Membrane/Module Scalability Manufacturing and Other Challenges

ARPA-E REFUEL Meeting
Denver
August 17, 2017

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Introduction to MTR

- Privately-held, 90 employees
- Started in 1982, initially funded by SBIR grants
- Developed membrane materials and commercialized products in petrochemical, natural gas and refinery industries
- Provides complete turn-key solutions with about 300 membrane systems installed worldwide

MTR Product Lines

MTR designs, manufactures, and sells membrane systems for industrial gas separations

Petrochemicals: Propylene/Nitrogen

Hydrogen (Refinery): H_2/CH_4, CO, CO_2

Natural Gas:

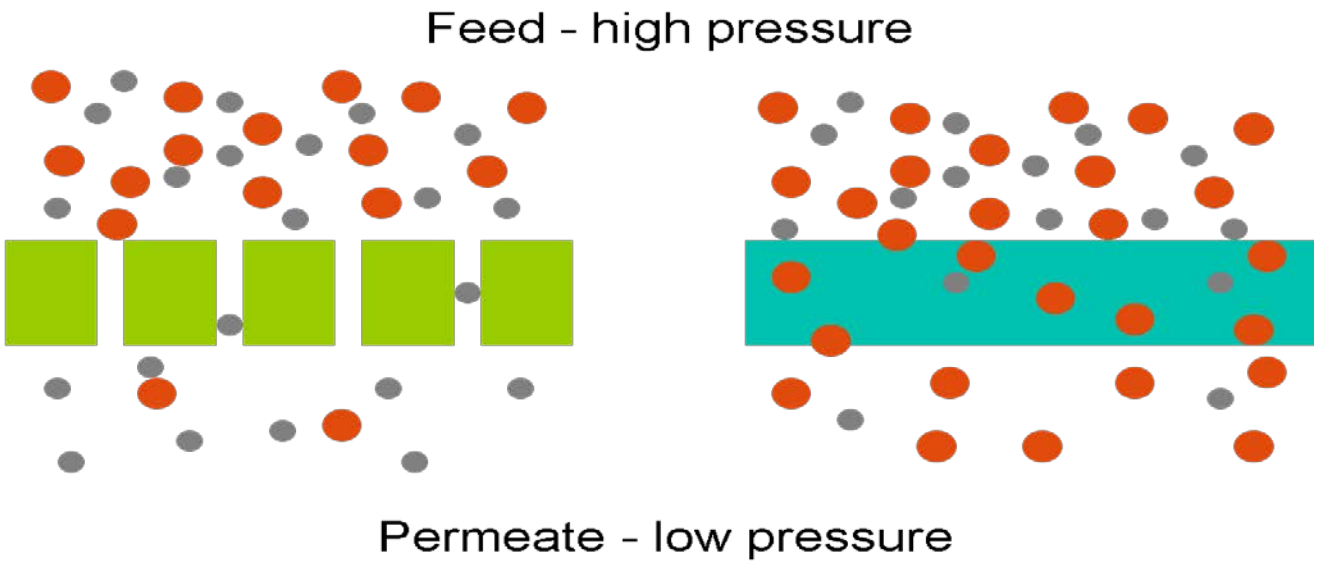
Fuel Gas Conditioning
N_2 Removal
H_2S Removal
CO_2 Separation

- 20 Years of Commercial Success
- A Leader in Membrane and Process Design
- Over 100 Patents on Membrane Technology
- Over 300 References in Various Applications Worldwide

