

Scale-Up of Hydrogen Transport Membranes for IGCC and FutureGen Plants

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PD009

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Overview

Timeline

- Phase I Start Oct. 1, 2005
- Phase II Start Oct. 1, 2009
- Phase II End June 2012
- ~75% Complete

Budget

- Total project funding: \$8,824,788
 - DOE Share: \$7,059,830
 - Contractor Share: \$1,764,958
- FY10 funding: \$2,500,000
- FY11 funding: \$1,869,229

Barriers Addressed

- Reducing hydrogen cost
- Membrane durability
- Membrane testing & analysis

Partners

- Project Lead: Eltron R&D
- Partners: Eastman Chemical Co.

Relevance

Overall Program Objectives

- Cost-effective H₂ / CO₂ separation system
- Retains CO₂ at gasifier pressures
- Operates near water-gas shift conditions
- Tolerates reasonably achievable levels of coal impurities

Objectives June 2010 – May 2011

- Membrane manufacturing – Scale-up
- Construct, Install, & Operate 12 lbs/day membrane reactor
- Continued bench-scale testing

Technical Approach

- **Materials Development**
 - Membrane substrate manufacturer comparison
 - Catalyst deposition scale-up
- **Performance Screening**
 - Membrane testing under expected operating conditions for scale-up
 - Establish range of operating conditions
- **Mechanical Design**
 - Assess strength of materials, embrittlement, welding techniques, flow dynamics
 - Address manufacturing costs and maintenance issues
- **Process Design and Economics**
 - Integrate into IGCC flow sheets – with and without co-production of H₂ & power
 - Compare process economics versus other technologies
- **Scale-up steps**
 - 12 lbs/day H₂ production – coal-based syngas slipstream
 - 250 lbs/day H₂ production – coal-based syngas slipstream + WGCU

