MEMBRANE TECHNOLOGY & RESEARCH

Bench-Scale Development of a Transformative Membrane Process for Pre-Combustion CO_2 Capture (DE-FE0031632)

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Membrane Technology and Research, Inc.

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Project Overview

Award name: Bench-Scale Development of a Transformative Membrane Process for Pre-Combustion CO_2 Capture (DE-FE0031632)

Project period: 10/1/18 to 12/30/21
Funding: $2.0 million DOE; $0.5 million cost share ($2.5 million total)
DOE program manager: Carl Laird
Participants: MTR, Susteon, Energy & Environmental Research Center (EERC)

Project scope: Optimize Gen-2 Proteus membrane and develop modules capable of operation at 200°C; demonstrate membrane module performance processing coal-derived syngas during field test at EERC; optimize integration of membrane processes into IGCC with carbon capture

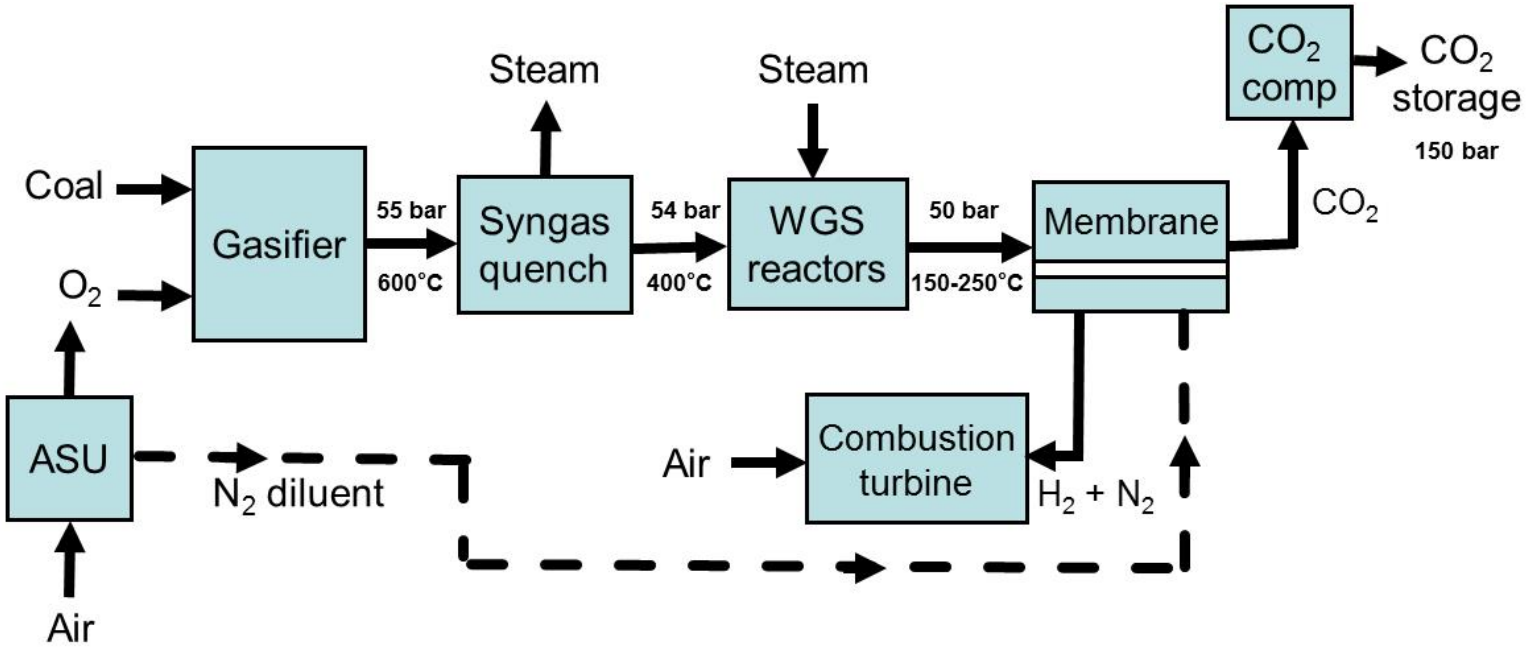
Project plan: The project is organized in three phases:

- **Budget Period 1/Year 1** – Gen-2 Proteus membrane optimized, high temperature module components identified
- **Budget Period 2/Year 2** – Gen-2 Proteus modules tested at MTR; fabricate field test skid
- **Budget Period 3/Year 3** – Install skid and conduct field test at EERC, analyze results, update TEA with field test performance and optimized membrane process design

Role of Participants

- MTR – project lead and liaison with DOE; responsible for membrane and module development; skid design, construction, installation and operation; will lead data analysis and all reporting to DOE
- Susteon (Raghubir Gupta, Cory Sanderson, Jim Zhou) – process optimization studies for integration of MTR's membrane capture process in IGCC and TEA report
- EERC (Tyler Newman, Mike Swanson) – host site for field test in Budget Period 3 of project; with MTR, will coordinate system installation, operation, decommissioning, and data analysis

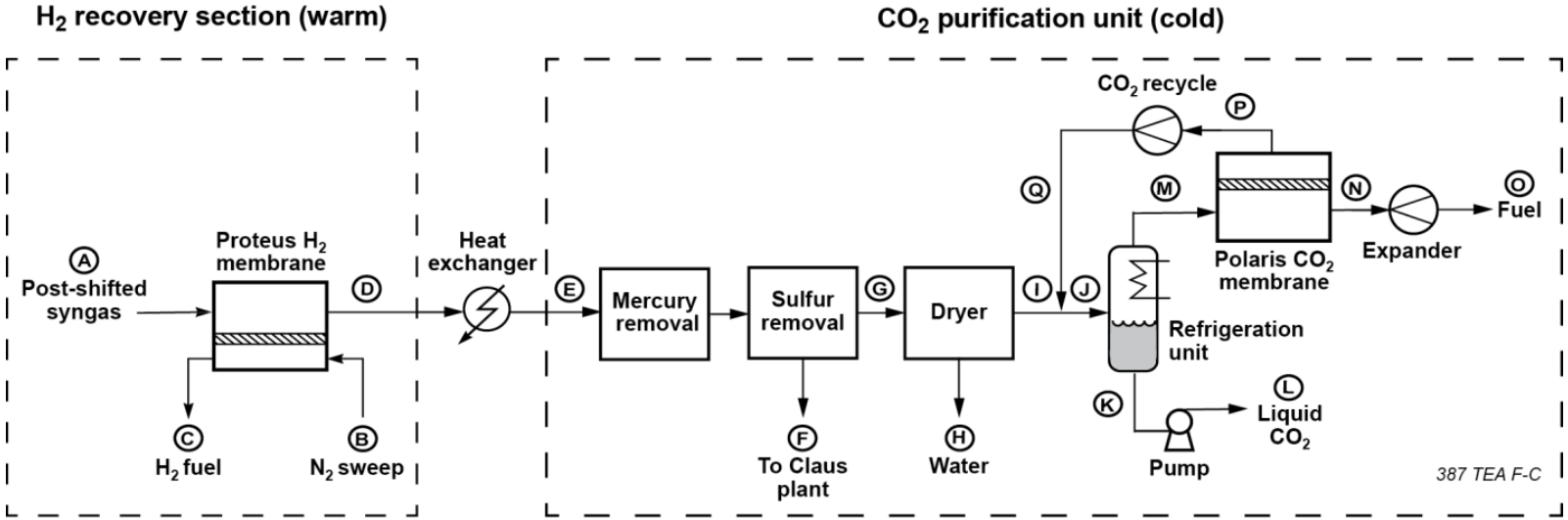
Background: Pre-Combustion CO_2 Capture with Membranes



Membrane advantages:

- Can operate warm/hot to reduce the need for heat exchange
- CO_2 is maintained at pressure; less compression compared to standard AGR
- Water goes with fuel gas; reduces CO_2 dehydration costs

