ADVANCED HYDROGEN TRANSPORT MEMBRANES FOR VISION 21 FOSSIL FUEL PLANTS

Presented by

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#PD11

Overview

Timeline
- Project start date: October 1, 2000
- Project end date: September 30, 2005
- 85% percent complete

Budget
- Total project funding: $2,800,000
  - DOE share: $2,240,000
  - Contractor share: $ 560,000
- Funding received in FY04: $ 377,765
- Funding for FY05: $ 736,244

Barriers Addressed
- Reducing hydrogen cost
- Hydrogen production from diverse pathways
- Hydrogen of sufficient purity for fuel cells

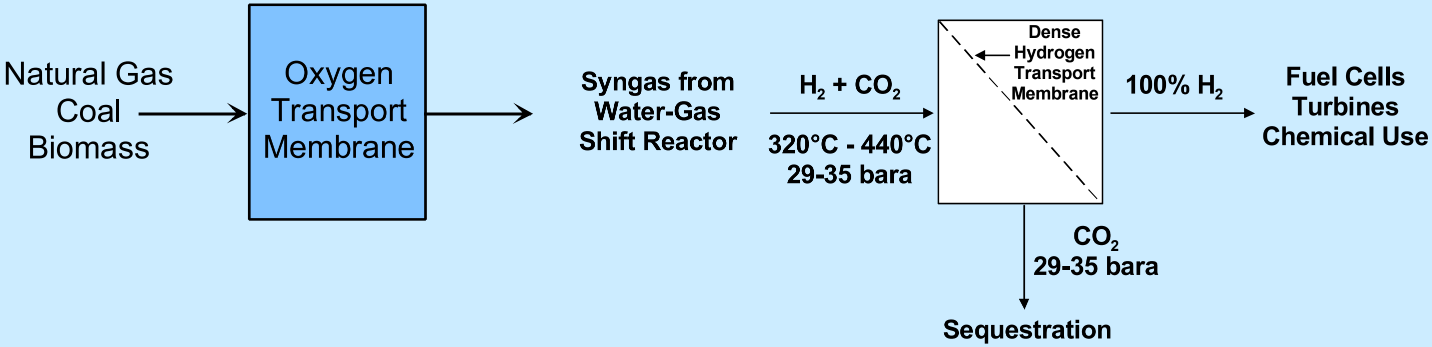
Technical Targets
- High hydrogen flux at temperatures compatible with water-gas shift catalysis
- Compatibility with simultaneous carbon dioxide sequestration
- Stable to syngas conditions

Partners
- CoorsTek
- Sűd Chemie
- Noram Engineering
- ANL

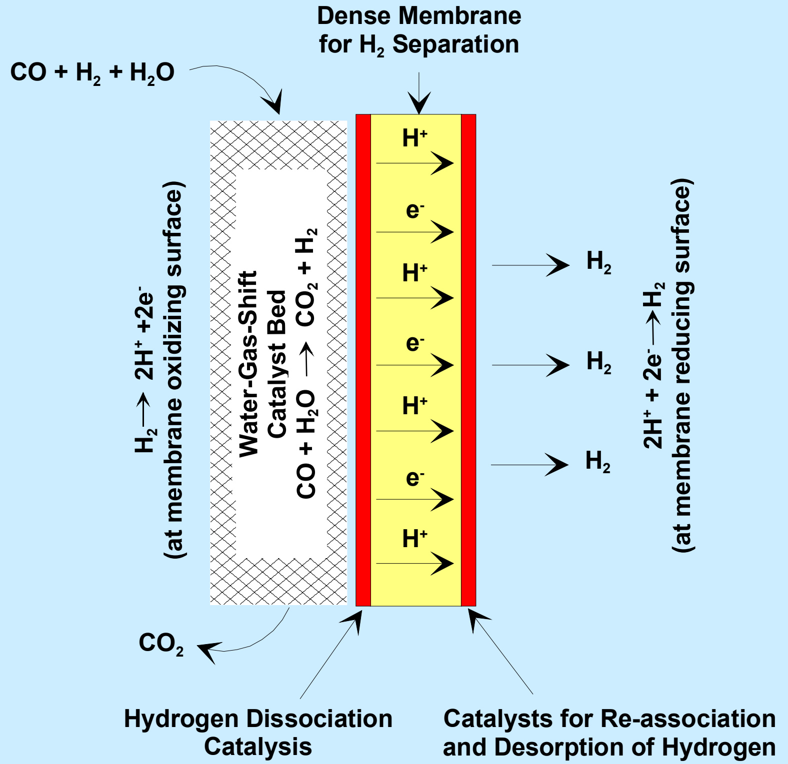
Objectives

- Identify low-cost high-performance hydrogen transport membranes
- Operate using representative synthesis mixtures
- Verify performance under high-pressure differentials comparable with simultaneous carbon dioxide sequestration
- Address sweep gas / no sweep gas issue on membrane permeate side
- Long-term performance
- Cost issues

Overall Scheme for Converting Hydrocarbon Feedstock to Hydrogen with Simultaneous Carbon Dioxide Sequestration



Integration of Water-Gas Shift Catalysts with Hydrogen Transport Membranes for Separation of Hydrogen from Carbon Dioxide



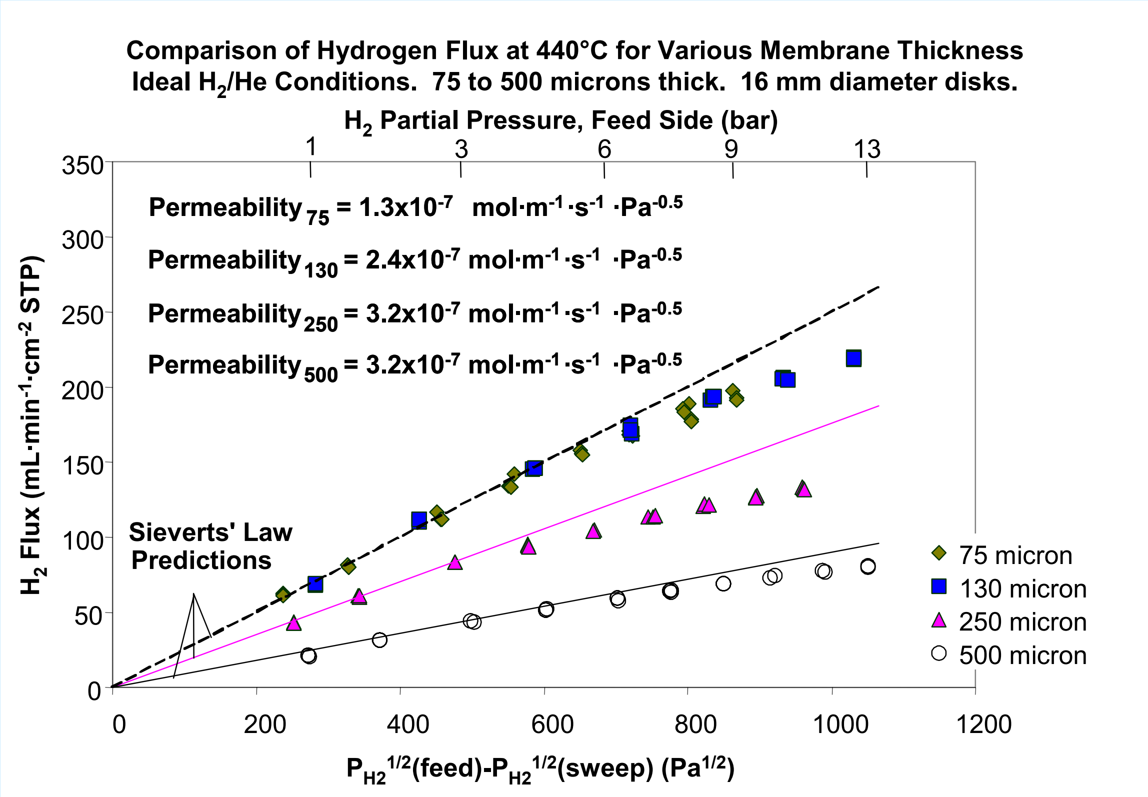
Eltron H_2 Separation Membrane Characteristics

