SRI International

Development of a Precombustion CO_2 Capture Process Using High-Temperature PBI Hollow-Fiber Membranes

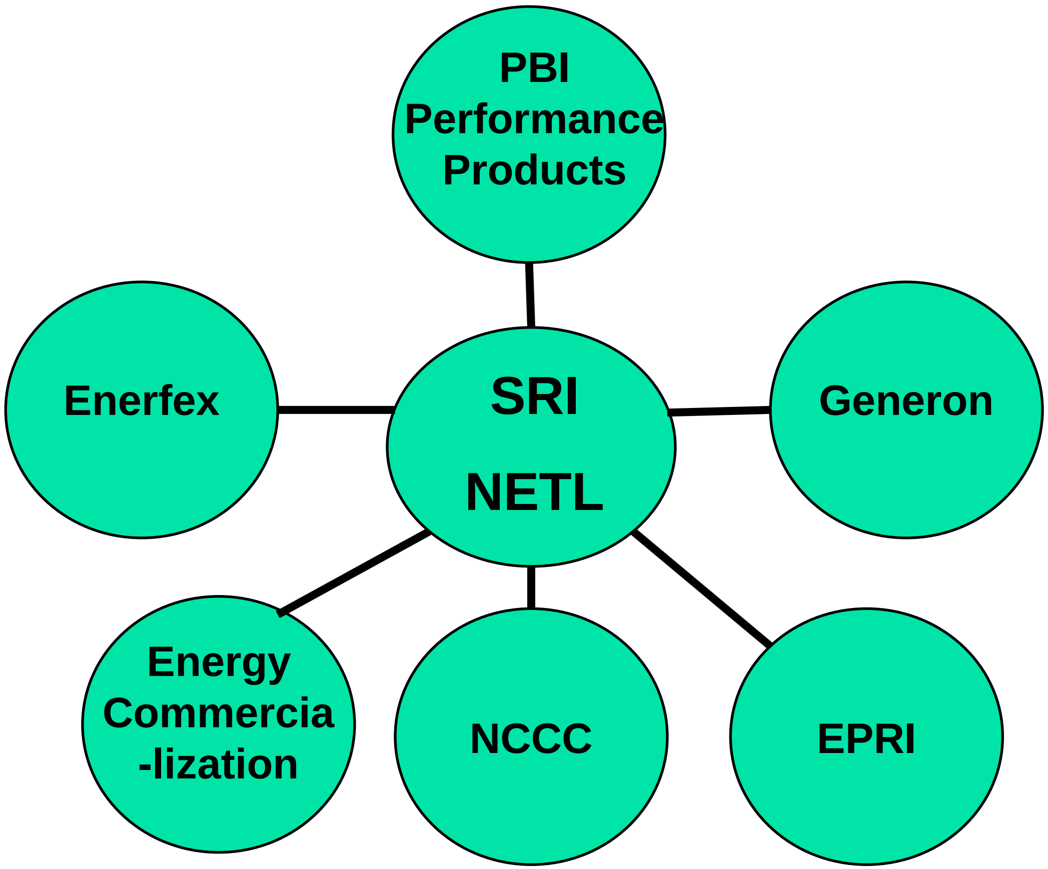
2014 NETL CO_2 Capture Technology Meeting

August 1, 2014 Pittsburgh, PA.

Project Overview

- Cooperative agreement grant with U.S. DOE-NETL (DE-FE0012965)
- Period of Performance:
  - Budget Period 1: 10-1-2013 through 7-31-2015 (Definitized on March 9, 2014)
  - Budget Period 2: 8-1-2015 through 10-30-2016
- Funding:
  - U.S.: Department of Energy: $2.25 million
  - Cost share: $0.56 million
  - Total: $2.81 million
- NETL Project Manager:
  - Ms. Elaine Everitt

Project Team



<u>SRI:</u>

PBI Membrane Fabrication Research;

Membrane Testing

<u>PBI Performance Products, Inc.</u>

PBI polymer Manufacturer

<u>Generon:</u>

Membrane Fabrication Scale-up;

