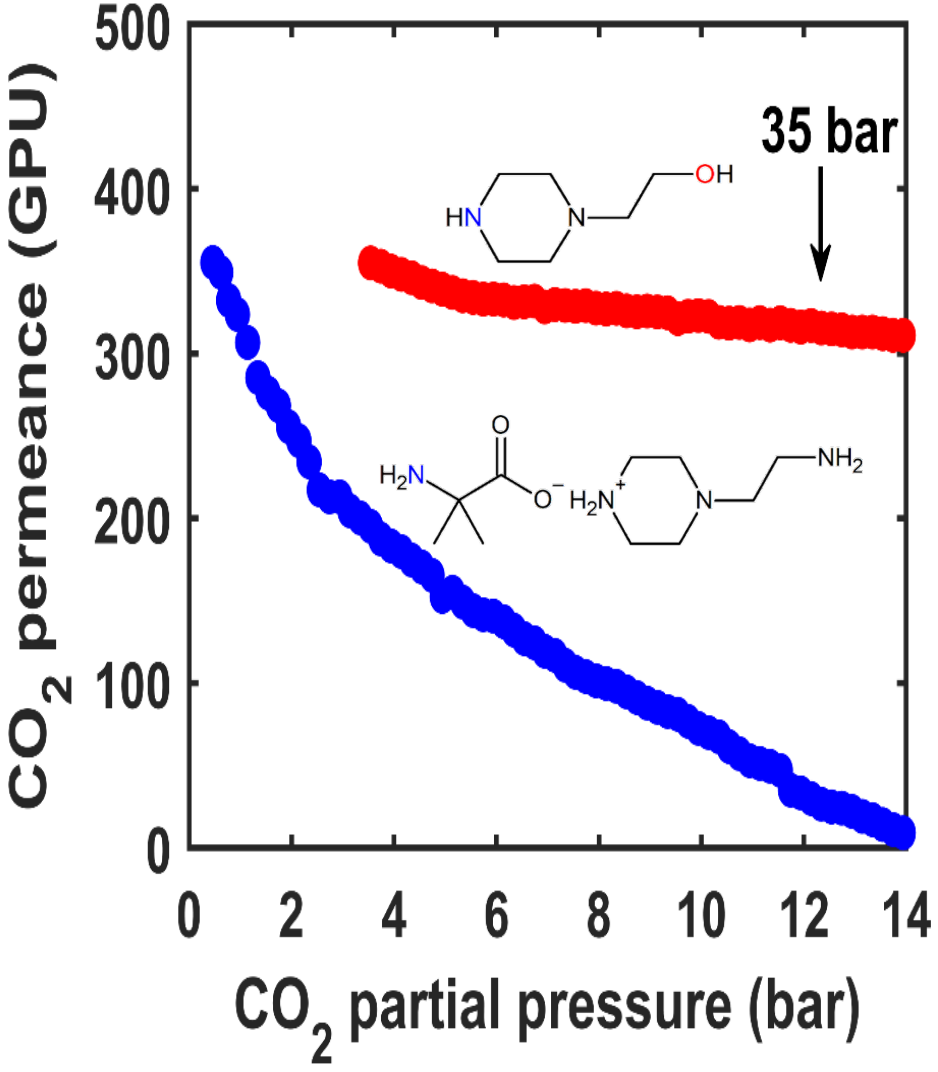


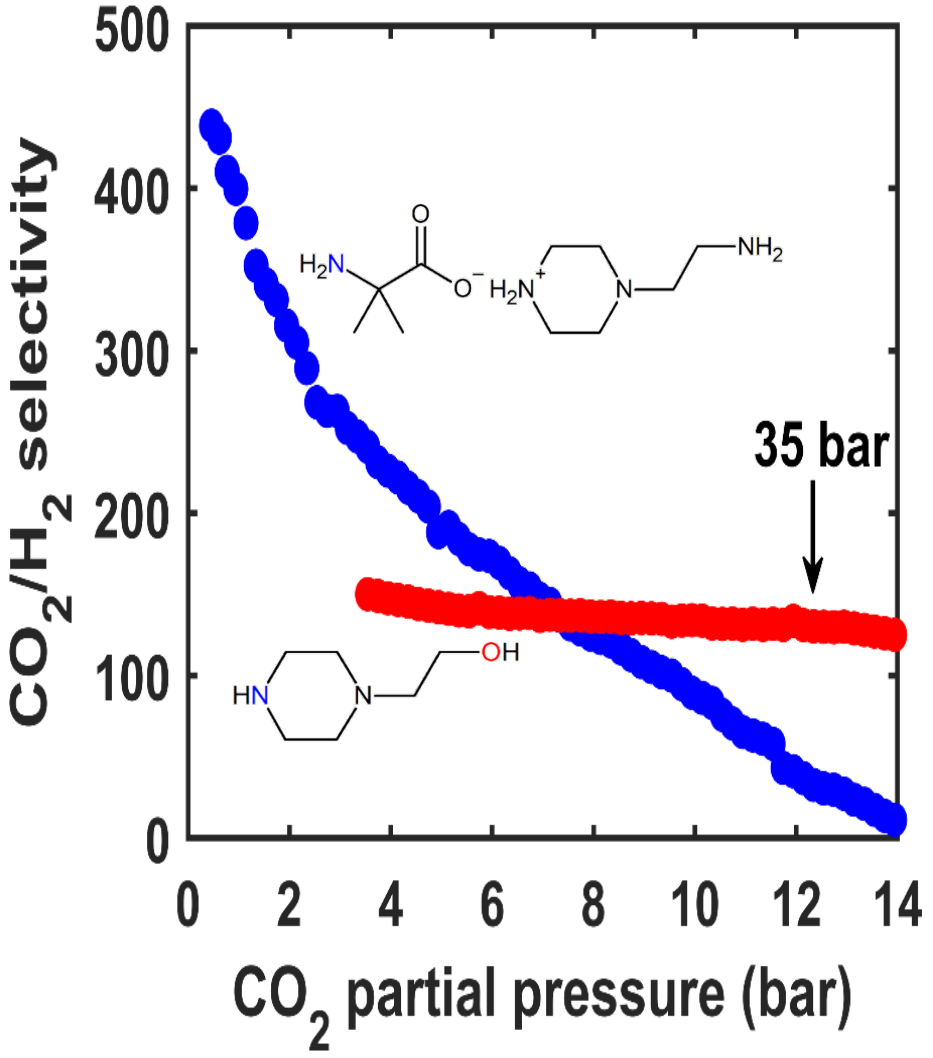




Membrane Performances

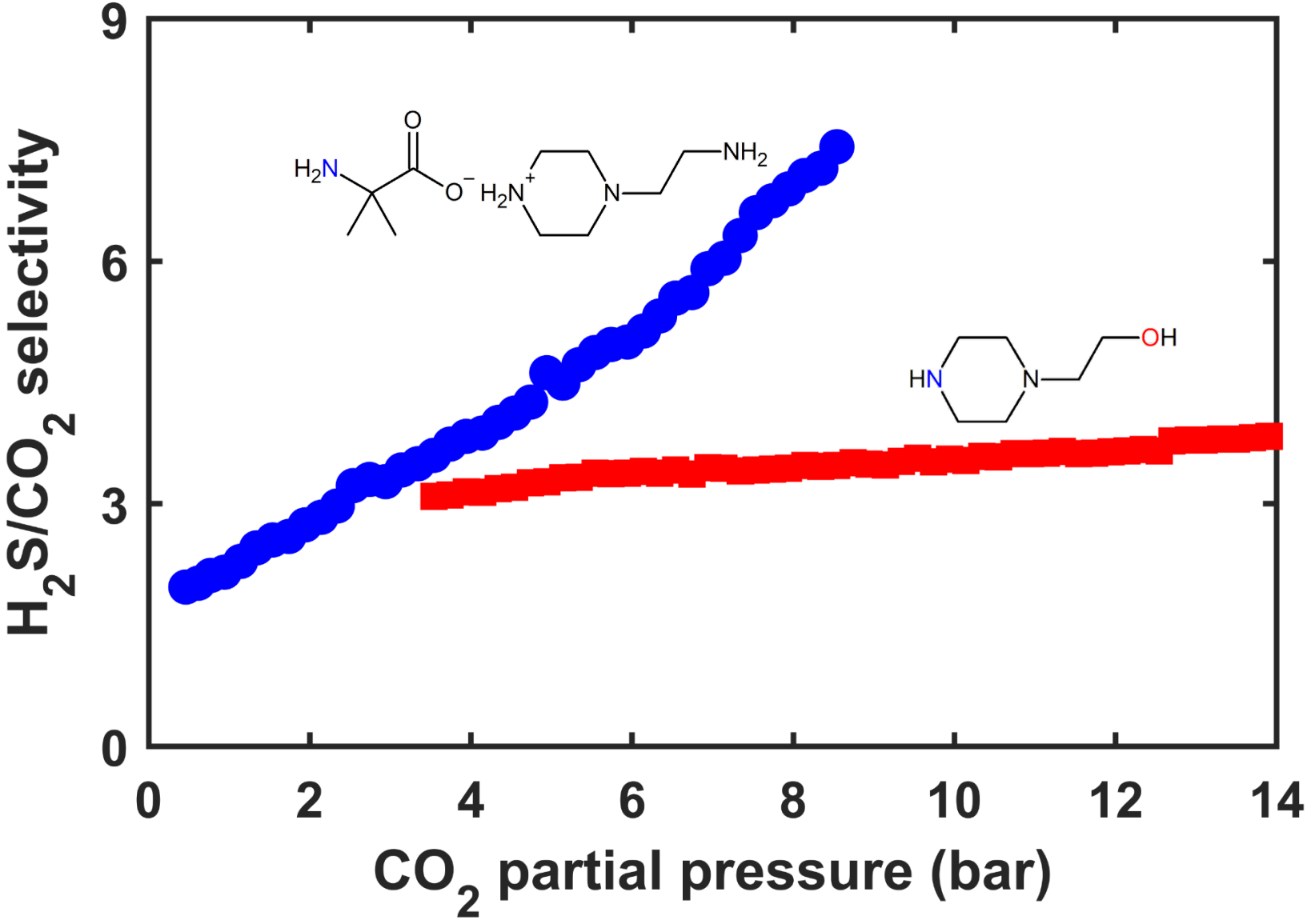
