THE OHIO STATE UNIVERSITY

GTI ENERGY

U.S. DEPARTMENT OF ENERGY

DE-FE0031946

Engineering Scale Design and Testing of Transformational Membrane Technology for CO_2 Capture

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3. Trimeric Corporation (Trimeric), 4. Wyoming Integrated Test Center (ITC)

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Management Project Review Meeting
August 15 – 19, 2022

Project Overview

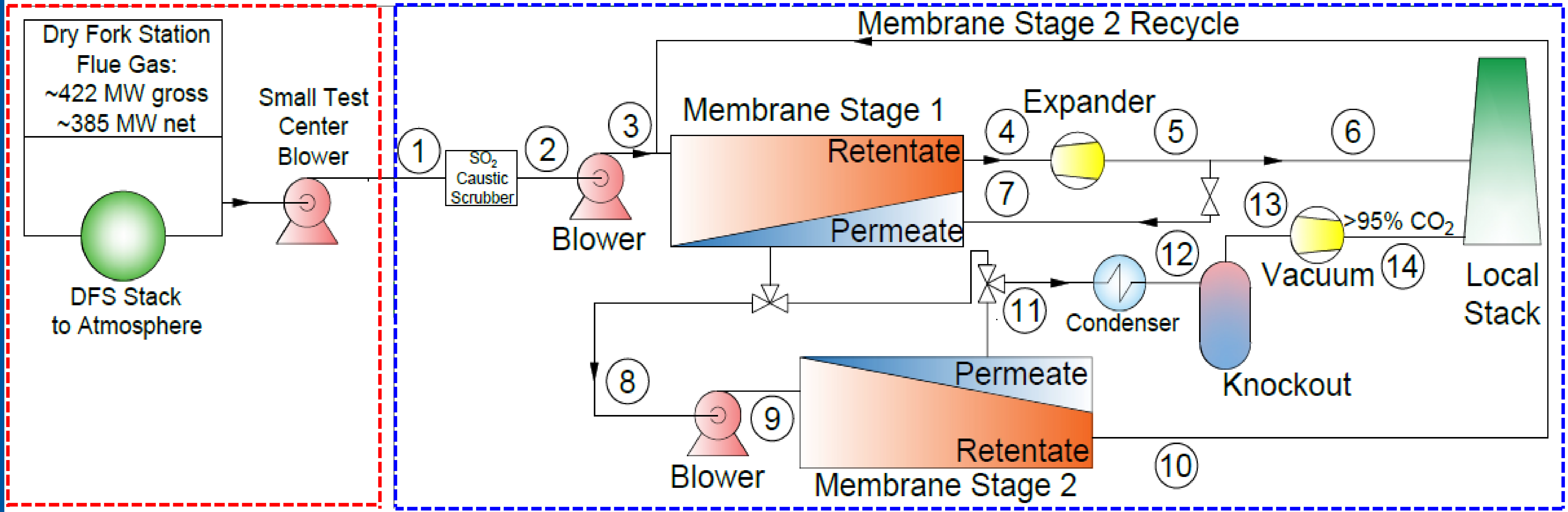
- **Performance period**: October 1, 2020 – July 31, 2025
- **Total funding**: $16.25 MM (DOE: $13 MM, Cost share: $3.25 MM)
- **Objectives**: 1) Design and build an engineering-scale CO_2 capture system using OSU's transformational membrane in commercial-sized modules; 2) Conduct tests on coal flue gas at ITC and demonstrate a continuous, steady-state operation for a minimum of two months; and 3) Gather data necessary for further process scale-up
- **Goal:** Achieve DOE's Transformational Carbon Capture performance goal of CO_2 capture with 95% CO_2 purity at a cost of $30/tonne of CO_2 captured and at a cost of electricity (COE) at least 30% less than baseline CO_2 capture approaches by 2030
- **Team**:

Member	Roles
GTI ENERGY	• Project management and planning • Skid design, selection of skid fabricator, skid installation, and testing • Support TEA and EH&S assessment
The Ohio State University	• Participate in project management and planning • Membrane and module fabrication and QA/QC testing • Support skid design and field testing, TEA and EH&S study
ITC	• Site host, lead on testing site preparation
Trimeric Corporation	• TEA and EH&S assessment

Testing on Coal Flue Gas at Wyoming Integrated Test Center

Component	Minimum	Maximum	Average
Pressure (psig)	0.36	0.54	0.45
Temperature (°C)	80	90	85
Gas composition (volume)			
CO_2	12.0%	13.1%	12.7%
O_2	1.7%	4.2%	2.5%
N_2 + Ar	66.7%	66.7%	66.7%
H_2O	15.2%	18.3%	18.1%
Contaminant levels (volume)			
SO_2	0.0 ppm	114.9 ppm	23.1 ppm
NO_x	19.2 ppm	38.4 ppm	27.8 ppm

Process Description



Roadmap

Task 1 – Project management and planning *(throughout the project)*

Engineering skid design, construction, installation, testing and TEA

BP1 10/1/20-10/31/22

- **Task 3 – Design and Costing of the Skid, and Manufacturer Selection**
- **Task 4 – Detailed Engineering Design of the Skid**

BP2 11/1/22-1/31/24

- **Task 5 – Procurement and Construction of Skid**
- **Task 7 – Testing Site Preparation**
- **Task 8 – Skid Installation at Testing Site**

BP3 2/1/24-7/31/25

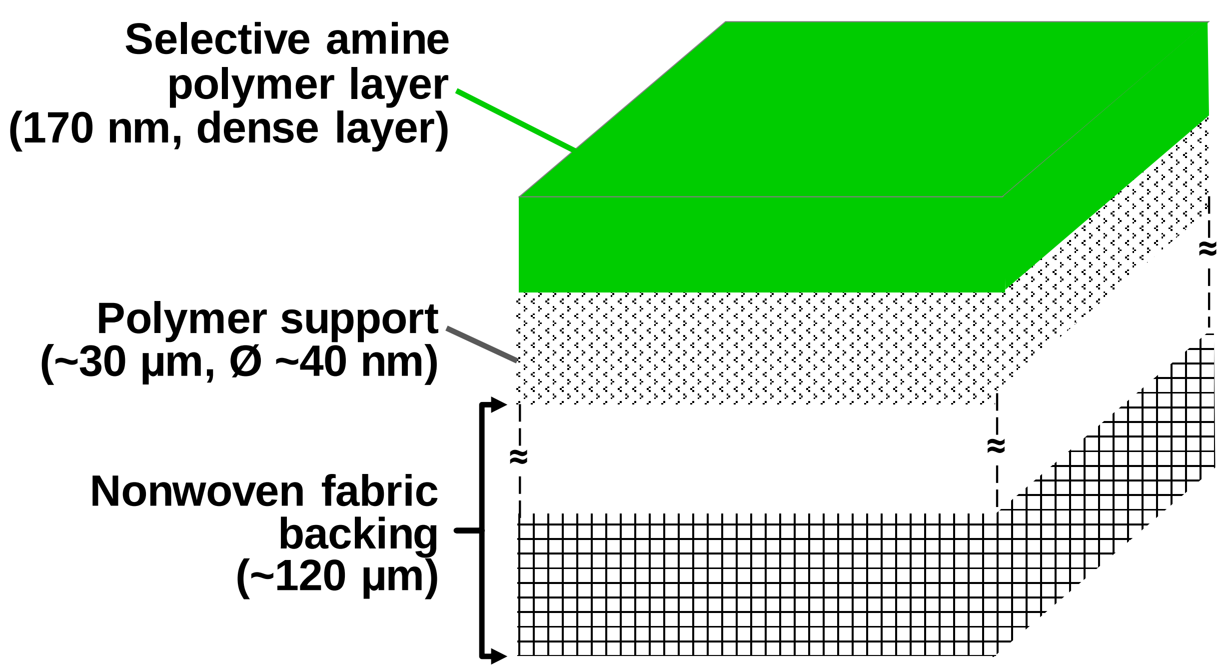
- **Task 9 – Skid Commissioning**
- **Task 10 – Parametric Testing**
- **Task 11 – Continuous Steady-State Operation**
- **Task 13 – Removal of the Skid from Testing Site**

Commercial-sized membrane module fabrication

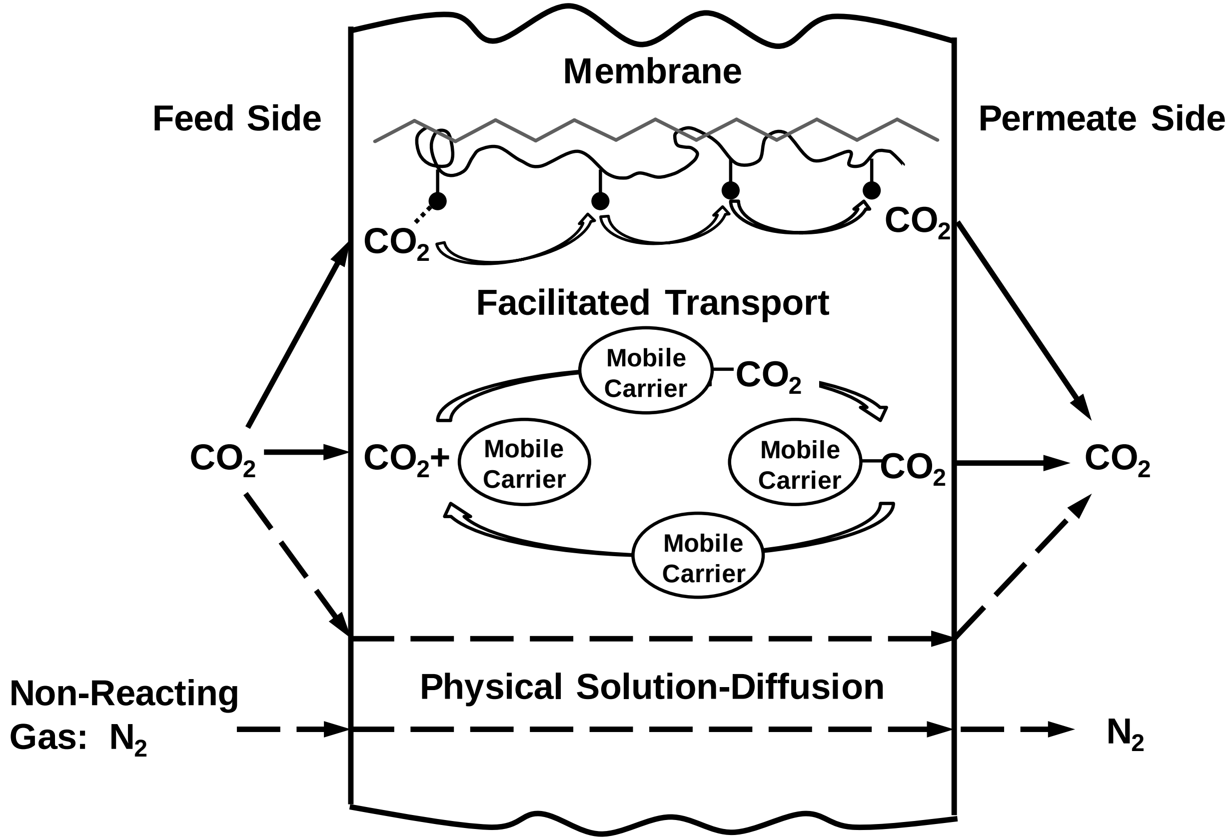
- **Task 2 – Fabrication and Testing of Prototype Membrane and Modules**
- **Task 6 – Membrane Module Fabrication and QA/QC Testing**
- **Task 12 – Identification of Commercial Membrane Manufacturer**

