Bench-Scale Development of a Transformative Membrane Process for Pre-Combustion CO_2 Capture

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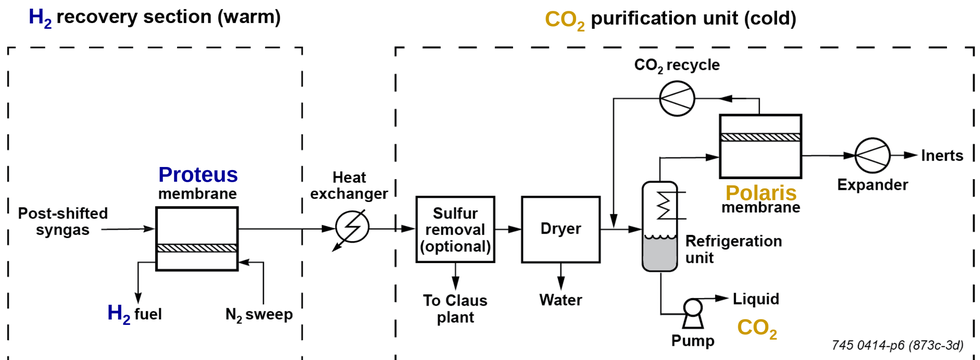
Introduction

MTR Pre-Combustion CO_2 Capture Process

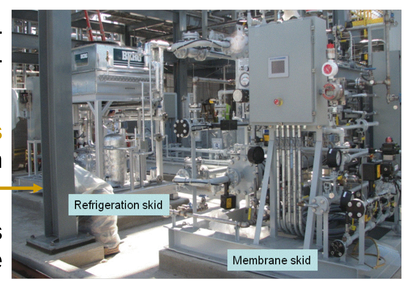
MTR has designed a dual-membrane process to capture CO_2 and recover H_2 in IGCC power generation:



- MTR previously collaborated with DOE NETL and WorleyParsons to analyze membrane process with MDEA sulfur pre-treatment[1]
- Compared to GEE Gasifier with 2-stage Selexol (Case 2 of DOE Bituminous Baselines Study), MTR process shows 27 MW_e net power improvement and 7.4% lower COE
- Uses MTR H_2-selective **Gen-1 Proteus**™ and CO_2-selective **Polaris**™ membranes
- ***Process economics can be improved using Proteus membranes with improved H_2/CO_2 selectivity and capable of operating above 150°C***

Prior Development of Polaris and Gen-1 Proteus Membranes

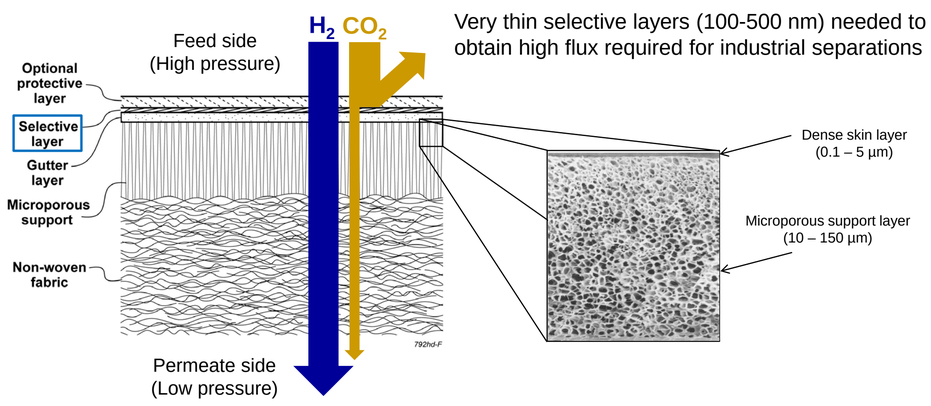
- **Polaris** membrane was developed for post-combustion CO_2 capture under project DE-NT0005312
- Under DE-FE0006138, commercial-scale **Polaris** modules were used in a 500 lb/h CO_2 purification demonstration unit



