# Tenth Annual Conference on Carbon Capture & Sequestration

*Post Combustion (1)*

## Membranes for Power Plant $CO_2$ Capture: Slipstream Test Results and Future Plans

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MTR Membrane Technology & Research

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# Outline

- Introduction to MTR
- Brief overview of membrane technology
- Membrane designs for $CO_2$ capture
- Field test results
- Next steps

# Introduction to MTR

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

Petrochemicals: Propylene/Nitrogen

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

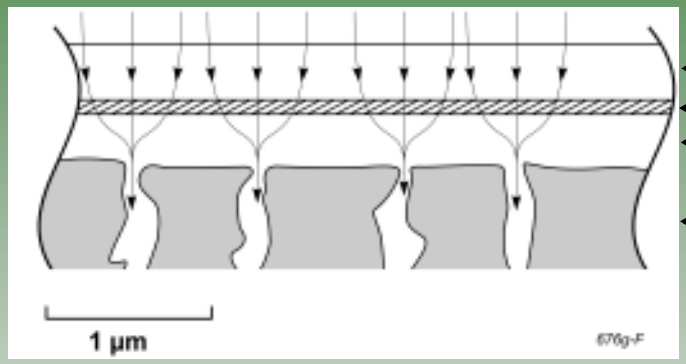
Natural Gas:

$CO_2/CH_4$, $CH_4/N_2$
$NGL/CH_4$

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

# Membrane Technology Basics

- Membranes have to be thin to provide useful fluxes.



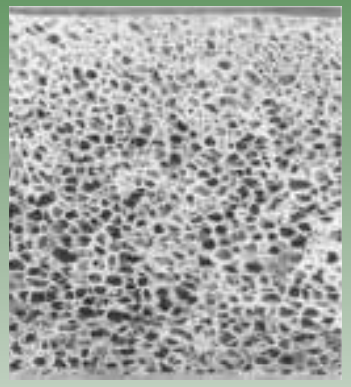

Protective coating

Selective layer
0.1 – 5 µm thick

Gutter layer

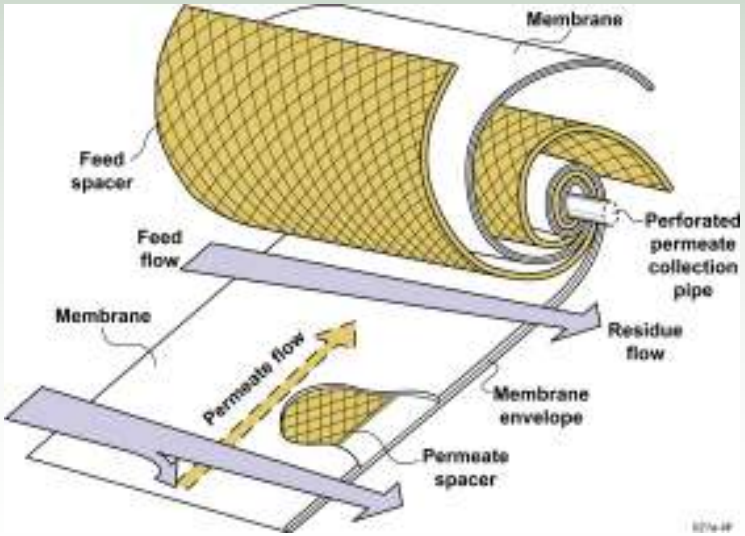
Support membrane

Dense
skin layer
(0.1-5 µm)

