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High-Performance, Durable, Palladium-Alloy Membrane for Hydrogen Separation and Purification

Presented by:
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This presentation does not contain any proprietary or confidential information

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Project Contributors

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Overview

Timeline

- July, 2005 start date
- September, 2009 end date
- 30% complete

2010 Targets

- Cost: $2.50 per GGE for H_2 (delivered/untaxed)
- H_2 Quality: 99.95%

Budget

- $4 Million Project Total
  - $2.4M DOE share
  - $1.6M Contractor share
- $100K DOE funding in FY05
- $175K DOE funding in FY06
- $540K DOE funding in FY07*

* Anticipated

Partners

- Chevron
- Colorado School of Mines
- ORNL – High Temperature Materials Lab

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Project Objectives

- Establish the technical and economic viability for use of a palladium alloy composite membrane in a distributed hydrogen production system
  - Propose a process that leverages the technical capabilities of the membrane for maximum economic benefit (reduced *gallon of gas equivalent* cost)
  - Optimize membrane performance in terms of hydrogen throughput, purity and durability
  - Minimize capital cost for the gas separation module
    - Pressure vessel
    - Internal hardware
    - Membrane
    - Substrate

Photo courtesy of Chevron

Why Membrane ?

- Capital and operating cost for a hydrogen production system can potentially be reduced through process intensification
- Membranes that can be operated at high temperatures allow for integration with high temperature reforming processes
- Simple, compact separation systems can be designed using membranes

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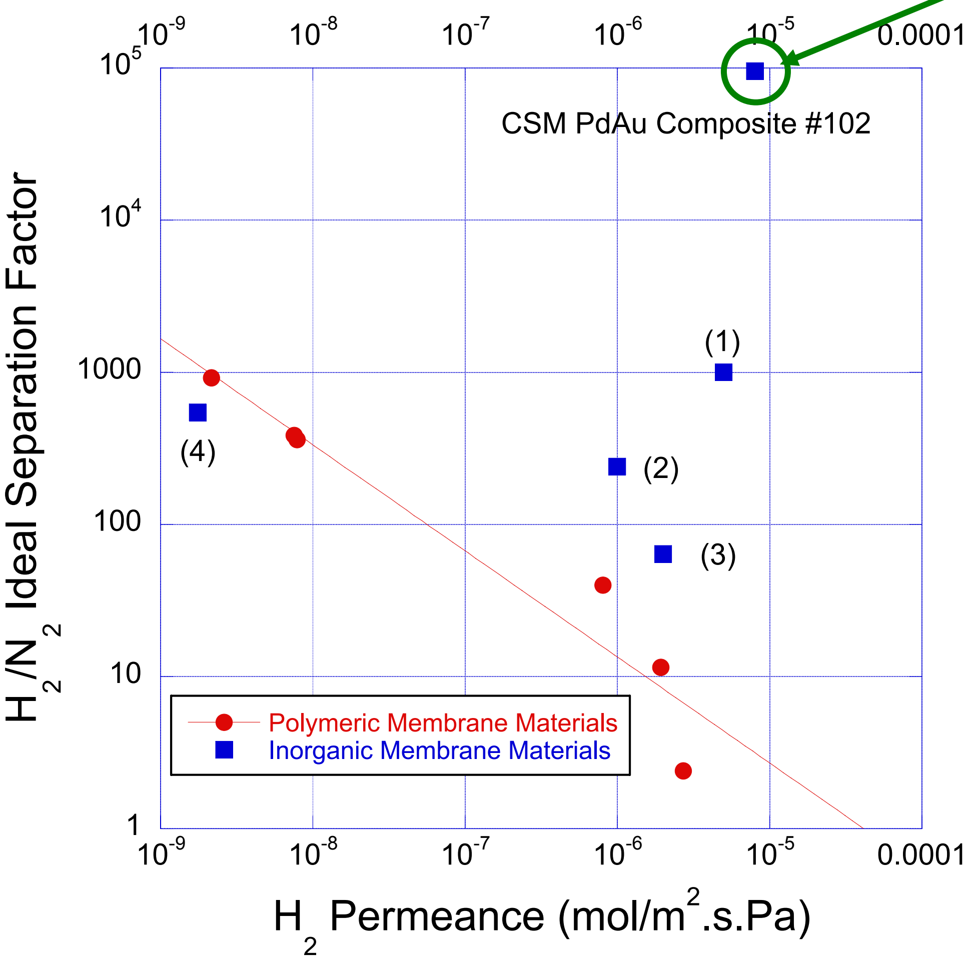
Why Palladium Membrane ?

