PRAXAIR

Advanced Hydrogen Transport Membranes for Coal Gasification

Project # PD084
DOE Annual Merit Review Meeting – May 13, 2011


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Overview

Phase I Budget

	Total	Spent (as of February 1)
DOE	1,284,368	160,519
Praxair	550,443	68,794
TOTAL	1,834,811	229,313

12% Complete

Program Timeline

10/10 – 12/11	1/12 – 12/13	1/14-12/14
Phase I	Phase II	Phase III

- Phase I – Small-Scale Demonstration
  - 2 lb/day of hydrogen from gasifier
- Phase II – Pilot-Scale Demonstration
  - 100 lb/day hydrogen produced from gasifier
- Phase III – Large-Scale Design
  - 8000 lb/day hydrogen produced from gasifier

Barriers Addressed

- K - Membrane Durability
- L - Impurity Resistance
- O - Operating Temperature
- P - Membrane Flux
- R - Membrane Cost

Partners

- Colorado School of Mines
  - Membrane Development, Testing, Modeling
- T3 Scientific
  - MembraGuard™ Coating
- General Electric

Relevance - Program Goals Being Addressed

- **Develop advanced energy technologies to facilitate the use of coal or coal-biomass**
  - **HTM separates hydrogen from syngas to feed combustion turbines with no CO_2 in exhaust or to use in fuel cells, which require high-purity H_2**
  - **CO_2 remains at pressure for possible sequestration**
- **Demonstrate the separation of hydrogen from coal or coal-biomass derived syngas**
  - **Key milestone of Phase I is to demonstrate H2 separation on a small scale**
  - **Key milestone of Phase II is to scale up the separation system to a pre-engineering/pilot scale**

Relevance – Phase I Goals

- **Demonstrate HTM performance integrated with a coal gasifier to produce at least 2 lb/day of H_2**
- **Develop contaminant management strategy**
- **Develop HTM manufacturing process**
- **Develop improved process for integrating HTM into coal gasification**
- **All goals based on scaling up HTM technology and integrating it with gasification to produce power and hydrogen while reducing CO_2 emissions**

Approach - Technology Development Pathways

- This program addresses the current barriers to commercialization
  - Membrane and substrate development
    - Focus on developing a membrane that is resistant to contamination
    - Test plan includes H_2S and other contaminants, life and cycling tests
  - Membrane and substrate manufacturing
    - Focus on reducing manufacturing costs and improving reliability
    - Scaling up current membranes to commercial size
  - Process development
    - Identify potential processes for HTM technology based on gasification to produce power and hydrogen
  - Reactor design
    - Complete reactor design and cost estimate

Approach – Scope of Work – Phase I

- Task 1 – Project Management
- Task 2 – Membrane Performance Testing
  - Mixed Gas Tests – syngas with and without sulfur
  - Develop Contaminant Management Strategy
    - Evaluate MembraGuard coating from T3 Scientific
  - Sweep Gas Evaluation
  - Membrane Material Tests – evaluate different alloys
  - Gasifier Modification and HTM Unit Integration
  - Life and Cycling Tests
- Task 3 – Engineering Studies
  - Process Integration and Intensification
  - Nitrogen and Alternate Sweep Streams
- Task 4 – Teaming Arrangements
  - Identify and Finalize Phase II Partners
  - Coal Gasifier Operator

