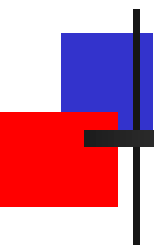


Development of a Precombustion CO₂ Capture Process Using High-Temperature PBI Hollow-Fiber Membranes

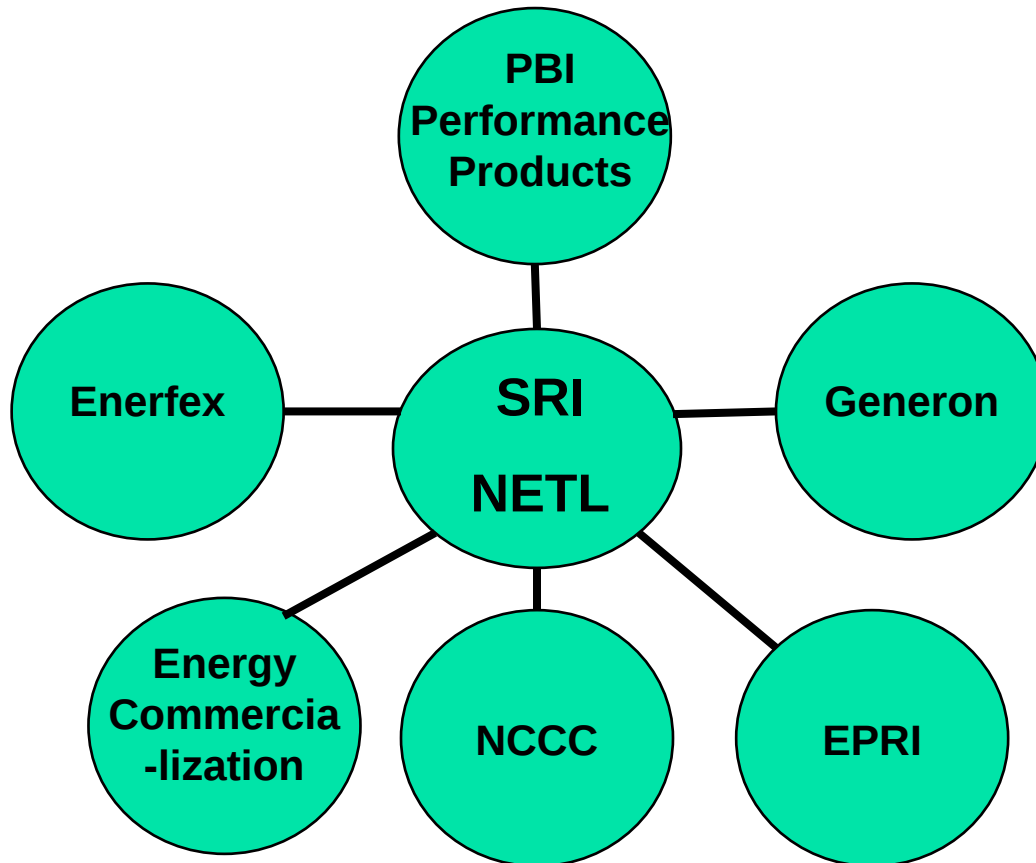
2014 NETL CO₂ Capture Technology Meeting
August 1, 2014 Pittsburgh, PA.



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



SRI:

PBI Membrane Fabrication Research;

Membrane Testing

PBI Performance Products, Inc.

PBI polymer Manufacturer

Generon:

Membrane Fabrication Scale-up;
Module Fabrication

Enerfex:

Membrane System Modeling

Energy Commercialization

Commercialization Analysis

NCCC:

Gasifier Facility Test Site

EPRI:

Electric Power Industry Perspective

NETL:

Funding and technology oversight

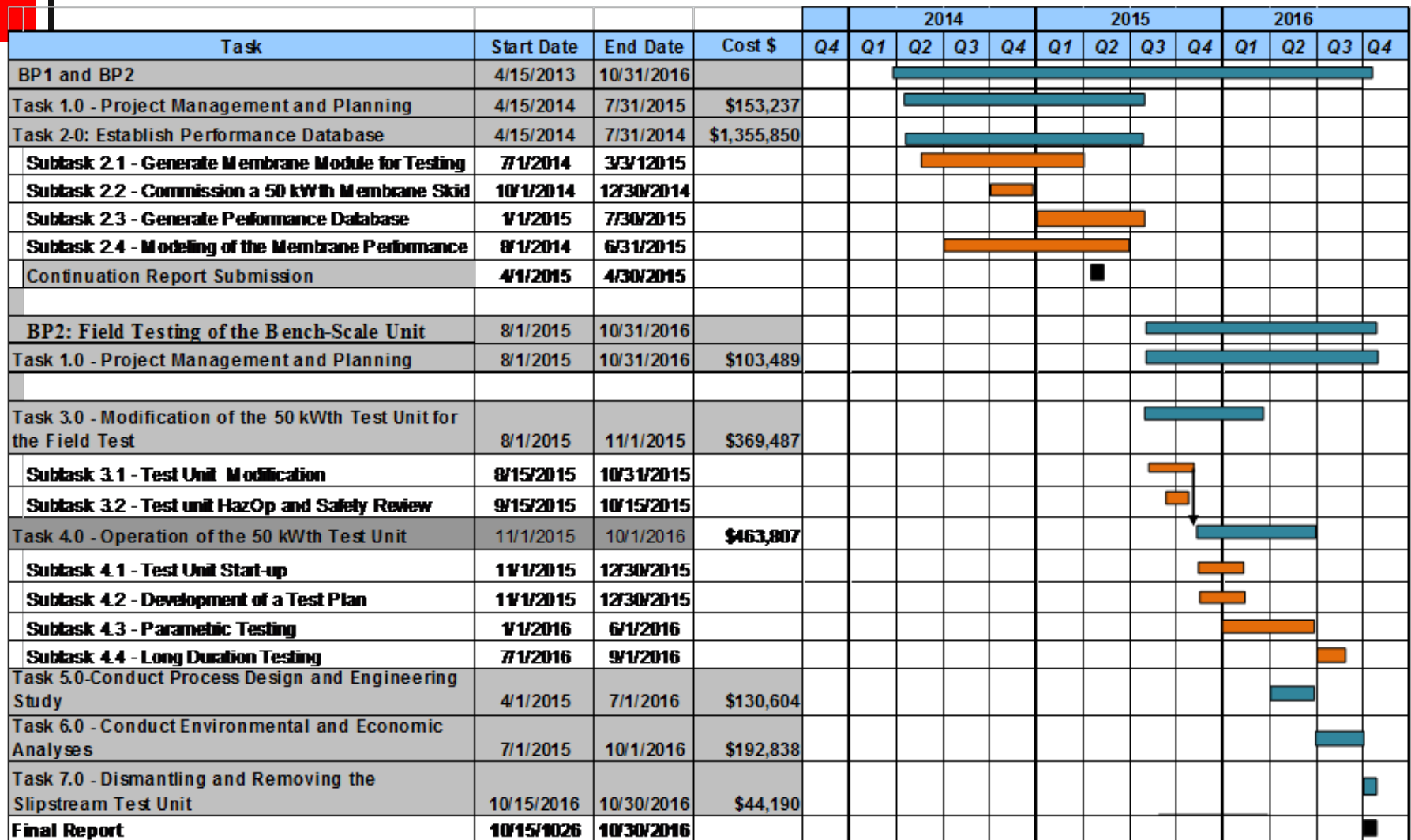
Project Objectives

■ Primary Objectives:

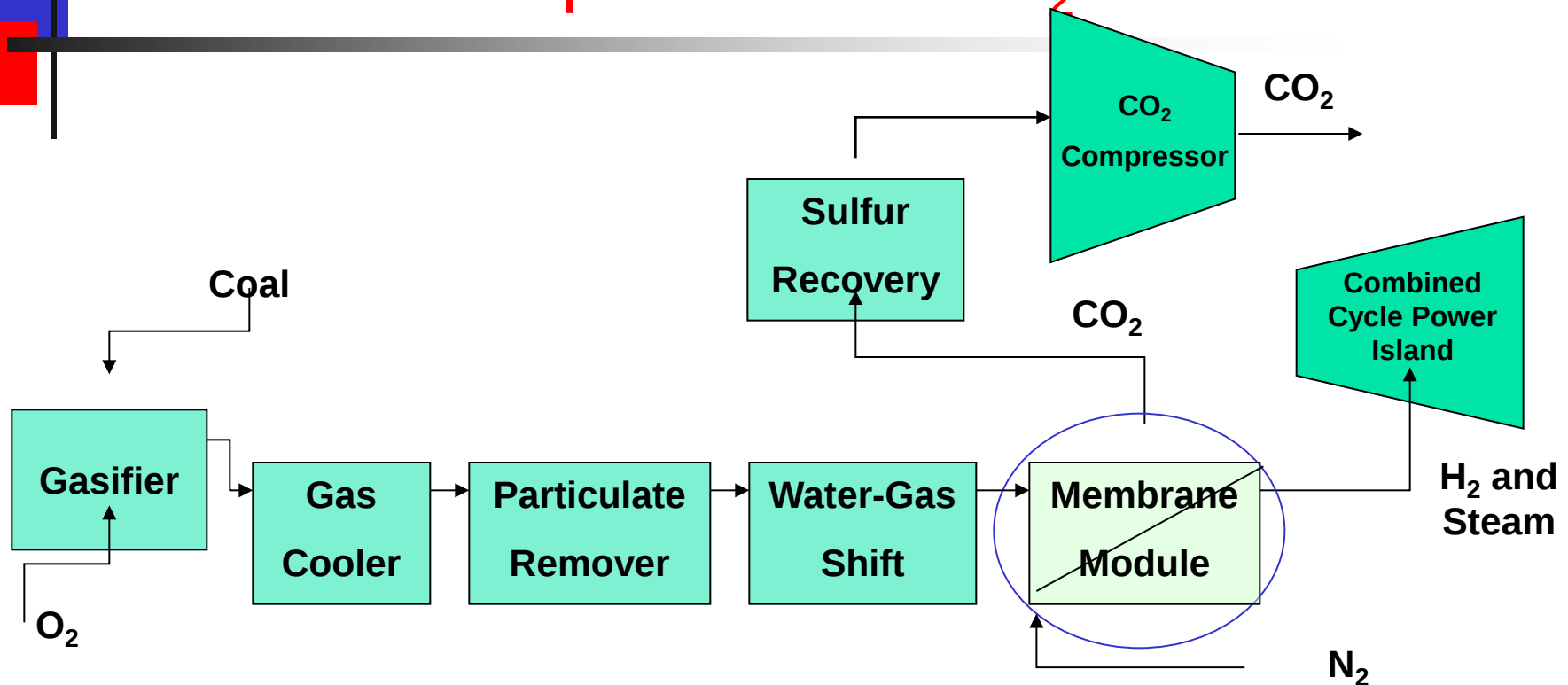
- To evaluate, at a bench-scale size, a technically and economically viable CO₂ capture system based on a high-temperature PBI polymer membrane separation system.
- To optimize the process for integration of that system into an Integrated Gasification Combined Cycle (IGCC) plant.

■ 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 CO₂ capture from precombustion gas streams.



Why the High Temperature Membrane Separation of CO₂?