Project Accomplishments

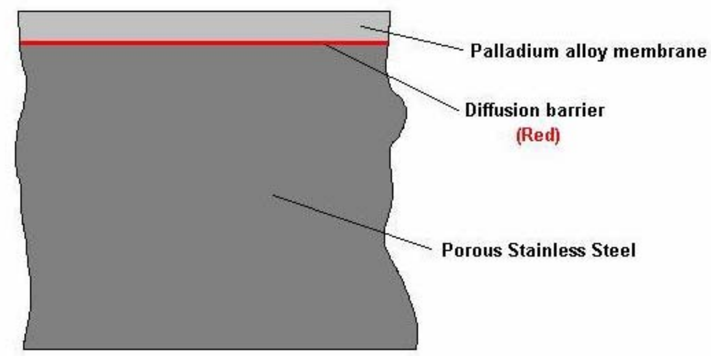


1. Lee, D., Zhang, L., Oyama, S. T., Niu, S., and R. F Saraf, *J. Membr. Sci*., **231**, 117(2004).
2. Kajiwara, M., Uemiya, S., Kojima, T., and E. Kikuchi, *Catal. Today*, **56**, 65(2000).
3. DeVos, R. M. and H. Verweij, *Science*, **279**, 1710(1998).
4. Hassan, M. H., J. D. Way, P. M. Thoen, and A. C. Dillon, *J. Membr. Sci.* , **104**, 27(1995).
5. Polymer line from : Robeson, L. M., *J. Membr. Sci*., **62**, 165(1991).

Components of a Composite Membrane

Pd alloy membrane

- Functional layer provides for gas separation
- Critical features: thickness, alloy composition and number of defects



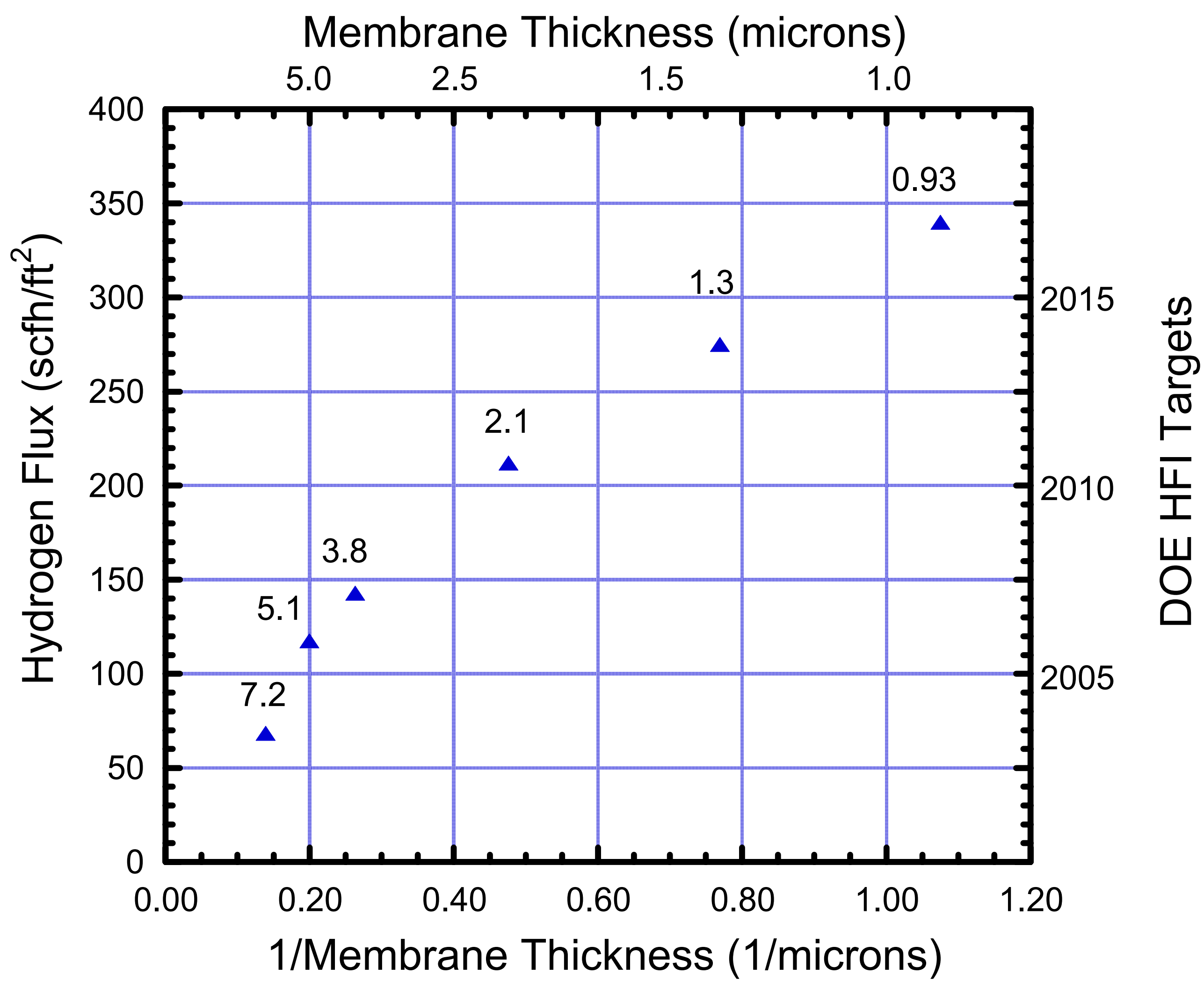
Diffusion barrier

- Enables formation of functional layer
- Critical features: surface properties, material, gas permeability, number of defects

