Composite Hollow Fiber Membranes for Post Combustion CO_2 Capture

Dhaval Bhandari (GE-GRC), Frederick Stewart (INL),
William Koros (Georgia Tech), Vijay Sethi (WRI)

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Project Team

GE Global Research

- Teresa Grocela-Rocha
- Joe Suriano
- Paul Glaser
- David Moore
- Hongyi Zhou
- Pat McCloskey
- Surinder Singh
- Kristi Narang
- Balajee Ananthasayanam
- Lauraine Denault
- Jeff Manke
- Paul Wilson
- Paul Howson
- Dhaval Bhandari (PI)

Idaho National Laboratory

- Chris Orme
- John Klaehn
- Fred Stewart (PL)

Georgia Institute of Technology

- William Seo
- Ali Rownaghi
- William Koros (PL)

Western Research Institute

- Tom Barton
- Jerrod Doss Isaak
- Vijay Sethi (PL)

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GE Global Research

- First U.S. industrial lab
- One of the most diverse industrial labs (over 3000 technologists)
- Founding principle - improve businesses through technology

AMSTC
Ann Arbor, MI

Global Research HQ
Niskayuna, NY

Global Research - Europe
Munich, Germany

China Technology Center
Shanghai, China

Global Software Center
San Ramon, CA

Brazil Technology Center
Rio De Janeiro, Brazil

John F. Welch Technology Center
Bangalore, India

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Project & Team Overview

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Project Summary

- 3-year, $ 3M program, 20 % cost share from GE
- Budget period 1: October 2011 – March 2013
- Budget period 2: April 2013 – September 2014

Project Objective: Develop bench-scale thin film coated composite hollow fiber membrane materials and processes for CO_2/N_2 separation from coal flue-gas at 60 °C with at least 90% CO_2 capture with less than 35% increase in cost of electricity

GE Global Research

- Hollow fiber fabrication & characterization
- Module design
- Technical & economic feasibility analysis

Idaho National Laboratory

- Polymer development
- Polymer property optimization
- Coating solution development

Georgia Institute of Technology

- Modeling of key membrane properties
- Effect of fly ash on membranes
- Fiber coating process development