Background: MTR Dual Membrane Process for Pre-Combustion CO_2 Capture

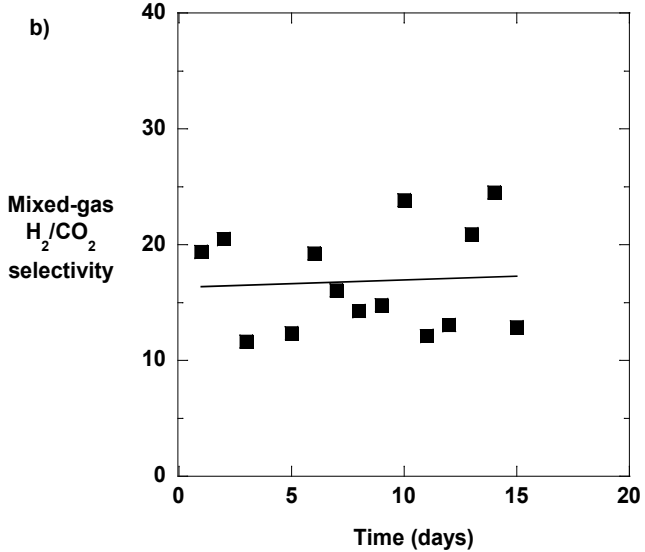


- Collaborated with Jim Black at DOE NETL and Peter Kabatek at WorleyParsons to analyze MTR process
- Compared to GE Gasifier with 2-stage Selexol (Case 2 of DOE Bituminous Baselines Study), MTR process shows 27 MW_e net power improvement and 7.4% lower COE with Gen-1 Proteus membrane properties
- Both warm (H_2 membrane) and cold (CO_2 membrane) portions of process tested at NCCC

MTR

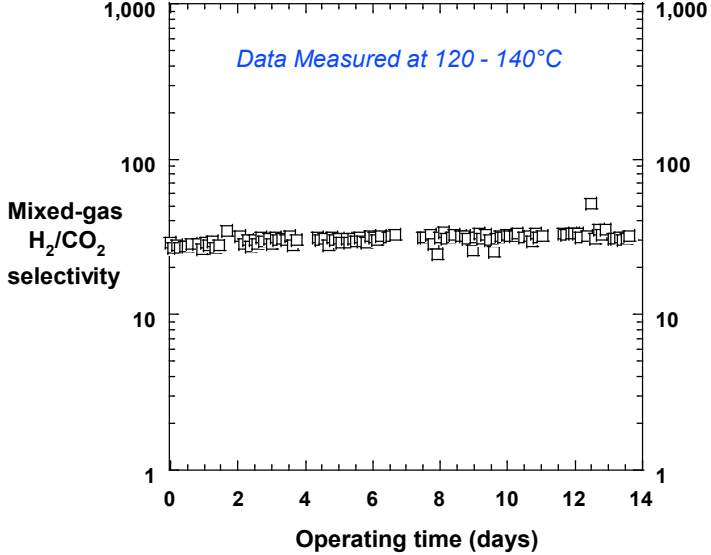
Background: H_2-Selective Proteus Membrane

Gen-1 Proteus Stamp Selectivity at NCCC



- Temperature limit: 150°C
- Average H_2/CO_2 = 15
- NCCC field tests (2009 – 2016)
  - Stamps and lab-scale modules: 5,500 hours
  - Semi-commercial modules: 3,625 hours
- Additional industrial field tests
  - H_2 recovery in bio-waste to ethanol process
  - Syngas ratio adjustment in gas to liquids process

Gen-2 Proteus Stamp Selectivity at NCCC



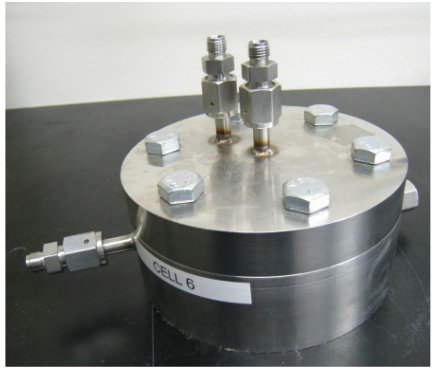
- Temperature limit: 200°C
- Average H_2/CO_2 = 30
- H_2/H_2S > 50
- H_2/CH_4, H_2/N_2, H_2/CO all >100
- Field test data consistent with lab results

Stages of Membrane Development

1) Membrane stamps (Budget Period 1)