Porous Stainless Steel

- Provides mechanical support that can withstand the operating conditions of the process
- Critical features: permeability,weld configuration,mechanical, thermal and chemical compatibility

The Influence of Pd Membrane Thickness on Pure H_2 Flux @ 400 °C, 20 psig



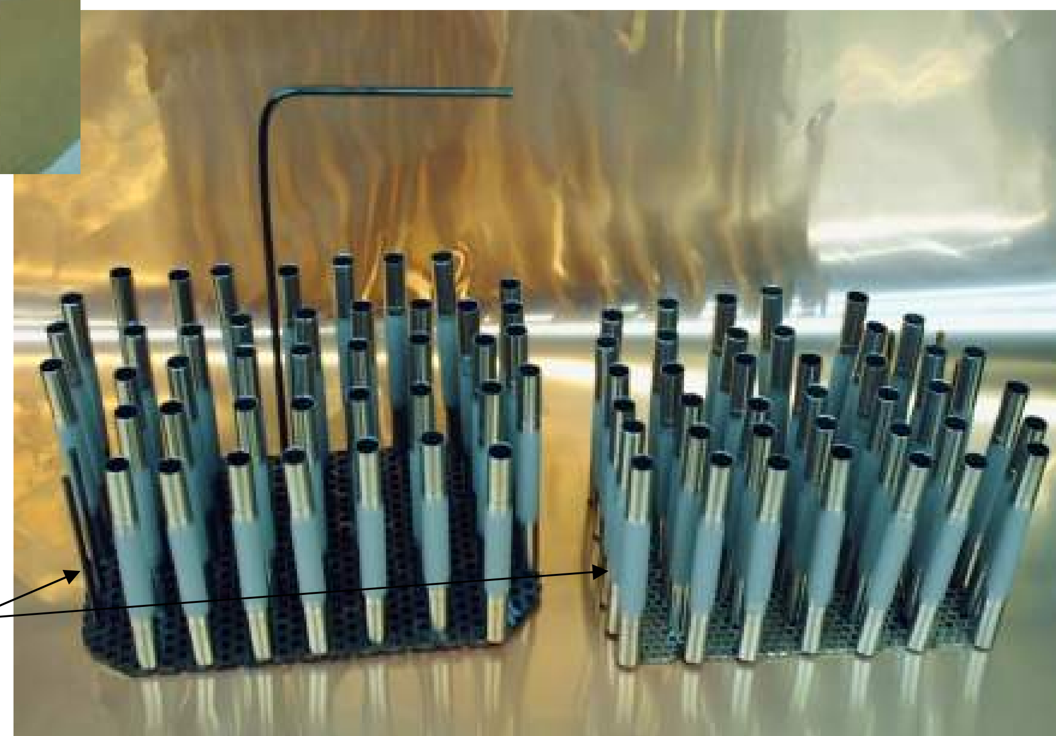
Technical Accomplishments/ Progress/Results
Diffusion Barrier Properties

- Surface roughness 2005: Ra = 25 – 35 micro inch
- Surface roughness 2006: Ra = 8 – 12 micro inch

- Membrane over welds 2005: no leaks up to 20 psi
- Membrane over welds 2006: no leaks up to 40 psi