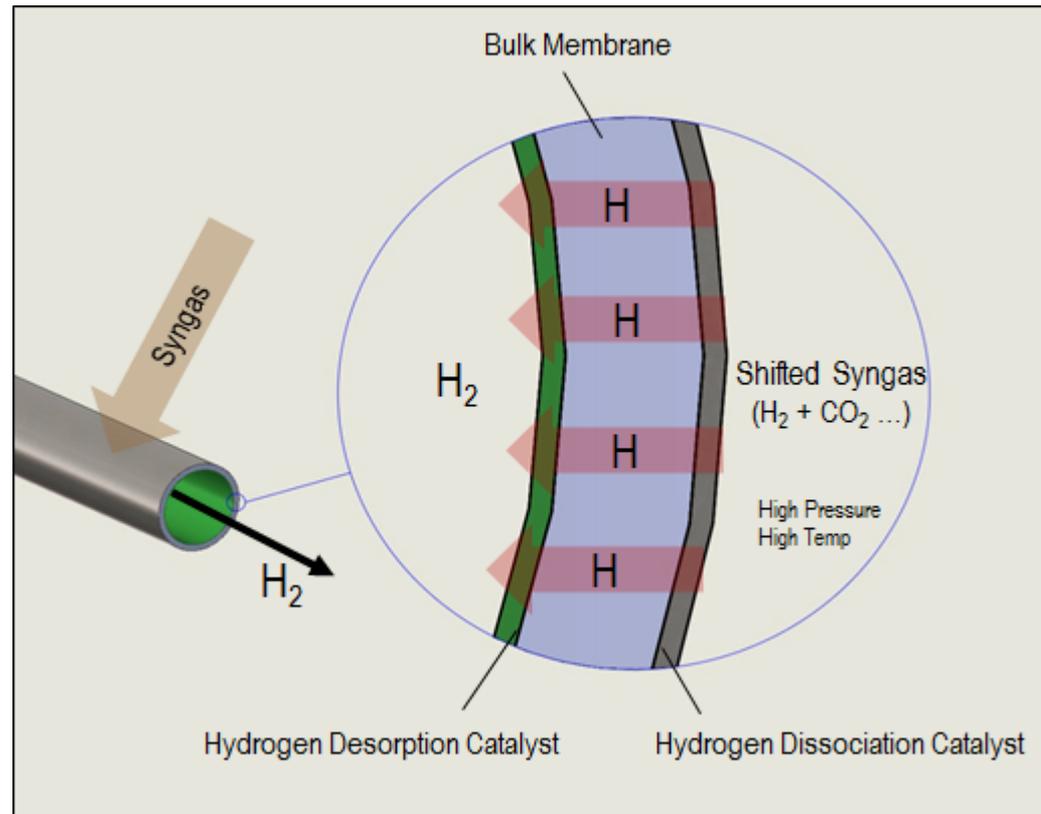
Approach - Milestones

| | Milestone |
|---------|---|
| FY10 Q3 | Complete membrane module design and skid layout. Status: Completed |
| FY10 Q4 | Complete construction of 12 lbs/day unit. Status: Completed |
| FY11 Q1 | Complete installation of the 12 lbs/day reactor. Status: Completed |
| FY11 Q2 | Complete mechanical shake-down of the 12 lbs/day reactor. Status: Completed |
| FY11 Q3 | Collect hydrogen separation material and process performance data on the 12 lbs/day reactor. Status: In Progress |
| FY11 Q4 | Update process economics based on 12 lbs/day performance. Status: In Progress |

Eltron's Membrane System

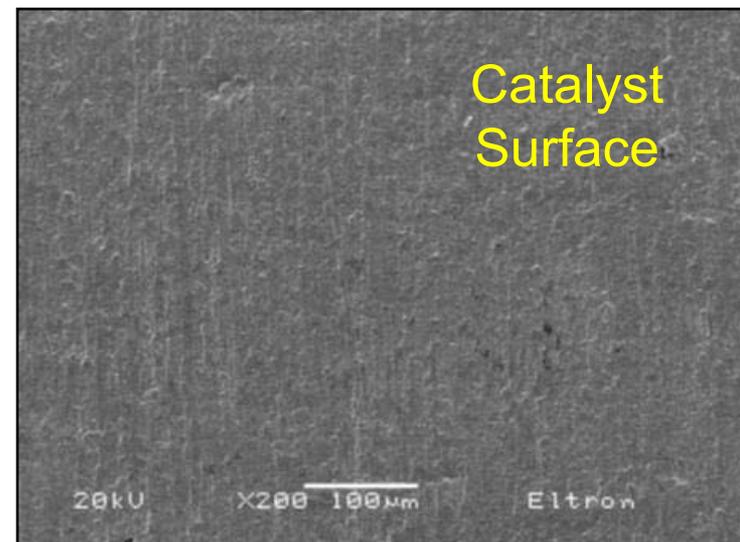
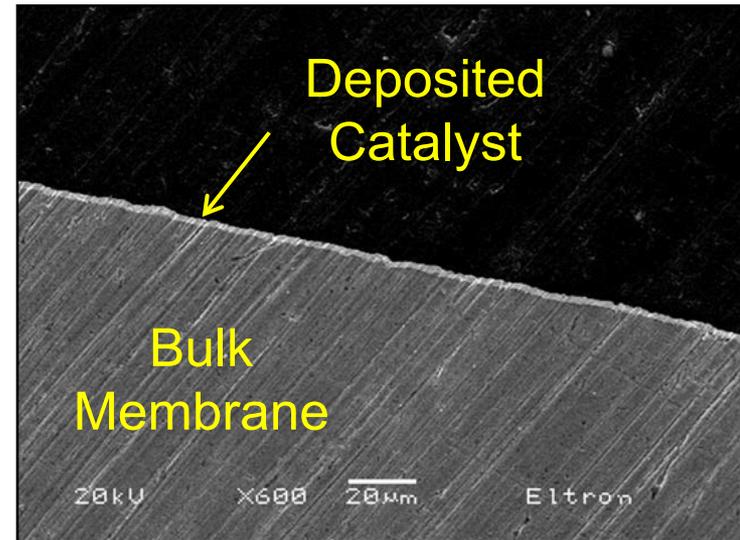
Key Features

- 3-layer, dense metal alloy
 - Self-supporting
 - 100% selective
- CO₂ retained at high pressure
- Operates near water-gas shift temperatures.



