MEMBRANE TECHNOLOGY & RESEARCH

Scale-Up and Testing of Advanced Polaris Membranes at TCM (DE-FE0031591)

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Carbon Management and Oil & Gas Research Project Review Meeting
Point Source Capture – Lab, Bench, and Pilot-Scale Research
August 12, 2021

Project Overview

Award name: Scale-Up and Testing of Advanced Polaris Membrane CO_2 Capture Technology (DE-FE0031591)

Project period: 8/1/18 to 12/31/21

Funding: $8.2 million DOE; $2.6 million cost share ($10.8 million total)

DOE program manager: Isaac “Andy” Aurelio (BP1 & 2), Andy O’Palko (BP3)

Participants: MTR, TCM, Trimeric, WorleyParsons

Project scope: Design, build, and operate a system at TCM with Gen 2 Polaris modules

Project plan: The project is organized in three phases:

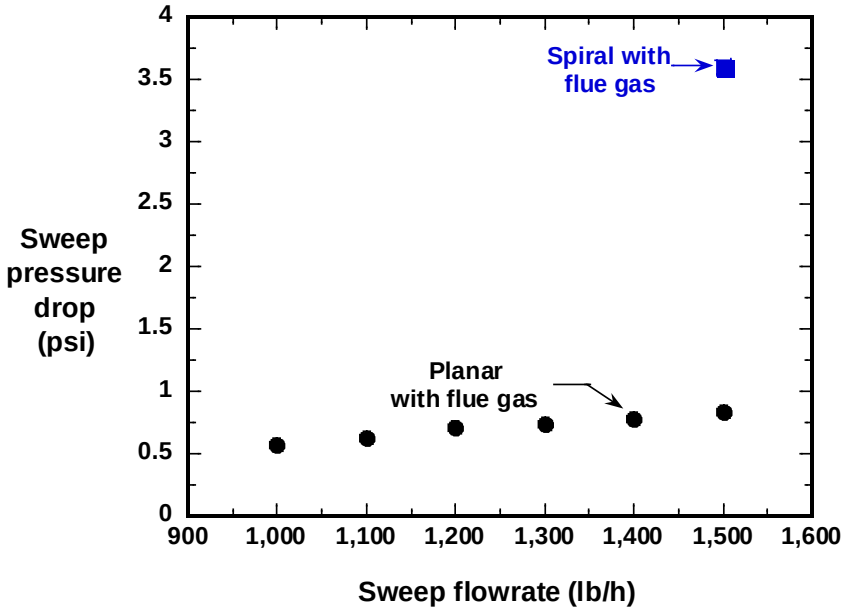
- **Phase 1** – Design system, fabricate membrane modules
- **Phase 2** – Build and install system at TCM
- **Phase 3** – Operate system, analyze results, decommissioning