OSU Membrane Structure and Transport Mechanism

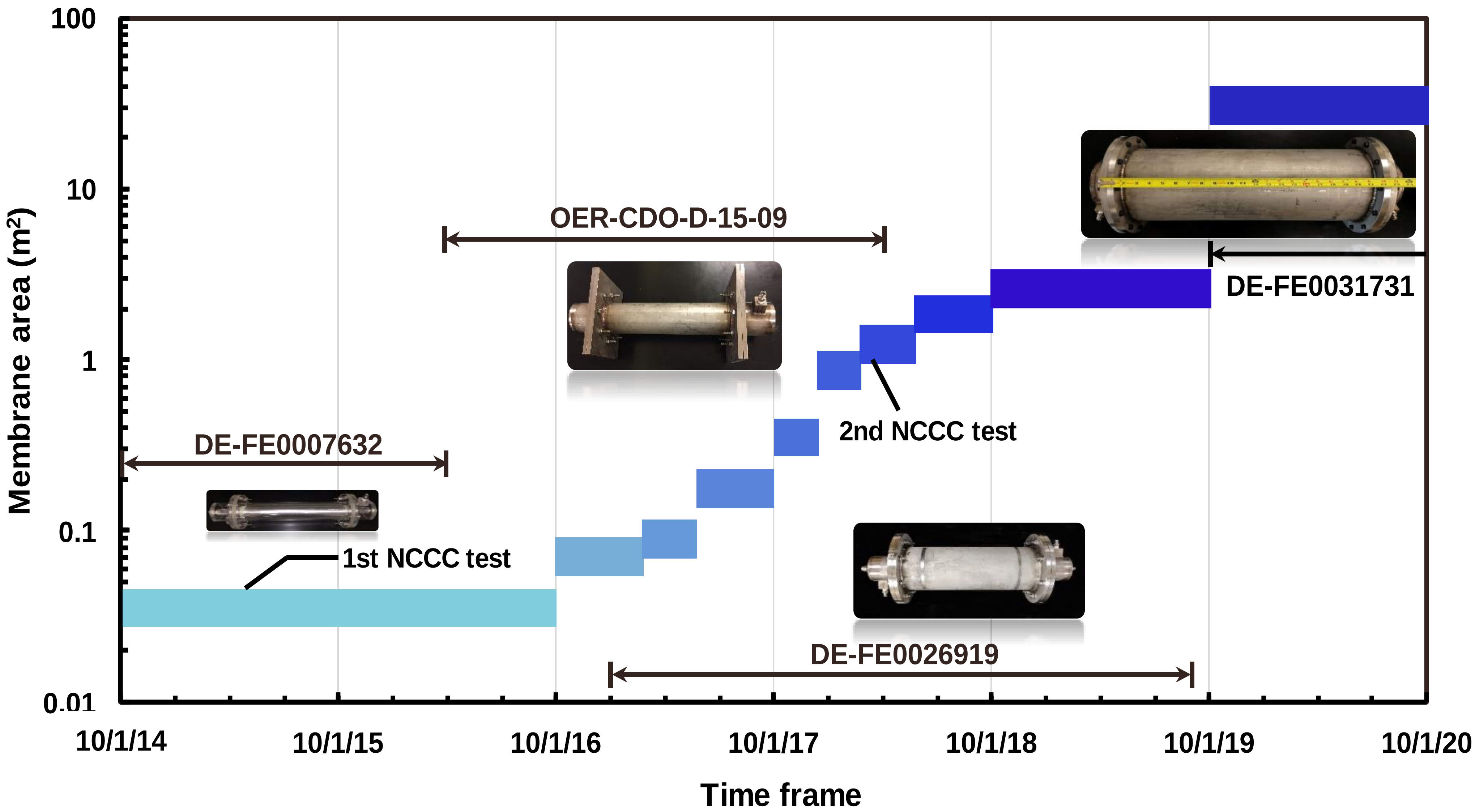
Simplicity of membrane for low cost: thin selective amine polymer layer on polymer support



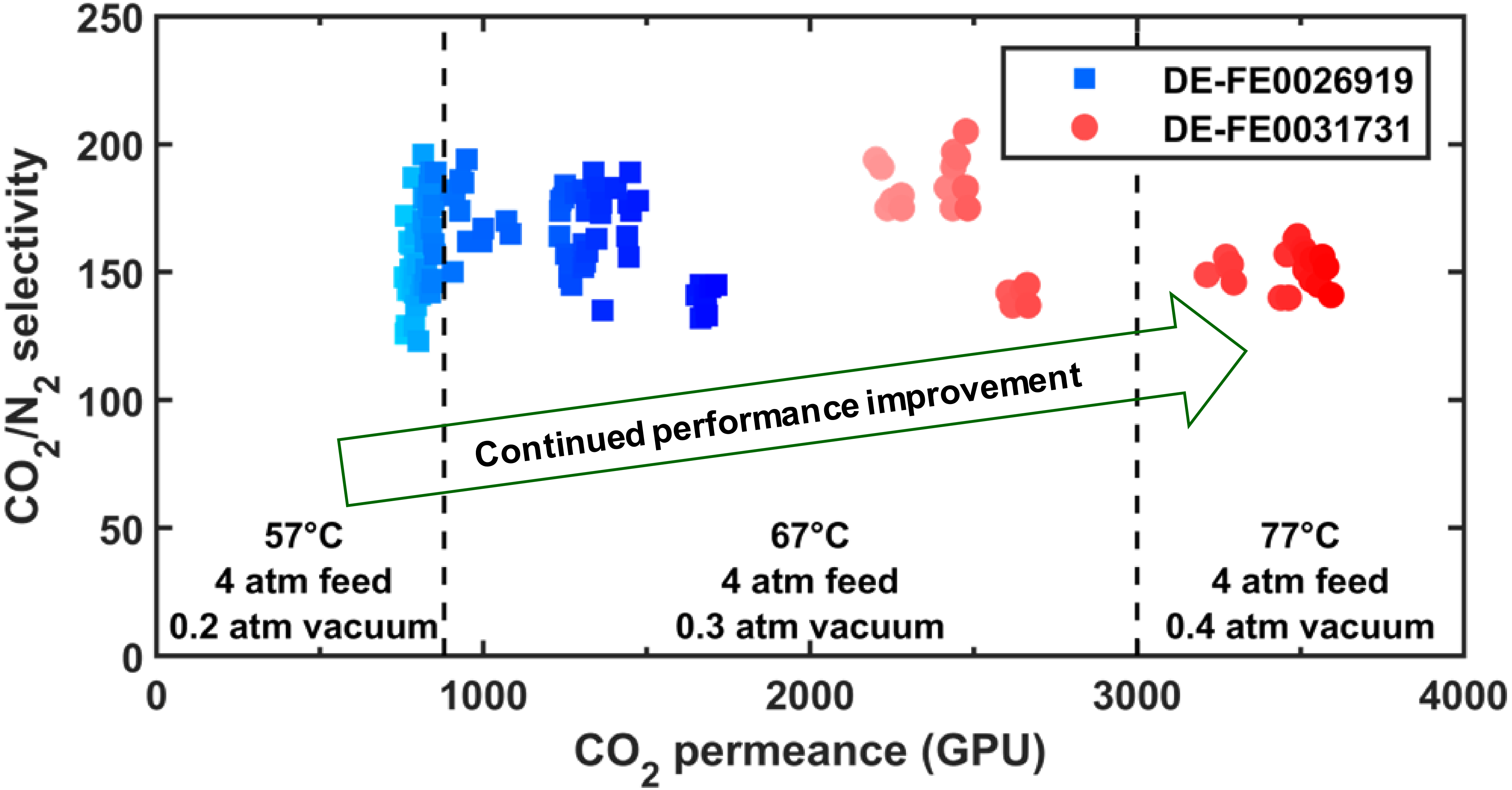
High-selectivity due to facilitated transport mechanism