Western Research Institute

- Membrane performance validation in coal flue-gas

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Technology Overview

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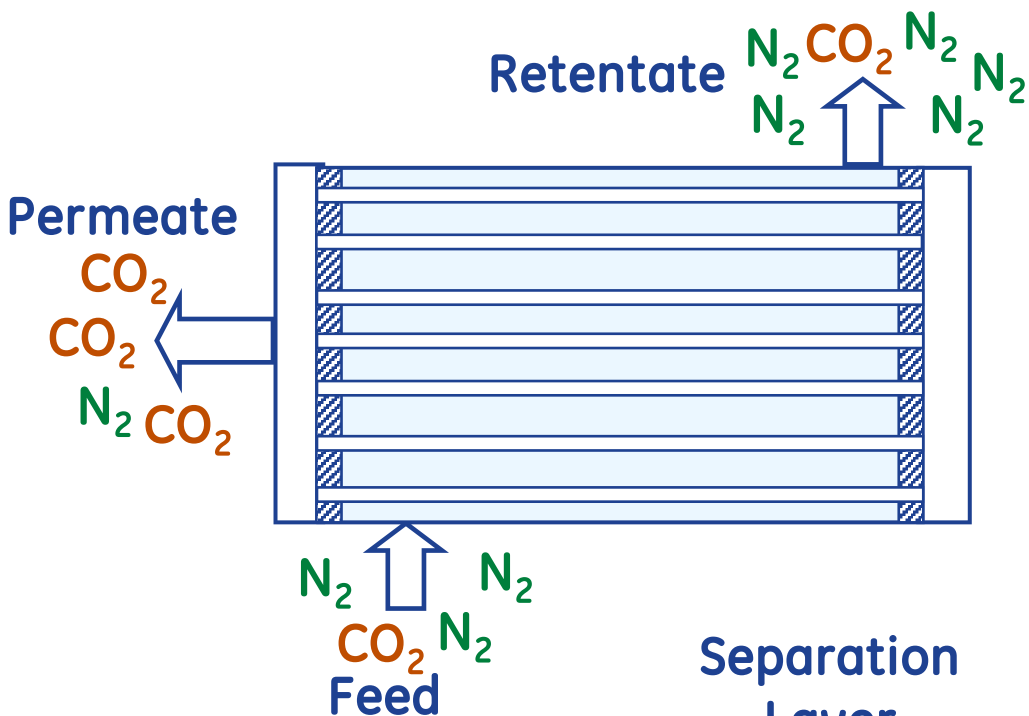
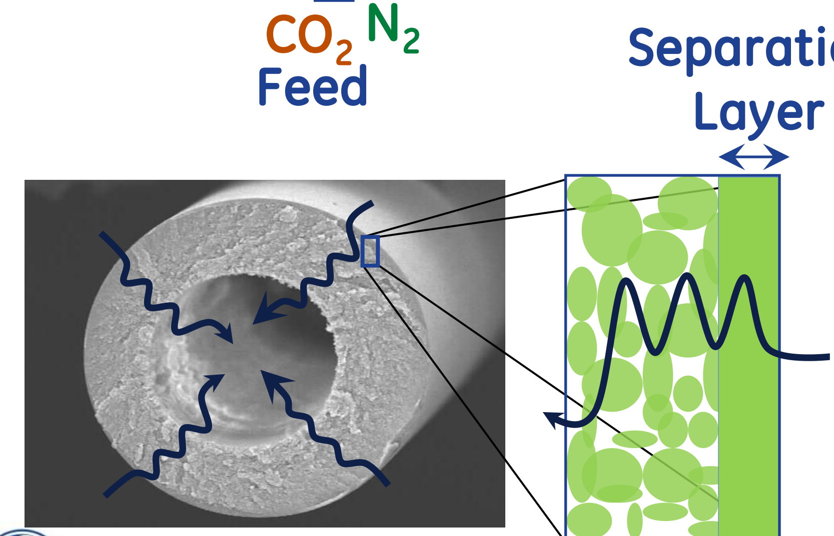
Gas Separation Membrane Fundamentals





Permeance (Productivity)

$$P_{CO2} = D_{CO2} * S_{CO2} = \frac{(\mathrm{Flux})_{CO2} * \ell}{\Delta p_{CO2}}$$

$$\frac{P_{CO2}}{\ell} [=] 1\,\mathrm{GPU} = 10^{\ 6} \frac{\mathrm{cm}^3(\mathrm{STP})}{\mathrm{cm}^2 \quad \mathrm{s} \quad \mathrm{cmHg}}$$

Selectivity (Purity)

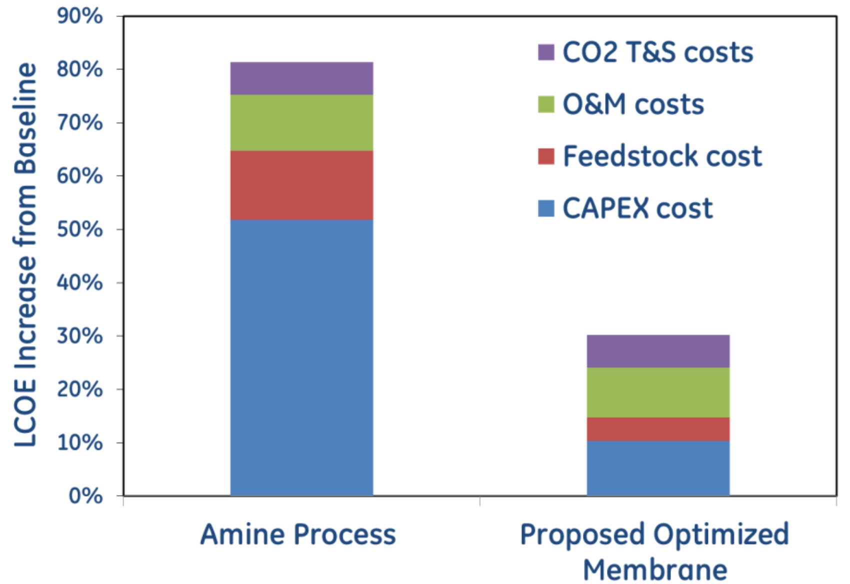
$$\alpha_{CO2\text{-}N2} = \frac{P_{CO2}}{P_{N2}}$$