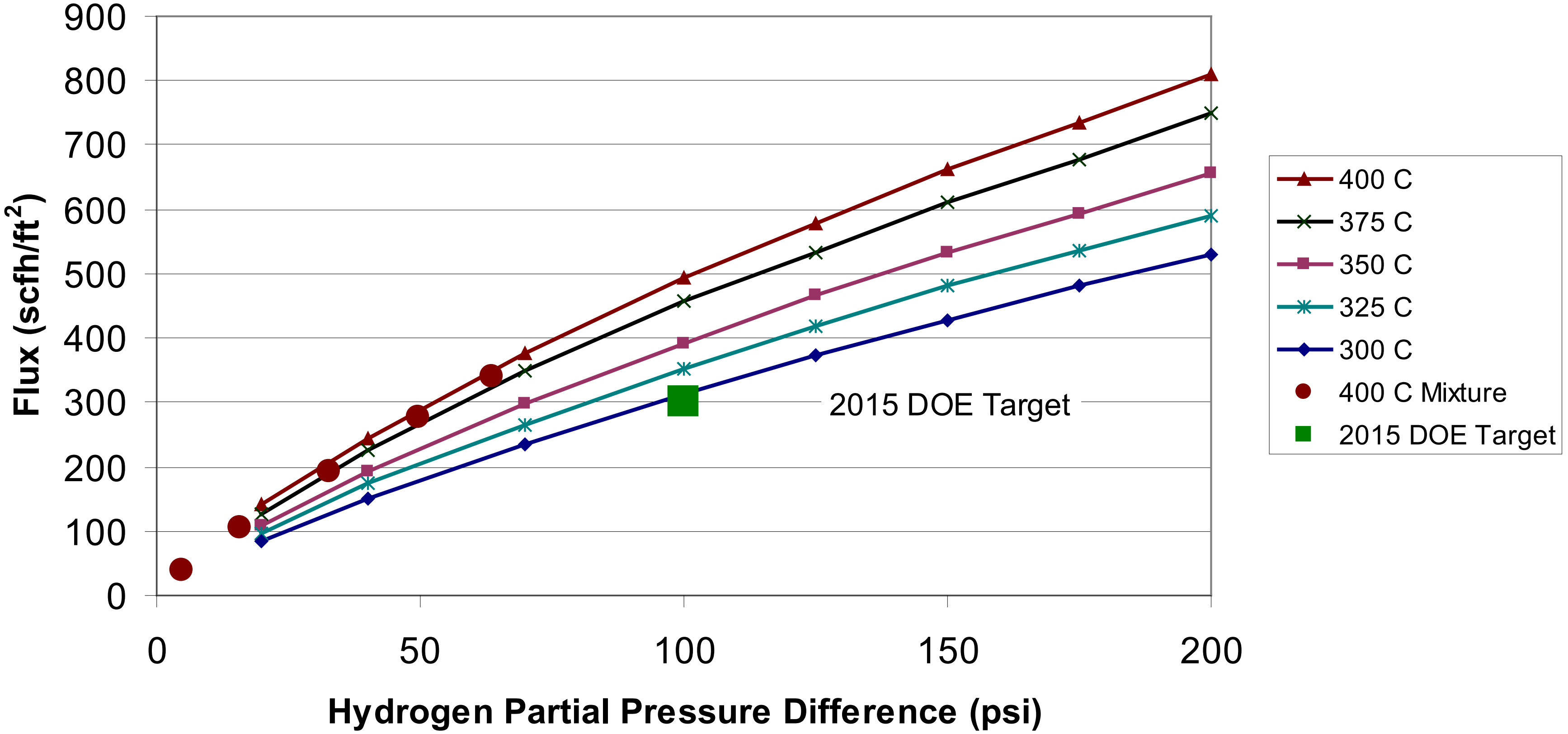
Approach – Scope of Work – Phase I

- Task 5 – Membrane Manufacturing Scaleup
  - Increase Tube Length
    - Important for scaleup
    - Must minimize defect frequency
    - Substrate production is relatively straightforward using extrusion
  - Develop Tube Coating System for Long Tubes
  - Reduce Number of Processing Steps
    - Simultaneous plating of alloy components
    - Manufacture advanced substrates
    - Important for reducing manufacturing costs at large scale
- Task 6 – Reactor Design
  - Conceptual Design of Phase II Reactor
  - CFD Modeling
- Task 7 – Cost Estimating
  - Phase II Reactor
  - Phase II Program Definition and Budget