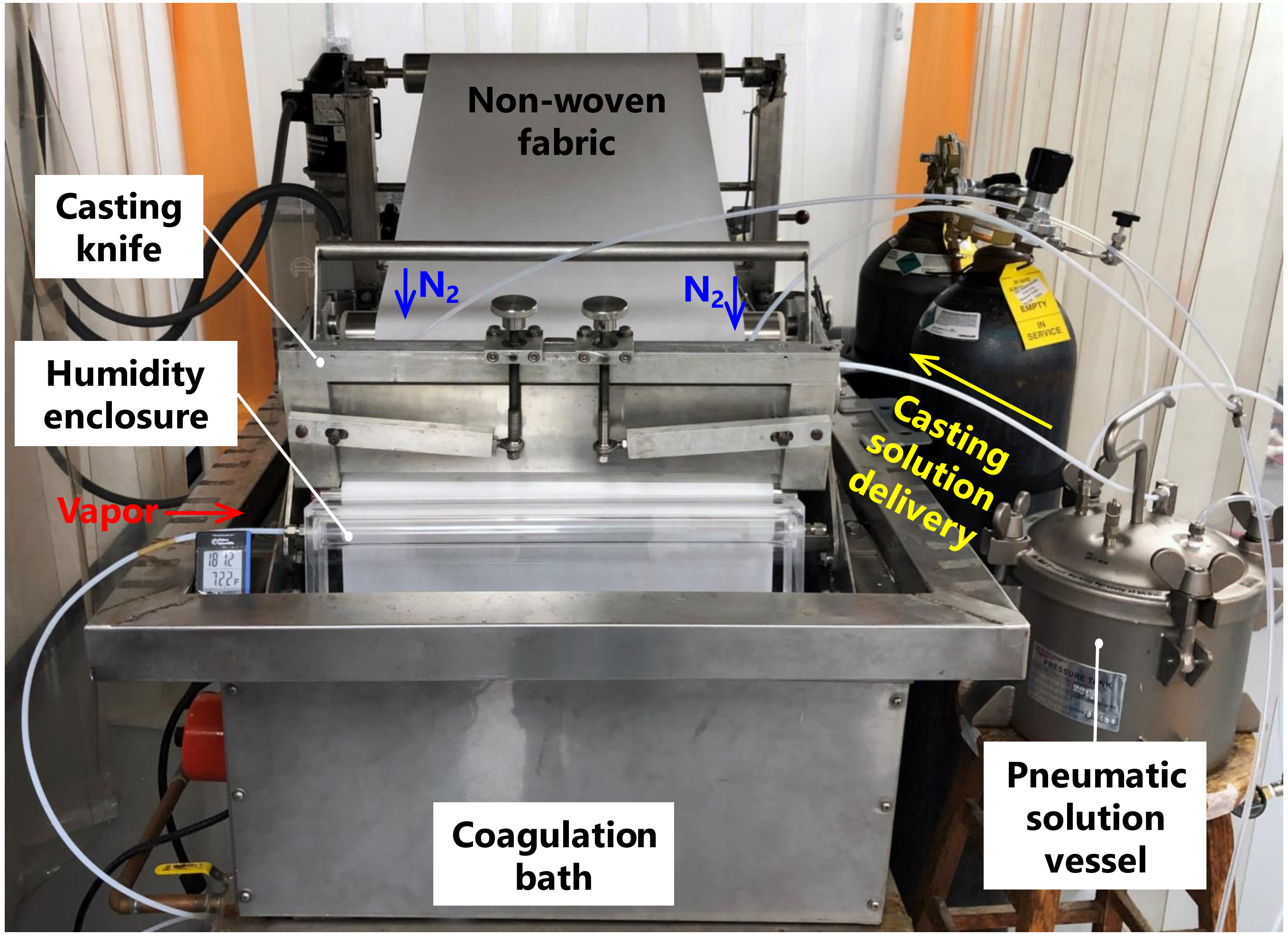
OSU Funding History and Progression of Module Scaleup

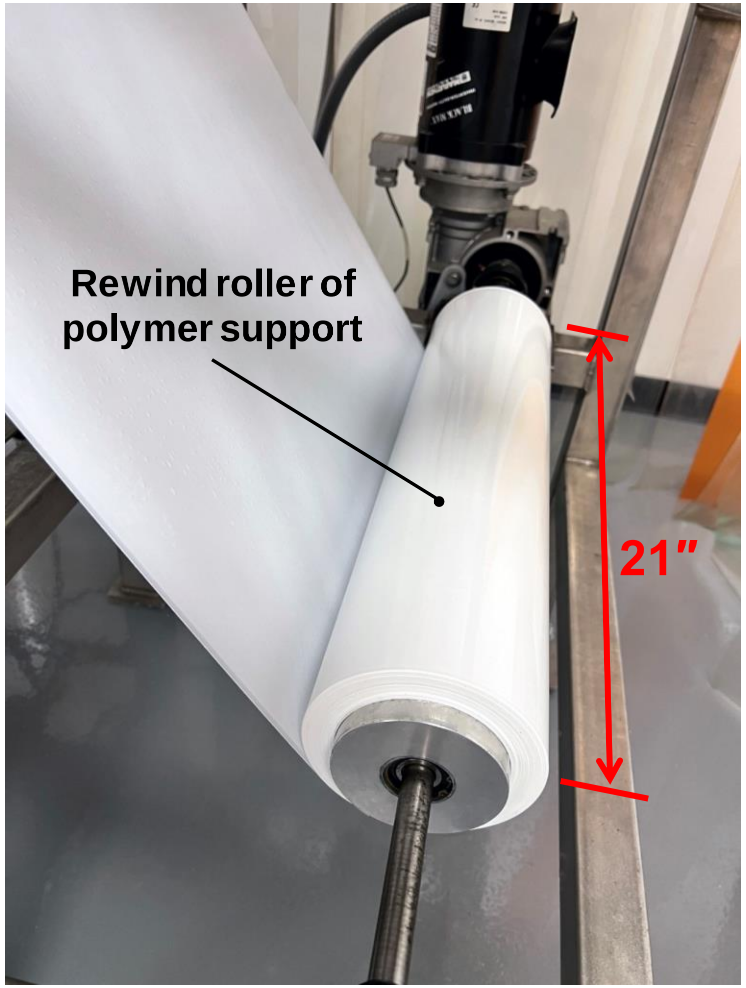


OSU Progression of Membrane Performance



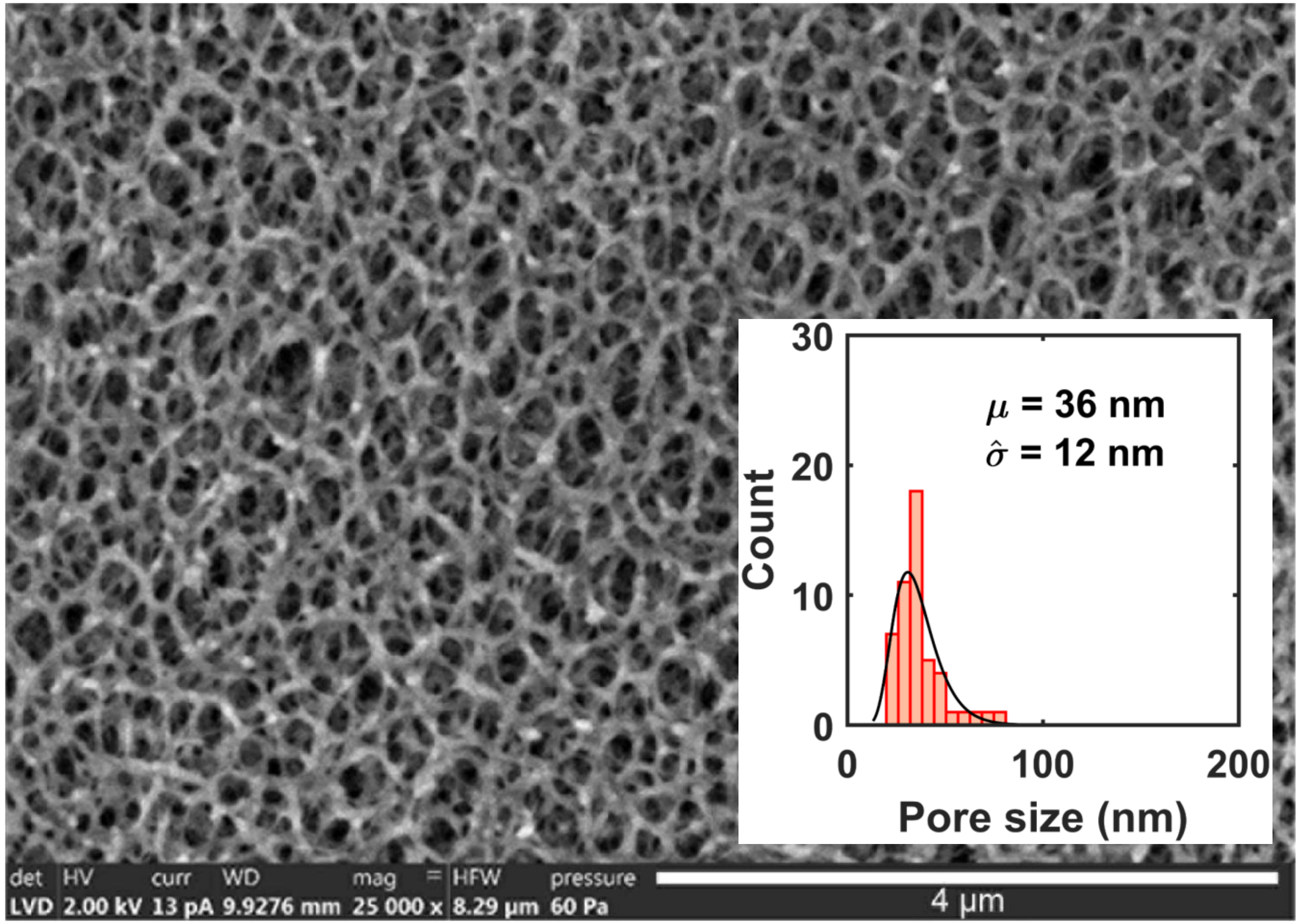
Continuous Fabrication of Polymer Support