Role of Participants

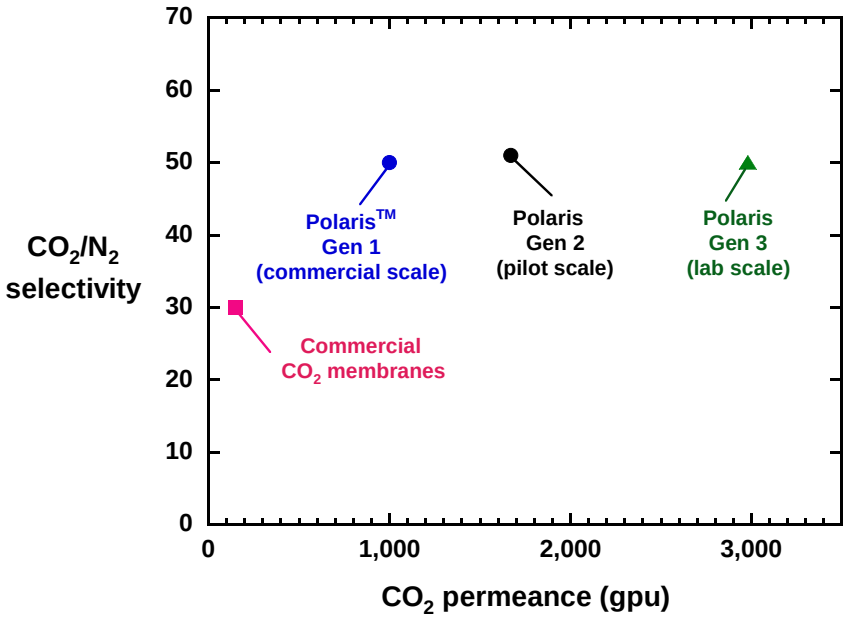
- MTR (Tim Merkel, Jay Kniep, Thomas Hofmann) – project lead and liaison with DOE; responsible for membrane system design, construction, installation and operation; will lead data analysis and all reporting to DOE
- TCM (Kjetil Hantveit, Sundus Akhter) – host site for the field test; with MTR, will coordinate system installation, operation, and data analysis
- Trimeric (Ray McKaskle) – Responsible for membrane capture process techno-economic analysis (TEA)
- WorleyParsons (Vlad Vaysman) – responsible for process environmental impact study

Background: Membrane and Module Improvements

Planar Modules



Polaris™ Membranes



- Moving from Gen 1 to Gen 2 Polaris cuts membrane area by >50% (~$10/tonne CO_2)
- Lower pressure drop of new modules saves 15 MW_e fan power on 500 MW_e system

Project Objectives

- Scale-up Gen 2 Polaris membrane packaged in low-pressure-drop, low-cost module stacks and test at TCM
- Demonstrate “containerized” skid as final form factor for future large-scale systems
- Test pilot system (~1 MW_e) over range of CO_2 capture rates and feed CO_2 content for TEA input
- Update overall process TEA

MTR

Primary Objective: Module-Scale Up

Plate-and-Frame Prototype with Gen-1 Polaris
(Tested at NCCC/B&W/UT-Austin 2015-18)

Verified low-pressure drop in field testing

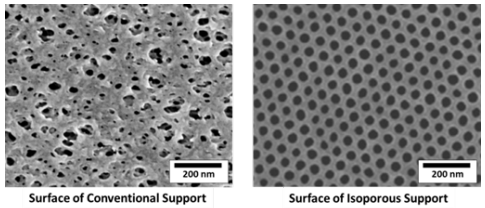
Containerized Module Stacks with Gen-2 Polaris
(2021 TCM Field Test)

Low pressure drop, plus optimized flow distribution and reduced cost (valves, etc)

This Project in Context

Self-Assembly Isoporous Supports, CA (DE-FE31596)

- Transformational new membrane (TRL 3 – 4)
- Reduces membrane area and energy use



Surface of Conventional Support | Surface of Isoporous Support

Pilot Testing at TCM, Norway (DE-FE0031591)

- Gen 2 Polaris™ membrane
- Low pressure-drop modules
- Containerized skid, 1 MW pilot scale

Large-Pilot Testing at WY ITC, WY (DE-FE31587)

- Phase I – Design 200 TPD pilot; secure host site
- Phase II – FEED and permitting
- Phase III – Fabricate, install and operate (TRL 7 – 8)

