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

Karl Amo, Richard Baker, Brice Freeman, Jenny He, Ivy Huang, Jay Kniep (PI), Tim Merkel, Witopo Salim

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)

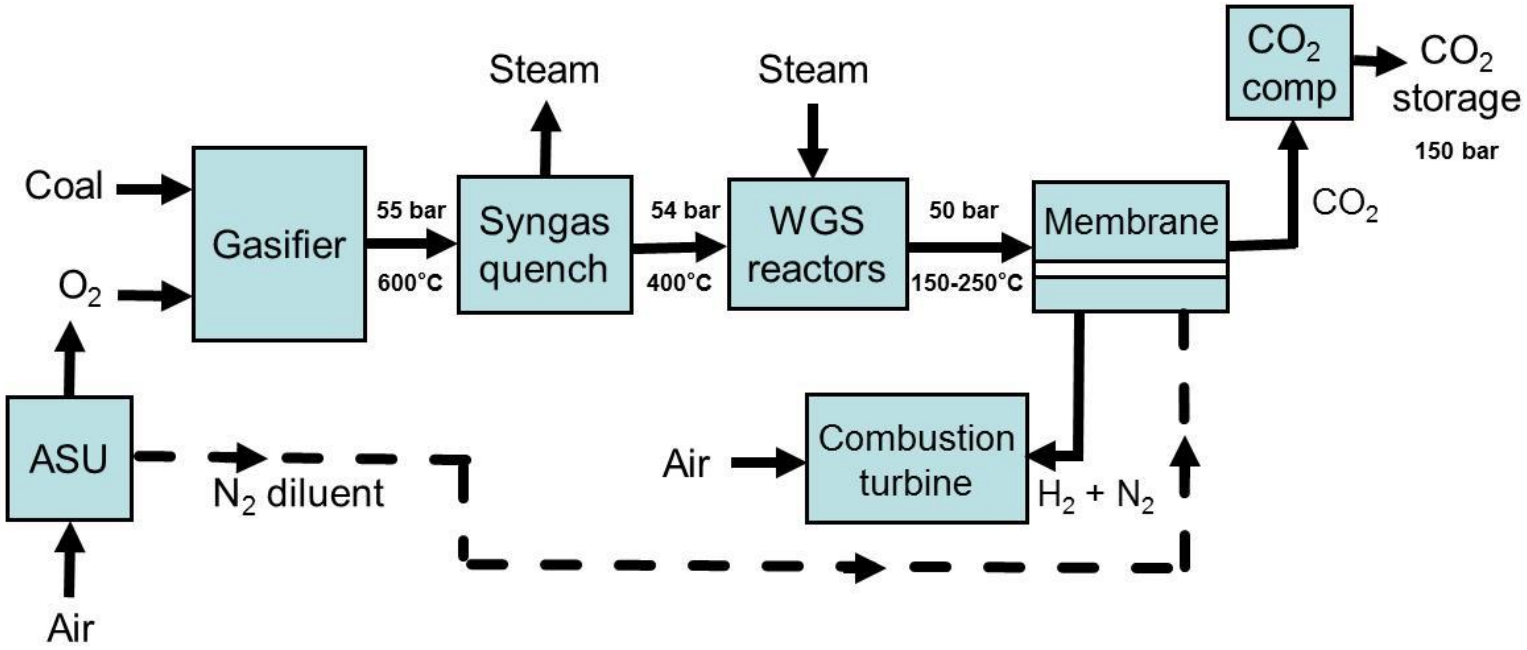
Project period: 10/1/18 to 9/30/21
Funding: $2.0 million DOE; $0.5 million cost share ($2.5 million total)
DOE program manager: Andy Aurelio
Participants: MTR, Susteon, Energy & Environmental Research Center (EERC)

