Novel CO_2-Selective Membranes for CO_2 Capture from <1% CO_2 Sources

DE-FE0026919

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2019 NETL Technologies Integrated Review Meeting
Pittsburgh, PA, August 27, 2019

Project Objective

- **Develop a novel cost-effective membrane and design of membrane modules that capture CO_2 from <1% CO_2 sources**
  - **90% CO_2 Capture**
  - **95% CO_2 Purity**

3-Budget Period Project

- **BP1: 03/01/2016 – 02/28/2017**
  - **Conduct laboratory-scale membrane synthesis, characterization and transport performance studies**
  - **Carry out high-level preliminary techno-economic analysis**
- **BP2: 03/01/2017 – 02/28/2018**
  - **Continue laboratory-scale membrane synthesis, characterization and transport performance studies**
  - **Fabricate larger size membrane (~ 14” by > 20’)**
  - **Fabricate, evaluate and down-select from plate-and-frame and spiral-wound membrane modules**
  - **Update techno-economic analysis performed in BP 1**
- **BP3: 03/01/2018 – 08/31/2019**
  - **Fabricate 3 pilot membrane modules**
  - **Test modules with <1% CO_2 simulated gas mixture**
  - **Update techno-economic analysis**

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

Funding and Performance Dates

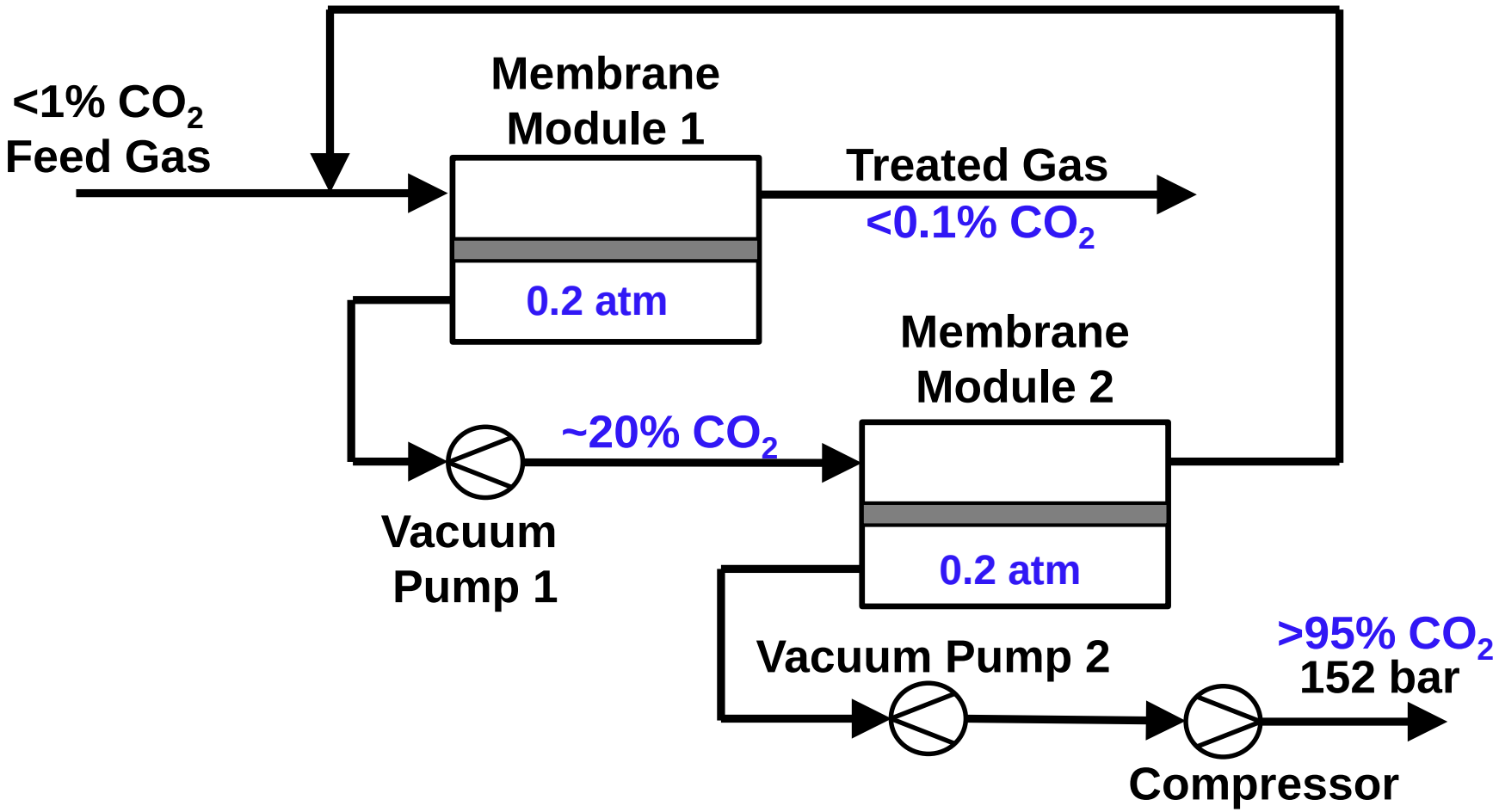
- **Total Budget: 03/01/2016 – 08/31/2019**
  DOE: $1,248,278; OSU: $372,864 (23% cost share)