2018 2019 2020 2021 2022 2023 2024 2025

Project Progress: Modules

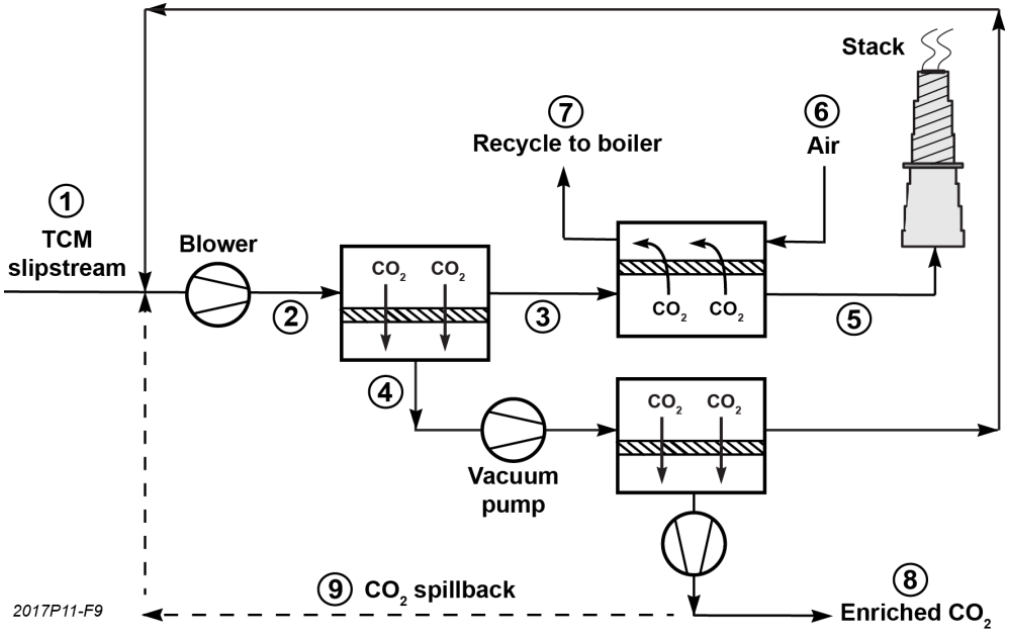
Membrane module stack trimming system

Module stack prepared for shipping

- Gen 2 Polaris produced on commercial roll-to-roll equipment
- Membrane stacks were assembled and passed QC testing at MTR, prior to installation on the test system

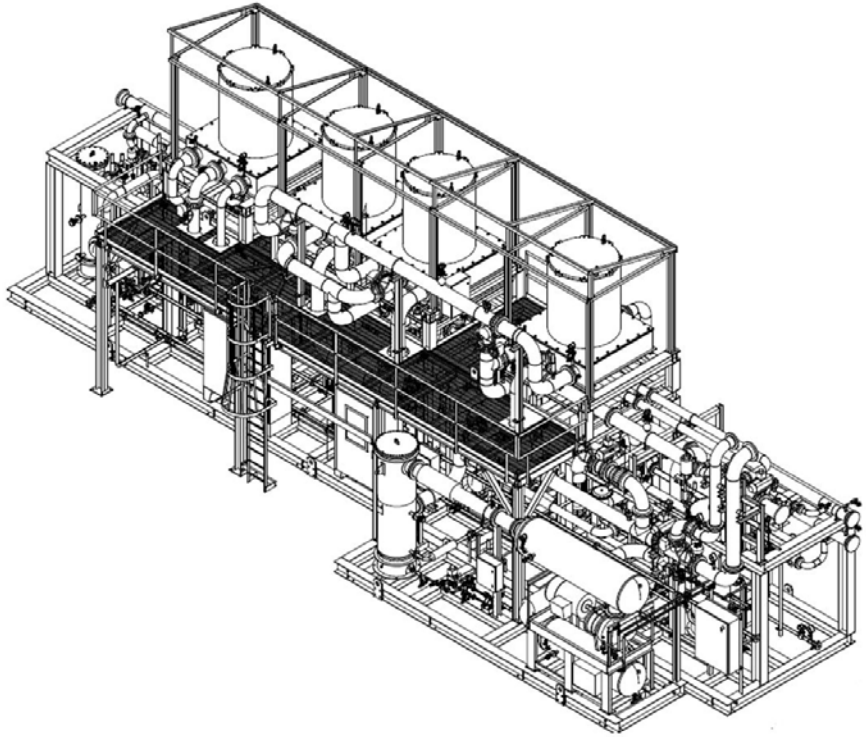
Test System Design

- 2 stage system with air sweep step (stream 6) and varying feed CO_2 content using recycle (stream 9)
- TCM slipstream flow rate of 2,000 Nm^3/h
- 50% to 95% CO_2 capture rates possible
- Progressive Recovery Inc. (PRI) of Dupo, Ill chosen as test system fabricator