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

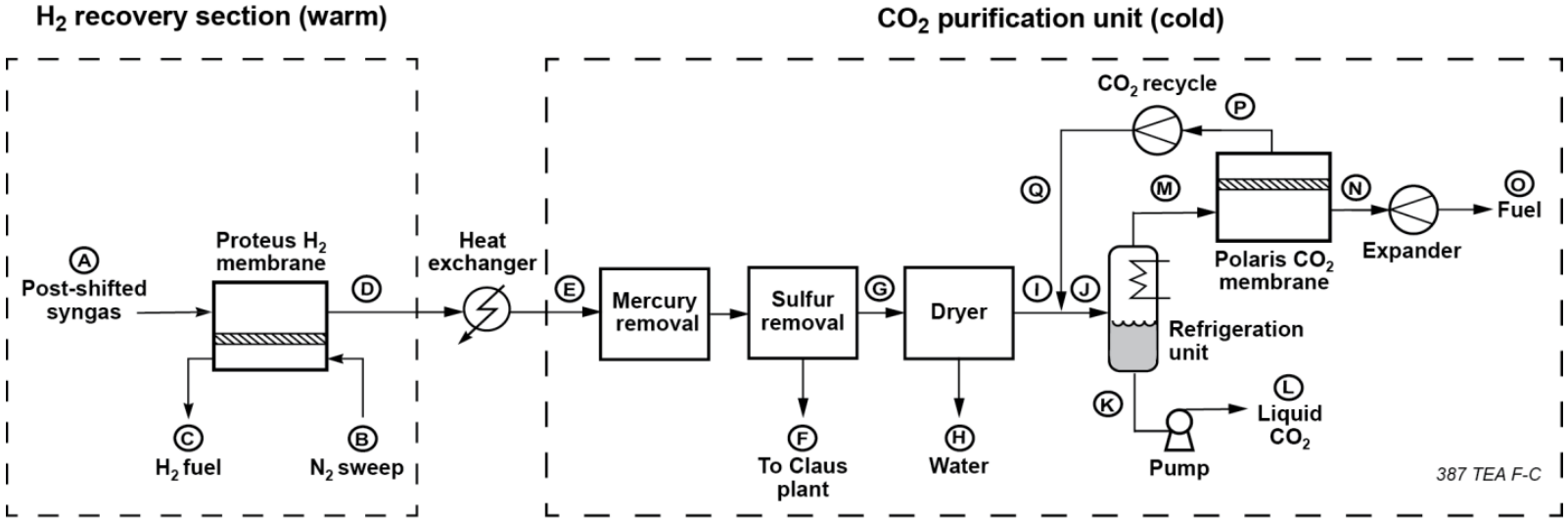
Background: Pre-Combustion CO_2 Capture with Membranes



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

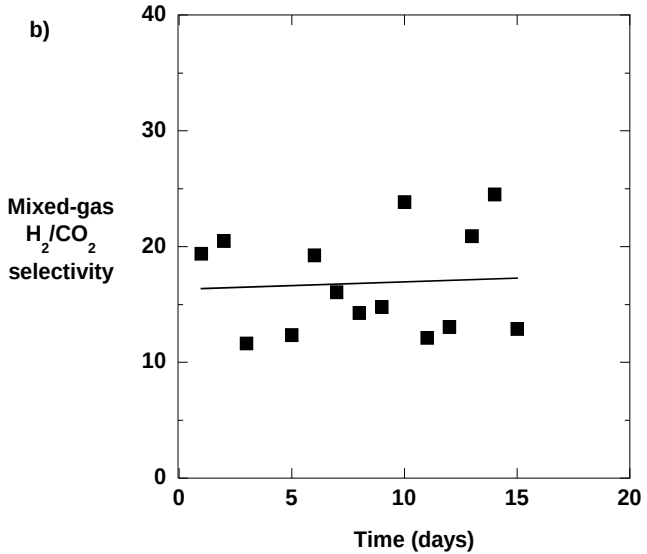
Background: MTR Dual Membrane Process for Pre-Combustion CO_2 Capture



- 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

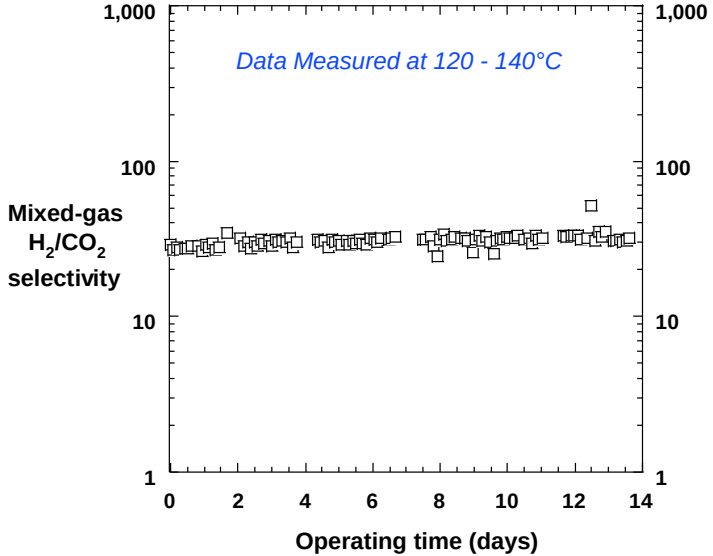
Background: H_2-Selective Proteus Membrane