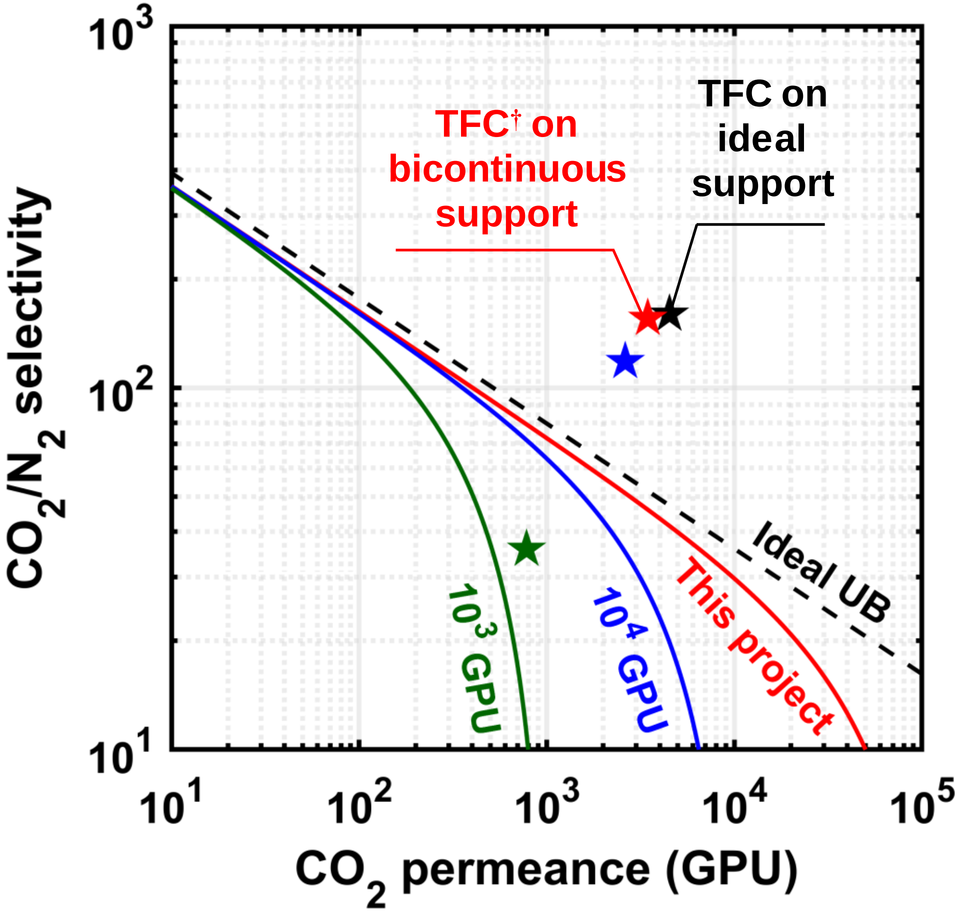




- **1,500 ft of quality support has been prepared; 100% of BP1 commitment**

Bicontinuous Polymer Support Fabricated

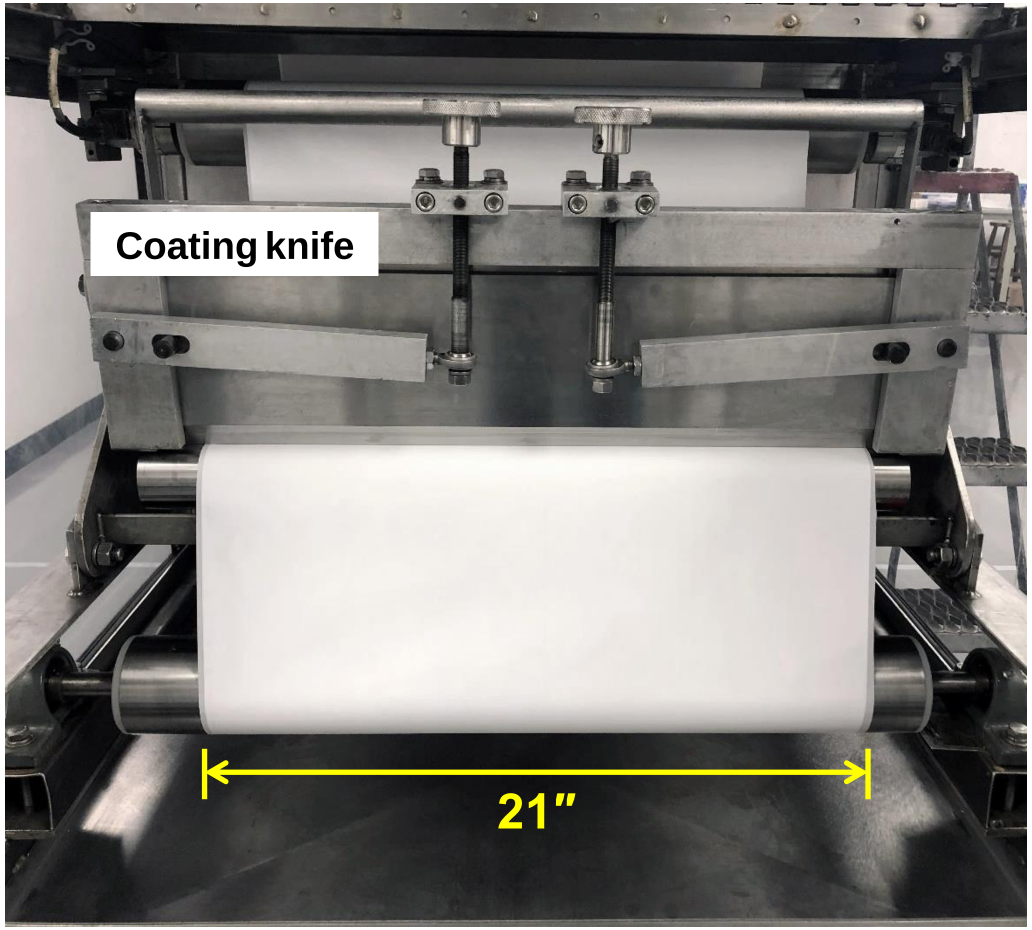




- **20% surface porosity; 130,000 GPU§ CO_2 permeance**

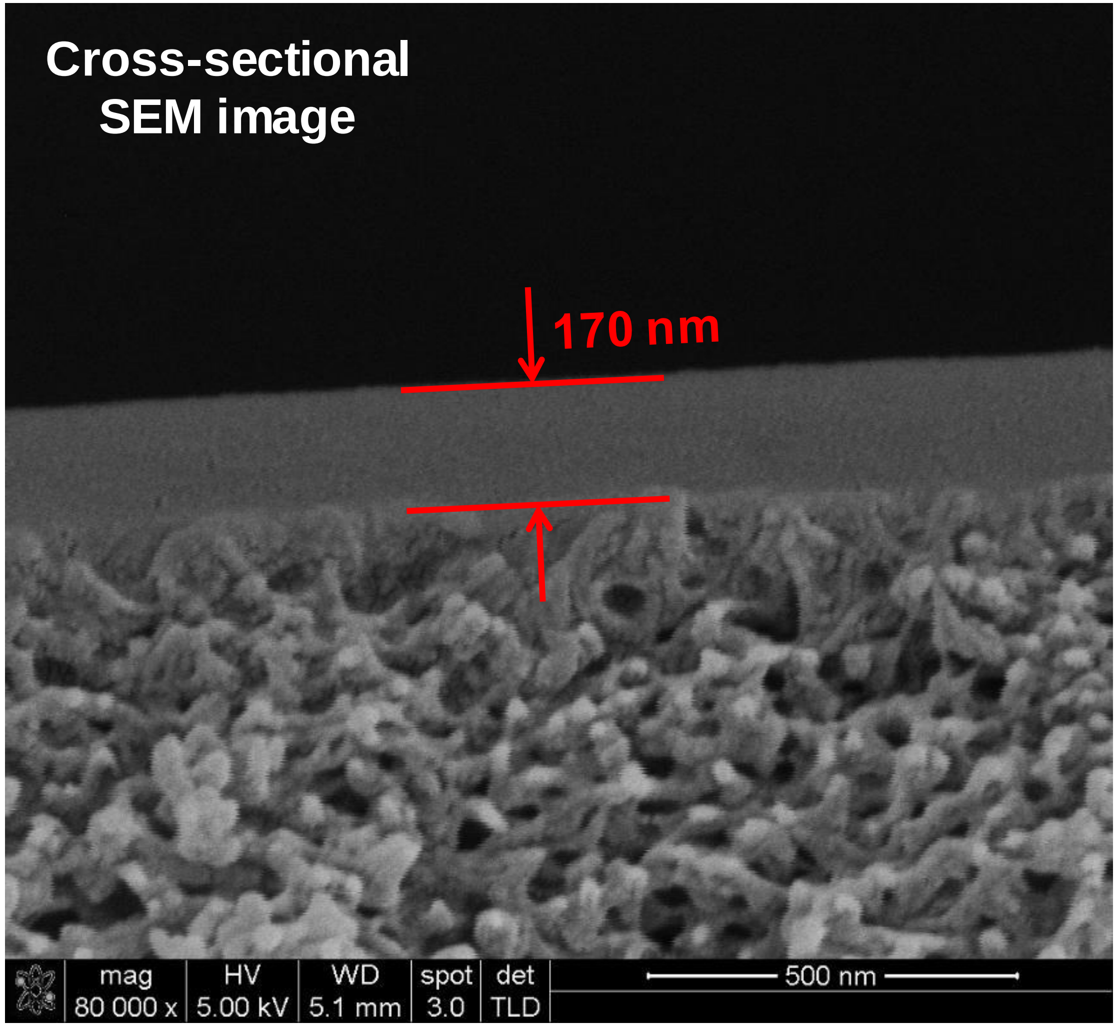
§ 1 GPU = 10^{-6} cm^3(STP) cm^{-2} s^{-1} $cmHg^{-1}$ † TFC = thin-film composite