Approach – Milestones and Go/No-Go Decision

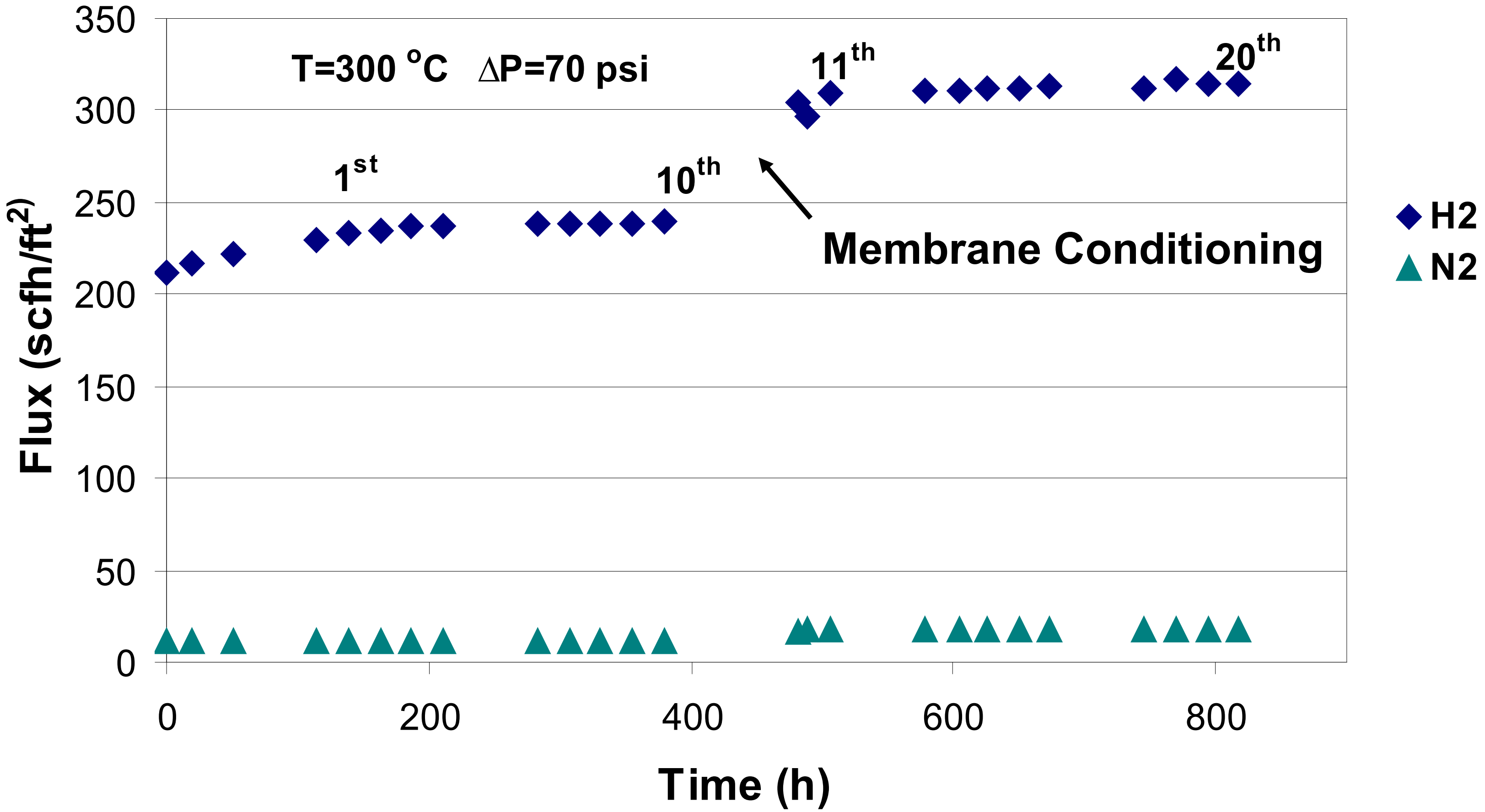
- **Integrate HTM test unit with gasifier**
  - Planned completion by June 30, 2011
  - Essential to reaching the Phase I goal
  - Gasifier modification might be required before integration
- **Separate at least 2 lbs/day of H_2 from gasifier product**
  - Complete by November 30, 2011
  - Major goal of Phase I specified by DOE
- **Go/No-Go Decision**
  - DOE will select two of four current projects for continuing to Phase II