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

Project Objectives

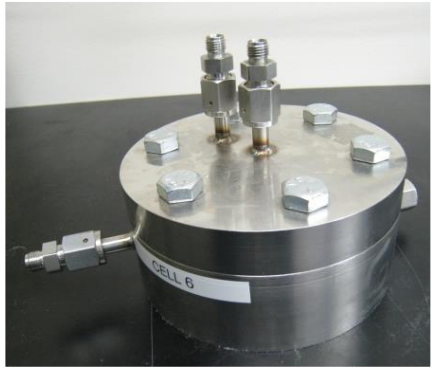
- Optimize and scale-up Gen-2 Proteus membrane
- Develop high temperature Gen-2 Proteus membrane modules for use in coal gasification environments
- Design, fabricate, and operate bench-scale membrane module skid at a EERC field test with coal-derived syngas
- Move the Gen-2 Proteus membrane pre-combustion capture technology from TRL 4 to TRL 5
- With project partner Susteon, evaluate sulfur treatment options and optimize alternative membrane process designs for integration into an IGCC plant
- Update TEA incorporating field test performance data and optimized membrane process design for pre-combustion CO_2 capture

Stages of Membrane Development

1) <u>Membrane stamps (Budget Period 1)</u>

Area: 0.0030 m^2

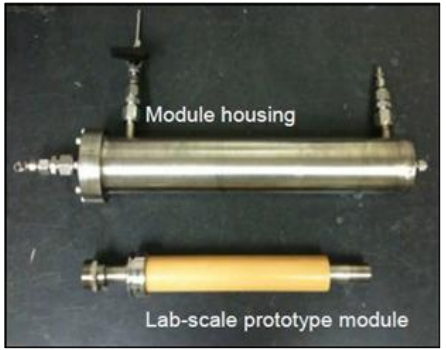
Flow: 1 lb/h



2) <u>Lab-scale module (Budget Period 2)</u>

Area: 0.130 m^2

Flow: 10 lb/h



3) <u>Semi-commercial module (Budget Period 3)</u>

Area: 1 - 4 m^2

Flow: bench-scale (50 lb/h)

4) <u>Commercial module</u>

Area: 20 – 50 m^2

Flow: field demonstration (500 lb/h)

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Budget Period 1 Tasks:
Prepare Gen-2 Proteus Membrane with Target Performance

- Gen-2 Proteus membrane has successfully been synthesized on various membrane substrates
- A post-fabrication treatment technique was developed that improved the membrane H_2/CO_2 = 50, a significant improvement over the project success criteria of 30