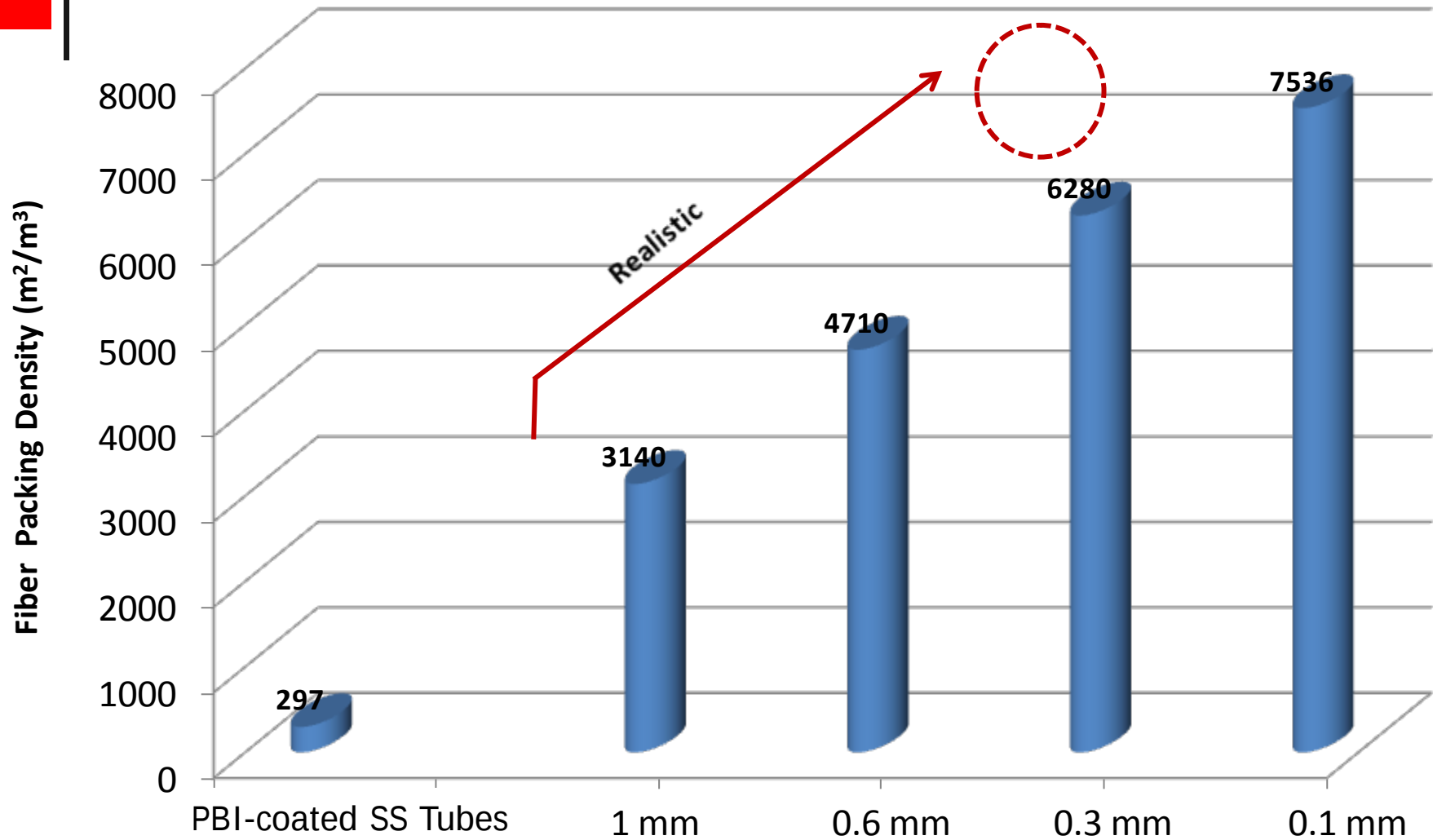
Characteristics of PBI Membranes

- 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

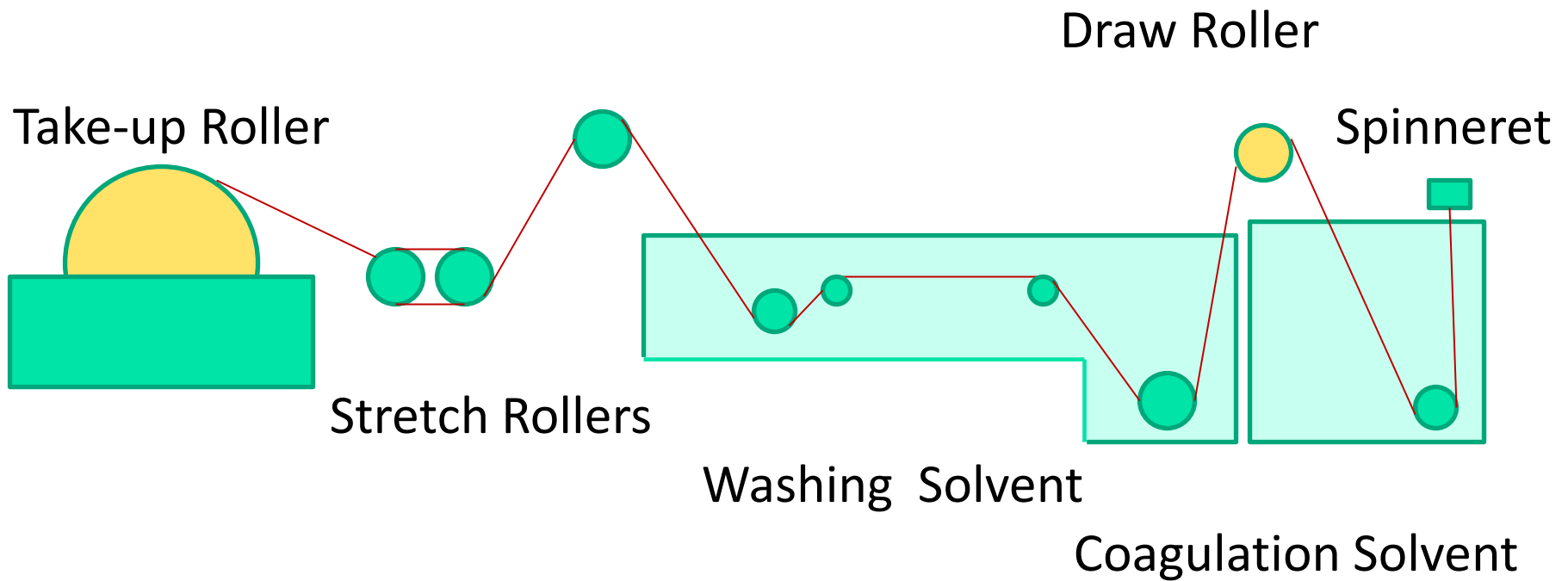
Advantages of Membrane-Based Separation

- No need to cool syngas; Increased mass flow to gas turbine
- Reduced CO₂ compression costs
- Emission free, i.e. no solvents
- Decreased capital costs
- Low maintenance