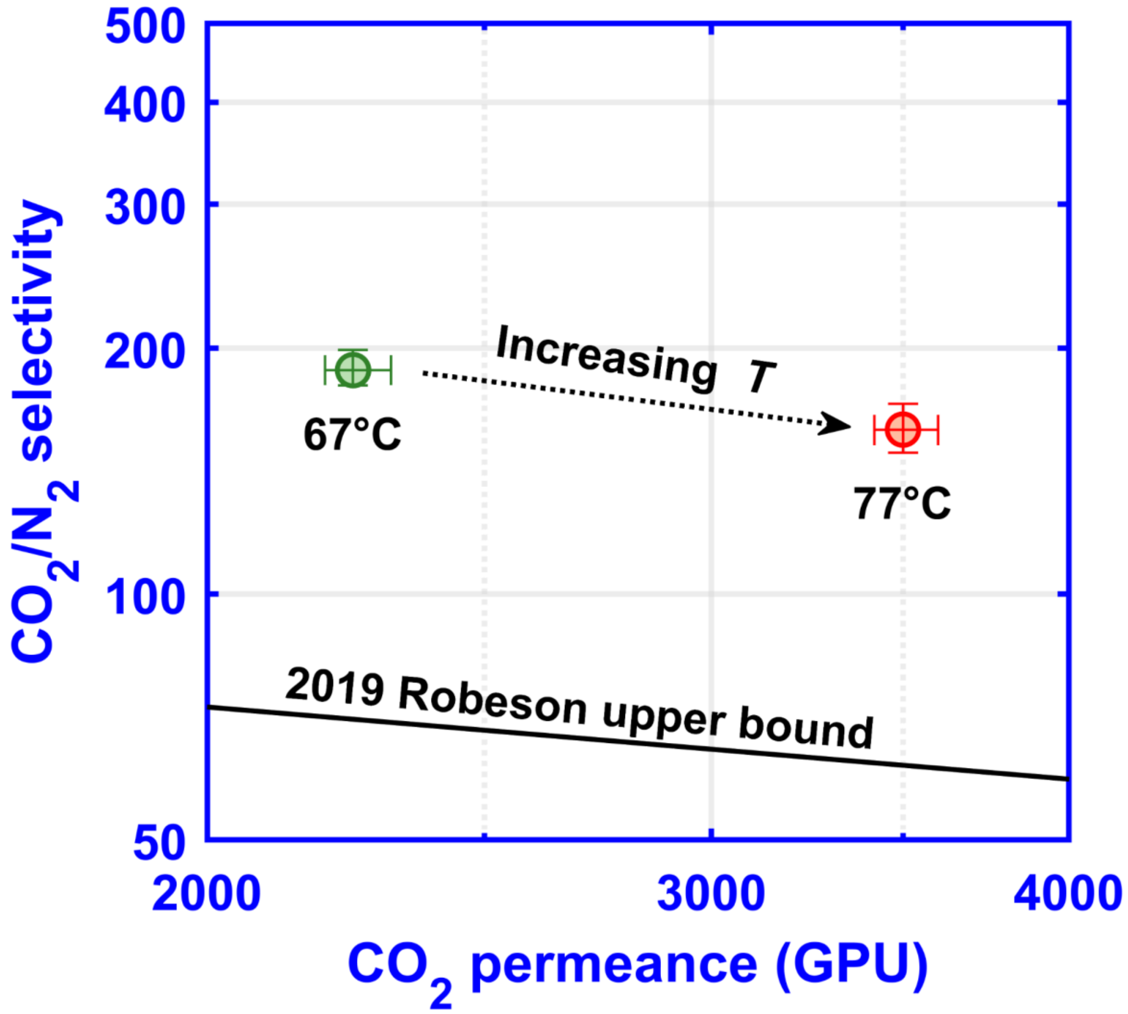
Continuous Fabrication of Transformational Membrane



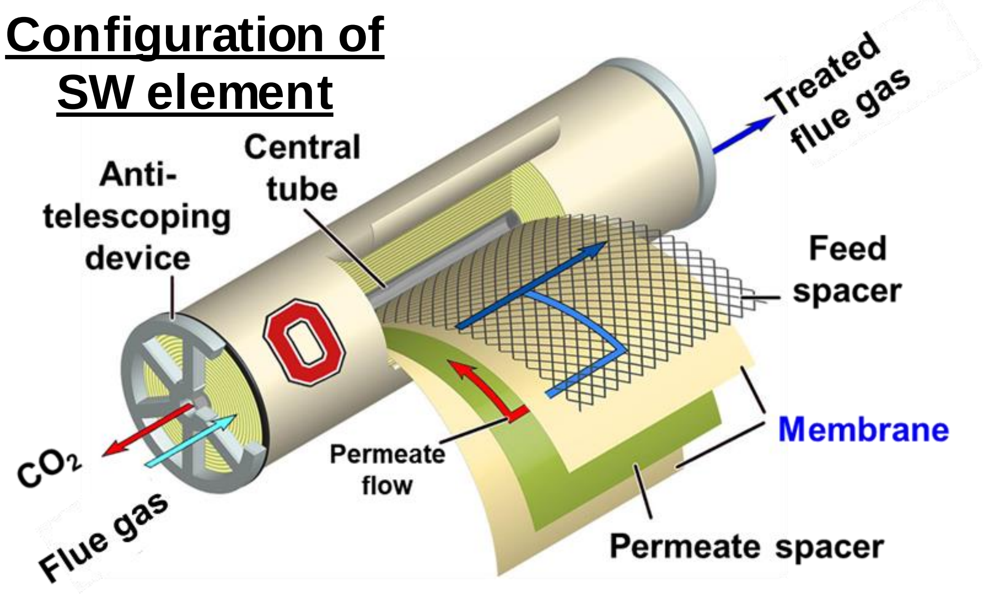
- **1,400 ft of prototype membrane has been prepared; 100% of BP1 commitment**

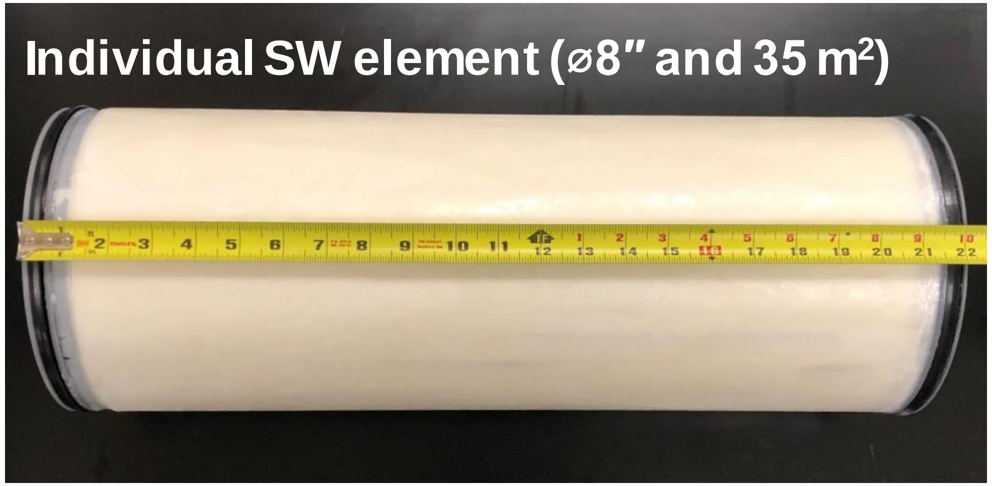
High CO_2/N_2 Separation Performance Achieved/Confirmed

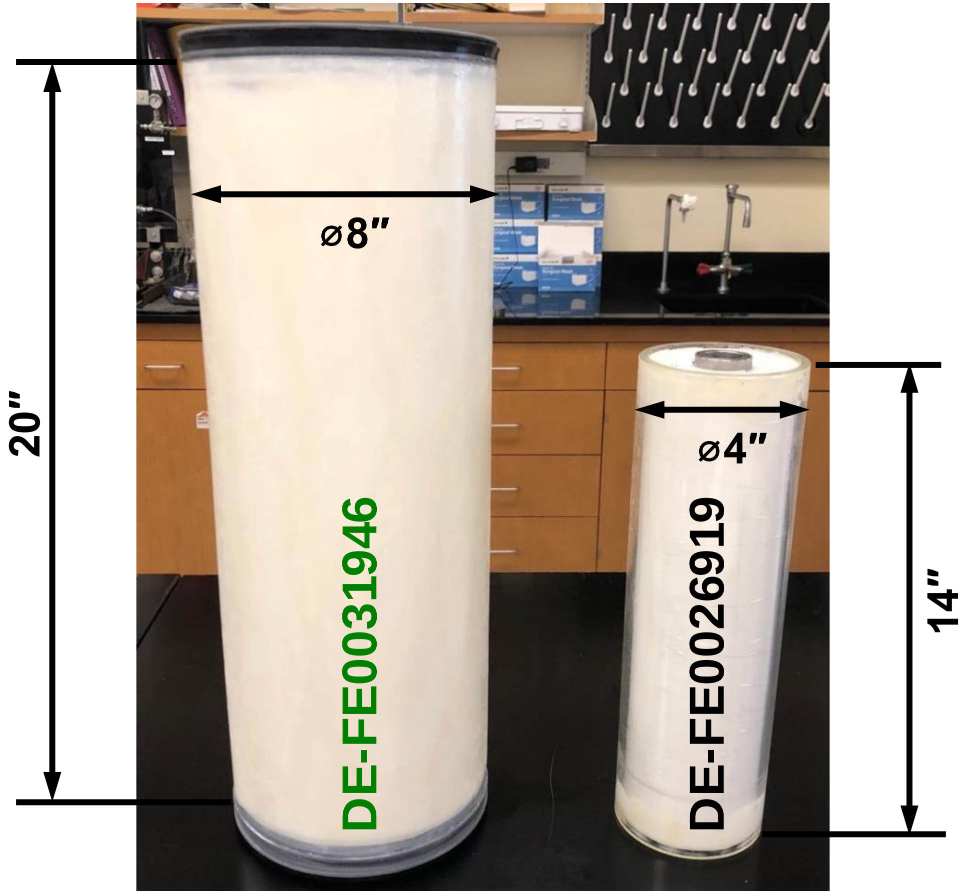




Commercial-Size 8-inch Diameter Spiral-Wound (SW) Membrane Elements/Modules Fabricated