Membrane Category	Temperature Range (°C)	Maximum Permeation Rate ($mL \cdot min^{-1} \cdot cm^{-2}$)
Single Phase Ceramic	**700 to 950**	**≈ 0.01**
Ceramic/Ceramic	**700 to 950**	**≈ 0.1**
High-Temperature Cermet With Non H_2-Permeable Metal (Ni)	**700 to 950**	**≈ 1**
High-Temperature Cermet with H_2-Permeable Metal (Pd)	**400 to 800**	**≈ 4**
Thin Film Palladium on Porous Support	**320 to 600**	**>50**
Intermediate-Temperature Composite	**320 to 440**	**>400**

High-Pressure Differential Hydrogen Separation Units

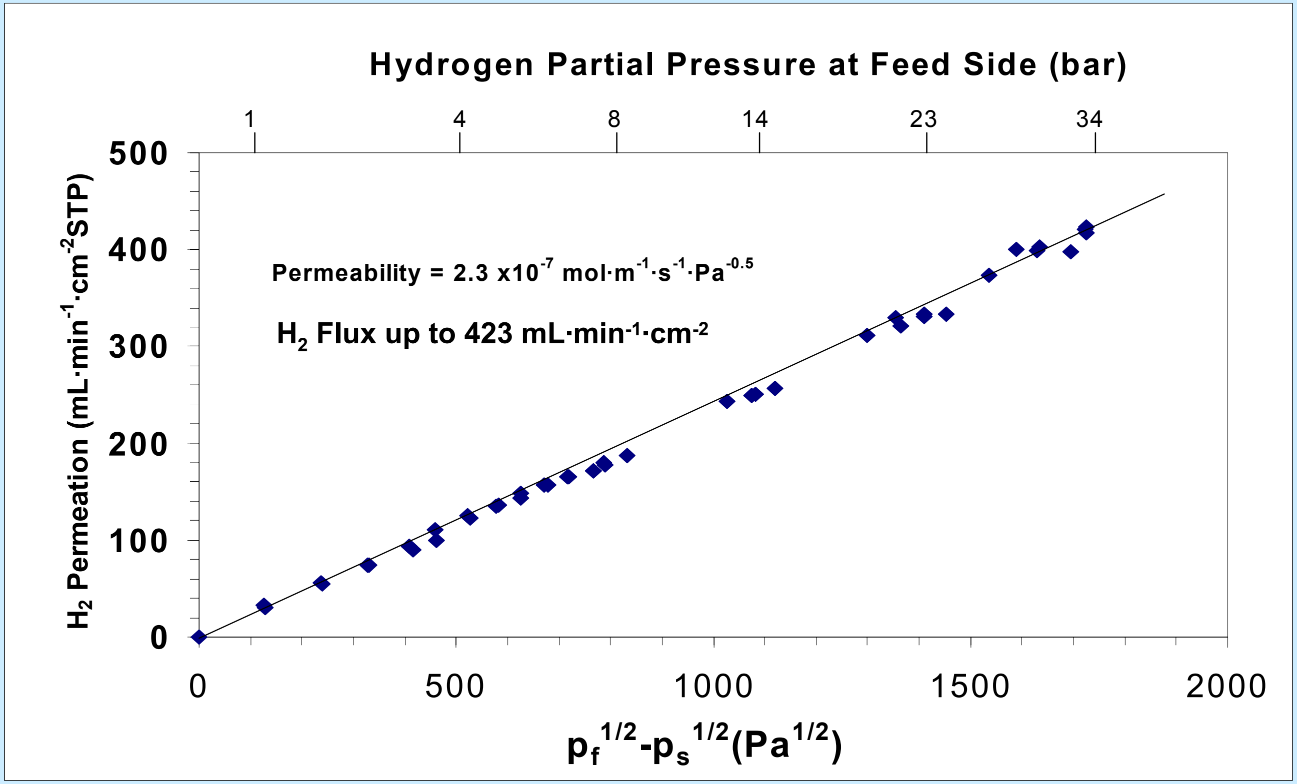
- Tests to 69 bar (1000 psi) differential pressure at 320-440°C
- Tests with high pressure WGS mixture

Pressure Differential Hydrogen Flux Measurements under Ideal 40% H_2/He Conditions as a Function of Membrane Thickness



- **Bulk diffusion is rate limiting for 250 and 500 micron thick membranes.**
- **Flux identical for 75 and 130 micron thick membranes. Bulk diffusion is not rate limiting.**
- **Gas phase diffusion limited.**