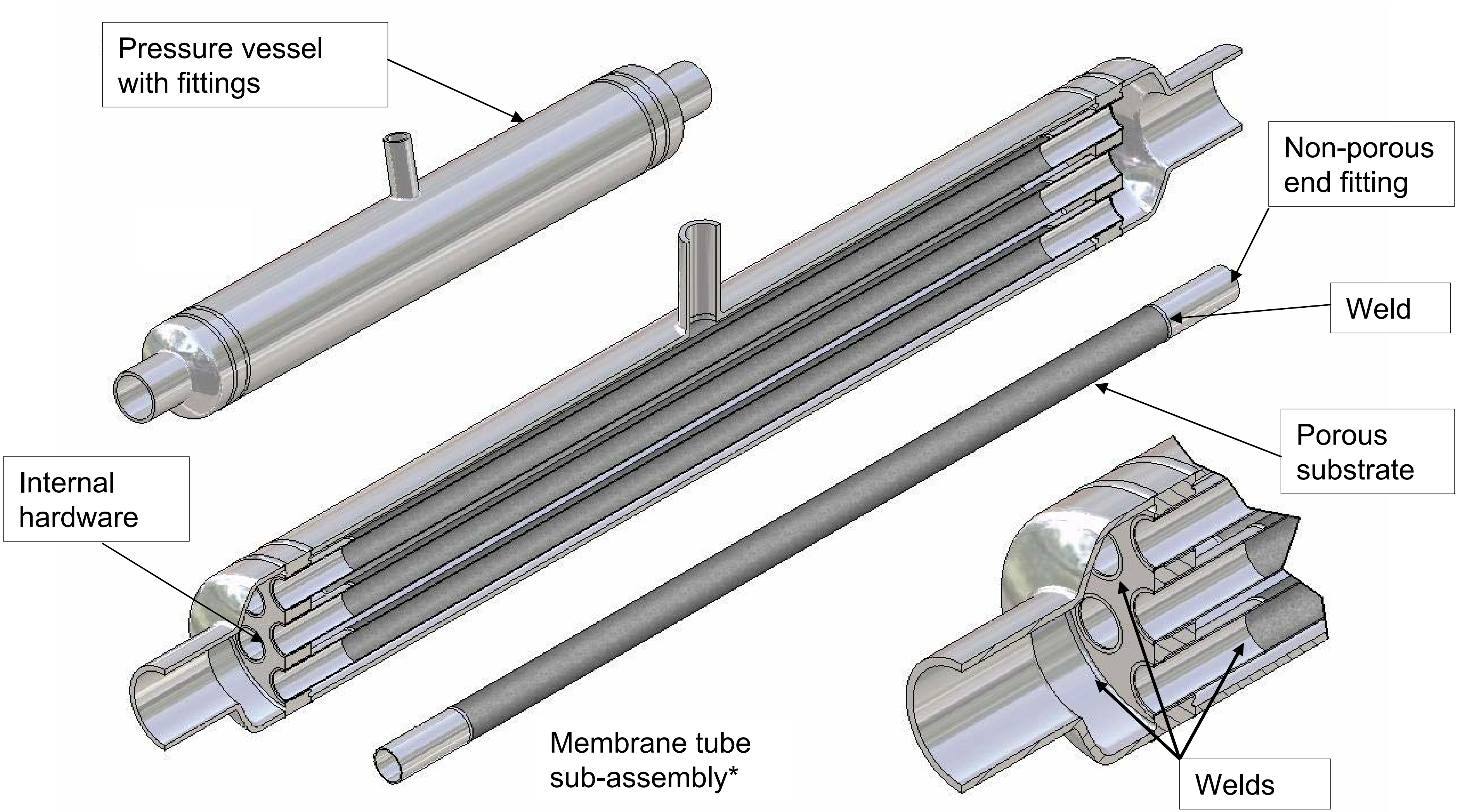
Porous Stainless Steel

Support tubes – as welded



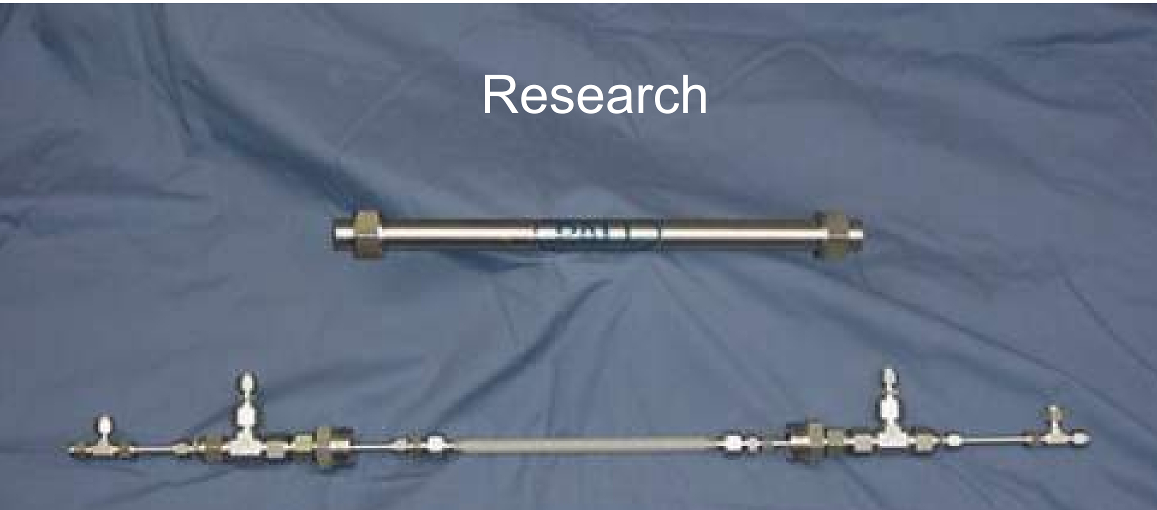
Support tubes ZrO_2 coated

Components of a Gas/Gas Separation Module



* Pd alloy membrane not shown, typically on the OD of the tube

Scalability of Metal Tube Technology



Development

Guidelines for Membrane Performance

