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)*

2023 Carbon Management Research Project Review Meeting
August 28 – September 1, 2023

# Project Overview

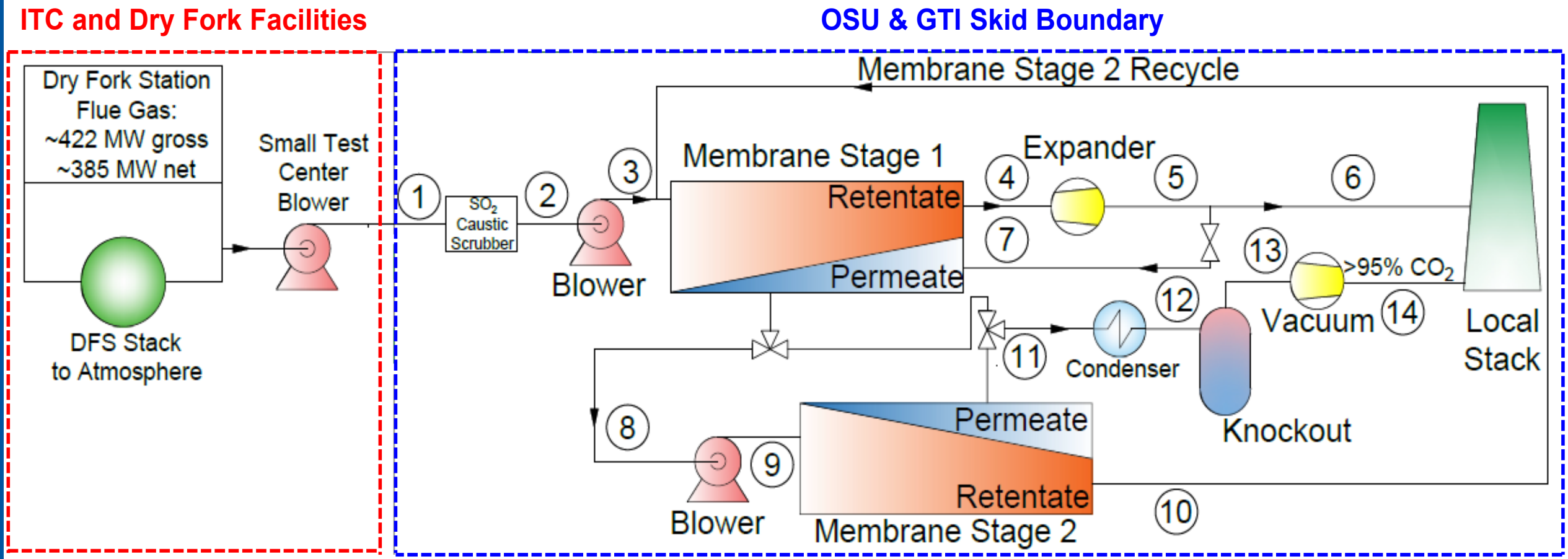
- **Performance period**: October 1, 2020 – July 31, 2025
- **Total funding**: $20,815,061 (DOE: $16,650,507, Cost share: $4,164,554)
- **Objectives**: 1) Design and build an engineering-scale $CO_2$ capture system using OSU's transformational membrane in commercial-sized modules; 2) Conduct tests on 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<br>• Skid design, selection of skid fabricator, skid installation, and testing<br>• Support TEA and EH&S assessment |
| THE OHIO STATE UNIVERSITY | • Participate in project management and planning<br>• Membrane and module fabrication and QA/QC testing<br>• Support skid design and field testing, TEA and EH&S study |
| ITC WYOMING INTEGRATED TEST CENTER | • Site host, lead on testing site preparation |
| TRIMERIC CORPORATION | • TEA and EH&S assessment |

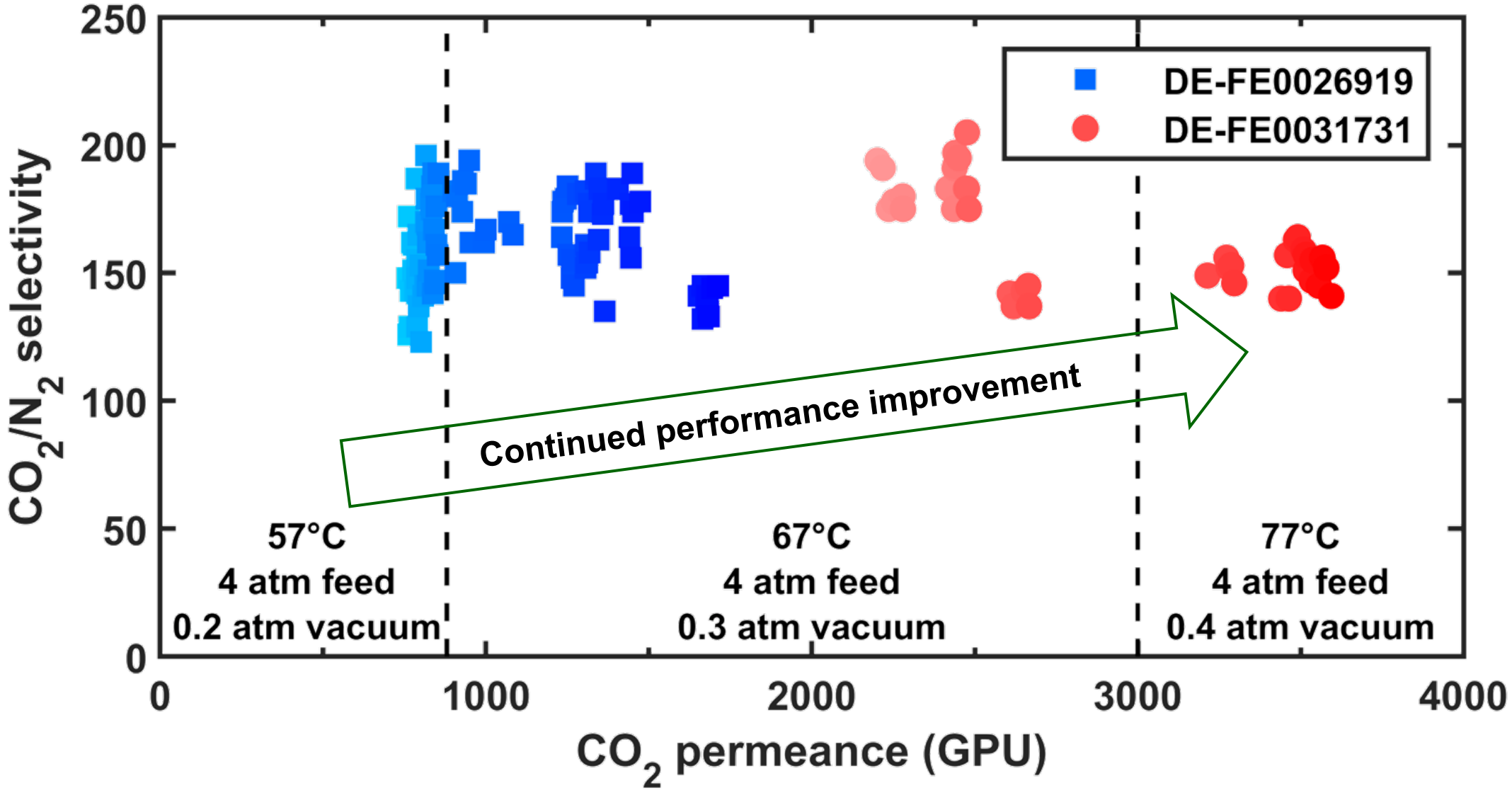
# Testing on Coal Flue Gas at Wyoming Integrated Test Center