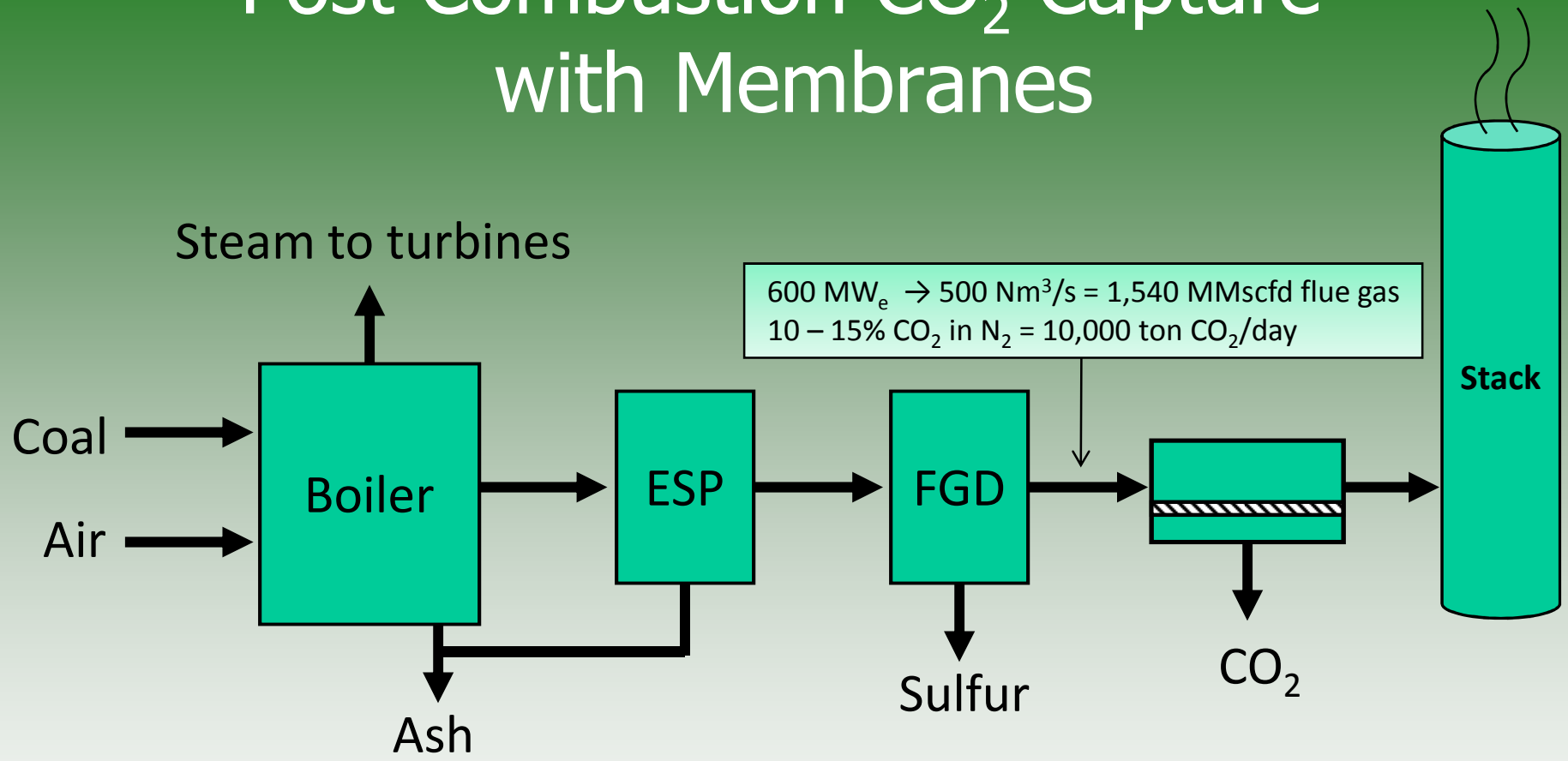


Microporous
support layer
(50-100 µm)

- Membranes are packaged in modules for industrial separations.