Membrane Classifications

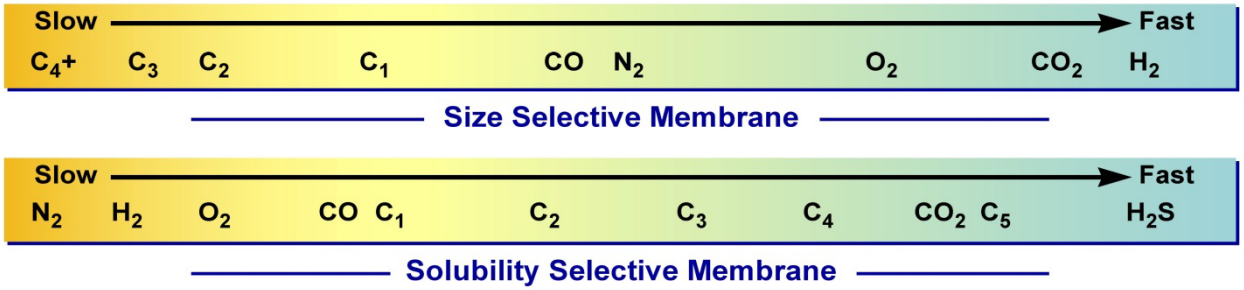
Size Selective

Solubility Selective



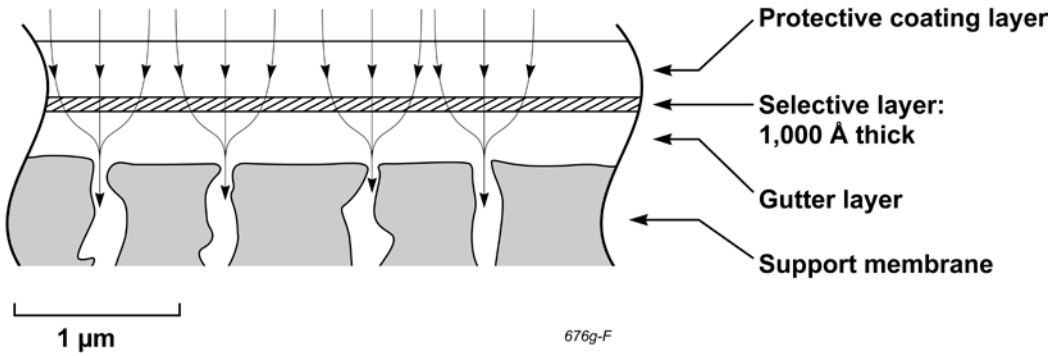
Small molecules pass through

Big molecules pass through



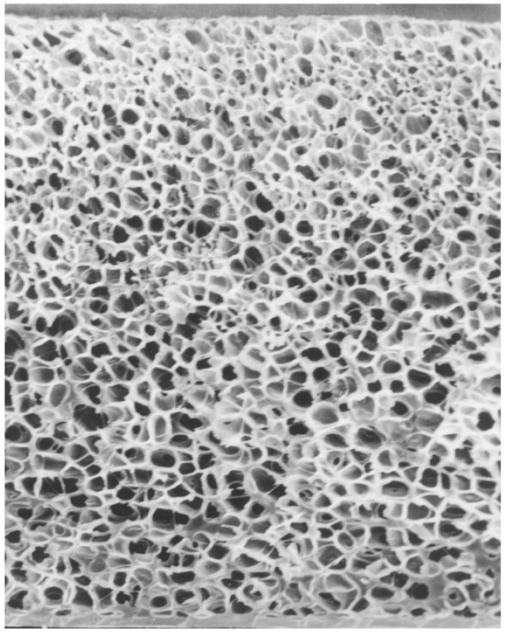
Gas Separation Membranes Have Asymmetric Structures

- Membranes have to be thin to provide useful fluxes.



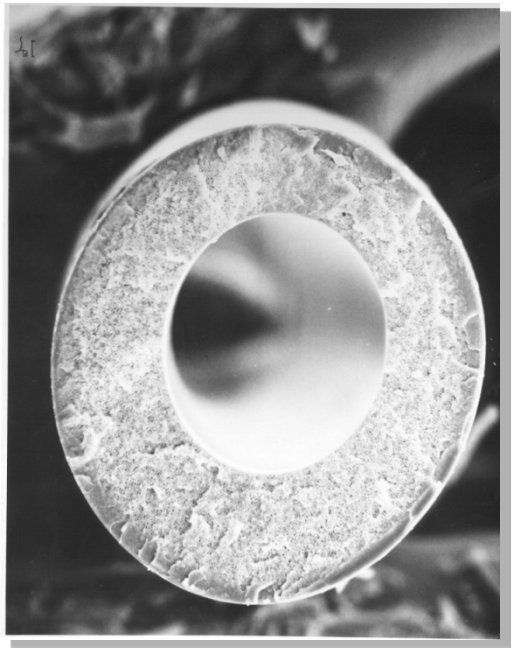
Dense skin layer

(0.1-5 µm)



