Development of Novel Water-Gas-Shift Membrane Reactor

Addressing
Barrier L: H_2 Purification/CO Clean-up
Target: <10 ppm CO in Product Stream

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Water-Gas-Shift Membrane Reactor

- **Relevance/Objectives**
  - Produce Enhanced H_2 Product with <10 ppm CO at High Pressure Used for Reforming
  - Overcome Barrier L: H_2 Purification/CO Clean-up
  - Achieve Target: <10 ppm CO in Product Stream

- **Approach: CO_2-Selective Membrane**
  - Remove CO_2 for H_2 Enhancement
  - Drive WGS Reaction to Product Side

    $$CO + H_2O \rightarrow H_2 + CO_2 \uparrow$$

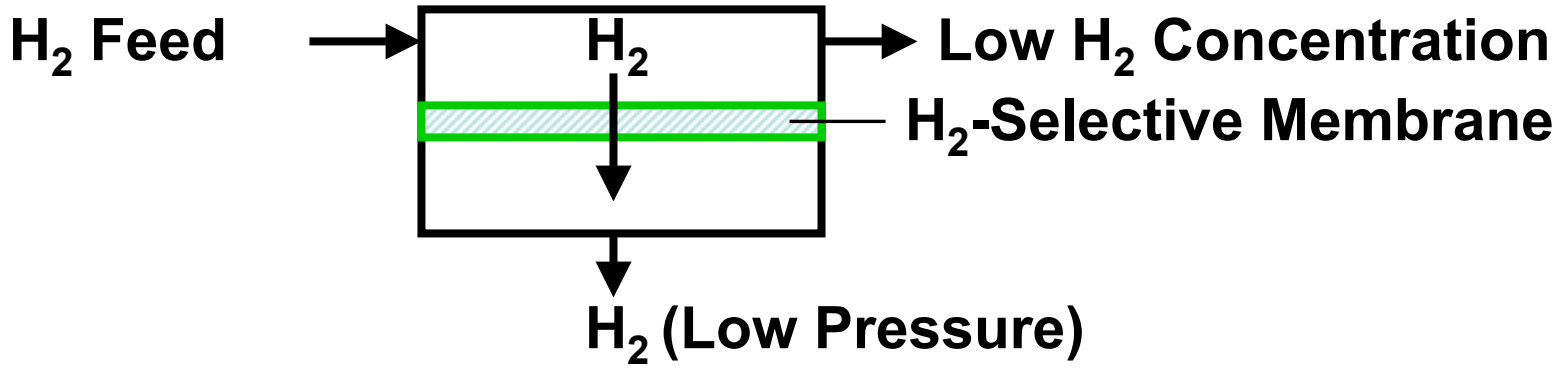
  - Decrease CO to <10 ppm

On-Board/Off-Board Purification of Reformed Gas with Membrane

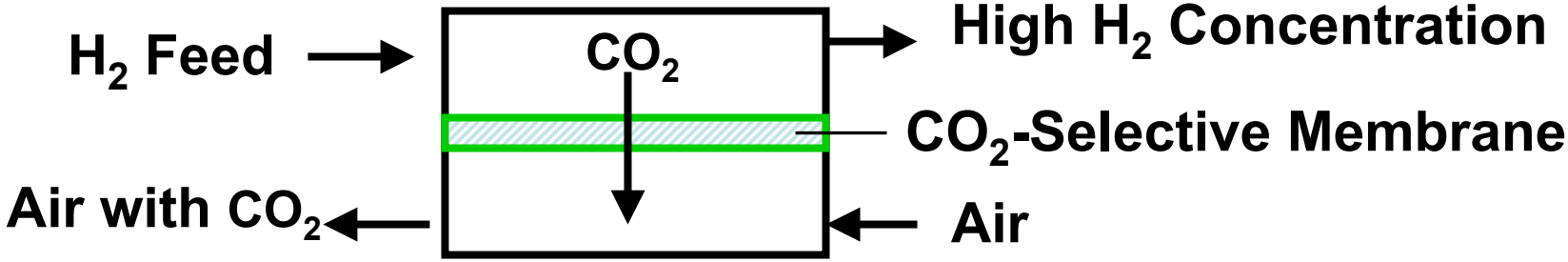
- Light Weight
- Compact – Membrane Module
- Simple Operation
  - Pressure Differential
  - No Moving Parts

