Membrane Process to Capture Carbon Dioxide from Coal-Fired Power Plant Flue Gas

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Membrane Technology and Research, Inc.

NETL Review Meeting
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Outline

- Project timeline and objectives overview
- Introduction to MTR
- Membrane technology background
- Results to date
  - NT43085
  - NT05312
- Future plans

Project Overview

MTR

Project number NT43085

Project period: 4/1/07 to 3/31/09 | Funding: $788,266 DOE; $197,066 MTR

DOE program manager: Heino Beckert, Bruce Lani | Participants: MTR, DOE

Project scope: Investigate the feasibility of new polymer membranes and process for cost-effective capture of CO_2 from power plant flue gas.

All project objectives were met within time and budget; details follow.

Project number NT05312

Project period: 10/1/08 to 12/31/10 | Funding: $3,439,200 DOE; $957,630 cost share

DOE program manager: Jose Figueroa | Participants: MTR, APS, EPRI, DOE

Project scope: Conduct field demonstration of the MTR membrane process with commercial-sized components at APS's Cholla coal-fired power plant.

At the conclusion of the project, be in a position to gauge the preliminary technical and economic viability of membrane-based CO_2 capture from flue gas.

Introduction to MTR

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

Petrochemicals: Propylene/Nitrogen

Hydrogen (Refinery):

H_2/CH_4, CO, CO_2

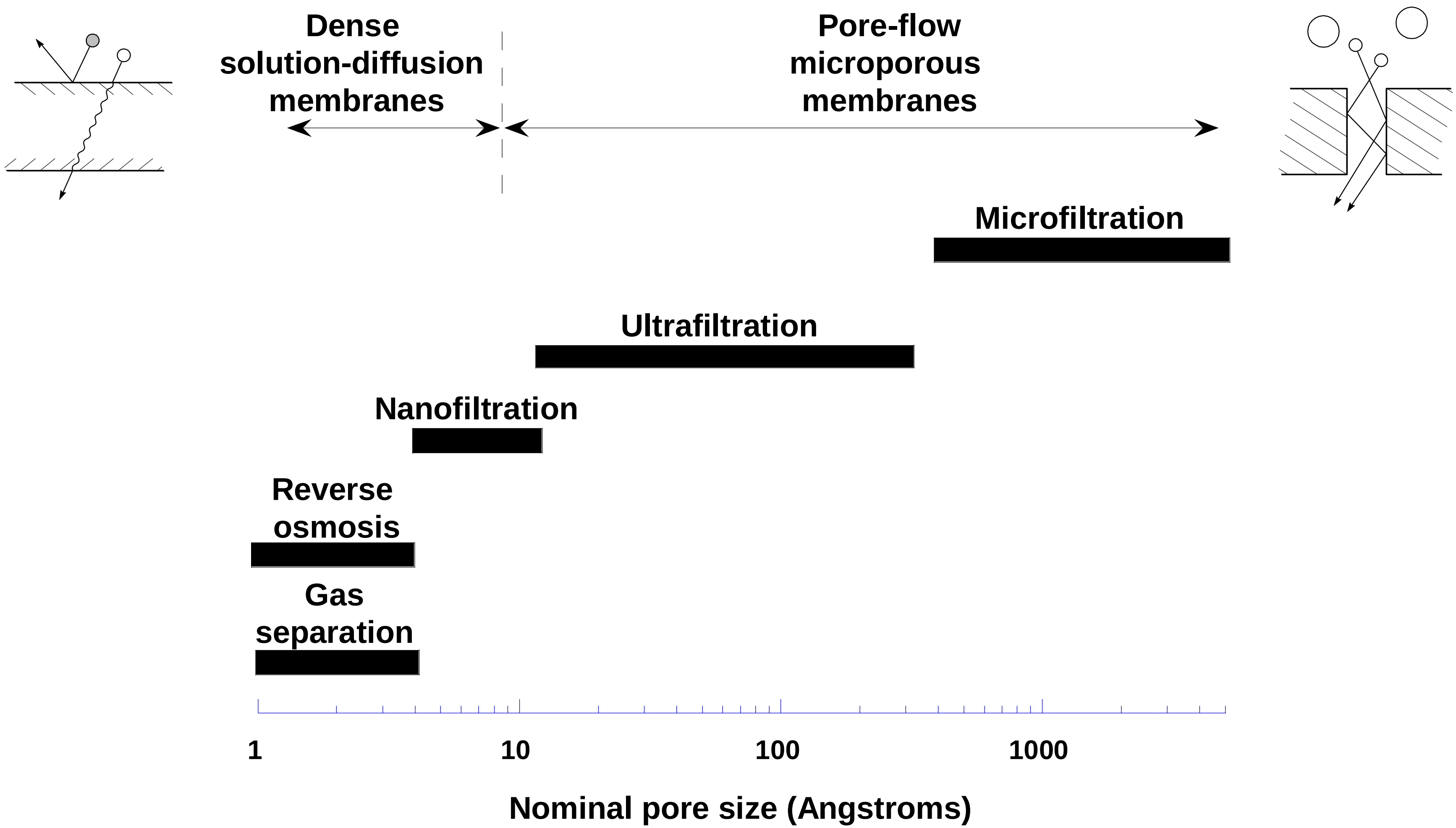
Natural Gas:

CO_2/CH_4, CH_4/N_2

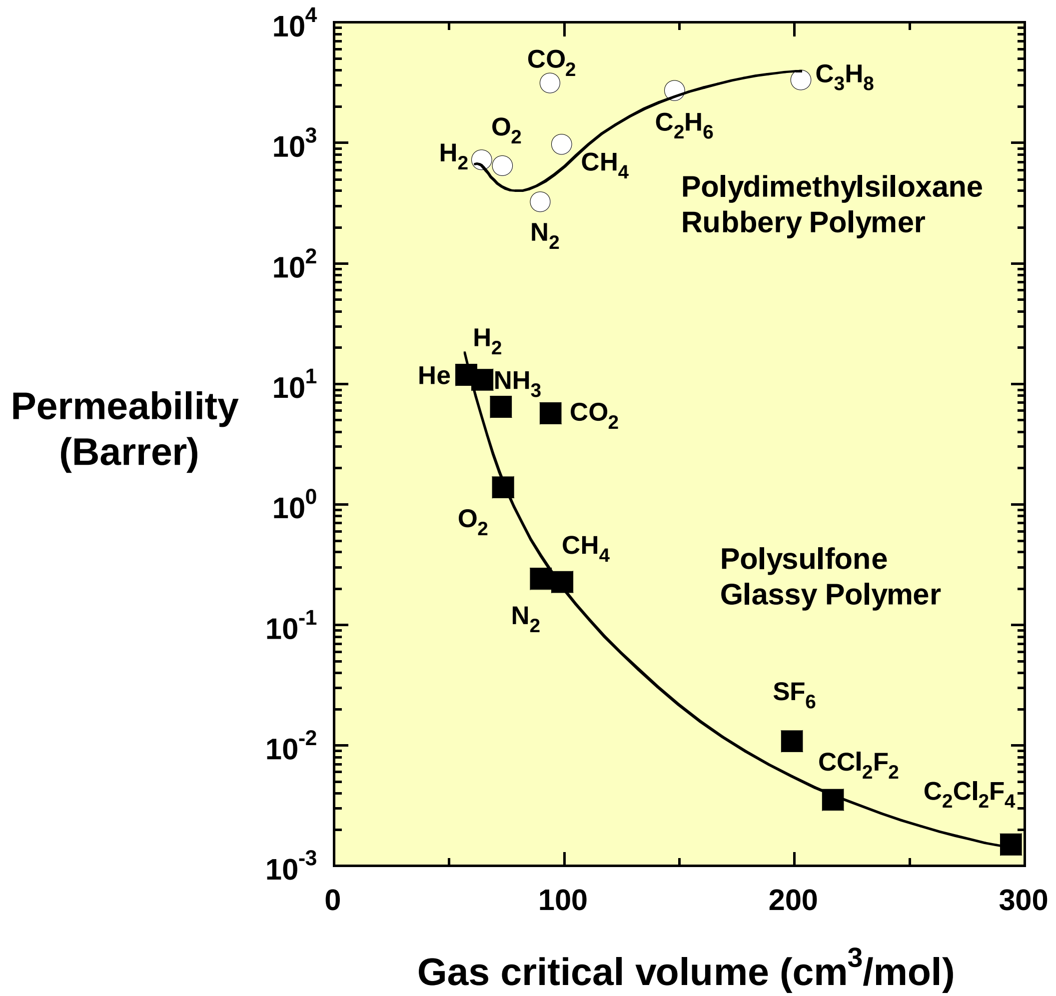
NGL/CH_4

Customers include: BP, Chevron, Dominion Exploration, Ercros, ExxonMobil, Formosa Plastics, Innovene, Sabic, Sasol, Sinopec, Solvay, and Statoil.

Membrane Technology Basics



Membrane Technology Basics



Diffusivity selectivity: favors small molecules

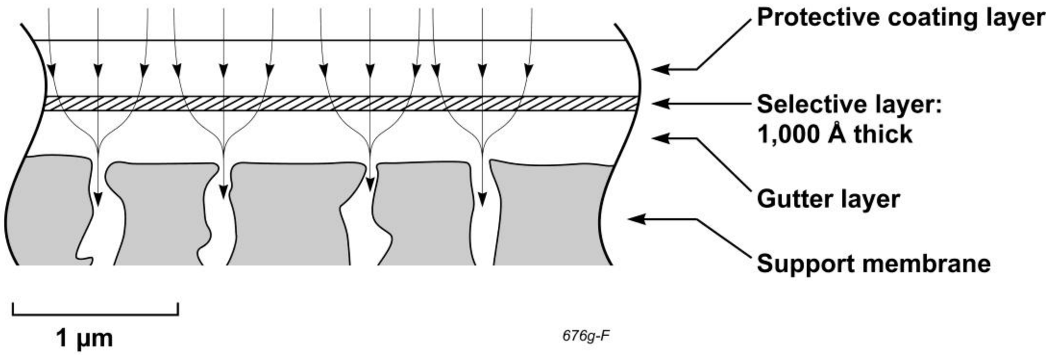
$$\alpha_{A/B} = \frac{P_A}{P_B} = \left(\frac{S_A}{S_B}\right) \times \left(\frac{D_A}{D_B}\right)$$

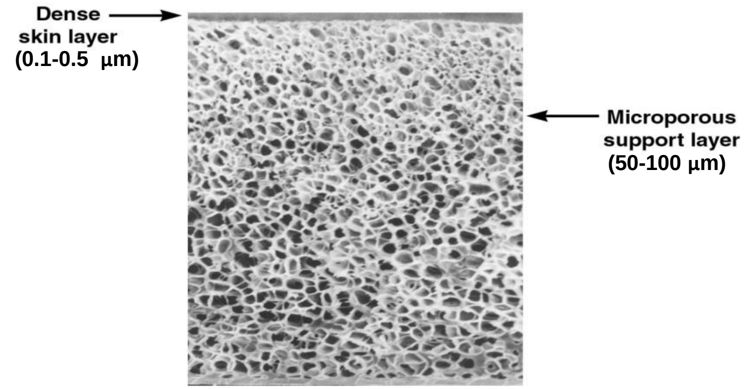
Solubility selectivity: favors large molecules

