New Amine-Based Membranes for Post- and Pre-Combustion CO_2 Capture

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8th Symposium for Innovative CO_2 Membrane Separation Technology

Tokyo, Japan, January 18, 2019

Outline

- **Post-Combustion CO_2 Capture**
  - **Flue Gas in Coal- and/or Natural Gas-fired Power Plants**
- **Pre-Combustion CO_2 Capture**
  - **Coal- and/or Natural Gas-derived Syngas**
  - **Integrated Gasification Combined Cycle (IGCC)**

Post-Combustion CO_2 Capture
Introduction

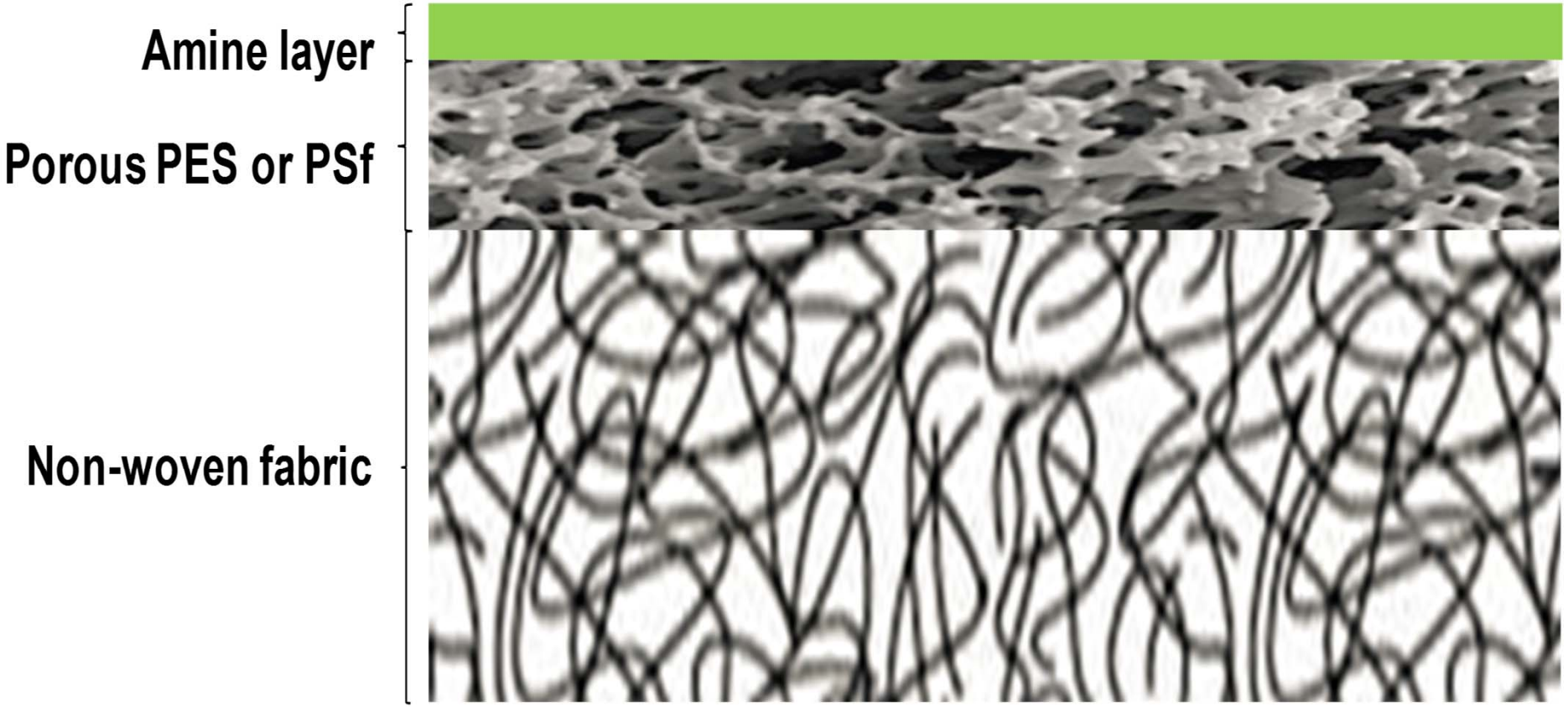
- **Coal-fired power plants**
  - **40% of global CO_2 emission**
  - **Remain as major energy supply**
- **Membranes for CO_2 capture from flue gas**
  - **System compactness**
  - **Energy efficiency**
  - **Operational simplicity**
  - **Kinetic ability to overcome thermodynamic solubility limitation**

CO_2 Capture from Flue Gas

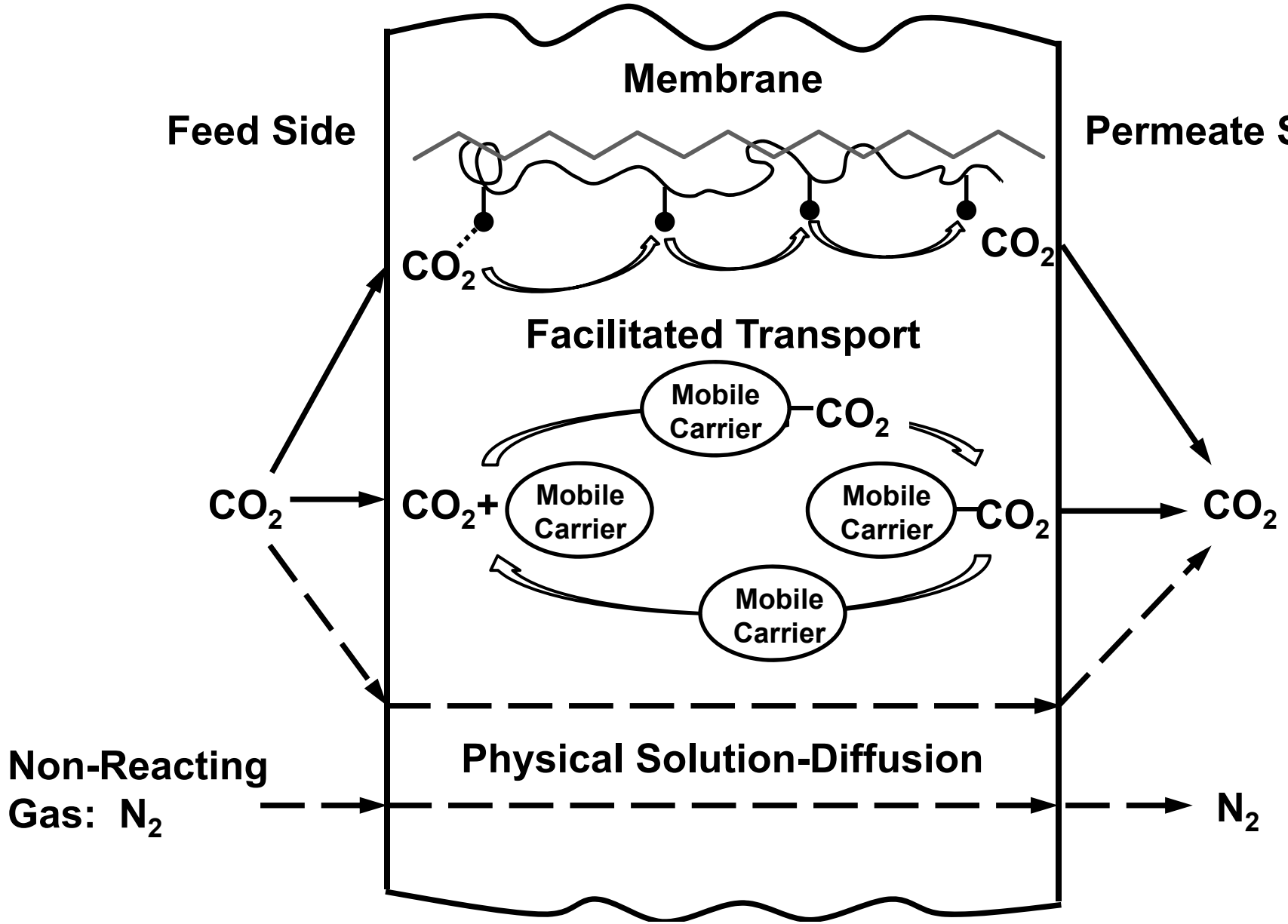
- **Flue Gas**
  - Low pressure: 1 atm
  - Low CO_2 concentration: ~ 6 – 14%
- **Low Driving Force**
- **Single-Stage Membrane Process Cannot Achieve DOE Targets**
  - 90% capture with ≥95% CO_2 concentration
  - ≤$40/tonne CO_2 captured (in 2007 dollar)