| 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 |

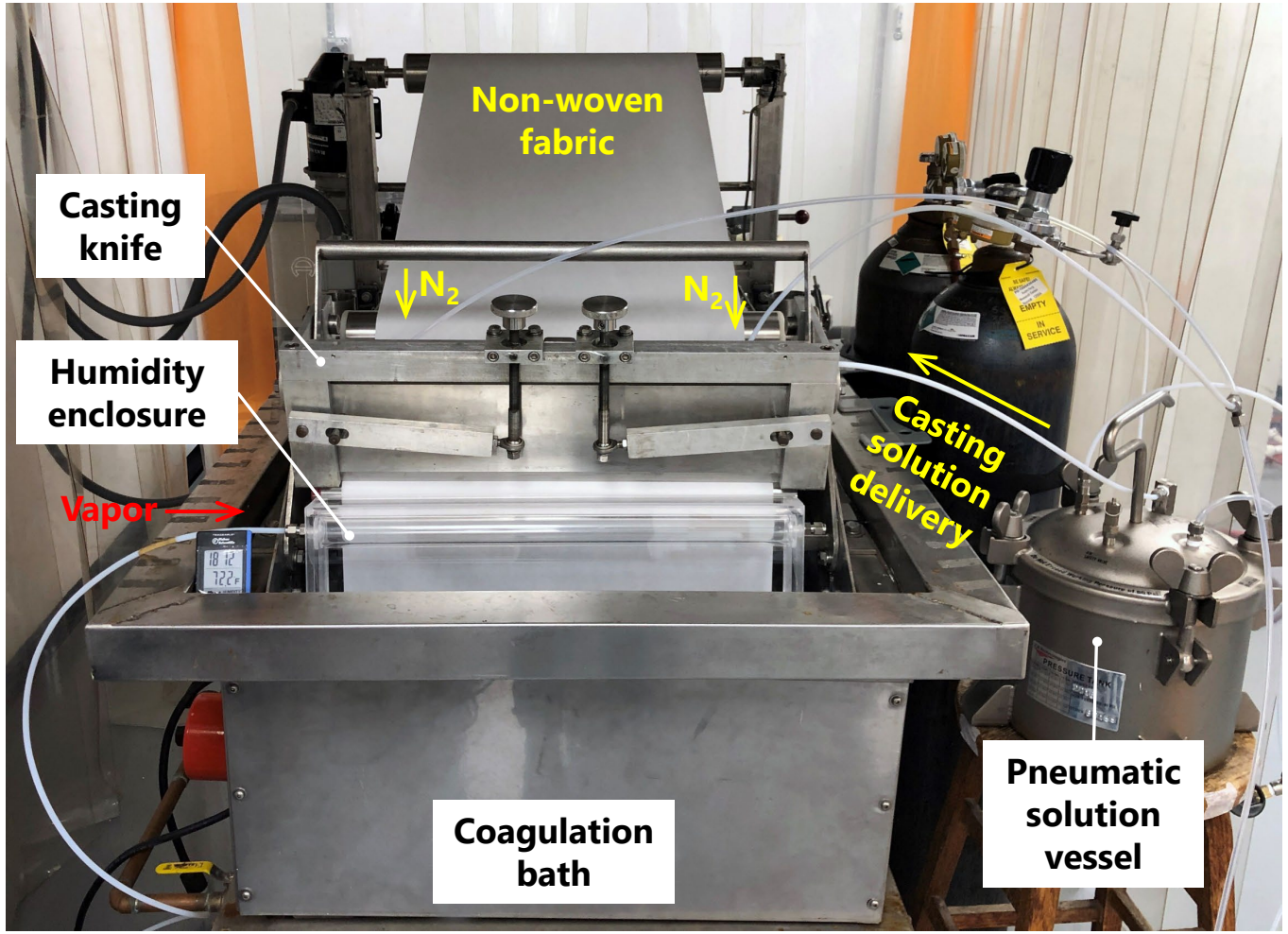
# Process Description

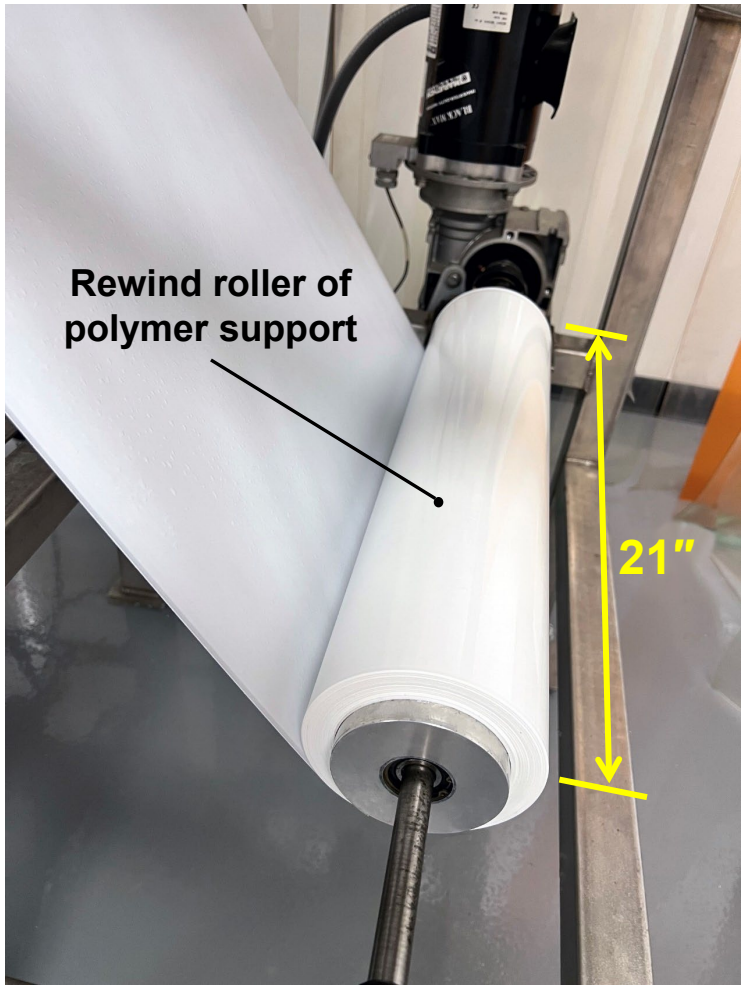


# OSU Progression of Membrane Performance



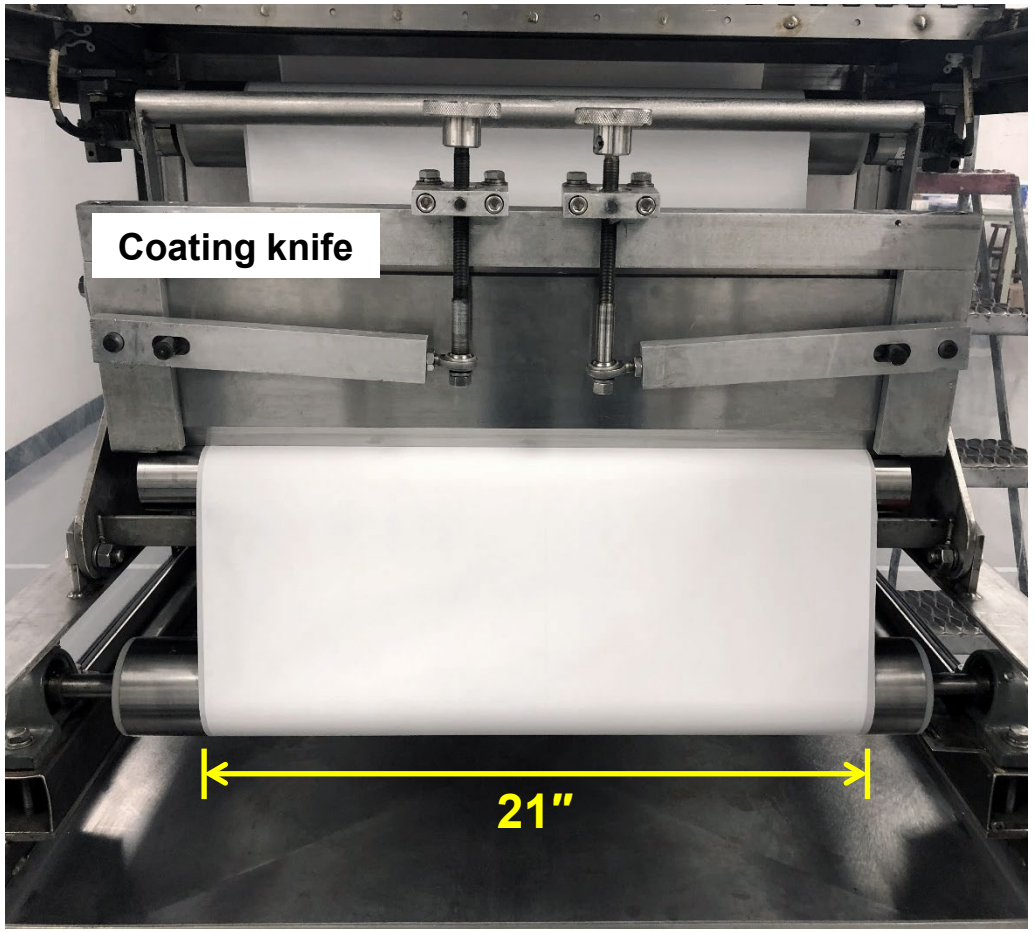
# Continuous Fabrication of Polymer Support