1 Barrer = 10^{-10} cm^3 (STP) cm / (cm^2 s cmHg)

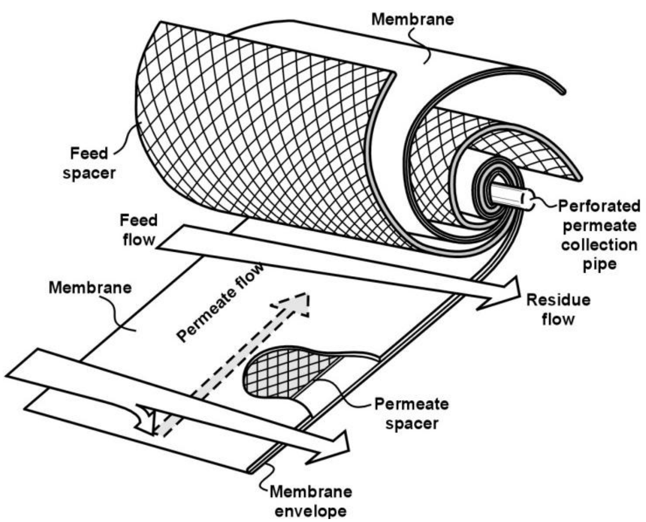
Membrane Technology Basics

- Membranes have to be thin to provide useful fluxes.





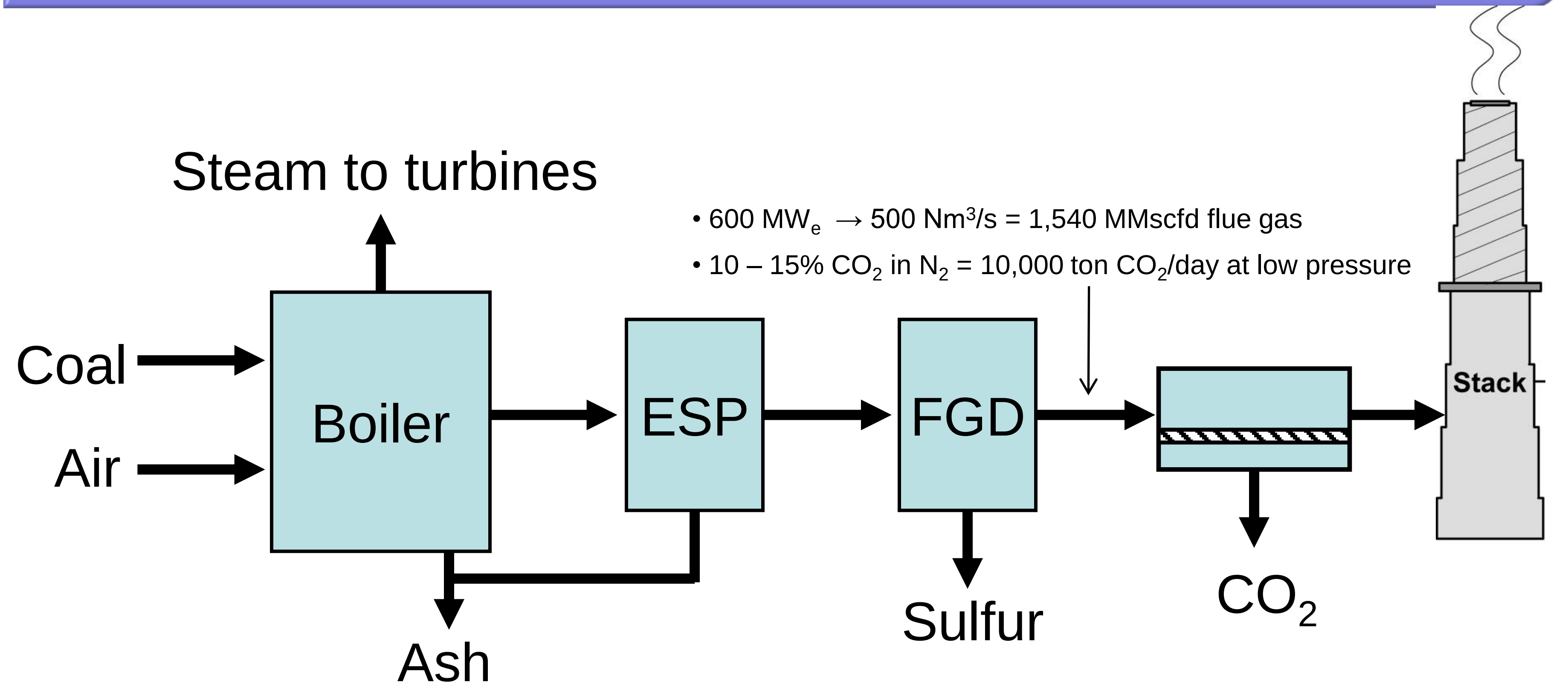
- Spiral-wound modules are used.



Advantages of a Membrane Process

- Simple operation; no chemical reactions, no moving parts, no heating required to recover CO_2, no use of hazardous chemicals
- Tolerance to high levels of wet acid gases; inert to oxygen
- Compact and modular with a small footprint; easily scalable
- Inherently energy efficient (~20 % plant energy at 90% capture)
- No additional water used (recovers water from flue gas)
- No steam use, so no modifications to existing boiler and steam turbine are required