2010 DOE / EERE Targets for Dense Metallic Membrane*

– Flux: 250scfh/ft^2 @20 psi & 400^{o}C

– Module Cost: \$1,000/ft^2

– Durability: 3 years

– Operating pressure: 400 PSI

– H_2 Recovery: > 80%

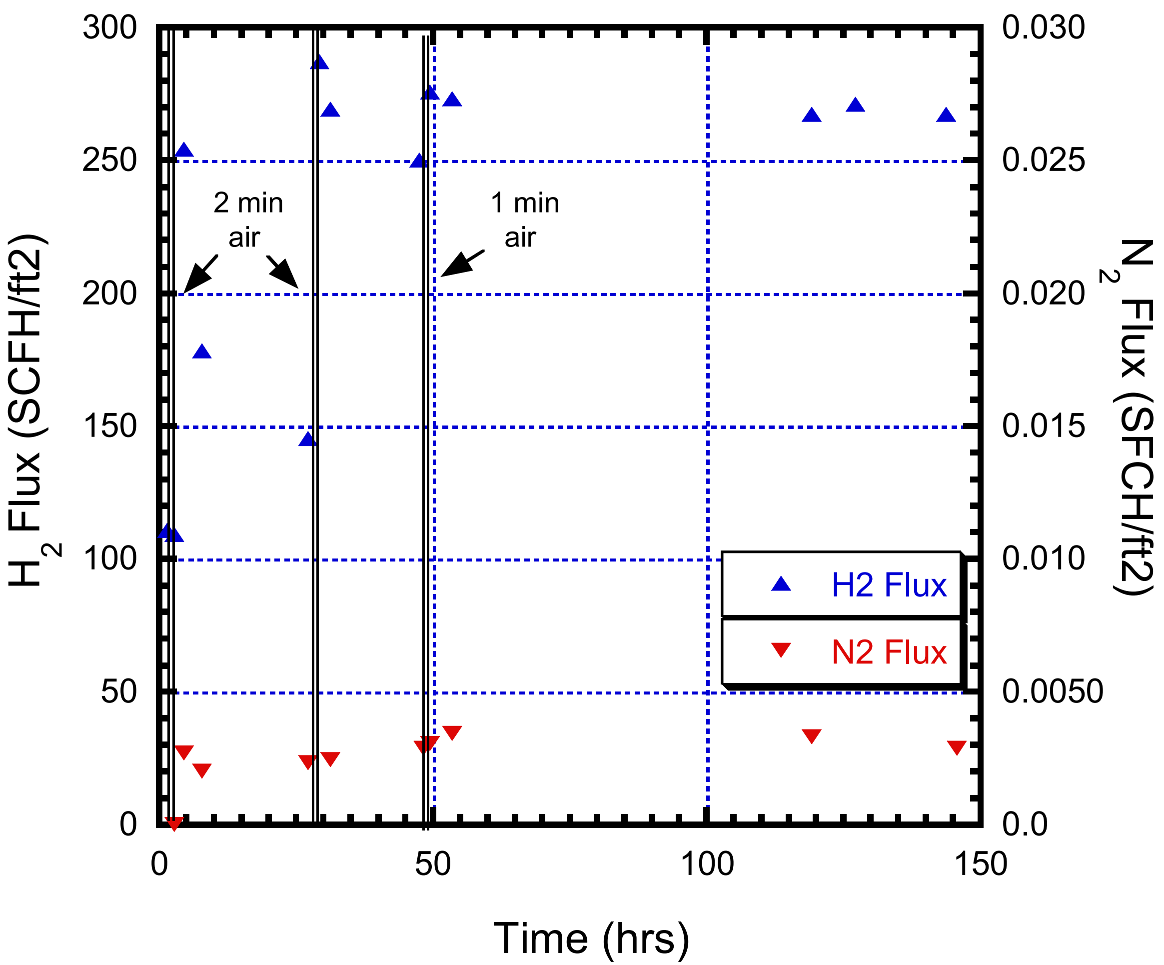
– H_2 quality: 99.99 %

* As per the Multi-Year RD&D Plan Updated 11/14/06
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/production.pdf