Module Fabrication

<u>Enerfex:</u>

Membrane System Modeling

<u>Energy Commercialization</u>

Commercialization Analysis

<u>NCCC:</u>

Gasifier Facility Test Site

<u>EPRI:</u>

Electric Power Industry Perspective

<u>NETL:</u>

Funding and technology oversight

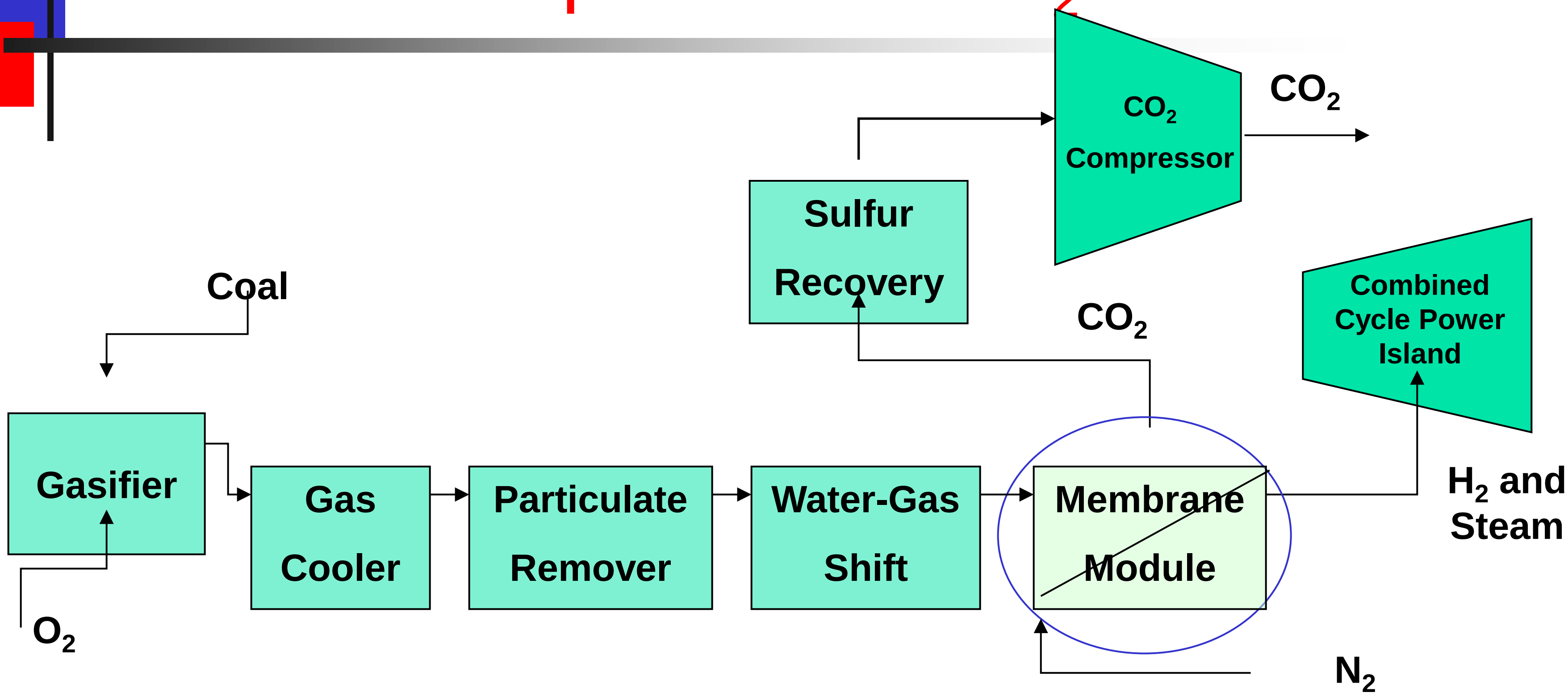
Project Objectives

- Primary Objectives:
  - To evaluate, at a bench-scale size, a technically and economically viable CO_2 capture system based on a high-temperature PBI polymer membrane separation system.
  - To optimize the process for integration of that system into an Integrated Gasification Combined Cycle (IGCC) plant.
- Specific Objectives
  - Collect laboratory data for separating hydrogen from simulated synthesis gas using PBI-based hollow fiber membranes.
  - Fabrication of membrane modules of 50 kWth equivalent of a shifted gas from an oxygen-blown gasifier using equipment of industrial relevance.
  - Collect design and steady-state performance data for membrane modules using syngas from an operating coal gasifier.
  - Transfer the membrane fabrication technology to an industrial firm that specializes in the manufacture of hollow fiber membranes.
  - Estimate the cost of CO_2 capture from precombustion gas streams.

Project Schedule

Task	Start Date	End Date	Cost $
BP1 and BP2	4/15/2013	10/31/2016	
Task 1.0 - Project Management and Planning	4/15/2014	7/31/2015	$153,237
Task 2-0: Establish Performance Database	4/15/2014	7/31/2014	$1,355,850
Subtask 2.1 - Generate Membrane Module for Testing	**7/1/2014**	**3/31/2015**	
Subtask 2.2 - Commission a 50 kWth Membrane Skid	**10/1/2014**	**12/30/2014**	
Subtask 2.3 - Generate Performance Database	**1/1/2015**	**7/30/2015**	
Subtask 2.4 - Modeling of the Membrane Performance	**8/1/2014**	**6/31/2015**	
Continuation Report Submission	**4/1/2015**	**4/30/2015**	
BP2: Field Testing of the Bench-Scale Unit	8/1/2015	10/31/2016	
Task 1.0 - Project Management and Planning	8/1/2015	10/31/2016	$103,489
Task 3.0 - Modification of the 50 kWth Test Unit for the Field Test	8/1/2015	11/1/2015	$369,487
Subtask 3.1 - Test Unit Modification	**8/15/2015**	**10/31/2015**	
Subtask 3.2 - Test unit HazOp and Safety Review	**9/15/2015**	**10/15/2015**	
Task 4.0 - Operation of the 50 kWth Test Unit	11/1/2015	10/1/2016	**$463,807**
Subtask 4.1 - Test Unit Start-up	**11/1/2015**	**12/30/2015**	
Subtask 4.2 - Development of a Test Plan	**11/1/2015**	**12/30/2015**	
Subtask 4.3 - Parametric Testing	**1/1/2016**	**6/1/2016**	
Subtask 4.4 - Long Duration Testing	**7/1/2016**	**9/1/2016**	
Task 5.0-Conduct Process Design and Engineering Study	4/1/2015	7/1/2016	$130,604
Task 6.0 - Conduct Environmental and Economic Analyses	7/1/2015	10/1/2016	$192,838
Task 7.0 - Dismantling and Removing the Slipstream Test Unit	10/15/2016	10/30/2016	$44,190
Final Report	**10/15/1026**	**10/30/2016**	

Why the High Temperature Membrane Separation of CO_2?