Novel Membrane Process for H_2 Purification

- **Conventional / Commercial Membrane Process**



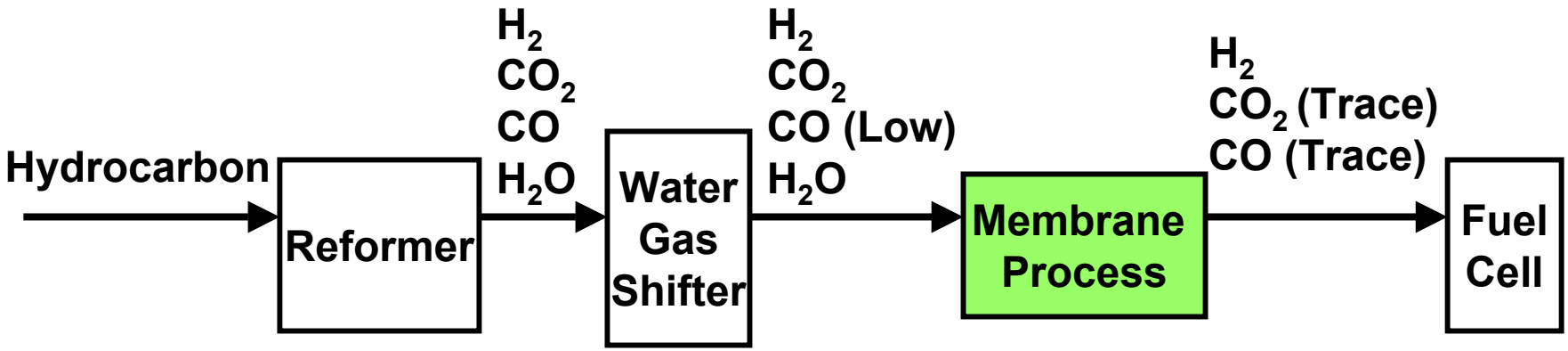
- **Novel Membrane Process**



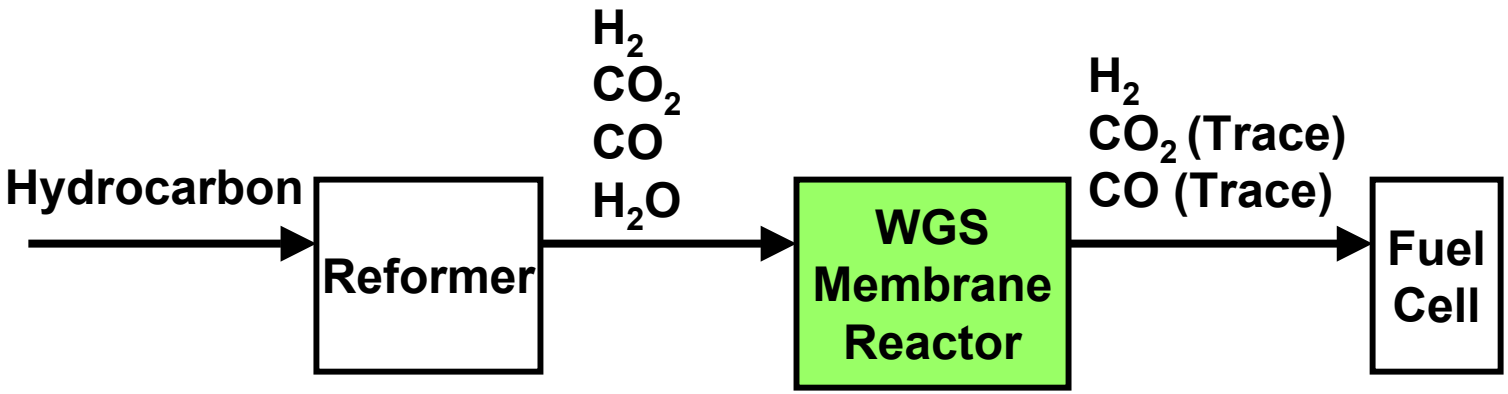
- High-purity H_2 Recovered at High Pressure
- High-purity H_2 Product without CO_2 Desirable
  + CO_2 acts as diluent / produces CO via reverse WGS reaction
- High H_2 Purity/Recovery via High Driving Force from Air Sweep
- Minimal Parasitic Power Required for Air Blown Separation

Fuel-Cell Fuel Processing with CO_2-Selective Membranes

- Low Temperature CO_2-Selective Membrane

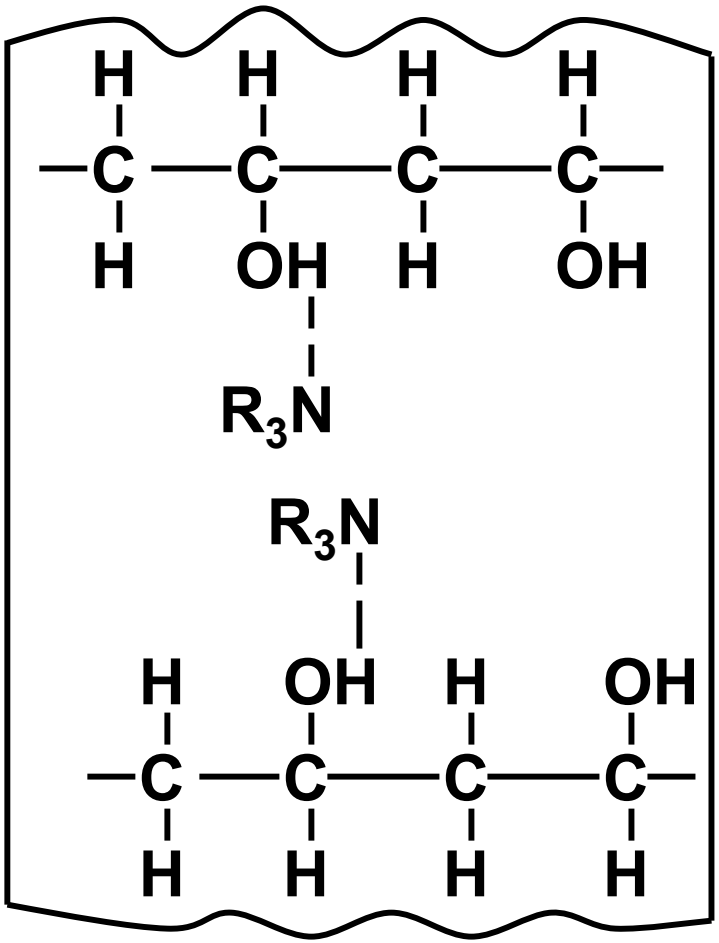


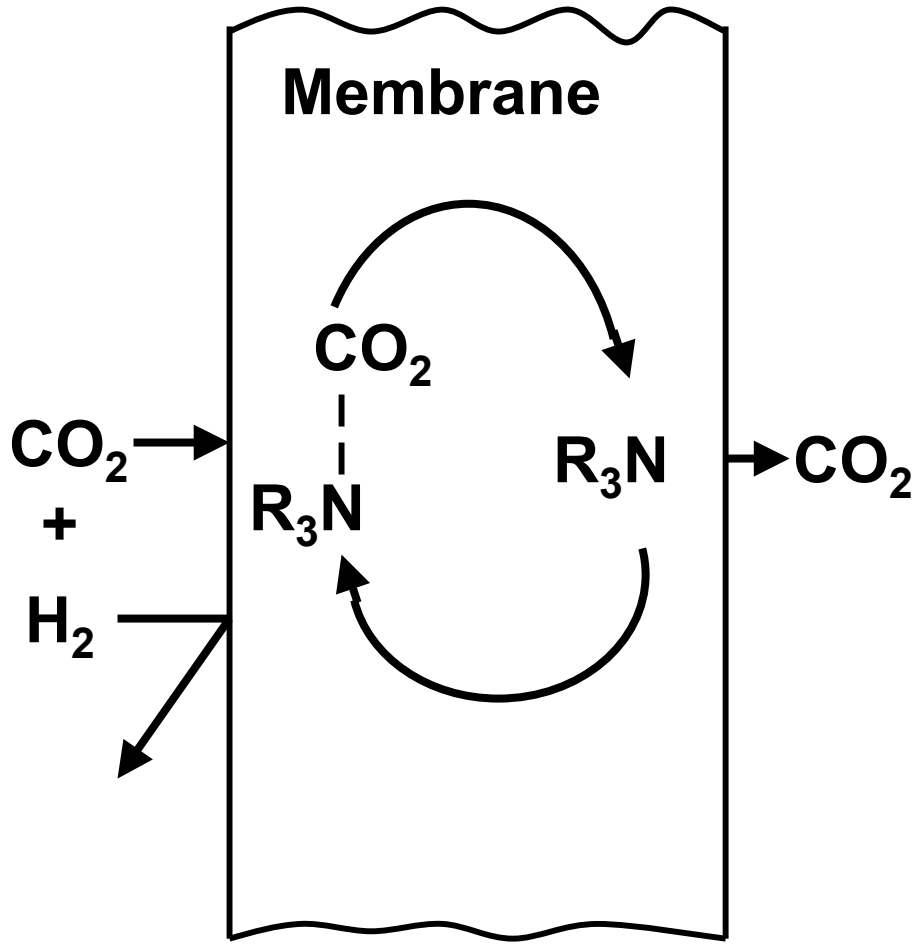
- High Temperature CO_2-Selective Membrane



CO_2-Selective Membranes by Incorporating Amines in Polymer Networks … Facilitated Transport