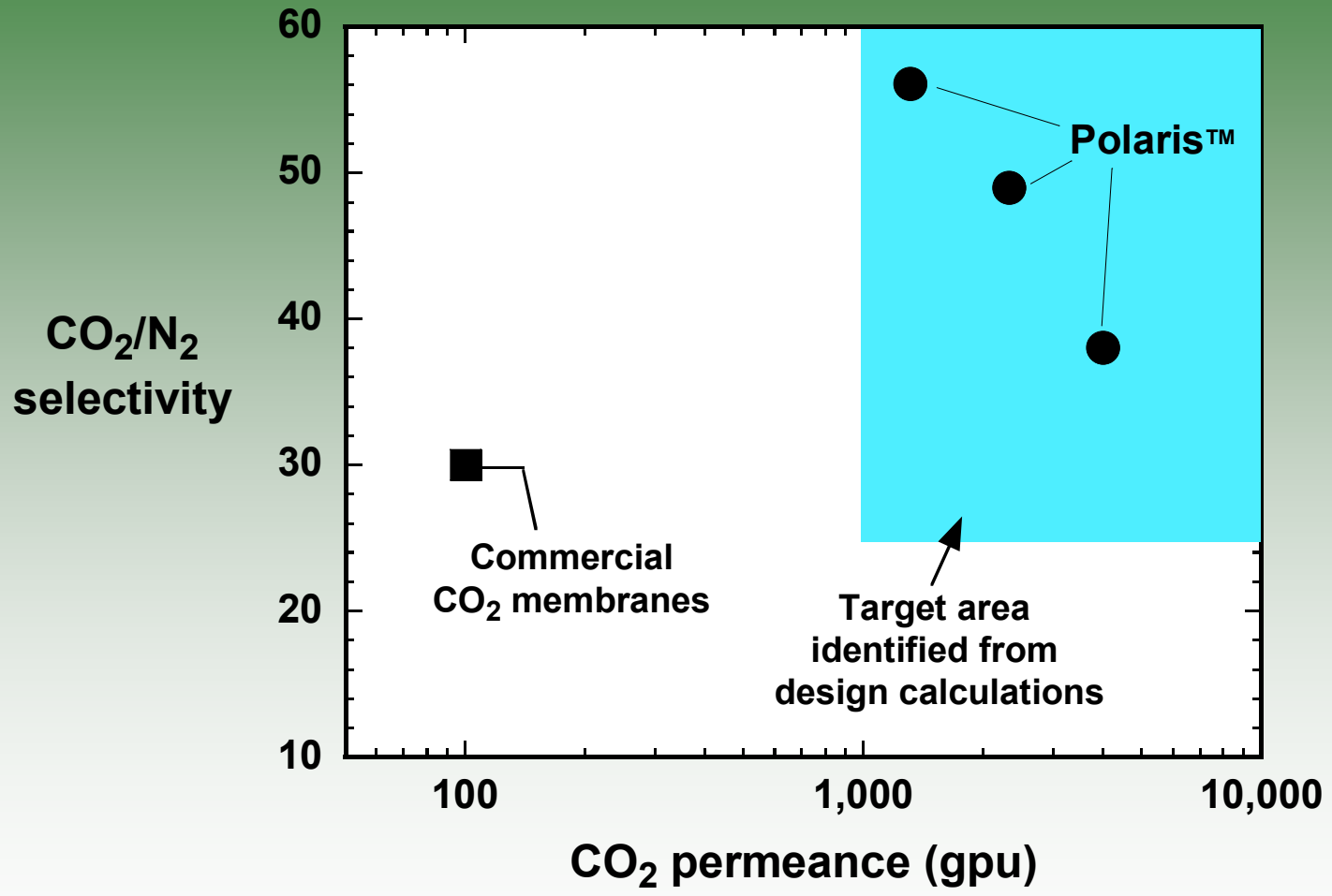

# Post Combustion $CO_2$ Capture with Membranes




The key membrane challenges for post-combustion $CO_2$ capture are:

- Large flue gas flow rate will require large membrane area → to be affordable, membranes must have very high $CO_2$ permeance.
- Membranes require partial pressure driving force to separate gases. How to generate this driving force affordably?