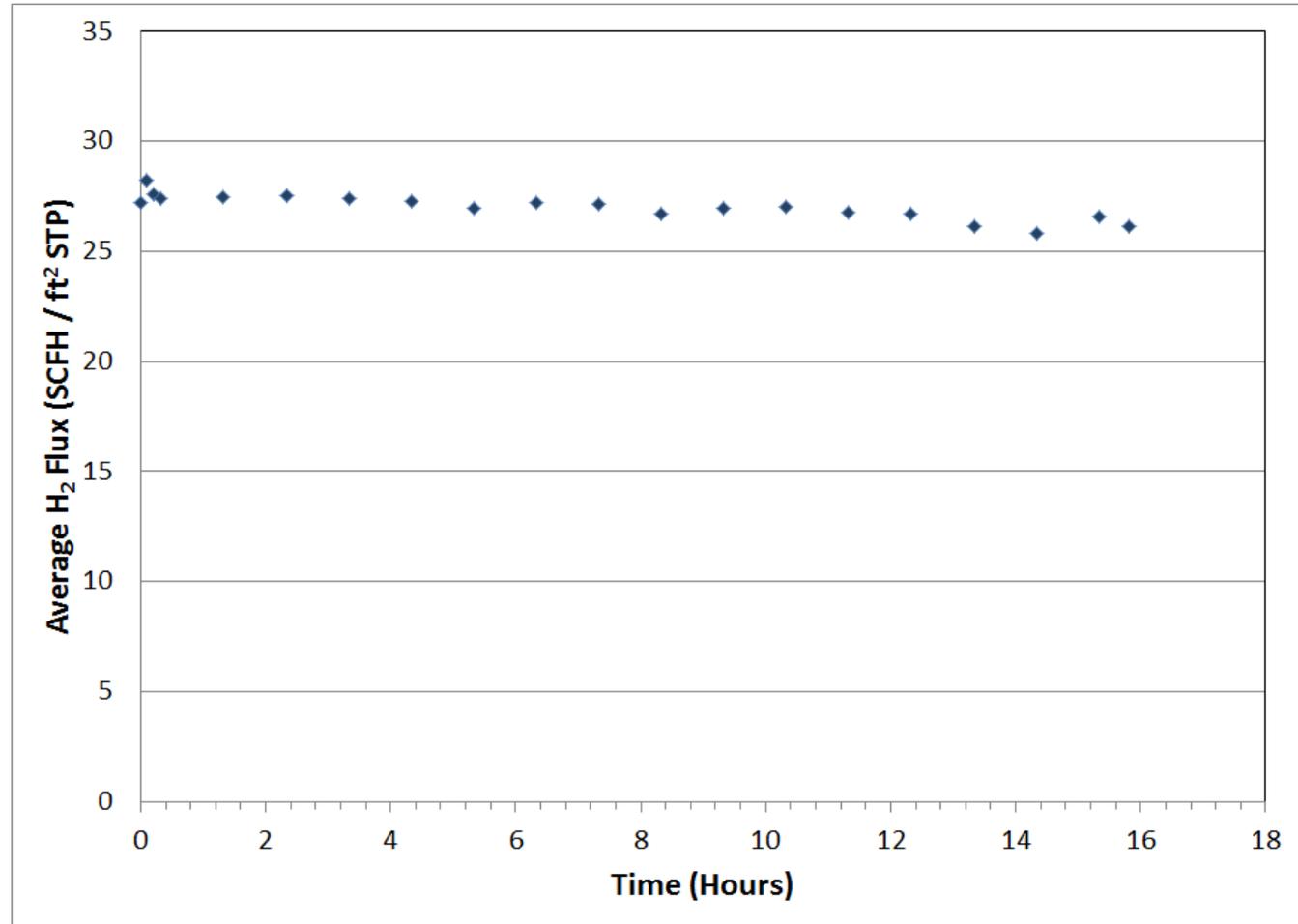
Technical Accomplishments

- Membrane Manufacturing
 - 5' long membrane tubes
 - 1/2" OD
 - 500 μm wall
 - Alloy catalyst deposited on the inside & outside surfaces
 - Uniform
 - Complete coverage