Technical Accomplishments – High Flux



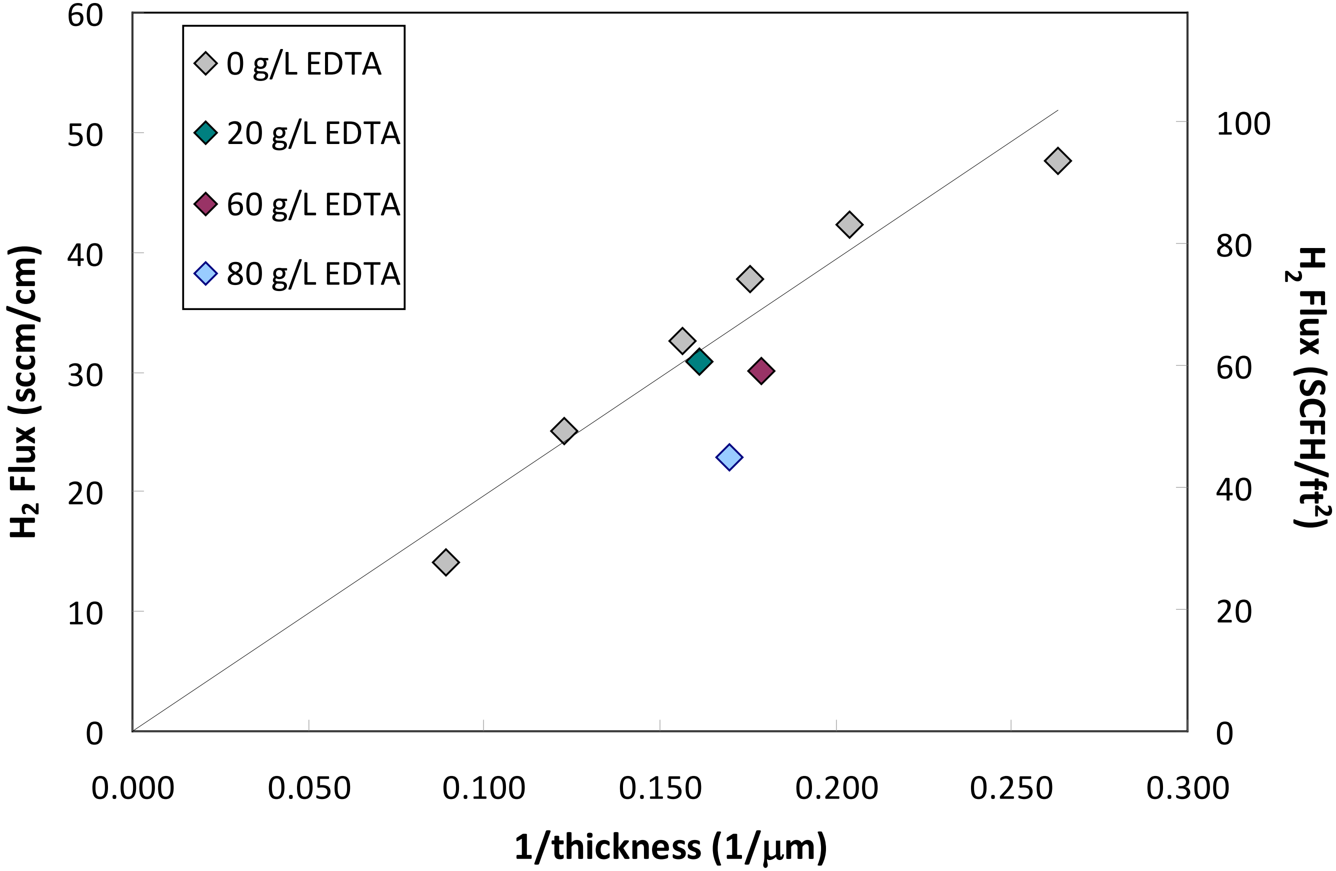
- **High flux achieved with ternary Pd-alloy membrane**
- **Binary Pd-alloy membranes slightly higher**
- **Mixture included H_2, CO, CO_2, H_2O, but no sulfur**