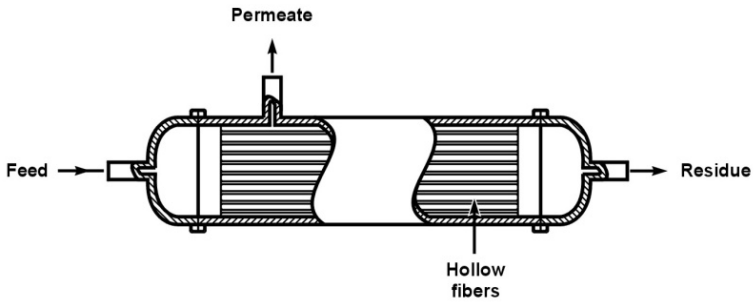
Microporous support layer

(50-100 µm)

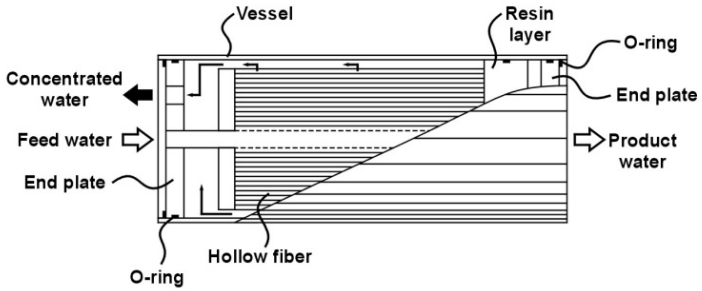


Membrane Module Designs in Current Use

Capillary Fibers



Hollow Fine Fibers



Spiral-Wound Modules

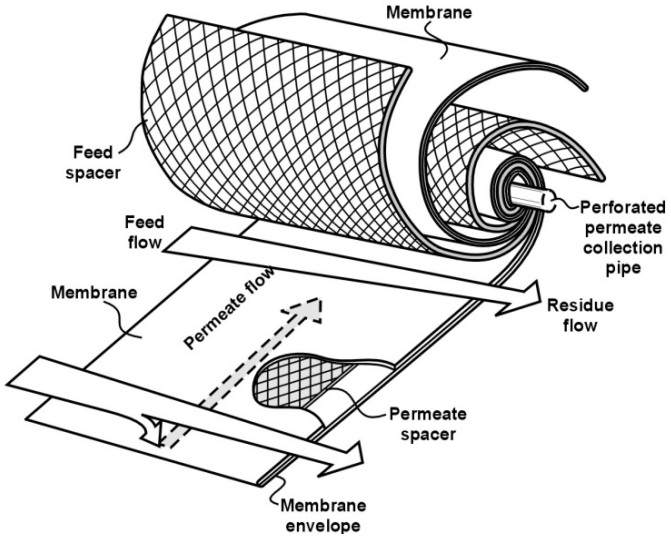
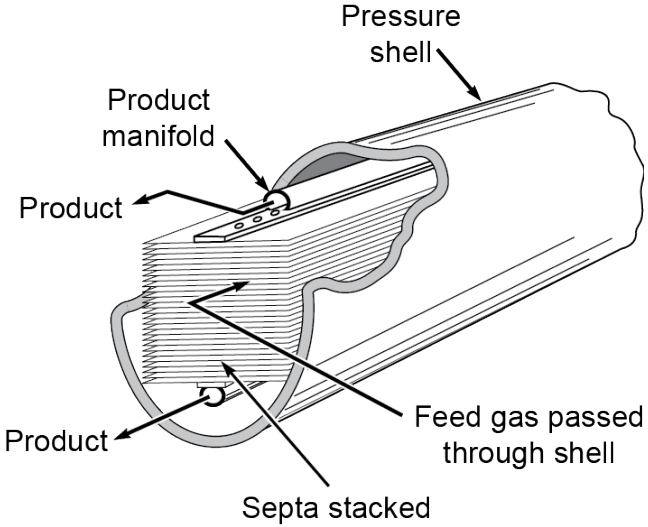