Technical Accomplishments

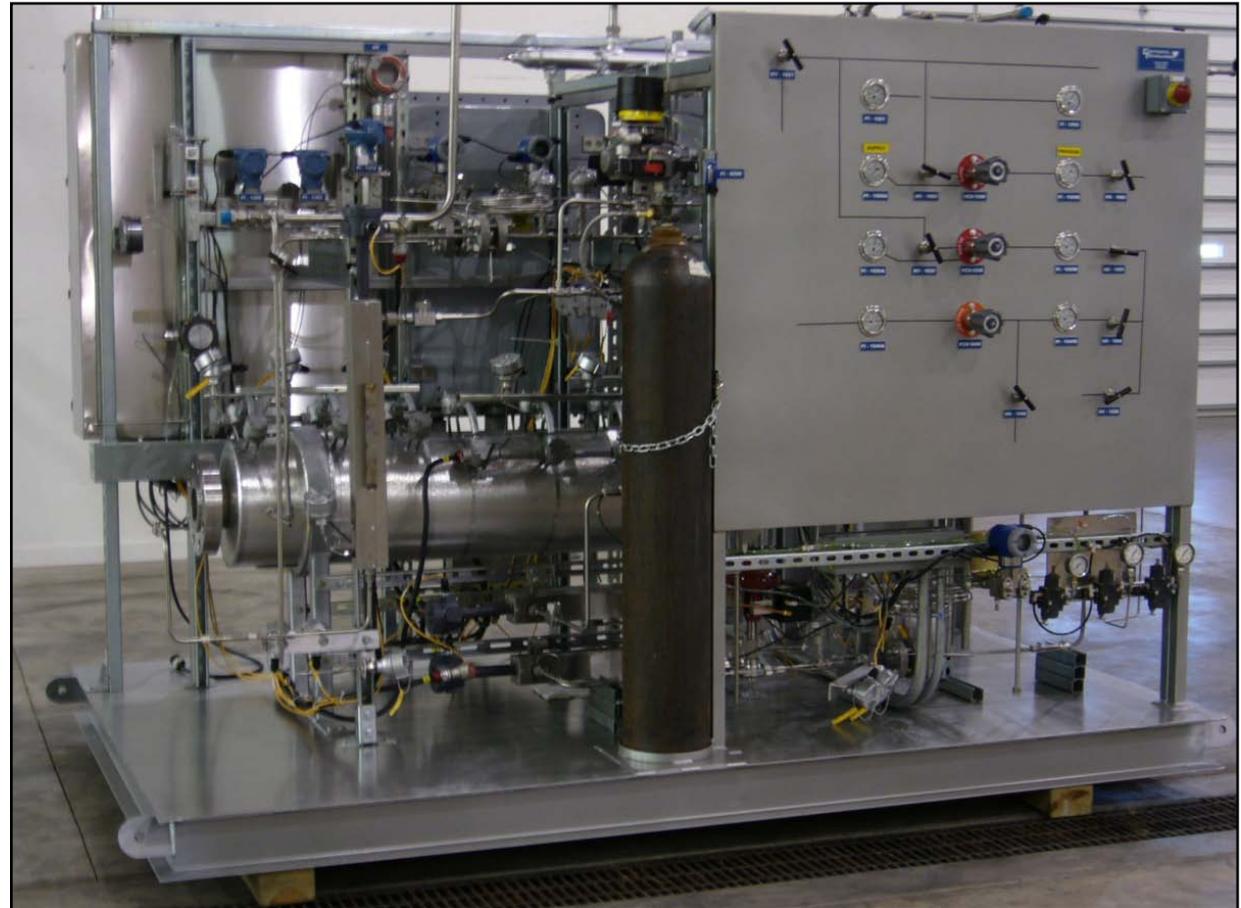
- 2' Tubular Membrane
 - 500 μm
 - 340°C
 - Feed
 - WGS
 - 450 psig
 - Sweep
 - N_2
 - 50 psig
- 70% H_2 Recovery



Technical Accomplishments

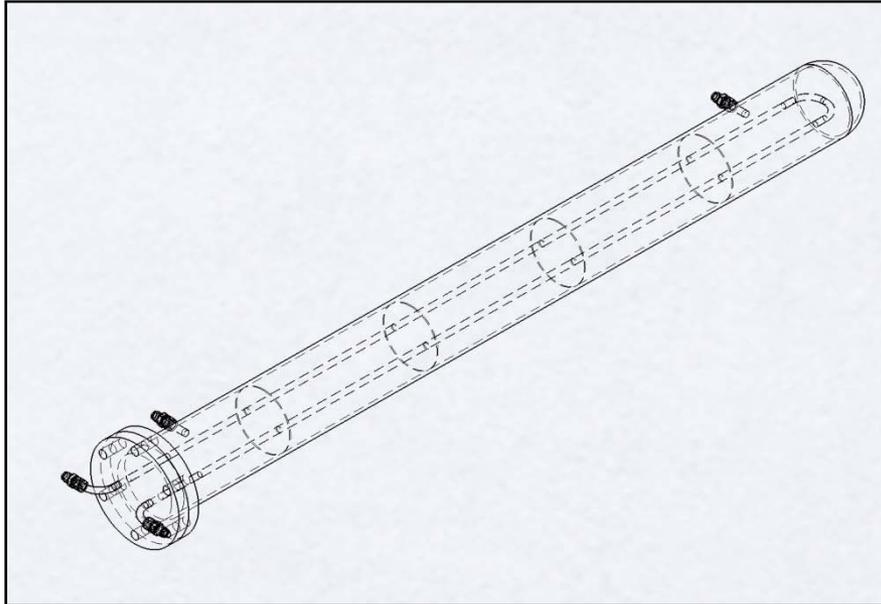
12 lbs/day H₂ Membrane Reactor Construction