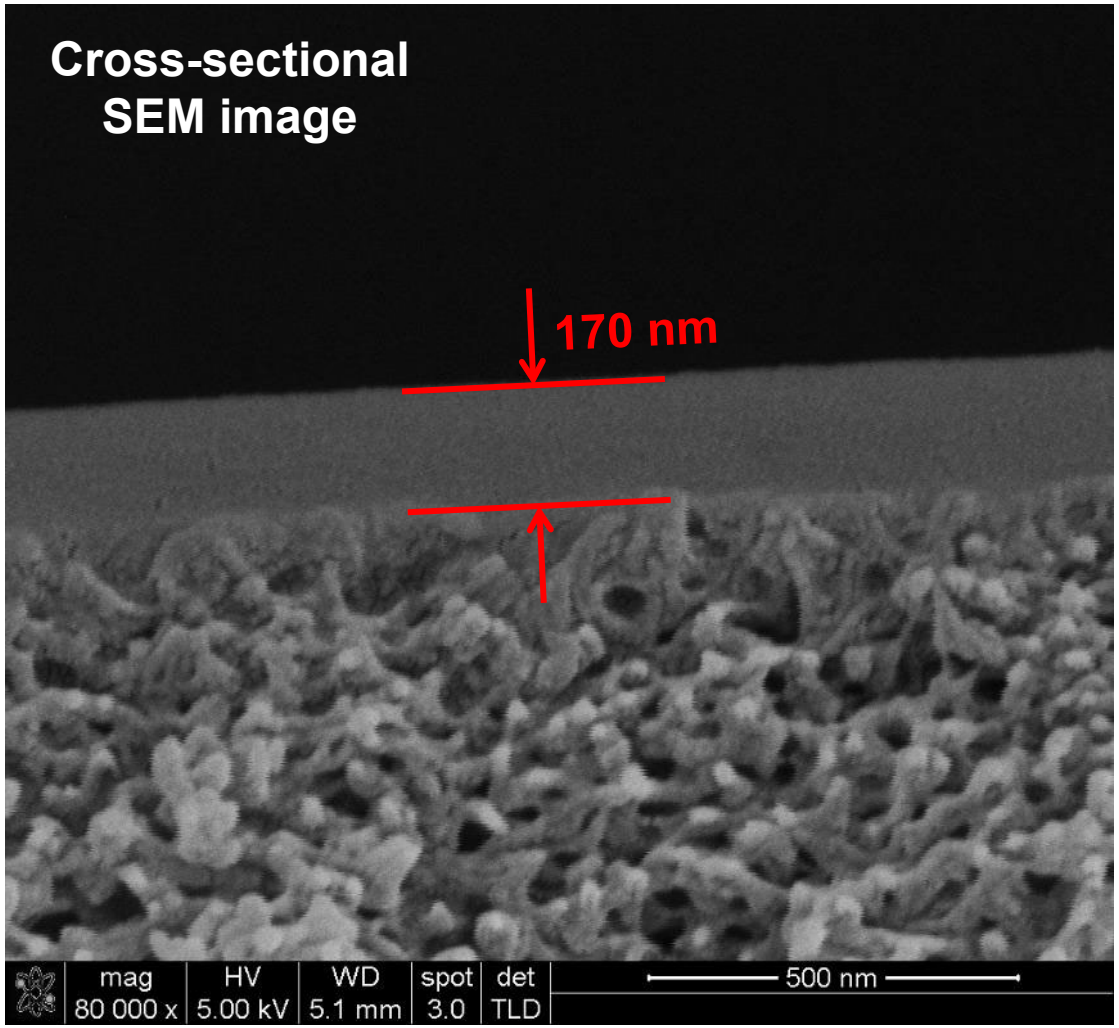

- **1,500 ft of quality support has been prepared**

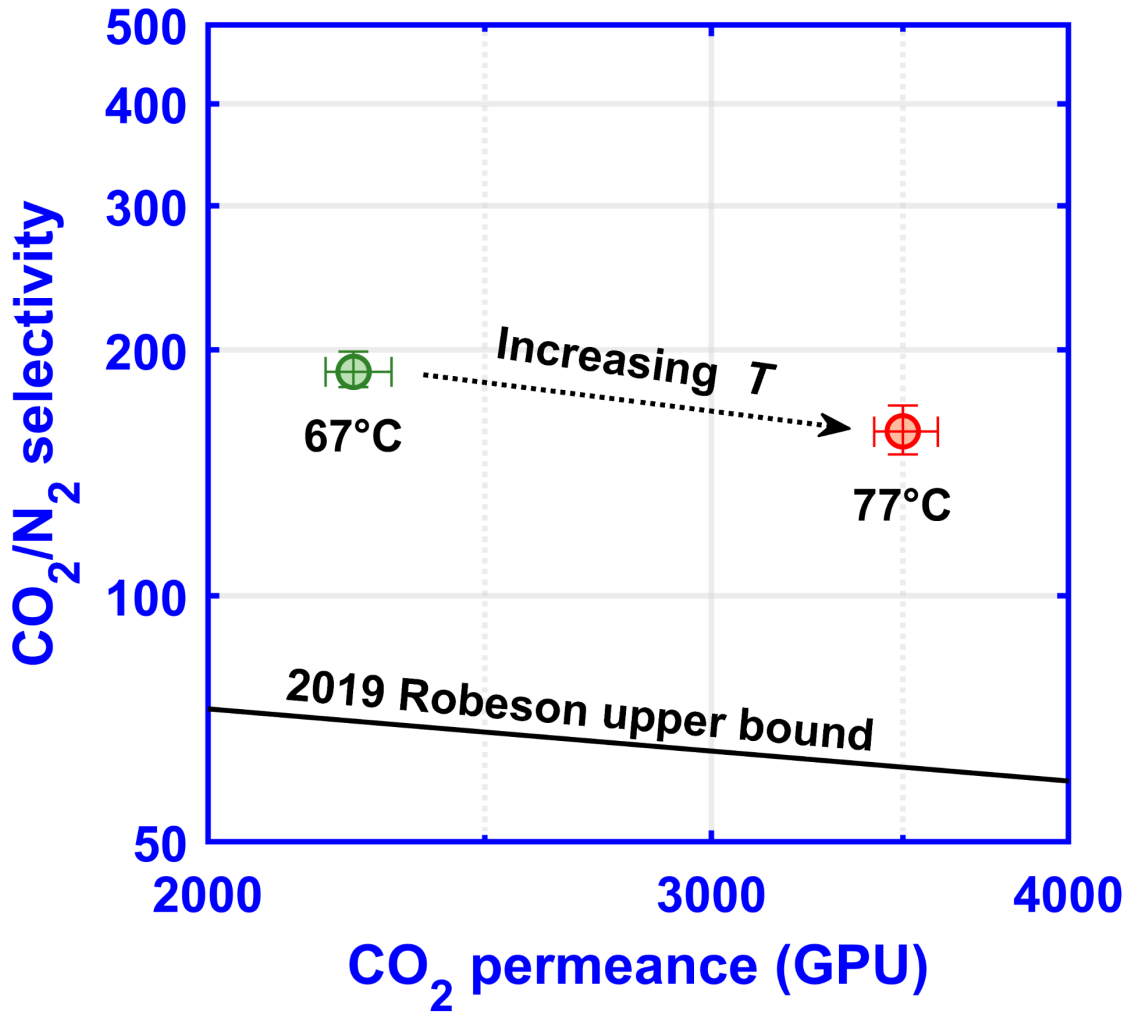
# Continuous Fabrication of Transformational Membrane