- The "cold section" of the CO_2 capture process was successfully demonstrated with 70% CO_2 capture and the production of high-purity liquid CO_2
- **Gen-1 Proteus** membrane was developed under DE-FE0001124 for elevated-temperature (150°C) pre-combustion H_2 separation; project culminated with stamp and small module tests using NCCC syngas
- MTR, with site support from NCCC, continued **Gen-1 Proteus** module scale-up and testing during gasification campaigns at NCCC between 2013 and 2017

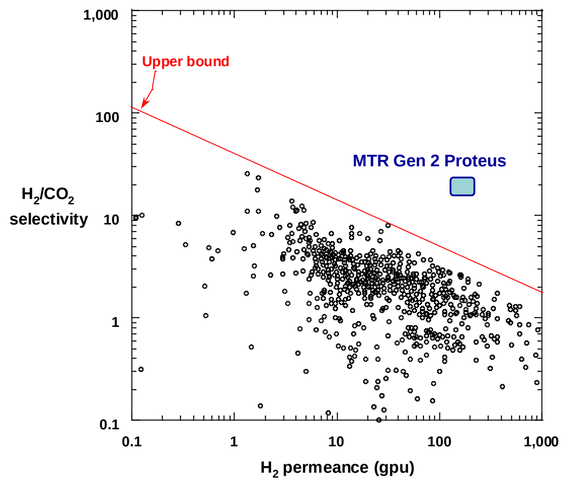
Membrane Background

Multi-Layer Composite Structure of Proteus Membrane



Gas Transport and Separation

Flux-Selectivity Tradeoff

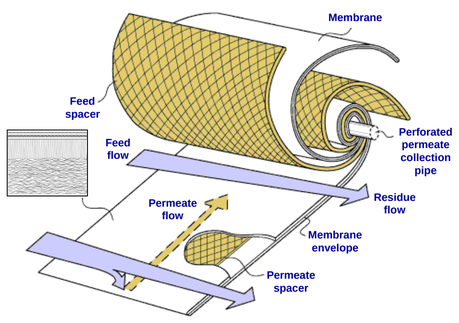


Permeance: Permeability/thickness (µm) (pressure-normalized flux)

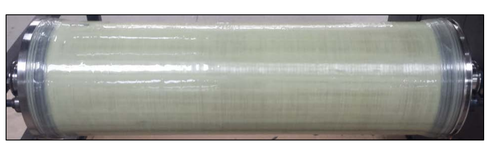
Selectivity: Ratio of gas permeance or permeability values

1 gpu = 10^{-6}cm³(STP) $s^{-1}cm^{-2}cmHg$

Spiral-Wound Membrane Modules



Packing density of spiral elements: 500-1,000 m^2/m^3



- Membrane sheets are packaged into spiral-wound modules for industrial separations
- Module components must be stable under process conditions

[1] Jim Black, Peter Kabatek, Tim Merkel, *"Analysis of MTR Membrane Technology for Pre-Combustion Carbon Capture,"* Eleventh Annual Conference on Carbon Capture, Utilization & Sequestration, April 30-May 3, 2012, Pittsburgh, PA

Overview of New Project

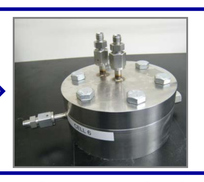
Project Details

- **Award Number:** DE-FE0031632
- **Project Period:** 36 months with anticipated official start date of September 1, 2018
- **Funding:** $2.0 million DOE; $0.5 million cost share ($2.5 million total)
- **DOE Project Manager:** Bruce Lani
- **Participants:** MTR, Susteon, Energy & Environmental Research Center (EERC)
- **Project Scope:** Scale-up the **Gen-2 Proteus** membrane to modules capable of operating at 200°C. A bench-scale field test skid processing a coal-derived syngas slipstream at the EERC will demonstrate the high-temperature performance of Gen-2 Proteus modules. A successful project will bring the **Gen-2 Proteus** membrane technology from a TRL 4 to 5 and signify readiness to test the full MTR Pre-Combustion CO_2 Capture Process on a larger scale.