Simulated Syngas at 107°C and 35 bar



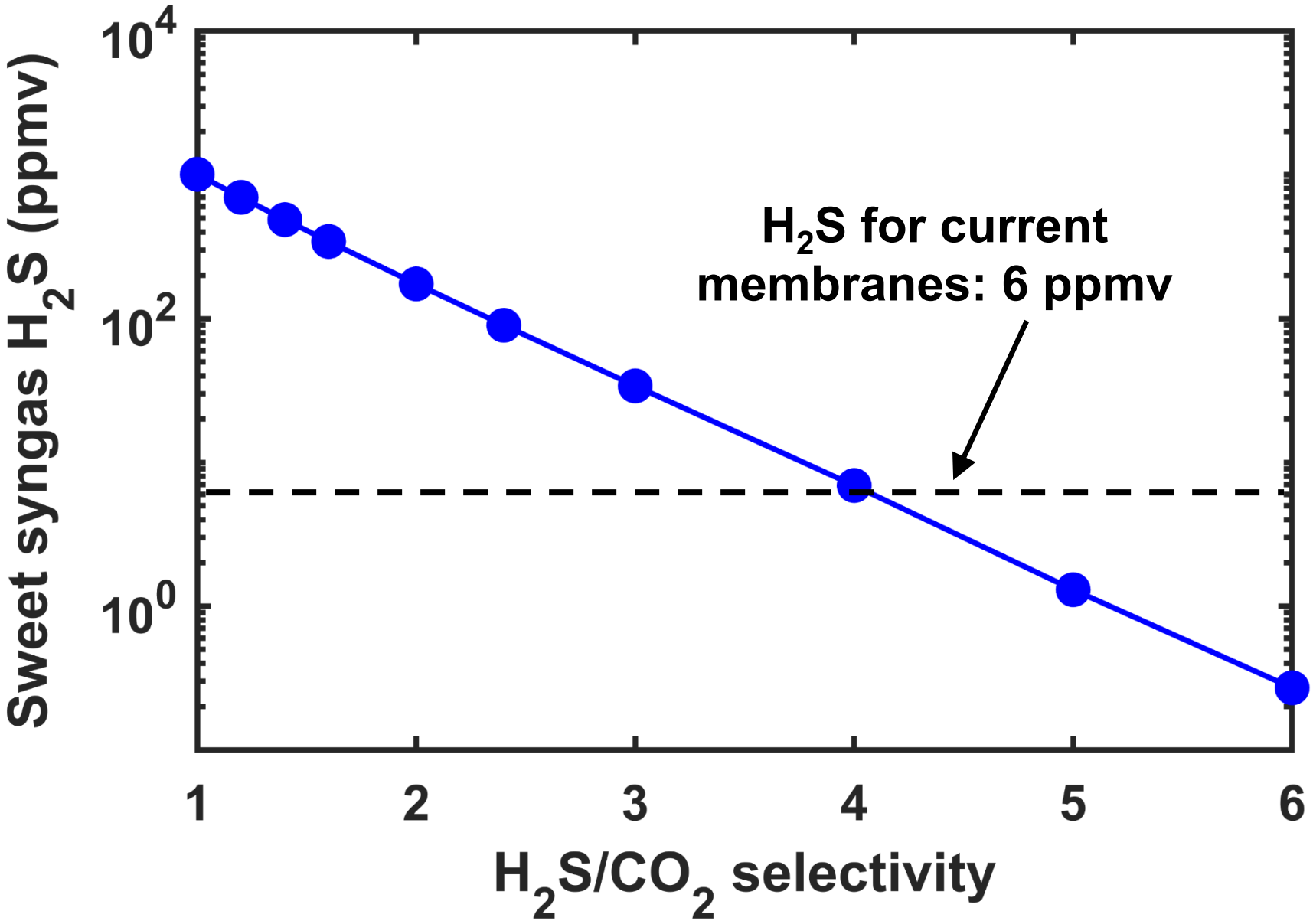


- **Hindered amine shows high