High temperature membrane substrate

Gen-2 Proteus membrane

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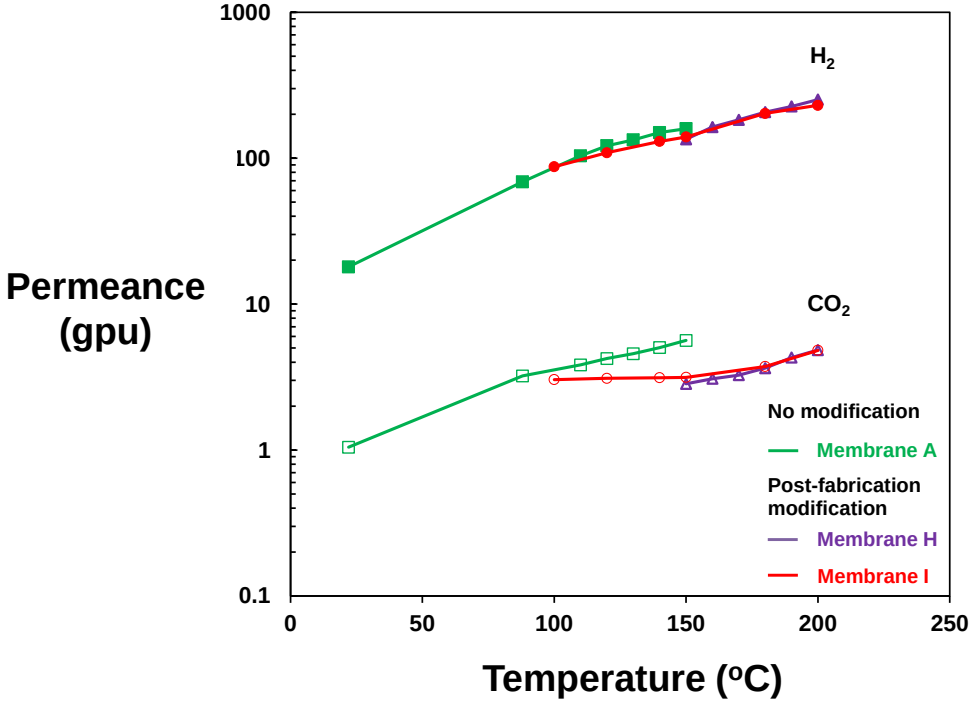
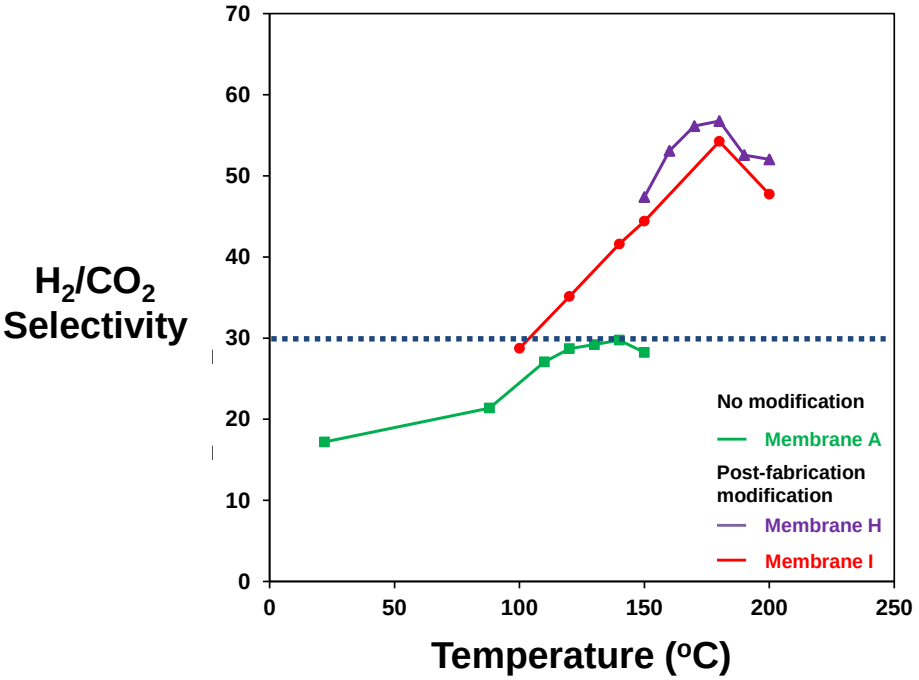
Budget Period 1 Tasks:
Prepare Gen-2 Proteus Membrane with Target Performance



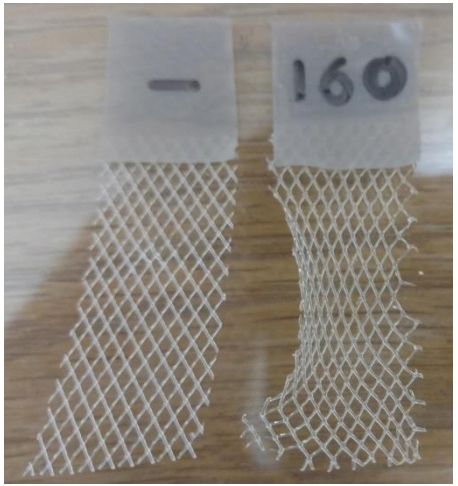


Newly developed technique significantly improves H_2/CO_2 selectivity while maintaining H_2 permeance values

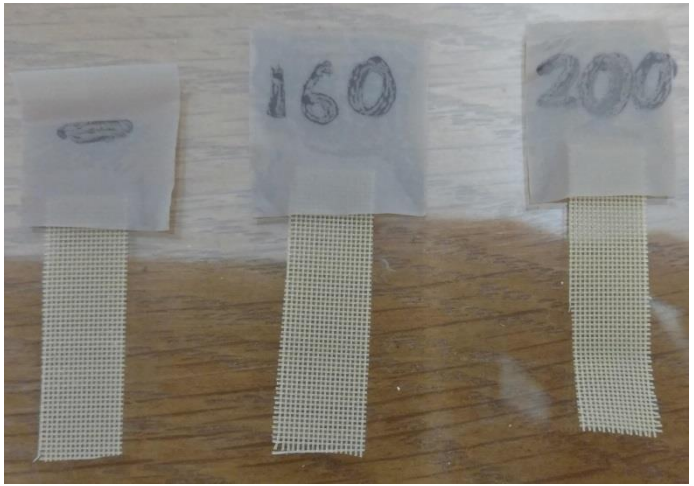
Budget Period 1 Tasks:
Identify High Temperature Module Components