  - **BP1: 03/01/2016 – 02/28/2017**
    DOE: $407,616; OSU: $121,756

  - **BP2: 03/01/2017 – 02/28/2018**
    DOE: $419,628; OSU: $125,344

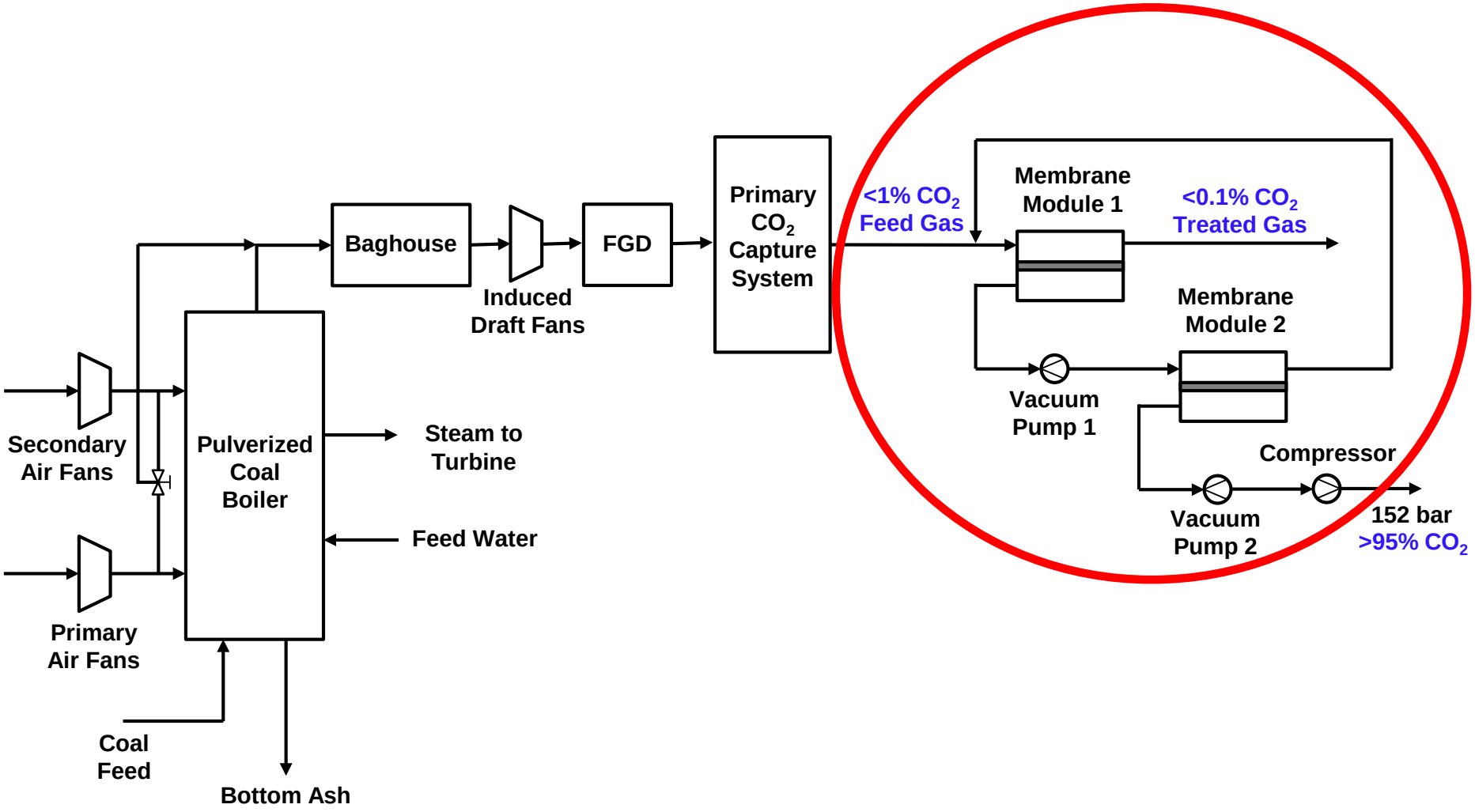
  - **BP3: 03/01/2018 – 08/31/2019**
    DOE: $421,034; OSU: $125,764