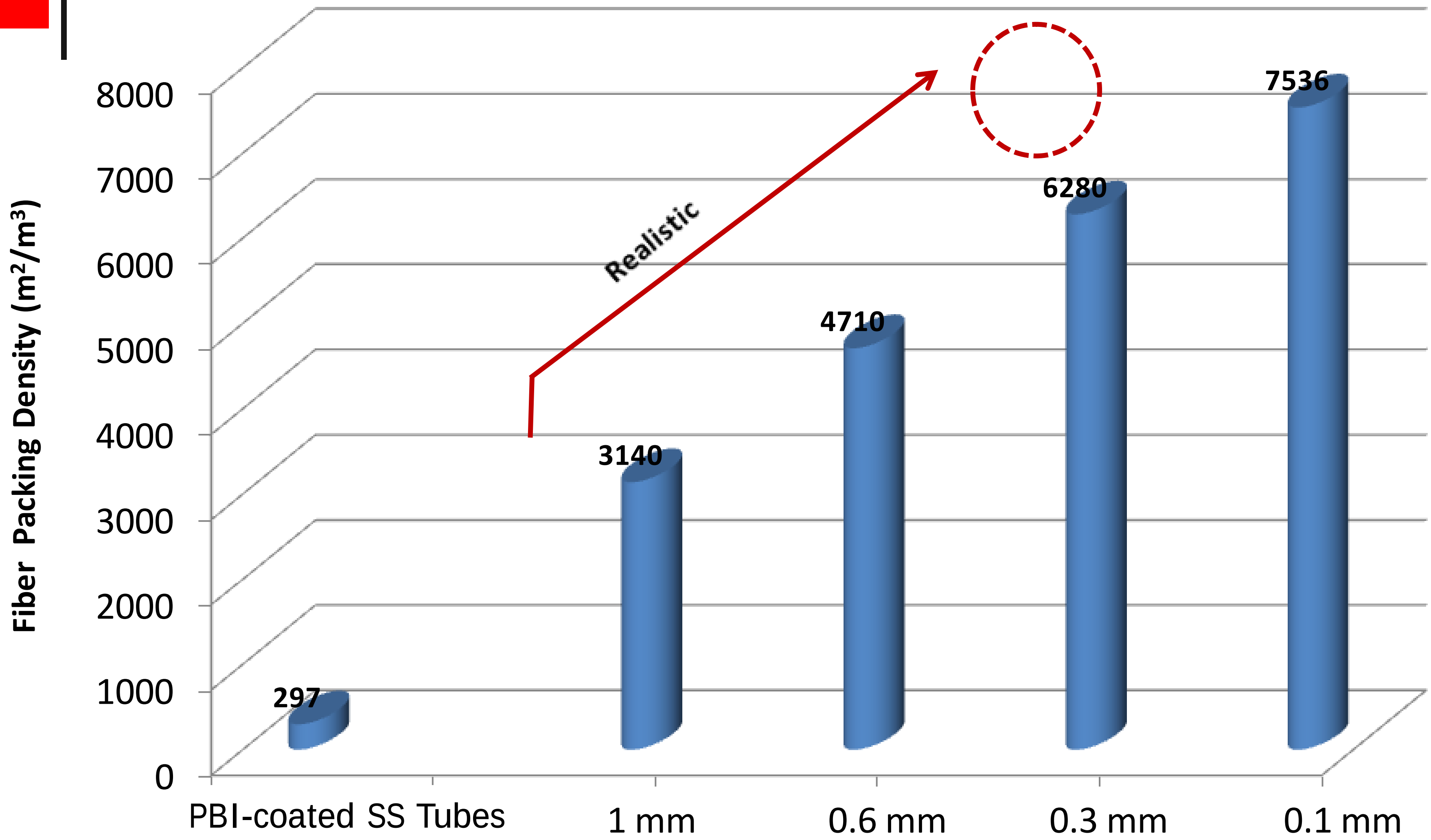
Characteristics of PBI Membranes

- PBI has attractive combination of throughput and degree of separation
- Thermally stable up to 450°C and sulfur tolerant
- Tested for 1000 h at 210°C by at SRI

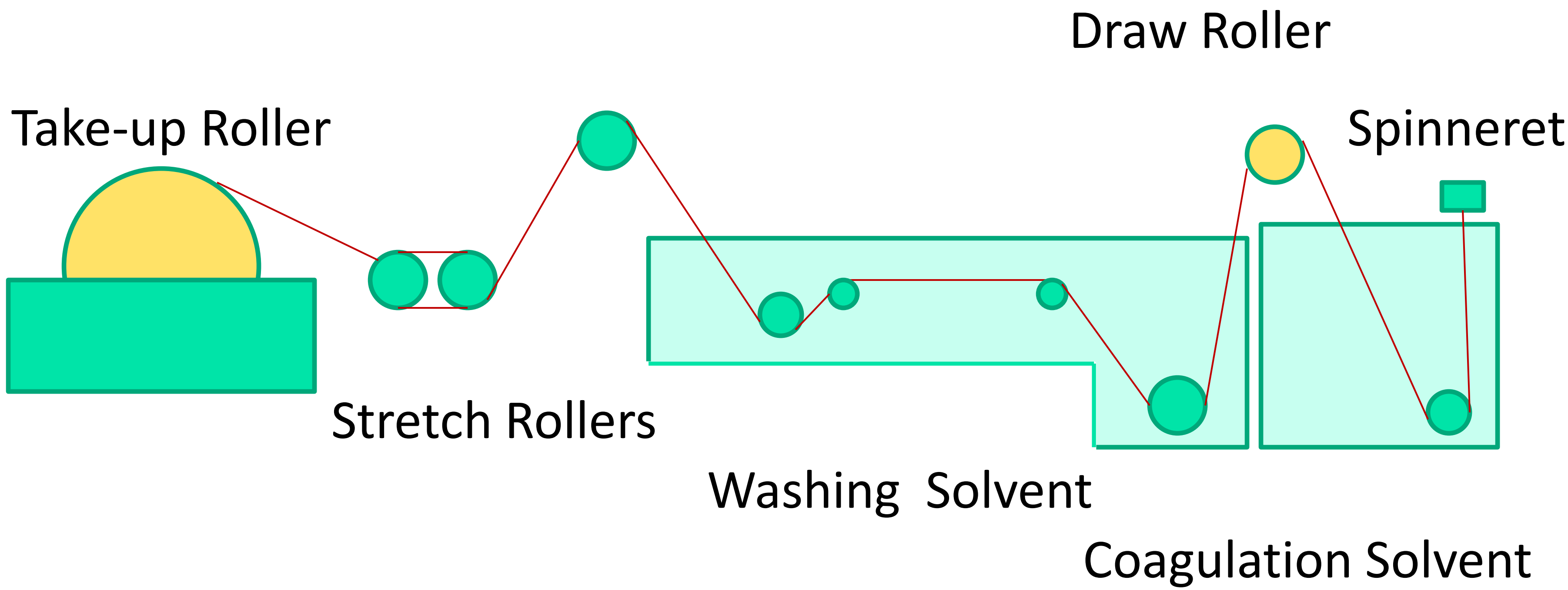
Advantages of Membrane-Based Separation

- No need to cool syngas; Increased mass flow to gas turbine
- Reduced CO_2 compression costs
- Emission free, i.e. no solvents
- Decreased capital costs
- Low maintenance

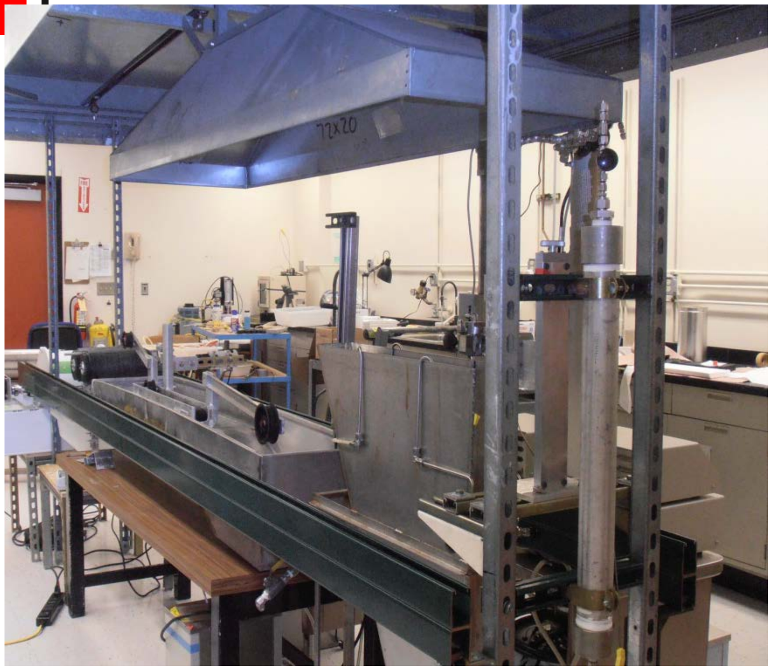
A Significant Size Advantage of Hollow Fiber Membranes

