CO_2 Separation and Sequestration from Flue Gas with Membranes

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

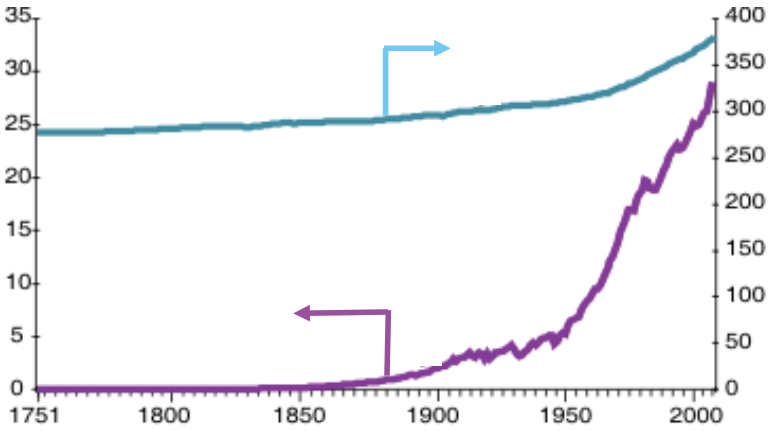
APS

Outline

- The nature of the problem
- Brief review of membrane gas separation technology
- Membrane-based CO_2 capture from power generation
- Where we are now
- The future

Atmospheric CO_2 Content is Increasing

CO_2 emissions (billion metric tons)



Atmospheric CO_2 concentration (ppm)

Source: Oak Ridge National Laboratory, Carbon Dioxide Information Center

1 billion metric tons CO_2 = 1 gigaton CO_2 > mass of all humans

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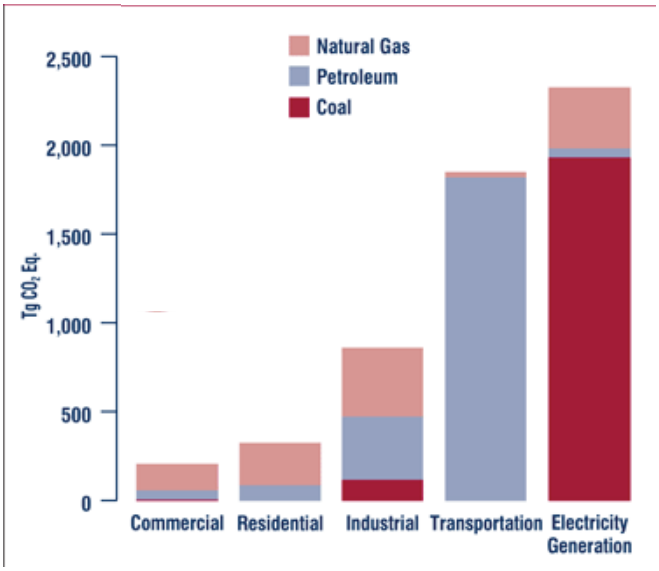
> 40% of U.S. CO_2 Emissions are Produced During Electricity Generation



- Rules of thumb:
  Coal → power
  Oil → transportation
  Natural Gas → mixed
- 1,100 coal-fired power plants in the U.S.
- 5,000 coal-fired power plants worldwide
- Coal generates 60% more CO_2 per MW compared to natural gas