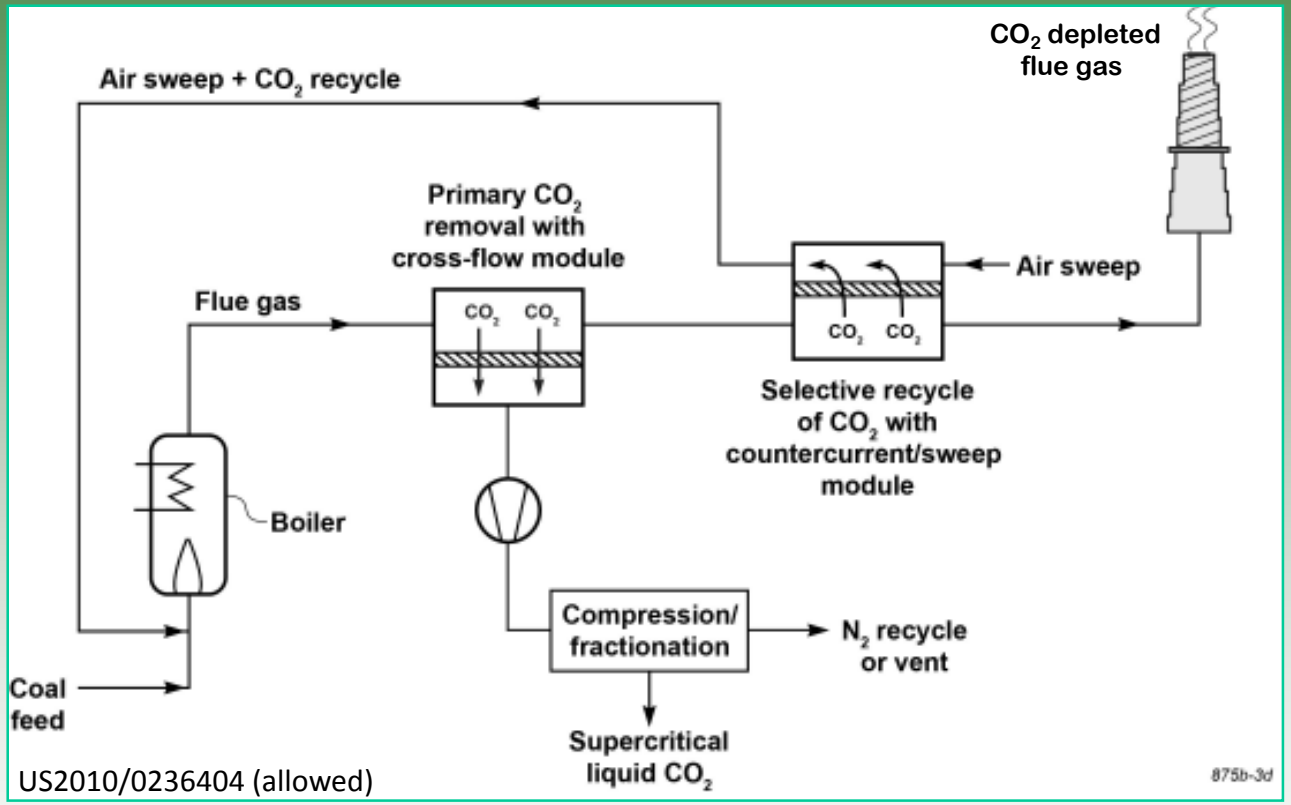
# MTR Polaris™ $CO_2$ Capture Membranes




At equivalent selectivity, Polaris is 50 times more permeable than conventional $CO_2$ membranes

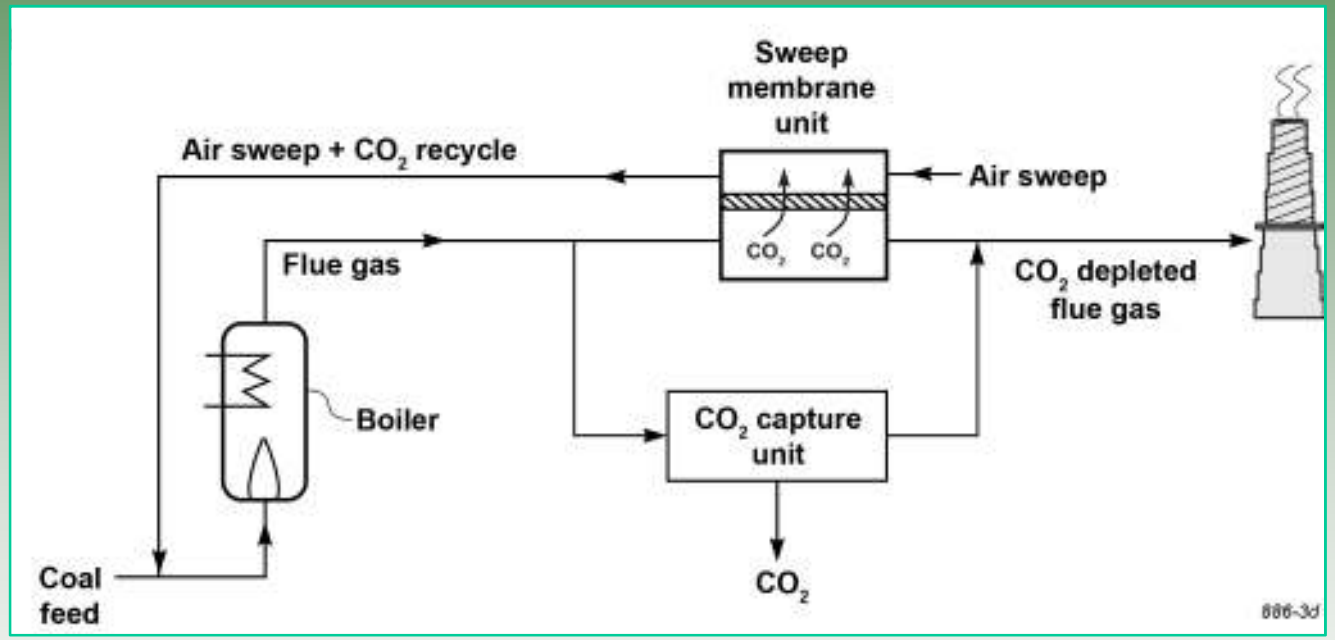
1 gpu = $10^{-6}$ $cm^3(STP)/(cm^2\ s\ cmHg)$= 3.35 x $10^{-10}$ $mol/(m^2\ s\ Pa)$;

# Membrane Process Designs for $CO_2$ Capture: (1) Serial Membrane




- Selective recycle by sweep membrane allows $CO_2$ to be pre-concentrated with almost no energy input
- Capture step only needs to do 50% $CO_2$ removal in a single pass
- Process uses ~20% of plant energy at 90% $CO_2$ capture