Amine-Containing Polymer Membrane Structure

Simplicity of Membrane for Low Cost

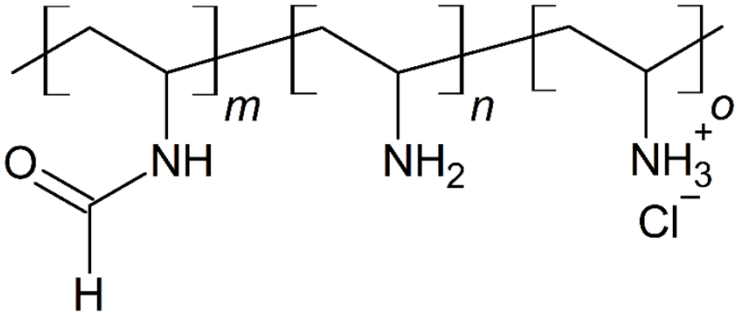


Amine Polymer Layer Contains Mobile and Fixed Carriers: Facilitated Transport



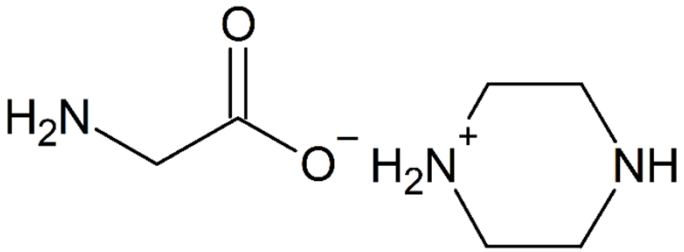
Amine-Containing Carriers

- **Fixed-Site Carrier**

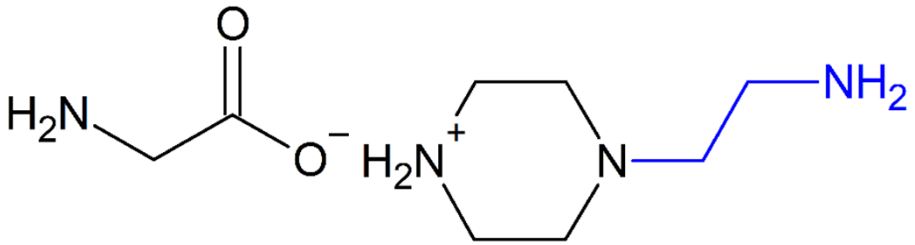


PNVF-*co*-VAm

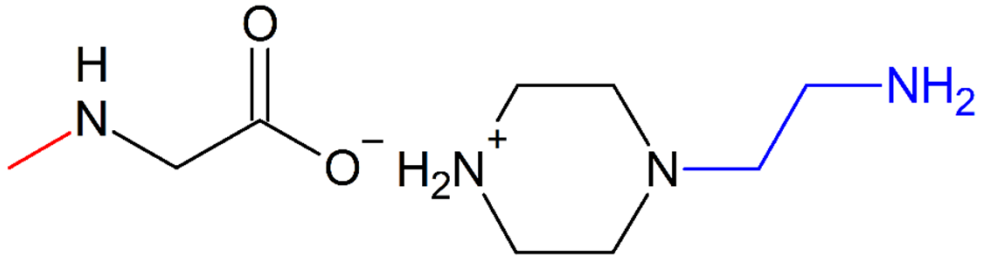
- **Mobile Carriers**



PZ-Gly

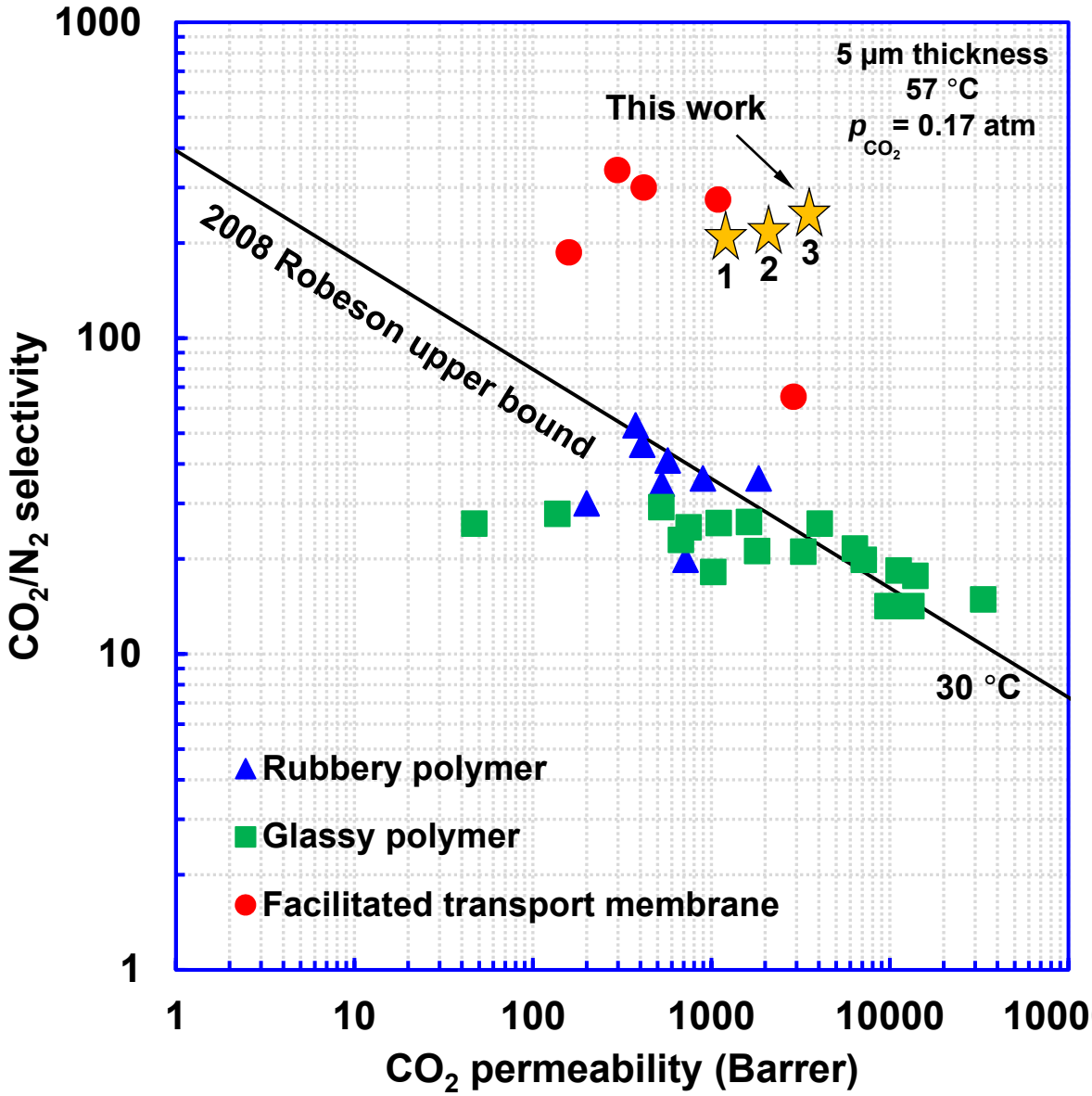


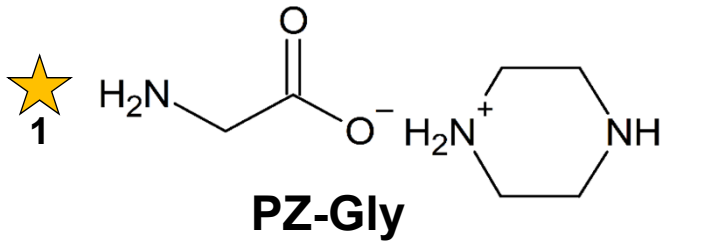
PZEA-Gly

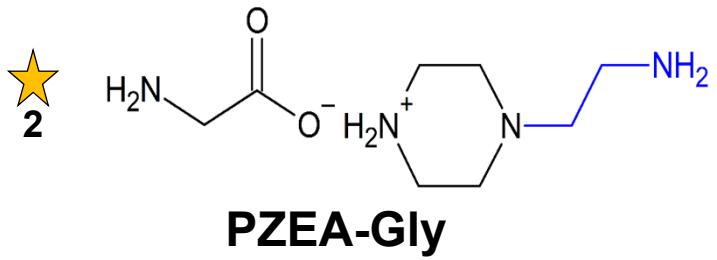


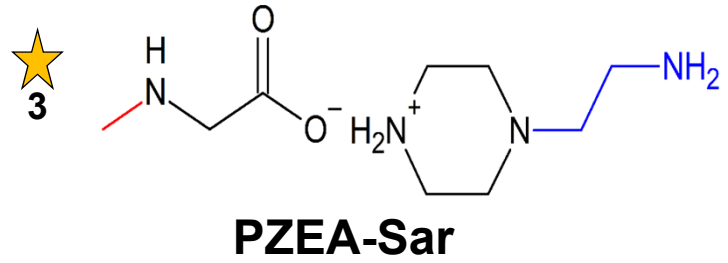
PZEA-Sar

High CO_2 Permeability/Selectivity Achieved



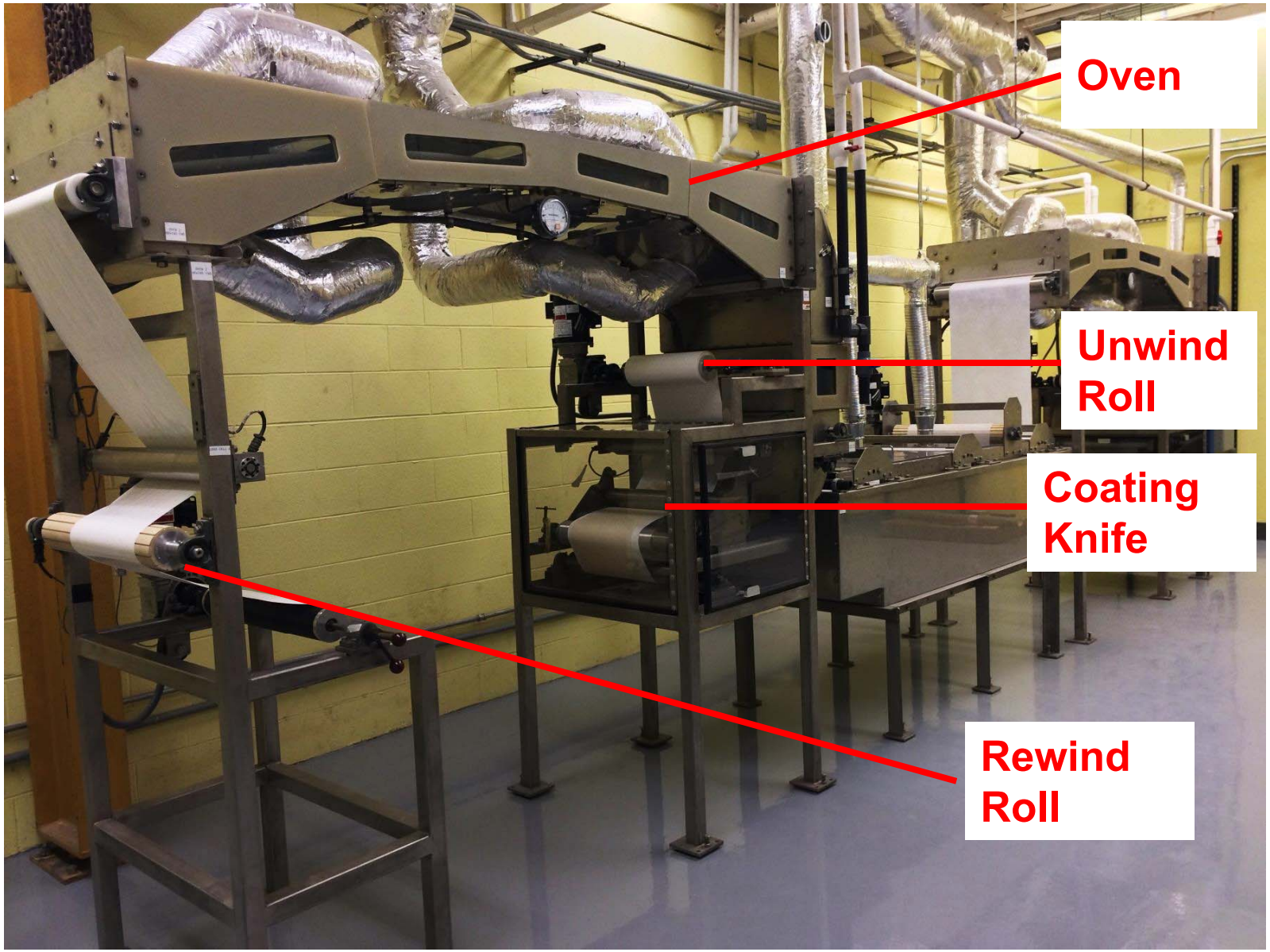






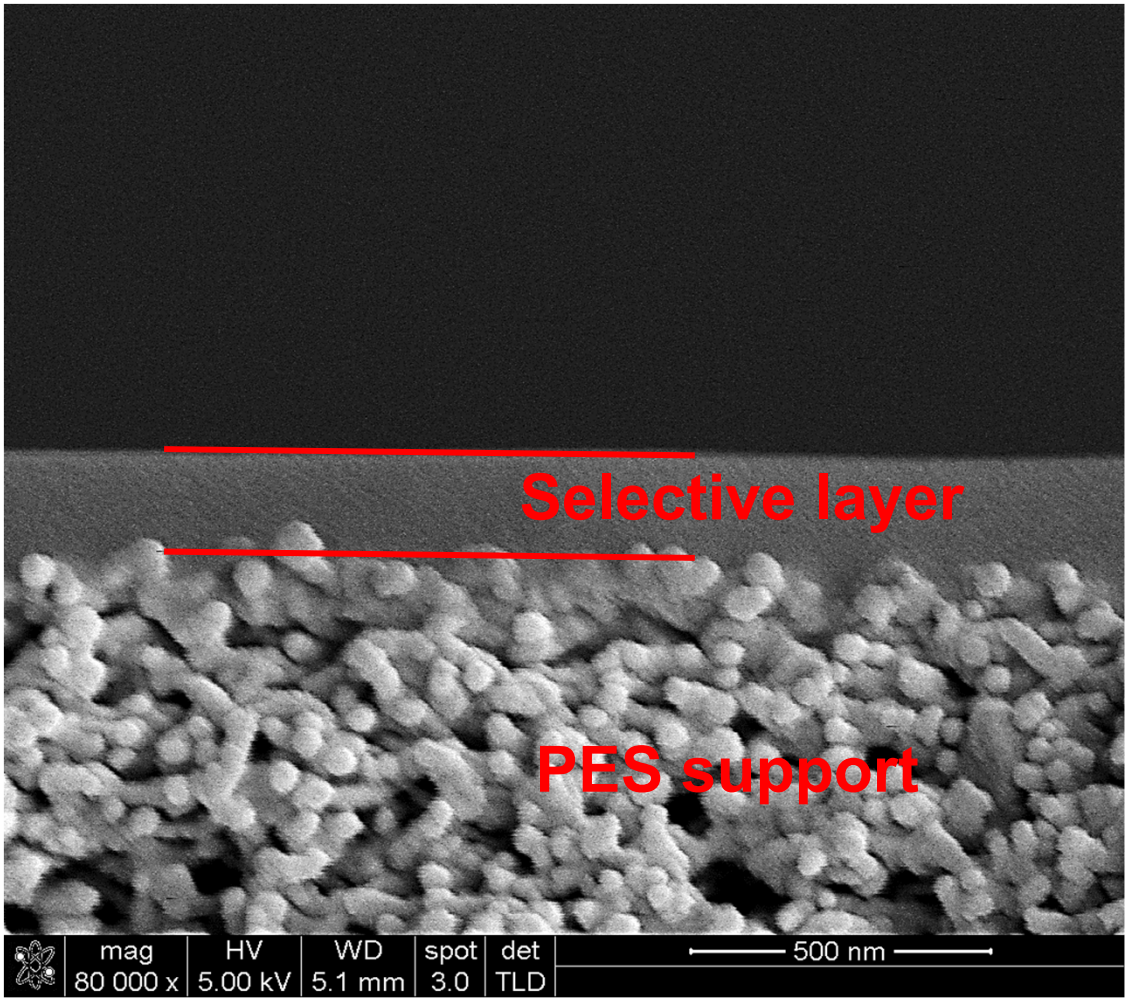
Han and Ho, Chin. J. Chem. Eng., doi:10.1016/j.cjche.2018.07.010 (2018)