System General Arrangement

- General arrangement drawings finalized in Summer 2020
- System splits into four skids for shipping
- Membrane “container” with 4 stacks on top floor (full container would be 6 stacks); blower/pumps on bottom floor
- Factory Acceptance Test (FAT) of system completed in March 2021
- Skids shipped to Norway in spring 2021, and currently installed at TCM



Construction Progress

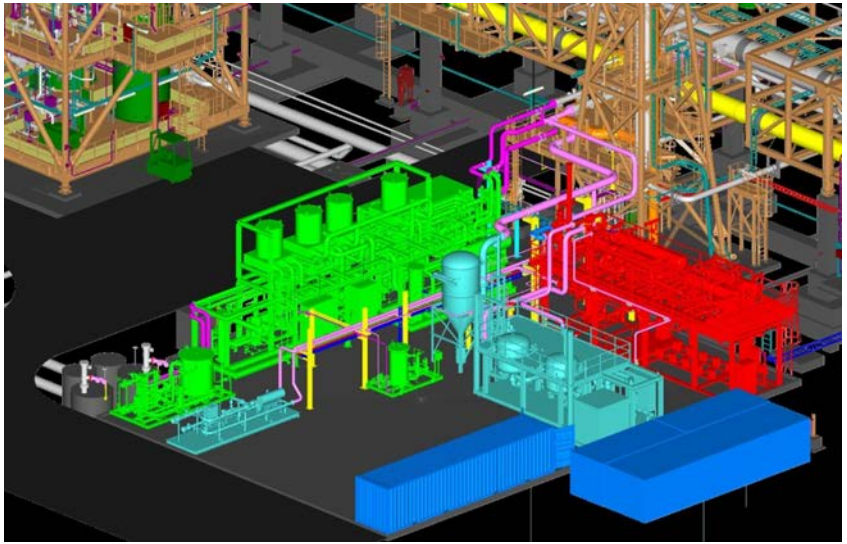
Main Test System during Fabrication

Main Test System Prepared for Shipping

- System construction started Fall 2020, completed in March 2021; shipped to TCM in April/May

Site Preparations

3rd site with MTR and TDA skids



Close up view of 3rd site foundation

- TCM approved development of the “3rd” site for testing of new technologies in 2019
- The site was ready for system installation by Fall 2020

System Installation at TCM

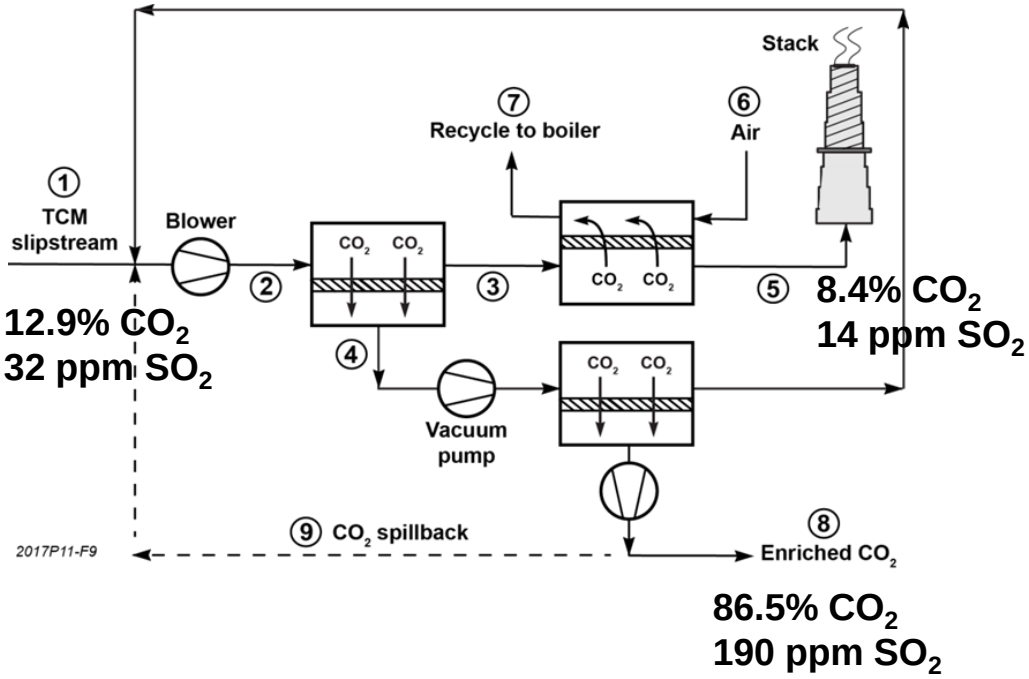
- System installation completed with TCM assistance in June 2021