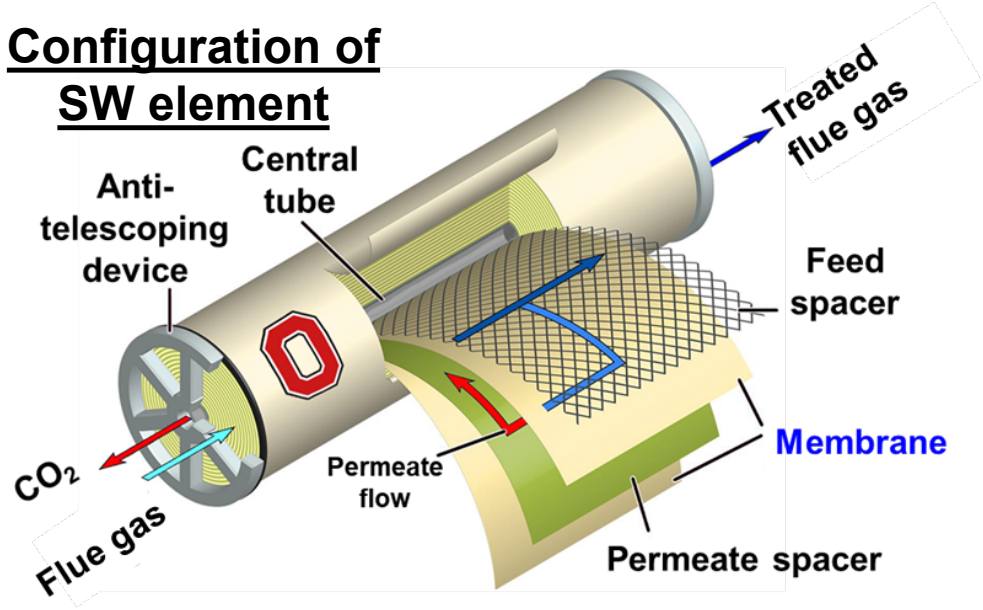

- 1,400 ft of prototype membrane has been prepared

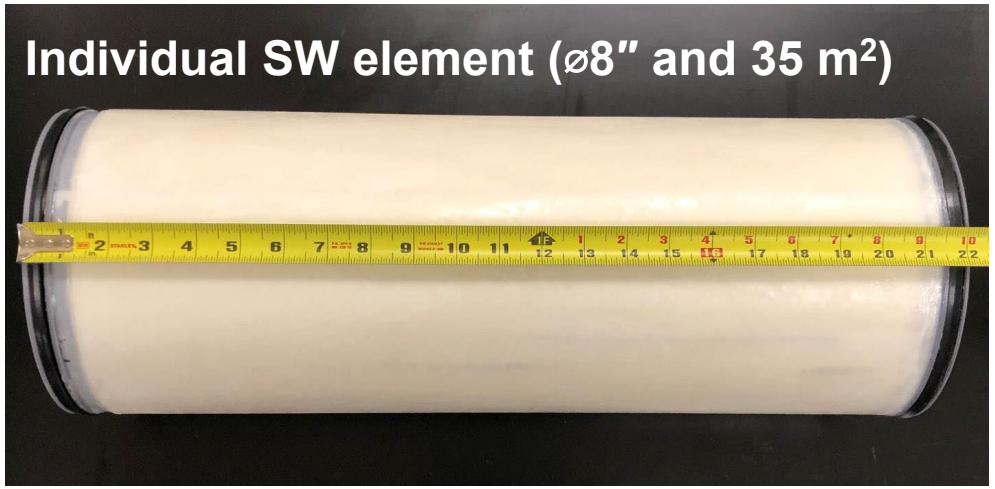
# High $CO_2/N_2$ Separation Performance Achieved/Confirmed