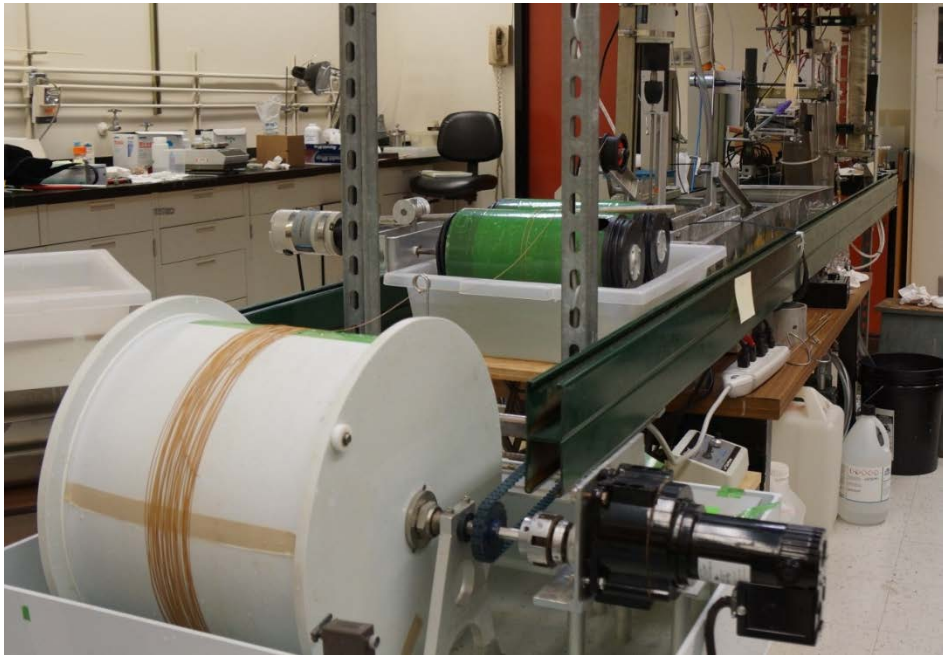


Bench-Scale Spinning Line at SRI

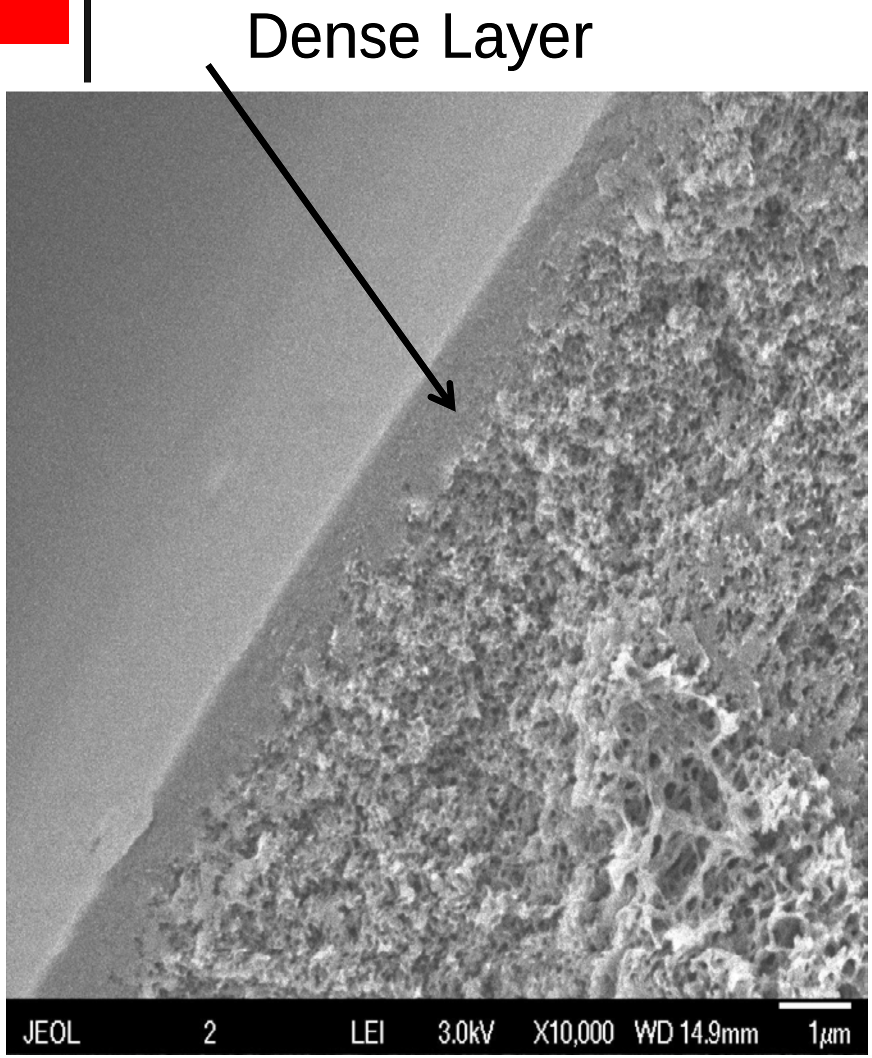


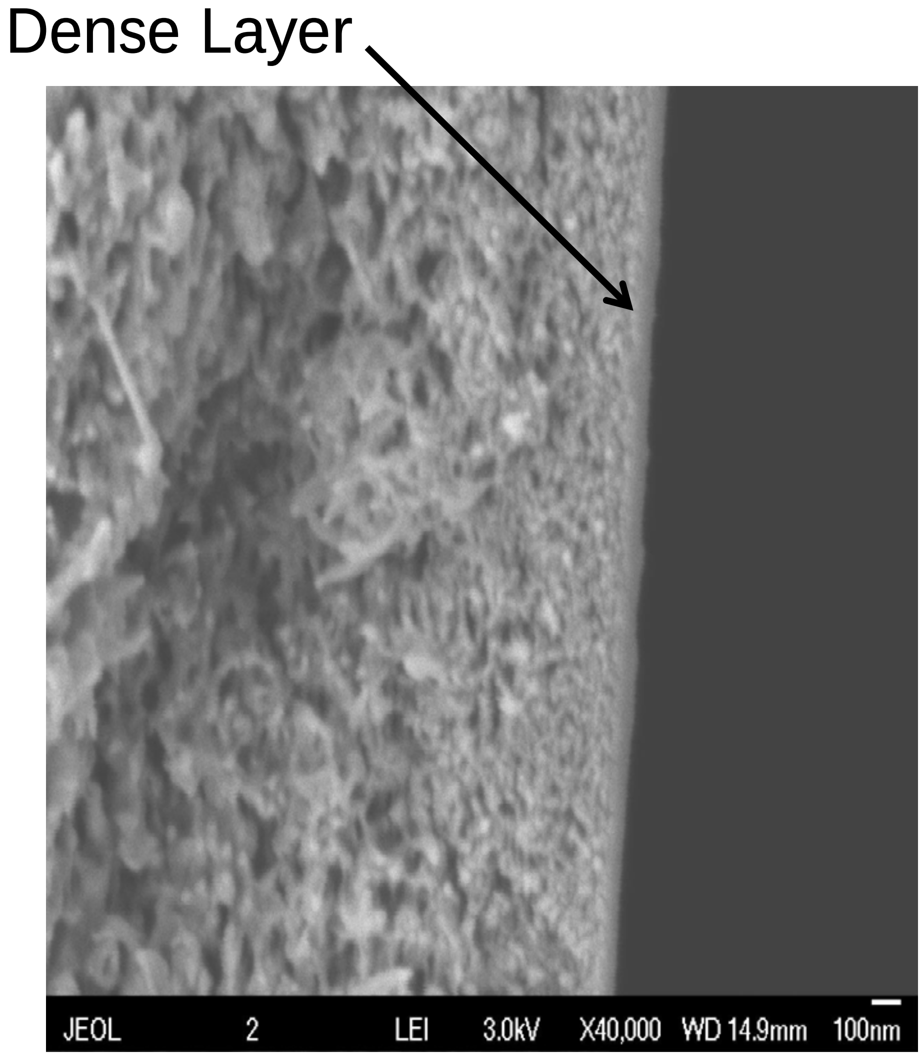
Views of Spinning Line at SRI





Dense Layer Optimization

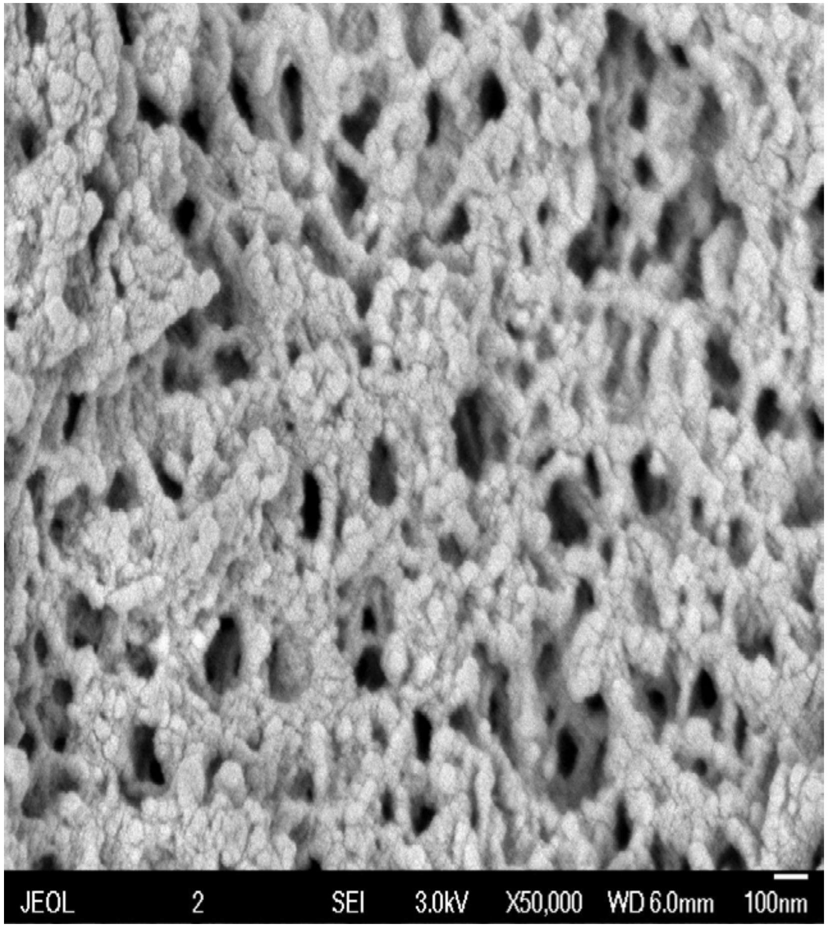