Example: Polyvinylalcohol-Containing Amine Membrane

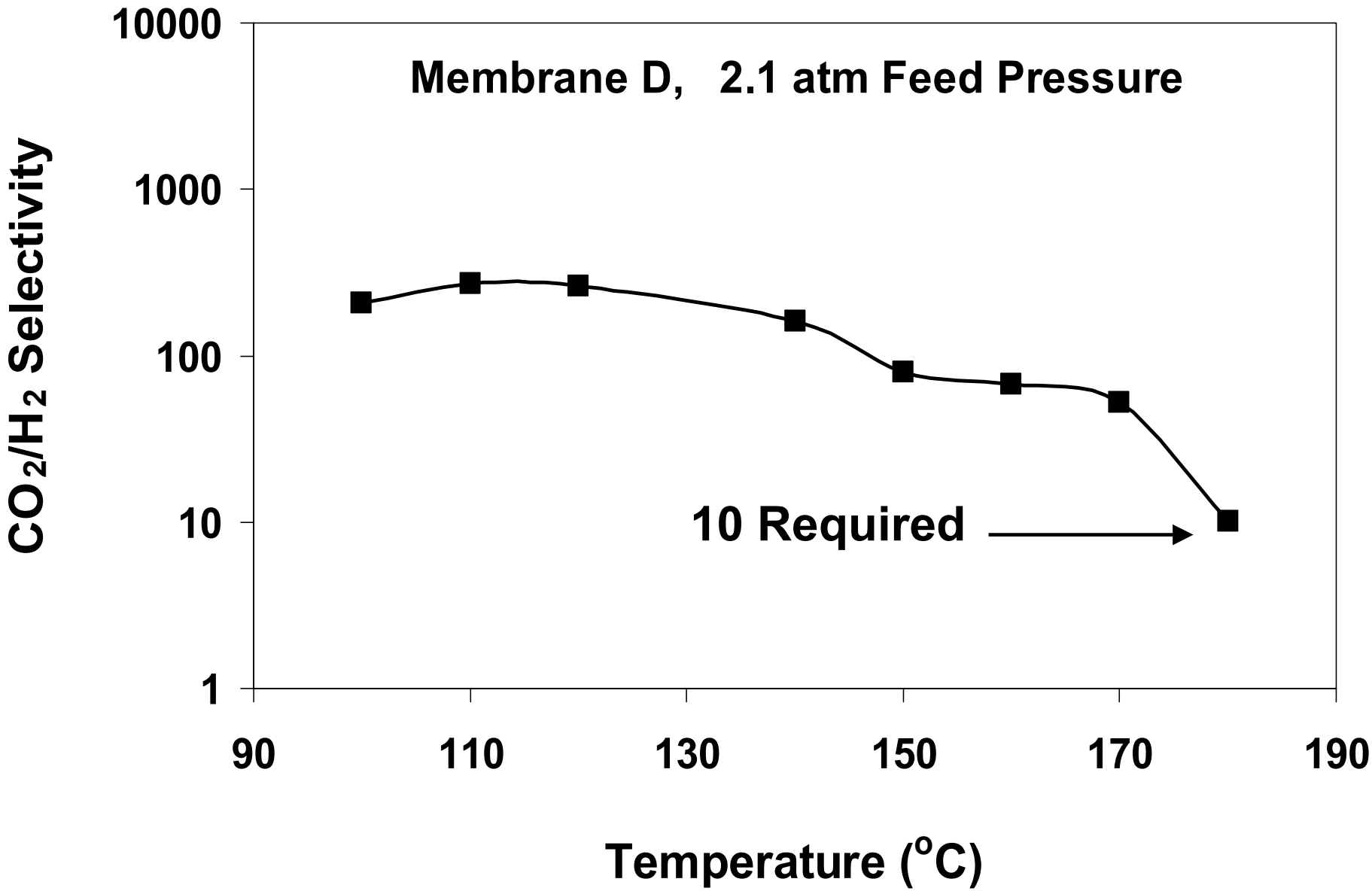




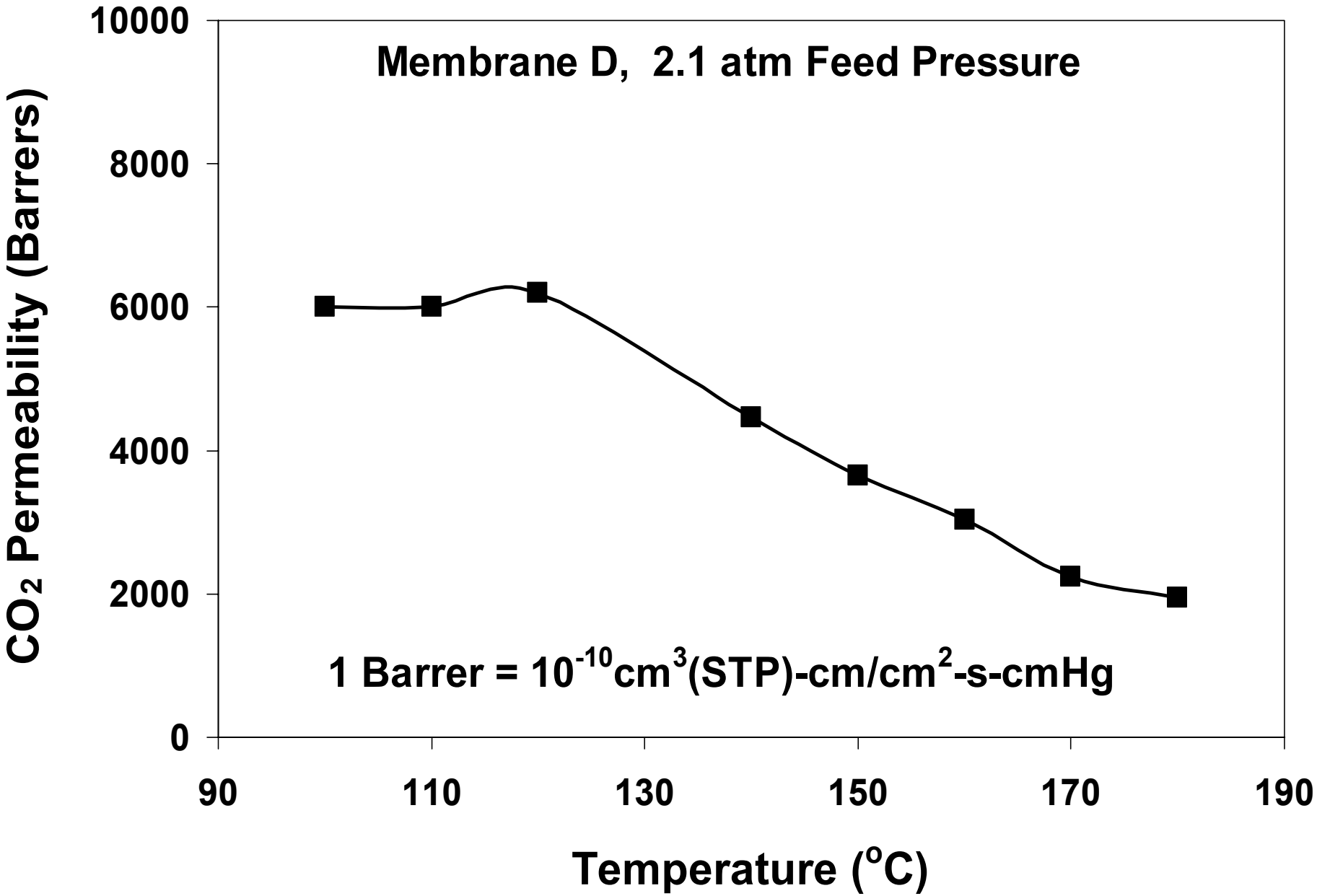
Project Timeline

Task	2001 4Q	2002 1Q	2002 2Q	2002 3Q	2002 4Q	2003 1Q	2003 2Q	2003 3Q	2003 4Q	2004 1Q	2004 2Q	2004 3Q
Phase 1												
1. Modeling Study to Show <10 ppm CO Feasible	———	———	———	———	Δ							
2. Synthesis of Novel Membranes	———	———	———	———	———							
Phase 2												
3. Characterization of Membranes					———	———	———	———	———			
4. Set-up of Lab Reactor					———	———						
5. Membrane Fabrication					———	———	———	———	———			
6. Proof-of-Concept Demo							———	———	Δ			
Phase 3												
7. Set-up of Membr. Reactor									———	———		
8. Fabrication of Prototype Membrane Module									———	———	———	———
9. Prototype Reactor Demo											———	Δ