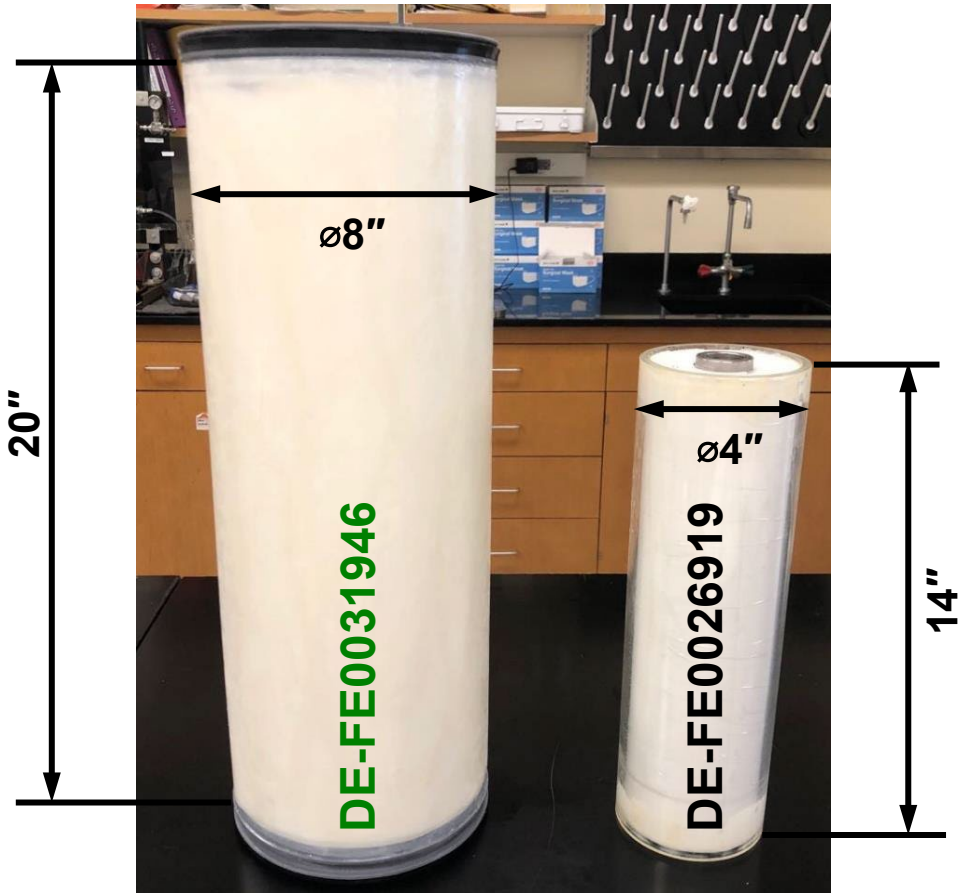


# Commercial-Size 8-inch Diameter Spiral-Wound (SW) Membrane Elements/Modules Fabricated

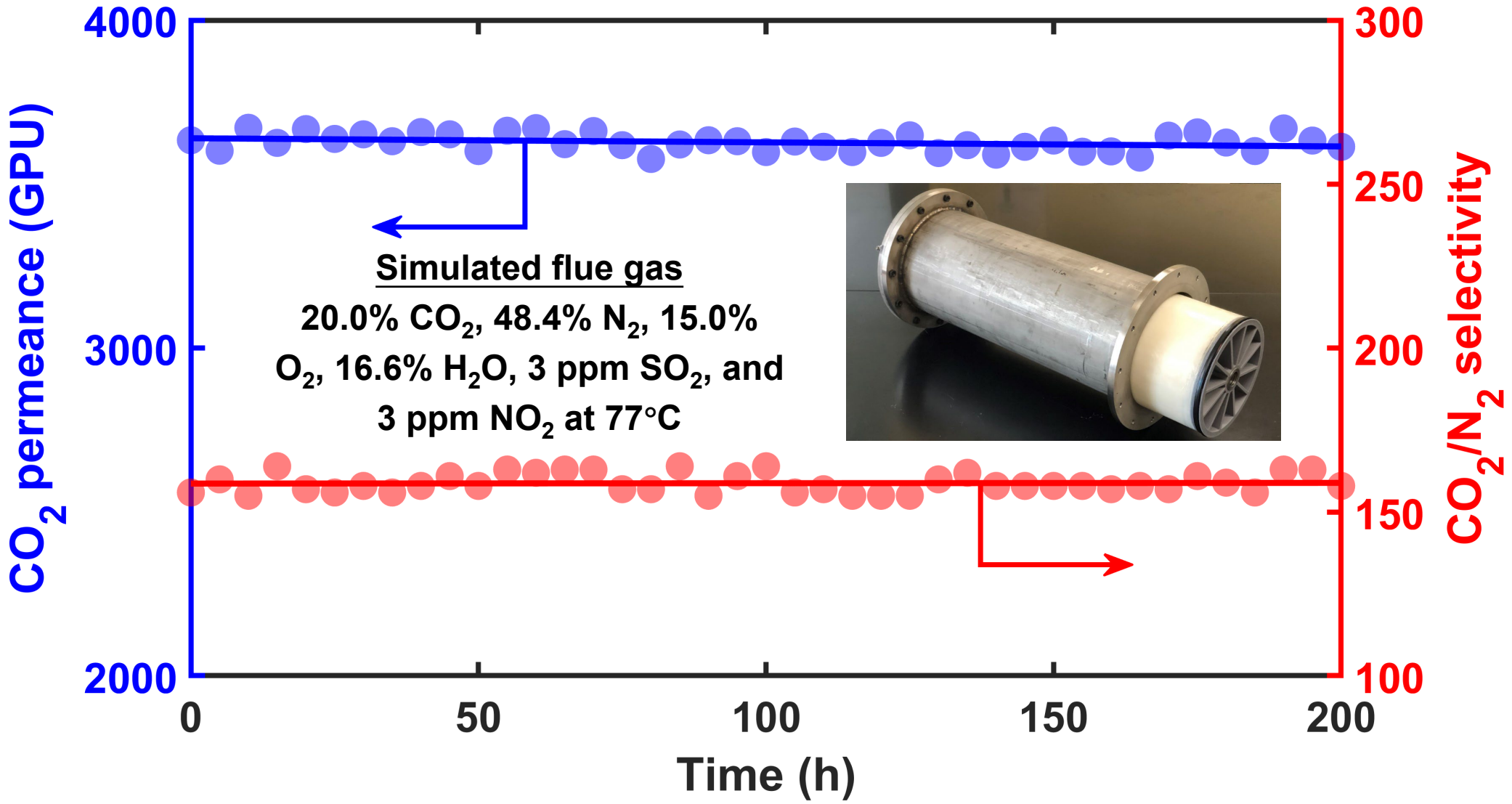


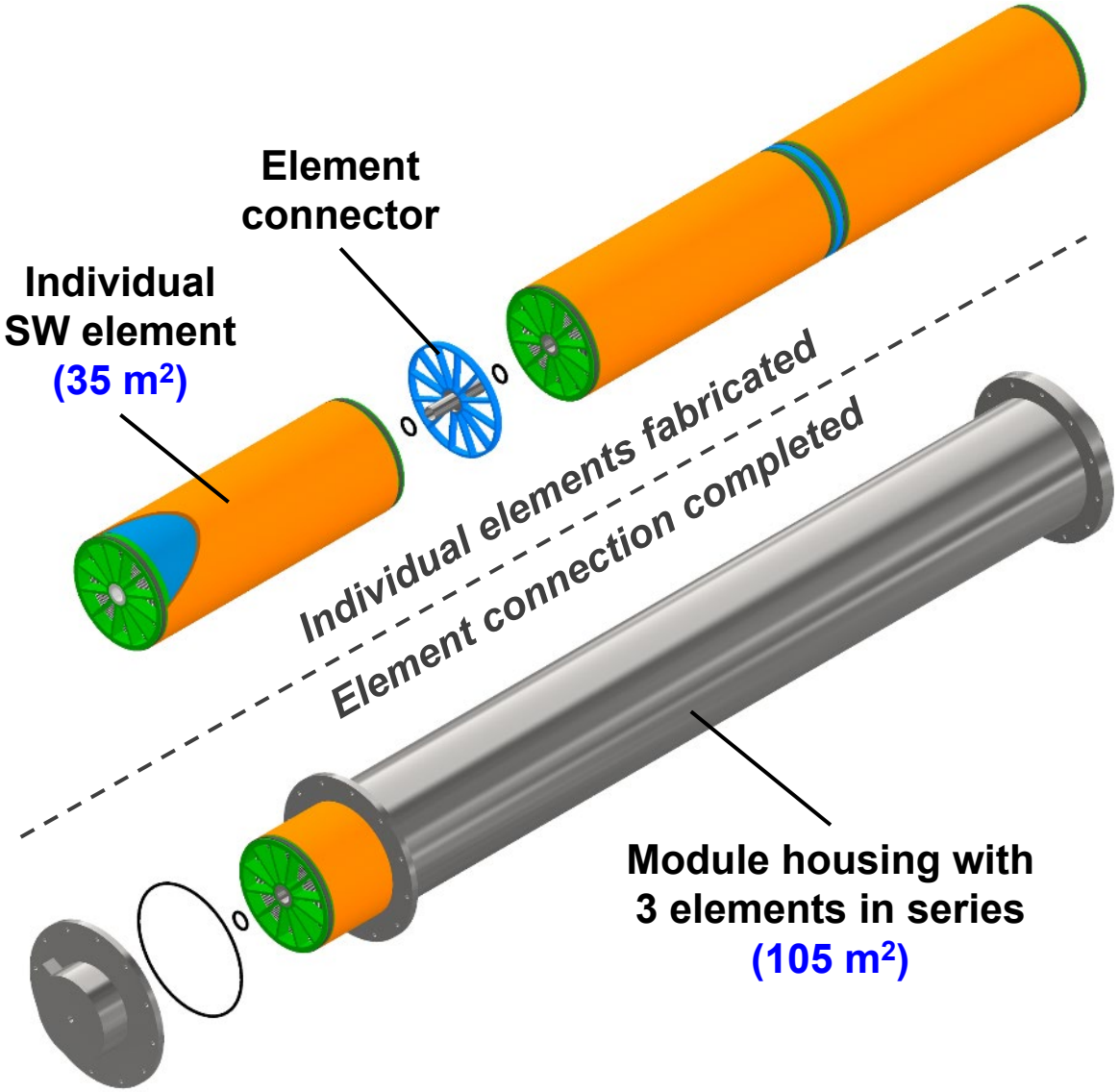




- 6 SW elements have been prepared

# Individual SW Element QA/QC: Good Quality Confirmed

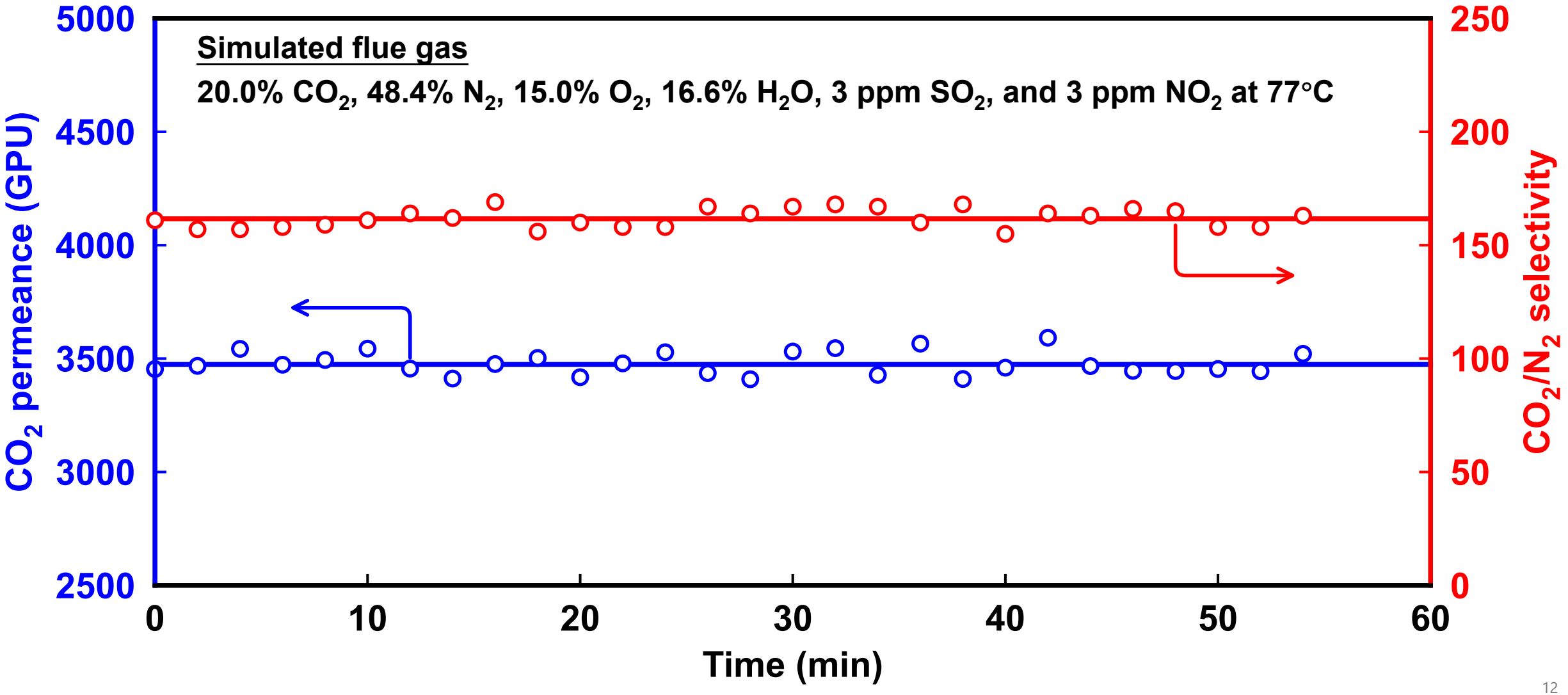


# SW Module Scaled up to 105 m² Membrane Area




**Two 105 m² modules have been fabricated**

# Separation Properties Validated for the 105-m² Modules



# Initial TEA: 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 |

Sensitivity study: costs can potentially decrease to $36.38 (@ 90% removal) and $33.61 (@ 70% removal) /tonne of $CO_2$ captured