Process Proposed for CO_2 Capture from <1% CO_2 Sources



- **Proposed membrane process does not require cryogenic distillation (compared to competition)**

Location of Proposed Technology in Coal-fired Power Plant



Selective Amine Polymer Layer on Polymer Support

- **Selective Amine Polymer Layer**
  - **Facilitated transport of CO_2 via reaction with amine**

$$CO_2 + R\text{-}NH_2 + H_2O \rightleftharpoons R\text{-}NH_3^+ + HCO_3^-$$

  - **Facilitated transport = flux augmentation via reaction**
  - **High CO_2 permeance and CO_2/N_2 selectivity**

BP1 Accomplishments

- **Improved 14”-wide PES Polymer Support Fabricated with Continuous Machine**
  - **13,900 GPU CO_2 permeance obtained**
- **Composite Membrane Synthesized in Lab**
  - **Elucidated carrier saturation phenomenon**
  - **980 GPU with 170 CO_2/N_2 selectivity obtained at 57°C from lab test using 1% CO_2 concentration feed gas**
    + 780 GPU with 150 CO_2/N_2 selectivity obtained using 20% CO_2 feed
- **High-Level Techno-economic Analysis Showed Capture Cost of ~$305/tonne CO_2 (in 2011 $)**
  - **~22% increase in COE**

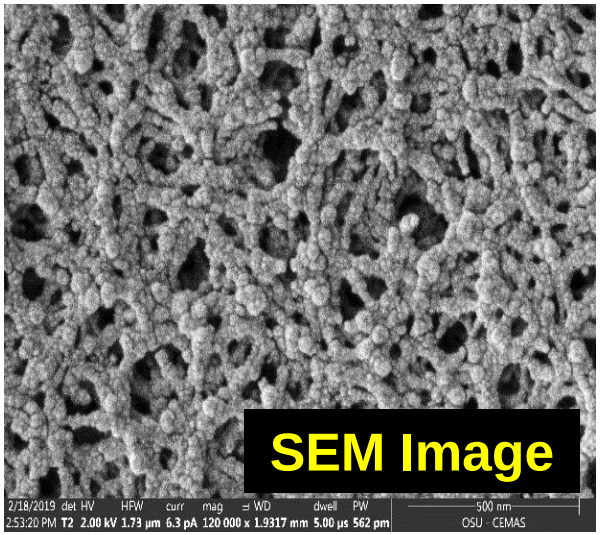
BP2 Accomplishments

- **Improved 14”-wide PES Support Fabricated with Continuous Machine (22,500 GPU)**
- **Pilot Composite Membranes Synthesized**
  - **Membrane scaled up to 14” by roll-to-roll successfully**
- **Plate-and-Frame and Spiral-Wound (SW) Modules Fabricated**
  - **Both showed ~1,500 GPU with ~220 selectivity at 57ºC**
    + Similar results to scale-up flat-sheet membrane
  - **Both gave similar and acceptable pressure drop results**
  - **Down-selected to SW module for ease of manufacture**
- **Good Module Stability (3 ppm SO_2 & 7% O_2): 1,700 h**
- **High-Level Techno-economic Analysis Showed Capture Cost of $268/tonne CO_2 (in 2011 $)**
  - **~19% increase in COE**

BP3 Accomplishments

- **Optimized Composite Membranes Synthesized**
  - **Membrane scaled up to 14” by roll-to-roll successfully**
  - **~2,300 GPU with 180 CO_2/N_2 selectivity obtained at 67ºC using 1% CO_2 conc. feed gas – similar to lab-scale results**
  - **~1,710 GPU & 145 Selectivity for 20% CO_2 conc. feed gas**
- **3-m^2 Spiral-Wound (SW) Modules Fabricated**
  - **~2,300 GPU with ~180 selectivity at 67ºC using 1% CO_2**
    - ~1,700 GPU & 140 Selectivity for 20% CO_2 conc. feed gas
    - Similar results to scale-up flat-sheet membrane
    - 1900-h good module stability obtained (3 ppm SO_2 & 7% O_2)
  - **All gave similar and acceptable pressure drop results**
- **SW Module Testing at NCCC (Related effort conducted under a separate ODSA-funded project)**
  - **Module showed ~1,450 GPU with ~180 selectivity at 67ºC**
    - Similar results to modules using simulated flue gas
  - **500-hour good module stability obtained**
  - **Similar and acceptable pressure drop results obtained**