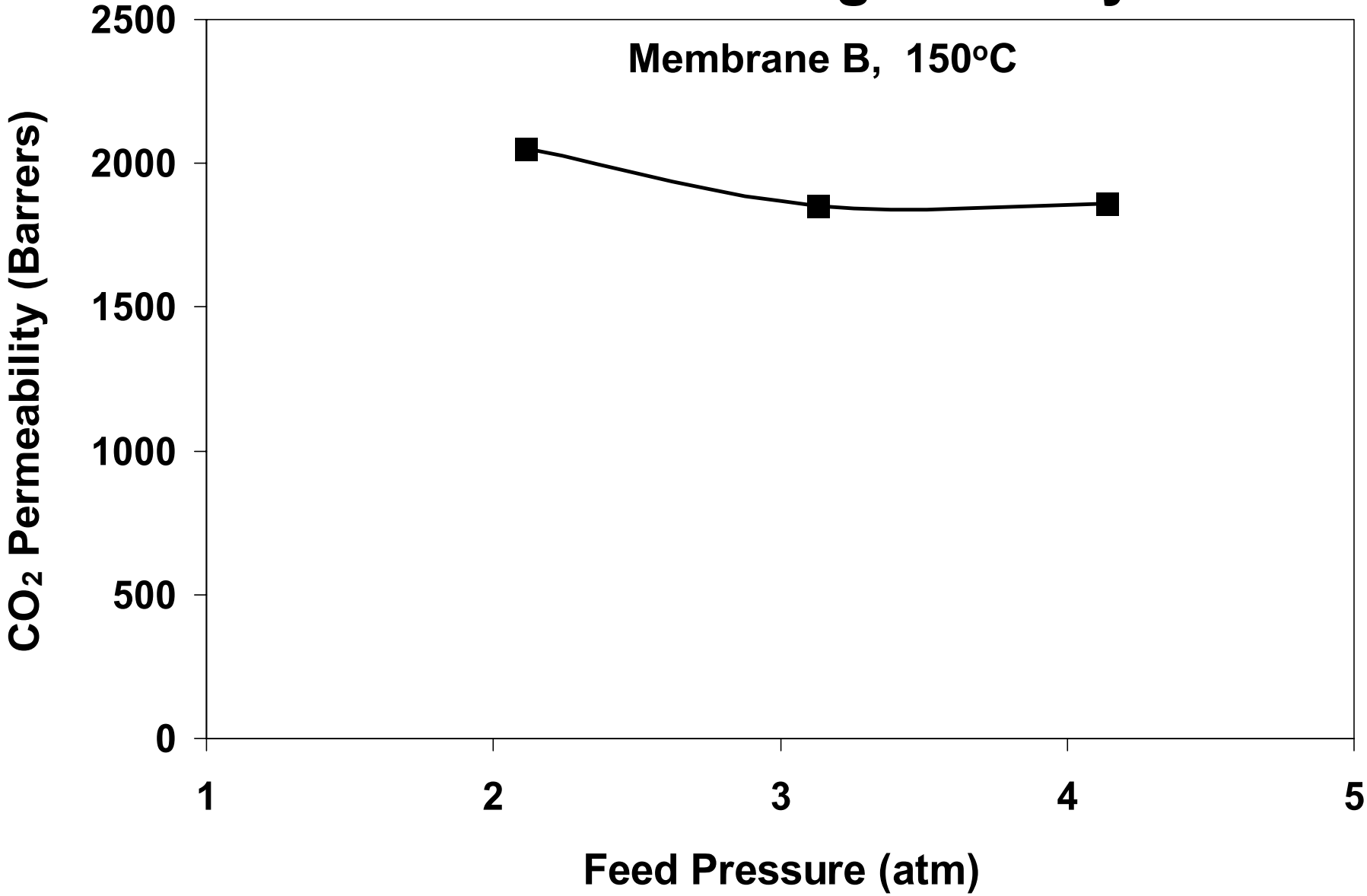
High CO_2/H_2 Selectivity Obtained



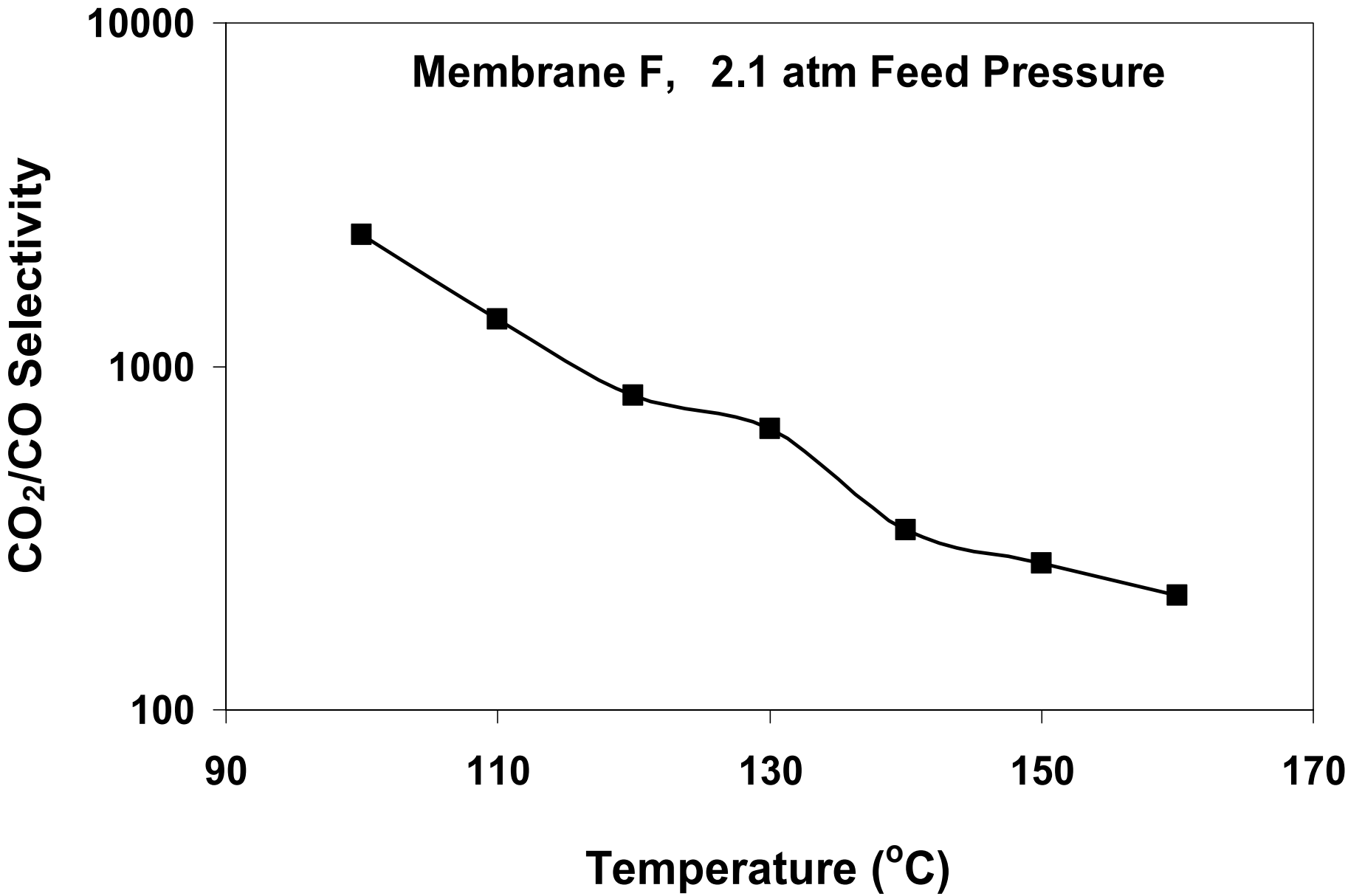
High CO_2 Permeability Obtained



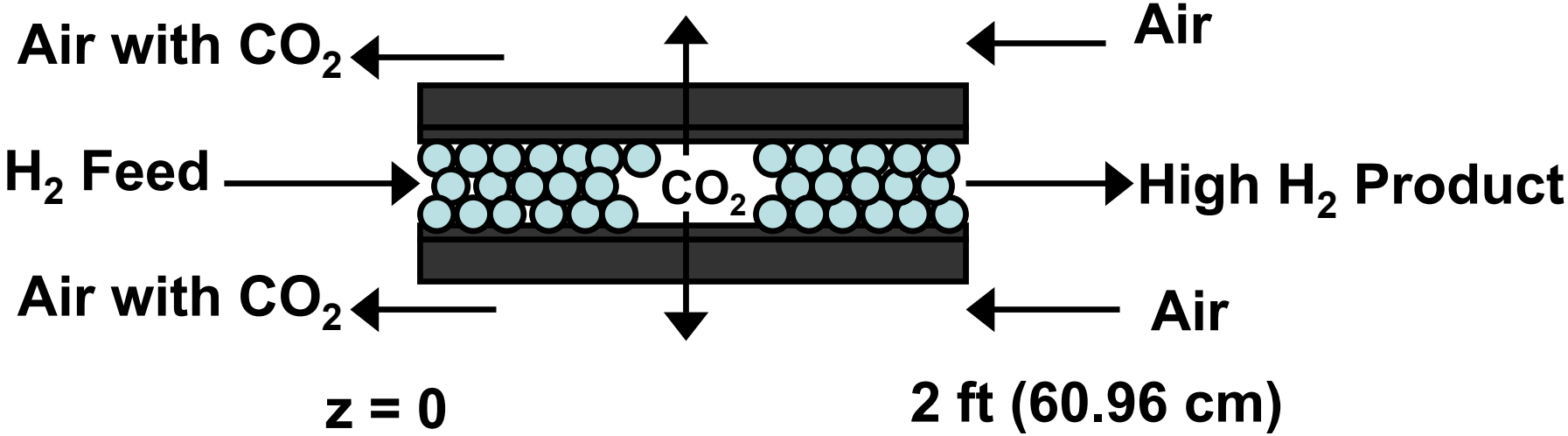
CO_2 Permeability Did Not Change with Pressure Significantly