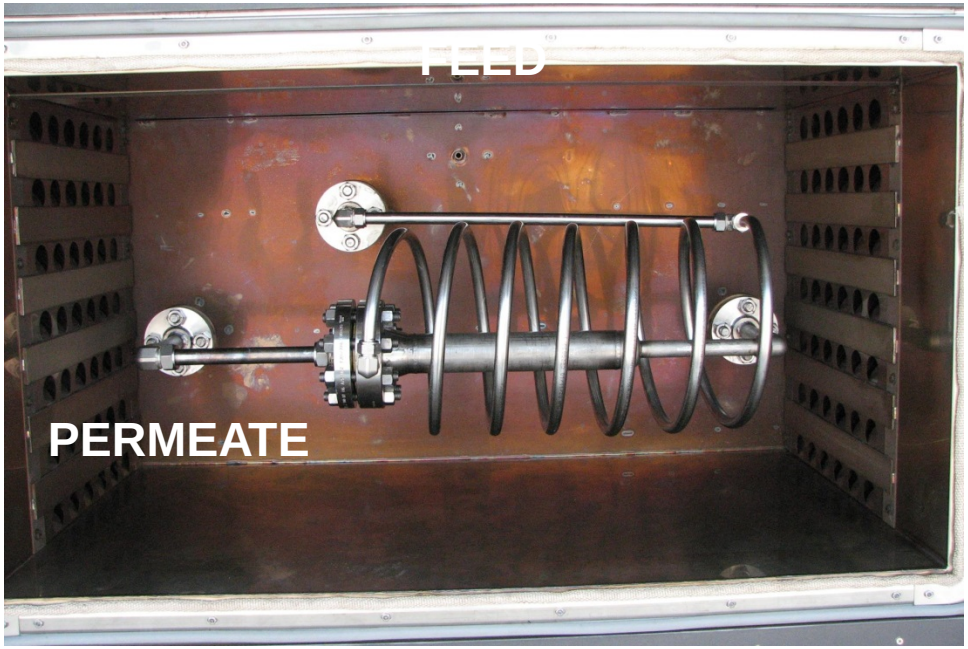
Plate-and-Frame Modules



Commercial Membrane/Module Development
(Concept to Commercialization)

Stage Challenges	Concept (6mths to 1 Yr to Go/NoGo)	Bench Scale (1-2 Yrs to Go/NoGo)	Pilot Scale (1-2 Yrs to Go/NoGo)	Demo/Commercial (2-4 Yrs to Go/NoGo)
Lab scale Performance Improvement	Many Iterations – Bench Top Membranes			
Reproducible Manufacturing – Lab Scale		Lab-scale Runs using Pilot Scale Membrane Equipment		
Reproducible Manufacturing – Commercial Scale			Are Formulations Scalable for Manufacturing lines	
Environmental Related Issues – Commercial Scale Manufacturing			Solvents/Chemicals Selection for larger Scale use – May need to Reformulate	
Lab-scale module Development – Performance Integrity		Challenges – Membrane integrity during assembly		
Pilot Scale module Development – Performance and Chemical Integrity			Challenges – Module leaks/sealing – Reproducible QA/QC Performance	
Commercial Scale Module – Pressure Drop – Mass Transfer Issues				Challenges – Mass Transfer issues based on Process Design Pressure Drop issues?

Example 1 - Membrane Development
Pd-Alloy Membranes for H_2 Separation



- Scaled Up Worcester Polytechnic Institute's Pd-Alloy membrane technology for H_2 and CO_2 separation from coal/biomass-derived synthesis gas
- Designed, fabricated skid, and supported field tests from 2011-2015 at NCCC, Alabama.
- Operated up to 450°C
- Single or multi-tube membrane modules designed and tested.
- 2 – 10 lb/day of H_2 separated at >99.99 vol%

Example 1 – Membrane/Module Development
Pd-Alloy Membranes for H_2 Separation

- Current Status (Early Stage)
- NCCC Field test Showed Good Results
- Membrane Stability was established to meet stated goals
- Single Tube Membranes were scaled to Tube-in-Shell Design with Multiple membrane tubes.

- Scale Up Challenges

  Membrane Scale-up Challenges
  - Process of Membrane Manufacture is Established- Scalable
  - Substrate materials availability limited – May require custom development
  - Long term mechanical and chemical stability in process environments
  - Cost of Materials may be a big cost concern

  Module Scale-up Configuration
  - Shell and Tube configuration – Manufacturing techniques well understood
  - High temp operations – Materials considerations
  - Catalyst addition – Membrane protection
  - Integrated heat management for membrane reactor design