Source:
http://epa.gov/climatechange/emissions

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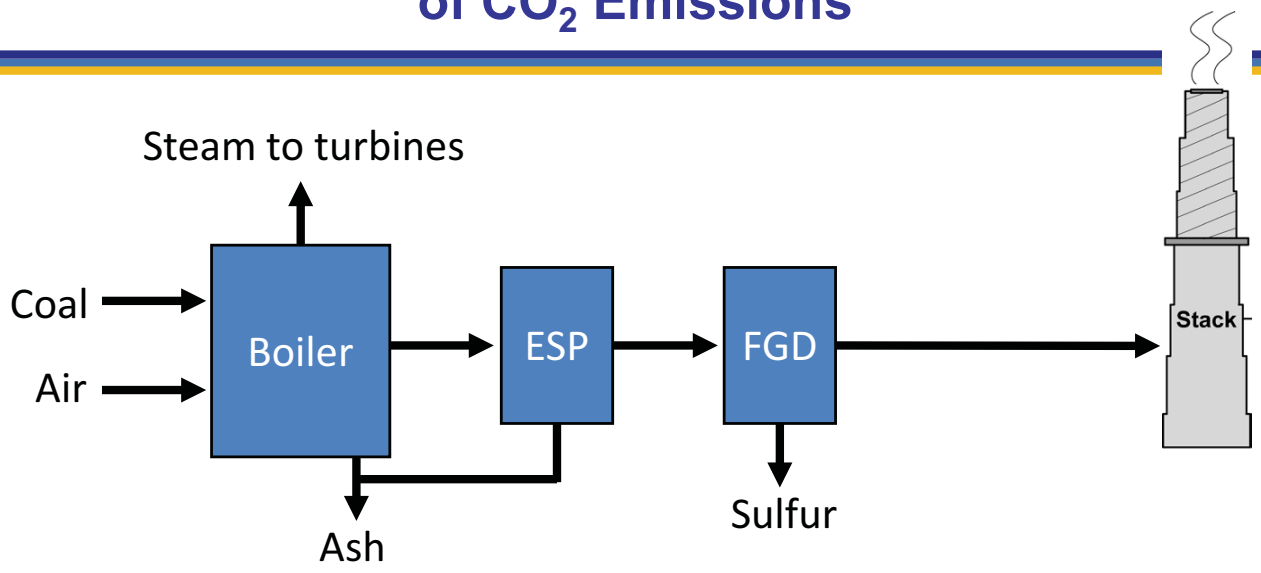
Coal-Fired Power Plants are Large Point Sources of CO_2 Emissions



600 MW_e plant emits ~10,000 tons CO_2/day

- Gas is at atmospheric pressure, contains ~10-13% CO_2 and is dirty: fly ash, SO_2, No_x, and trace metals are present.
- Several CCS technologies are being considered (absorption, adsorption, membranes)

Membrane Technology and Research

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

Petrochemicals: Propylene/Nitrogen

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

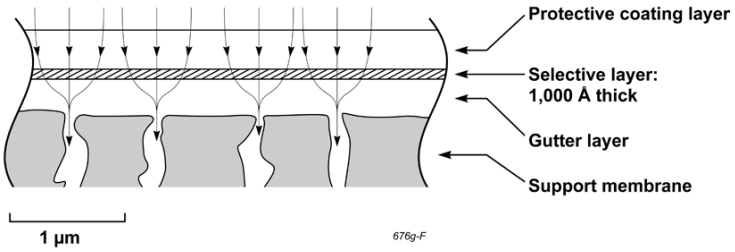
Natural Gas:

CO_2/CH_4, CH_4/N_2
NGL/CH_4

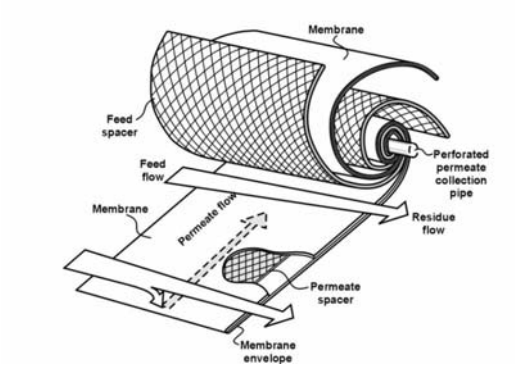
Customers include: BP, Chevron, Dominion Exploration, Ercros, ExxonMobil, Formosa Plastics, Innovene, Sabic, Sasol, Sinopec, Solvay, and Statoil.

MTR Uses Composite Membranes Packaged as Spiral Wound Modules

- Composite membranes are thin to provide useful fluxes.