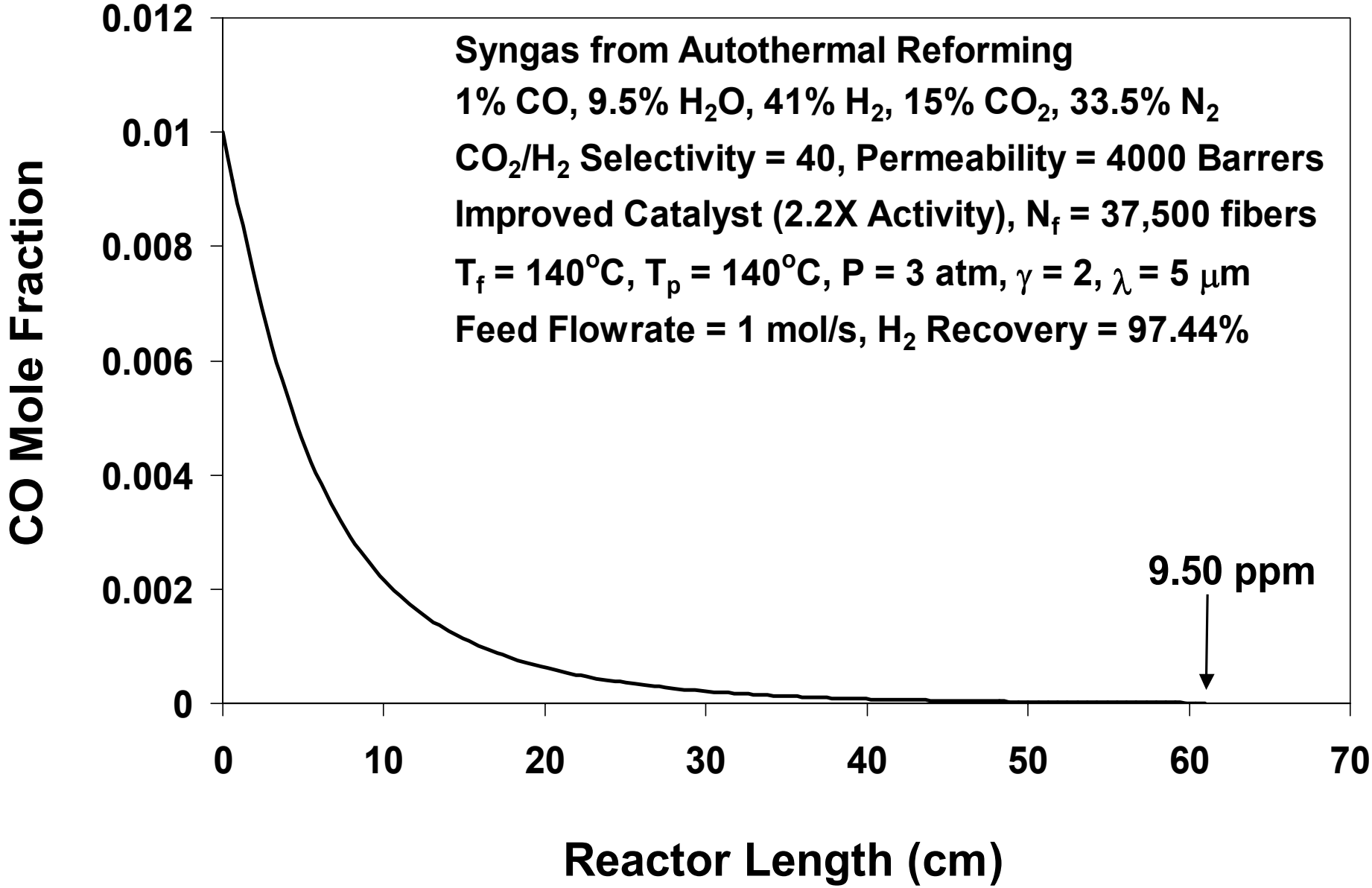
High CO_2/CO Selectivity Obtained



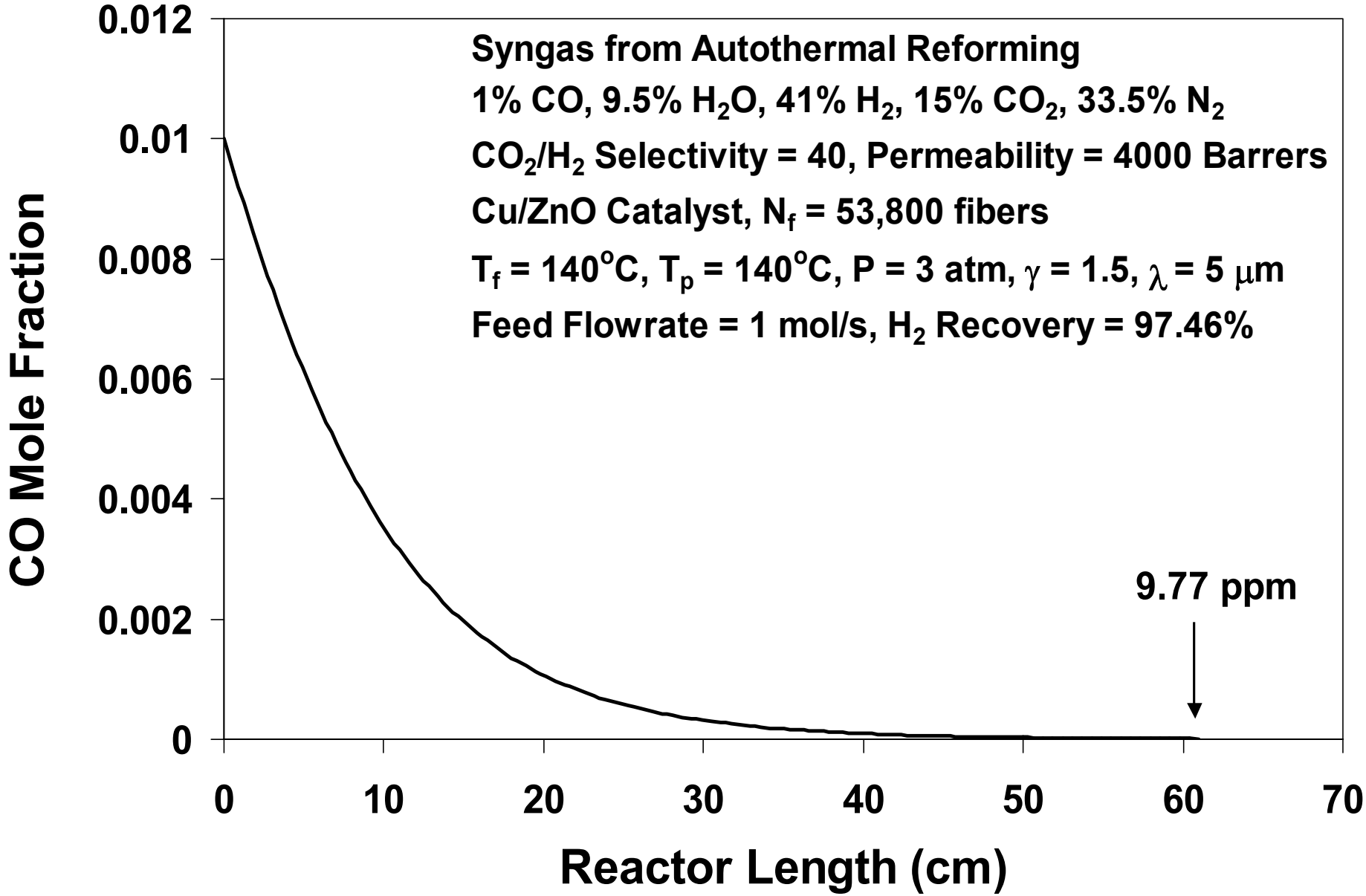