selectivity at low p_{CO2}**

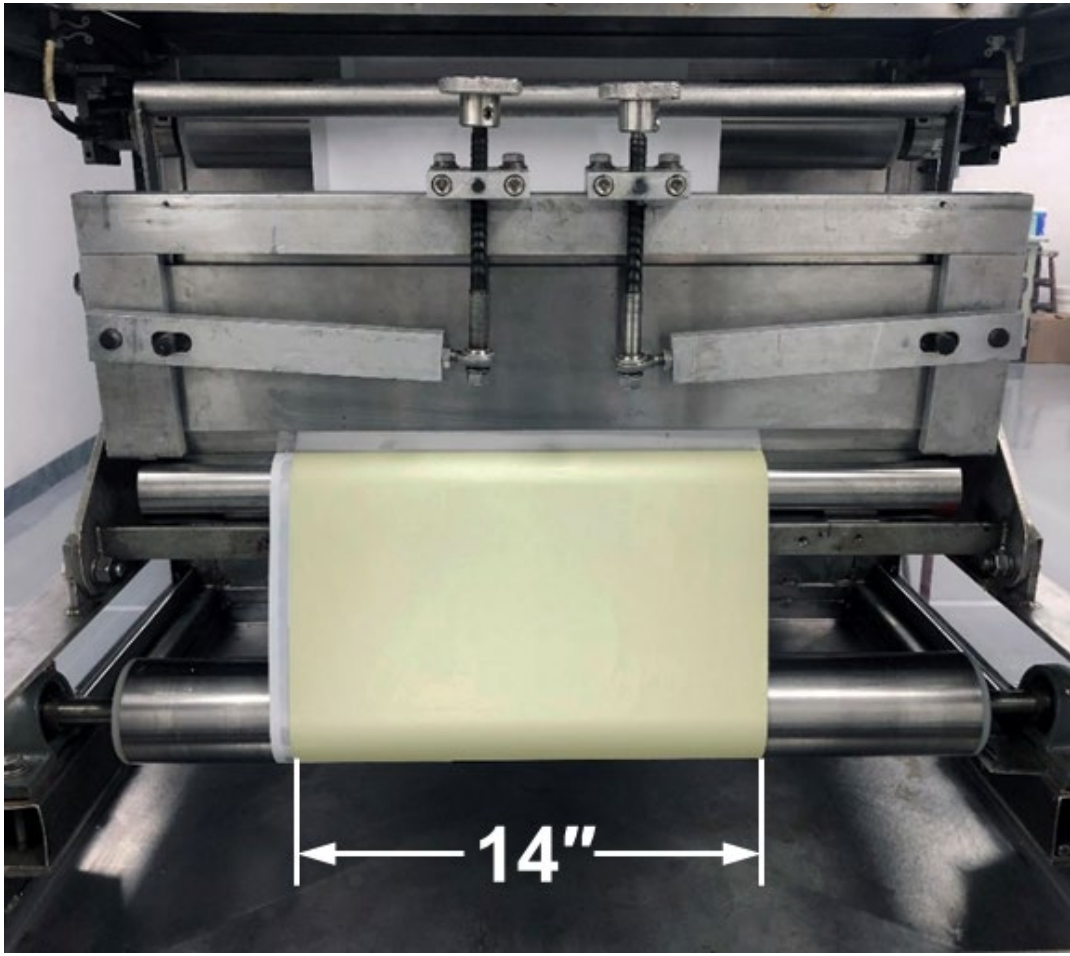
Membranes Synthesized with Tuned H_2S/CO_2 Selectivities