Successful Continuous Fabrication of Affordable PES Support

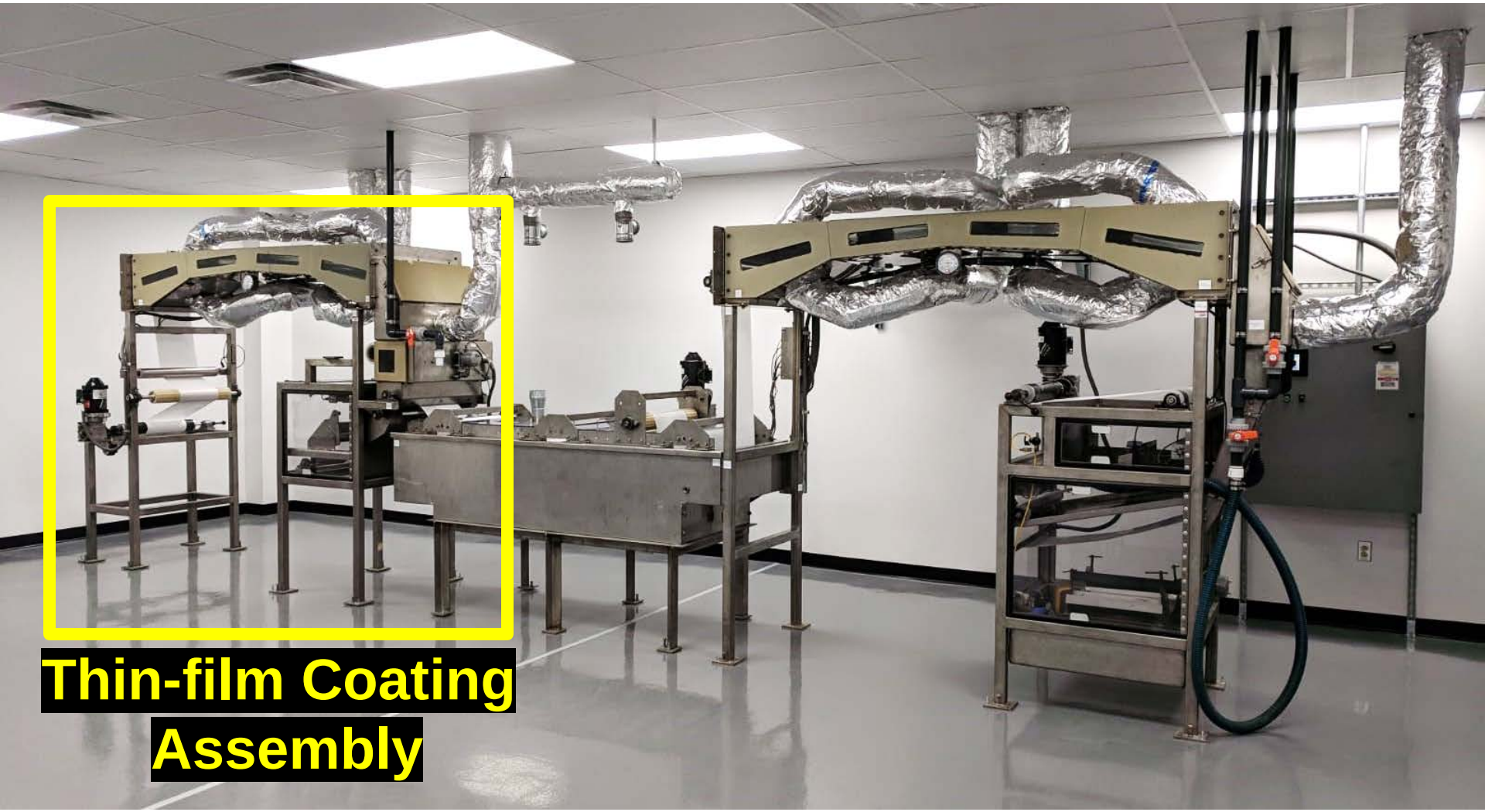


Ave. pore size = 38.6 nm, Porosity = 18.0%

- **Optimal pore size identified to reduce penetration during coating**
- **Hydrophilic additives improved adhesion & open porous morphology**