Area: 0.0030 m^2

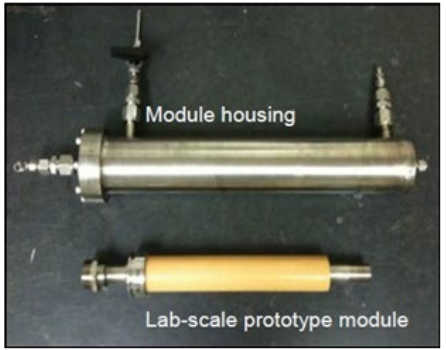
Flow: 1 lb/h



2) Lab-scale module (Budget Period 2)

Area: 0.130 m^2

Flow: 10 lb/h



3) Semi-commercial module (Budget Period 3)

Area: 1 - 4 m^2

Flow: bench-scale (50 lb/h)

4) Commercial module

Area: 20 – 50 m^2

Flow: field demonstration (500 lb/h)

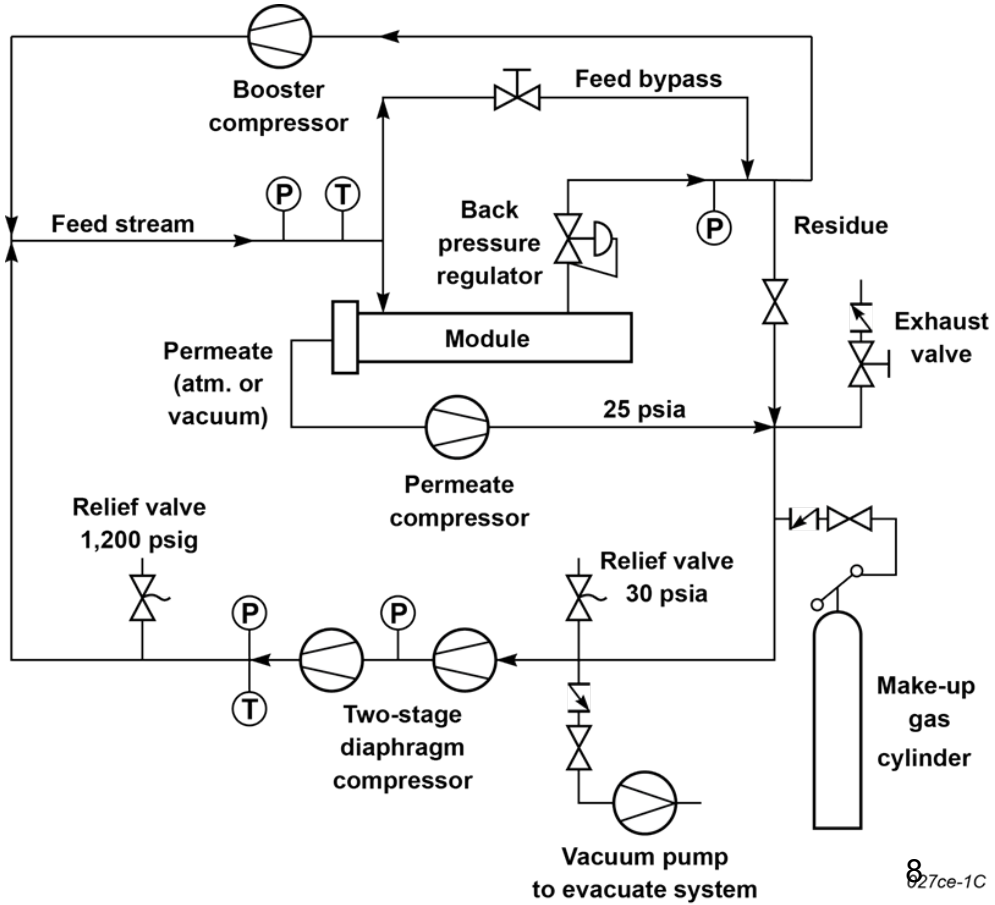
MTR

Membrane and Module Component Screening

Module Component Exposure System

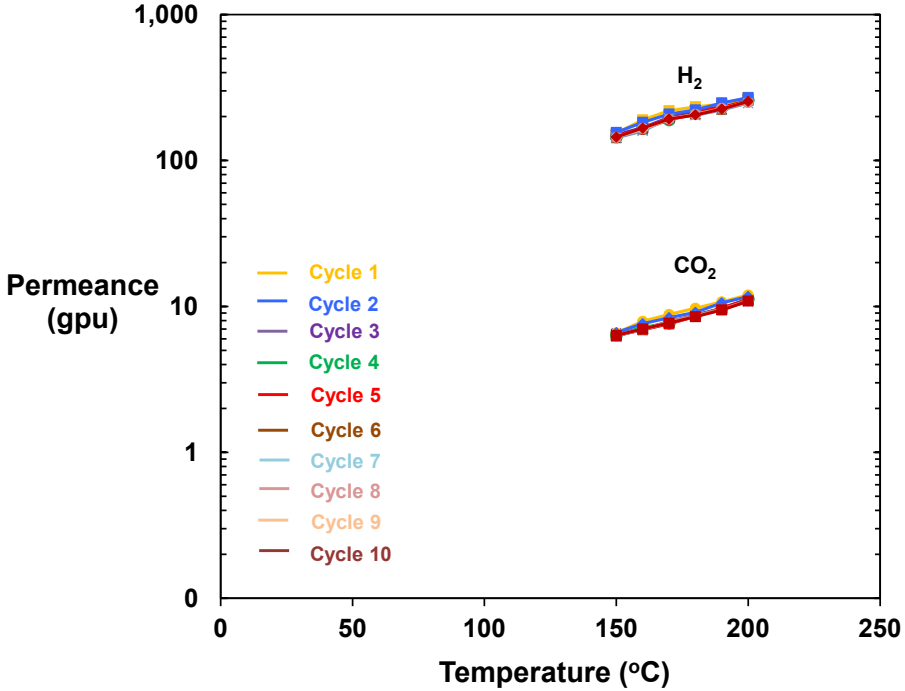
- Test conditions
  - Up to 1000 psig, 200°C
  - Inert gas, steam, or wet/dry gas mixtures (H_2, CO_2, N_2)