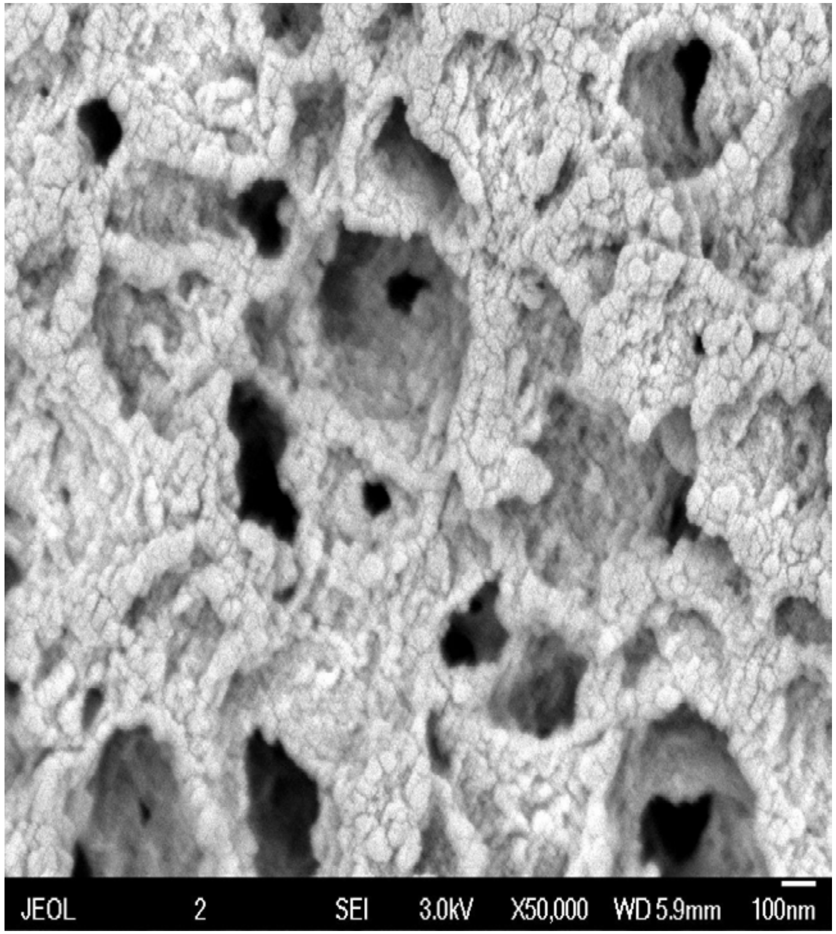
Dense layer =~ 1 micron

Dense layer = ~0.1 micron

Support Pore Structure Optimization

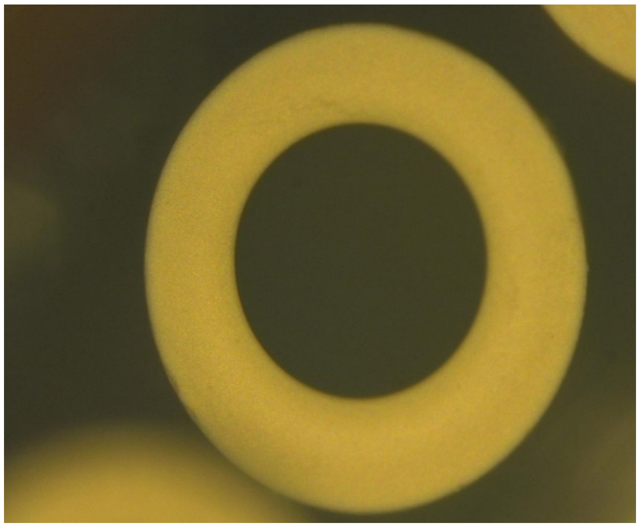


50- 200 nm open pores



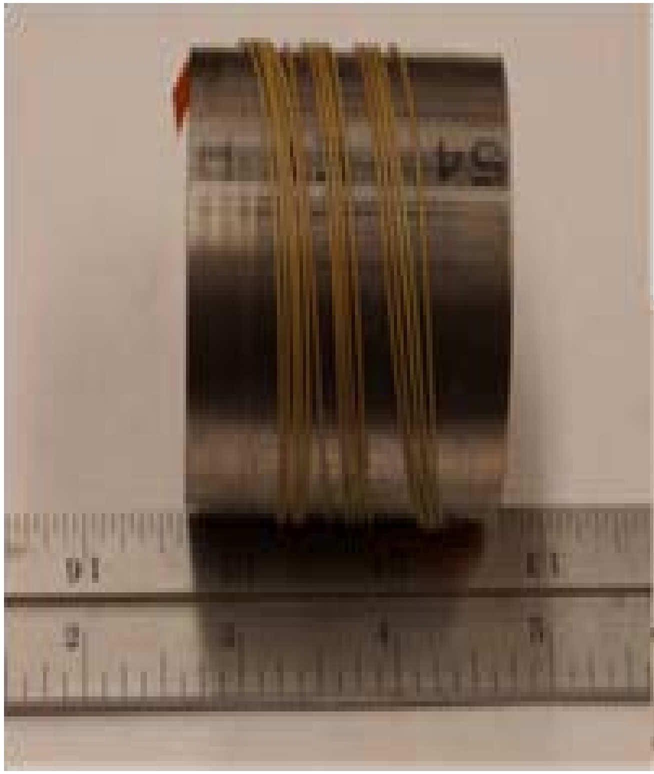