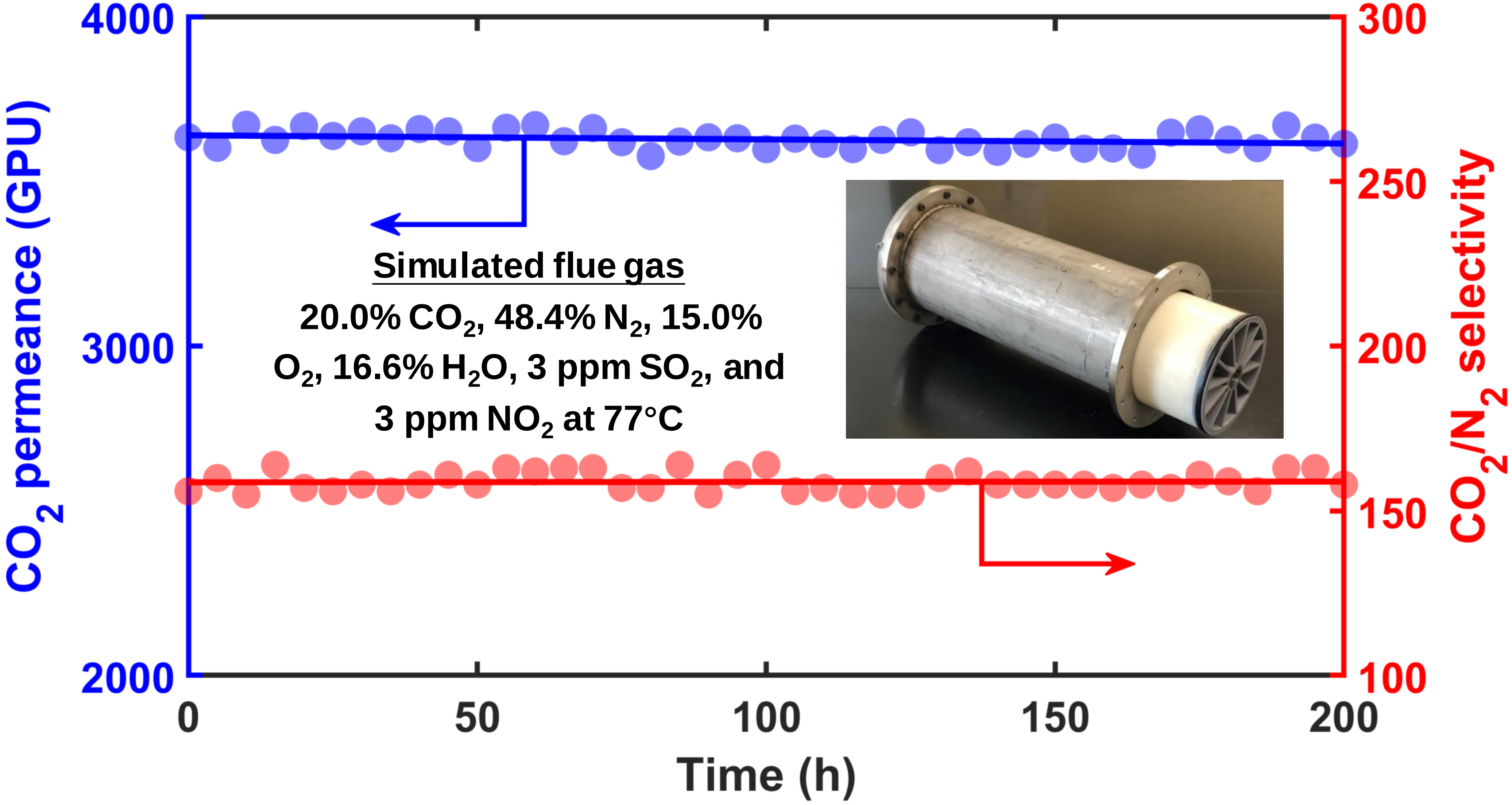






- **3 SW elements have been prepared; 50% of BP1 commitment**

Individual SW Element QA/QC: Good Quality Confirmed



Initial TEA Basis

- **Two Cases:**
  - Two stage (90% capture): for comparison to DOE reference cases
  - Single stage (70% capture): believed to be most economical process configuration
- **Membrane Performance:**
  - Operating temperature: 77°C
  - Impurity tolerance: 3 ppmv SO_2, 4 ppmv NO_2
  - CO_2 permeance: 3,500 GPU
  - CO_2/N_2 selectivity: 167
- **Product:** CO_2 Purity >95 vol%, O_2 <10 ppmv

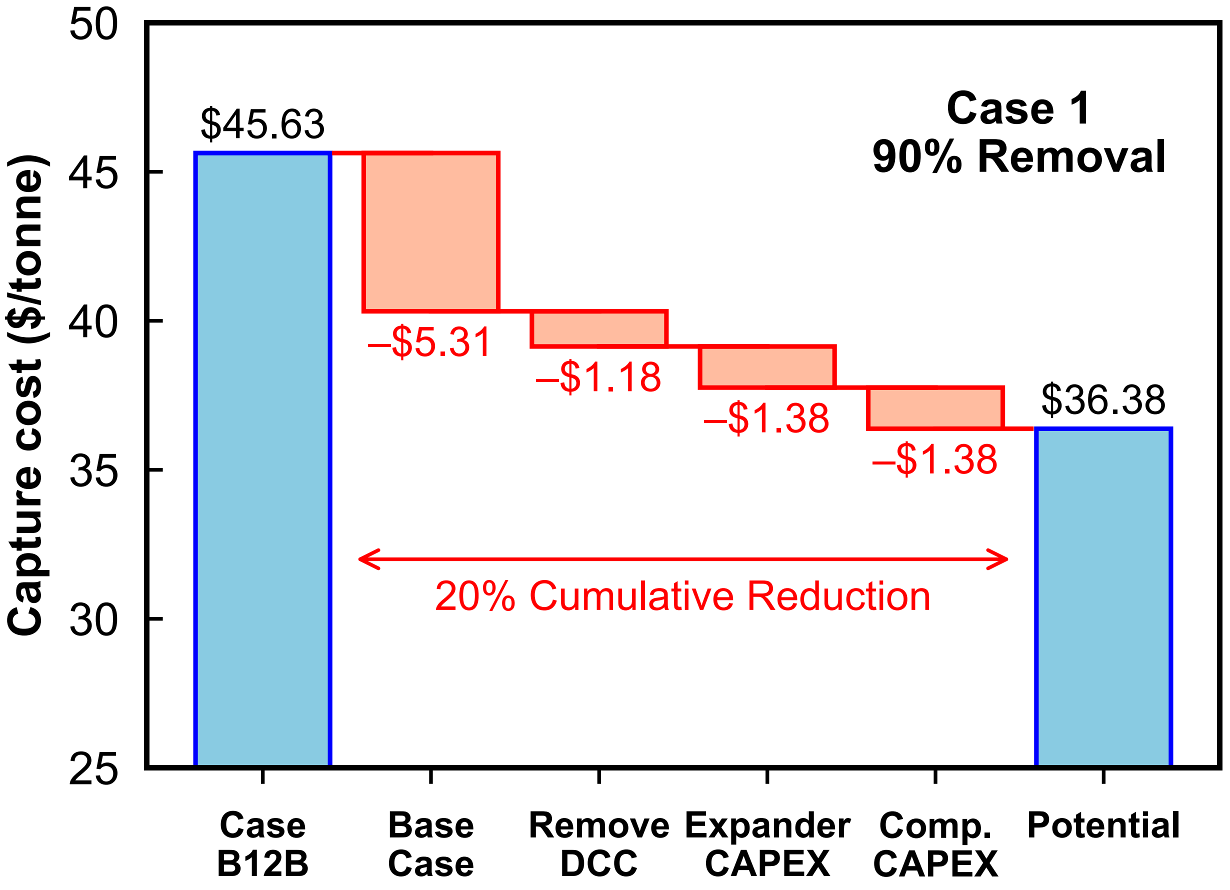
Cost of Electricity and Cost of CO_2 Capture

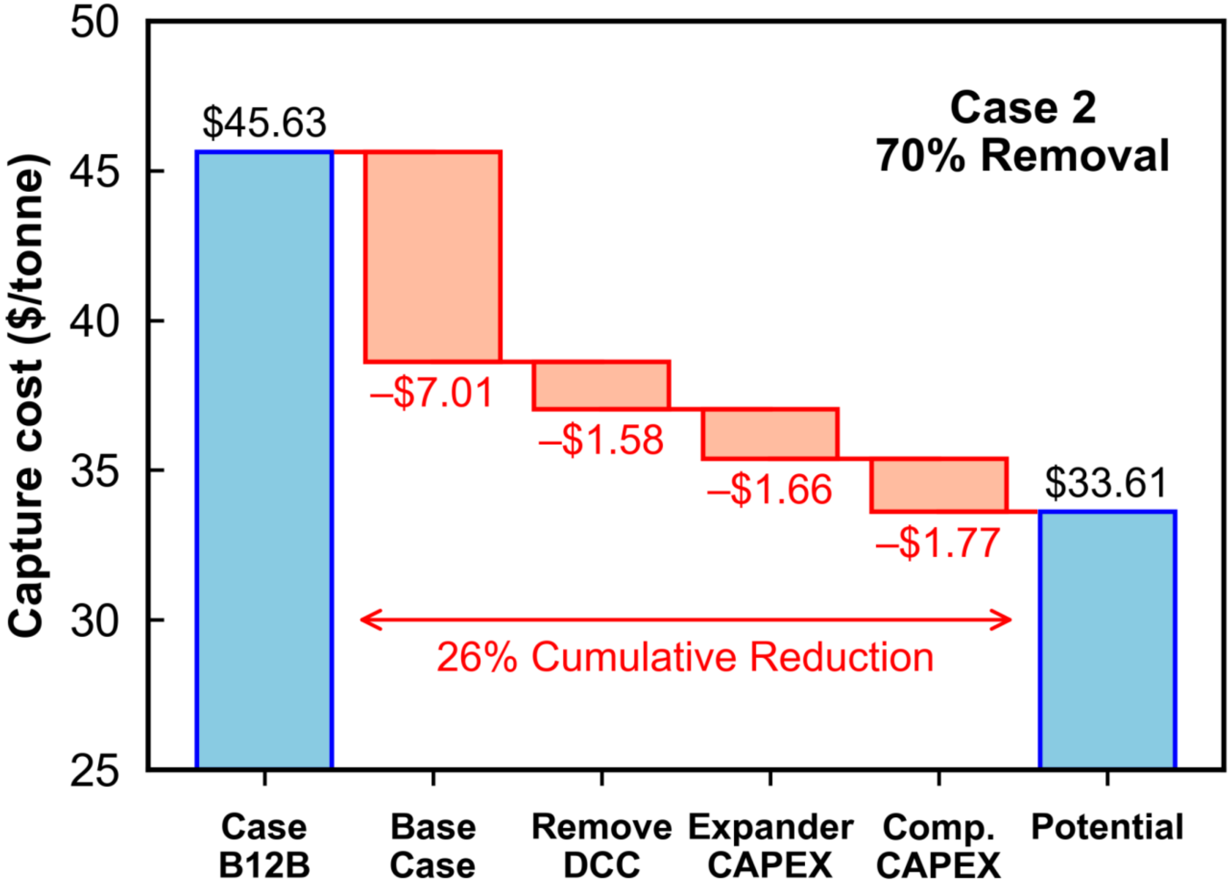
	Unit	Case B12A (no CO_2 capture)	Case B12B (90% capture)	Two Stage Membrane (90% capture)	Single Stage Membrane (70% capture)	DOE Goal
COE	mills/kWh	64.4	105.2	100.5	89.1	
Incremental Cost of CO_2 Capture	mills/kWh	-	40.8	36.1	24.7	
Increase in COE vs. Case B12A	%	-	63.4%	56.1%	38.4%	30%
Cost of CO_2 Capture	$/tonne	-	45.63	40.32	38.62	30