Recirculating Compressor System for Mixed-Gas Tests

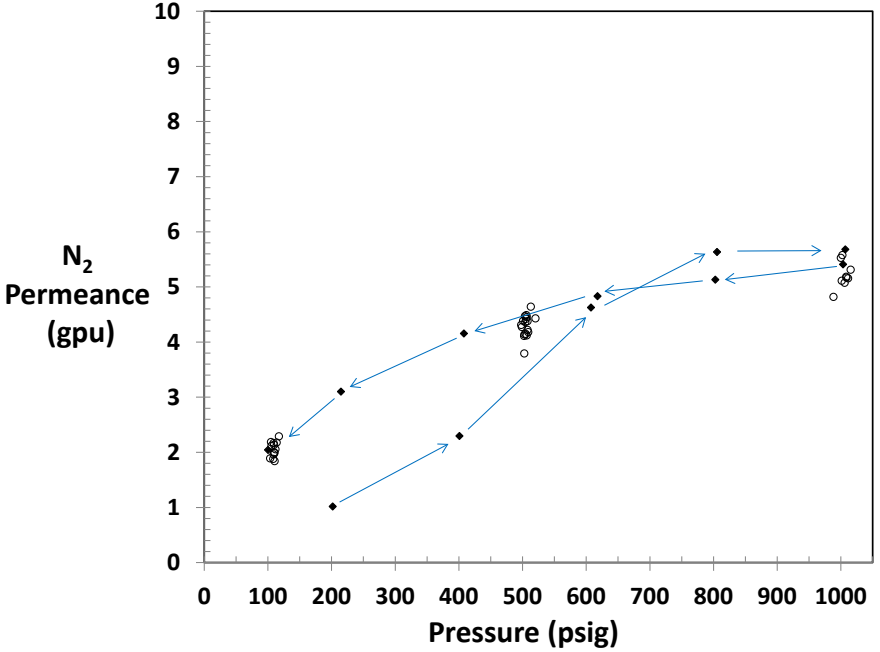


Robust Gen-2 Proteus Membrane Developed with Target Performance

Temperature Cycling



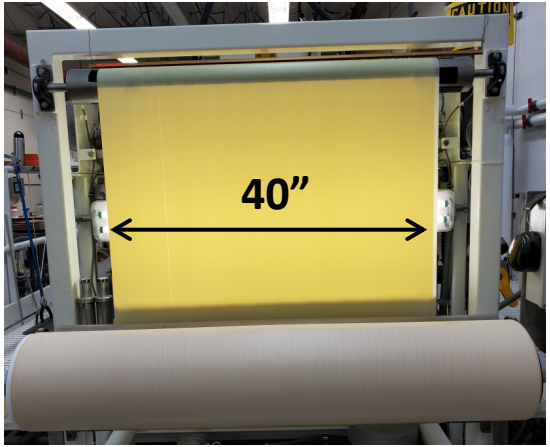
Pressure Cycling with Nitrogen



Optimized Gen-2 Proteus Membrane has a H_2/CO_2 = 37