Hydrogen Flux at High Pressure Differential

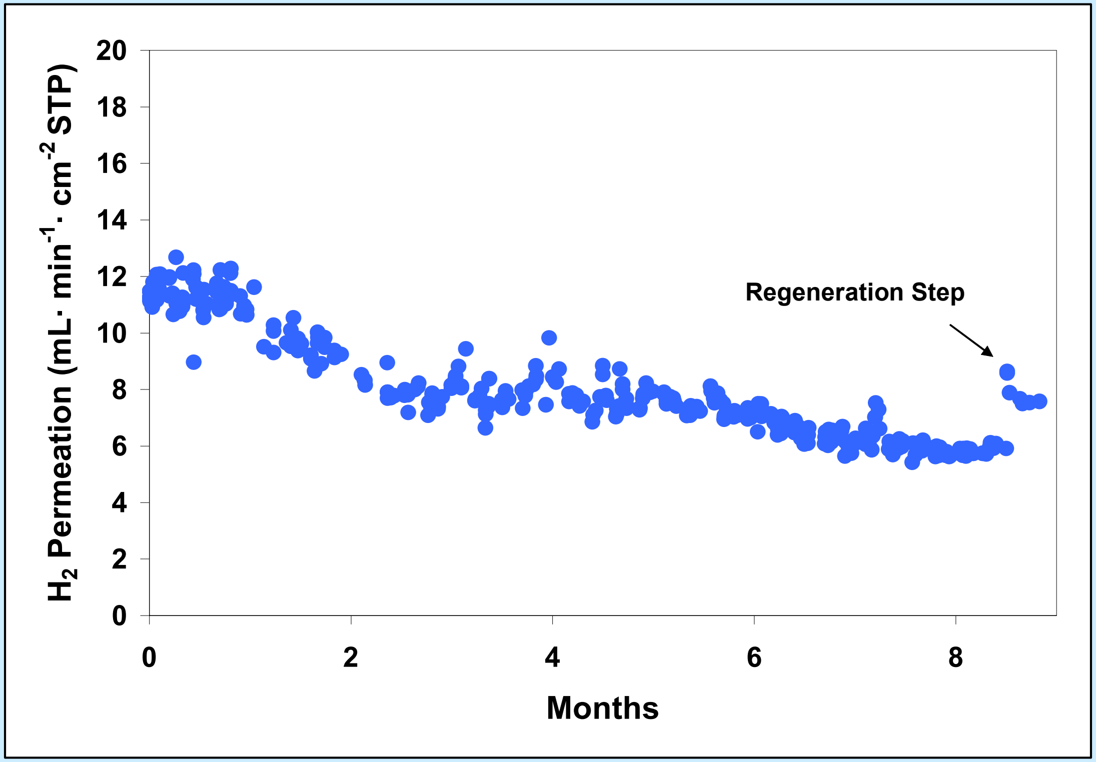


- Permeability of 2.3x10^{-7} mol·m^{-1}·s^{-1}·Pa$^{-0.5}$ and hydrogen flux of 423 mL·min^{-1}·cm^{-2} (STP) achieved at 440°C (713K) under ideal hydrogen-helium mixture up to 33 bar (476 psi) differential pressure and partial pressure of hydrogen of 34 bar (488 psi).

Long-Term Ambient Pressure Performance

Performance of Hydrogen Transport Membrane

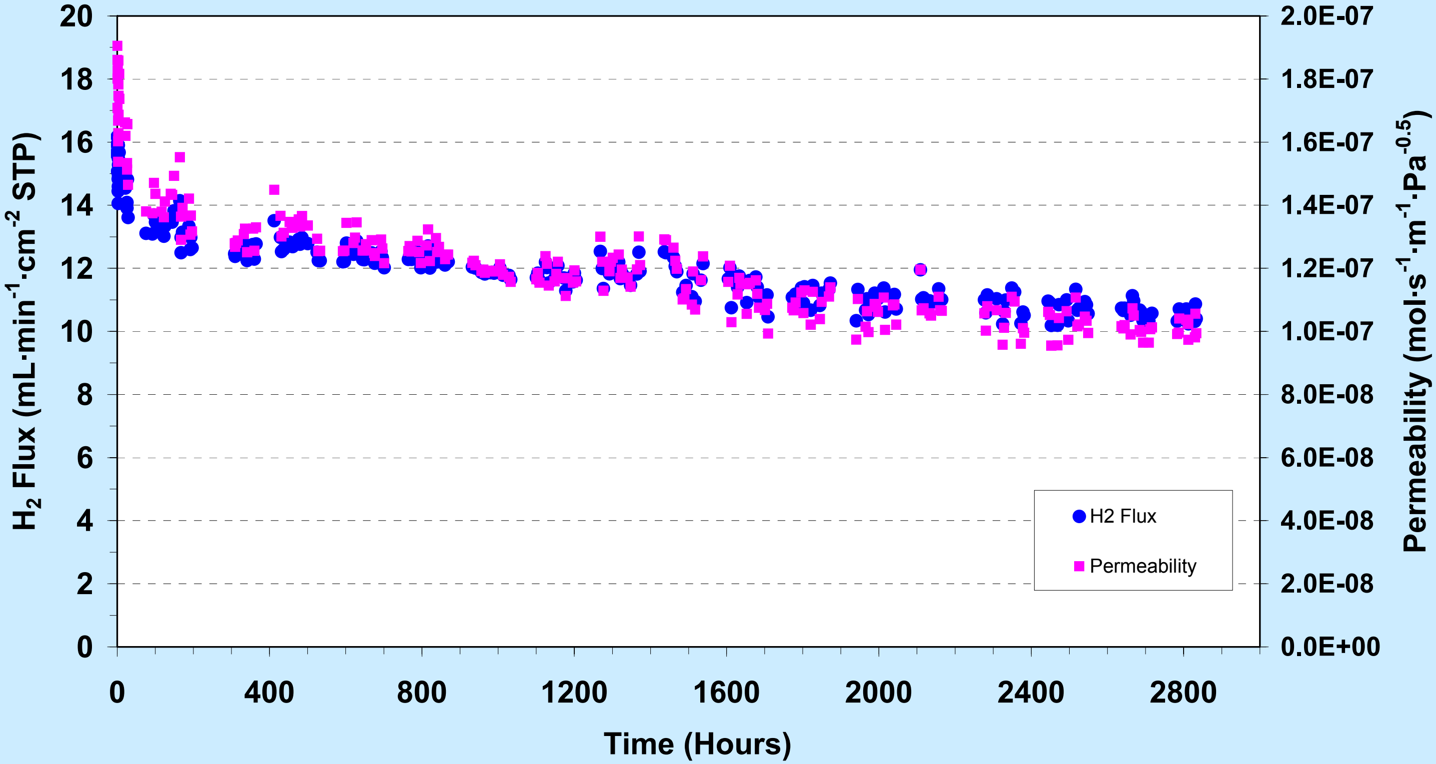
(80% H2 / 20% He Feed at 320°C)