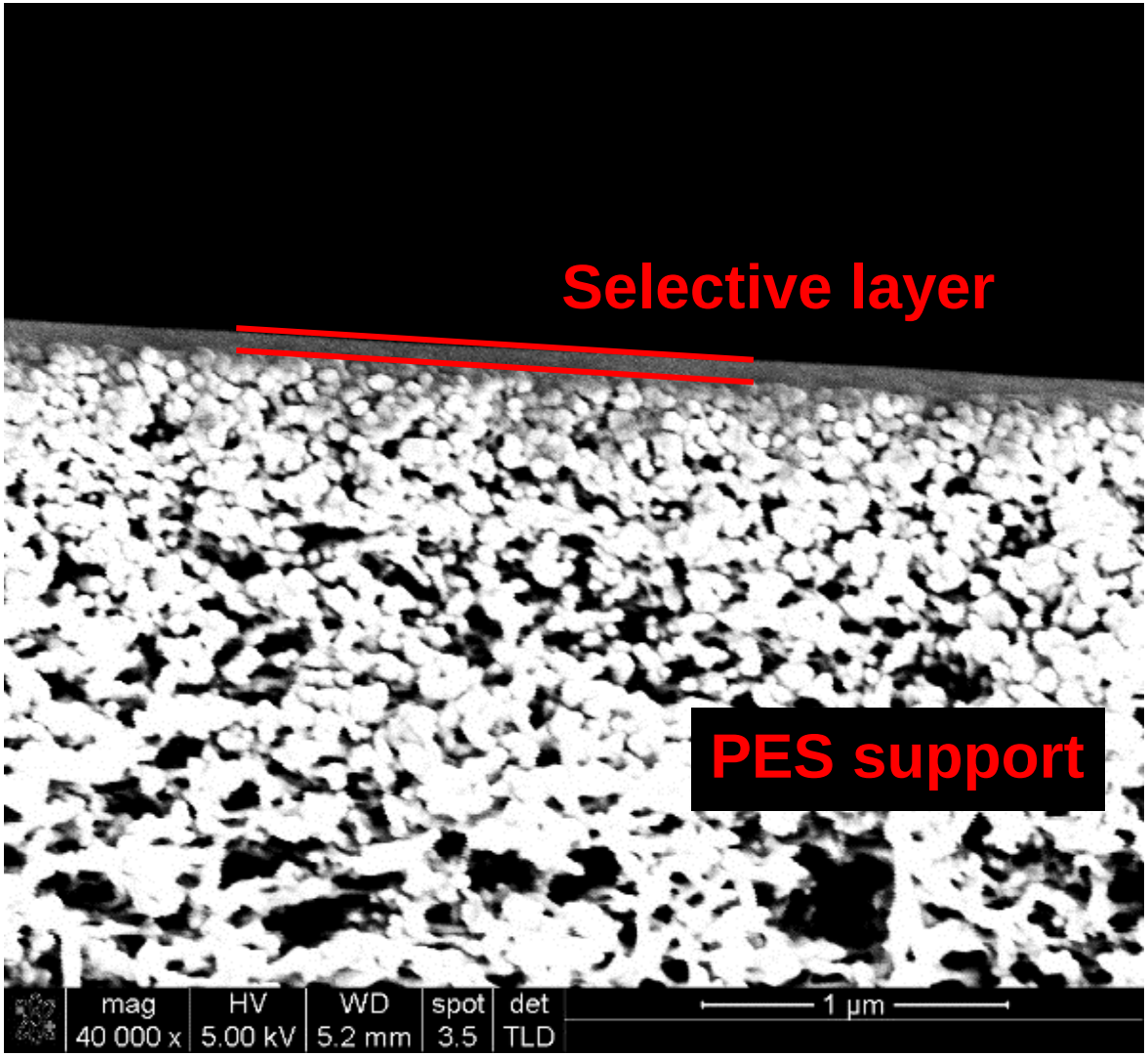
Scale-up of PES Support and Composite Membrane