# Initial Design Completed, Bid Package Issued, Bids Received and Evaluated, Skid Fabricator Selected

**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

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**HAZOP review and recommendations**

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**Finalize package and send to bidders**

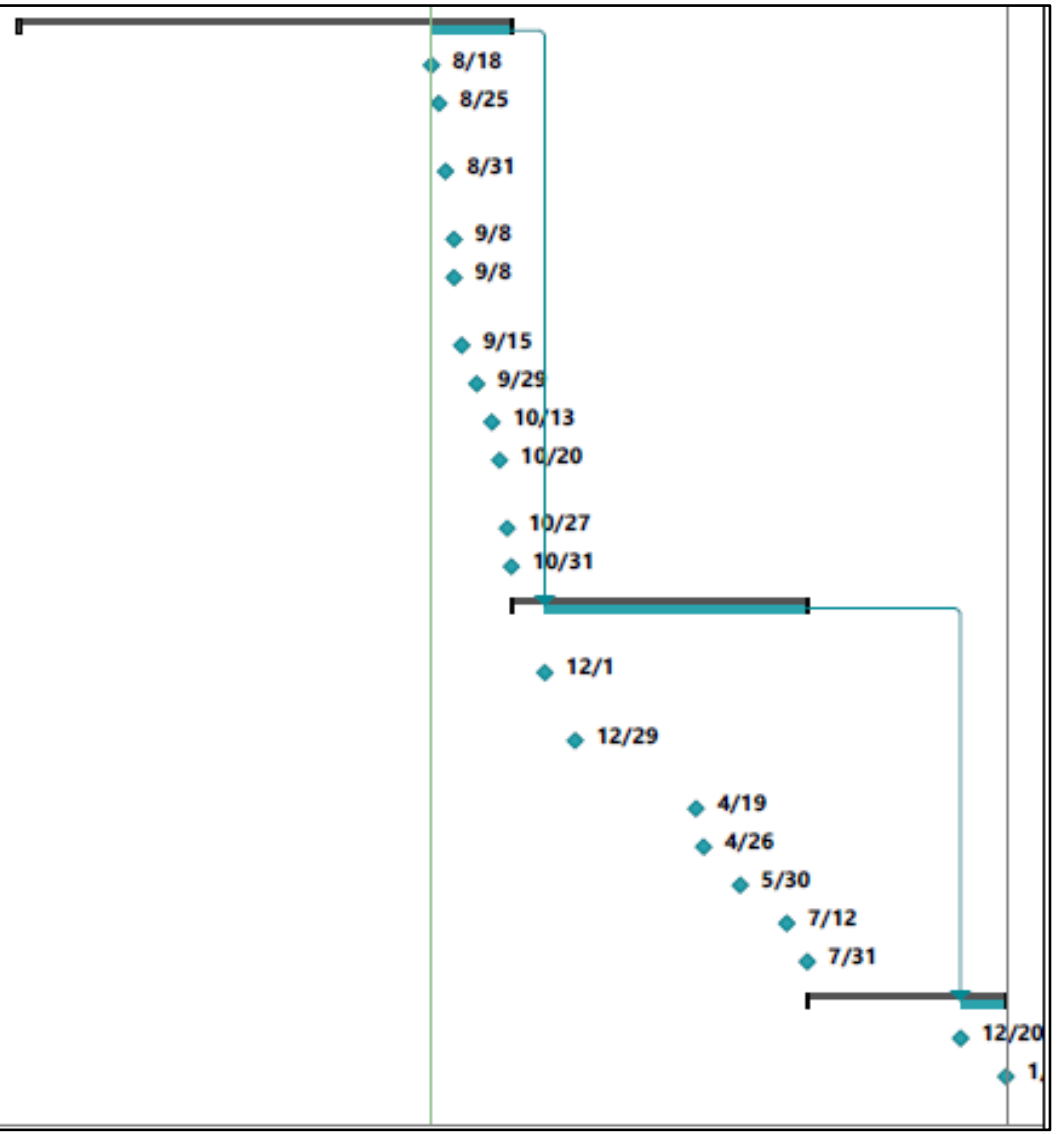
↓

**Review bids and select skid fabricator**

- **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
- **AmeriChem Systems, Inc. (ASI) selected**

# Detailed Engineering Design of the Skid Ongoing, Schedule for Procurement, Construction, FAT and Site Installation Planned

| | | |
|---|---|---|
| **Detailed engineering design of skid** | **Tue 10/31/23** | |
| Conduct kickoff meeting | Fri 8/18/23 | GTI |
| Vendor to schedule weekly progress update meetings with GTI | Fri 8/25/23 | ASI |
| OSU to finalize membrane module design and specifications | Thu 8/31/23 | OSU |
| Vendor generates detailed project schedule | Fri 9/8/23 | ASI |
| Finalize construction deliverables and metrics for factory acceptance test | Fri 9/8/23 | GTI |
| Conduct detailed process design review | Fri 9/15/23 | GTI |
| Review 2D and 3D plant design | Fri 9/29/23 | GTI |
| Conduct HAZOP Review | Fri 10/13/23 | GTI,OSU,ASI |
| Submit finalized 2D and 3D plant design packet to DOE for review | Fri 10/20/23 | GTI |
| Identify any potential cost saving approaches | Fri 10/27/23 | ASI |
| Issue engineering plan design package | Tue 10/31/23 | ASI |
| **Procurement, construction, factory acceptance test of skid** | **Wed 7/31/24** | |
| Long lead time equipment and material orders placed | Fri 12/1/23 | ASI |
| Major equipment requisition submitted and purchased | Fri 12/29/23 | ASI |
| Skid framing and grating complete | Fri 4/19/24 | ASI |
| OSU to deliver membrane modules to vendor | Fri 4/26/24 | OSU |
| Skid construction complete | Thu 5/30/24 | ASI |
| FAT Complete at vendor | Fri 7/12/24 | ASI |
| Skid ready for shipment | Wed 7/31/24 | ASI |
| **Skid Delivery, installation, and commissioning** | **Fri 1/31/25** | |
| Skid delivered to ITC | Fri 12/20/24 | ASI |
| Skid installation complete at ITC and installation verfication complete | Fri 1/31/25 | GTI,OSU,ASI |