- Inlet flue gas compression is the largest capital cost center
- Membranes are less than 10% of the total purchased equipment costs

Sensitivity Study: Costs Can Potentially Decrease to \$36.38 (90% Removal) and \$33.61 (70% Removal) /tonne of CO_2 Captured

- **Sensitivities**: 1) direct contact cooler (DCC) removal, 2) turboexpander cost reduction, and 3) flue gas compressor cost reduction





Initial Design Completed, Bid Package Issued, Bids Received, Selection of Skid Fabricator in Work

Task 3

Generate initial design package

- PFD, P&ID drawings w/ process description
- Equipment, sizing and data sheets
- Instrumentation and data sheets
- Data acquisition requirements
- Power and controls engineering
- Plant electricity, heat, and water consumption
- Waste generation and management
- Flue gas inlet and outlet conditions
- Start-up, steady-state operation, and shutdown procedures

HAZOP review and recommendations

Finalize package and send to bidders

Review bids and select skid fabricator

Task 4 → **Detailed engineering design of the skid**

BP2 → **Skid construction and acceptance testing**

- **Evaluation criteria**:
  - Project costs and clarifications
  - Project schedule and ability to manage
  - Ability to provide expected deliverables
  - Project team, experience, references
  - Approach to quality control

Risk Assessment: Challenges and Mitigation Strategies

Technical Challenges/Risks

1) Corrosion or particulates fouling of membrane equipment

Mitigation:

- 1a: Select materials of construction based on lessons learned from GTI's previous engineering scale project
- 1b: Modify process conditions and add pre-treatments

2) 95% CO_2 purity not achieved

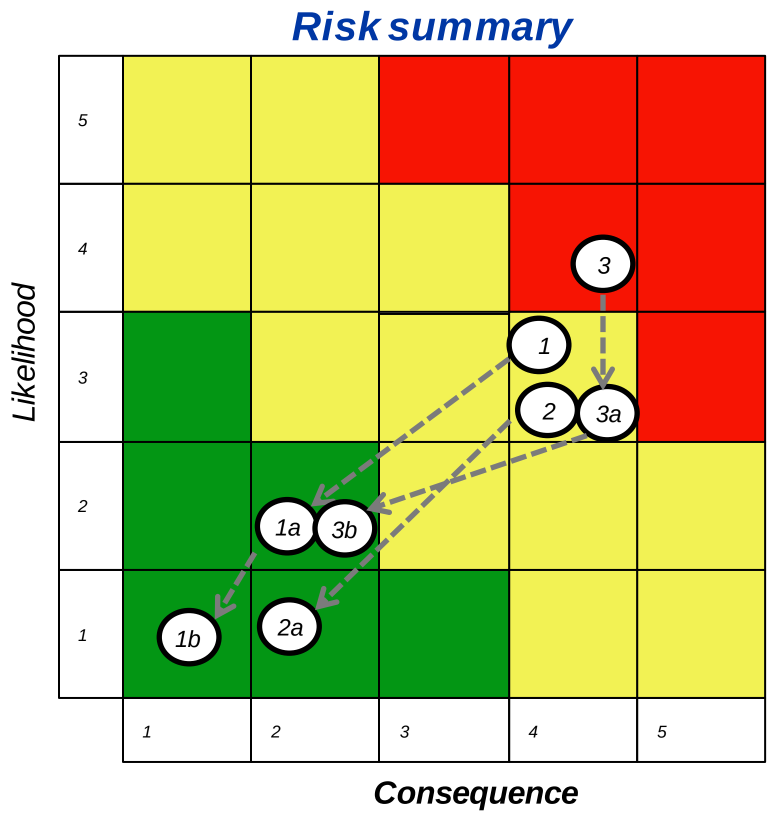
Mitigation:

- 2a: Adjust pressure, temperature, flow rate conditions

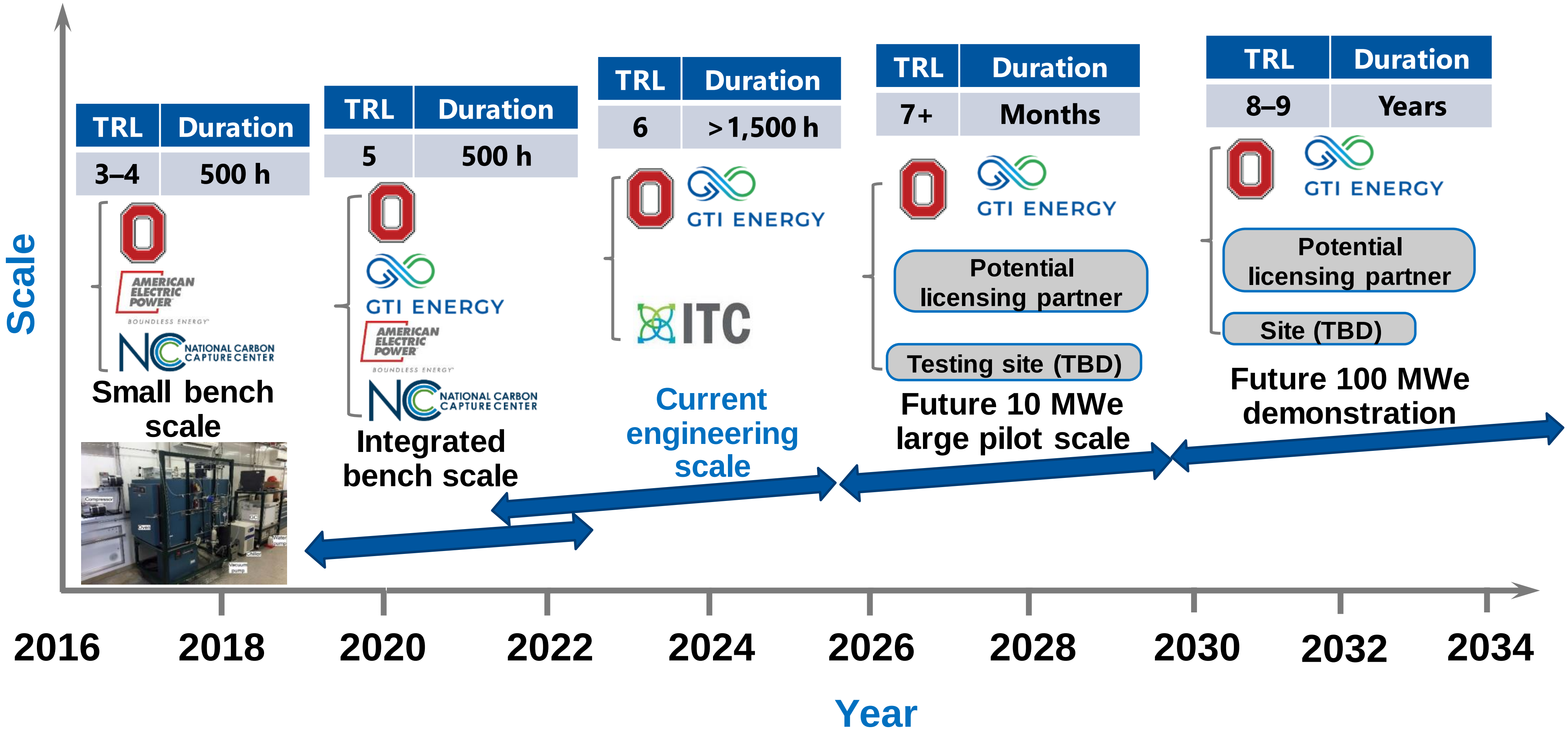
3) CO_2 capture cost not in line with the expected outcome

Mitigation:

- 3a: Optimize process design
- 3b: Optimize equipment selection



Technology Development Path / Future Plan



Summary

- 1,400 ft of the prototype membrane fabricated, which is 100% of the total amount for BP1
- Prototype membrane exhibited CO_2 permeance of ~3,500 GPU and a CO_2/N_2 selectivity of ~160 at 77°C, which was consistent with the OSU Gen II membrane performance obtained previously
- Initial EH&S and TEA Topical Reports submitted to DOE in 2021
  - 90% CO_2 removal: $40.32/tonne of CO_2 captured (12% reduction vs. B12B)
  - 70% CO_2 capture: $38.62/tonne of CO_2 captured (15% reduction vs. B12B)
  - Cost has potential to be further decreased to $33.61 (70% removal) /tonne of CO_2 captured
- Initial design package completed; selection of skid fabricator ongoing