100 - 500 nm open pores

Fabricated Hollow Fibers



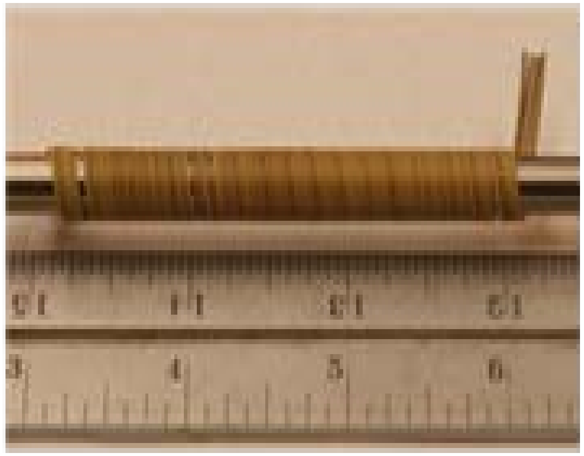
Improving Fiber Toughness

Fiber winding on several size mandrels



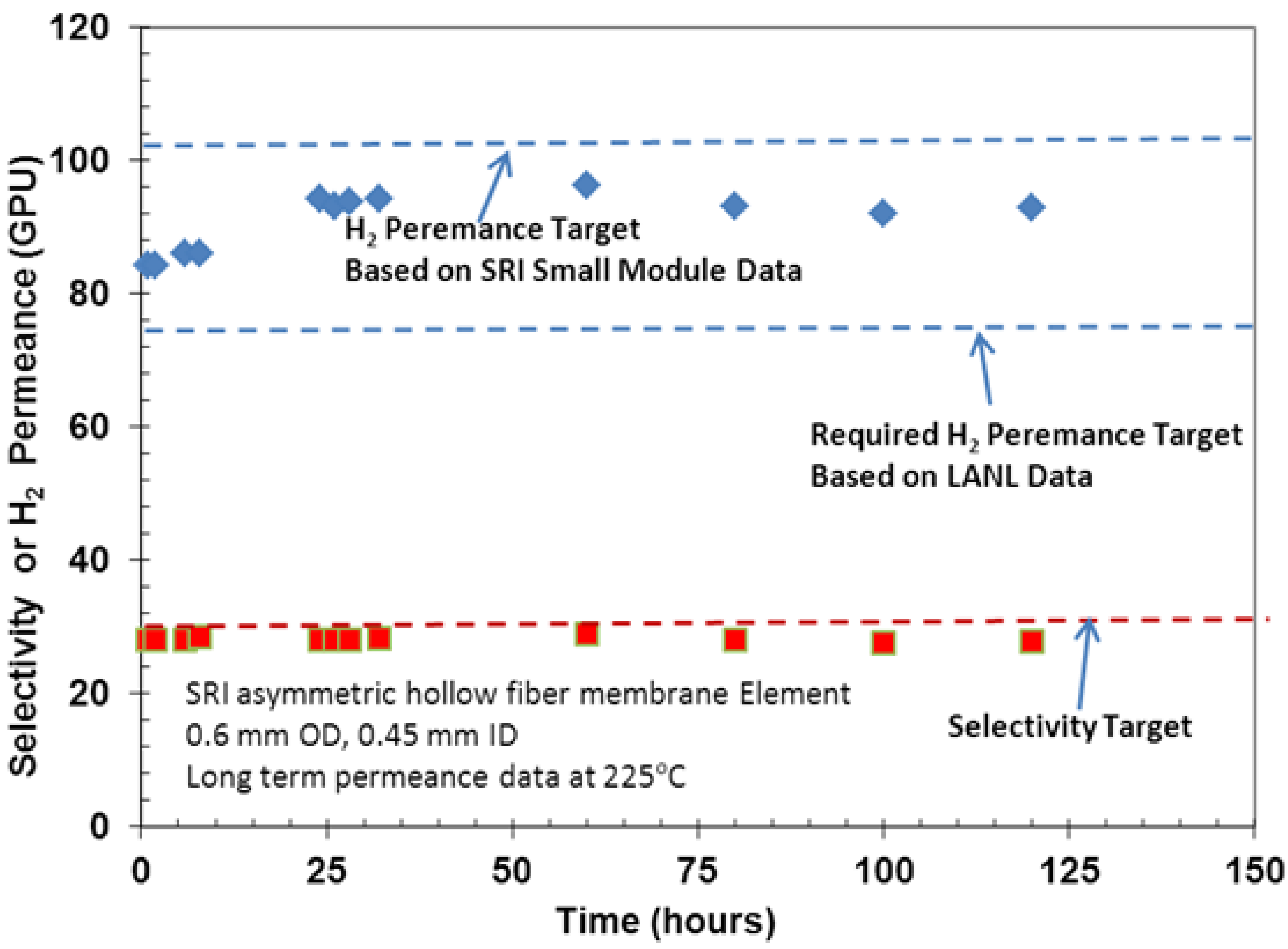
2.5-in diameter

0.75-in diameter