MTR System at TCM

Membrane Stacks Container

- System has a single membrane container. Future larger systems will have multiples of this unit building block

System Start Up



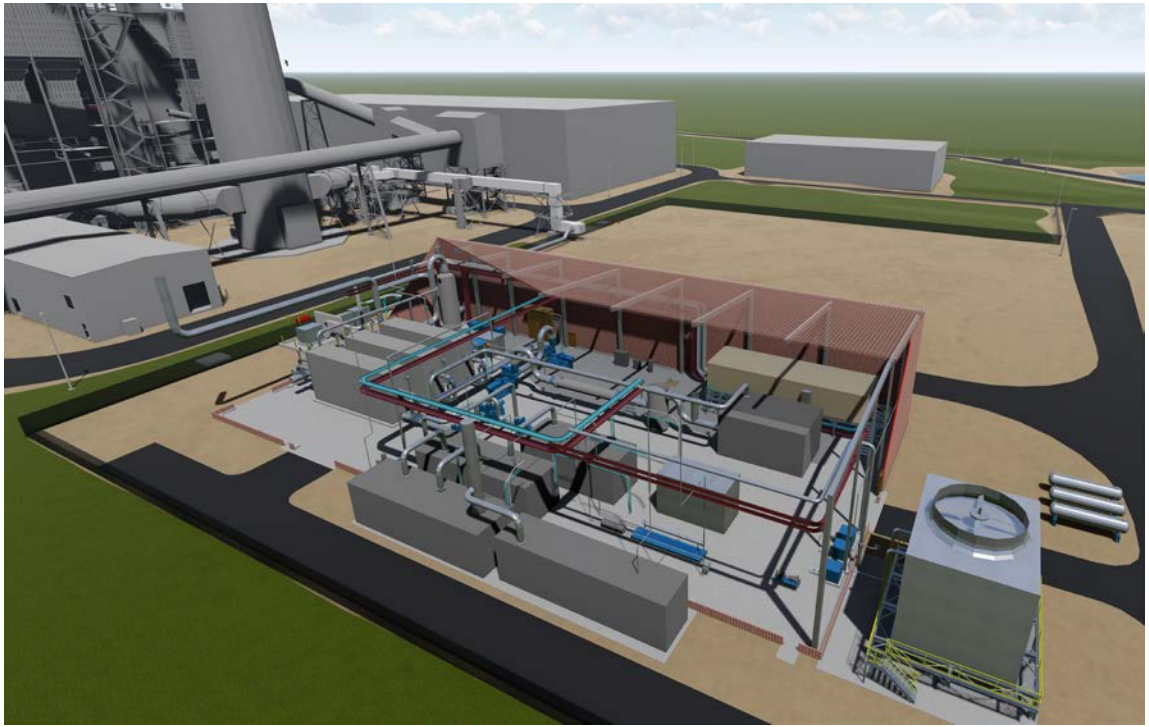
- Test system first ran on flue gas on July 28
- Initial run time focused on shakedown operations, verifying measurements, etc
- Preliminary results from baseline operation at full flow show expected removal and enrichment of CO_2
- Parametric test to start in Aug; about a month of parametric testing planned, followed by SS operation at optimal conditions