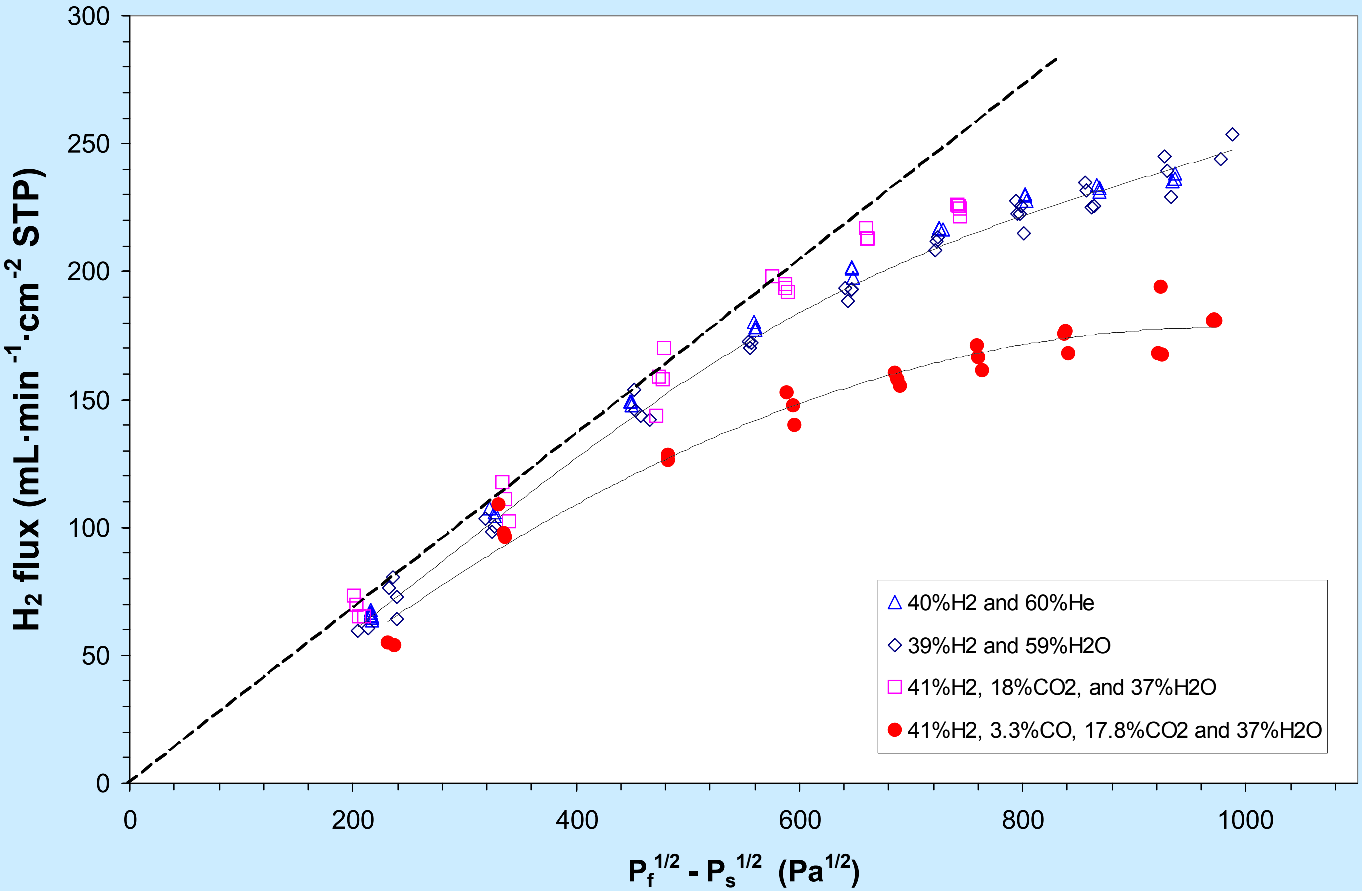
- No guard bed used to adsorb impurities.

Long-Term Results

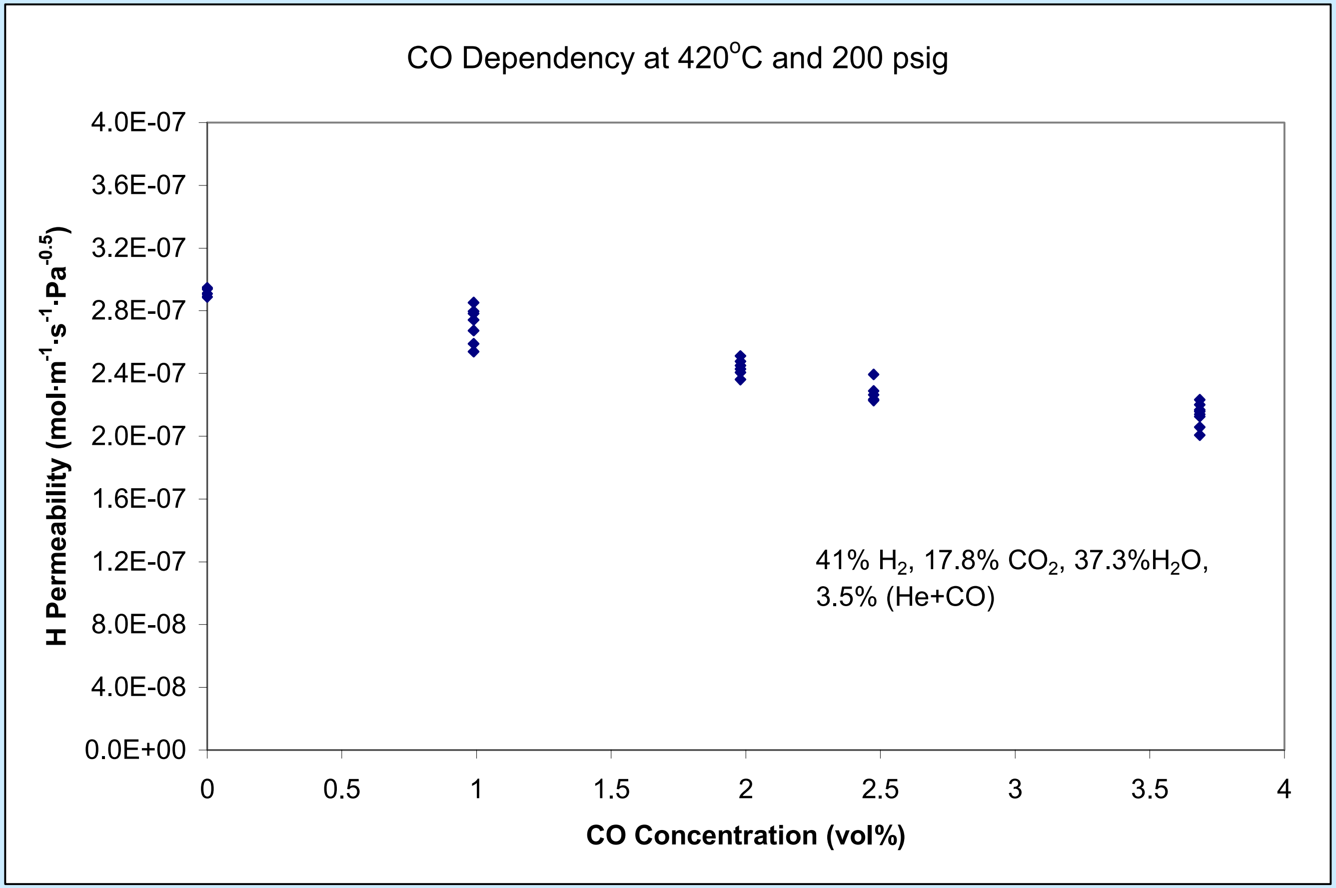
Long-term test @ 340 °C with a feed containing 41.4% H_2, 37.3% H_2O, 3.3% CO and 17.8% CO_2 and a Cu/ZnO guard bed