CO_2 Capture at a Coal-Fired Power Plant

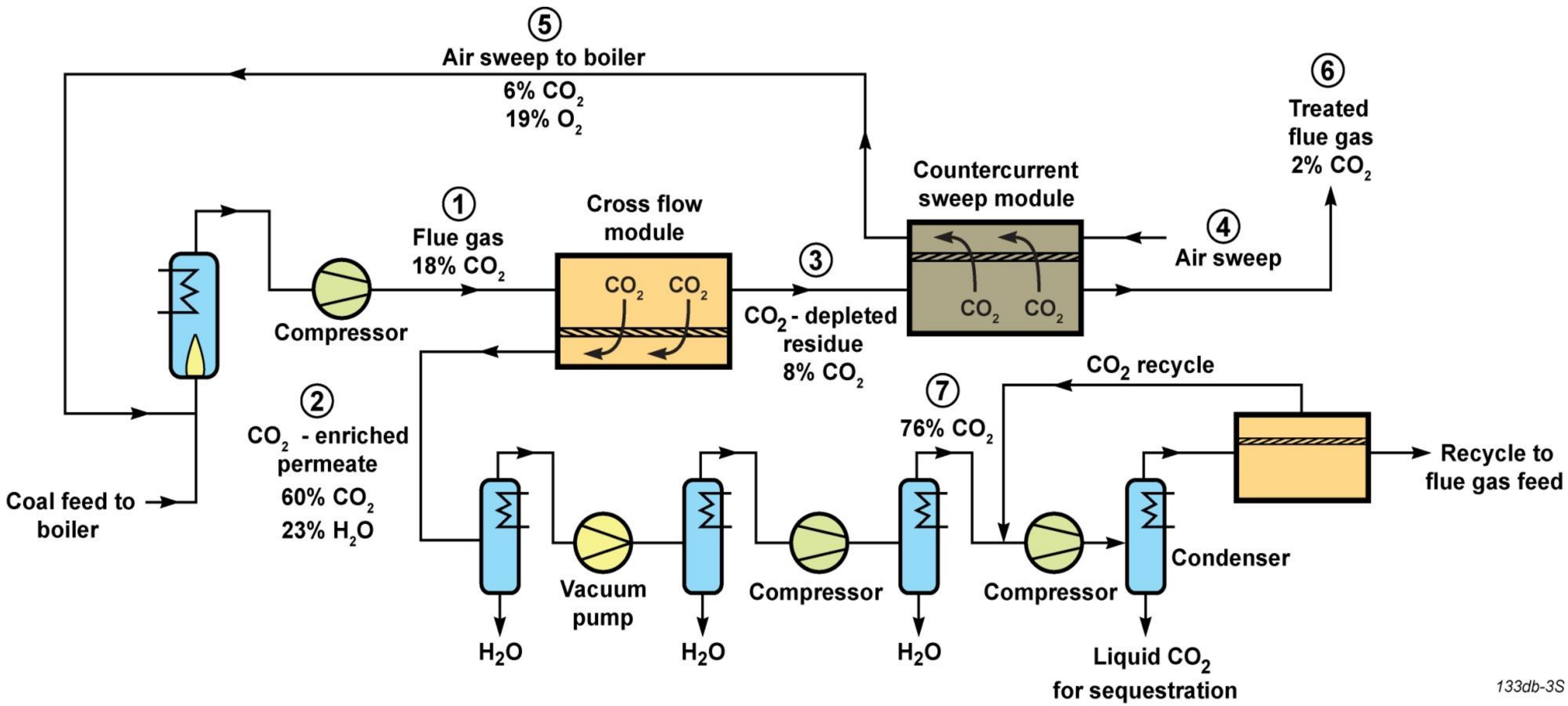


Membrane challenges for treating this large volume of gas:

- Large membrane area needed → high CO_2 permeance is a must!
- How to generate driving force w/o using large compression or vacuum power
- Potential harmful contaminants (fly ash, SO_2, NOx, water, and trace metals) may reduce effectiveness and lifetime.