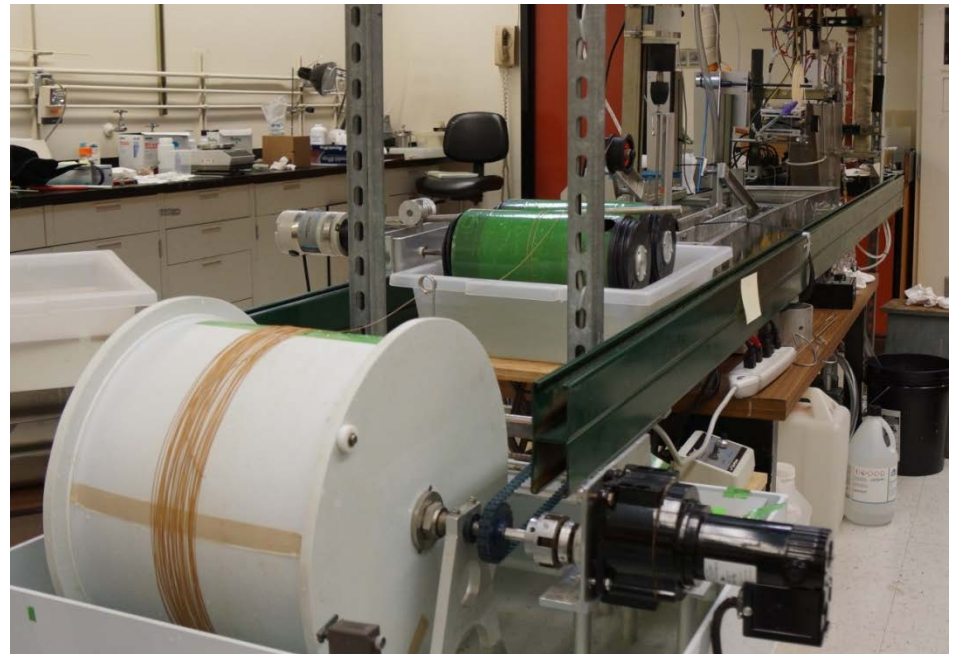
A Significant Size Advantage of Hollow Fiber Membranes