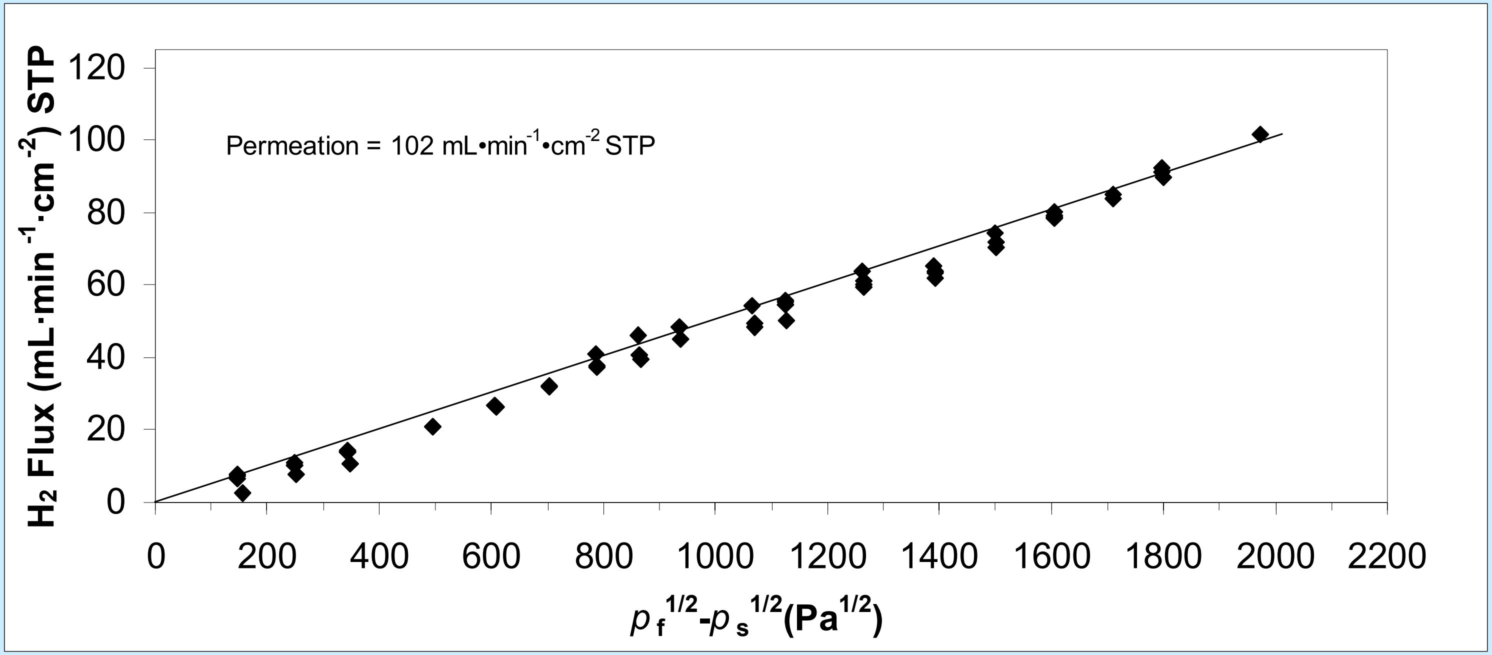
Membrane Performance upon Going from Ideal to Syngas Conditions



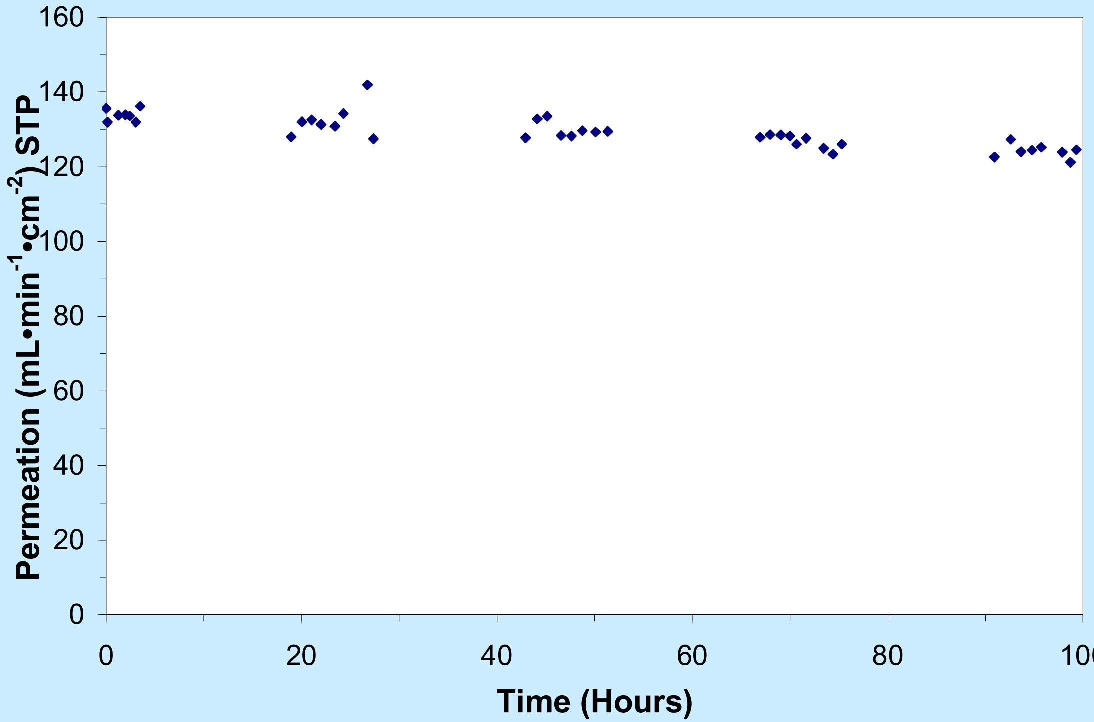
Dependency of Membrane Performance on Carbon Monoxide Fraction



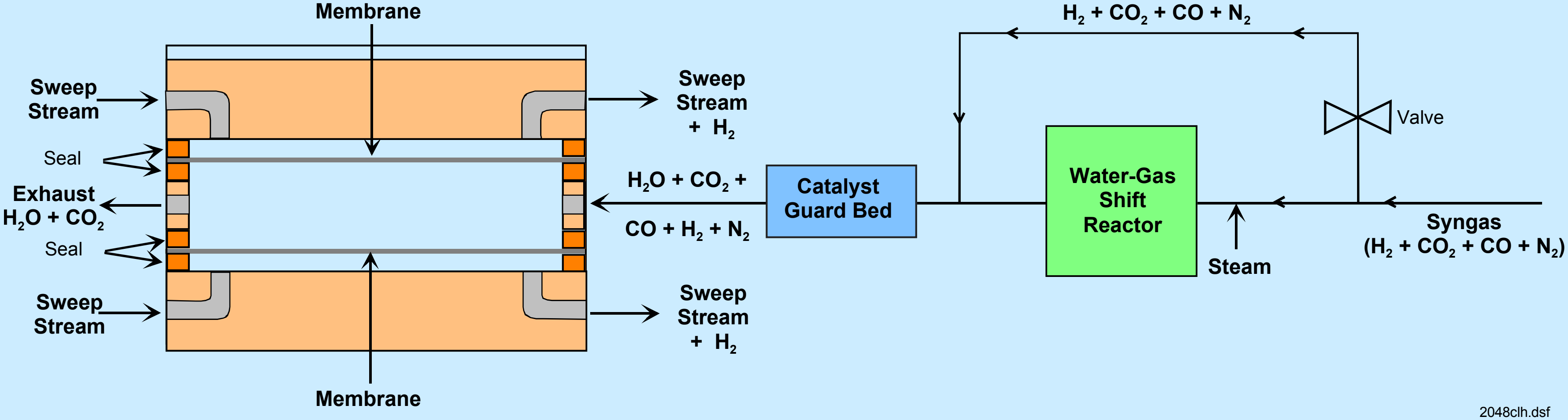
Performance of a 250-Micron Hydrogen Transport Membrane up to 1000 psi Pressure Differential at 420°C