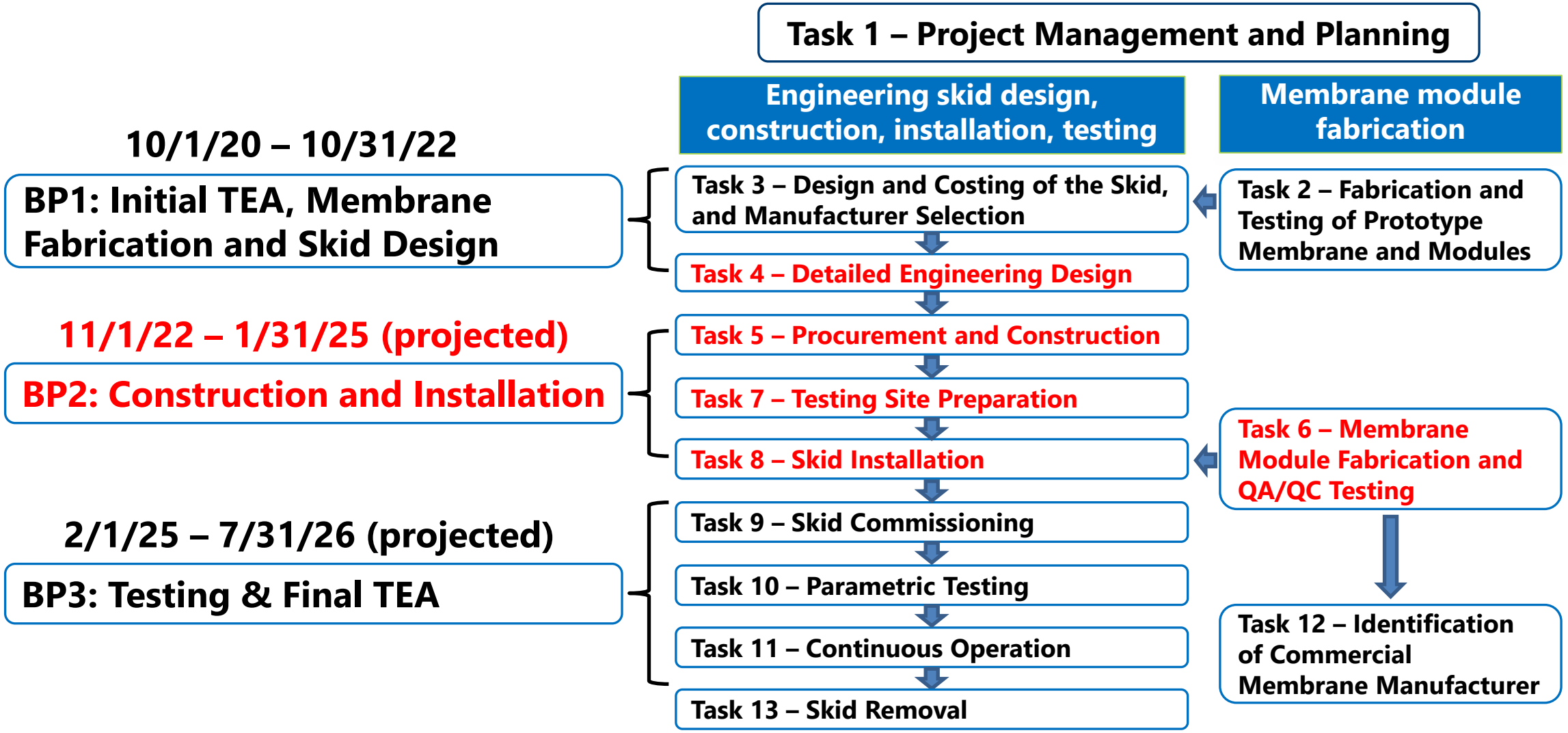



FAT = factory acceptance test

# Lessons Learned and Mitigation Strategies Employed during Technology Development and Project Execution

- **Lessons learned:**
  - Skid cost higher than budgeted due to significantly increased costs on equipment/material/labor
- **Mitigation strategies employed**:
  - Actively worked with bidders for cost reduction; financial gap dropped from $7,137,846 to $3,650,507
  - Requested additional funds from DOE
  - Project Team committed additional cost share to mitigate financial risks on installation and testing at ITC

# Plan/Roadmap for the Current Project



# Technical 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

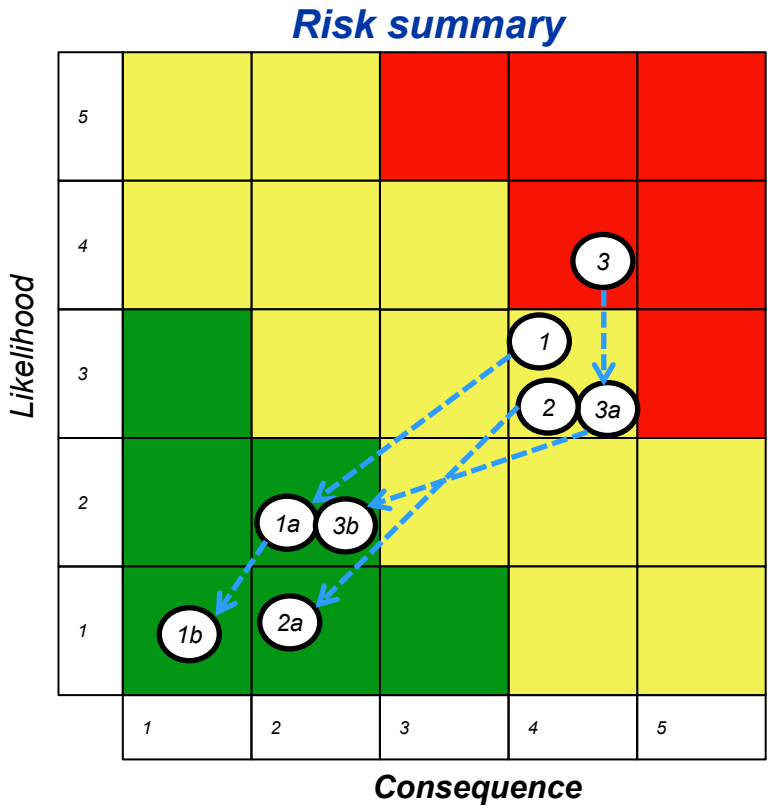
**Mitigation:**

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

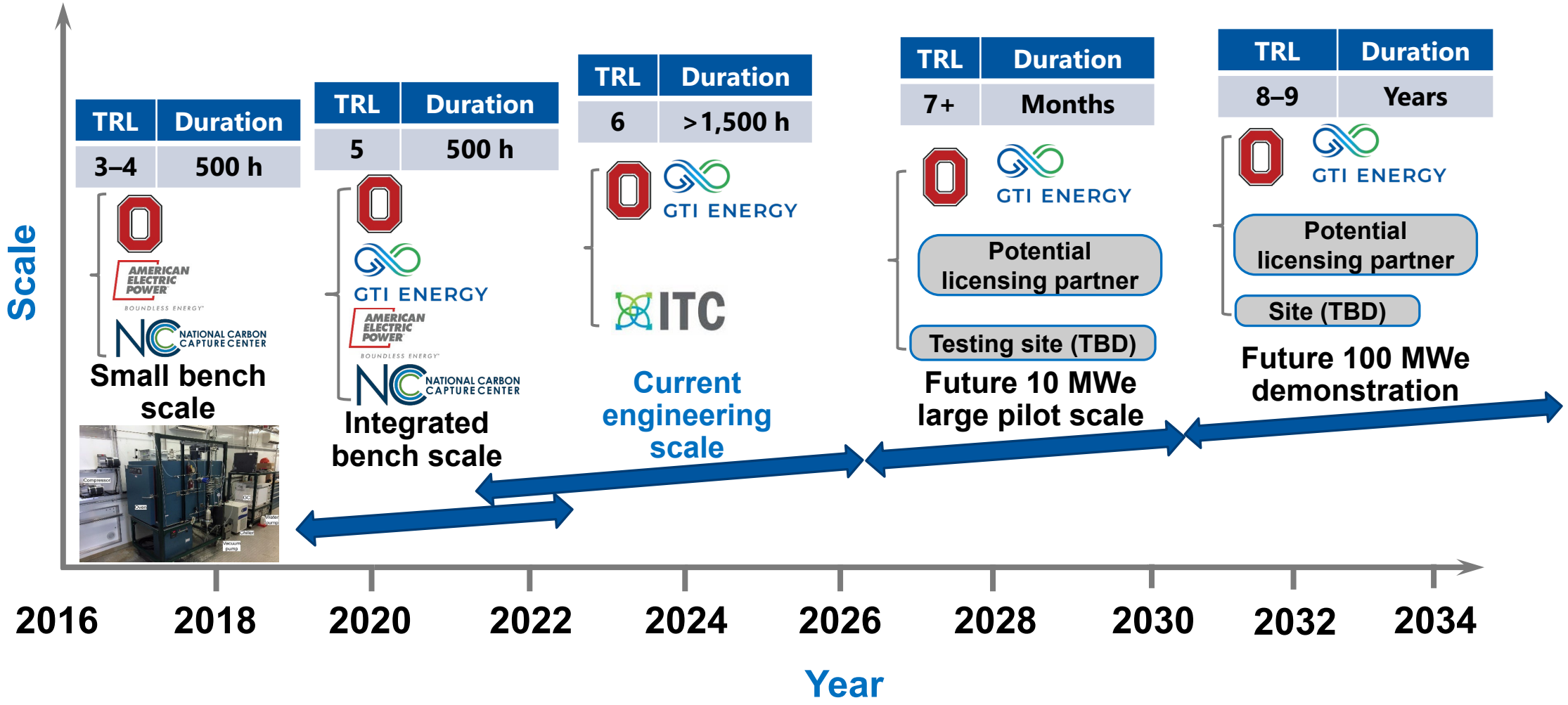
### 3) $CO_2$ capture cost not in line with the expected outcome