Membrane Scale-up: Continuous Roll-to-Roll Fabrication Machine at OSU



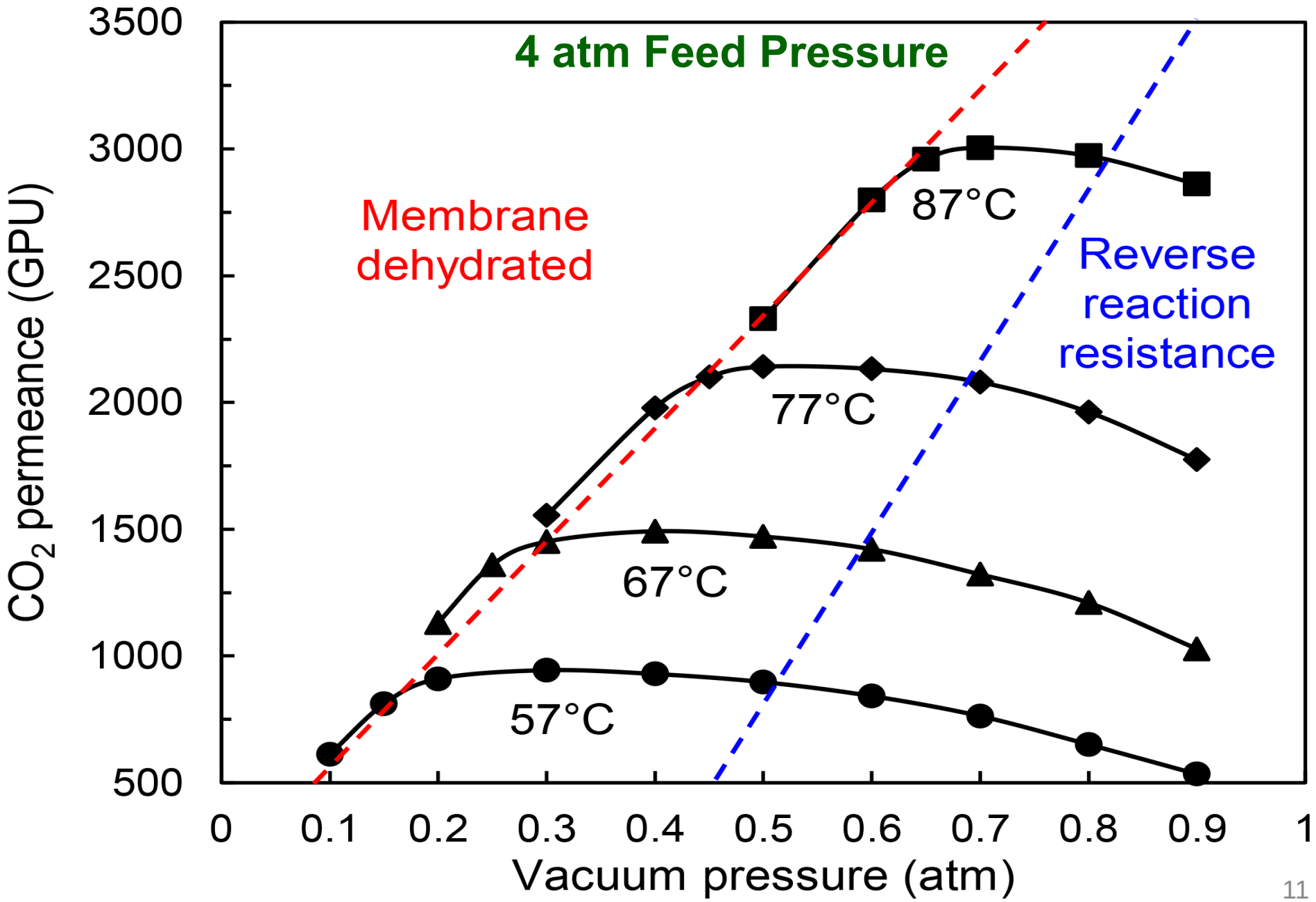
Composite Membrane Synthesized

Selective Amine Polymer Layer on PES Support



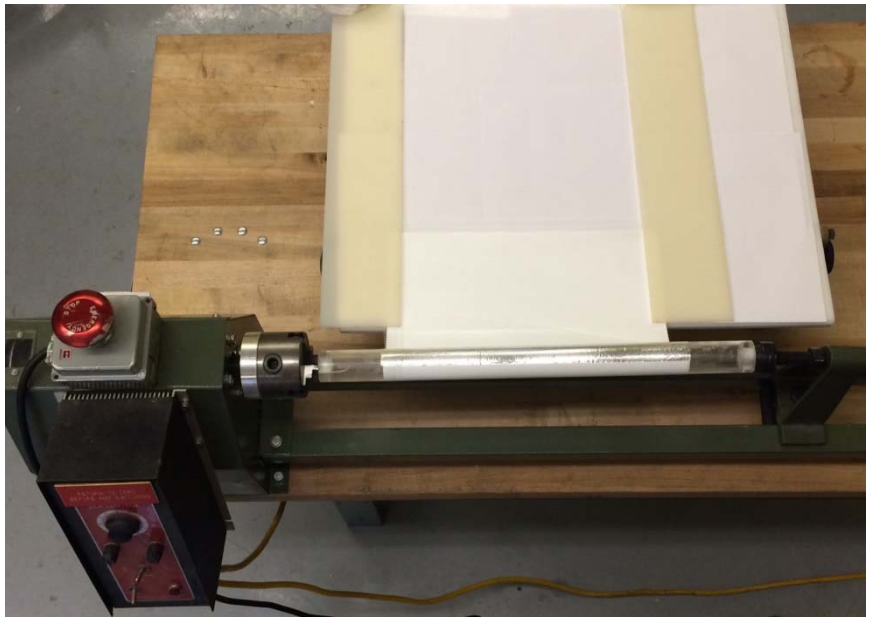
Selective layer = 165 nm

Effects of Temperature and Permeate Vacuum



Spiral-Wound Module Fabrication

Element Rolling Machine

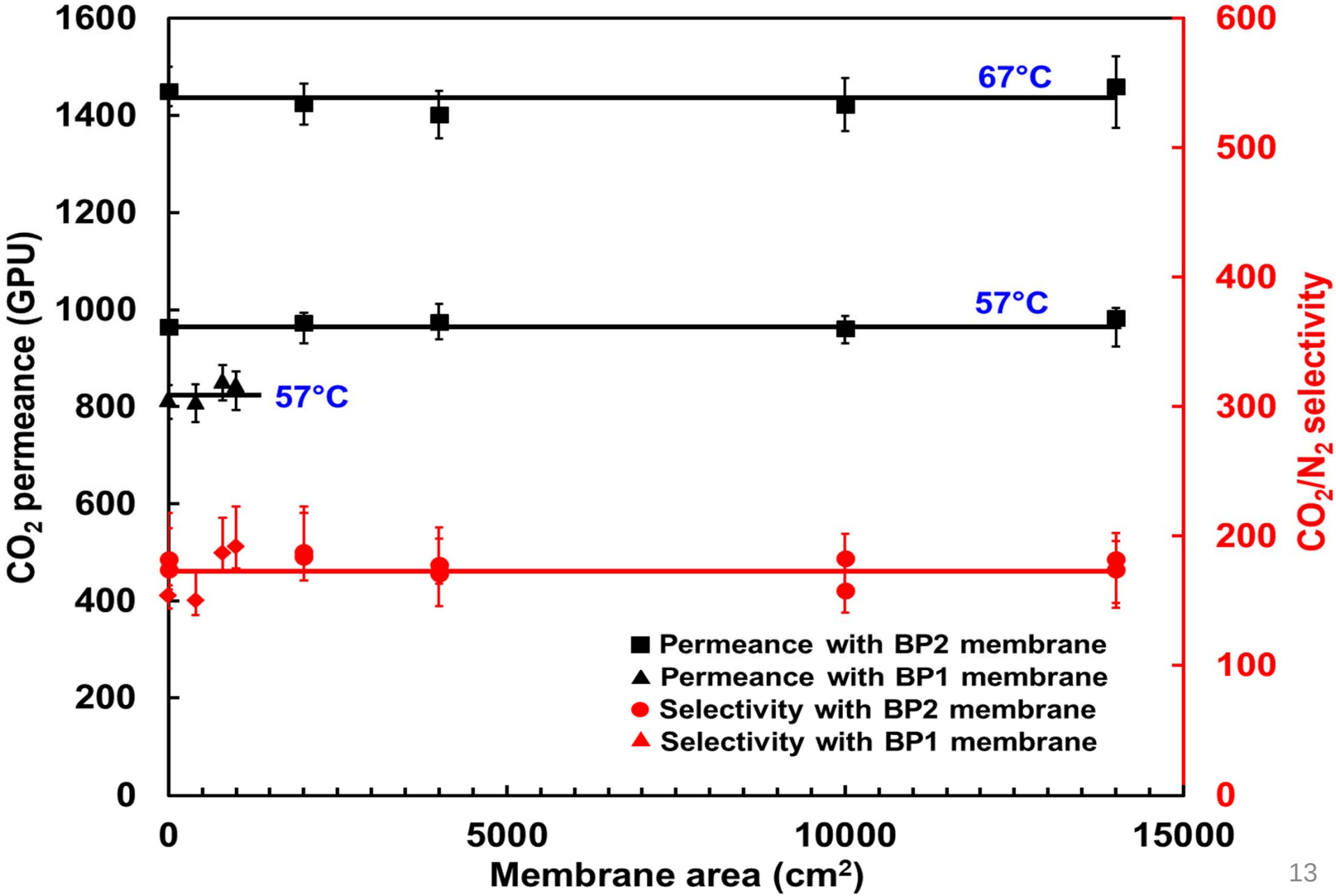


Spiral-Wound Membrane Element

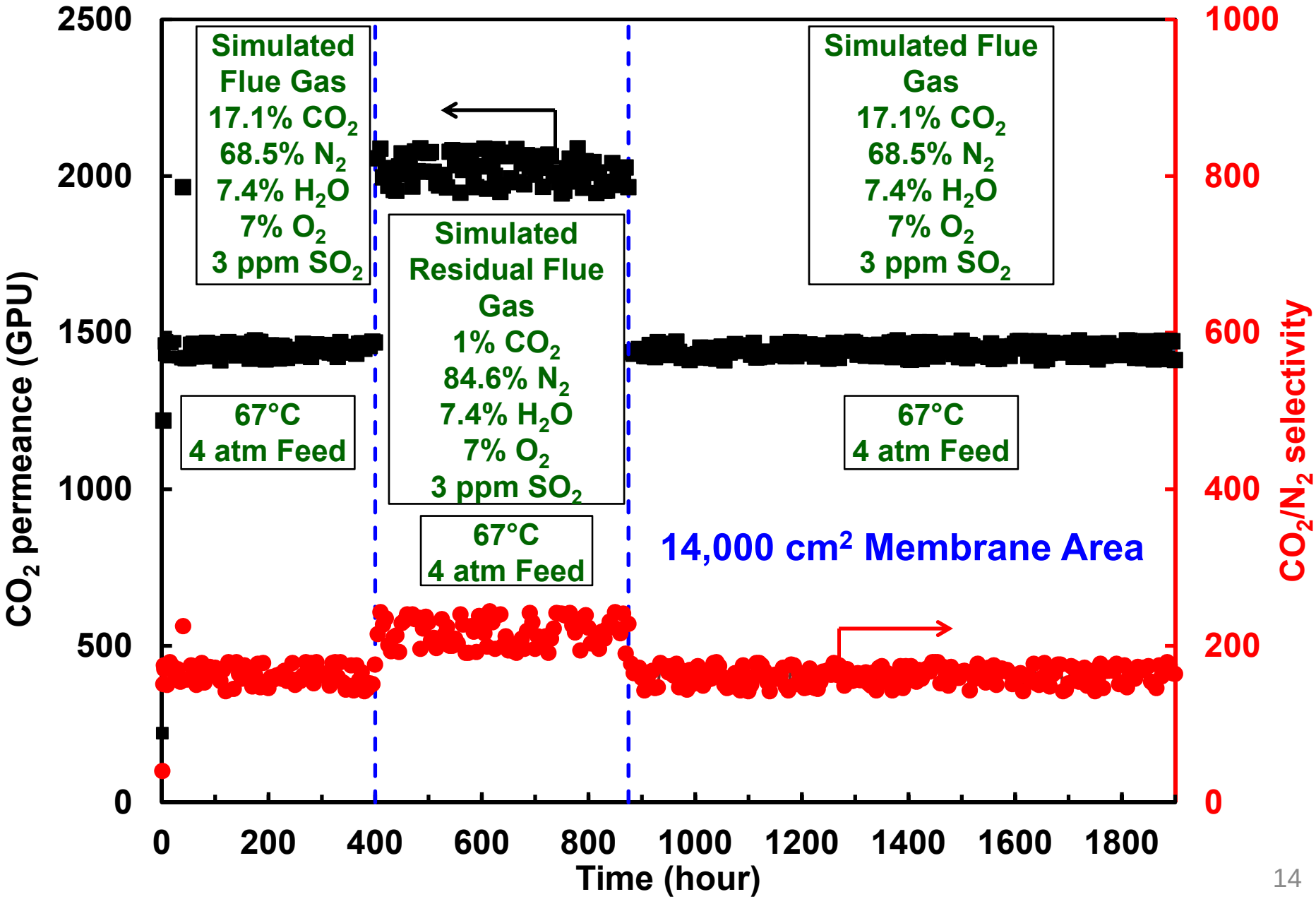
Membrane Module

Salim et al., *JMS*, *556*, 126 (2018)