Acknowledgements

- Financial and technical support

U.S. DEPARTMENT OF ENERGY NATIONAL ENERGY TECHNOLOGY LABORATORY

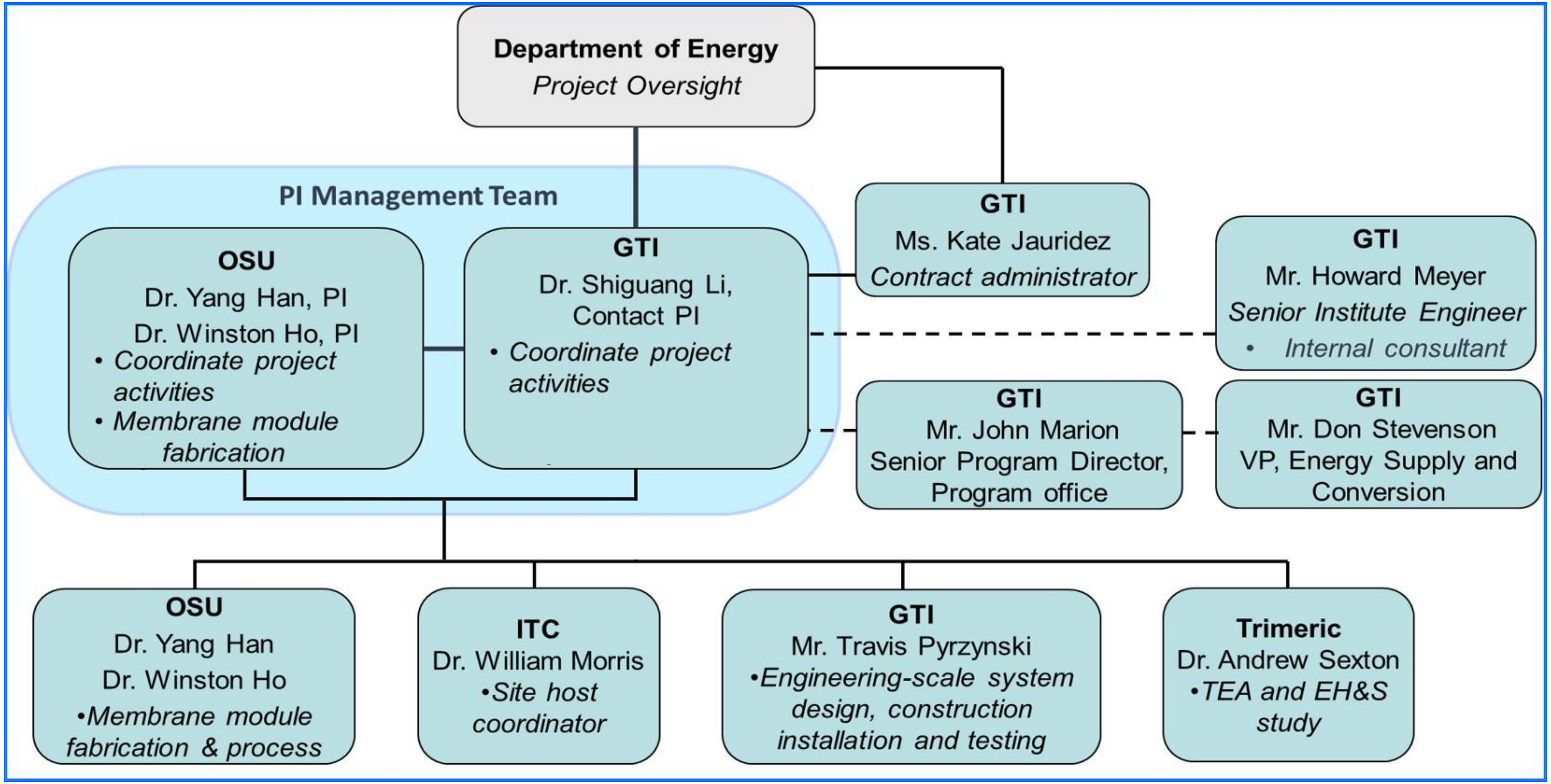
DE-FE0031946

- DOE: Andrew O'Palko, Andy Aurelio, Dan Hancu, José Figueroa and Lynn Brickett
- Partners

ITC

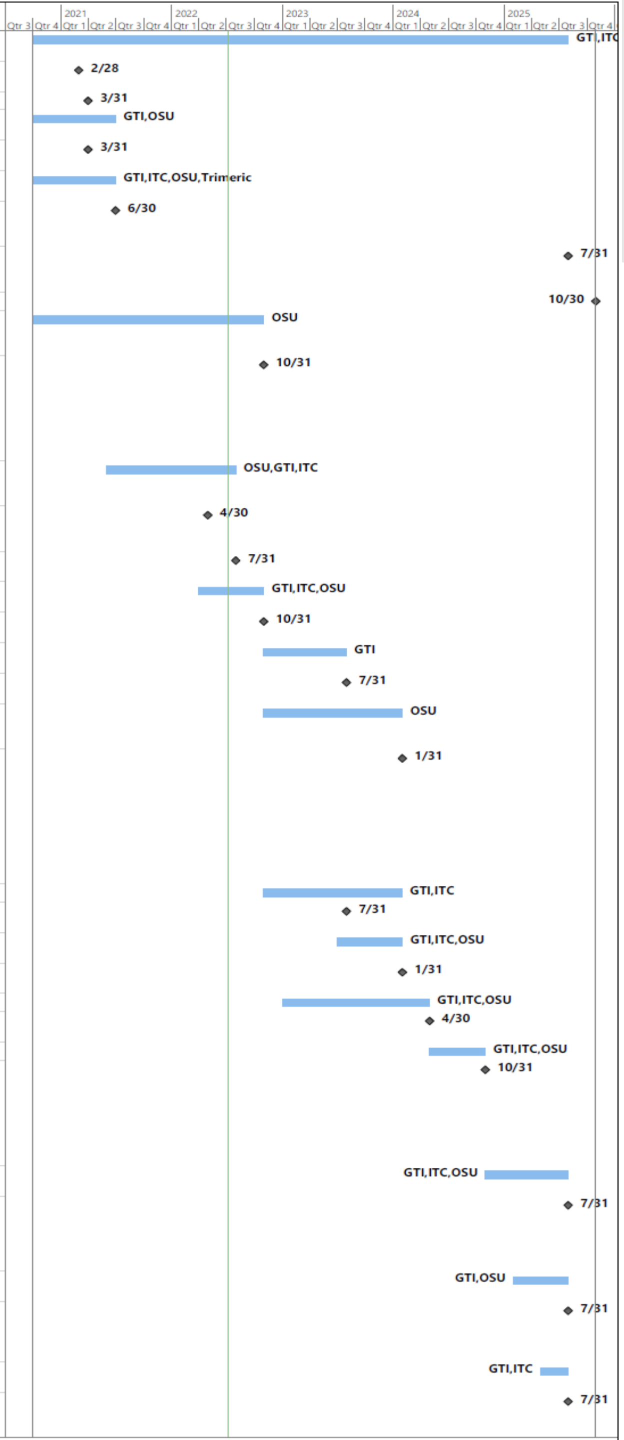
TRIMERIC CORPORATION

Appendix – Project Organization and Structure



Appendix – Gantt Chart

ID	Task No	MS No	Task Name	Start	Finish
1	1.1		Project management and planning	Thu 10/1/20	Thu 7/31/25
2		M1.1	Submit updated project management plan to DOE	Sun 2/28/21	Sun 2/28/21
3		M1.2	Complete kickoff meeting	Wed 3/31/21	Wed 3/31/21
4	1.2		Technology maturation plan	Thu 10/1/20	Wed 6/30/21
5		M1.3	Submit technology maturation plan to DOE	Wed 3/31/21	Wed 3/31/21
6	1.3		Initial and final detailed TEA and EH&S studies	Thu 10/1/20	Wed 6/30/21
7		M1.4	Submit initial TEA and EH&S assessment topical reports	Wed 6/30/21	Wed 6/30/21
8		M1.5	Issue final detailed TEA and EH&S assessment topical reports	Thu 7/31/25	Thu 7/31/25
9		M1.6	Submit final technical repo	Thu 10/30/25	Thu 10/30/25
10	2.0		Fabrication and testing of prototype membane and modules	Thu 10/1/20	Mon 10/31/22
11		M2.1	Achieve CO2/N2 selectivity ≥140 (minimum requirement for 95 vol.% purity in the permeate side) and CO2 permeance ≥3,000 GPU for prototype membrane modules	Mon 10/31/22	Mon 10/31/22
12	3.0		Design and costing of the skid and skid manufacturer selection	Tue 6/1/21	Sun 7/31/22
13		M3.1	Issue initial engineering plant design package for bidding and costing	Sat 4/30/22	Sat 4/30/22
14		M3.2	Complete selection of skid manufacturer	Sun 7/31/22	Sun 7/31/22
15	4.0		Detailed engineering design of the skid	Fri 4/1/22	Mon 10/31/22
16		M4.1	Issue engineering plant design package	Mon 10/31/22	Mon 10/31/22
17	5.0		Procurement and construction of the skid	Mon 10/31/22	Mon 7/31/23
18		M5.1	Complete construction of the engineering scale skid	Mon 7/31/23	Mon 7/31/23
19	6.0		Membrane module fabrication and QA/QC testing	Mon 10/31/22	Wed 1/31/24
20		M6.1	Sufficient commercial-sized modules fabricated for engineering scale testing; QC/QC tests indicate >3,000 CO2 permeance achieved and CO2/N2 selectivity ≥140 achieved for these modules	Wed 1/31/24	Wed 1/31/24
21	7.0		Testing site preparation	Mon 10/31/22	Tue 1/30/24
22		M7.1	Complete site preparation at ITC	Mon 7/31/23	Mon 7/31/23
23	8.0		Skid installation at testing site	Sat 7/1/23	Wed 1/31/24
24		M8.1	Complete engineering skid installation at ITC	Wed 1/31/24	Wed 1/31/24
25	9.0		Skid commissioning	Sun 1/1/23	Tue 4/30/24
26		M9.1	Complete on-site system shake-down at ITC	Tue 4/30/24	Tue 4/30/24
27	10.0		Parametric testing	Tue 4/30/24	Thu 10/31/24
28		M10.1	Validate the achievement of 60-90% CO2 removal rate with 95% CO2 purity during parametric testing; continuous steady-state operation conditions identified	Thu 10/31/24	Thu 10/31/24
29	11.0		Continuous steady-state operation	Fri 11/1/24	Thu 7/31/25
30		M11.1	Complete steady-state operation for a minimum of two months; achieve a 60-90% CO2 removal rate with 95% CO2 purity	Thu 7/31/25	Thu 7/31/25
31	12.0		Identification of commercial membrane	Sat 2/1/25	Thu 7/31/25
32		M12.1	Commercial membrane manufacturer identified for the next phase 10 MWe scale development	Thu 7/31/25	Thu 7/31/25
33	13.0		Removal of the skid from testing site	Thu 5/1/25	Thu 7/31/25
34		M13.1	Remove pilot-scale system and clean up the testing site	Thu 7/31/25	Thu 7/31/25



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