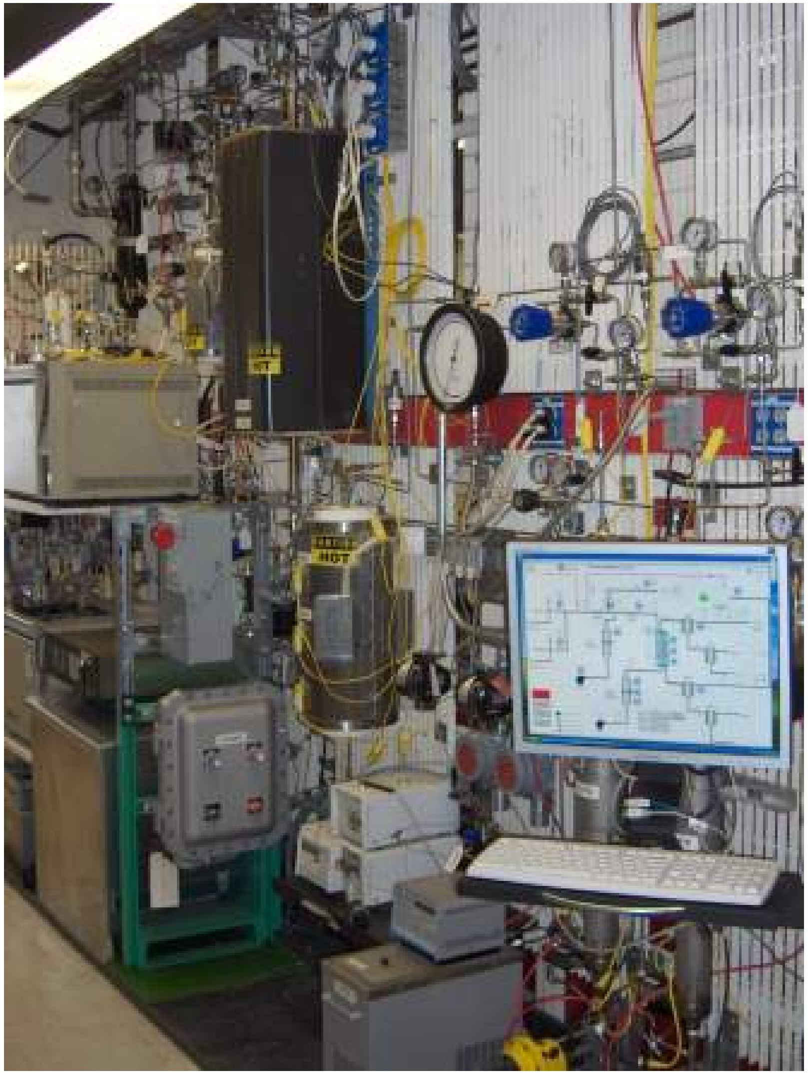
Technical Accomplishments/ Progress/Results

H_2 and N_2 Flux for PdAu Membrane, CSM-Pall-102,

at 20 psi Transmembrane Pressure and 400 °C.