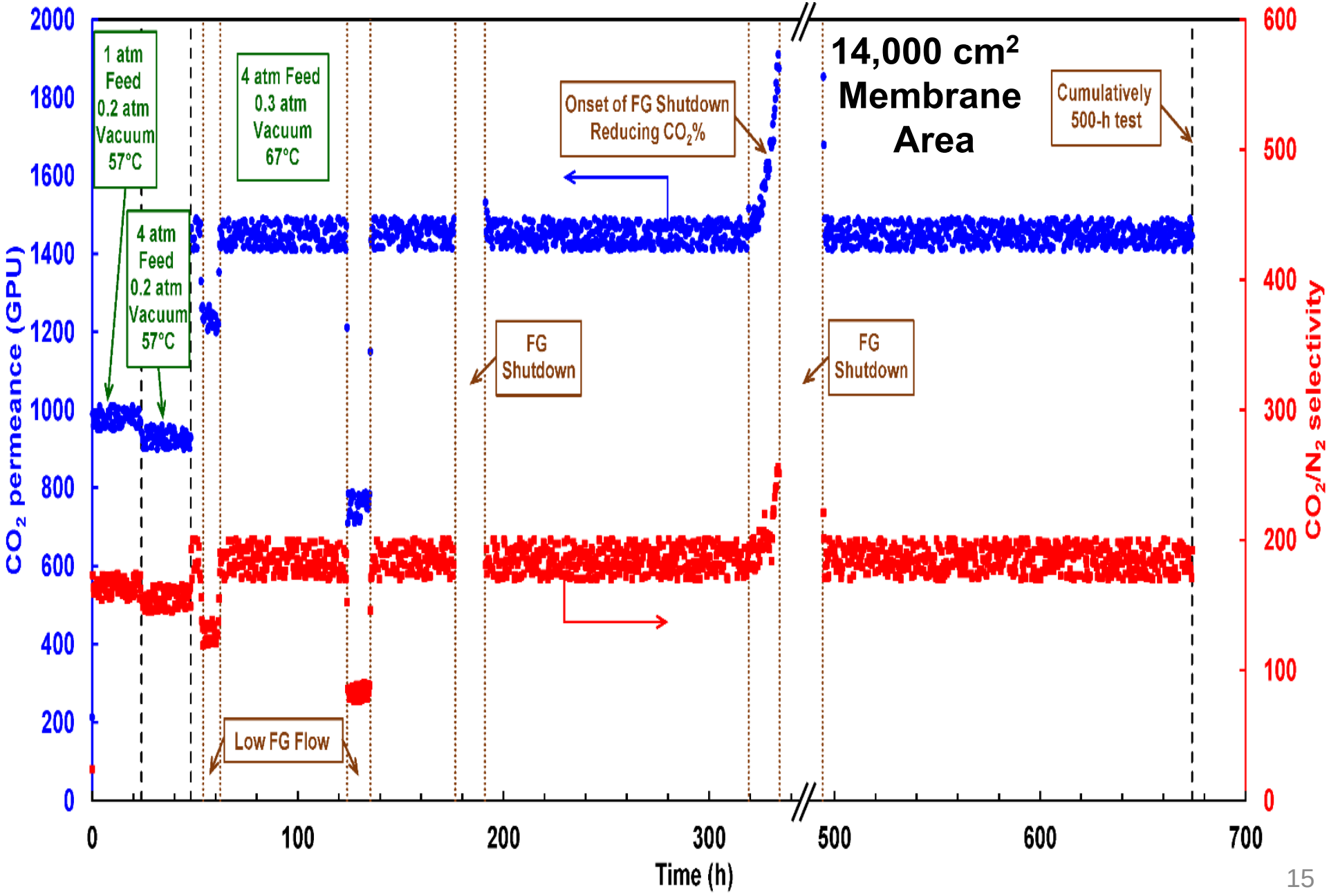
Scale-up of SW Modules



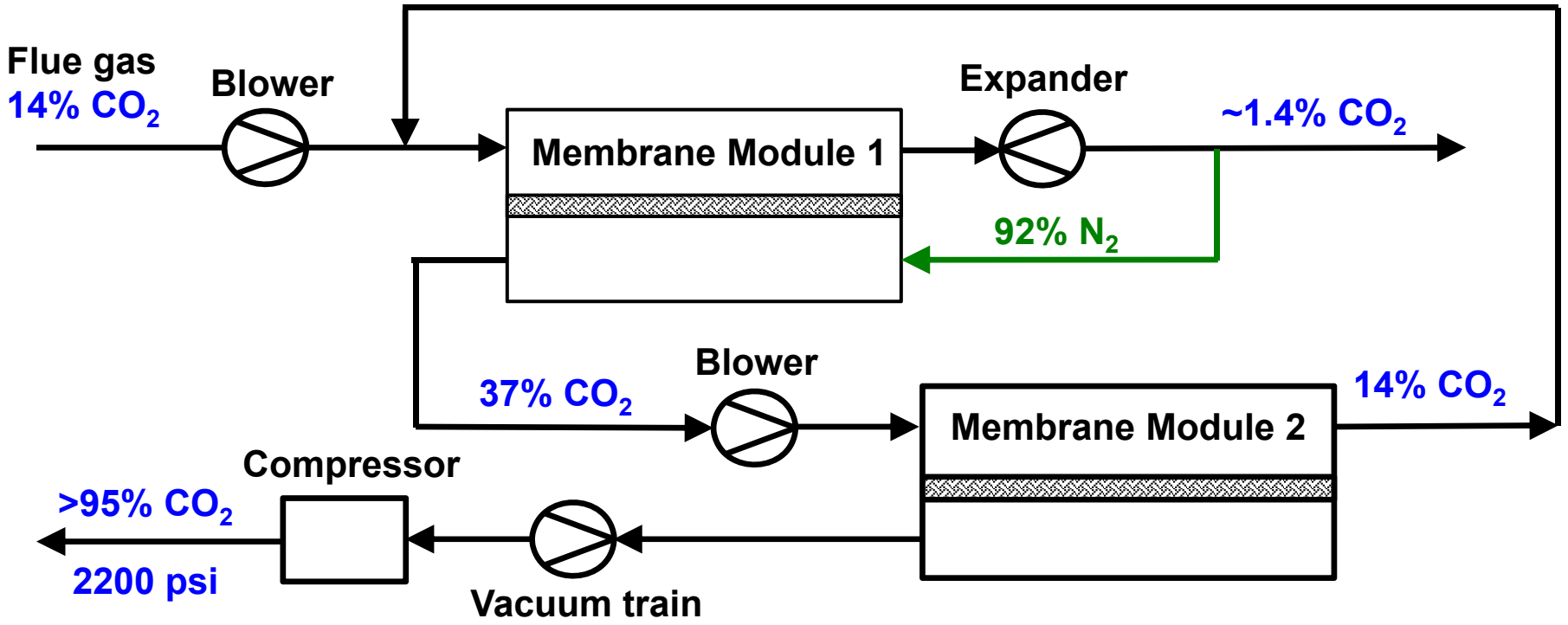
Good SW Module Stability Obtained



Good SW Module Stability at NCCC



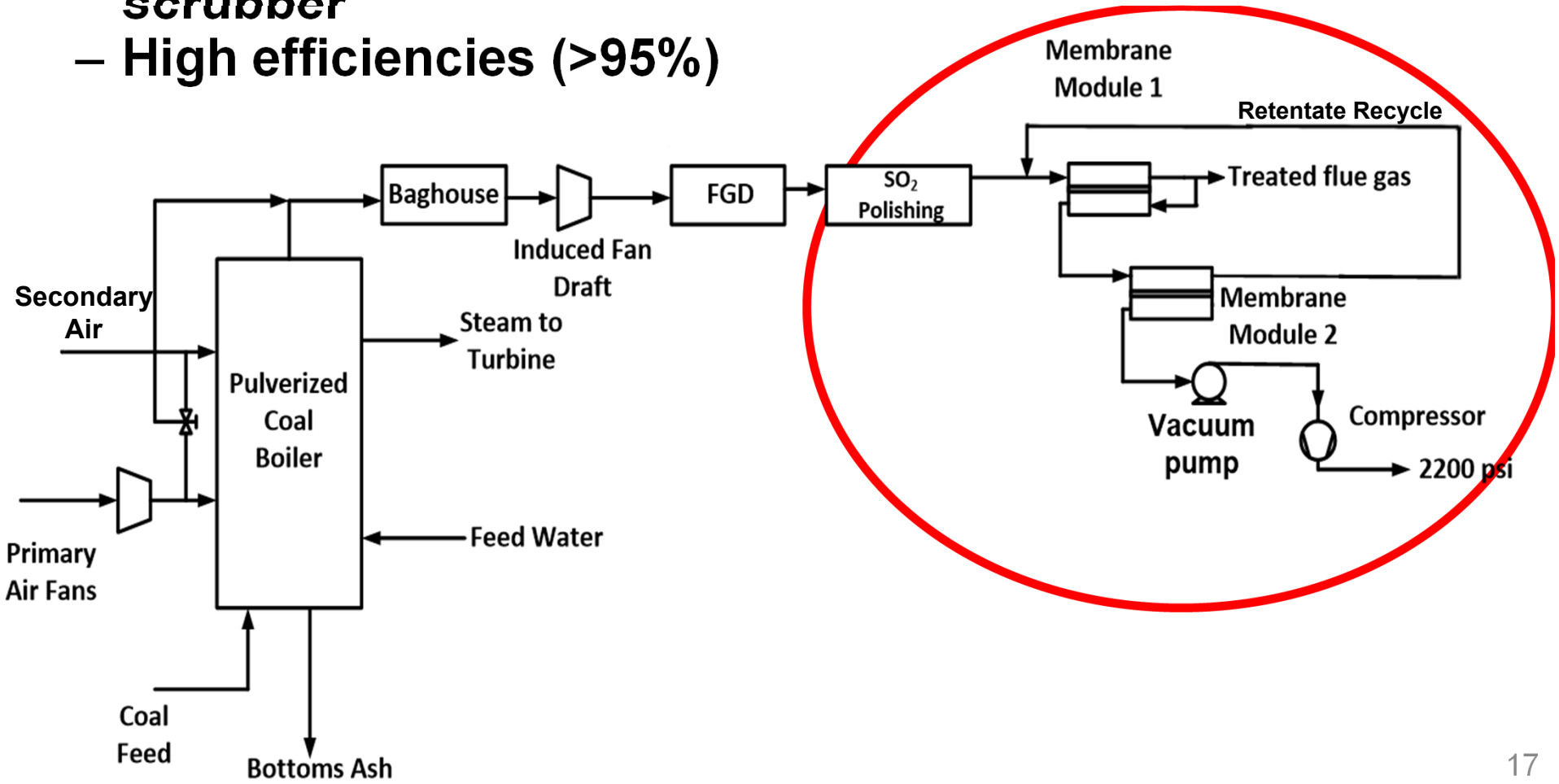
Process Proposed for CO_2 Capture from Flue Gas in Coal-Fired Power Plants



- **Retentate Recycle – No Air Sweep Needed**
  - No need to modify combustion air system of existing power plant
  - Capital cost of retrofitting the existing ductwork is avoided
  - Avoiding reduced O_2 content encountered in CO_2 laden air
  - Boiler efficiency is not affected
- **Proposed Membrane Process**
  - Does not require cryogenic distillation (compared to competition)

SO_2 Polishing & Membrane Process

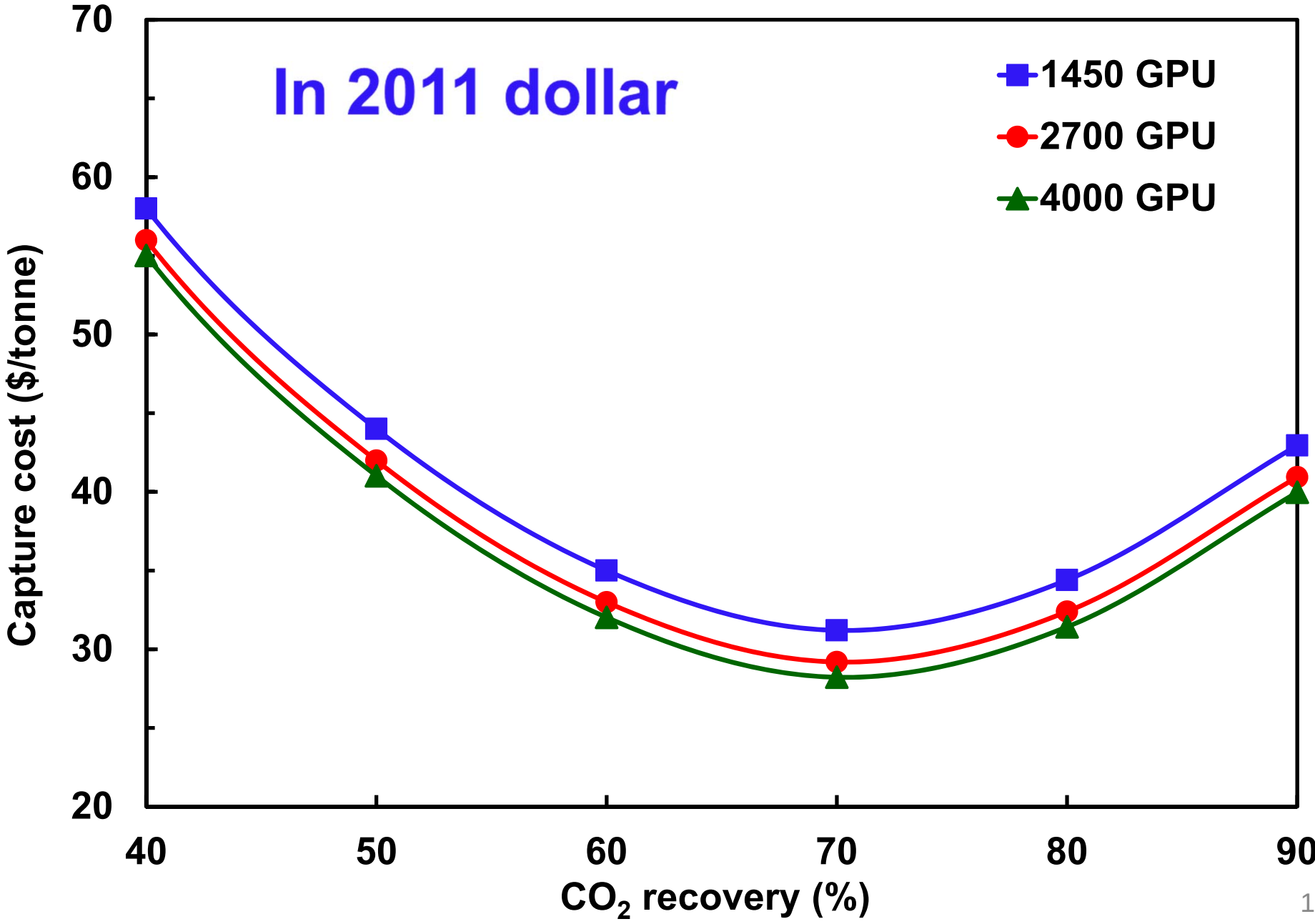
- **Absorption into 20 wt% NaOH Solution**
  - **Polishing step based on NETL baseline document**
    - **Estimated to be ~ \$4.3/tonne CO_2 (in 2007 \$, 6.5% COE increase)**
  - **Non-plugging, low-differential-pressure, spray baffle *scrubber***
  - **High efficiencies (>95%)**