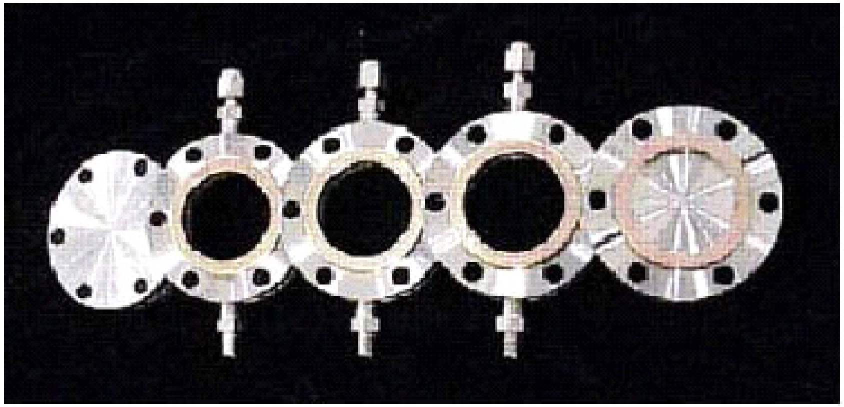


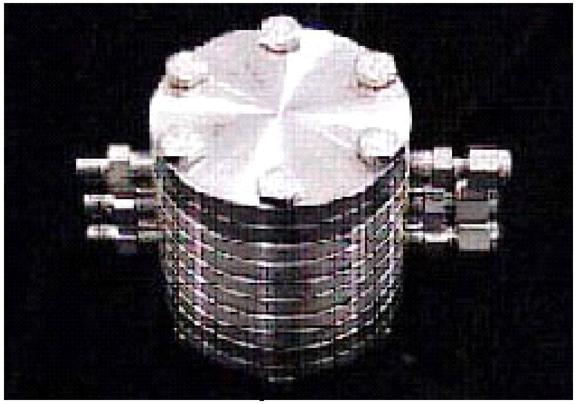
Membrane Performance under Pressure (300 psig); 40% Hydrogen; No Sweep Gas. Hydrogen Pressure on Permeate Side 15 psia.



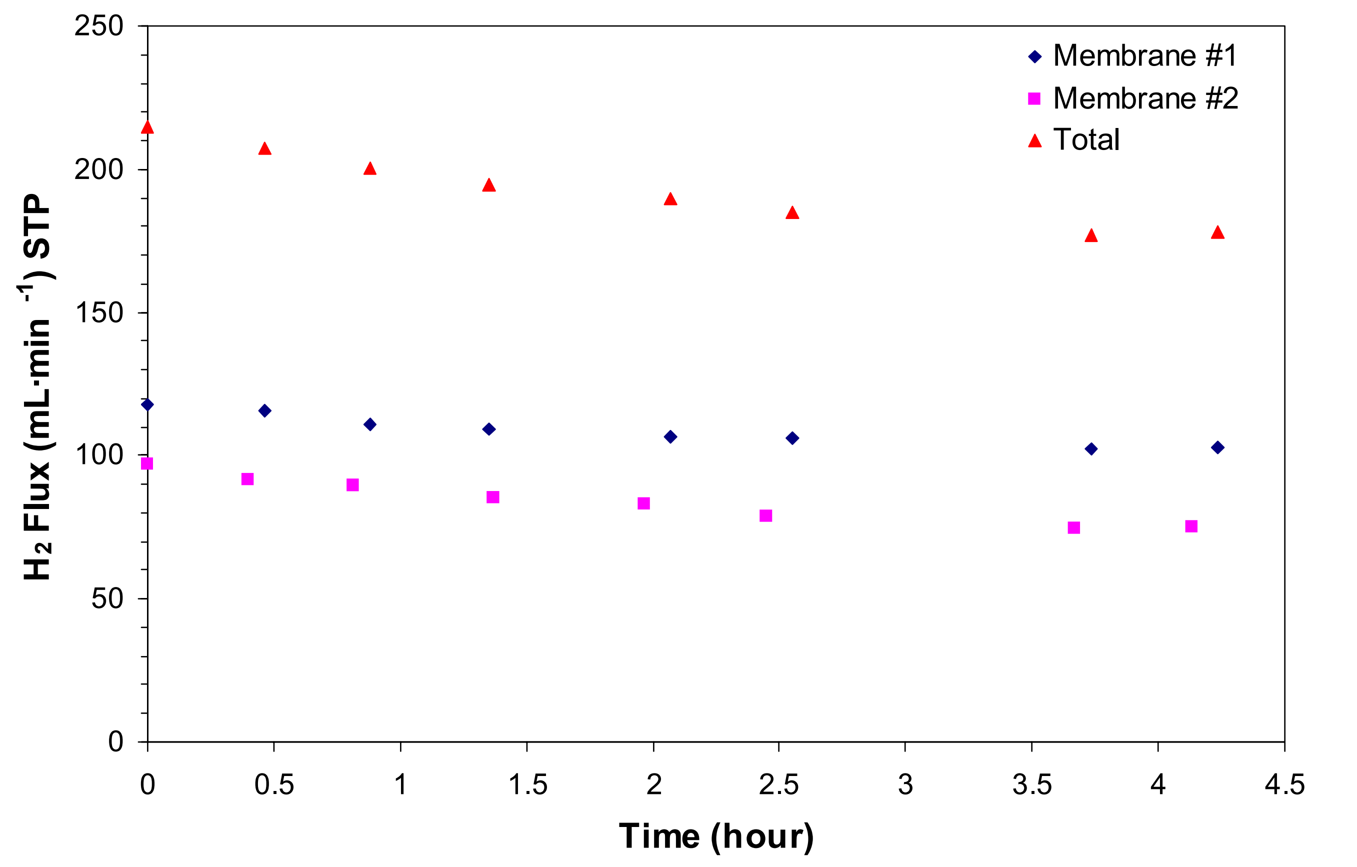
Cross-Sectional Schematic of Stacked Hydrogen Separation Membrane Unit