Technical Accomplishments – Thermal Cycling



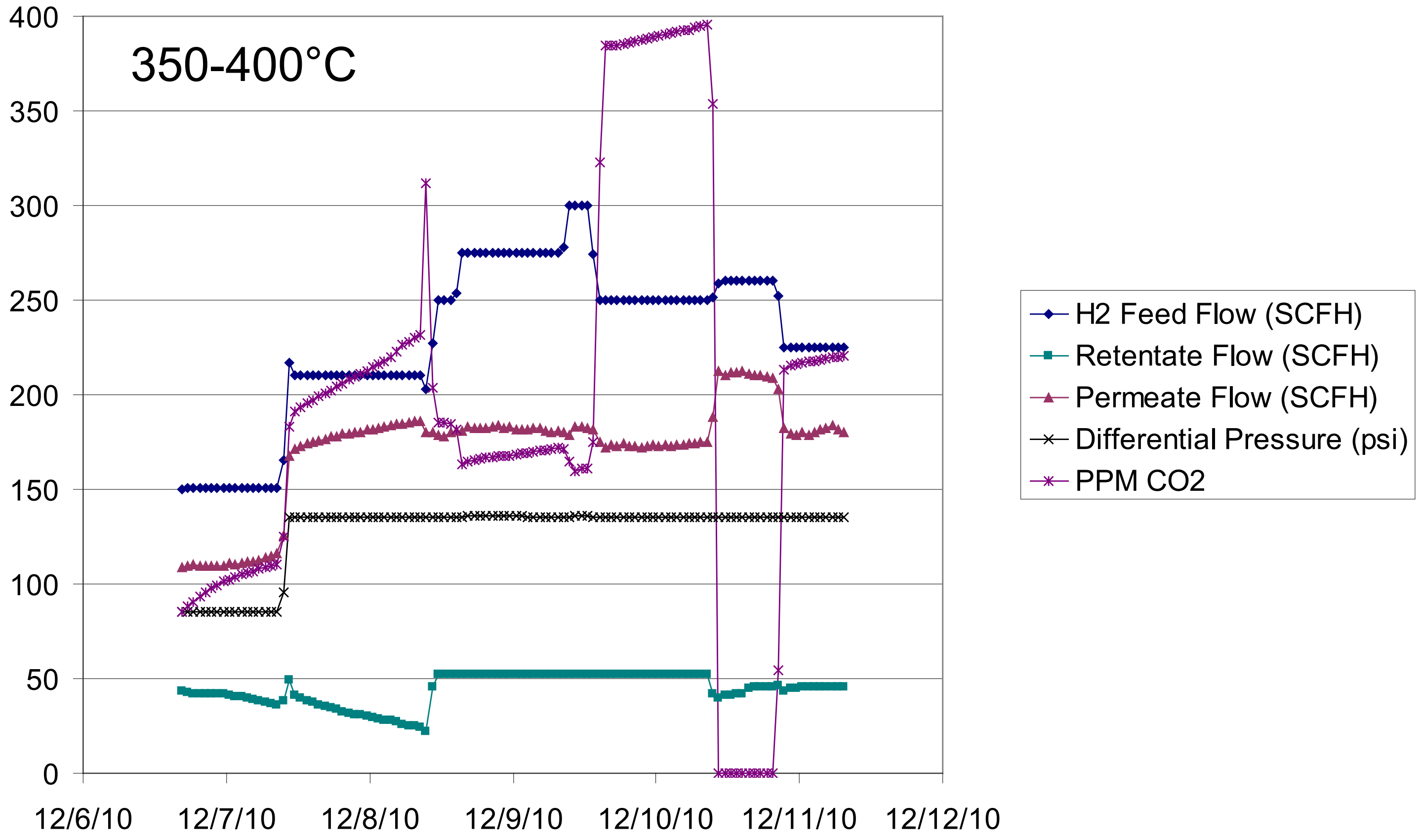
- Twenty thermal cycles completed
- Flux improvement due to membrane conditioning demonstrated

Technical Accomplishments – Effects of EDTA



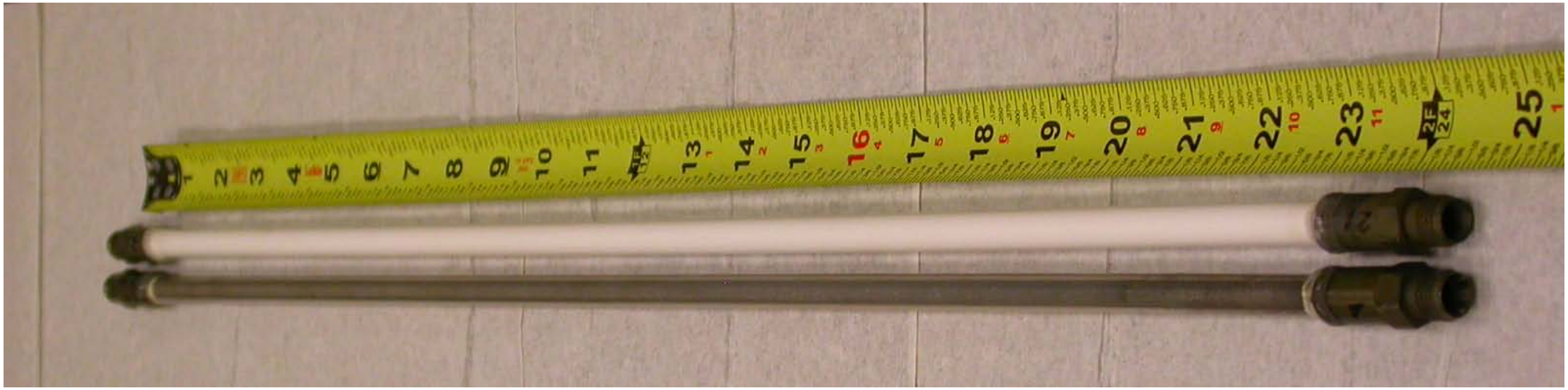
- **EDTA (ethylenediaminetetraacetic acid) stabilizes electroless plating baths**
- **High concentrations reduce flux and stability in mixed gases containing CO or CO_2**
- **Goal is to find a concentration that provides benefit without hurting performance and durability**