CO_2-Selective Membrane Reactor



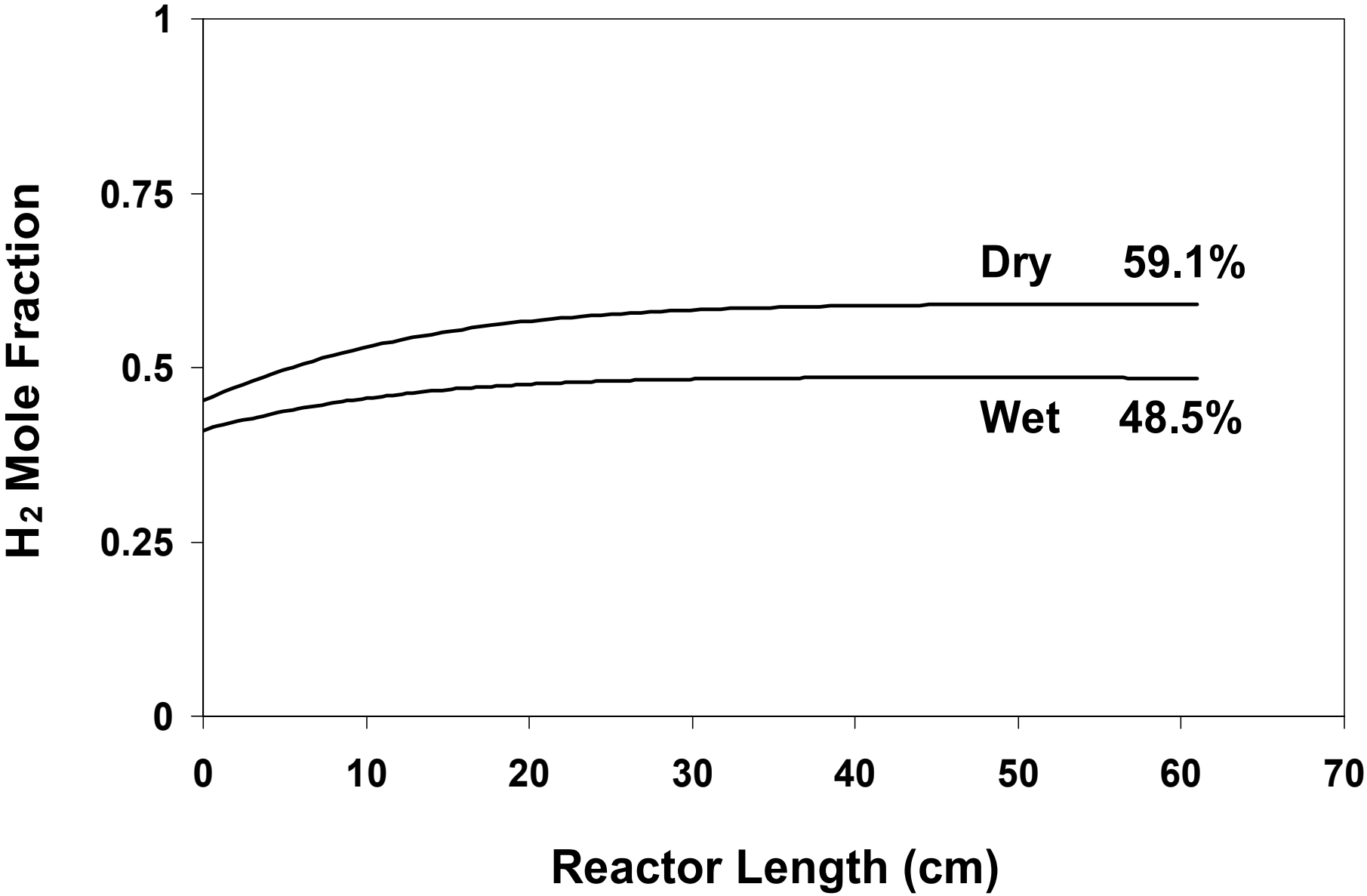
Modeling of Water Gas Shift Membrane Reactor Shows < 10 ppm CO Achievable