**Mitigation:**

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



# Technology Development Path / Future Plan



# Summary

- GTI and OSU are scaling up OSU's FTM process to engineering-scale for carbon capture; initial TEA based on bench-scale testing data indicates potential to achieve $33.61/tonne of $CO_2$ at 70% capture.
- Prototype membrane modules exhibited $CO_2$ permeance of ~3,500 GPU and $CO_2/N_2$ selectivity of ~160 at 77°C, consistent with the OSU Gen II membrane performance obtained previously.
- Prototype SW Module scaled up to 105 $m^2$; gas separation properties validated.
- Initial design package completed; skid fabricator selected.
- Detailed engineering design of the skid ongoing; schedule for procurement, construction, factory acceptance test and site installation planned.

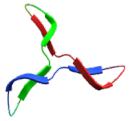
# Acknowledgements


- Financial and technical support



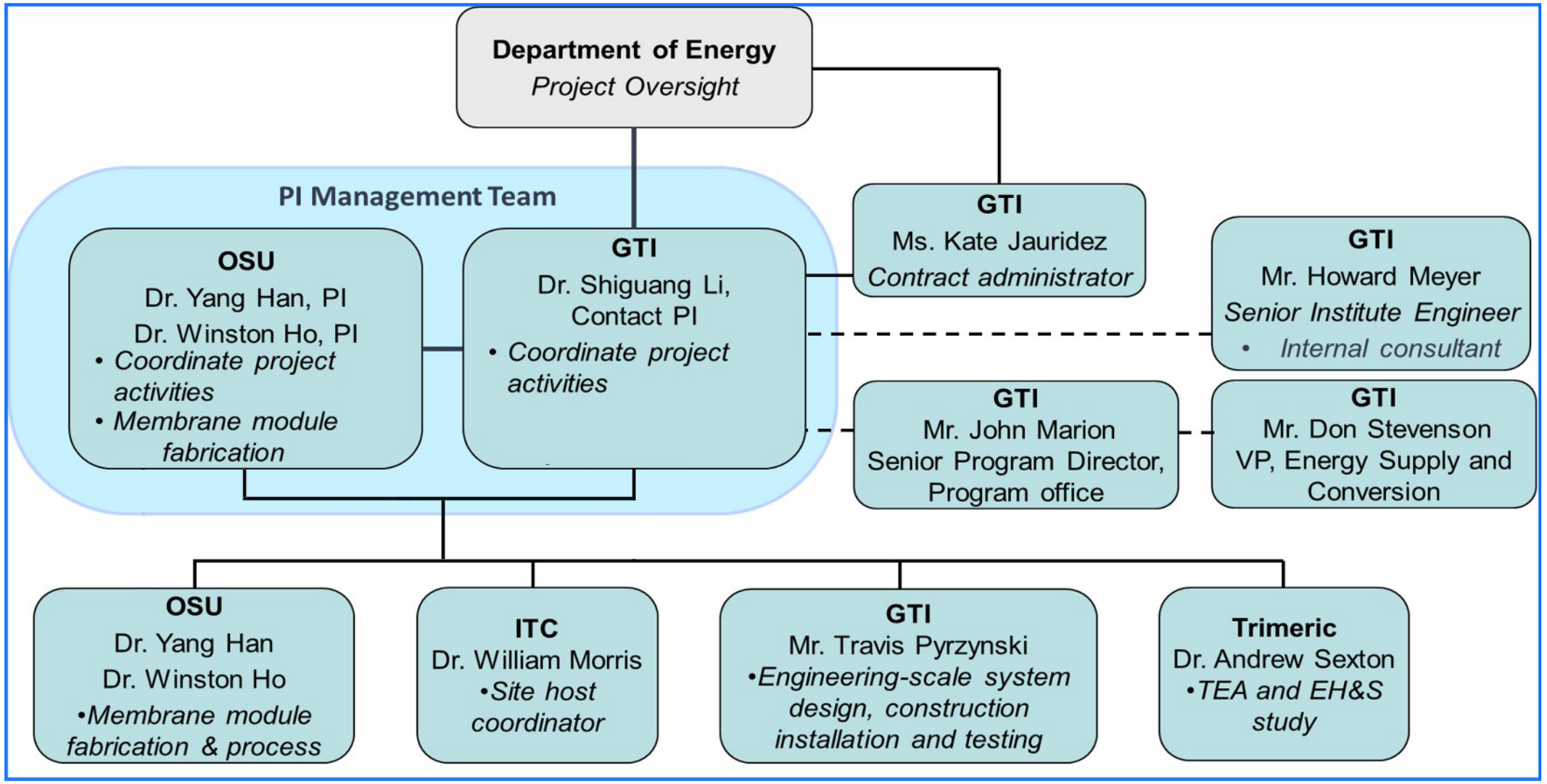
**DE-FE0031946**

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

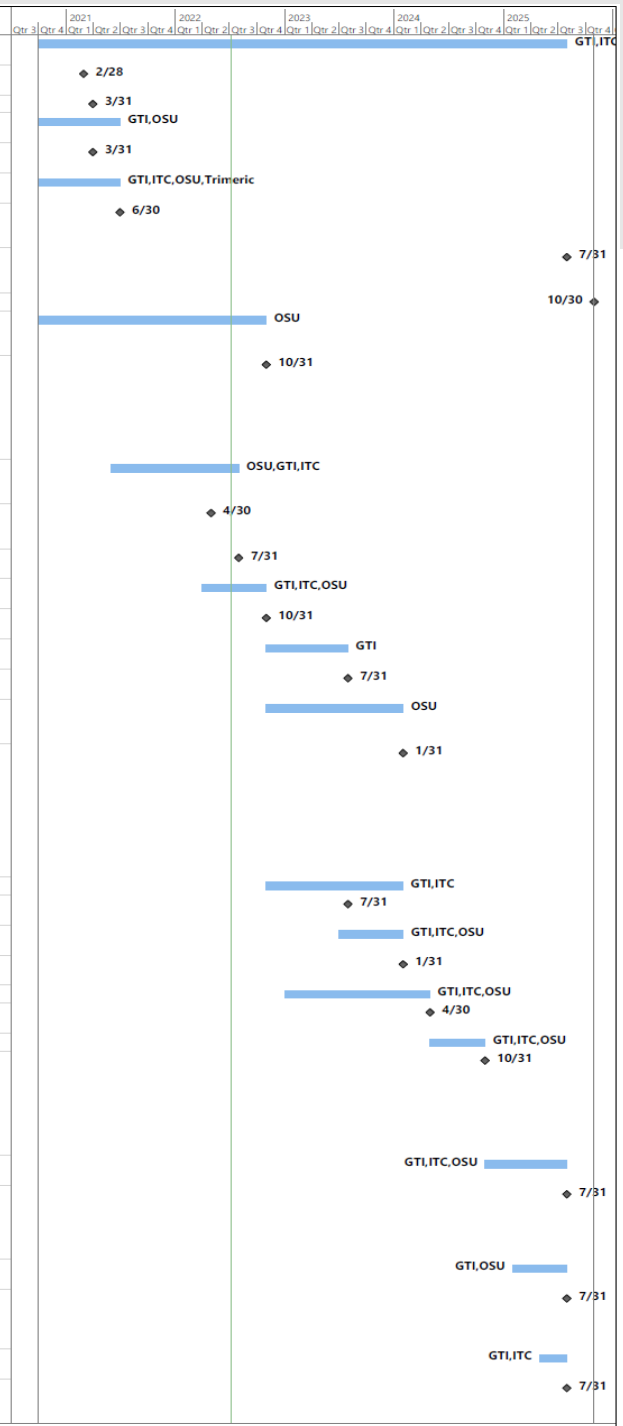
TRIMERIC CORPORATION

# 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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