Technical Accomplishments – Multitube Reactor



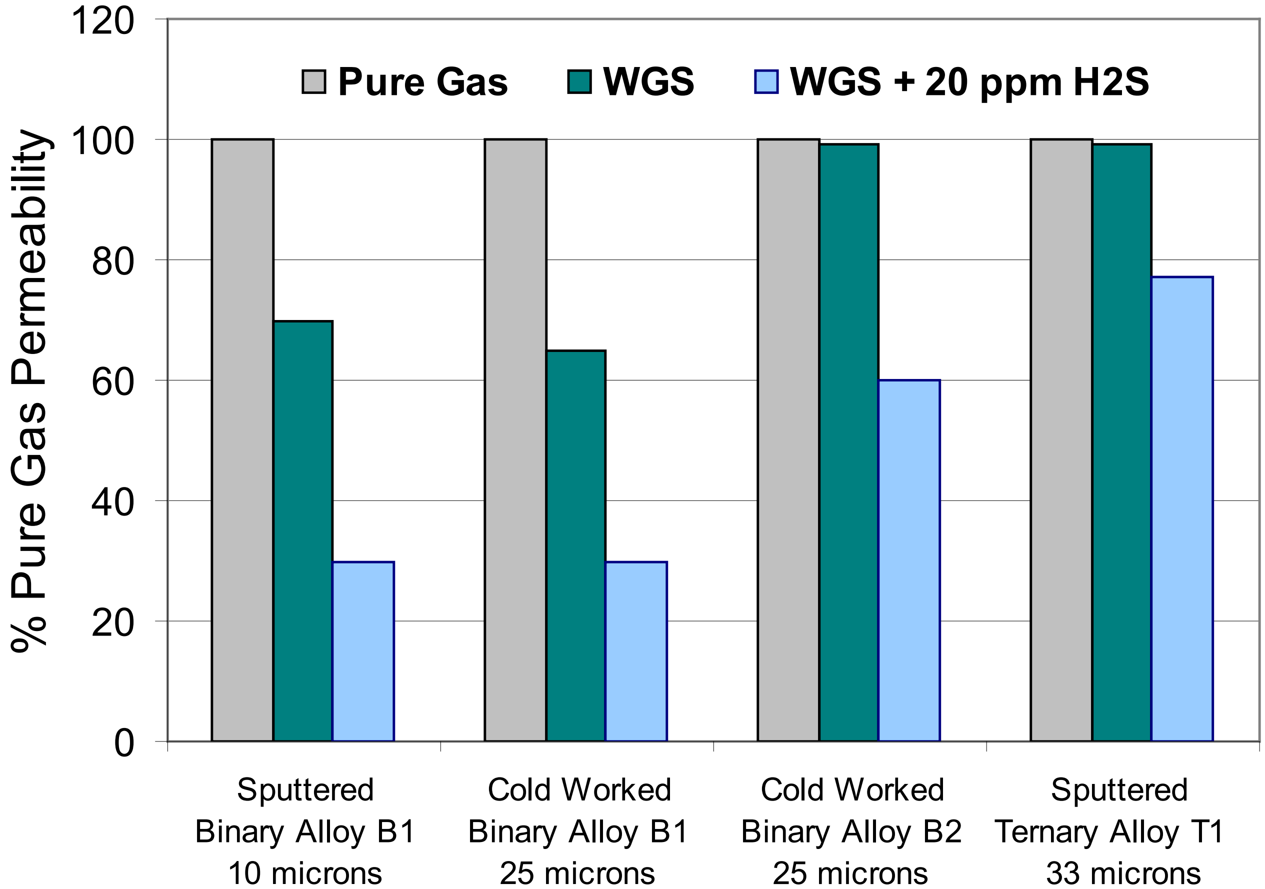
- Continuously purified almost 200 scfh of hydrogen over 100 hours
- 12-tube reactor - 0, 1, or 2% CO_2 in feed

Technical Accomplishments – Membrane Scaleup



- Substrates produced by extrusion
- Tubes up to 2 feet long can be produced and coated in our current system
- Current processing techniques are scalable to larger diameters and lengths