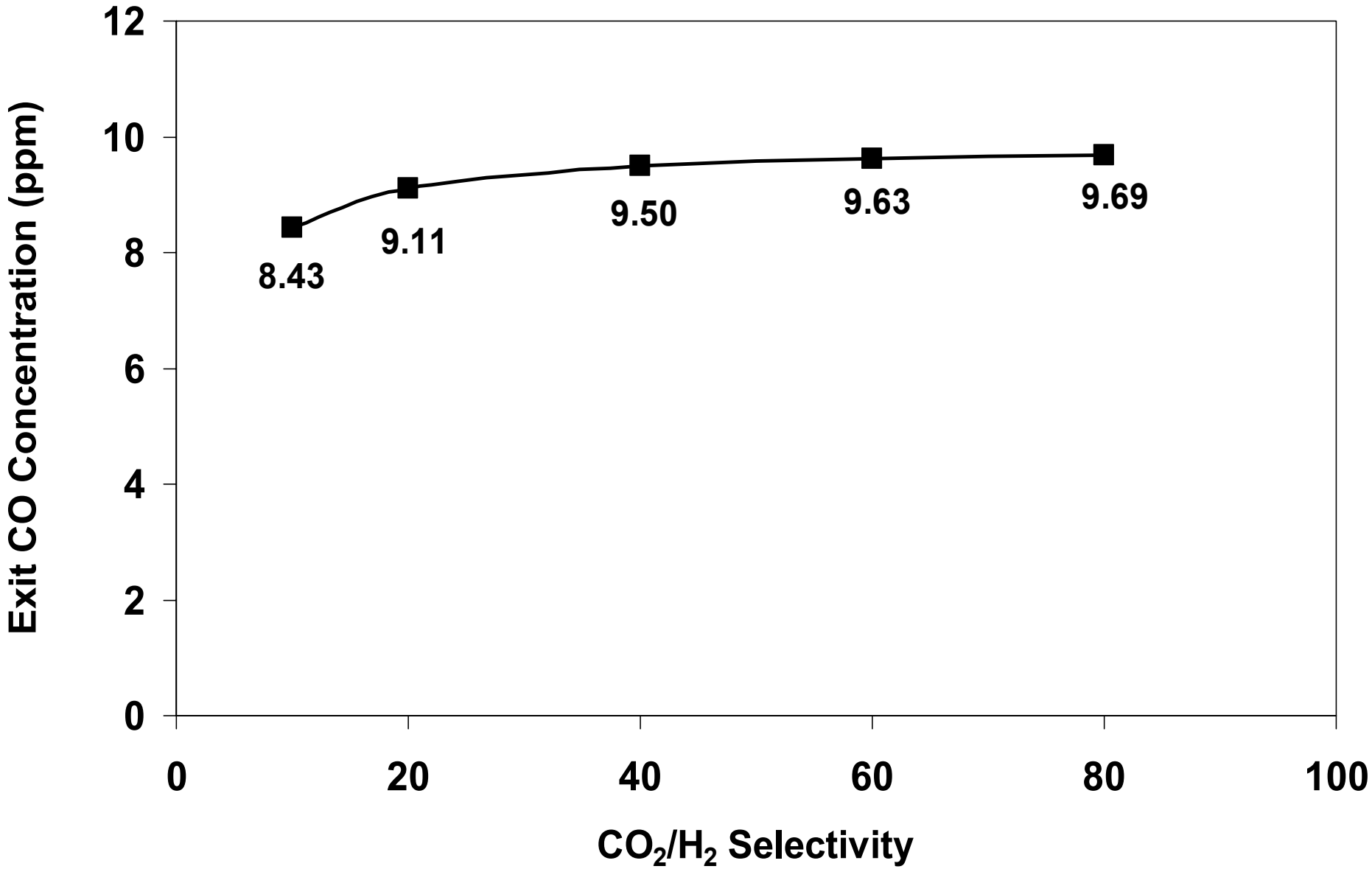
Modeling of WGS Membrane Reactor Shows <10 ppm CO Achievable with Cu/ZnO Catalyst