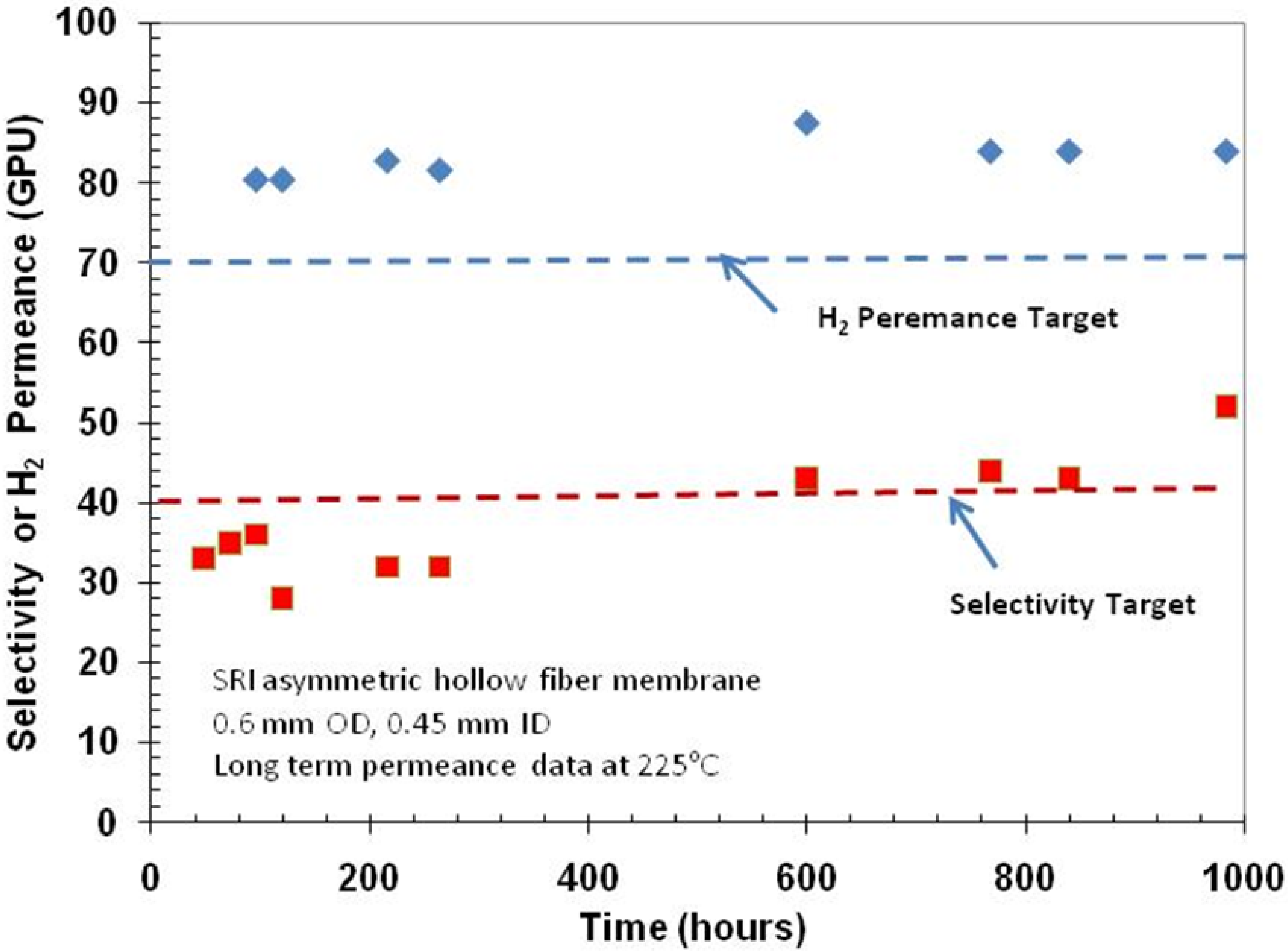


0.25-in diameter tube

H_2/CO_2 Selectivity of and H_2 Permeance of Fibers at 225°C



Long-Term Testing



Preliminary Economic Analysis: PBI Approaches the DOE Goals

CO_2 capture: 3.3 Million tonnes/yr.