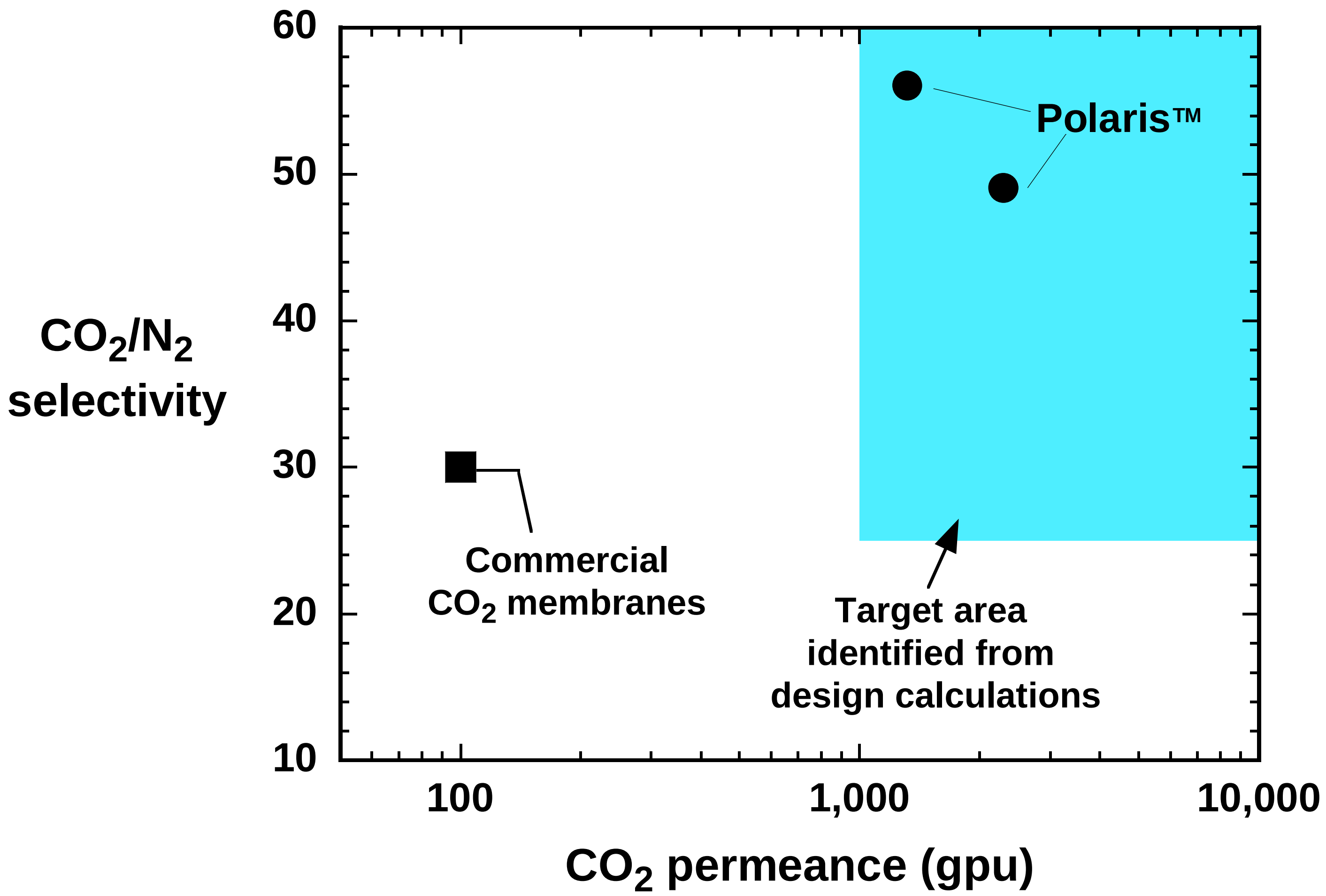
MTR CO_2 Capture Process

MTR



- Countercurrent sweep with combustion air provides “free” driving force that lowers the required energy
- CO_2 recycled in combustion air stream decreases membrane area required

Polaris™ Membranes

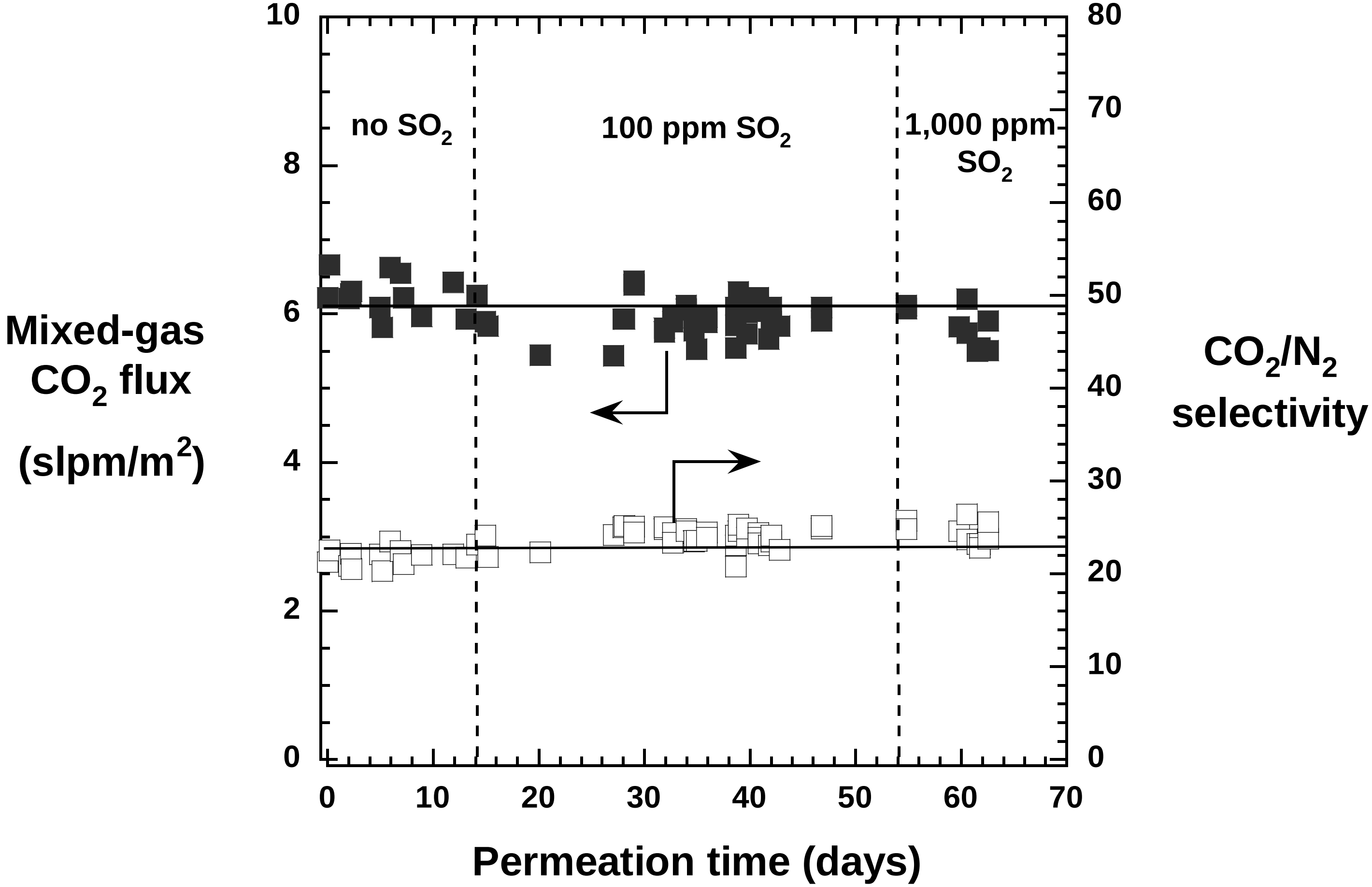


Pure-gas data at 25°C and 50 psig feed pressure

1 gpu = 10^{-6} cm^3(STP)/(cm^2 s cmHg)= 3.35 x 10^{-10} mol/(m^2 s Pa))