Gen-2 Proteus Production Scaled Up to Commercial Roll-to-Roll Equipment

MTR Commercial Casting Machine



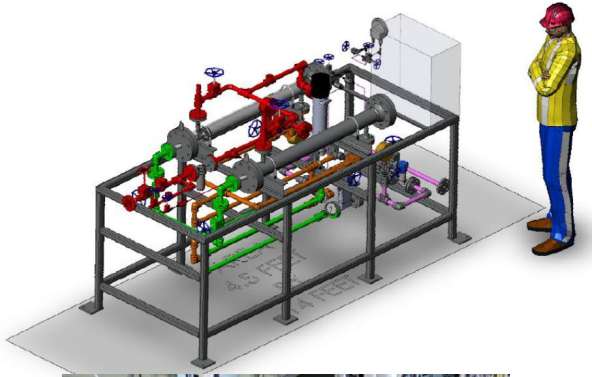
MTR R&D Coating Machine

Fabrication of Full-Length Module for Field Test

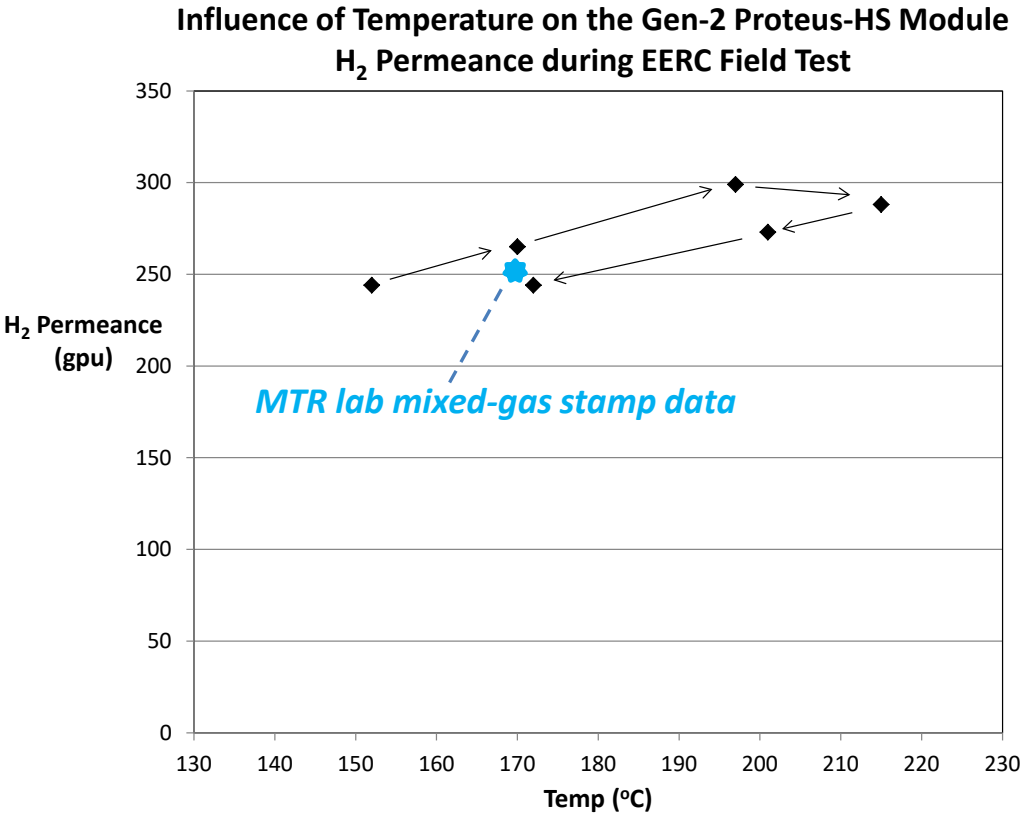
Gen-2 Proteus Modules Developed in this Project