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

Example of steam tests with Spacers A and B



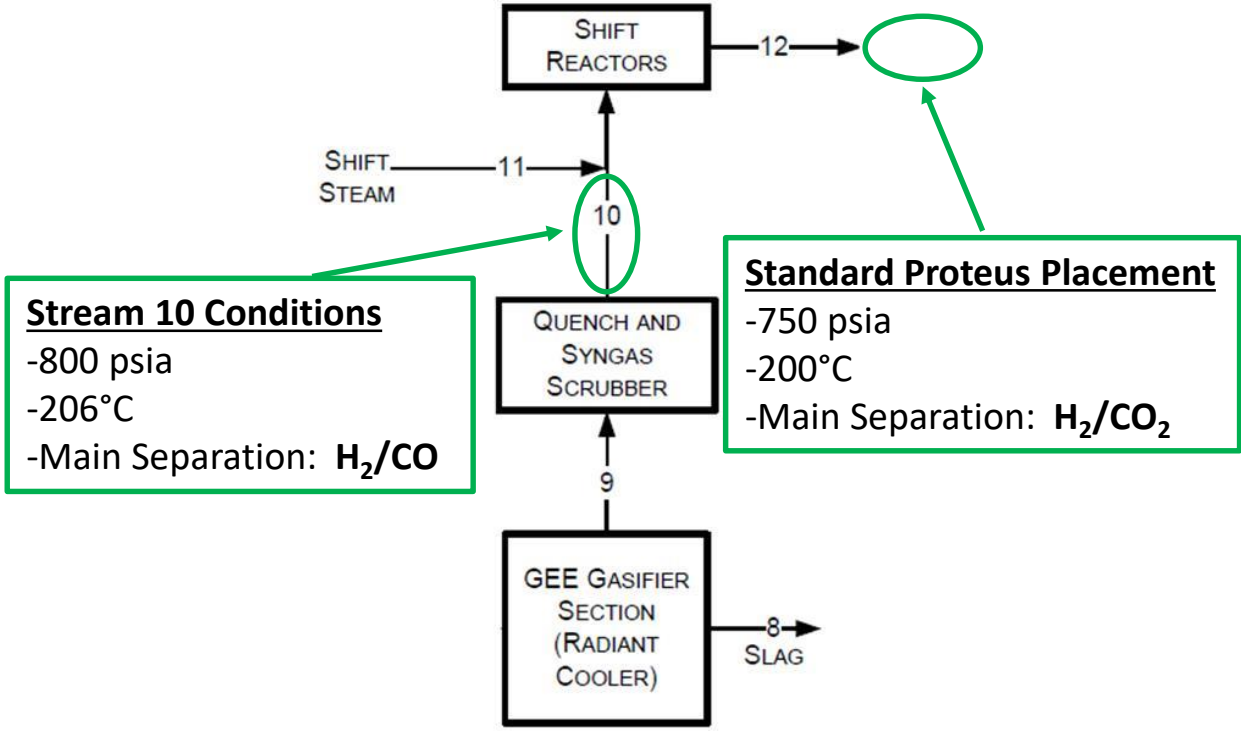
Spacer A showed deformation at 160°C, results at higher temperatures were worse



Spacer B showed no signs of deformation or brittleness after exposure tests up to 200°C

Budget Period 1 Tasks: Evaluate Alternative Process Designs

- Working with Susteon to identify and optimize integration of membranes into the IGCC process for pre-combustion CO_2 capture
- One example: Placing the Proteus membrane after the Quench and Syngas Scrubber (Case B5B Stream 10)



Reference: NETL Cost and Performance Baseline for Fossil Energy Plants Volume 1b: Bituminous Coal (IGCC) to Electricity Rev. 2b-Year Dollar Update, 2015. (pg, 198)

Budget Period 2 Scope of Work

- No deviations planned in BP2 work scope or budget
  - Task 6: Prototype High Temperature Module Tests at MTR
  - Task 7: Design and Fabricate Bench-Scale Field Test Skid
  - Task 8: Optimize Process Designs
- BP2 budget: $823,265
  - $658,612 Federal, $164,653 Cost Share
- BP2 milestones associated with:
  - Scale-up and preparation of Gen-2 Proteus membrane (Q5)
  - Lab-scale Gen-2 Proteus modules prepared (Q6)
  - Finalize bench-scale field test system design (Q6)
  - Field test system passes FAT, ready to ship to field test site (Q8)

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Summary

- Membranes have some advantages for pre-combustion CO_2 capture and H_2 purification
- Gen-2 Proteus membrane has been made with $H_2/CO_2 = 50$ (success criteria was $H_2/CO_2 = 30$)
- Module components have been identified for use in syngas environments at high temperatures
- Budget Period 2 tasks include mixed-gas module testing at MTR and fabrication of field test skid

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Acknowledgements

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