Solution–Diffusion Process

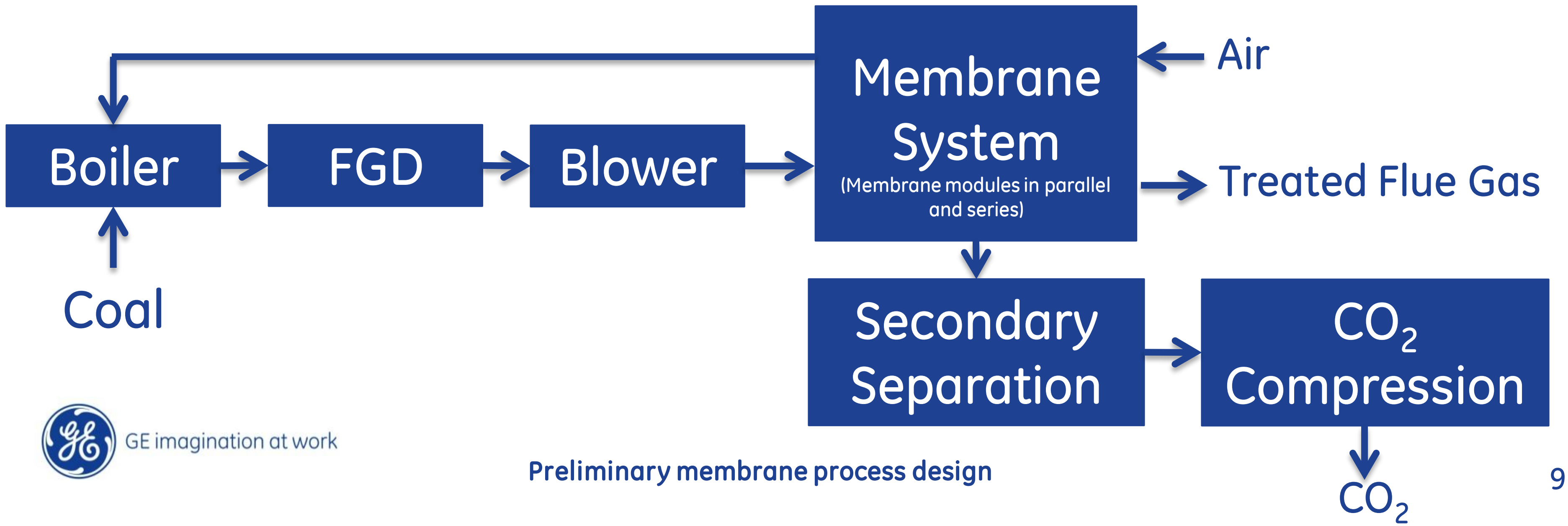
Gases dissolve in and then diffuse through a membrane

Proposed Economic Advantages

- Hybrid membrane process: membrane + secondary separation (cryogenic)
- Reduce membrane CAPEX – ↓ membrane cost, ↑ permeance
- Reduce cryogenic CAPEX/OPEX - ↑ membrane selectivity
- Easier cleanability to provide longer membrane life