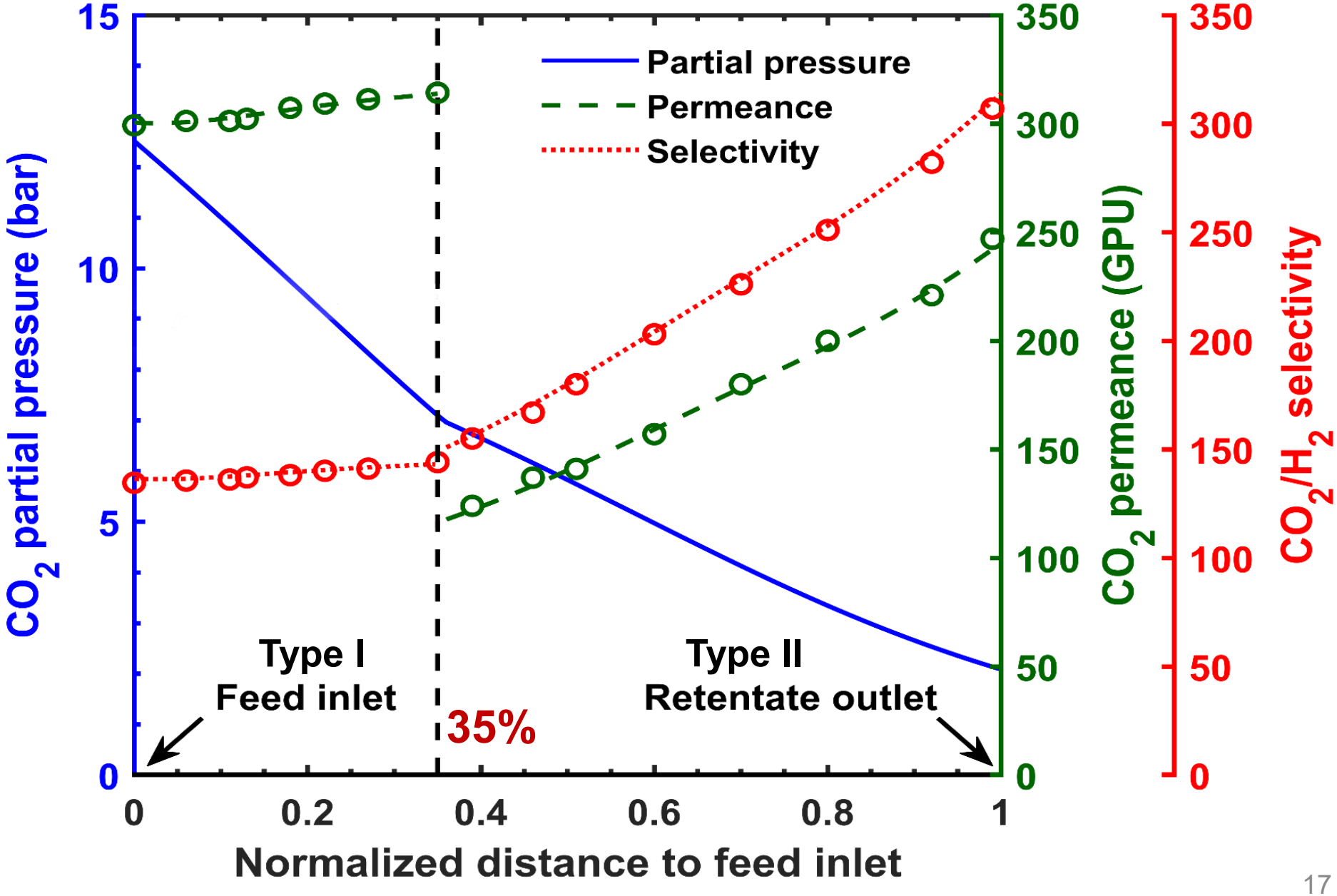
Effect of H_2S/CO_2 Selectivity on H_2S Concentration in Retentate