- Skid Mounted System
- PLC Safety System
- 10' of ½" OD tubular membrane



Technical Accomplishments

12 lbs/day H₂ Membrane Module



Technical Accomplishments

12 lbs/day H₂ Membrane Reactor Installation

- Eastman Chemical Co. Kingsport, TN
- All utilities connected
- Mechanical shake-down
- Operator training

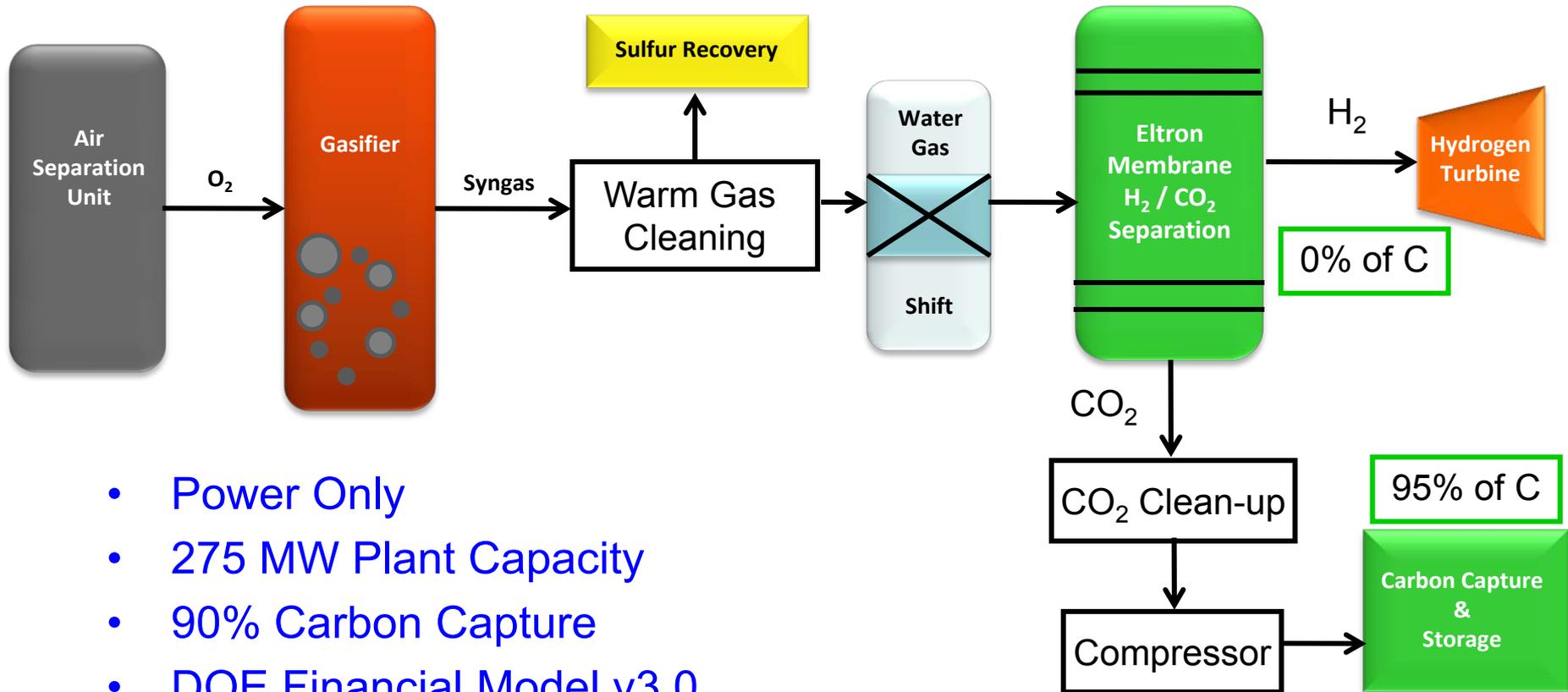
Operation

- 30 days
- Effect of operating conditions under coal-derived syngas and operating procedures on membrane performance
- Cycling
- Lifetime