Test Plan for TCM Campaign

- Received input from DOE, TCM and CCSI2 team on test plan
  - 25 parametric tests identified
  - Adjustable parameters: flue gas flow rate, temperature, sweep air flow rate, and CO_2 concentration to 1st stage membrane
  - Will use these variables to explore capture rates from 50% to 95% and CO_2 feed content from ~13% to 20%
- Unique aspects of TCM field test
  - Ability to measure dynamic response of test system
  - Ability to measure particulate concentration/size distribution and impact on performance
  - Metal coupon testing of membrane generated streams: carbon steel, Ni plated CS, 304 SS, 316 SS, Al 6061, etc

MTR

Next Steps



- The TCM small pilot test campaign will end after 6 months of operation in Q1 2022
- This membrane test system will be available for other pilot demonstrations; interest for industrial capture trials in US and Europe
- The modular membrane capture approach will be further demonstrated at larger scale (150 TPD) at the Wyoming ITC

Summary

- Membrane stacks and test system were fabricated, QC tested, and shipped to Norway in spring 2021
- TCM prepared their 3rd test site for system arrival and then assisted MTR personnel with installation and startup activities, culminating with flue gas operation in July
- Shakedown operations now underway; initial performance on TCM flue gas is consistent with expectations
- Parametric test plan to start soon; about a month of parametric testing within 6 month campaign
- Test data will be used to update TEA, TGA, and EH&S report in BP3
- Project will finish Q1 2022, after which we plan to reuse test system

Acknowledgements

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Disclaimer

EXTRA SLIDES

Budget Period 3 Milestones

Milestone Number	Task/ Subtask No.	Milestone Description	Planned Completion Date (*)	Verification Method
Phase 3 / Budget Period 3				
11	8.1	Test System Commissioned on Flue Gas	7/31/21	Quarterly Report
12	8.3	Parametric Tests Completed, Long Term Performance Testing Begins	9/30/21	Quarterly Report
13	8.4	Long Term Performance Testing Completed	12/31/21	Quarterly Report
14	10	Complete Techno-Economic Analysis Report	2/1/22	Topical Report
15	11	Complete Technology Gap Analysis Report	2/1/22	Topical Report
16	12	Complete Environmental Health and Safety Risk Assessment Report	2/1/22	Topical Report
17	M1	Submit Final Report	5/31/22	Final Report

Budget Period 3 Scope of Work

- Main objective of BP3 is operation of the test system; tasks include:
  - Task 8: Operate Membrane Test System
  - Task 9: Decommissioning and Site Clean-Up
  - Task 10: Refine Techno-Economic Analysis
  - Task 11: Technology Gap Analysis
  - Task 12: Environmental Health and Safety Risk Assessment
- BP3 budget: $2,614,694
  - $1,333,694 Federal, $1,281,000 Cost Share

MTR

BP2 Budget

Budget Details	Federal Share	Cost Share	Total
Total Project (Award Value)	$8,166,304	$2,579,429	$10,745,732
Total Budget Period 1+2 (Planned)	$6,832,610	$837,093	$7,669,702
Total BP1+2 (Actual through May 2021)	$6,832,610	$1,132,992	$7,965,602
Total BP1+2 Variance	$0	$295,900	$295,900

- Cost share from MTR and TCM through the end of May 2021 exceeds the original project plan
- This additional contribution from MTR reflects higher than expected costs for system fabrication and installation at TCM
- Most recent estimate for BP3 cost share, reflecting 6 months of testing, indicates total project cost share contribution of ~22.8%