Continuous Membrane Fabrication Machine at OSU



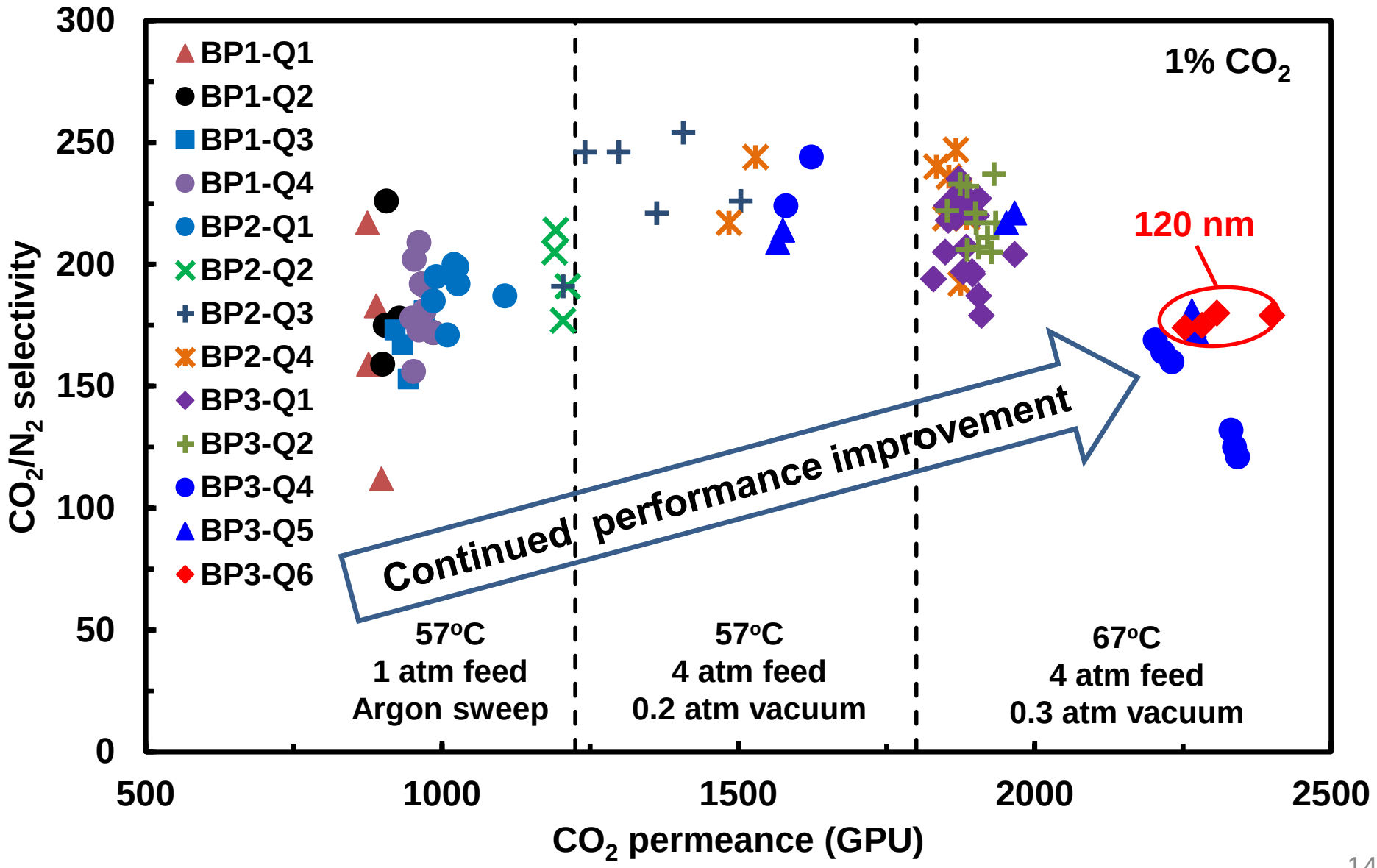
Composite Membrane Synthesized

Selective Amine Polymer Layer on PES Support



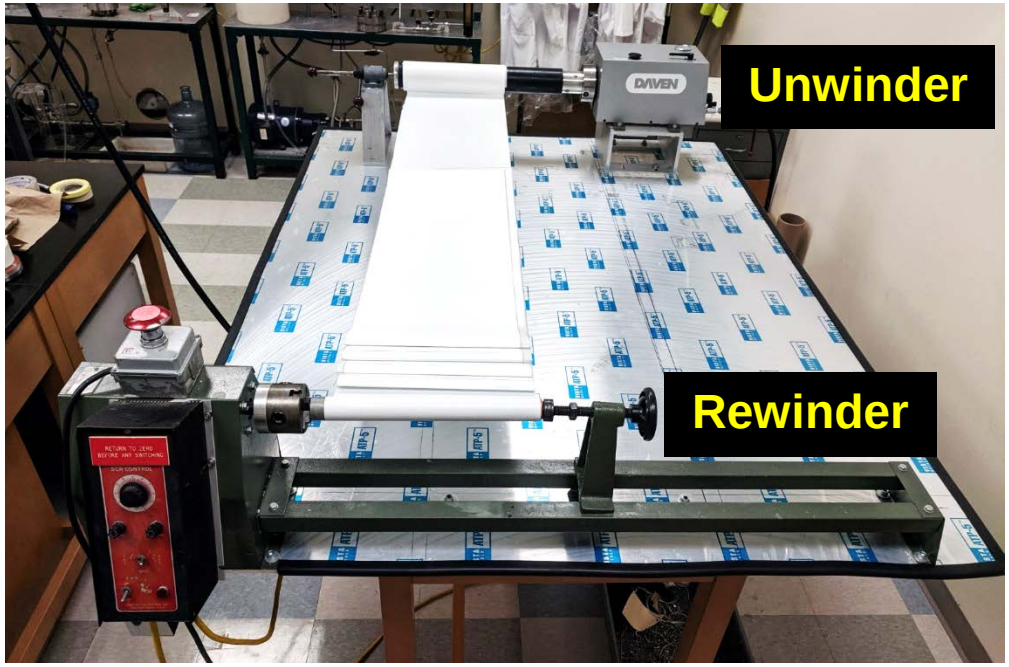
Selective layer = 120 nm

Significant Membrane Performance Improvement Achieved



Spiral-Wound Membrane Module Fabricated

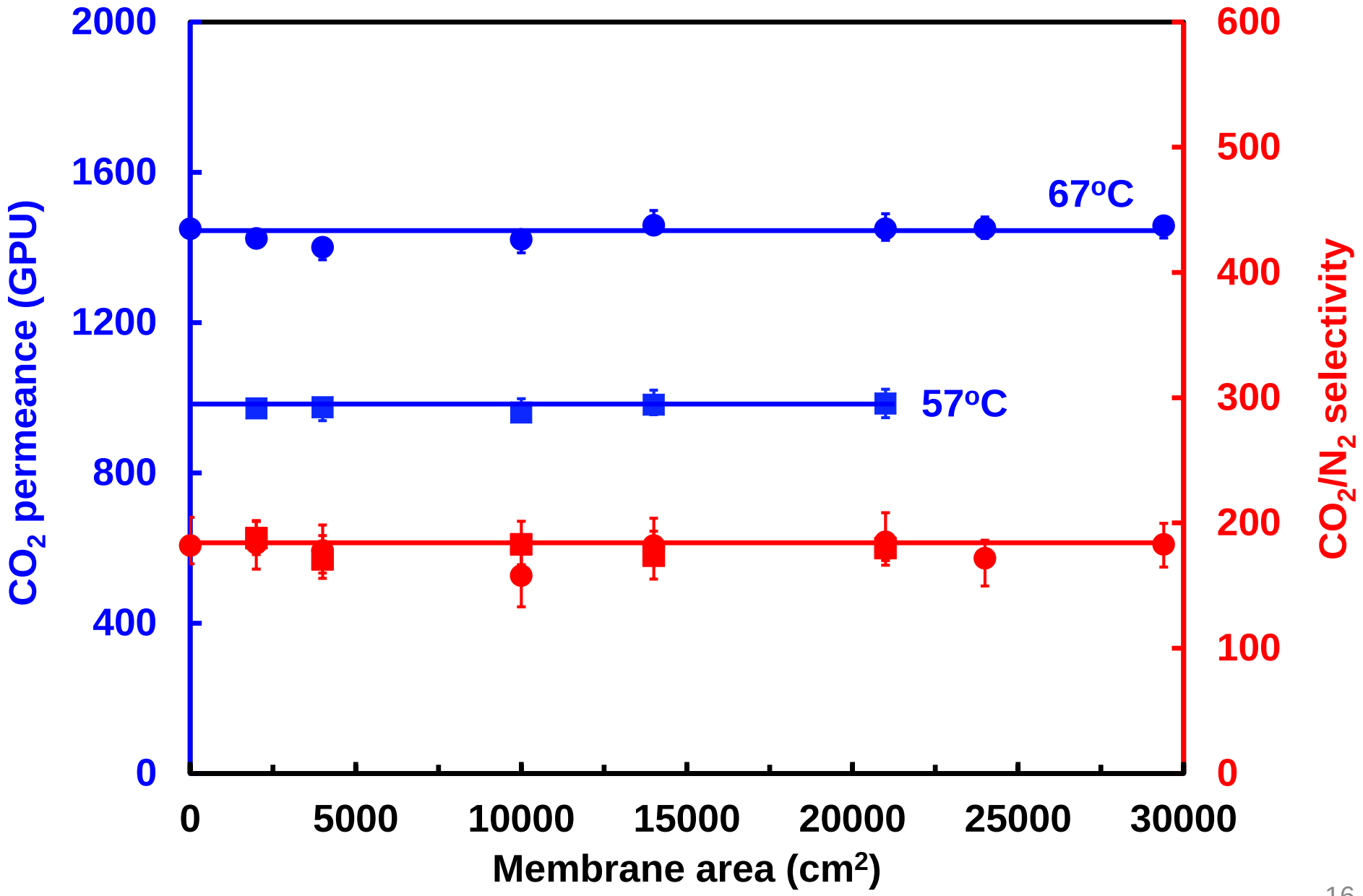
Element Rolling Machine



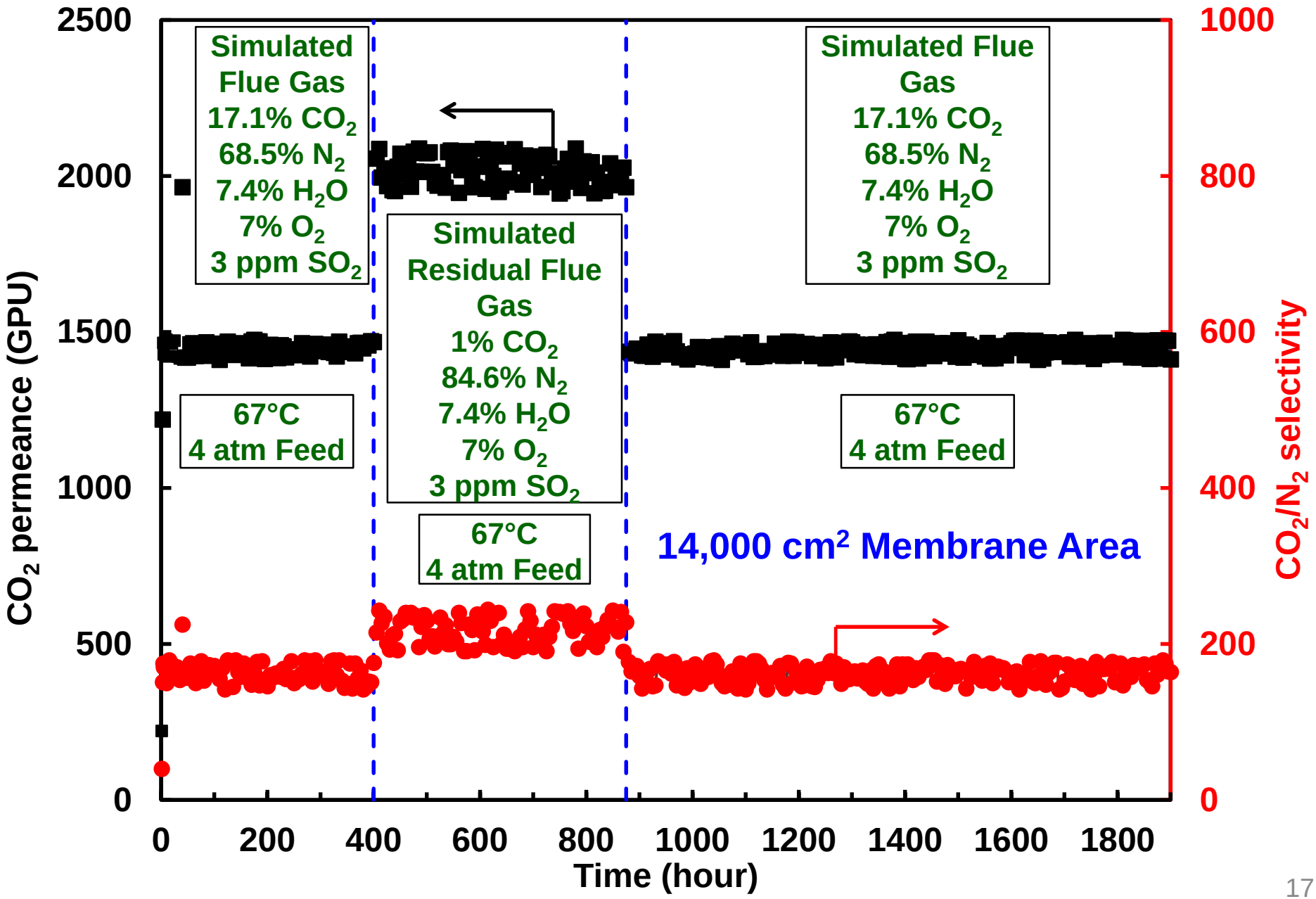
Spiral-Wound Membrane Element

Membrane Module

Successful Scale-up of SW Modules



Good SW Module Stability Obtained