Technical Accomplishments

Process Modeling / Techno-Economics



- Power Only
- 275 MW Plant Capacity
- 90% Carbon Capture
- DOE Financial Model v3.0

Technical Accomplishments

- Process Modeling / Techno-Economics

| | Case 1 | Case 2 | Case 3 | Case 4 |
|--|-----------------|---|-------------------------------------|-------------------------------------|
| Pre-Combustion Gas Cleaning & CO ₂ Capture Method | 2-Stage Selexol | Cold Gas (Amine) Cleaning & Eltron Membrane | Warm Gas Cleaning & Eltron Membrane | Warm Gas Cleaning & Eltron Membrane |
| Gasifier Cooling Method | Quench | Radiant-Convective | Radiant-Convective | Quench |
| Thermal Efficiency | 27.4% | 32.0% | 33.6% | 31.6% |
| % CO ₂ Captured | 90% | 90% | 95% | 95% |
| Cost of Electricity (\$/MWh) | 115.5 | 114.5 | 106.0 | 100.4 |

Collaborations

- Eltron Research & Development Inc.
 - Prime Contractor
- Eastman Chemical Co.
 - Subcontractor
 - Gasified coal slip-stream
 - WGCU
- Two Key Membrane Manufacturers

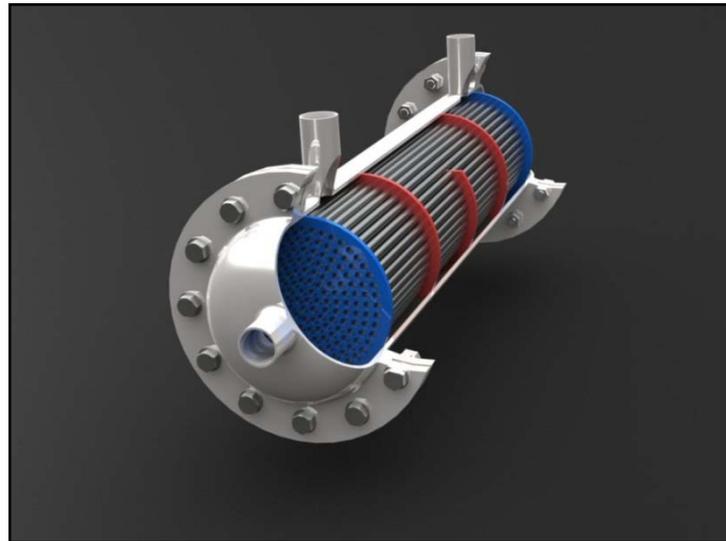
Future Work

- FY2011 Q3
 - Operate 12 lbs/day H₂ Unit
- FY2011 Q4
 - Preliminary Design 250 lbs/day H₂ Unit
 - Go / No-Go Decision
- FY2012
 - Design, build, operate 250 lbs/day H₂ Unit integrated with WGCU

Future Work – ARRA Project

- 10/1/10 - 9/30/15
- Total Project Cost: \$73.7 MM
- Scope
 - Accelerate 250 lbs/day pilot
 - Design, build, operate 4-10 T/day Pre-Commercial Module (PCM) demonstration reactor on coal-derived syngas
- Goal
 - Scale-up of HTM system for energy efficient carbon capture and hydrogen separation from industrial sources