Bench-Scale Field Test at EERC

- Field test conditions confirmed early in BP2
  - Oxygen-blown fluidized bed gasifier
  - 300 - 500 psig
  - 30 – 35% H_2, 40 – 50% CO_2
  - Up to 3000 PPM H_2S
- Skid was fabricated in Northern California, arrived at EERC in January 2021
- Two MTR engineers were on-site from April 21 through May 1 for all field test activities
- Great support from EERC throughout project and field test



Gen-2 Proteus Field Test Performance



- Full parametric test matrix of temperature and feed syngas pressures was completed
- Module was temperature cycled up to a simulated process upset condition 215°C at a syngas pressure of 300 psig
- Initial/final 170°C H_2 permeance values in excellent agreement with MTR lab mixed gas value reported in Q10 report (255 gpu)

Post-Field Test Membrane Module Analysis

- Post-Field Test pure gas measurements in excellent agreement with pre-test values
- Dye test and autopsy results:
  - Membrane/spacer compatibility not an issue
    - No membrane pin-hole leaks
  - Module components can operate in syngas conditions
    - Spacers in excellent condition
    - Glue lines intact
- All post-field tests did not find evident of membrane or module degradation due to exposure to high temperature syngas conditions

Process Optimization and Techno-Economic Analysis

- TEA report activities ramping up
  - Aspen Plus simulation of IGCC Case B5B set up and reviewed directly with NETL modeling team to ensure match of performance
    - Simulation also capable of producing H_2, NH_3, and/or syngas
  - TEA framework set up to calculate LCOE, matching B5B
    - TEA can also determine cost of H_2 from IGCC or ATR/SMR
  - MTR Dual Membrane Process will be evaluated with MDEA and WDP processes for desulfurization step
    - Processes chosen by Susteon after desulfurization review of 11 different technologies
  - Gen-2 Proteus membrane temperature and selectivity sensitivity studies
    - 150, 175, and 200°C updated membrane performance to find LCOE impact

Process Optimization and Techno-Economic Analysis

- Susteon and MTR have also evaluated several potential near term industrial applications for MTR membranes
  - H_2 Purification and CO_2 capture from a Modular Hydrogen Generation System
    - MTR Proteus and Orion (commercial CO_2-selective) membranes
  - CO_2 capture from Steam Methane Reformer Syngas
    - Multiple process designs with Proteus and Polaris membranes
  - CO_2 capture from Autothermal Reformer Syngas
    - Simulation of this process design will be included in TEA report
  - Removing blended H_2 from Natural Gas Pipelines
    - Used DOE-NREL technical report NREL/TP-5600-51995 as a reference
    - Two MTR lower temperature H_2-selective membranes have potential for this application

Summary

- Membranes have some advantages for pre-combustion CO_2 capture and H_2 purification
- Gen-2 Proteus membrane has been made on roll-to-roll equipment with a $H_2/CO_2 = 37$
- Gen-2 Proteus membrane modules successfully test at EERC in syngas conditions up to 215°C
- Techno-Economic Analysis and other deliverable project reports are underway

Acknowledgements

- **U.S. Department of Energy,**

  National Energy Technology Laboratory
  - Carl Laird
  - Andy Aurelio
  - Bruce Lani
- **Susteon**
  - Raghubir Gupta
  - Cory Sanderson
  - James Zhou
- **EERC**
  - Tyler Newman
  - Mike Swanson
  - Joshua Stanislowski

EXTRA SLIDES

FE31632 Organization Chart

- **MTR** will provide membrane, module, and membrane process expertise; make the membranes and modules required for this project; design and build a membrane skid for CO_2 capture from pre-combustion syngas; work with EERC to install and operate the skid at their site; and participate in process optimization studies and techno-economic analysis with Susteon. As the lead organization, MTR will also act as technical and administrative liaison with DOE.
- **Susteon** will conduct process optimization studies to understand the best integration of MTR's membrane capture process into a syngas cleanup train including contaminants handling. Susteon will also work with MTR personnel to conduct the project techno-economic analysis.
- The **Energy and Environmental Research Center (EERC)** will be the host site for testing of MTR's bench-scale system in the third year of the program. EERC will provide the test site, all utilities, and syngas delivery and disposal to the project. EERC engineers will also work with MTR to design, install and operate the bench skid.