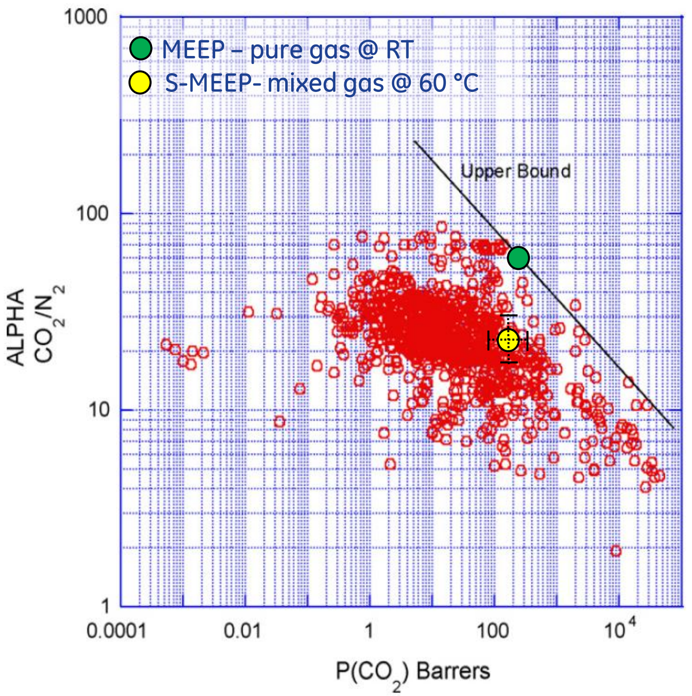
Levelized COE comparison for the membrane process



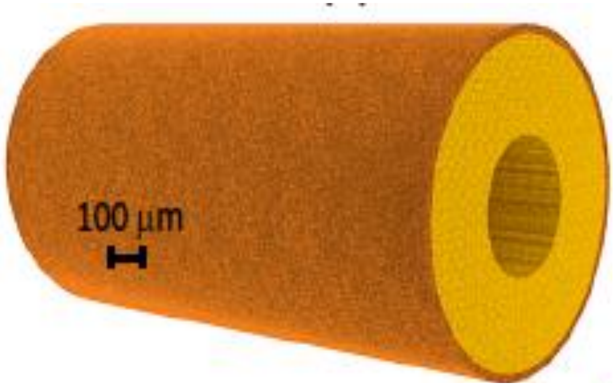
Preliminary membrane process design

Technical Strategies to Meet Economics

- Polyphosphazene polymers - Low Tg polymers with excellent CO_2 separation & permeability
- Highly scalable, low cost hollow fiber support platform
- Thermally & chemically robust membrane materials
- Surface property optimization to reduce fly ash adhesion
- Membrane module & system designs to improve performance



Permeability-selectivity plot for CO_2/N_2 gas pair*+



Hollow fiber support material

* L. M. Robeson, The Upper Bound Revisited. J. Membr. Sci. 2008, 320, 390

+C.J. Orme, M.K. Harrup, T.A. Luther, R.P. Lash, K.S. Houston, D.H. Weinkauf, F.F. Stewart, Characterization of gas transport in selected rubbery amorphous polyphosphazene membranes, J. Membr. Sci. 186 (2001) 249

Expected Challenges & Mitigation Strategy

Description of Challenge	Mitigation Strategy
Technical Challenges	
Flue gas component stability (SO_x, NO_x, H_2O)	Polymer inherently tolerant towards flue gas components , coal flue-gas testing of membranes at WRI
Fouling potential from fly-ash/particulates	Create non-adhesive surface properties to resist fouling
Economic Challenges	
Permeability and selectivity at 60 °C lower than anticipated	Develop processes for thin film coating on hollow fibers, optimize stabilizer & cross-linker content
Large membrane area requirements & process integration	Hollow fibers scalable; explore various membrane process schemes