Bench-Scale Spinning Line at SRI

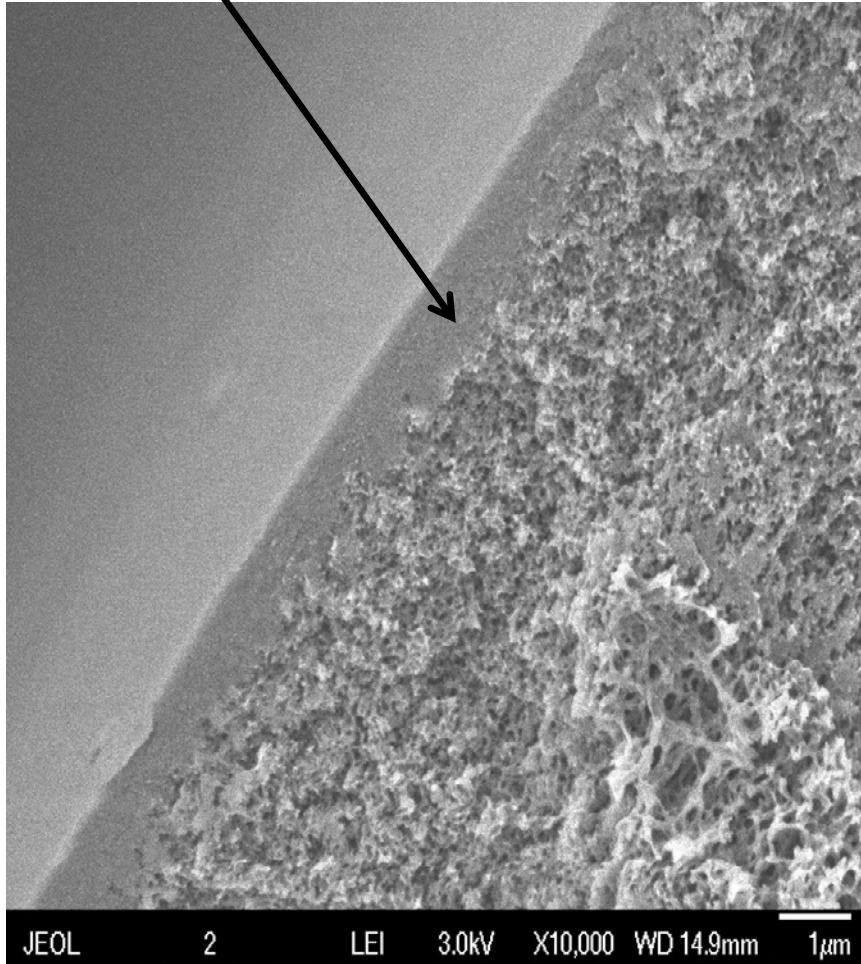


Views of Spinning Line at SRI



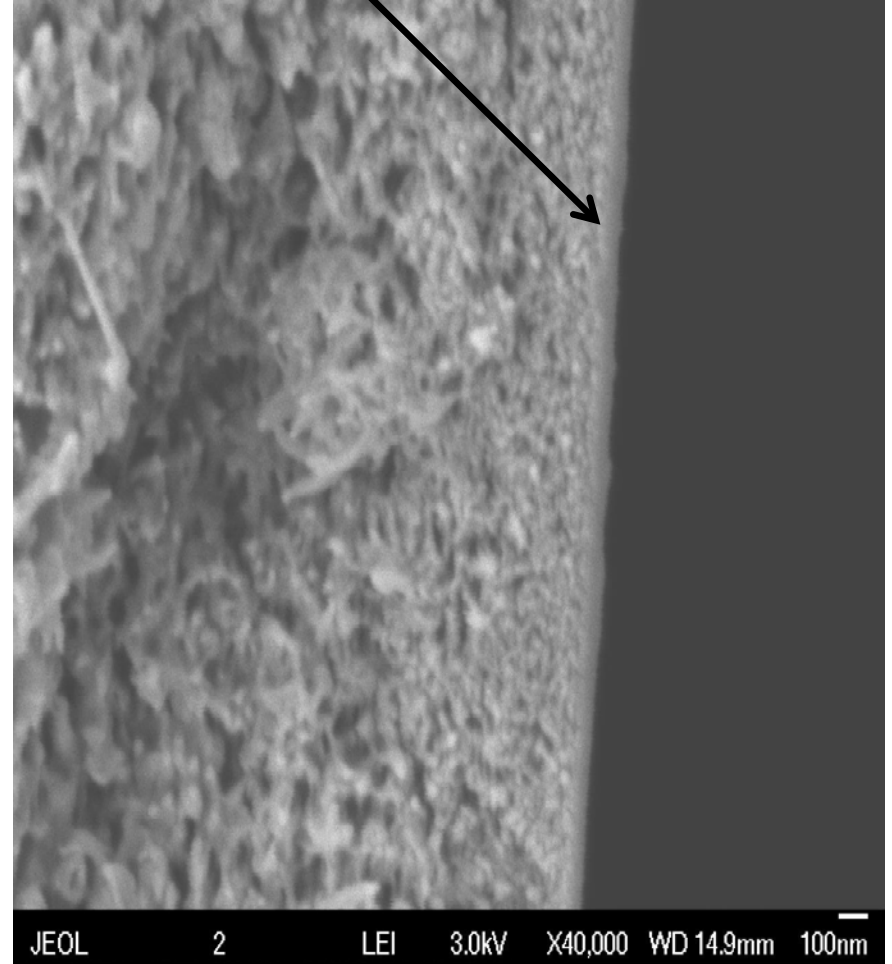
Dense Layer Optimization

Dense Layer



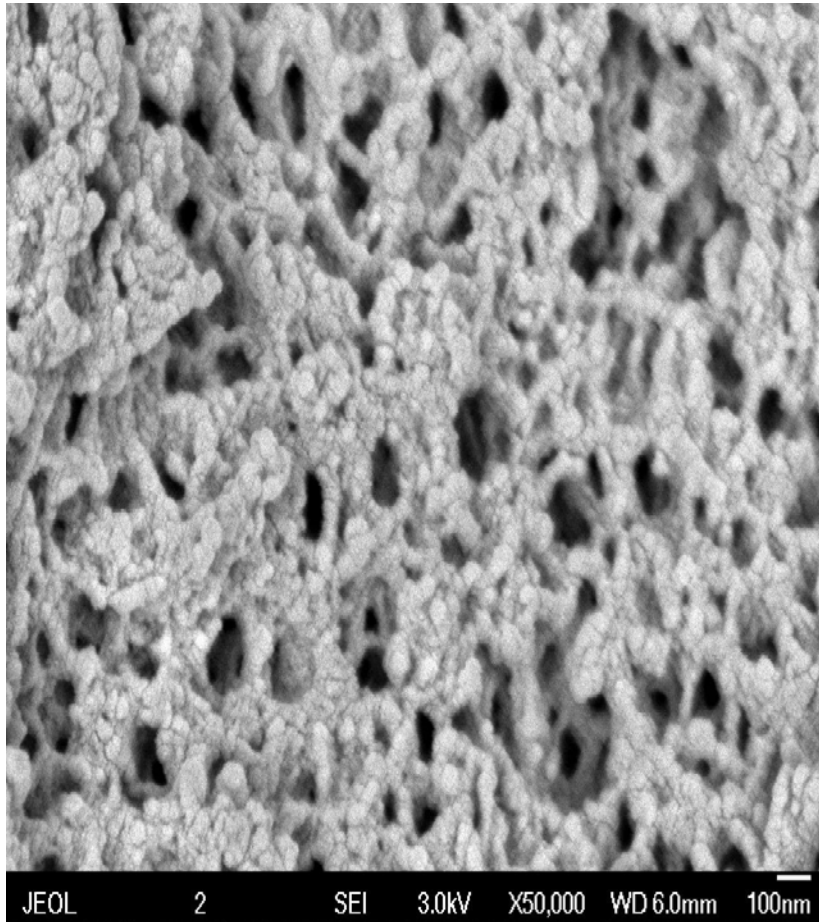
Dense layer = ~ 1 micron

Dense Layer

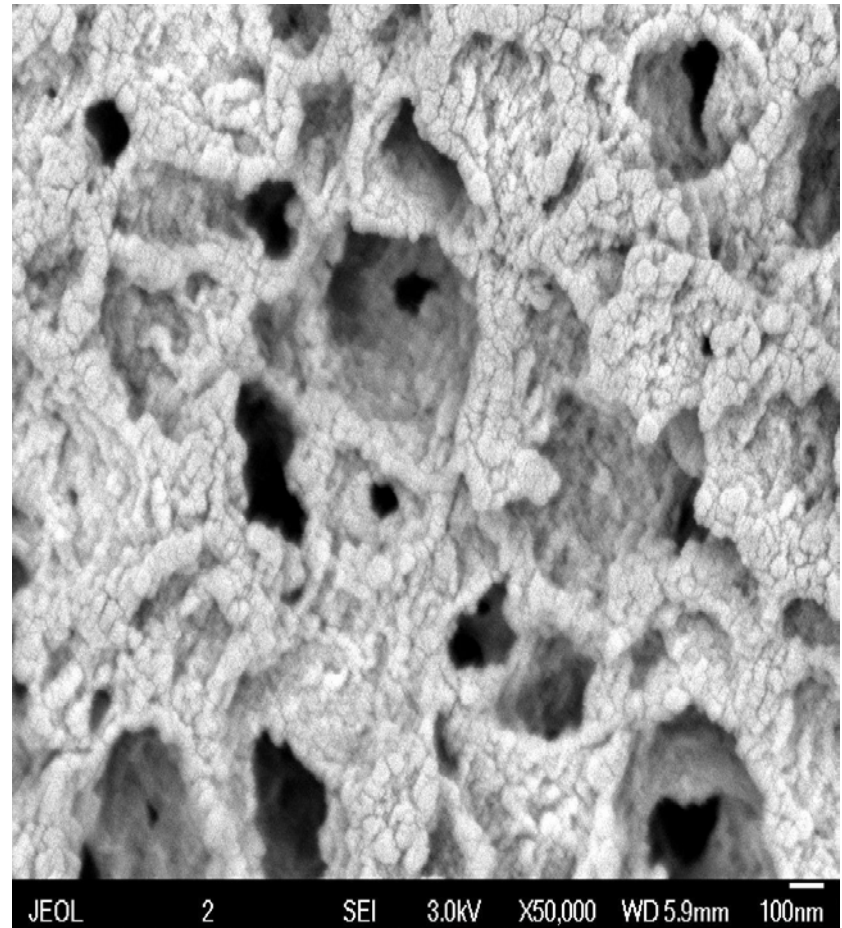