- Demo Scale – 3 to 5 years from current status

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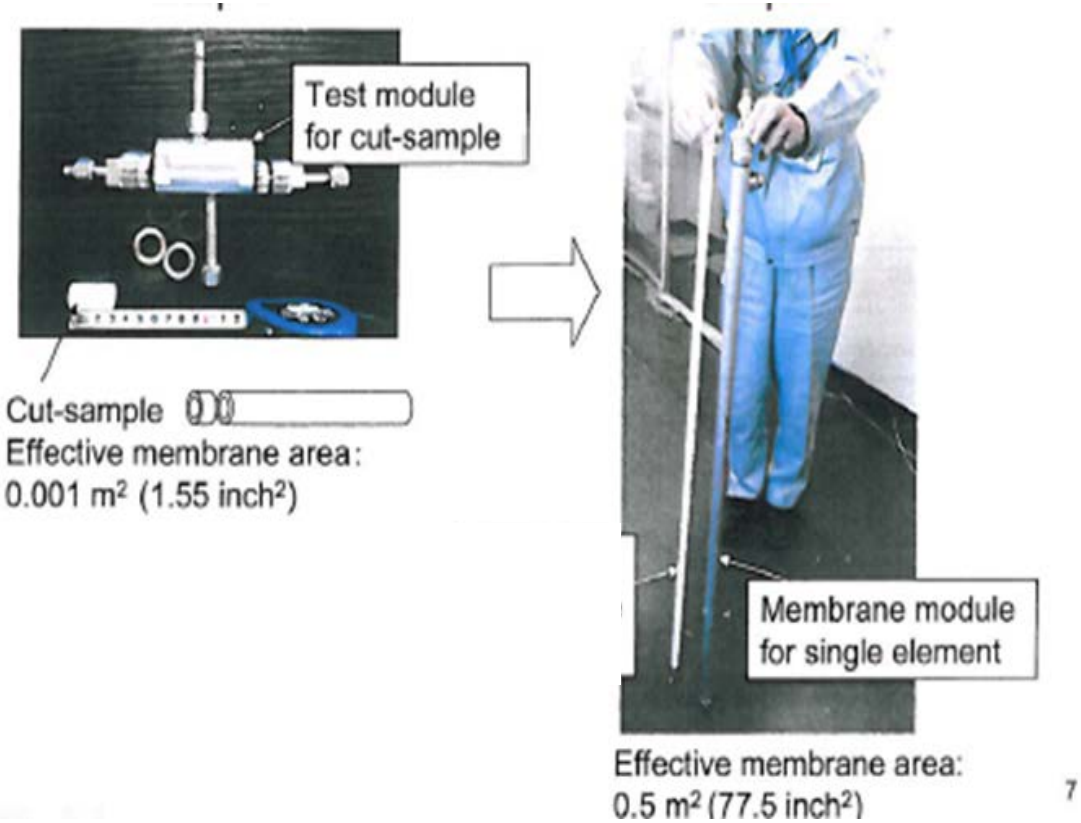
Example 2 - Olefin/Paraffin Separations
Membrane/Module Development

- Market pull exists if membranes with sufficient performance and stability can be demonstrated.
- MTR has explored polymer membranes for these separations for >10 years (we know what doesn't work)
- Ceramic Membranes offer better separation performance



Example 2 - Olefin/Paraffin Separations
Membrane/Module Development

- MTR established collaboration on zeolite-based tubular membranes.
- Laboratory mixture results and long term lab tests were encouraging.
- Full-length Pilot Scale modules have been successfully tested in lab. Commercial-scale module design has been vetted in lab tests.
- A large demonstration plant is being installed in a site for 6-12 month testing performance with real process stream.

Scale Up Challenges

Membrane Scale-up Challenges

Tubular Zeolite membranes already being manufactured in Commercial scale – Scale-up not an issue.
Membrane Stability with trace components – Long term effects unknown.