# Membrane Process Designs for $CO_2$ Capture: (2) Parallel Hybrid




- Parallel design avoids the use of any compression or vacuum equipment
- For coal, sweep membrane can double the $CO_2$ concentration and halve the flow rate going to the capture step with little energy input
- For natural gas, an enrichment factor of 4 to 5 can be achieved

# Slipstream Tests at APS Redhawk

- Redhawk is a 1,060 $MW_e$ natural gas combined cycle power plant located near Phoenix, Arizona
- Membrane system uses one 8-inch diameter Polaris module


- System captured 250 lb $CO_2$/day for delivery to an algae biofuel farm
- Ran smoothly in fall 2009 and showed stable membrane performance

# Slipstream Tests at APS Cholla

- A 995 MW PC plant using sub-bituminous coal from the El Segundo mine in New Mexico
- Unit 1 commissioned in 1962; currently 4 units in operation


- MTR membrane skid treats post-FGD flue gas (50 ppm $SO_2$) from Unit 3
- 0.25 MMscfd of flue gas fed to the membrane unit

# MTR Test Skid at Cholla

- Skid houses 8-inch diameter cross-flow and counter-current sweep modules
- Designed to capture 1 ton $CO_2$/day
- Field test ran April – July 2010


- Objectives were to (1) investigate membrane lifetime and (2) demonstrate sweep with commercial-sized modules