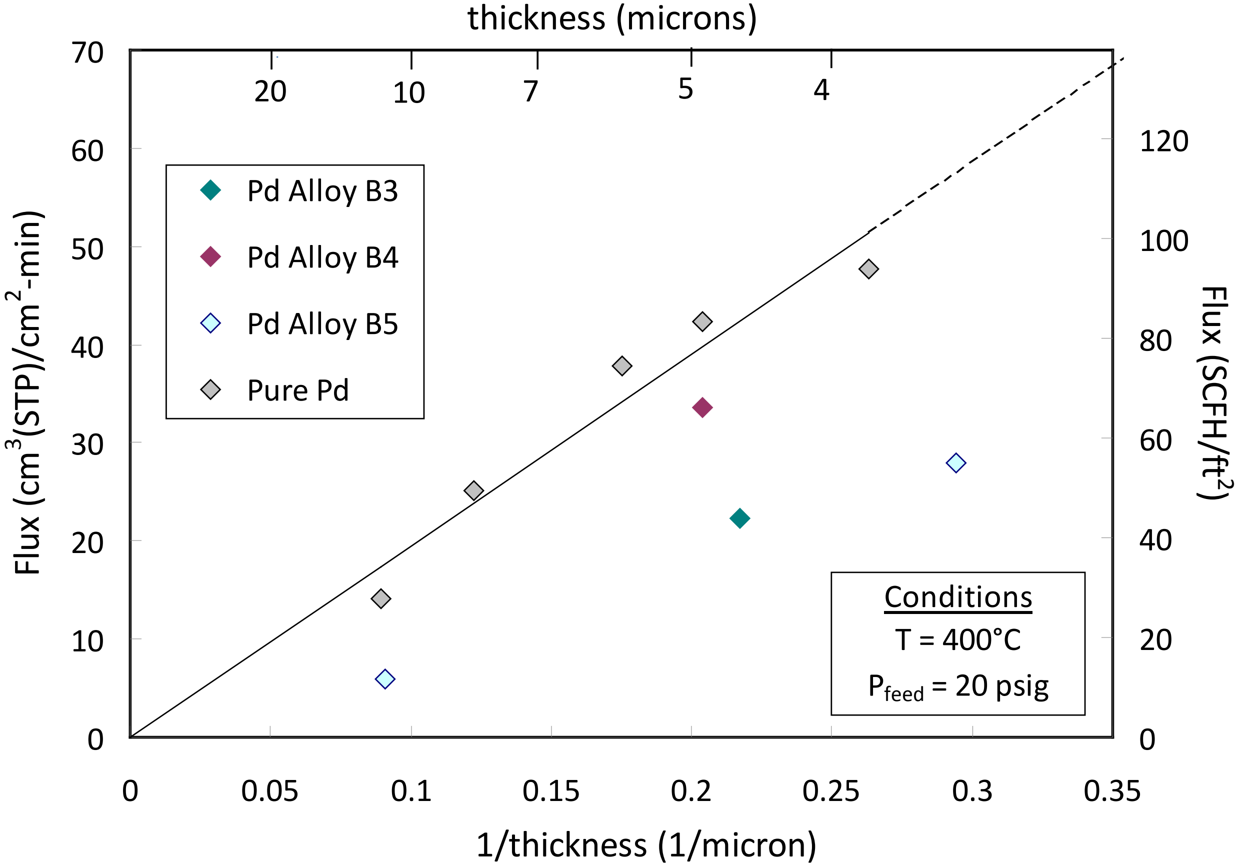
Technical Accomplishments – Sulfur Testing



- Increased alloy metal content improves sulfur resistance over the range tested, regardless of fabrication technique
- Ternary alloy component improves sulfur tolerance.