Module Scale-up Configuration

Shell and Tube configuration – Sealing issues

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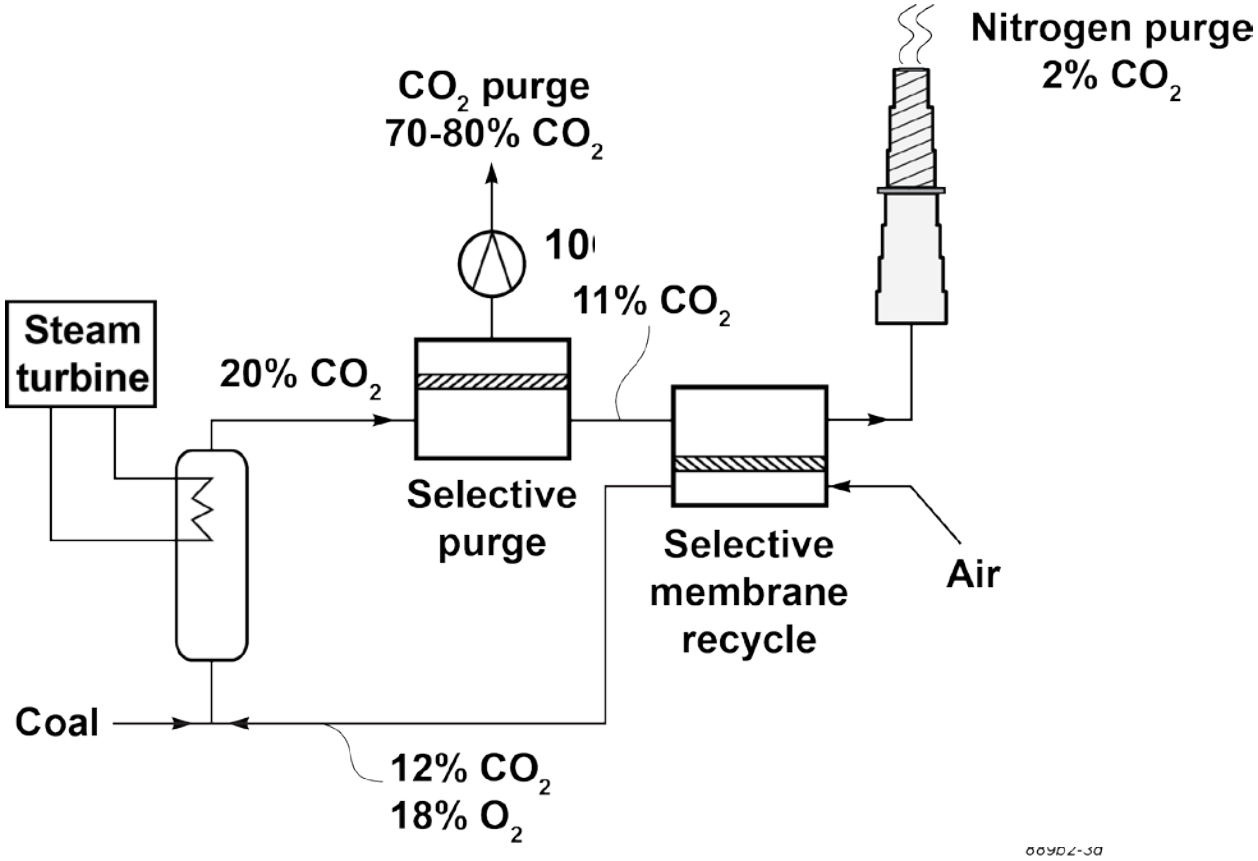
Example 3 – Large Area Applications
Module scale-up Large Area Requirements