Dense layer = ~0.1 micron

Support Pore Structure Optimization

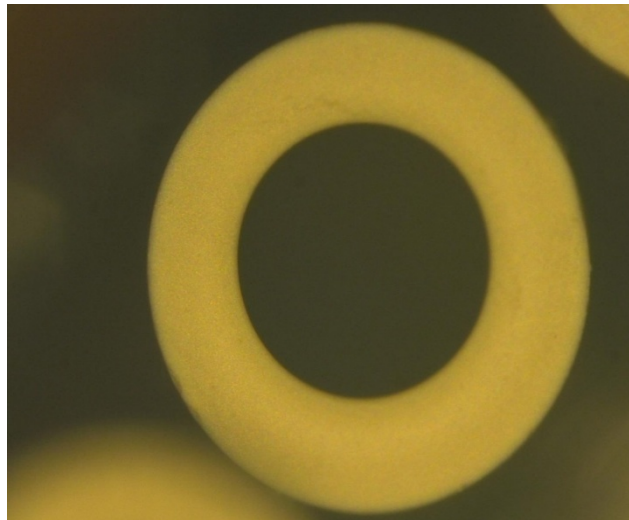


50- 200 nm open pores



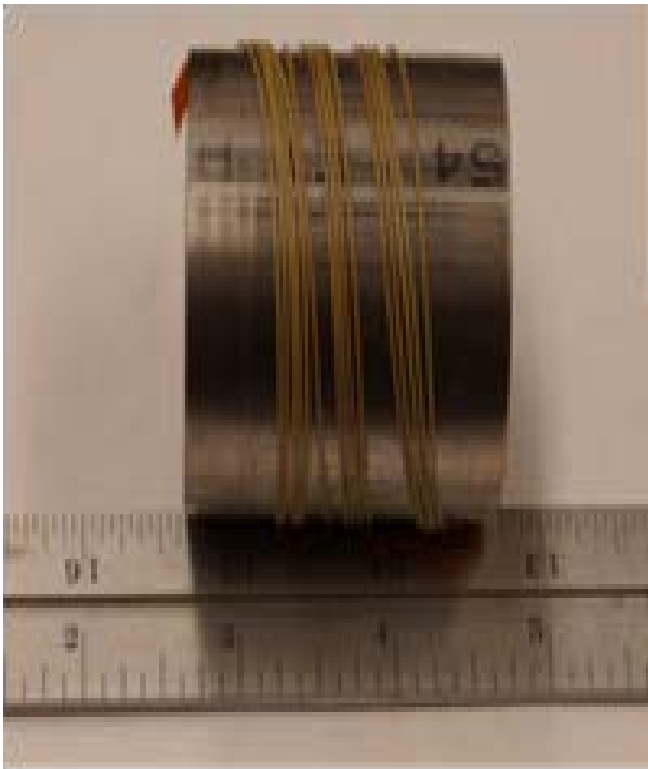
100 - 500 nm open pores

Fabricated Hollow Fibers



Improving Fiber Toughness

Fiber winding on several size mandrels



2.5-in diameter