High-Level Techno-Economic Calculations

- **Basis: Membrane Results at 67ºC**
  - **2,307 GPU & 180 Selectivity for 1% CO_2 concentration feed gas**
  - **1,713 GPU & 145 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**
  - **32.3 tonne/h of CO_2 captured from 1% CO_2 source**
  - **$81 million bare equipment cost**
    - ➢ Membrane 18%, blowers and vacuum pumps 76%, others 6%
  - **1.45 ¢/kWh (1.01 ¢/kWh capital cost, 0.21 ¢/kWh fixed cost, 0.20 ¢/kWh variable cost, and 0.03 ¢/kWh T&S cost)**
    - ➢ COE = 8.09 ¢/kWh for 550 MW supercritical pulverized coal power plant
  - **$247/tonne capture cost ($14.5/MWh × 550 MW/(32.3 tonne/h))**
  - **17.9% Increase in COE (1.45/8.09 = 17.9%)**

Acknowledgments

David Lang & José Figueroa, **DOE/NETL**
Matt Usher & Dean Bell, **AEP Eng. Services**
Great efforts and strong inputs

Tony Wu & Bob Lambrecht, **NCCC Team**
Excellent analytical and mechanical supports

Financial Supports

DOE/NETL

DE-FE0026919

- Also serving as cost share to ODSA project

ODSA (Ohio Development Services Agency)

OER-CDO-D-15-09

- AEP cost sharing
- NCCC membrane module testing