Flue gas membranes must be robust

MTR



Feed composition 18% CO_2 in N_2; Temperature: 50°C

Cholla Power Plant Field Test Objectives

MTR

- A six-month field test of 8-inch diameter Polaris™ membrane modules started operation in April 2010
- Capacity is 1 ton CO_2/day

  (1/10,000 of 90% capture from a 600 MW power plant)
- Objectives:
  - Demonstrate performance of commercial-sized modules with real coal-fired flue gas
  - Demonstrate air sweep operation in commercial-sized modules
  - Obtain experience on operating rotating equipment with real flue gas

Field Tests at APS Cholla Power Plant

- A 995 MW PC plant using sub-bituminous coal from the El Segundo mine in New Mexico
- Unit 1 commissioned in 1962; 4 units currently in operation
- MTR membrane skid treats post-FGD flue gas from Unit 3

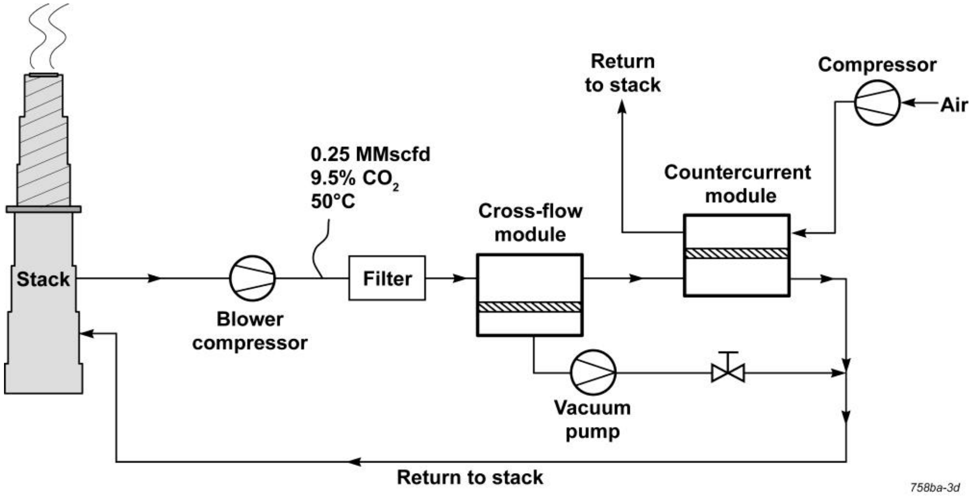
Cholla Power Plant

Flue gas delivery line to membrane

Flue gas vent line

FGD

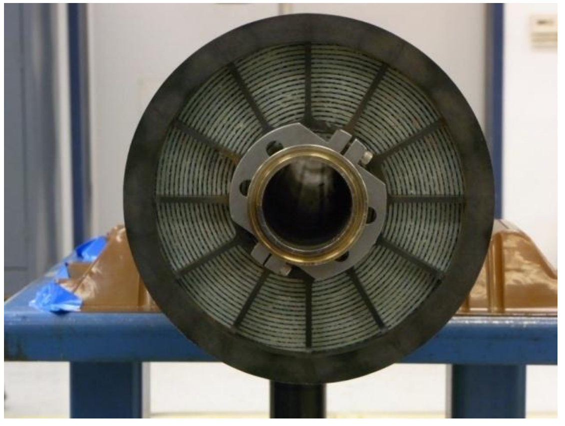
MTR Skid at Cholla



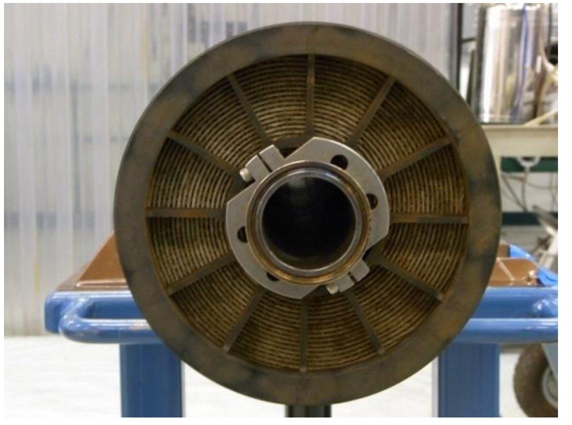
- Skid houses 8-inch diameter cross-flow and countercurrent/sweep modules
- Treats ~0.25 MMscfd of post-FGD flue gas containing about 1 ton CO_2/day (0.05 MW_e)