Future Work – ARRA Project

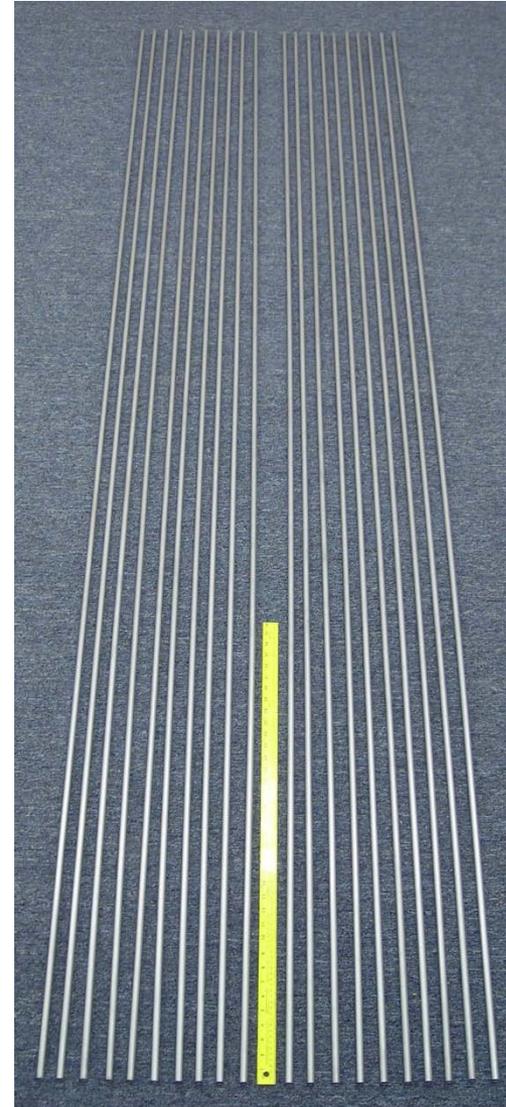


| ID | Task Name | 2010 | | 2011 | | | | 2012 | | | | 2013 | | | | 2014 | | | | 2015 | | | | | |
|----|--|---------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4 | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4 | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4 | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4 | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4 | Qtr 1 | Qtr 2 | Qtr 3 | Qtr 4 |
| 1 | Scale-Up of Hydrogen Transport Membranes | [Gantt bar: 2010 Q1 to 2015 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Project Management | [Gantt bar: 2010 Q1 to 2015 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Task 1 Project Management, Planning, and Reporting | [Gantt bar: 2010 Q1 to 2015 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | Membrane Scale-Up | [Gantt bar: 2010 Q1 to 2013 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | Task 2 Membrane Technology Development Acceleration & Scale-Up | [Gantt bar: 2010 Q1 to 2013 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | Pre-Commercial Module | [Gantt bar: 2010 Q1 to 2015 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | Task 3 PCM Pre-FEED | [Gantt bar: 2010 Q1 to 2011 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 21 | Task 4 PCM FEED | [Gantt bar: 2011 Q1 to 2012 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 24 | Task 5 PCM Detailed Design & Construction | [Gantt bar: 2012 Q1 to 2014 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 29 | Task 6 PCM Operation & Analysis | [Gantt bar: 2014 Q1 to 2015 Q4] | | | | | | | | | | | | | | | | | | | | | | | |
| 32 | Task 7 Process Modeling, Techno-Economics, & Commercial Applications E | [Gantt bar: 2010 Q1 to 2015 Q4] | | | | | | | | | | | | | | | | | | | | | | | |

Future Work

ARRA Project - Status

- Cooperative agreement signed Feb. 18, 2011
- 10' tubular membrane procured
- RFP issued to EPC firms
- Evaluating 3 potential sites



Summary

- **Relevance**
 - Cost-effective H₂ / CO₂ separation system
- **Approach**
 - Demonstrate performance and economics on gasified coal feed streams
- **Technical Accomplishments**
 - Catalyst deposition was successfully scaled up
 - 12 lbs/day reactor designed, constructed, installed at Eastman Chemical Co.
- **Collaborations**
 - Evaluating membrane substrate tubing from two manufacturers.
- **Future Work**
 - Scale-up testing on gasified coal feed stream
 - 250 lbs/day H₂ membrane unit

Backup Slides

DOE Performance Targets

| Performance Criteria | 2010 Target | 2015 Target | Eltron Membrane |
|-----------------------------------|-------------|-------------|-----------------|
| Flux (SCFH / ft ²) | 200 | 300 | 320 |
| Operating Temperature (°C) | 300-600 | 250-500 | 300-400 |
| S Tolerance (ppmv) | 2 | 20 | 2-20 |
| System Cost (\$/ft ²) | 500 | <250 | <200 |
| ΔP Operating Capability (psi) | 400 | 800-1000 | 1000 |
| Carbon Monoxide Tolerance | Yes | Yes | Yes |
| Hydrogen Purity (%) | 99.5 | 99.99 | 99.999 |
| Stability / Durability (Years) | 3 | >5 | 0.9 |
| Permeate Pressure (psi) | N/A | N/A | >400 |