FE31632 Gantt Chart

Task	Project Tasks	Task Start Date	Task End Date	Budget Period 1 (10/1/2018 - 9/30/2019)				Budget Period 2 (10/1/2019 - 9/30/2020)				Budget Period 3 (10/1/2020 - 9/30/2021)			
				Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
M1	**Project Management and Planning**	10/1/18	9/30/21												
1	**Prepare Preliminary Technology Maturation Plan**	10/1/18	12/31/18												
2	**Prepare Preliminary Techno-Economic Analysis**	10/1/18	12/31/18												
3	**Prepare Gen-2 Proeteus Membrane with Target Performance**	10/1/18	6/30/19												
3.1	*Optimize Gen-2 Proteus Membrane*	10/1/18	3/31/19												
3.2	*Evalaute Gen-2 Proteus Membrane Performance and Lifetime*	1/1/19	6/30/19												
4	**Fabricate Prototype High Temperature Modules**	1/1/19	9/30/19												
5	**Evaluate Alternative Process Designs**	10/1/18	9/30/19												
6	**Prototype High Temperature Module Tests at MTR**	10/1/19	9/30/20												
6.1	*Gen-2 Proteus Membrane Production Scale-Up*	10/1/19	12/31/19												
6.2	*Continued Gen-2 Proteus Membrane Lifetime Testing*	10/1/19	6/30/20												
6.3	*Prepare Lab-Scale Gen-2 Proteus Modules*	10/1/19	3/31/20												
6.4	*High Temperature Lab-Scale Module Tests*	4/1/20	9/30/20												
7	**Design and Fabricate Bench-Scale Field Test Skid**	10/1/19	9/30/20												
7.1	*Prepare Preliminary Design*	10/1/19	12/31/19												
7.2	*Review EERC Site Specifications*	10/1/19	12/31/19												
7.3	*HAZOP review and Finalize Design*	1/1/20	3/31/20												
7.4	*Select Vendors and Fabricator*	1/1/20	3/31/20												
7.5	*Fabricate Skid*	4/1/20	9/30/20												
7.6	*Factory Acceptance Test (FAT) at Fabricator Site*	7/1/20	9/30/20												
8	**Optimize Process Designs**	10/1/19	9/30/20												
9	**Host Site Preparations**	10/1/20	12/31/20												
9.1	*Prepare EERC Host Site*	10/1/20	12/31/20												
9.2	*Ship Bench-Scale Test System to EERC*	10/1/20	12/31/20												
10	**Prepare Bench-Scale Field Test Modules**	10/1/20	12/31/20												
11	**Bench Scale Membrane System Installation and Shakedown**	1/1/21	3/31/21												
11.1	*Tie-In All Utility and Process Connections*	1/1/21	2/15/21												
11.2	*Install Gen-2 Proteus Modules in Test System*	1/1/21	2/15/21												
11.3	*Installation of Heat Tracing and Insulation*	2/16/21	3/31/21												
11.4	*Develop A Preliminary Test Plan*	1/1/21	2/15/21												
11.5	*Job Site Safety Practices Review and Operation Training*	2/16/21	3/31/21												
12	**Operate Bench-Scale Membrane Field Test System**	4/1/21	9/30/21												
12.1	*System Commissioning*	4/1/21	5/15/21												
12.2	*Finalize Test Plan*	4/1/21	5/15/21												
12.3	*Operation of Test System Under Syngas Conditions*	5/16/21	6/30/21												
12.4	*Analyze System Performance*	4/1/21	9/30/21												
13	**Decommissioning Activities**	7/1/21	9/30/21												
14	**Prepare Project Reports**	10/1/20	9/30/21												
14.1	*Prepare Final Techno-economic Analysyi*	4/1/21	9/30/21												
14.2	*Final State Point Data Table Updated*	7/1/21	9/30/21												
14.3	*Prepare Final Technology Maturation Plan*	7/1/21	9/30/21												
14.4	*Technology Gap Analysis Completed*	7/1/21	9/30/21												
14.5	*Environmental Health and Safety Risk Assessment Completed*	7/1/21	9/30/21												
14.6	*Final Report Prepared*	10/1/20	9/30/21												