Preliminary Cholla Test Results

Fresh module



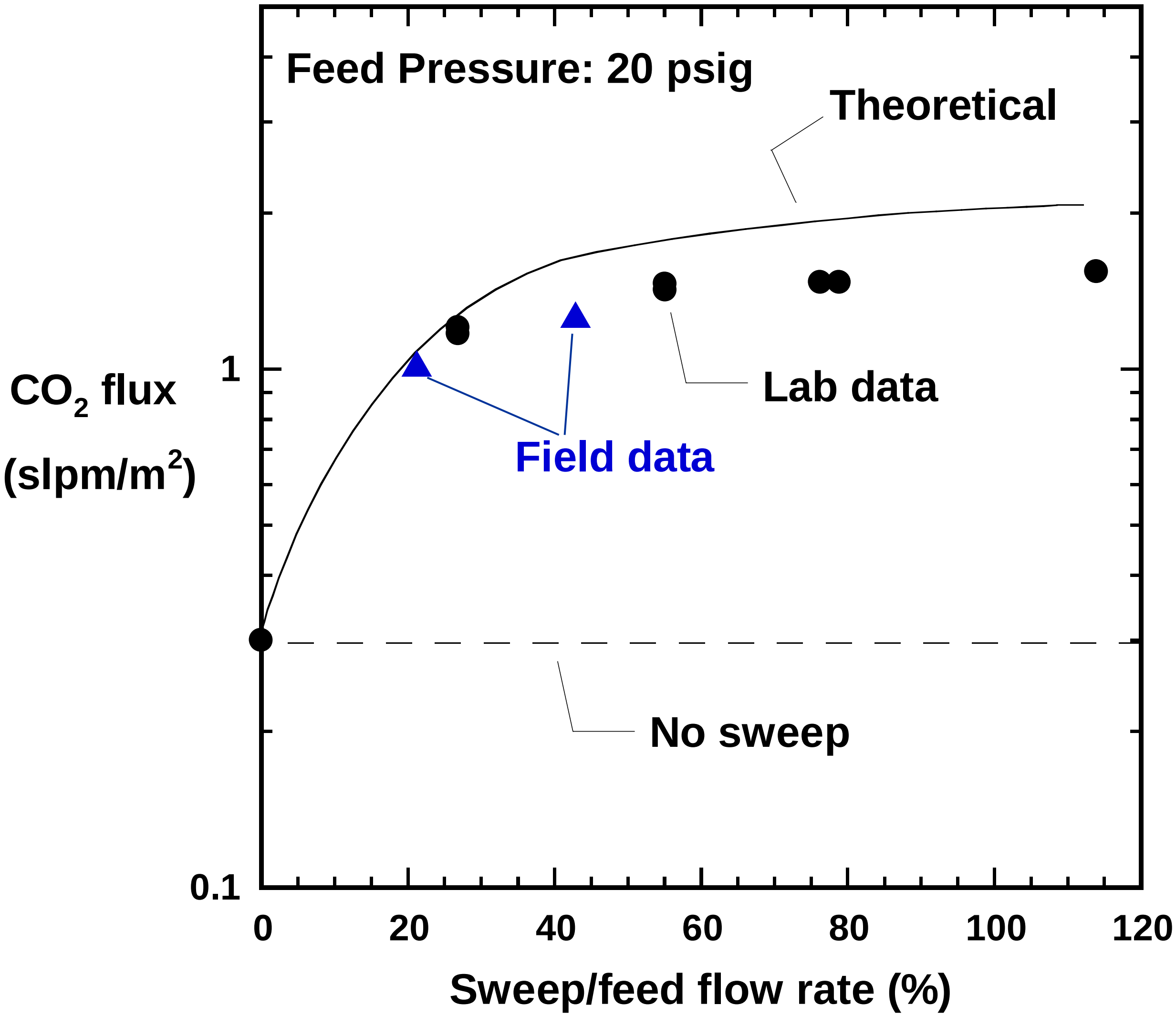
After 45 days operation at Cholla



Module Number	Normalized CO_2 Permeance		Normalized CO_2/N_2 Selectivity	
	Before	After	Before	After
5839 (Cross-flow)	100%	110%	100%	118%
5879 (Sweep)	100%	108%	100%	96%

The module looks rusty, but no performance degradation!

Preliminary Cholla Test Results



- CO_2 flux increases dramatically
- Field and lab data agree well with the simulation

Preliminary Cholla Test Results

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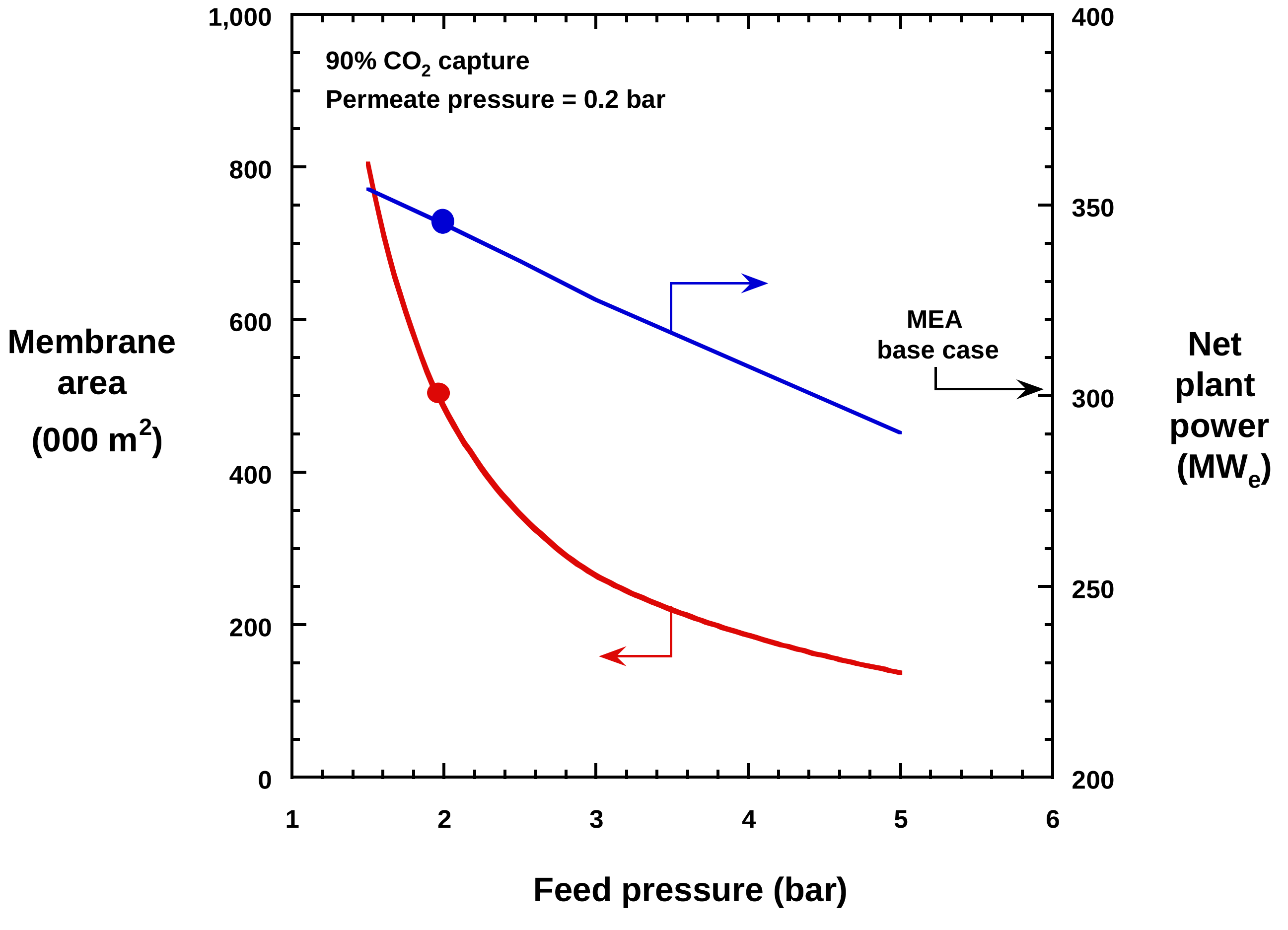
Cumulative Run Time (days)	CO_2 Captured (ton)	Feed CO_2 (%)	Treated Flue Gas CO_2 (%)	1st Permeate CO_2 (%)
1	0.6	9.4	5.0	43.9
15*	0.9	9.4	2.2	43.6
30	0.9	9.6	2.3	43.8