		Project Cases			
	Units	No Capture	CO_2 and H_2S Capture w/Selexol	CO_2 Capture w/PBI & H_2S w/Selexol	CO_2 Capture w/PBI no H_2S removal
Power Production @100% Capacity	**GWh/yr**	5,455	4,461	4,943	5,035
Power Plant Capacity	**cents / kWh**	4.50	6.19	5.49	5.02
Power Plant Fuel	**cents / kWh**	1.90	2.47	2.31	2.26
Variable Plant O&M	**cents / kWh**	0.78	1.00	0.92	0.91
Fixed Plant O&M	**cents / kWh**	0.60	0.79	0.71	0.70
Power Plant Total	**cents / kWh**	7.78	10.45	9.43	8.89
Cost of Electricity* (COE)	**cents / kWh**	**7.78**	**10.45**	**9.43**	**8.89**
Increase in COE (over no capture)	**%**	***n/a***	***34%***	***21%***	***14%***

*** Separation and Capture Only**

Plant operating life: 30 years; Capacity Factor: 80%; Capital charge factor: 17.5%

Capture with Selexol uses slightly different parameters than NETL cases.

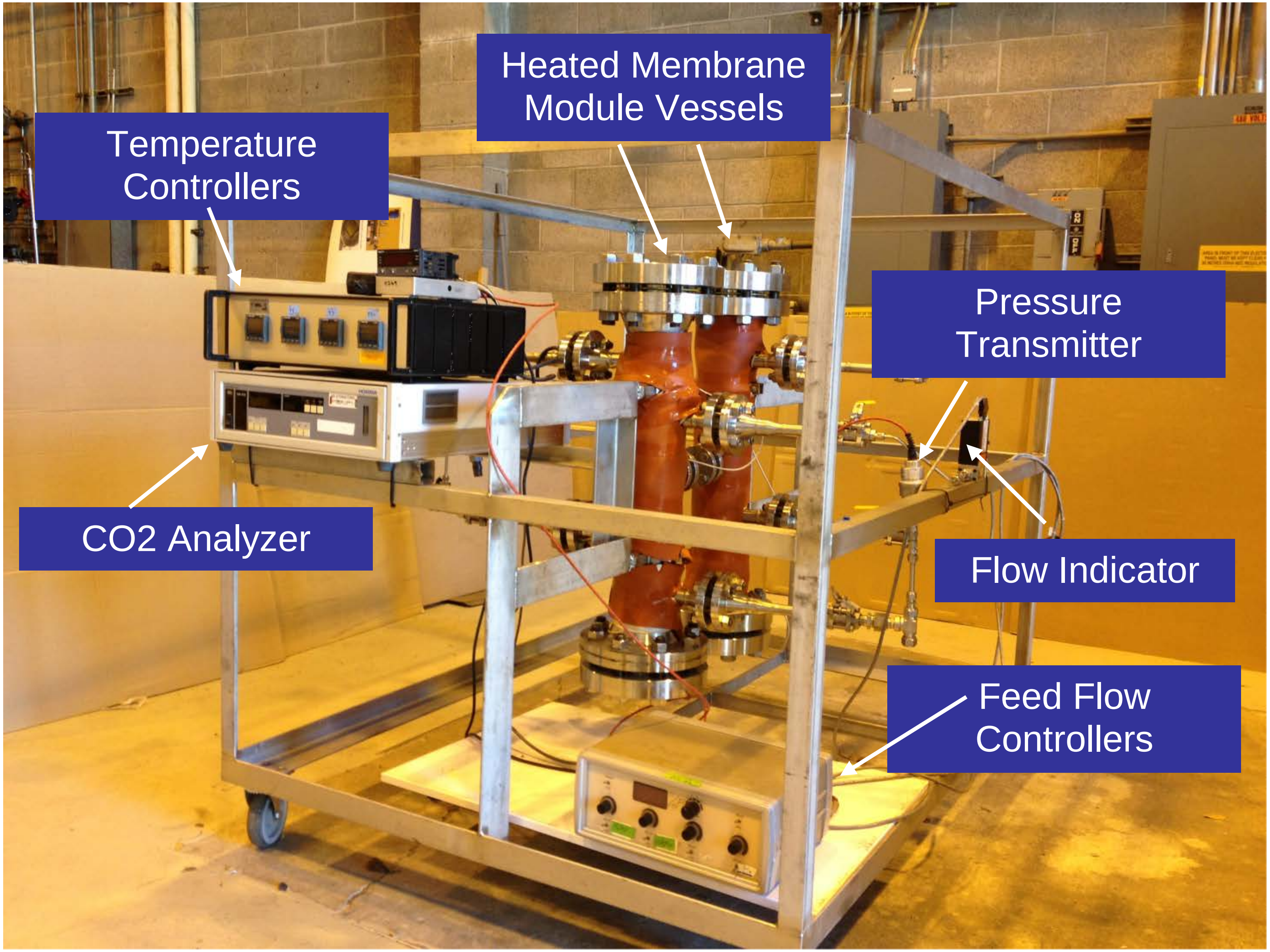
BP 1: Fabrication of PBI Hollow Fiber membrane for Bench-Scale Testing

- Fabricate PBI hollow fiber modules for tests with a bench-scale system.
- Engage the expertise of Generon that specializes in the manufacturer of hollow fiber membranes.
- Transfer technical know-how of PBI fiber spinning to Generon.
- Evaluate, at a bench-scale level, the thickness of the selective and support layer as they affect the separation of the gas components.
- Evaluate seal integrity at the high temperature and pressure of shifted syngas.
- Use the test results to model the membrane performance.

50 kWth Membrane Skid

- An existing 50 kW_{th} bench-scale membrane skid will be modified to collect performance data over a range of conditions relevant for the proposed field tests.
- Fabricated under a prior DOE-funded project.
- Test at SRI facilities using simulated gas representative of a water-gas shifted syngas stream.

Photograph of the Skid for PBI Membrane Testing



Generate Performance Database

- Preliminary scoping tests will be conducted with a sub-scale module to:
  - Provide data for the optimization of the fiber spinning and module assembly processes.
- Evaluate the effectiveness of the membrane:
  - Potting material, the gas permeance, and selectivity of the PBI-based membranes.
- The 50 kWth membrane skid will be operated:
  - Temperatures up to 225°C, pressures up to 450 psig, and simulated syngas flow rates up to 1000 scfh.
- Simulated syngas tests will include:
  - Gas mixtures containing $H_2/CO_2/H_2O/CO$ with and without H_2S.

Budget Period 2 Tasks

- Task 3: Modification of the 50 kWth Test Unit for the Field Test
  - 3.1: Test Unit Modification
  - 3.2: Test unit HazOp and Safety Review
- Task 4: Operation of the 50 kWth Test Unit
  - 4.1: Test Unit Start-up
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- Task 7: Dismantling and Removing the Slipstream Test Unit

Acknowledgement

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- National Carbon Capture Center: Frank Morton
- EPRI: Jeffrey Phillips
- DOE-NETL
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