Project Plan

Gen-2 Proteus Membrane Development Pathway:

Stamp	Small Module	Semi-Commercial Module	Commercial Module
~ 0.003 m^2	0.1-0.2 m^2	~ 2-4 m^2	~ 20-50 m^2
Budget Period 1	Budget Period 2	Budget Periods 2 and 3	Future Project



Year 1 (Budget Period 1)

- Prepare preliminary techno-economic analysis (Task 2)
- Optimize **Gen-2 Proteus** membrane; target H_2/CO_2 = 30 at 200°C (Task 3)
- Identify high-temperature module components and fabricate prototype modules (Task 4)
- Evaluate alternative process designs (Task 5)

Year 2 (Budget Period 2)

- Scale-up production of **Gen-2 Proteus** membrane (Subtask 6.1)
- Prepare lab-scale **Gen-2 Proteus** modules and perform high-temperature test at MTR (Subtasks 6.3, 6.4)
- Design and fabricate bench-scale field test skid (Task 7)
- Optimize process designs (Task 8)

Year 3 (Budget Period 3)

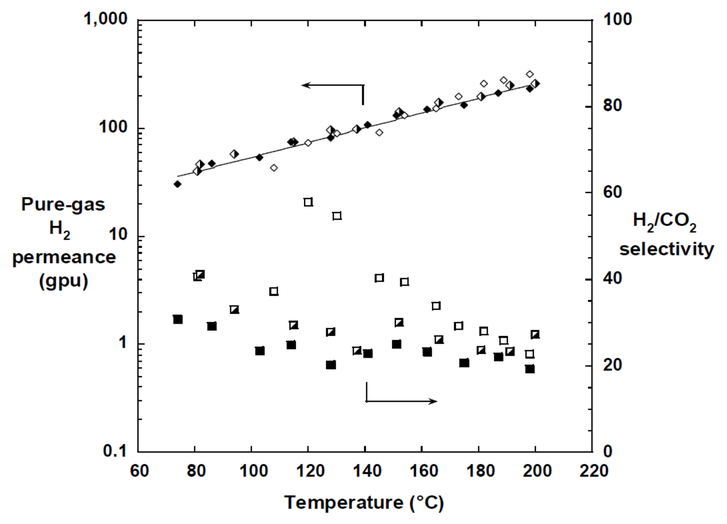
- Prepare EERC host site for field test (Task 9)
- Prepare **Gen-2 Proteus** modules for field test (Task 10)
- Install and shakedown MTR bench-scale skid at EERC (Task 11)
- Operate MTR bench-scale skid with **Gen-2 Proteus** modules on syngas at EERC (Task 12)
- Prepare Project Reports including:
  - Final techno-economic analysis (Subtask 14.1)
  - Technology gap analysis (14.4)
  - Environmental health and safety risk assessment (Subtask 14.5)
  - Final technology maturation plan (Subtask 14.3)
  - Final report (Subtask 14.6)

Preliminary Gen-2 Proteus Performance Data

Membrane Stamp Pure-Gas Temperature Cycling

- H_2 permeance and H_2/CO_2 selectivity measured at 50 psig
- Three temperature cycles up to 200°C
- Membrane stamp stable at all temperatures
- H_2 permeance increases with temperature, up to ~300 gpu
- No H_2 permeance hysteresis, no membrane damage
- H_2/CO_2 selectivity averages ~30
- Results are extremely promising for a prototype membrane

Gen-2 Proteus Membrane Stamps at MTR Labs



Field Test Conditions at NCCC

- Shifted syngas: ~13% H_2, 13% CO_2, 70% N_2, 2.5% CO, 1.5% CH_4
- Feed: 300 – 800 ppmv H_2S, 165-180 psig, 120 - 200°C
- 50 lb/h syngas to main MTR skid, 1 lb/hr slipstream to stamp cell

NCCC Field Test Stamp Results

- Membrane stamps were stable up to 200°C
- H_2/CH_4, H_2/N_2, H_2/CO selectivities were all > 100
- H_2/H_2S selectivity > 50
- Average H_2/CO_2 selectivity = 32
- Findings consistent with lab results

Gen-2 Proteus Membrane Stamps at NCCC Field Test