Carbon Capture Applications



500 MW_e plant requires one million m^2 of membrane

Low pressure high membrane packing density required

Membrane Plants of these Sizes Exist

The Ashkelon desalination plant

- 1.5 million m^2 membrane area

- 40,000 spiral-wound RO membrane modules
- 7,000 housings

Source: http://www.water-technology.net/projects/israel/

Example 3 – Large Area Applications
Module scale-up Large Area Requirements

Key Challenges

- Skid packing density
- Manifolding
- Footprint Minimization

} Large area, compact module skids

- A sweep process
- Needs low pressure drop

} Needs wide, straight channels on both sides of the membrane

Flat Sheet Plate and Frame modules are a Preferred Configuration

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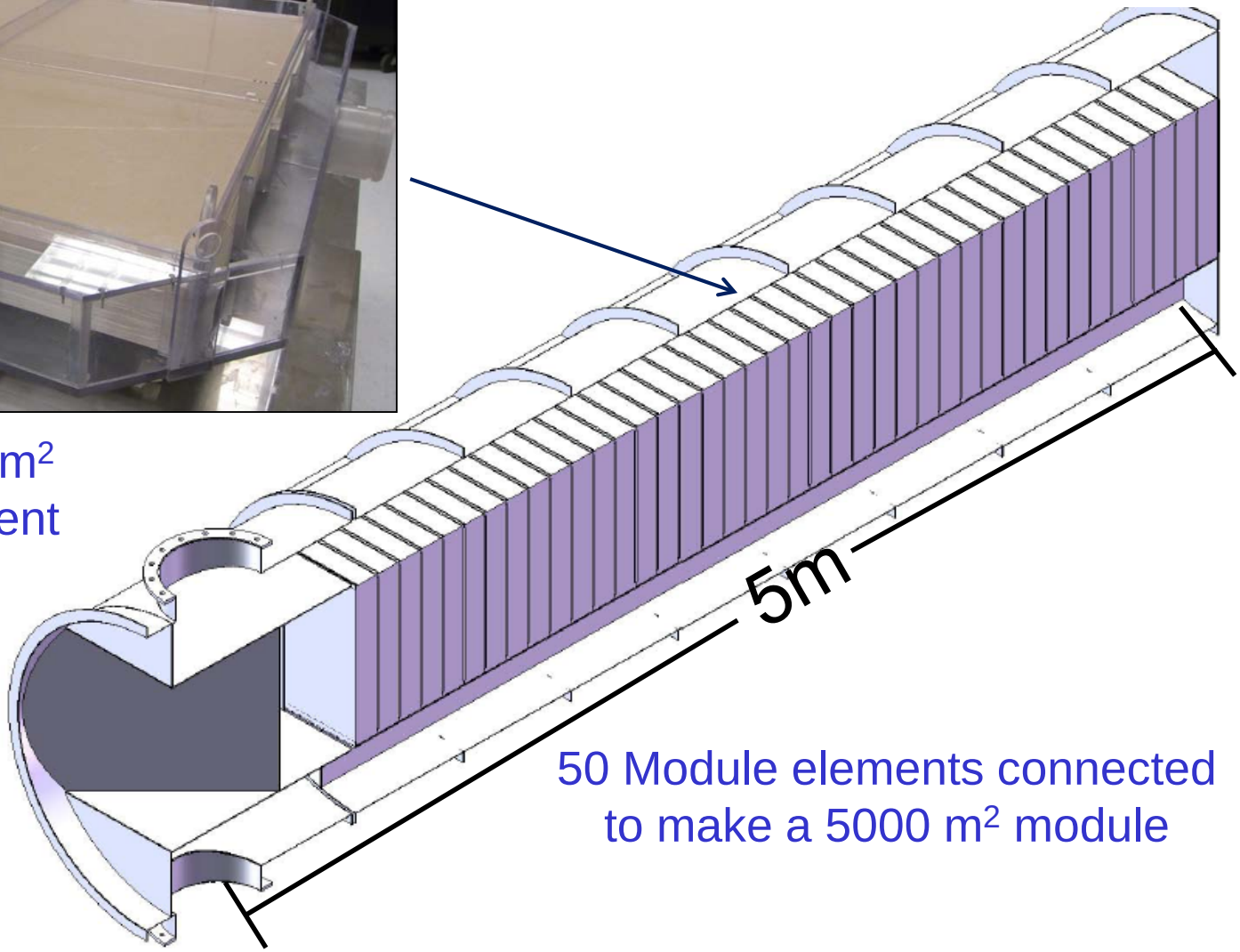
Module Packing Density
Scale-up to Larger modules

- **Year 1**
  - Footprint: 1ft x 2 ft
  - Modules: 20 m^2
- **Year 2**
  - Footprint: 1m x 1m
  - Modules: 100 m^2