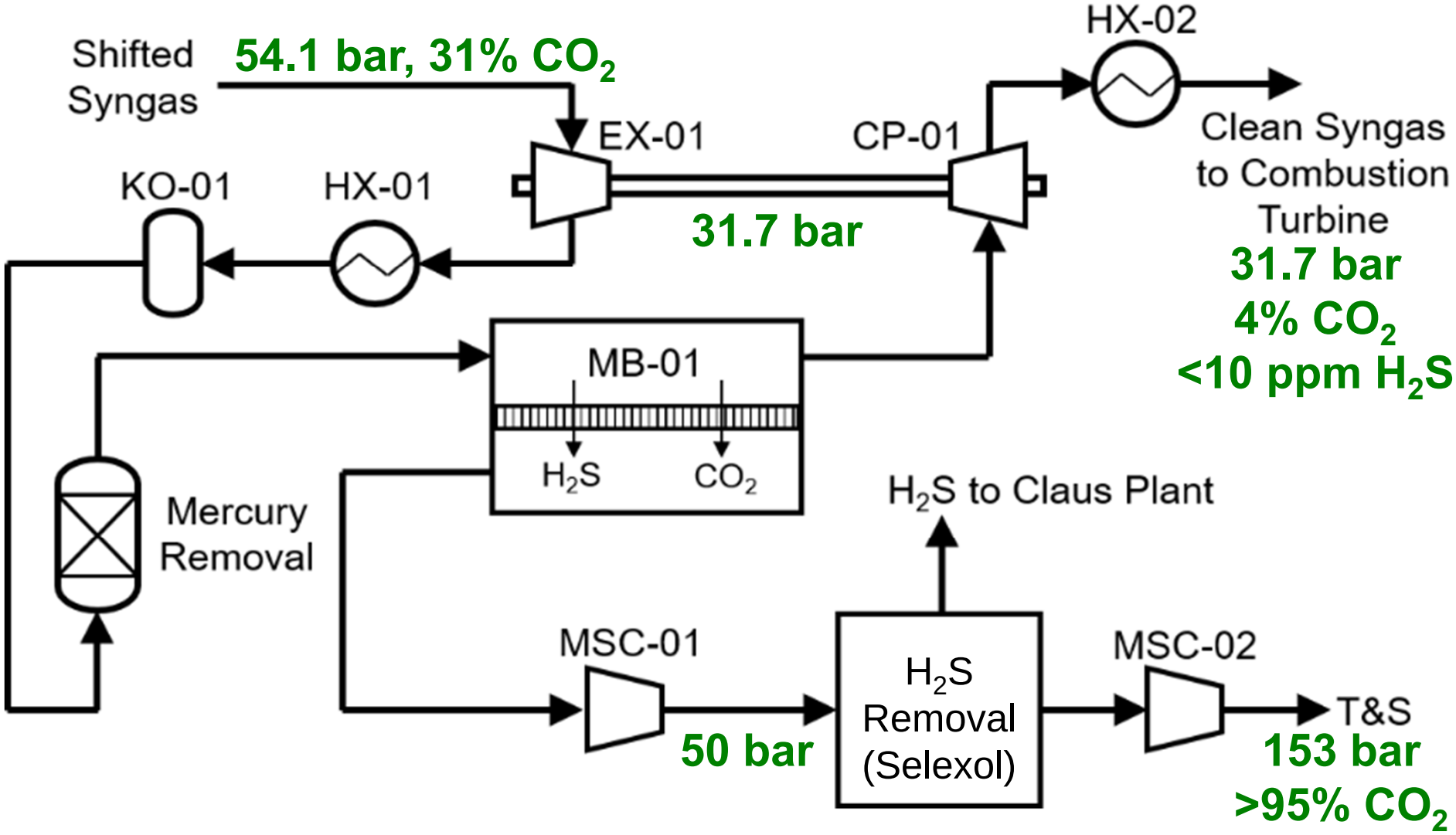
Techno-Economic Calculations for Flue Gas (In 2011 dollar)

- **Basis: Membrane Results at 67°C**
  - **1911 GPU & 256 Selectivity for 1% CO_2 concentration feed gas**
  - **1450 GPU & 185 Selectivity for 20% CO_2 conc. feed gas**
  - **Include Membrane Module Installation Cost and 20% Process Contingency**
  - **In 2011 dollar: NETL Case 12 of *Updated Costs (June 2011 Basis) for Selected Bituminous Baseline Cases***
- **Calculated Cost Results**
  - **490.6 tonne/h of CO_2 captured from flue gas**
  - **$378 million bare equipment cost**
    - Membrane 45%, blowers and vacuum pumps 45%, others 10%
  - **3.72 ¢/kWh (2.81 ¢/kWh capital cost, 0.40 ¢/kWh fixed cost, 0.51 ¢/kWh variable cost)**
    - COE = 8.09 ¢/kWh for 550 MW supercritical pulverized coal power plant
  - **$41.7/tonne capture cost ($37.2/MWh × 550 MW/(490.6 tonne/h))**
  - **46.0% Increase in COE (3.72/8.09 = 46.0%)**

Lower Capture Cost for 70% CO_2 Recovery



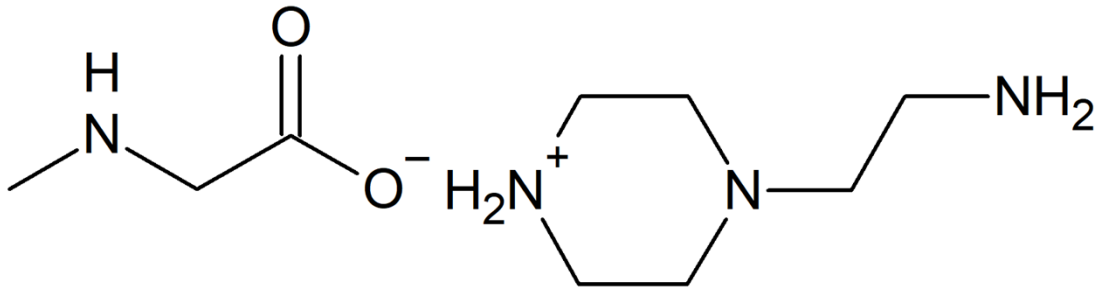
Pre-Combustion CO_2 Capture: Proposed Process