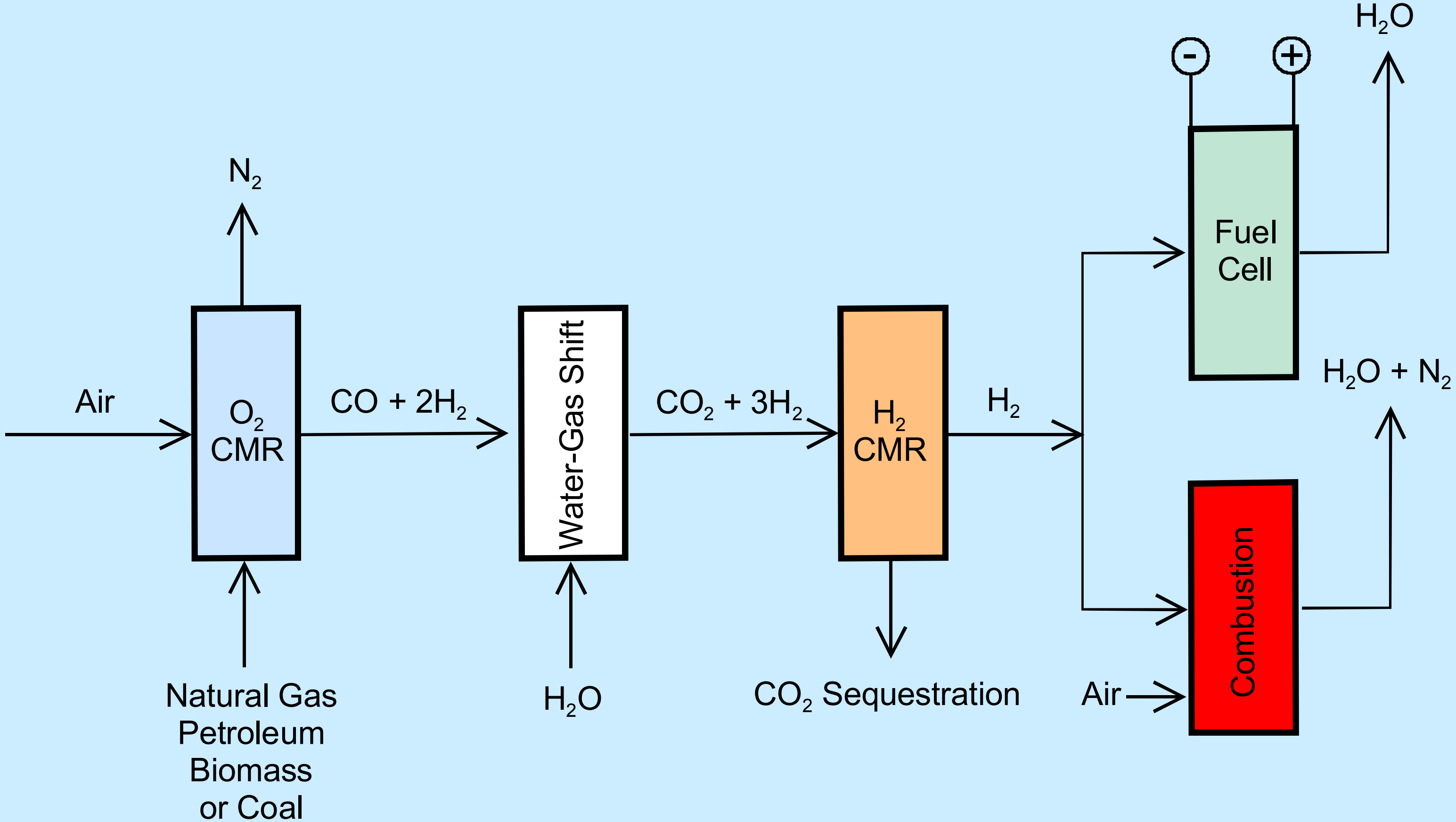
Performance of Two Membrane Stack at Ambient Pressure



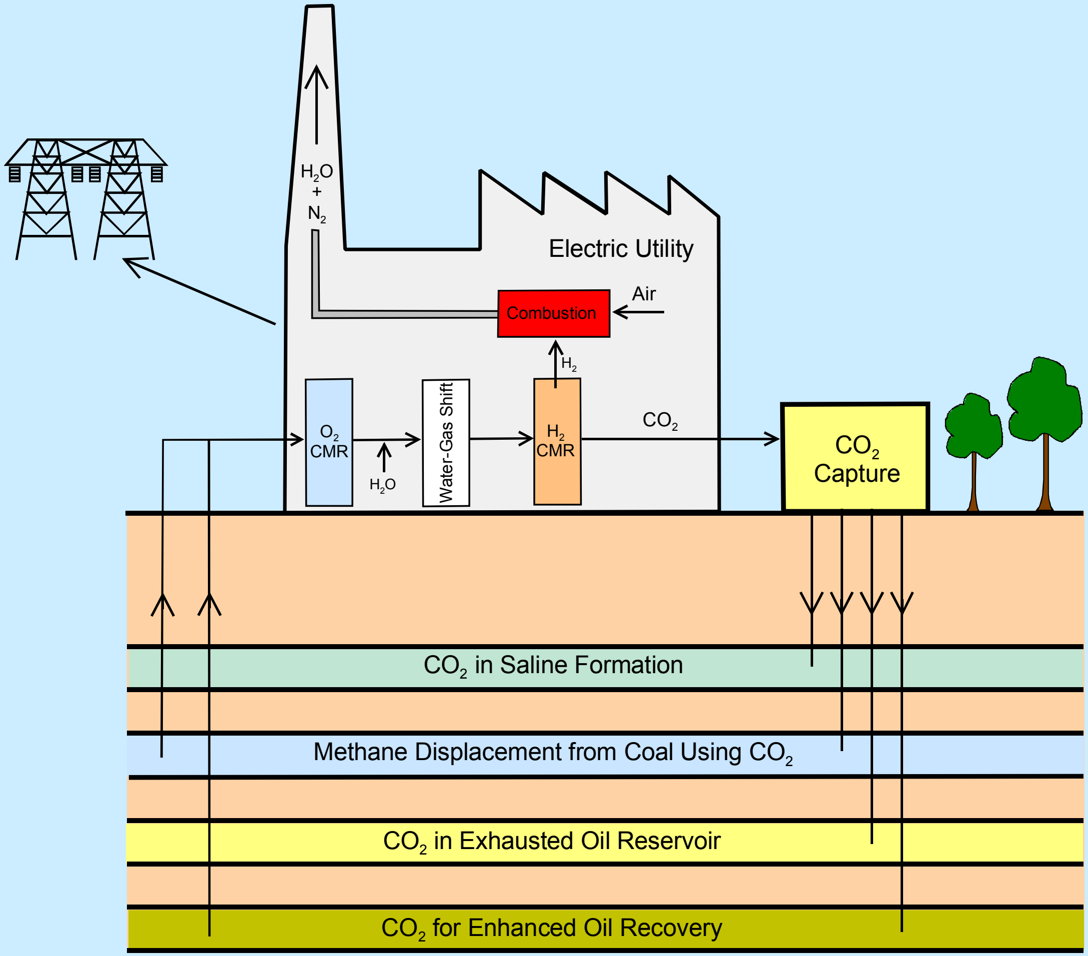
Relative Costs of H_2 Production Using Membrane Technologies