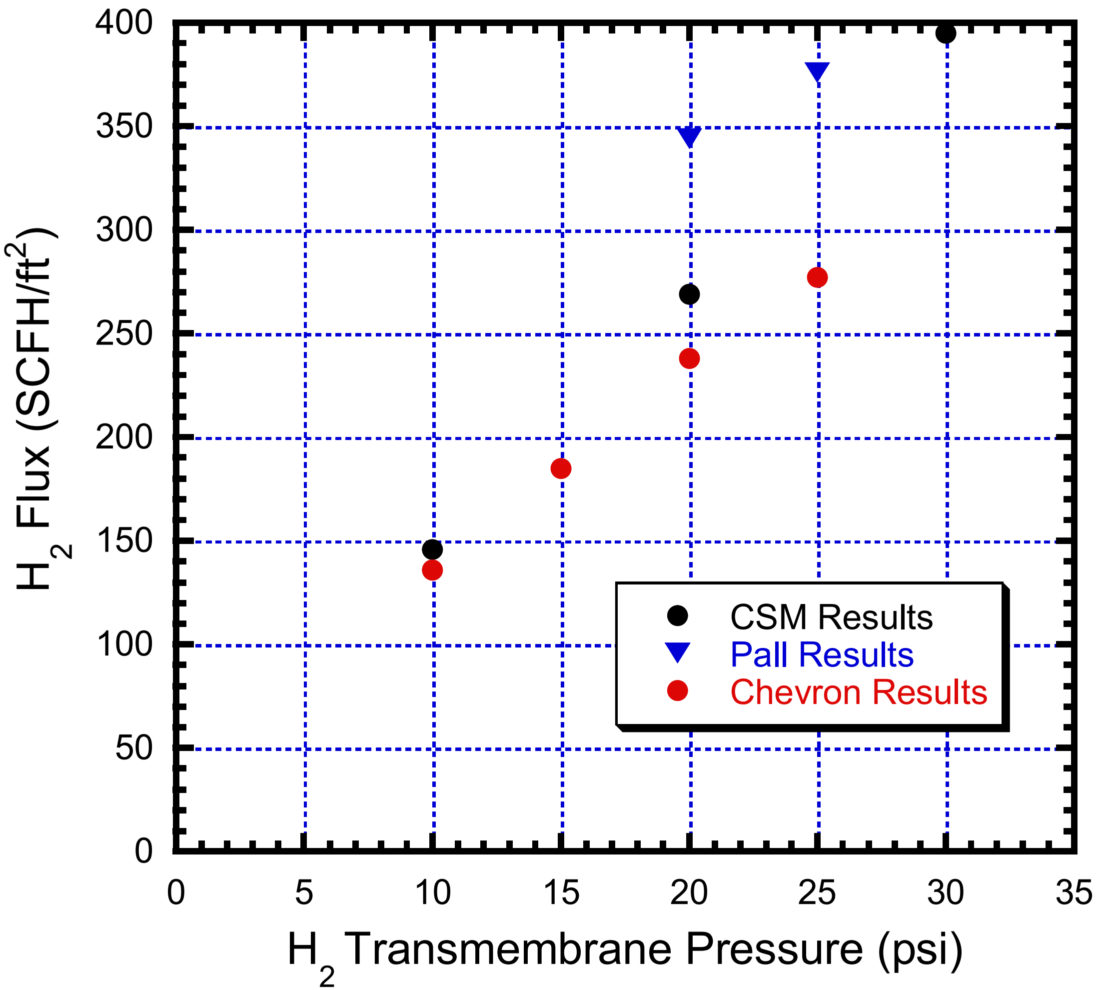


Automated Gas/Gas Separation Test Stand



Photos courtesy of Chevron

CSM Test Data Confirmed at Pall Corp and Chevron



Note: Same membrane sample tested at all three locations

Test Location	Ideal H_2/N_2*
CSM	90,000
Pall	∞
Chevron	∞

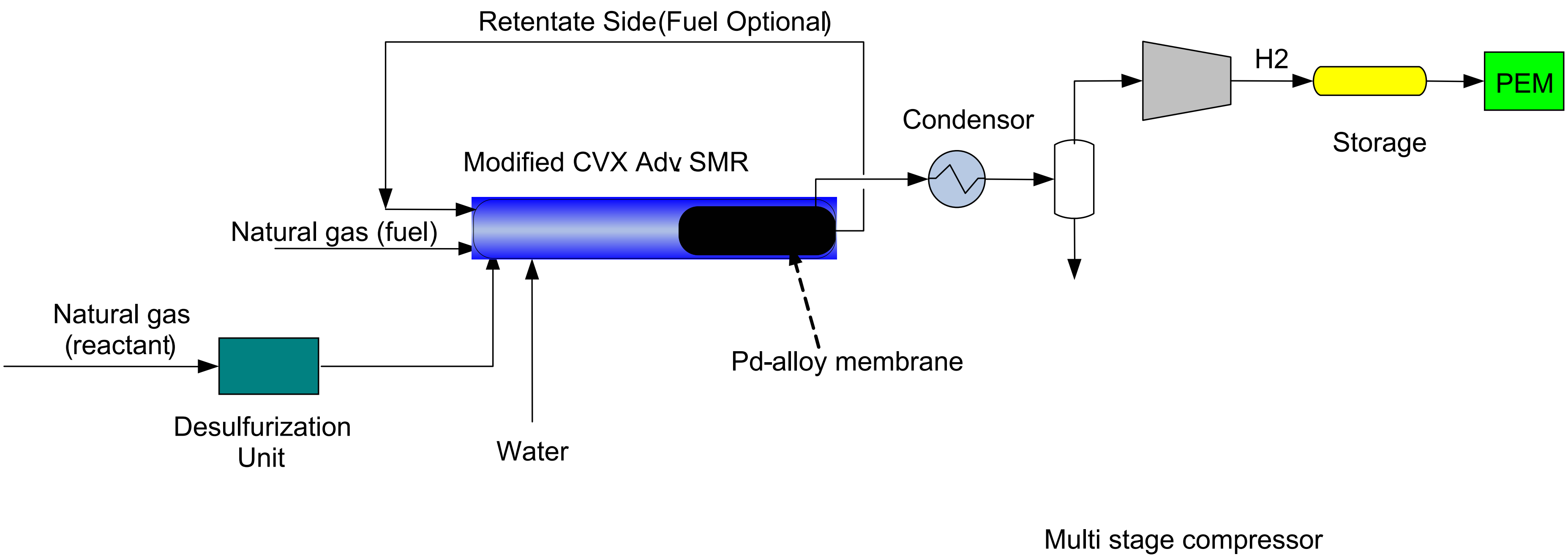
* Ideal H2/N2 selectivity at 20 psi

Future Work

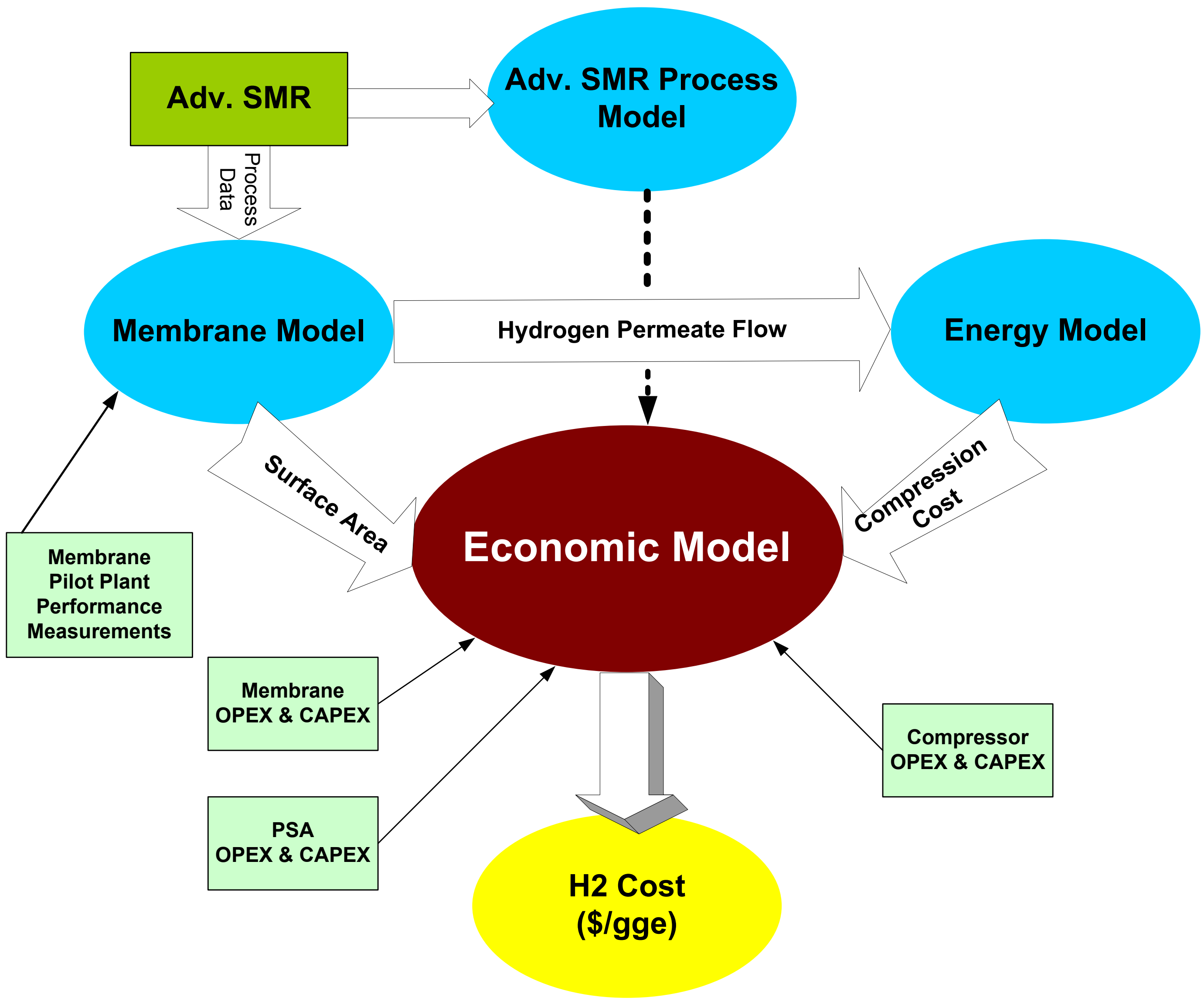
- Optimize substrate and alloy properties to meet or exceed membrane targets
- Test membrane in synthetic reformate streams to establish conditions for >80% hydrogen recovery
- Establish long term durability testing at temperature
- Use membrane properties for economic analysis of advanced process design to achieve targeted H_2 production costs

Proposed Use of Pd Alloy Membrane in a Hydrogen Production System

<u>Modified Chevron Adv . SMR Integrated with Pd -alloy Membrane</u>



Economic Analysis Strategy



Summary

- Developed porous stainless steel substrate and diffusion barrier that enables formation of high flux Pd alloy membranes
- Produced Pd alloy membranes that exceed the 2010 target for H_2 flux and purity
- Analyzed membrane and module manufacturing costs to confirm the current cost basis ($1,500 ft2)
- Completed fabrication of an automated test stand for long term testing with synthetic reformate
- Established membrane, process and energy models that will be used to determine overall economics for H_2 production

Hydrogen Safety

The most significant hydrogen hazards associated with this project are:

- A test system that leaks hydrogen while at temperature. Plumbing is tested for leaks prior to installation in the furnace
- Mixing hydrogen with air while system is at temperature. An argon or nitrogen purge is used to evacuate the system of residual air after an air purge cycle, prior to introducing hydrogen to the system.