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

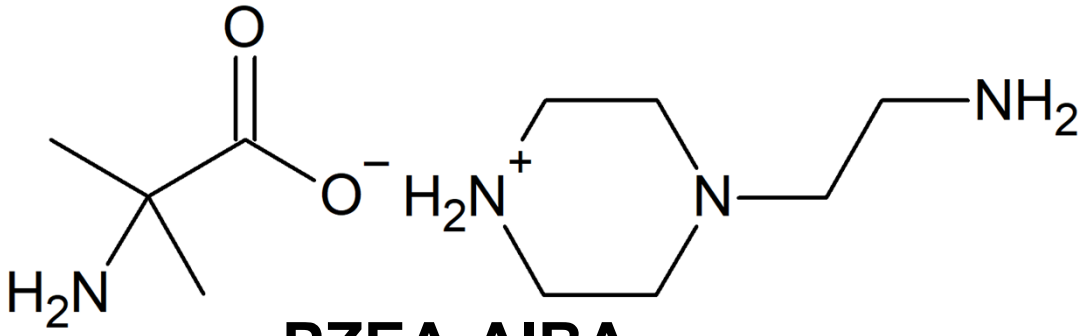
Composite Membranes Synthesized

Membrane M1



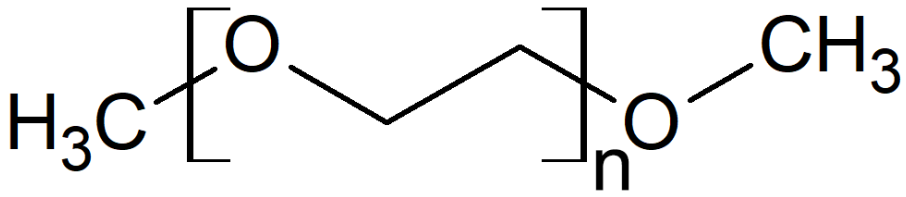
PZEA-Sar

Membrane M2



PZEA-AIBA

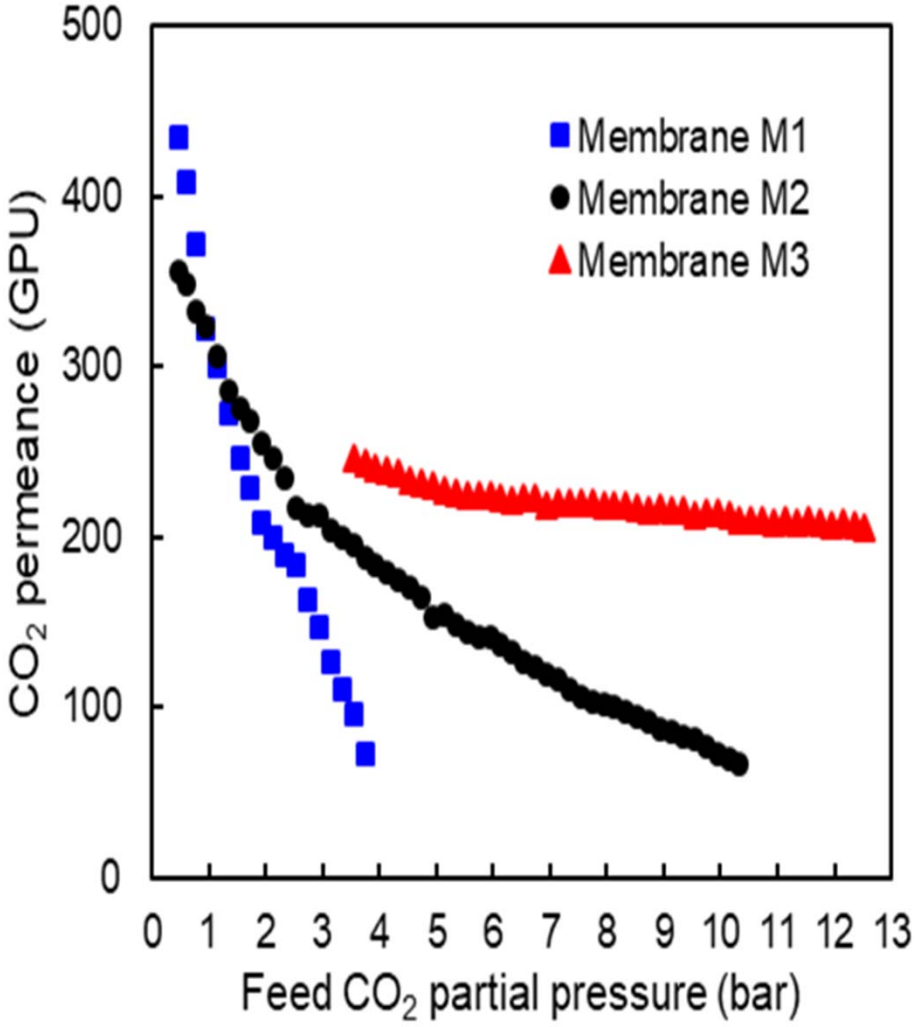
Membrane M3