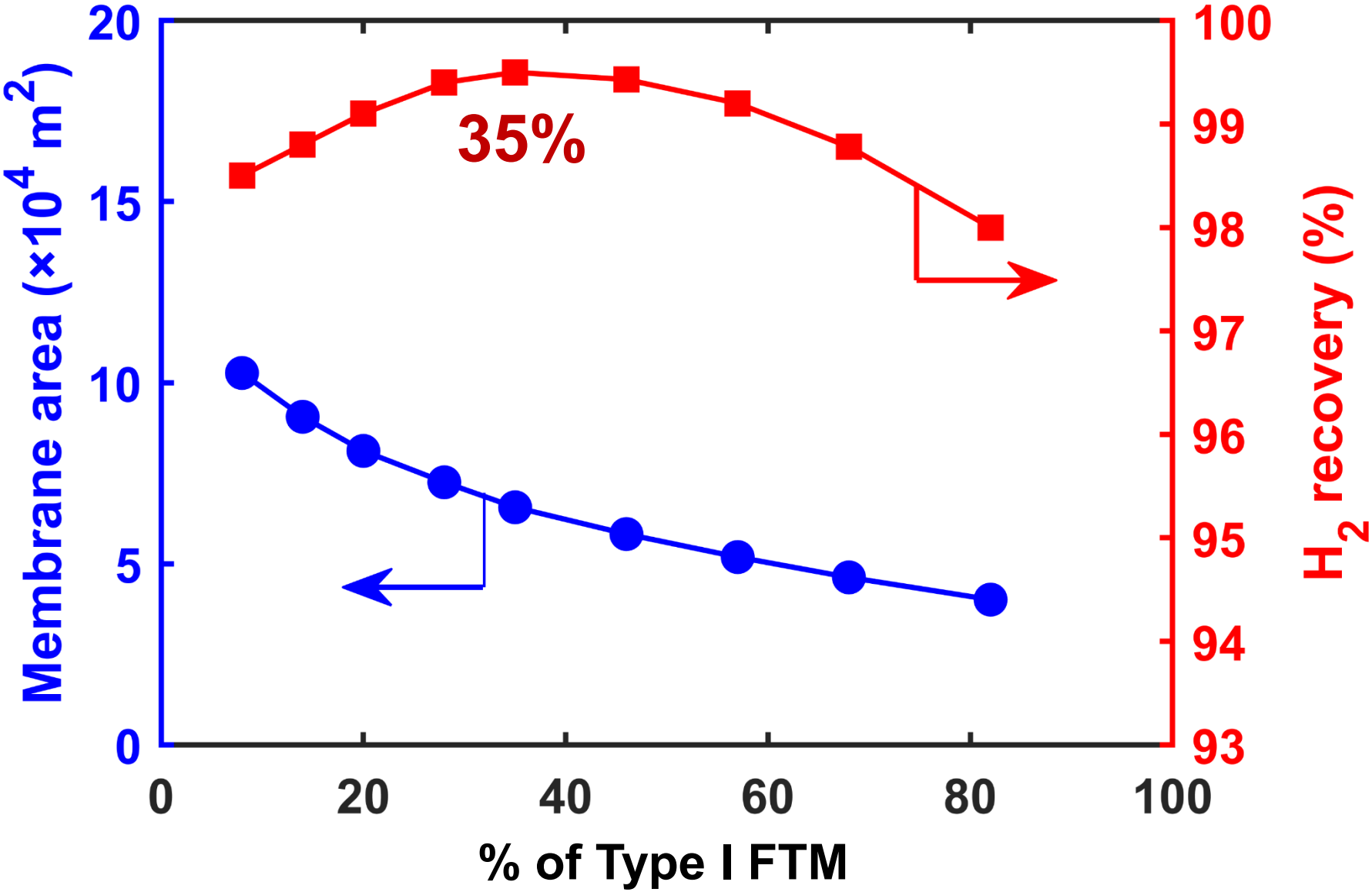
Continuous Membrane Fabrication



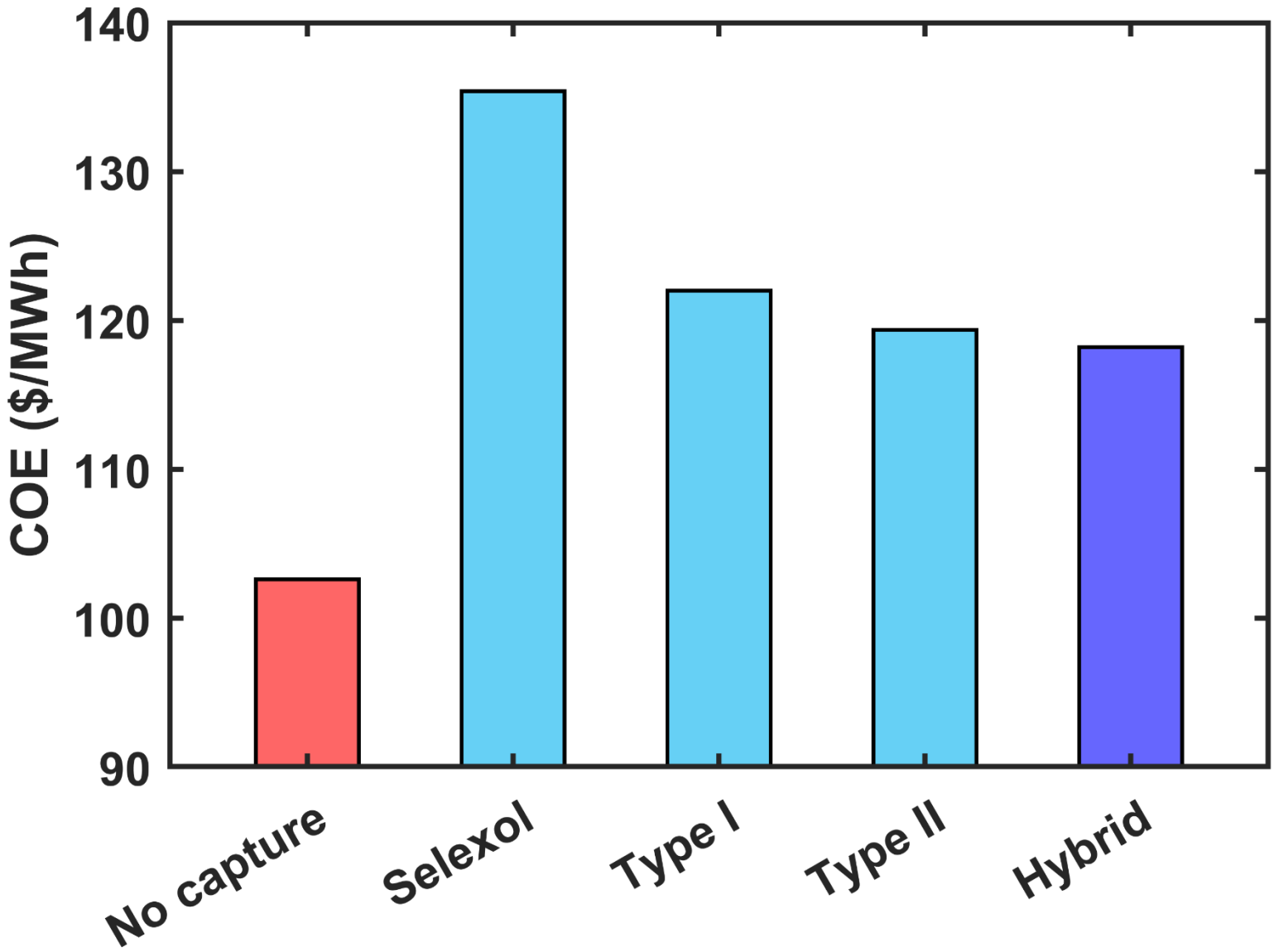
Hybrid Membrane Allocation



Effects of Membrane Allocation