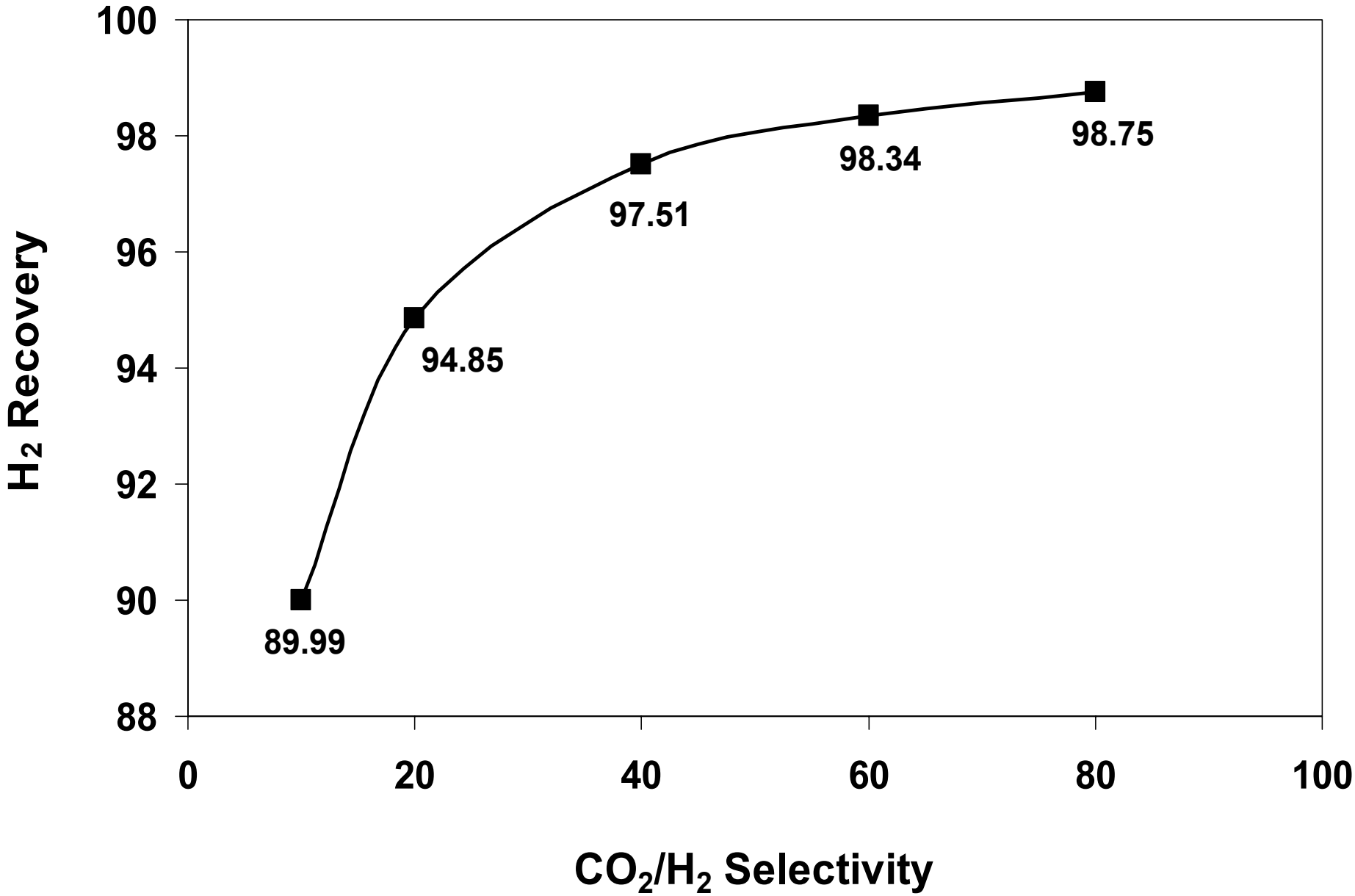
High H_2 Enhancement Achievable



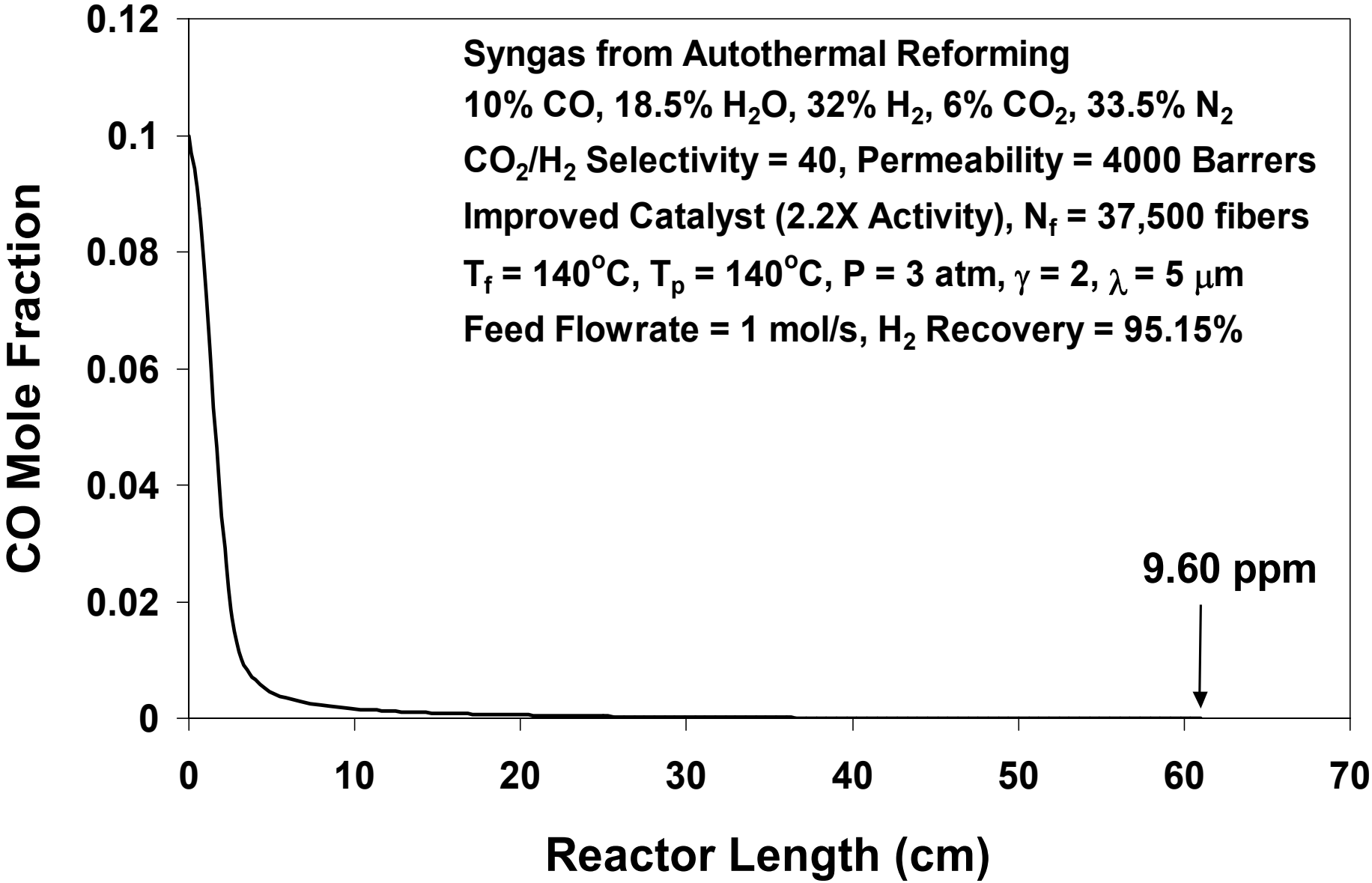
CO_2/H_2 Selectivity Does Not Affect Exit CO Concentration Significantly



CO_2/H_2 Selectivity Affects H_2 Recovery



Modeling Shows < 10 ppm CO Also Achievable for 10% CO Feed



Significant Interactions/Collaborations

- **Work with H2fuel / Unitel Technologies / Avista Labs on Membrane Scale-up**
  - **Successful Scale-up to 40 Inches Wide by ~500 ft Long**
  - **Membrane Evaluation by Auto Company**

- **Two Presentations to Freedom CAR Fuel Cell Tech Team**

Summary

- **Membranes with High CO_2/H_2 & CO_2/CO Selectivities & CO_2 Flux Synthesized**
- **Modeling Results for Synthesis Gases from Autothermal Reforming Show:**
  - **< 10 ppm CO Achievable**
  - **High CO Conversion Achievable**
  - **High H_2 Enhancement Achievable**
  - **High H_2 Recovery Achievable**

Future Plans

- **Continue to Synthesize / Characterize Membranes with Improved Permeability**
- **Conduct Proof-of-Concept Demonstration**
- **Carry out Prototype Membrane Reactor for Fuel Cell (50 kW)**