- H2 separation membranes could reduce purification cost by ~30% relative to Pressure Swing Absorption (PSA). (S. Lasher et al., Hydrogen Technical Analysis, *Proc. 2002 DOE Hydrogen Program Review*)
- Eltron H2 separation membranes are ~200 times cheaper than analogous Pd membranes and permeate 10x faster.
- Estimated H2 cost using combined oxygen and hydrogen transport membrane technologies is $4/MMBtu or $0.55/kg. (Hydrogen Production Facilities: Plant Performance and Cost Comparison, Final Report for Contract No. DE-AM26-99FT40465, Parsons)

Membranes for Hydrogen Supply



Concept for Emission-Free Electric Utility



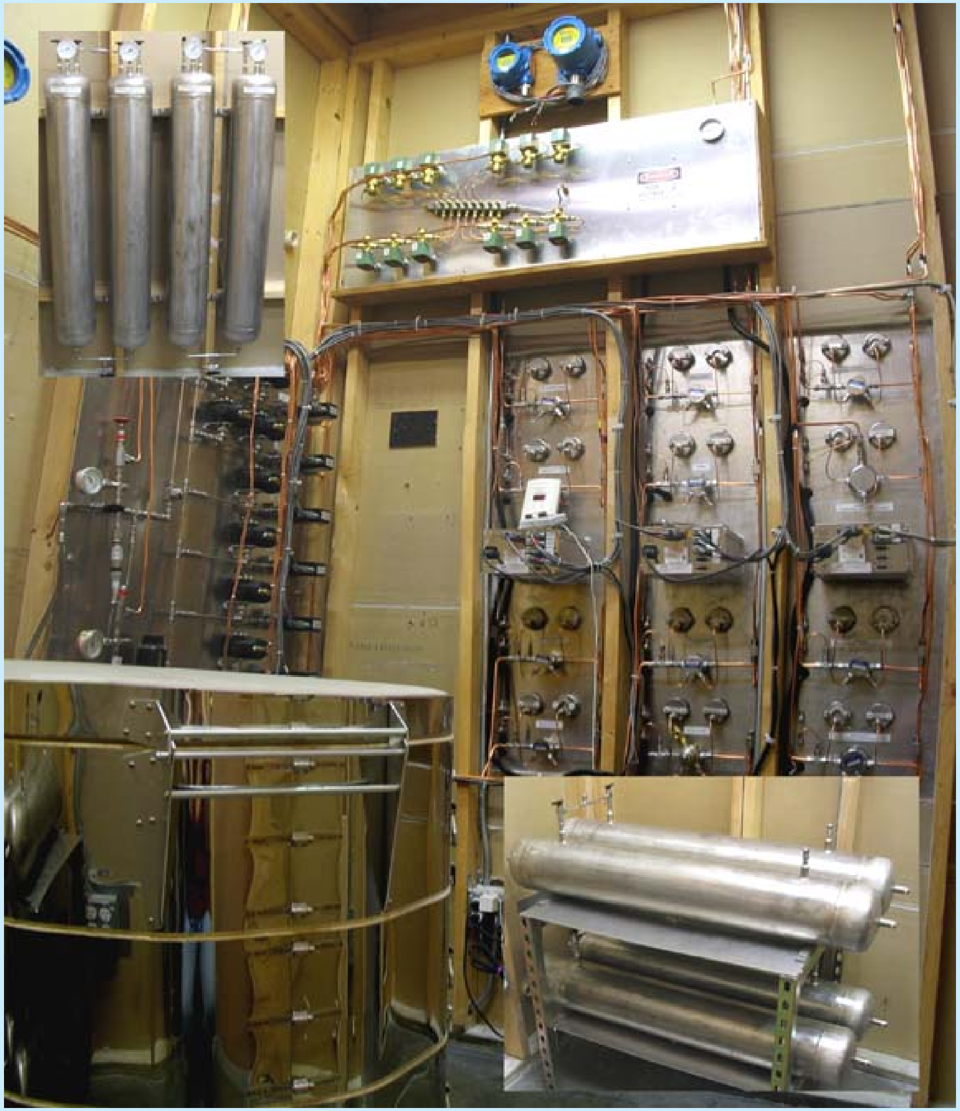
Future Work

- Remainder of FY 2005
  - Complete build and performance verification of 1.3 lb/day membrane separation unit
- FY 2006
  - Build and test 5 lb/day PDU
  - Integrate with coal gasifier slip stream

Participants:

Eltron Research Inc.
CoorsTek
Emery Energy
Noram Engineering and Constructors
Praxair

Hardware for Performance Testing of 1.3 lb/day Hydrogen Separation Unit



Acknowledgements

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Publications and Presentations

• *Hydrogen and Oxygen Transport Membranes for Spontaneous Conversion of Coal to Hydrogen*	29th International Conference on Coal Utilization and Fuel Systems, Clearwater, FL, April 2004	A.F. Sammells M.V. Mundschau S.E. Roark T.F. Barton
• *Simultaneous Hydrocarbon Reforming, Carbon Dioxide Sequestration and Hydrogen Separation Using Dense Inorganic Membranes*	Annual Carbon Capture and Sequestration Conference, Alexandria, VA, May 2004	M.V. Mundschau X. Xie C.R. Evenson A.F. Sammells
• *Oxygen and Hydrogen Transport Membranes for Combined Hydrocarbon Reforming and Hydrogen Separation*	8th International Conference on Inorganic Membranes, Cincinnati, OH, July 2004	A.F. Sammells M.V. Mundschau X. Xie

Publications and Presentations (cont.)

• *Dense Membranes for Separation of H_2 from CO_2 in High-Pressure Water-Gas Shift Reactors*	7th International Conference on Greenhouse Gas Control Technology, Vancouver, BC, Sept. 2004	M.V. Mundschau X. Xie A.F. Sammells
• *Advanced Membranes for the Spontaneous Conversion of Coal to Hydrogen*	21st Annual International Pittsburgh Coal Conference, Osaka, Japan, Sept. 2004	A.F. Sammells M.V. Mundschau X. Xie C.R. Evenson
• *Advances in Hydrogen Separation Membrane Technology for the Separation of CO_2 and the Purification of Hydrogen Produced from Coal*	30th International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, FL, April 2005	M.V. Mundschau X. Xie A.F. Sammells

Hydrogen Safety

The most significant hydrogen hazards associated with this project are:

- Carbon monoxide poisoning
- Hydrogen leakage
- Hydrogen feed explosion

Hydrogen Safety

Our approach to dealing with these hazards is:

- Continuous monitoring for reducing gases
- Operation of hydrogen separation units in contained, well-ventilated conditions
- Hydrogen membrane hardware has incorporated rupture disks vented to the outside