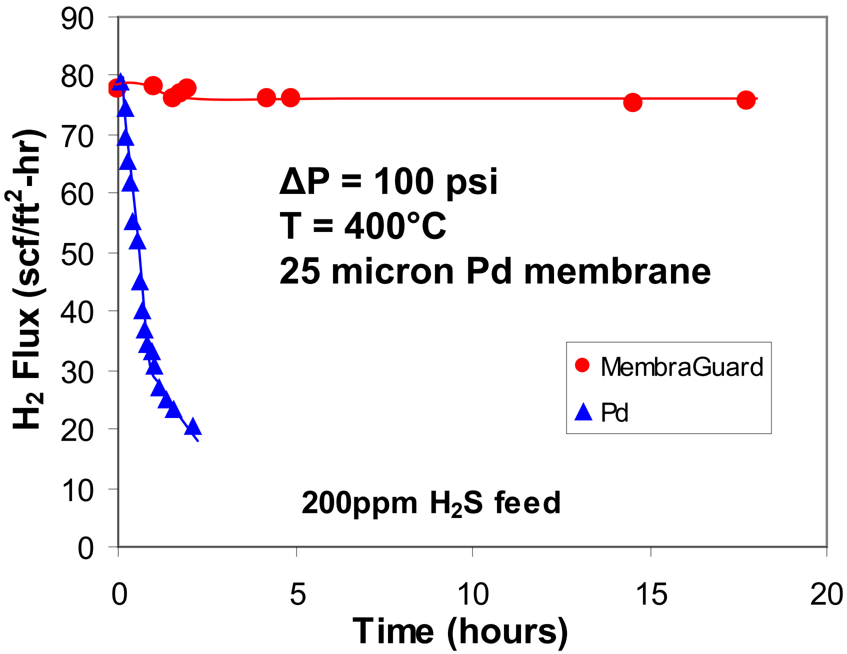
Work done by CSM as part of DE-FC26-07NT43056 “High Permeability Ternary Palladium Alloy Membranes with Improved Sulfur and Halide Tolerances,” final report, by K. Coulter et al.

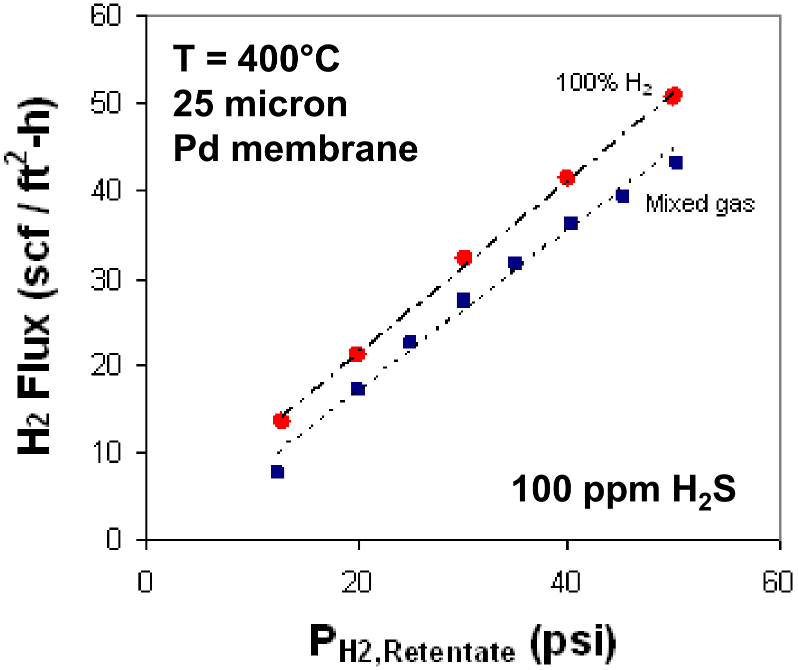
Technical Accomplishments – Alloy Development



- Alloys B3, B4, and B5 have better sulfur resistance than Pd
- Alloys B3, B4, and B5 have shown excellent performance in mixed gas tests
- Flux of alloys is not as high, but expected to be much better in H_2S
- Alloy B5 composition is not optimized - Significant improvement is possible

Technical Accomplishments – MembraGuard





- MembraGuard significantly improved resistance to high sulfur content (200 ppm)
- Flux was stable for over 250 hours of testing in 200 ppm H_2S
- Mixed gas included 50% H_2, 1% CO, 30% CO_2, 19% H_2O, 100 ppm H_2S
- Some flux reduction is typical in mixed gas tests, even with no sulfur
- No leak detected in mixed gas test

Collaborations

- Colorado School of Mines
  - Palladium alloy coating
  - Membrane testing
  - Reactor modeling
  - Gasifier testing
- T3 Scientific
  - MembraGuard coating for improved contaminant resistance
- General Electric
  - Advisory role

Future Work – Phase I

- Identify, produce, and test alloys with high flux in mixed gas feed and good sulfur resistance
- Demonstrate MembraGuard performance using our membranes
- Demonstrate membrane performance in gasification stream
- Identify gasification partner for Phase II

Summary

- Alloys with good sulfur resistance and high flux have been identified, produced, and tested without sulfur
  - Plan to begin sulfur testing in 2Q11
- MembraGuard coating is underway
  - Initial test results expected in 2Q11
- Large membranes have been produced
- Substrate manufacturing process is scalable