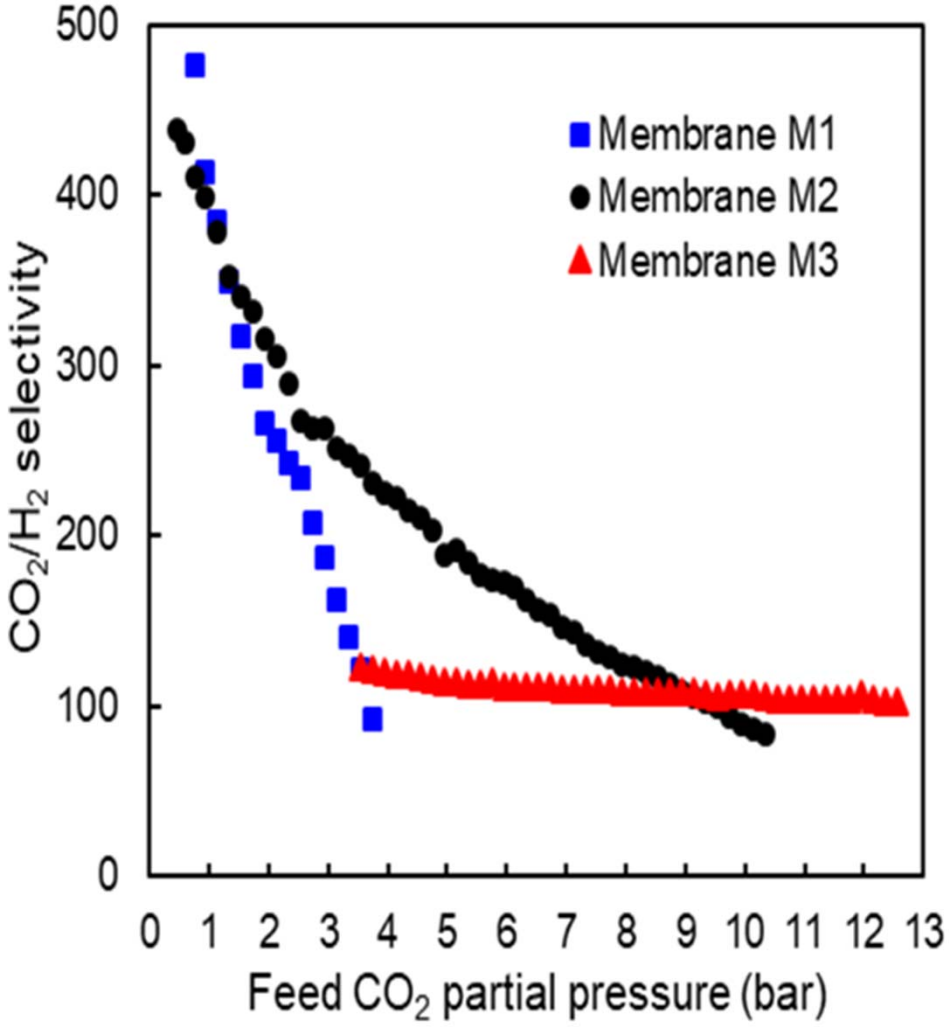


PEGDME

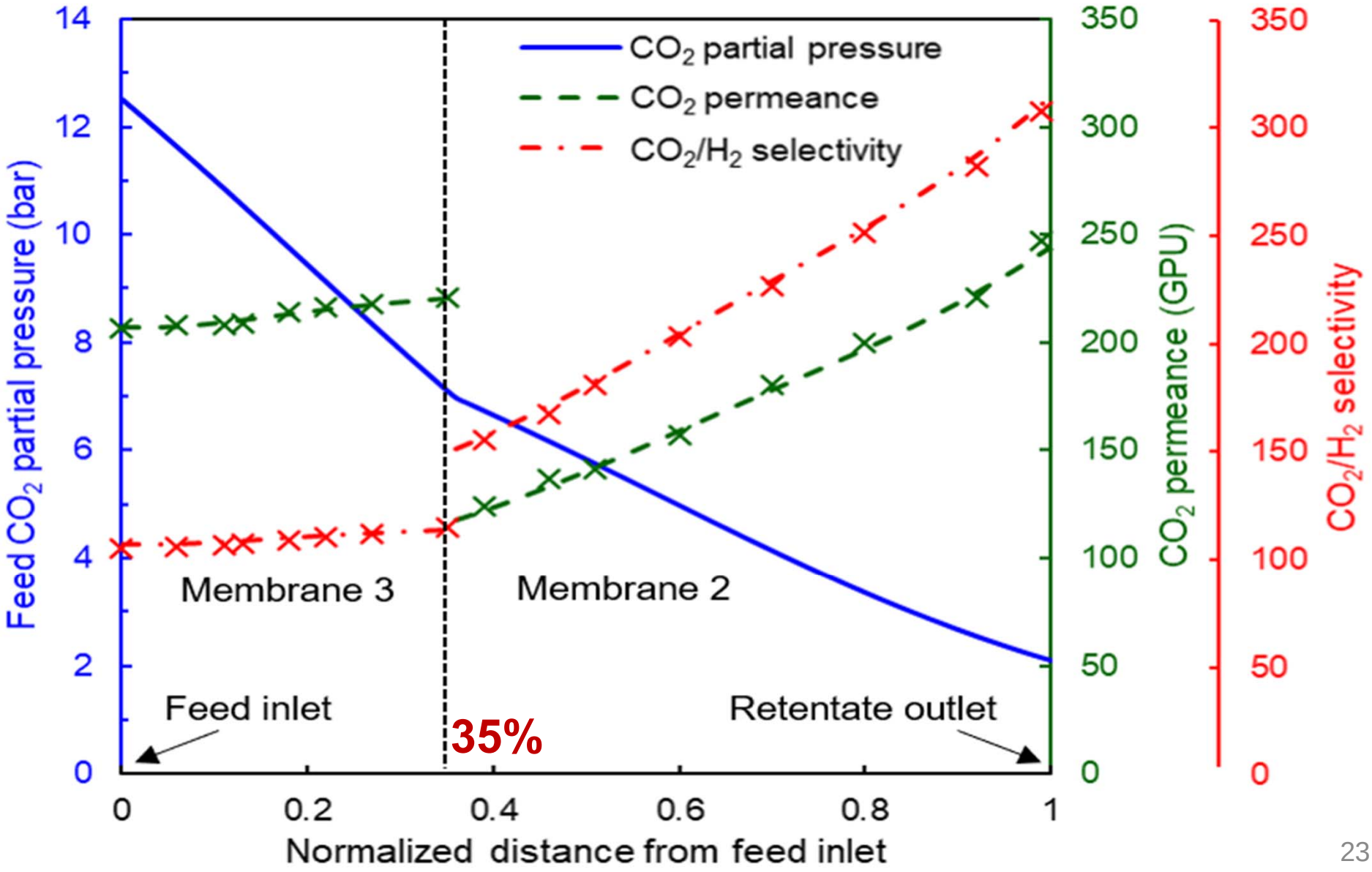
Membrane Performances

Simulated Syngas at 107°C and 31.7 bar

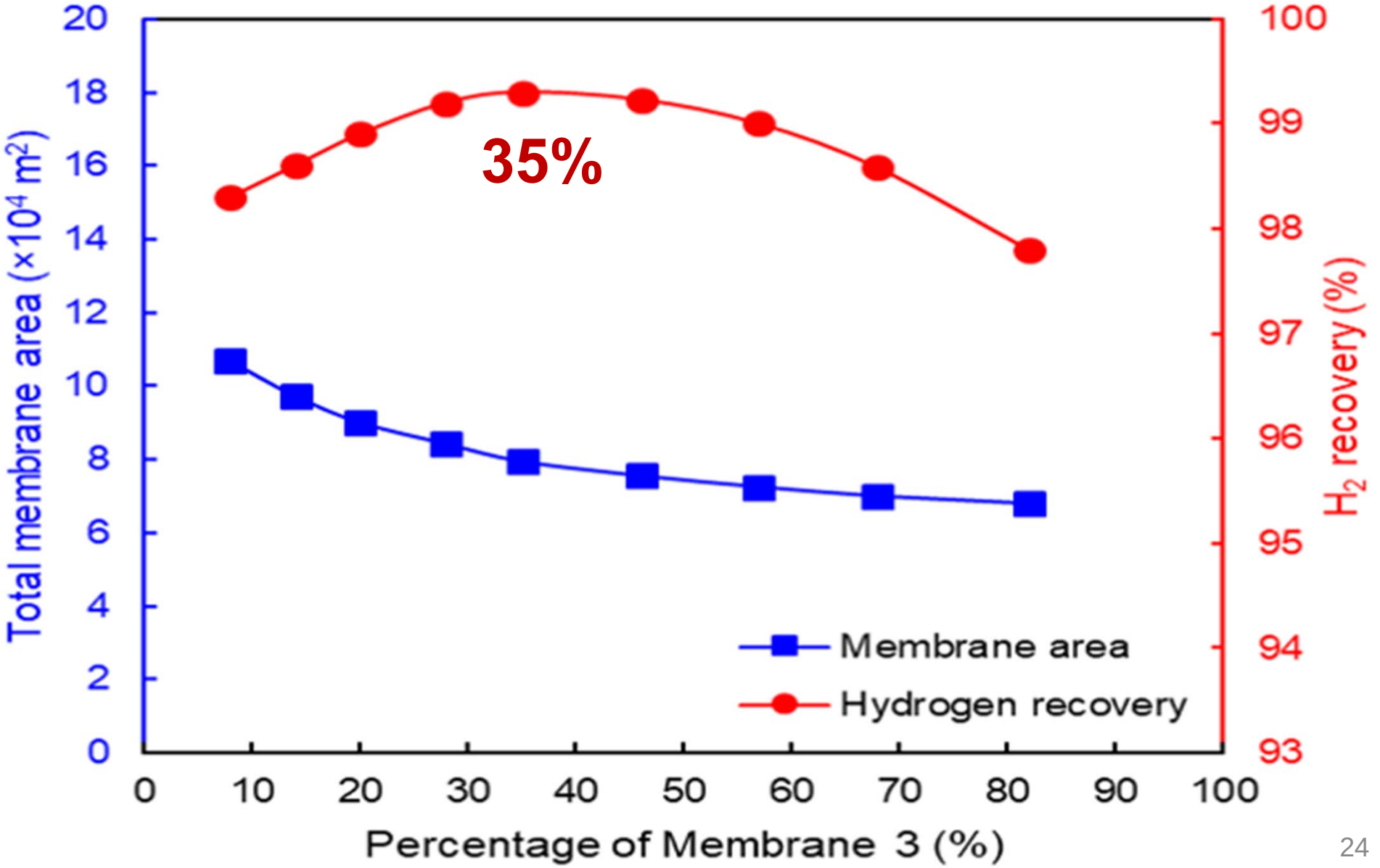




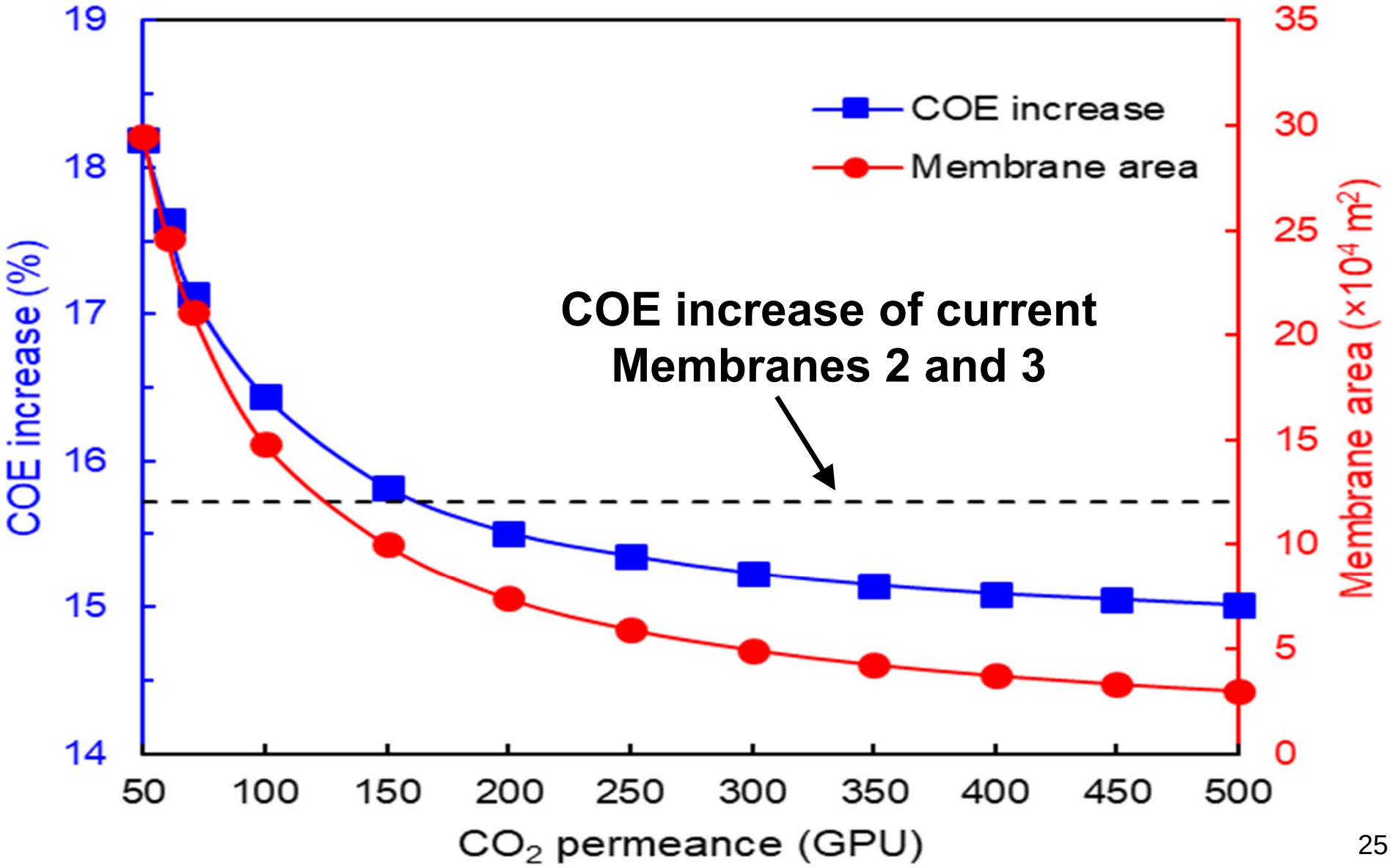
Effect of Carrier Saturation Phenomenon on Performance