* Increased capture capacity by adding cross-flow modules

- The membrane modules show no performance degradation or pressure drop increases so far
- Most of the early issues are related to water and auxiliary equipment corrosion rather than ash
- Rotating equipment, particularly the feed compressor, bears the brunt of the contaminants (acidic water, particulates)

Energy Use Favors Low Pressure Operation



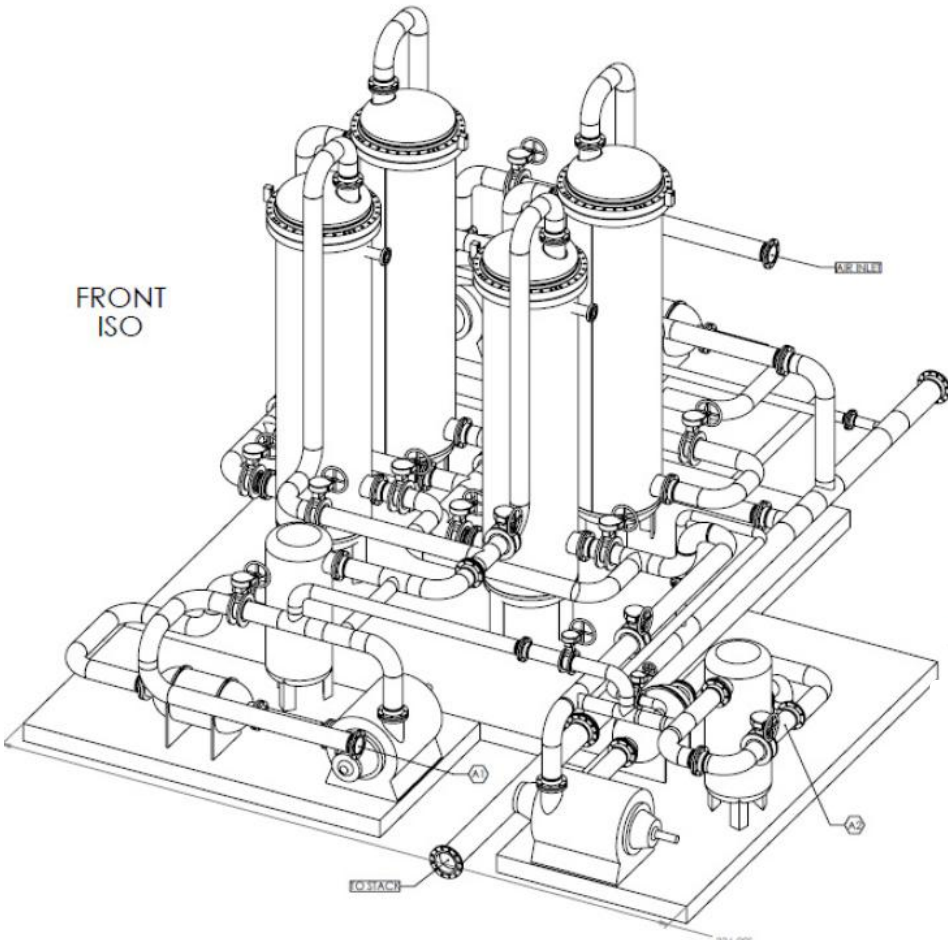
- Net plant output w/o CCS is 434 MW_e
- Base case amine gives 30% energy penalty and 85% increase in LCOE
- Base case membrane process gives 20% energy penalty and 40-45% increase in LCOE

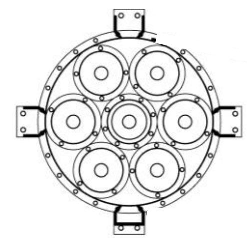
Process conditions, calculation methods, and cost assumptions are based on the DOE baseline report of November 2007 (DOE/NETL-401/110907)

Next Steps: Cholla II

Cholla II skid (20 ton CO_2/day or 1 MW_e) will begin operation in early 2013

FRONT
ISO





Cross section

- Will use vertical module bundles to reduce particulate fouling
- Low-pressure housing, piping, and module components to reduce cost
- Flow distribution will be addressed

Summary

- No technology is a clear winner; membranes have some advantages
- Process design is vital to controlling energy use
- Better membranes (higher permeance, better selectivity, stable) can help competitiveness
- Field demonstrations with real gases are key to determining process viability

Acknowledgements

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