on Membrane Area and H_2 Recovery

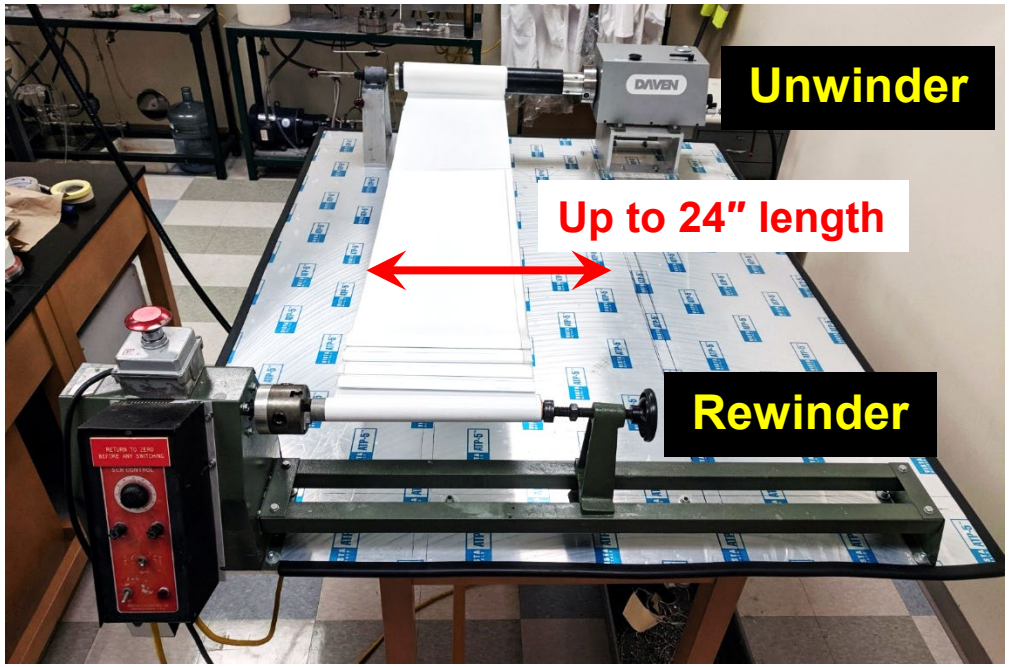


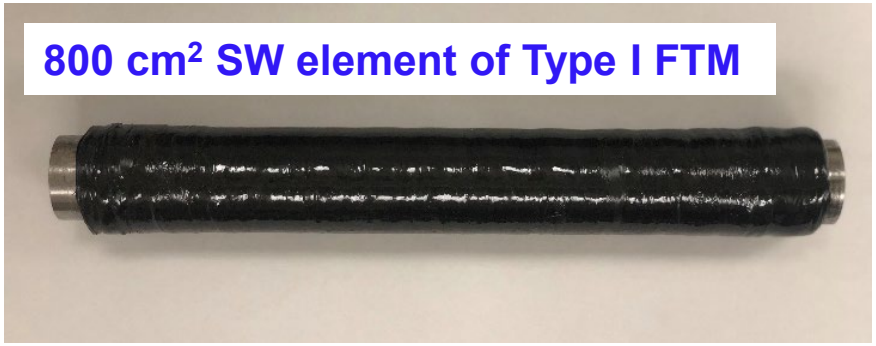
Hybrid Membrane Configuration Results in Lower COE