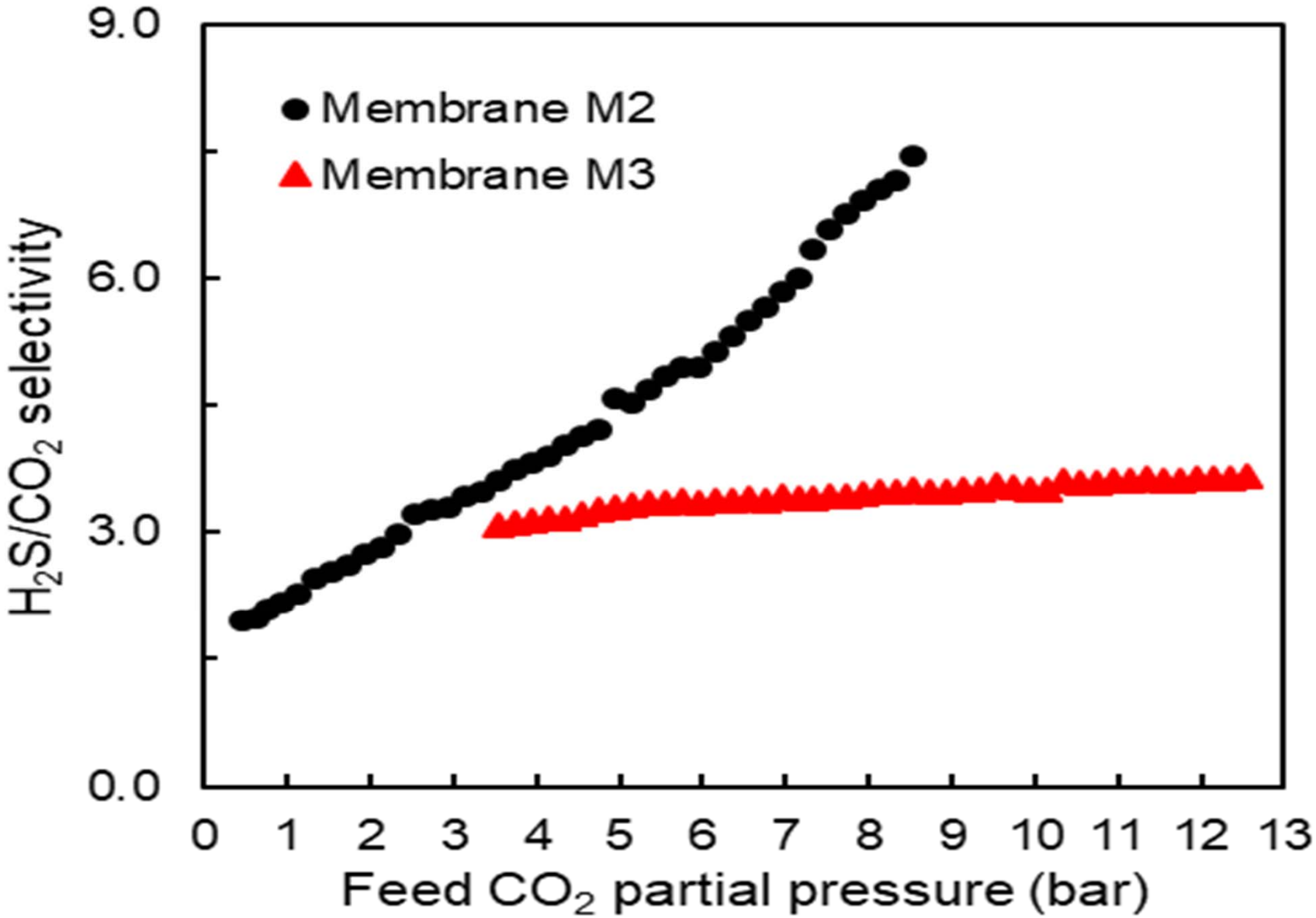
Effects of Membrane Allocation on Membrane Area and H_2 Recovery



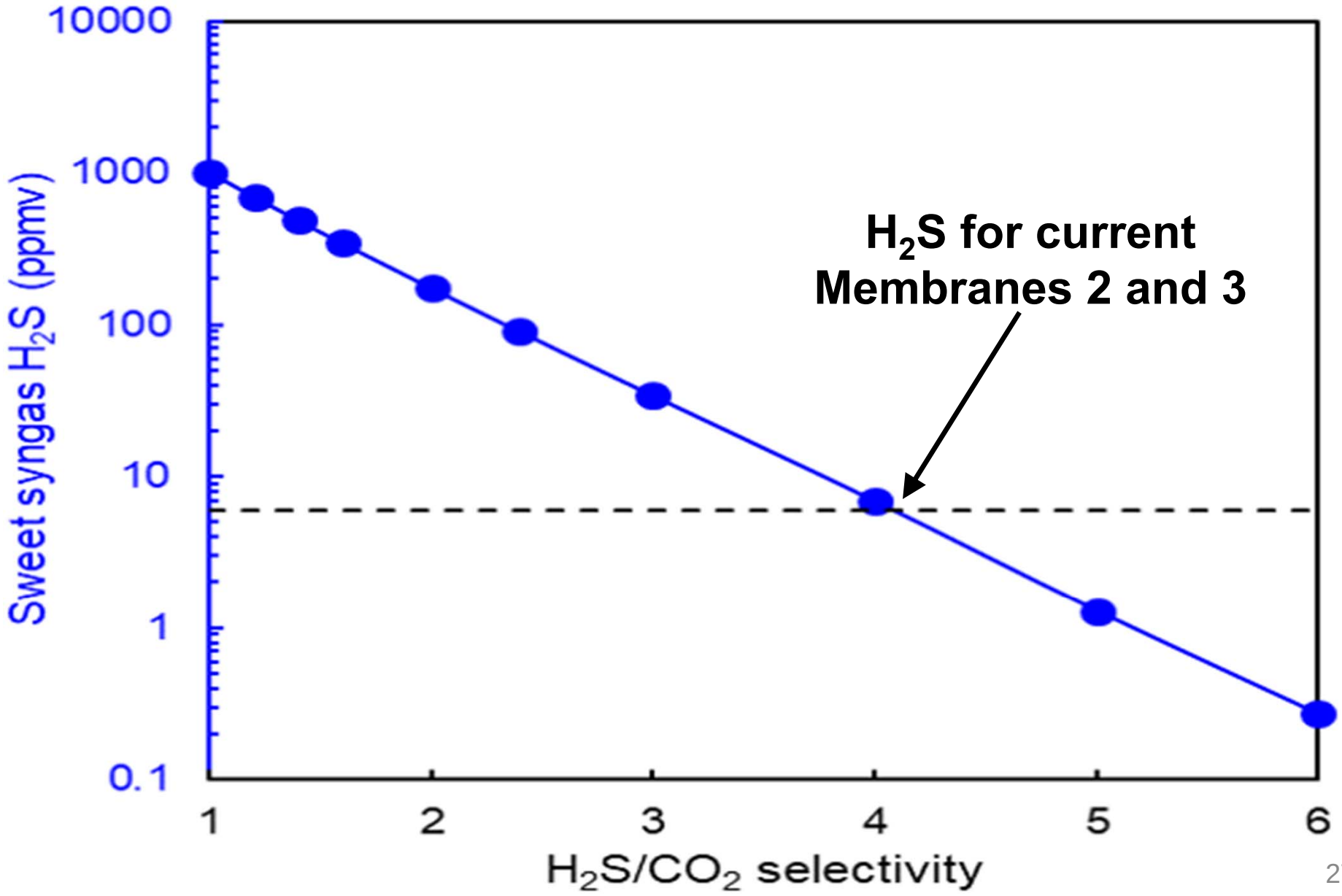
Effect of CO_2 Permeance on Cost of Electricity Increase



Membranes Synthesized with Tuned H_2S/CO_2 Selectivities



Effect of H_2S/CO_2 Selectivity on H_2S Concentration in Retentate



Summary

- **Post-Combustion CO_2 Capture from Flue Gas**
  - **Composite membranes synthesized in lab**
    + 1450 GPU with 185 selectivity at 67°C
  - **Membrane scaled up successfully**
  - **Membrane modules fabricated & scaled up successfully**
  - **Modules tested at NCCC performed similarly to those in OSU lab**
    + Good module stability demonstrated with actual flue gas
  - **Scale-up membrane / modules promising for meeting DOE cost target of $40/tonne CO_2 (in 2007 $) for 2025**
- **Pre-Combustion CO_2 Capture from Syngas**
  - **Composite membranes synthesized in lab**
    + 206 GPU with 103 selectivity at 107°C and 12.5 bar CO_2
  - **CO_2 capture process proposed for 107°C and 31.7 bar**
  - **6 ppm H_2S in H_2 product achievable**
  - **TEA shows 15.66% increase in COE**

Acknowledgments

José Figueroa **David Lang** **Dean Bell**
Robert Lambrecht **Tony Wu** **Matt Usher**
– Strong Efforts & Helpful Inputs for CO_2-Sel. Membranes

Luca Ansoloni **Yuanxin Chen** **Kartik Ramasubramanian**
Zi Tong **Varun Vakharia** **Dongzhu Wu**
Lin Zhao **Yanan Zhao**
– CO_2-Selective Membranes

Norman N. Li **Richard Song**
– Nanoporous Membrane Support

BASF in Wyandotte, MI – Free PES Samples
Kuraray America Inc. in Houston, TX – Free PVA Samples
Purolite Corp., Bala Cynwyd, PA – Free Ion-Exchange Resin Samples

Acknowledgments
for Financial Support

- U.S. Department of Energy
- National Science Foundation
- Ohio Development Services Agency
- Office of Naval Research

Decreasing Emissions Preserves Environment