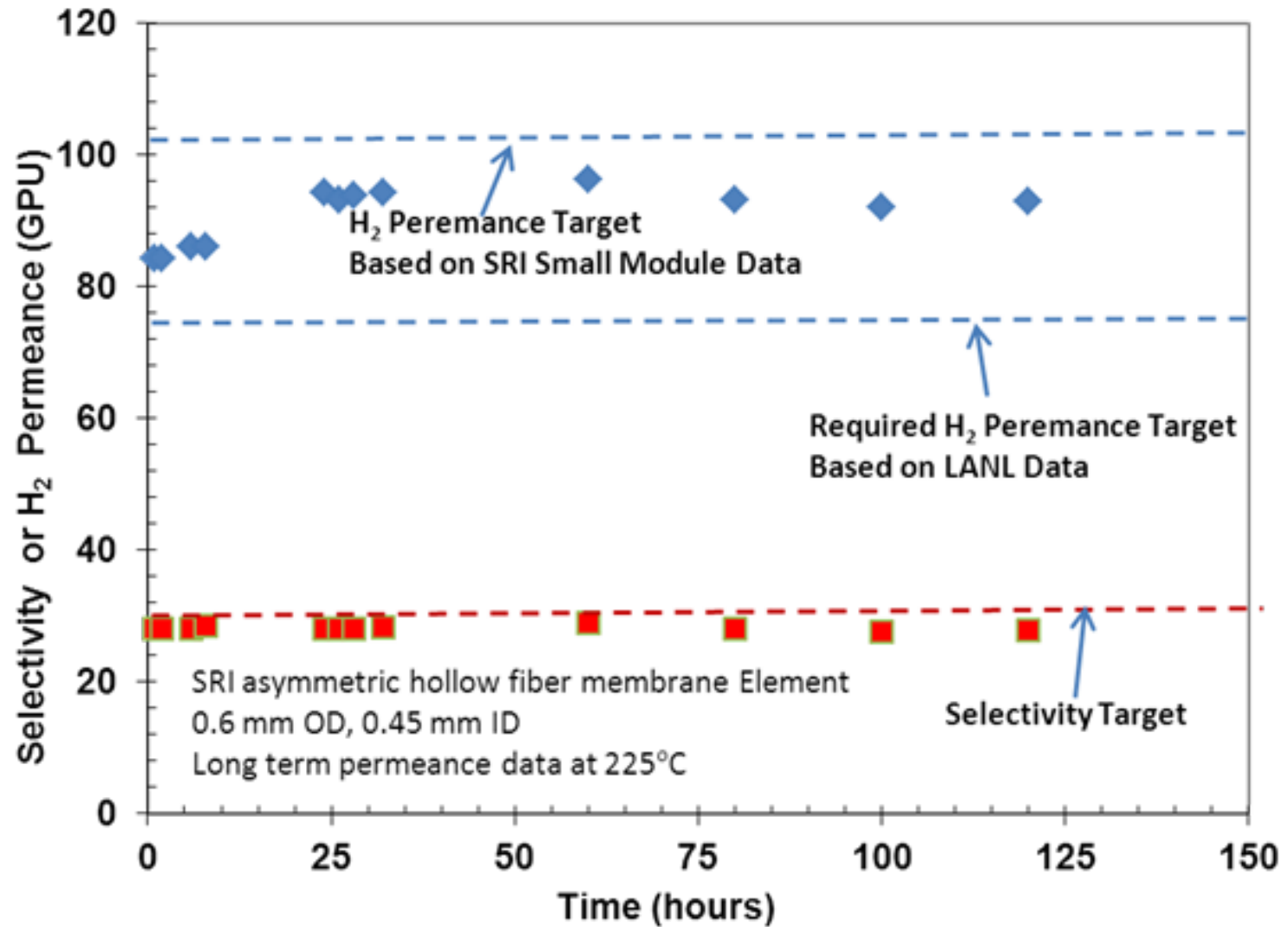


0.75-in diameter

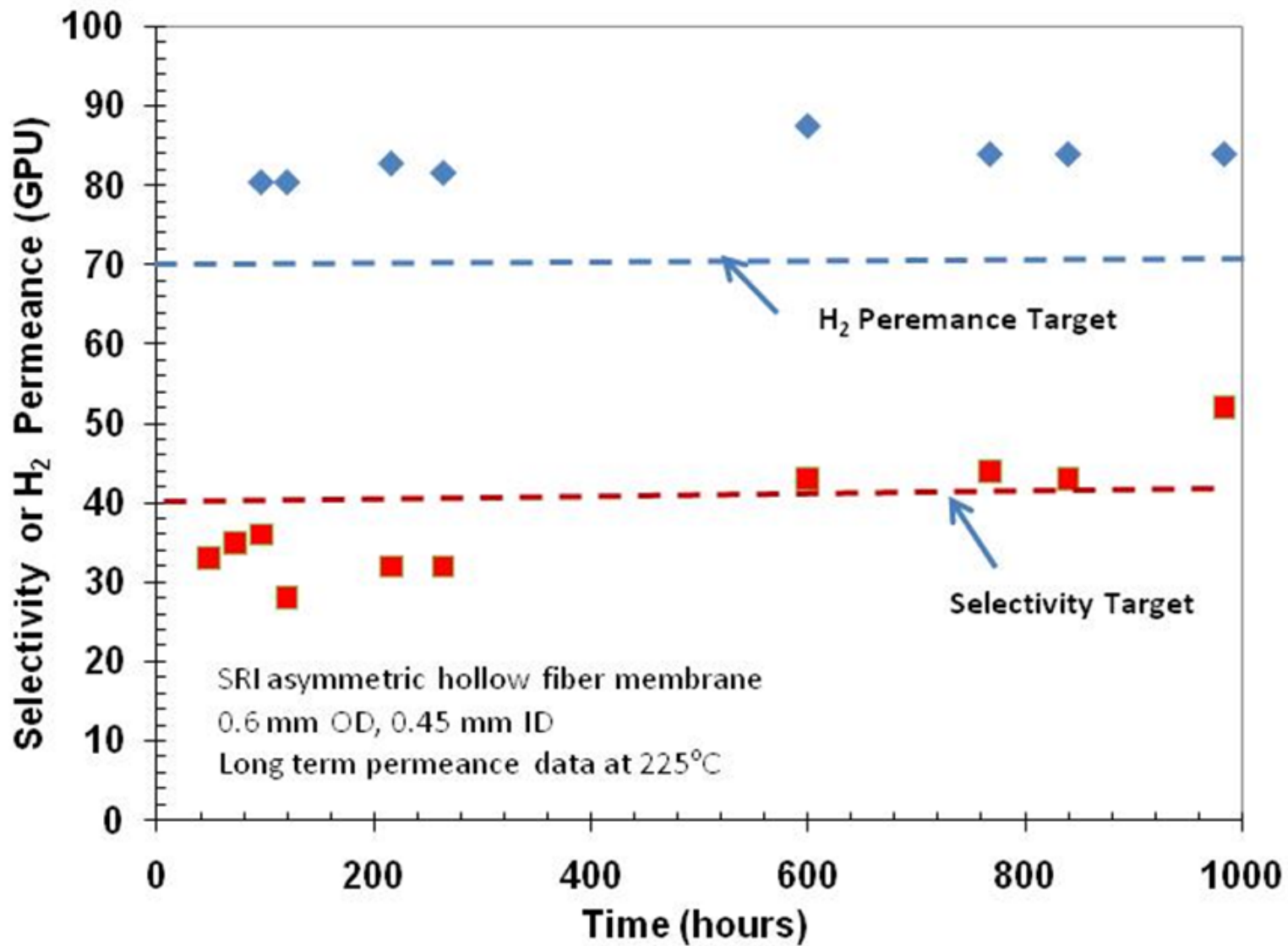


0.25-in diameter tube

H₂/CO₂ Selectivity of and H₂ Permeance of Fibers at 225°C



Long-Term Testing



Preliminary Economic Analysis: PBI Approaches the DOE Goals

CO₂ capture: 3.3 Million tonnes/yr.