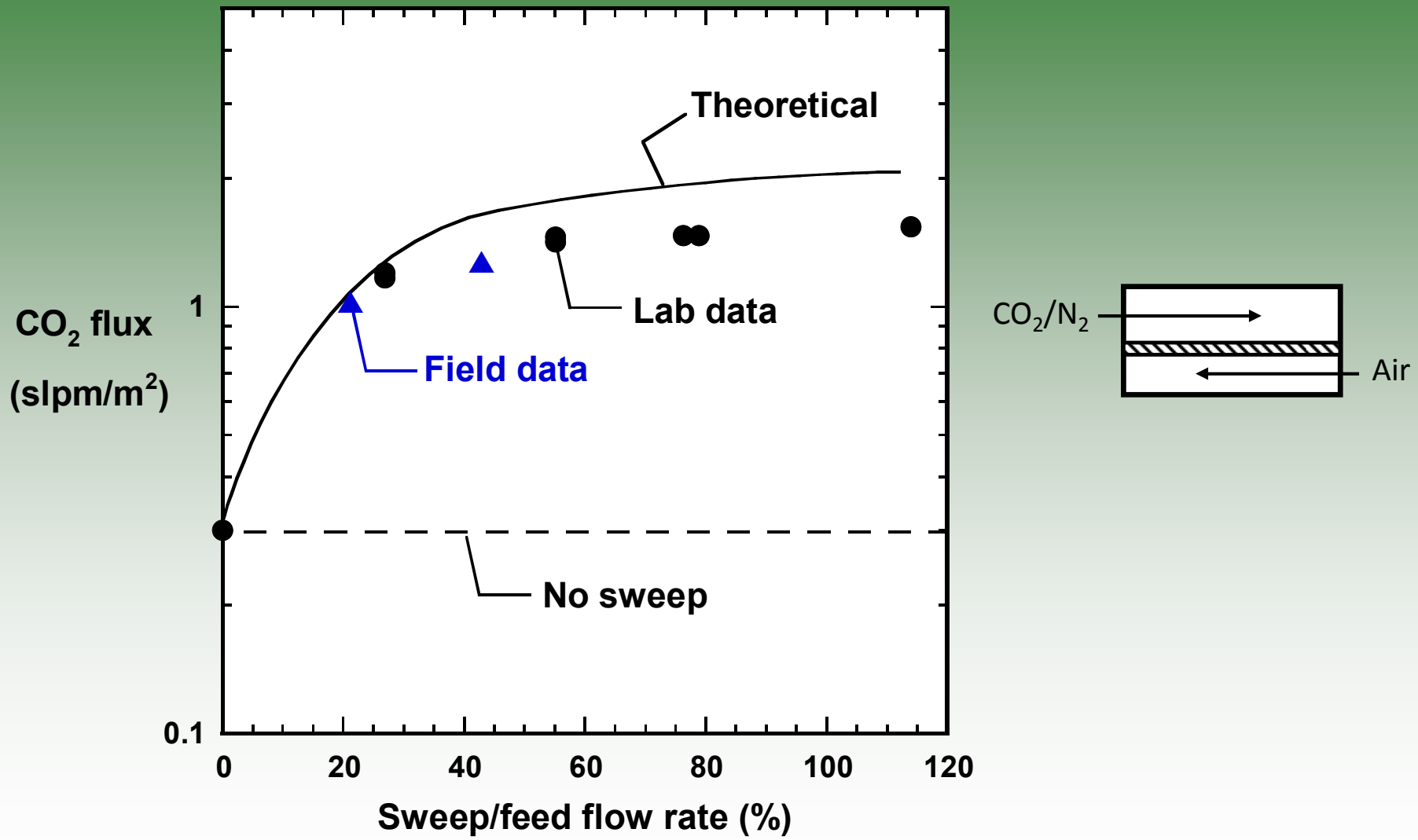
# Cholla Test Results

Fresh module

After 45 days operation at Cholla

| Module Number | Module Performance after Testing at Cholla | |
|---|---|---|
| | Normalized $CO_2$ Permeance | Normalized $CO_2/N_2$ Selectivity |
| 5839 (Cross-flow) | 110% | 118% |
| 5879 (Sweep) | 108% | 96% |

# Sweep Modules Work in the Field

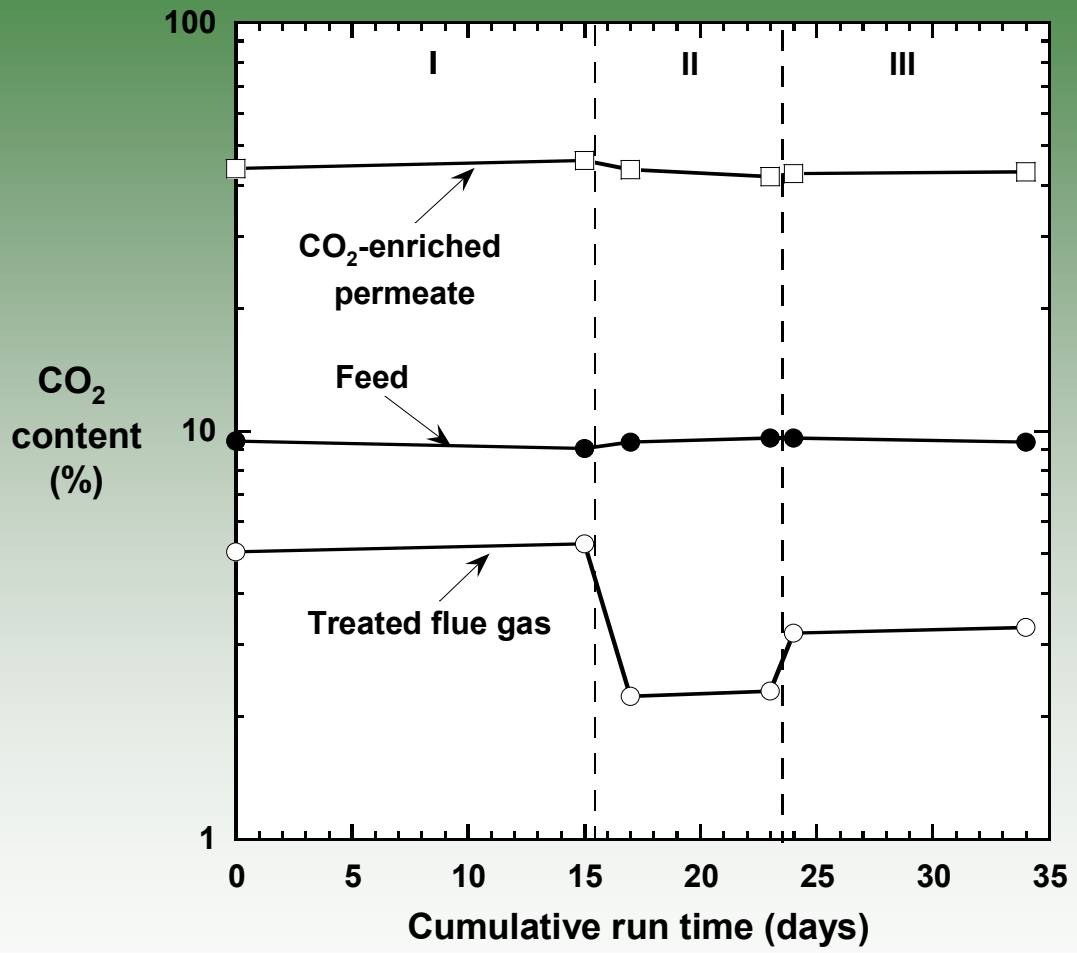







MTR

# Cholla System Performance Over Time




- I → II: increased membrane area; II → III: reduced feed pressure

# Future Plans

- Currently building a 20 ton $CO_2$/day (1 MW) membrane capture system; a 6 month demonstration is scheduled for 2013