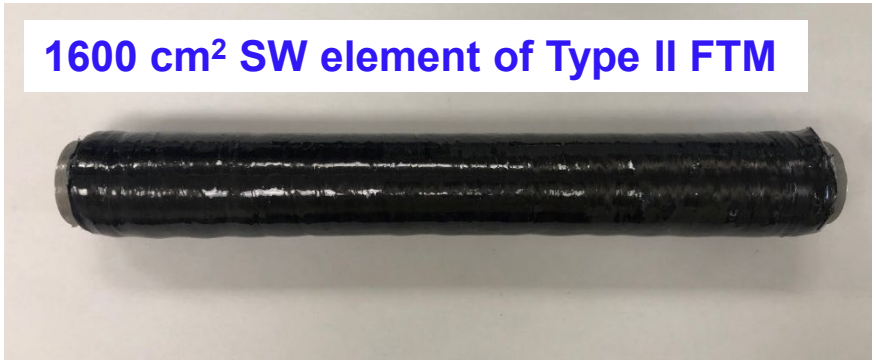


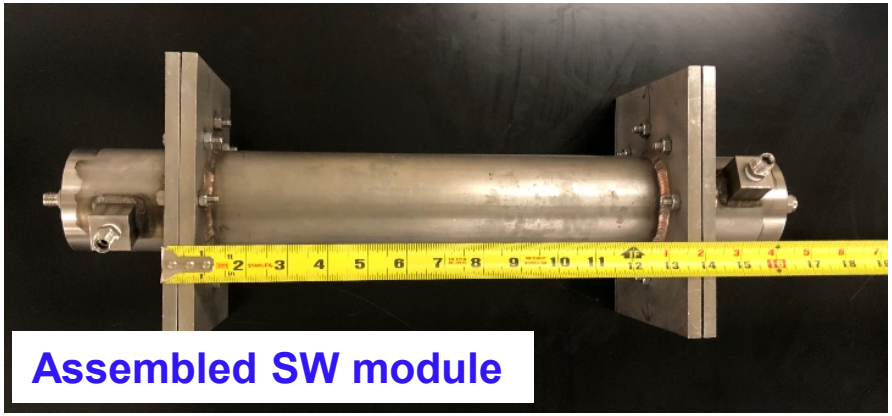
Spiral-Wound Modules Fabricated

Element Rolling Machine



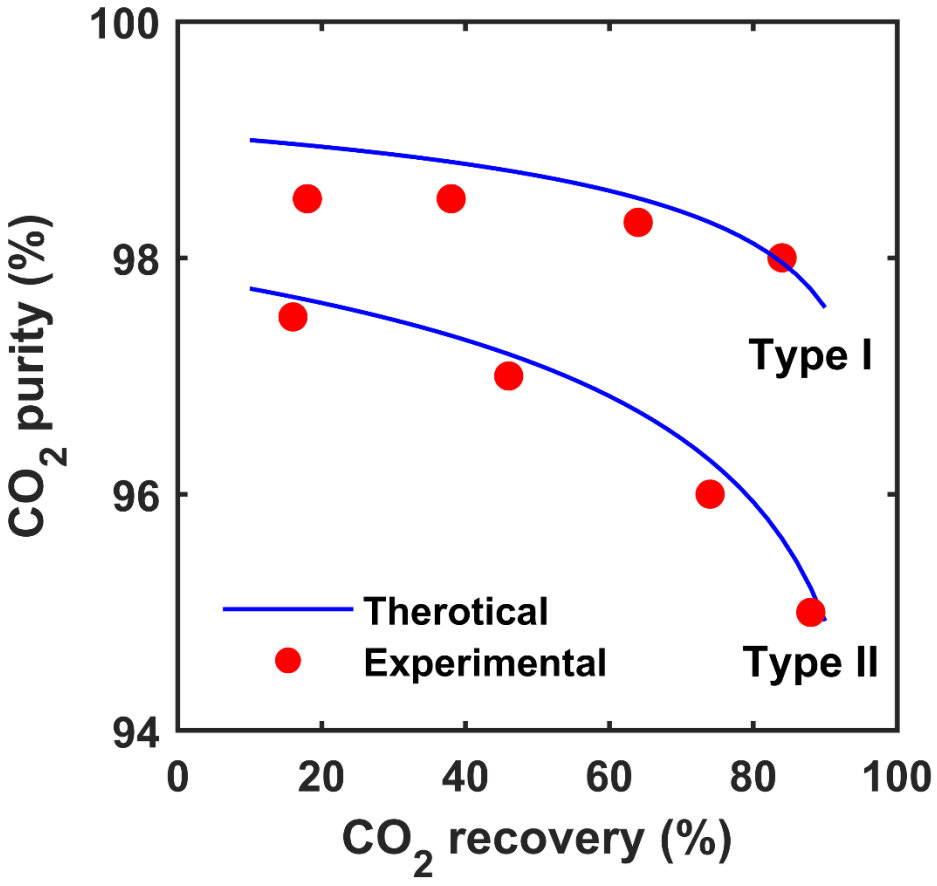


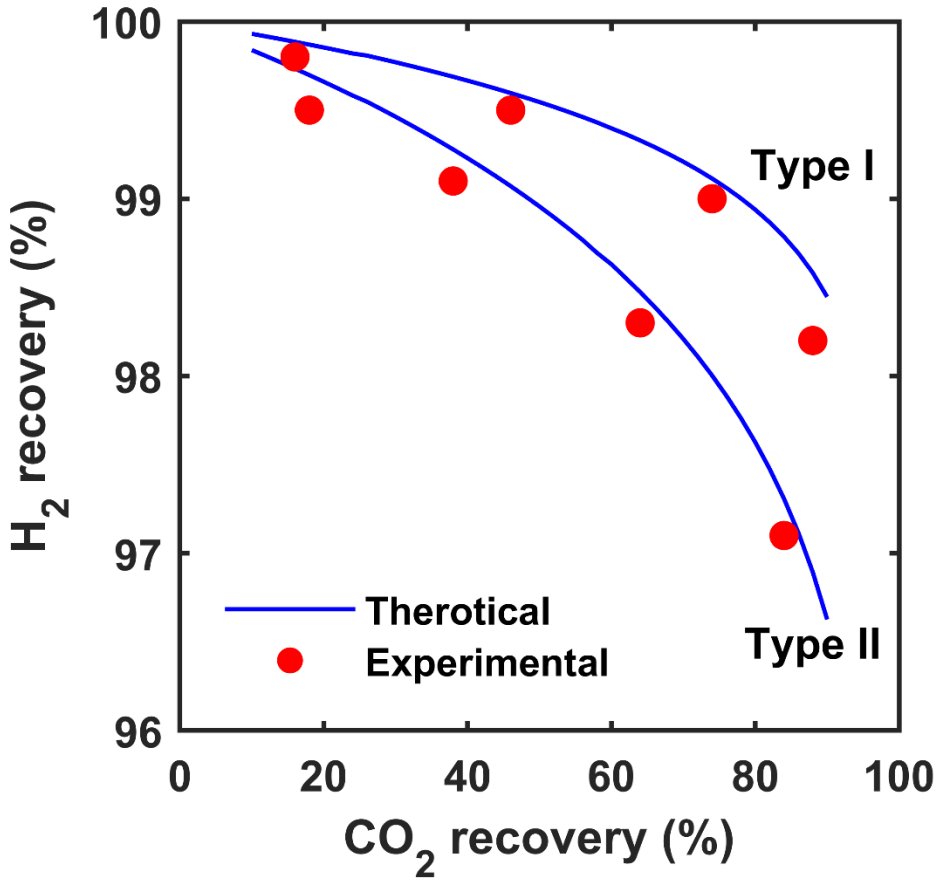




Spiral-Wound Module Testing

Simulated Syngas at 107°C and 35 bar





Summary/Outlook

- **Achieved milestones/success criteria**
  - CO_2 permeance = 275 – 350 GPU
  - CO_2/H_2 selectivity = 120 – 140
  - TEA: 15% COE increase
  - Scale-up membranes fabricated (14″ wide by 20′ long)
  - Prototype SW modules fabricated (800 and 1600 cm^2)

- **Remaining tasks**
  - 200-h stability test with simulated syngas
  - Final Techno-Economic Analysis

Acknowledgments

Katharina Daniels, Project Officer, DOE/NETL

DOE/NETL, Financial Support

Appendix

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

Project Organization and Roles

Ohio State University

- Technical lead
- New membrane synthesis/characterization
- Prototype membrane & module fabrication
- Testing of the membrane modules
- Cost calculations