		Project Cases			
			CO ₂ and H ₂ S Capture w/Selexol	CO ₂ Capture w/PBI & H ₂ S w/Selexol	CO ₂ Capture w/PBI no H ₂ S removal
	Units	No Capture			
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%

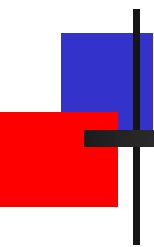
** Separation and Capture Only*

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

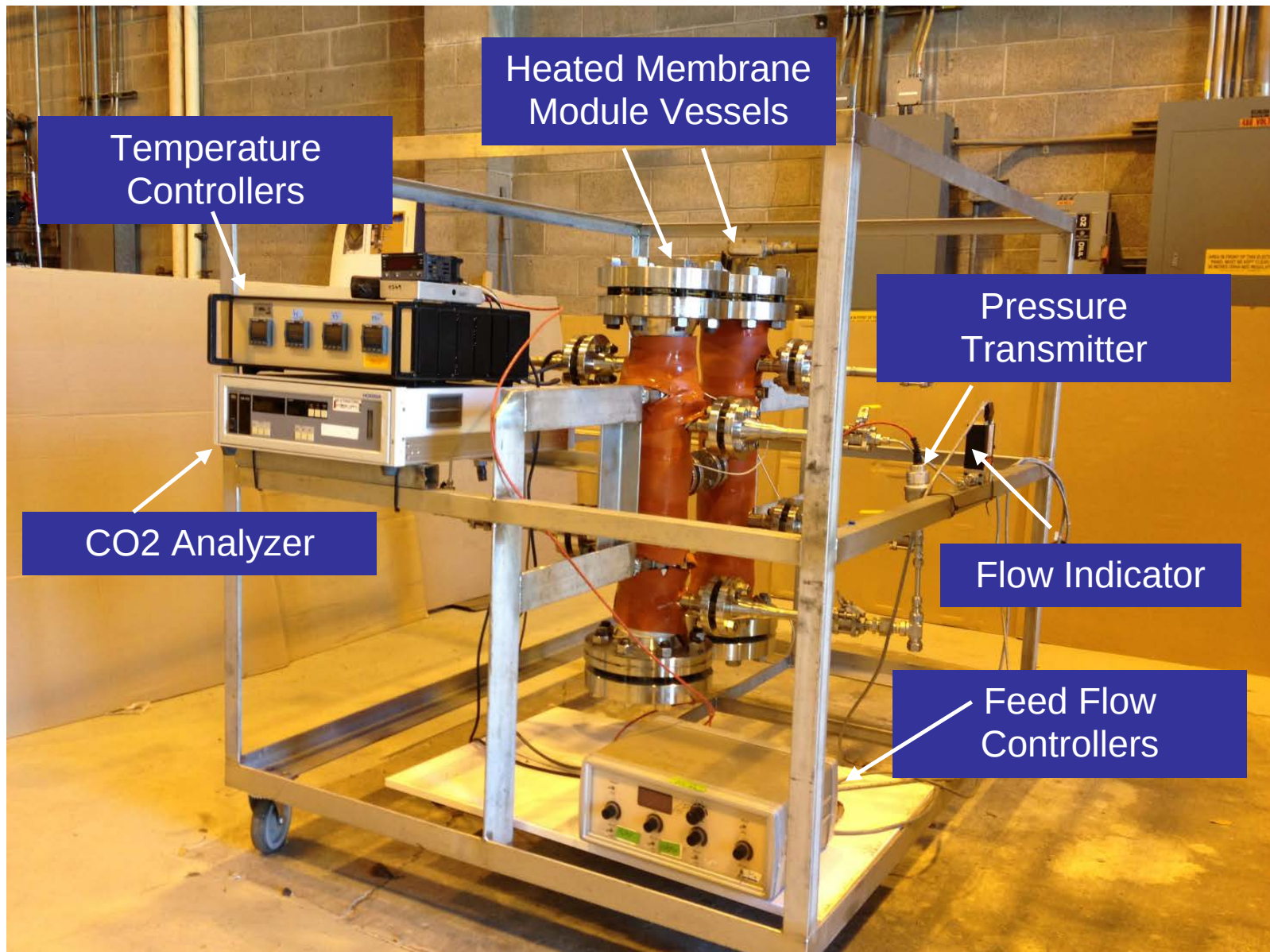
- Fabricate PBI hollow fiber modules for tests with a bench-scale system.
- Engage the expertise of Generon that specializes in the manufacturer of hollow fiber membranes.
- Transfer technical know-how of PBI fiber spinning to Generon.
- Evaluate, at a bench-scale level, the thickness of the selective 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.

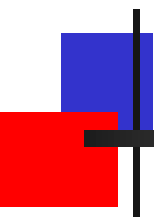


50 kW_{th} Membrane Skid

- 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.

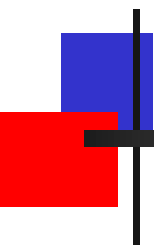
Photograph of the Skid for PBI Membrane Testing





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
 - 4.2: Development of a Test Plan
 - 4.3: Parametric Testing
 - 4.4: Long Duration Testing
- Task 5: Conduct Process Design and Engineering Study
- Task 6: Conduct Environmental and Economic Analyses
- Task 7: Dismantling and Removing the Slipstream Test Unit

Acknowledgement

■ SRI International

- Gopala Krishnan, Indira Jayaweera, Anoop Nagar, Srini Bhamidi, Regina Elmore, and Palitha Jayaweera

■ Generon:

- John Jensvold, Fred Coan, and Kyle Jensvold

■ Enerfex, Inc.: Richard Callahan

■ PBI Performance Products, Inc.

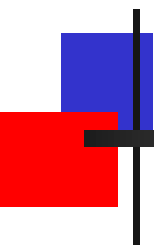
- Gregory Copeland and Michael Gruender

■ National Carbon Capture Center: Frank Morton

■ EPRI: Jeffrey Phillips

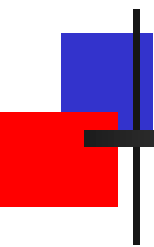
■ DOE-NETL

- Elaine Everett, Lynn Brickett, Michael Matuszewski



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