**Ashkelon desalination plant**

- 1.5 million $m^2$ membrane area

**Flue gas membrane vessels**

- 0.5 million $m^2$ or ~100 module vessels required for 550 $MW_e$ plant with current membranes
- Double permeance → halve the vessels

# Summary

- Many technologies are being evaluated for post-combustion $CO_2$ capture; membranes may play a role
- MTR's novel air sweep design can be used as a $CO_2$ concentrator to reduce $CO_2$ capture energy requirements
- Slipstream tests at natural gas and coal-fired plants with commercial-scale modules show stable performance
- A 1 MW demo unit is being built
- higher membrane permeance will reduce footprint and cost

# Acknowledgements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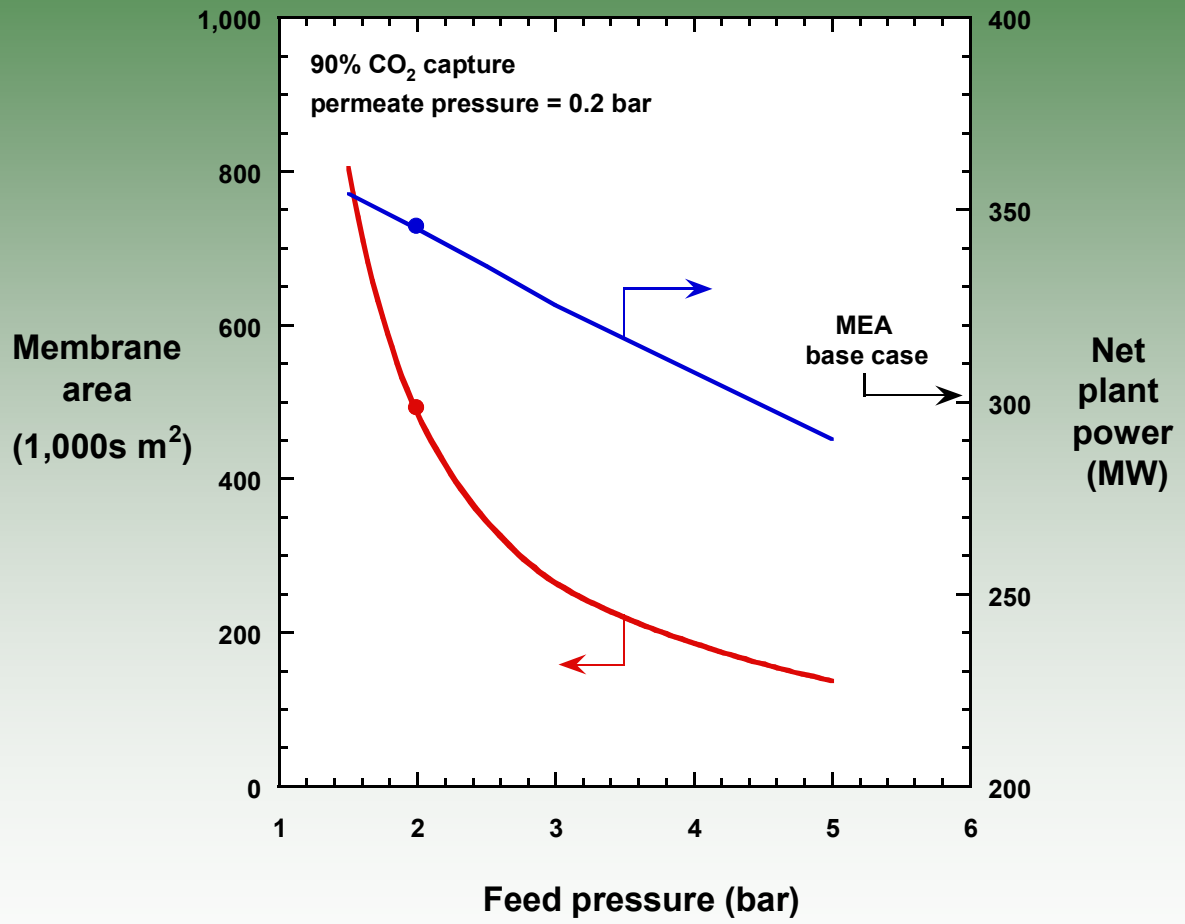
  - Abhoyjit Bhown