Progress & Current Status

Project Activity Schedule

Major Tasks		GE	INL	GT	WRI
Task 1	Project Management	●			
Task 2	Optimize Polyphosphazene Polymer and Coating Solution				
2.1	Produce coating solutions in appropriate solvents		●		
2.2	Adjust Phosphazene cross-linking		●		
2.3	Optimize Phosphazene stabilization		●		
2.4	Refine Phosphazene solution properties		●		
2.5	Optimize Phosphazene performance and coating properties		●		
2.6	Document final results and path forward		●		
Task 3	Fabricate Hollow Fiber Support Layer				
3.1	Produce high porosity hollow fiber supports	●		●	
3.2	Refine hollow fiber spinning process and support material	●			
3.3	Optimize hollow fiber spinning process	●			
3.4	Document final results and path forward	●			
Task 4	Fabricate Composite Coated Hollow Membranes				
4.1	Demonstrate defect-free individual coated hollow fiber	●			
4.2	Adapt fiber coating for "continuous dip coating" process	●			
4.3	Refine continuous fiber dip coating process	●			
4.4	Adapt "in-situ" fiber module coating process			●	
4.5	Refine "in-situ" fiber module coating process			●	
4.6	Reduce coating defects in multi-fiber modules	●		●	
4.7	Create defect-free coated fiber in multi-fiber modules	●		●	
4.8	Conduct preliminary studies on key membrane properties			●	
4.9	Conduct focused studies on key membrane properties			●	
4.10	Refine and develop membrane models			●	
4.11	Document final results and path forward	●		●	
Task 5	Test Membranes at Bench-Scale in Coal Flue Gas				
5.1	Enhance bench-scale testing facilities	●			●
5.2	Coal flue gas performance test to benchmark flat membranes				●
5.3	Coal flue gas performance test composite hollow fiber membrane modules				●
5.4	Coal flue gas performance test optimized composite hollow fiber membrane modules				●
Task 6	Conduct Process Evaluation and Module Design				
6.1	Conduct preliminary technical and economic feasibility study	●			
6.2	Conduct final technical and economic feasibility analysis and EH&S assessment	●			
6.3	Analyze tradeoffs for module designs and flow configuration	●			

Year 1: Q1 Q2 Q3 Q4 | Year 2: Q5 Q6 Q7 Q8 | Year 3: Q9 Q10 Q11 Q12

Legend: ◆ Milestone ▽ Deliverable ◇ Decision Point

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Tasks, sub-tasks & ownership are inter-linked

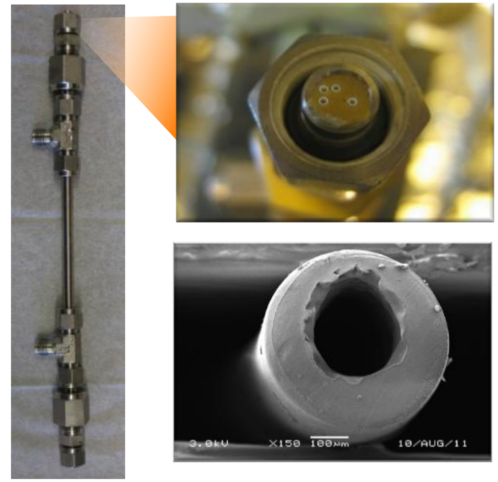
Project Key Objectives

- **Task 1** – Bring together processes, materials & information generated in the project to move the technology towards deployment
- **Task 2** – Synthesize polymer, optimize separation performance & develop easily processable coating solutions
- **Task 3** – Produce highly porous, robust hollow fiber supports
- **Task 4** - Develop processes to apply ultra-thin layer coatings on hollow fiber supports & elucidate fundamental polymer properties
- **Task 5** - Exposure & performance test materials & membranes under coal flue-gas
- **Task 6** - Explore system technical & economic feasibility; conduct module design & fabrication

Membranes Fabrication & Testing

- Single & multi layer hollow fiber membrane fabrication facility

GE hollow fiber fabrication line



Hollow fiber mini-module

- Simulated & coal flue-gas testing facilities

INL test rig – Flat sheet

GE test rig – Flat sheet & hollow fibers

WRI test rig - Coal flue-gas

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Technology Development Path

Technology Development Path

- The team plans to validate a promising bench scale membrane material & process configuration by the end of the project
- GE has commercial membranes in the Energy, Water & Healthcare space
- Membrane benefits for post combustion CO_2 capture need to be demonstrated on a relatively larger scale for industrial acceptance

Thank You

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