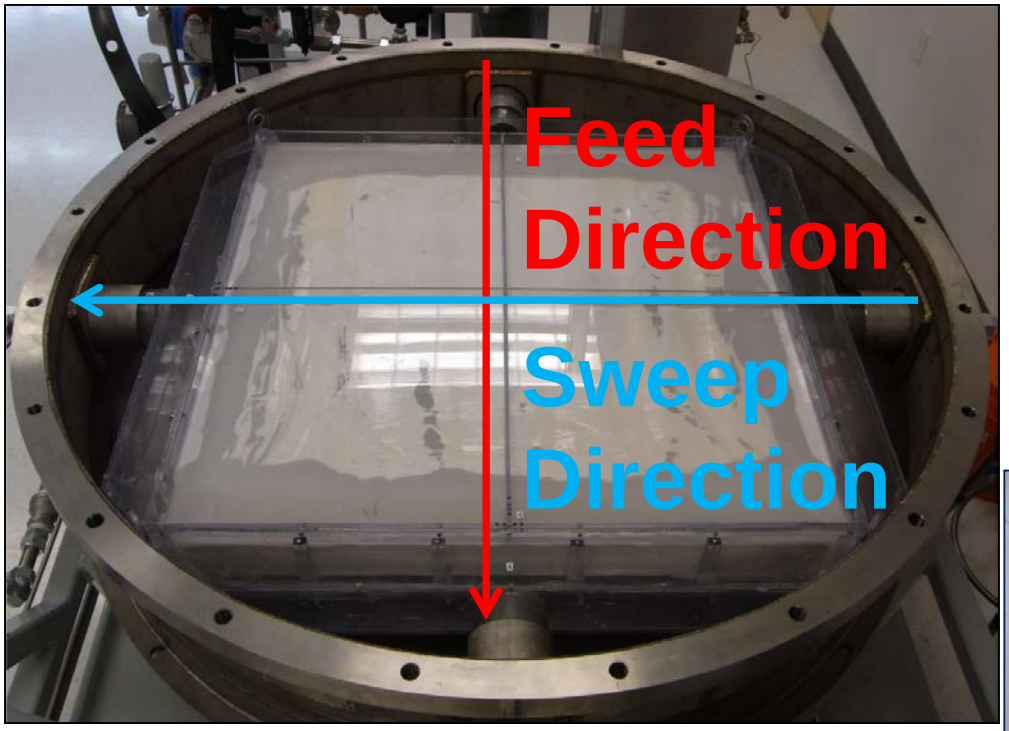
MTR's Approach to Large Compact Packing

A single 100 m^2 module element



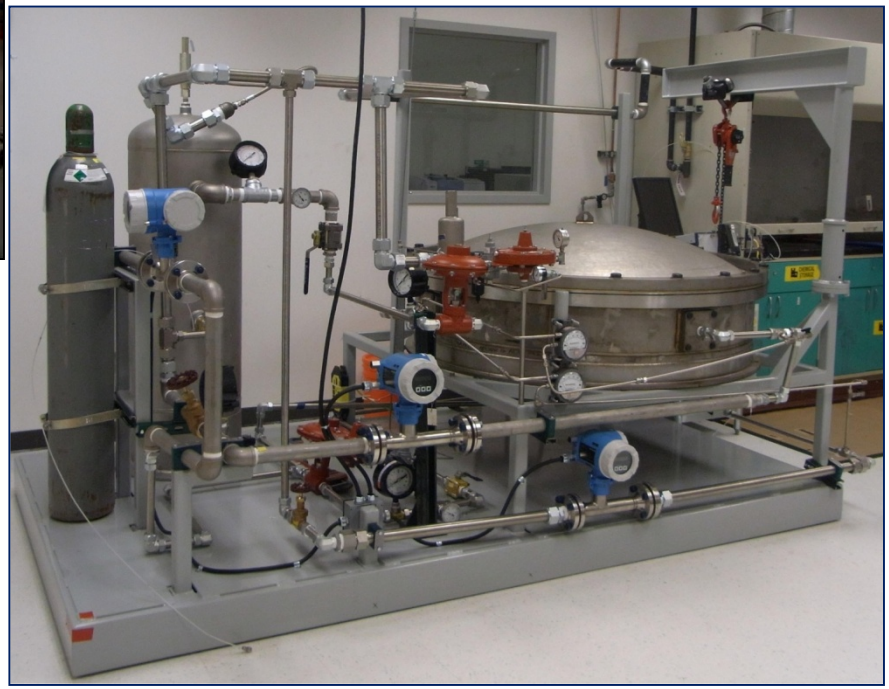
50 Module elements connected to make a 5000 m^2 module

Membrane Module and Test System



Membrane Contactor
with Vessel

Test System



Scaled Modules and Demo System

Summary

- MTR has developed and commercialized the use of membranes for various applications in the Gas, Refinery and Petrochemical industries and has over 300 industrial references all over the world.

- MTR has developed 5 different membrane types from Concept phase to commercial or semi-commercial phase.

- MTR has developed novel Membrane packaging into industrial size modules for commercial use.

- MTR can partner with companies and institutions in developing specific applications using MTR expertise in membrane scale-up, module design, and pilot testing for applications of industrial interest.

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