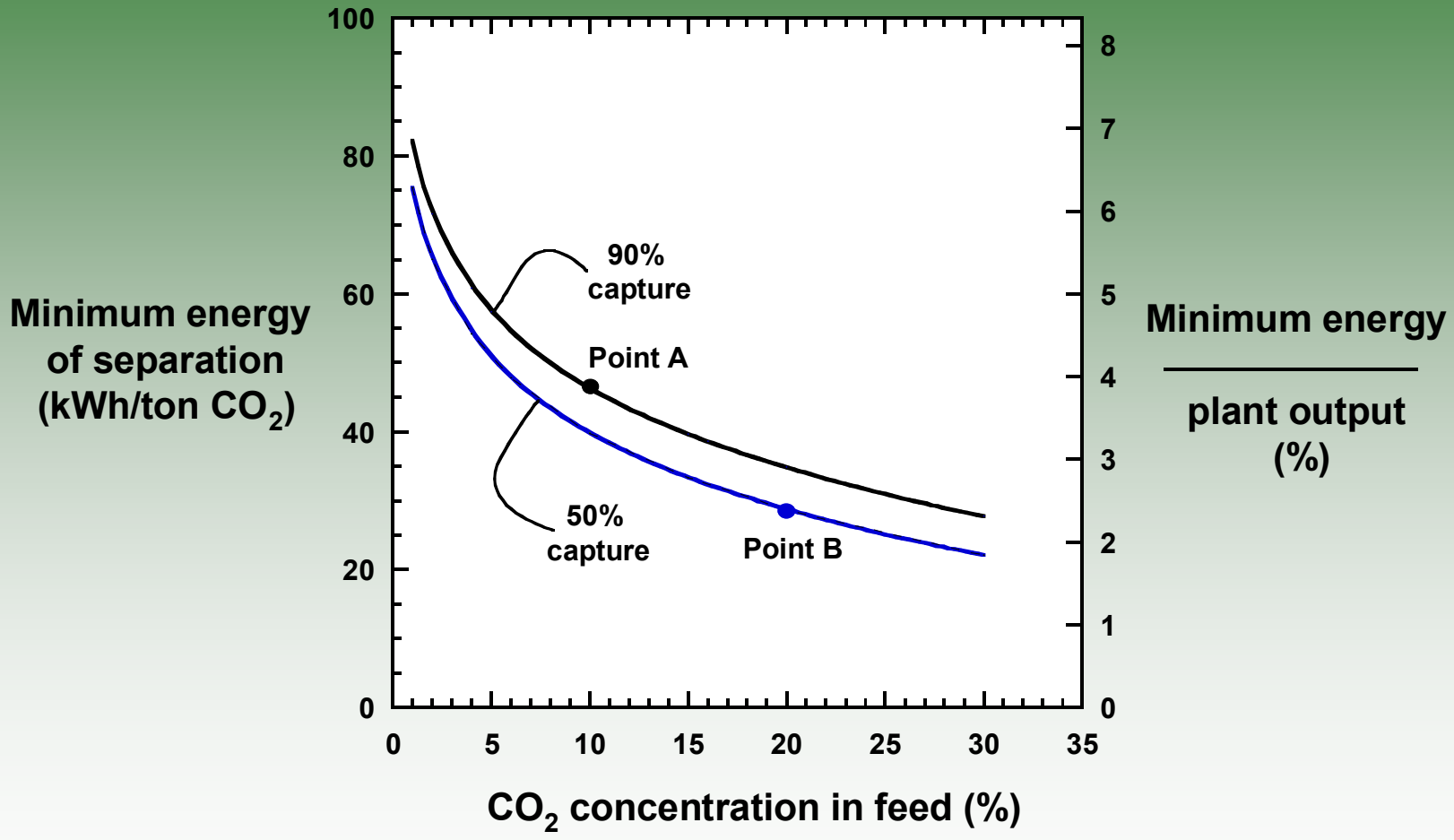
# Energy Use Favors Low Pressure




- Net plant output without CCS is 434 $MW_e$
- At low feed pressures, the membrane process can give lower energy use than the MEA base case

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

# Sweep Reduces Minimum Energy of $CO_2$ Capture




- Energy of separation = change in Gibbs free energy to take a $N_2$-$CO_2$ mixture at 1 bar and 25°C to pure $CO_2$ at 150 bar and 25°C

# Advantages of a Membrane Process

- Simple operation; a passive, continuous process
- No use of hazardous chemicals; no chemical handling or disposal issues
- Tolerance to high levels of $SO_x$ and $NO_x$; inert to oxygen
- Compact and modular; easily scalable; easy turndown
- Inherently energy efficient (20% parasitic energy at 90% capture)
- Recovers water from flue gas
- No steam use, so no modifications to existing boiler and steam turbine are needed
- Builds on existing, low-cost technology already used at a similar scale for water desalination and natural gas treatment