Winston Ho / Yang Han

DOE NETL

Project Officer

David Lang
Katharina Daniels

AEP

- Consult on plant integration and demonstration considerations

Randy Keefer

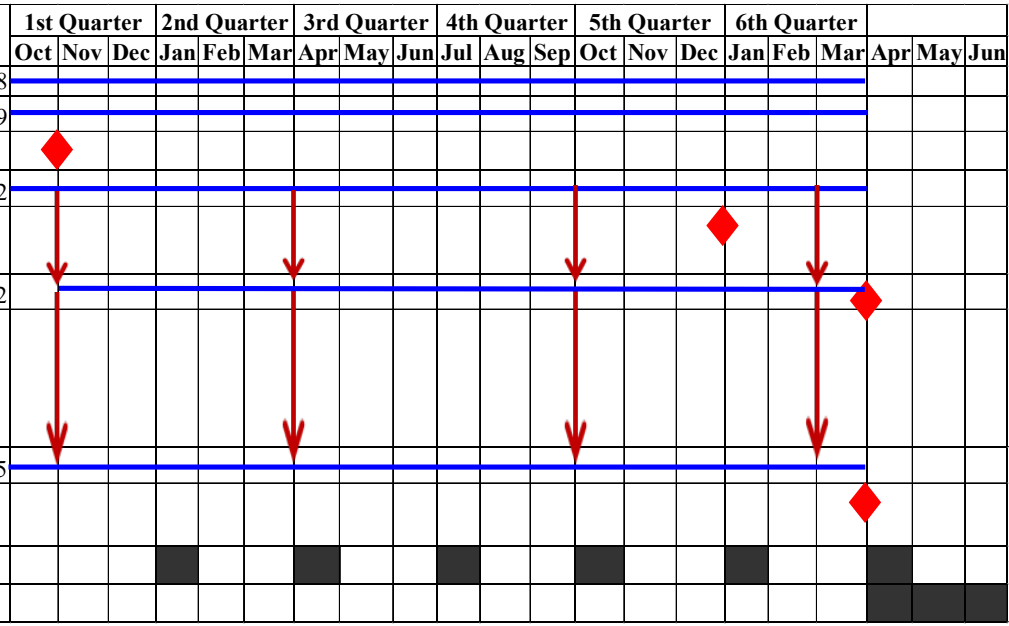
Microdyn-Nadir US Inc.

- Consult on membrane scale-up and module fabrication

Peter Knappe

Gantt Chart

Task Name	Start Date	End Date	Cost ($)
Budget Period 1	10/1/2018	3/31/2020	483,368
Task 1: Project Management and Planning	10/1/2018	3/31/2020	48,339
Updated PMP submitted		10/30/2018	
Task 2: Synthesis of Transformational Membranes	10/1/2018	3/31/2020	193,402
Complete investigation of 5 of the 7 proposed membrane synthesis approaches		12/31/2019	
Task 3: Membrane Characterization	11/1/2018	3/31/2020	193,402
Complete membrane characterization and demonstrate CO_2 permeance = 200 – 275 GPU and CO_2/H_2 selectivity = 100 – 120 at ~110° C and 31.7 bar feed inlet (12.5 bar CO_2)		3/31/2020	
Task 4: Preliminary Techno-economic Analysis	10/1/2018	3/31/2020	48,225
Complete preliminary techno-economic analysis showing the feasibility of a COE increase of 15.3%		3/31/2020	
Quarterly Progress Reports	1/1/2019	4/30/2020	
Budget Period 1 Annual Report	4/1/2020	6/30/2020	



Gantt Chart

Task Name	Start Date	End Date	Cost ($)
Budget Period 2	4/1/2020	9/30/2021	516,618
Task 1: Project Management and Planning	4/1/2020	9/30/2021	51,662
Task 5: Optimized Membrane Synthesis	4/1/2020	6/30/2020	53,268
Task 6: Optimized Membrane Characterization	5/1/2020	7/31/2020	53,268
Complete optimized membrane characterization and demonstrate CO_2 permeance = 275 – 350 GPU and CO_2/H_2 selectivity = 120 – 140 at ~110° C and 31.7 bar feed inlet (12.5 bar CO_2)		7/31/2020	
Task 7: Optimized Membrane Scale-up Fabrication	7/1/2020	10/15/2020	63,868
Task 8: Optimized Scale-up Membrane Characterization	8/1/2020	10/31/2020	43,658
Complete optimized scale-up membrane characterization and demonstrate CO_2 permeance = 275 – 350 GPU & CO_2/H_2 selectivity = 120 – 140 at ~110° C and 31.7 bar feed inlet (12.5 bar CO_2)		10/31/2020	
Task 9: Prototype Membrane Module Fabrication	9/1/2020	12/31/2020	58,338
Task 10: Prototype Membrane Module Testing	12/1/2020	3/31/2021	53,328
Complete prototype membrane module testing and demonstrate CO_2 permeance = 275 – 350 GPU & CO_2/H_2 selectivity = 120 – 140 at ~110° C and 31.7 bar feed inlet (12.5 bar CO_2)		3/31/2021	
Task 11: Parametric Testing with Prototype Modules in Series	4/1/2021	6/30/2021	50,210
Complete parametric testing with prototype modules in series and conditions for steady state operation identified		6/30/2021	
Task 12: Continuous Steady Operation with Modules in Series	7/1/2021	9/30/2021	50,210
Complete steady state operation with modules in series and demonstrate feasibility on capture of the CO_2 with >95% CO_2 purity with simulated syngas for 200 hours		9/30/2021	
Task 13: Final Updated Techno-economic Analysis	5/1/2021	9/30/2021	38,808
Complete final techno-economic analysis showing the feasibility of a COE increase of 15.0%		9/30/2021	
Task 14: State Point Data Table	9/1/2021	9/30/2021	0
State point data table submitted		9/30/2021	
Task 15: Final Technology Maturation Plan	9/1/2021	9/30/2021	0
Final technology maturation plan submitted		9/30/2021	
Task 16: Environmental Health & Safety Risk Assessment	9/1/2021	9/30/2021	0
EH&S risk assessment submitted		9/30/2021	
Quarterly Progress Reports	7/1/2020	10/30/2021	
Final Project Report	10/1/2021	12/30/2021