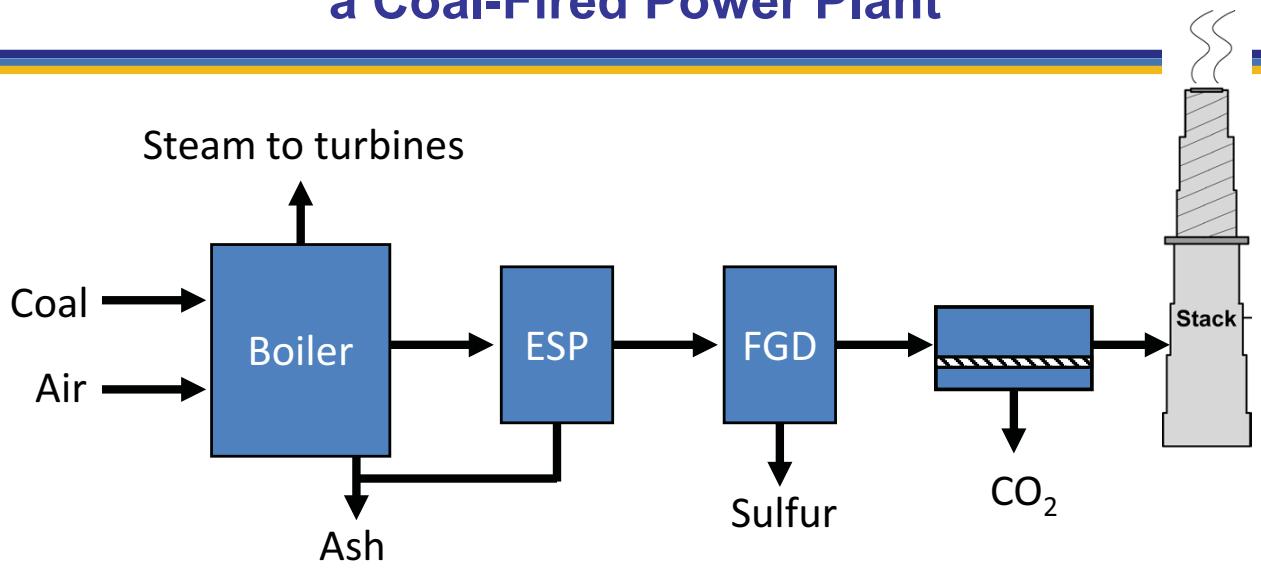


- Spiral-wound modules



Each module contains 20 to 100 m^2 of membrane

CO_2 Capture with Membranes at a Coal-Fired Power Plant

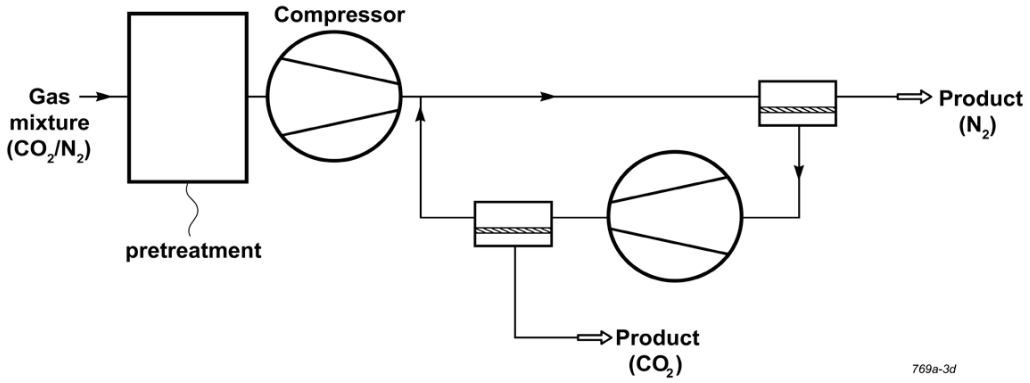


Membrane challenges for treating this large volume of gas include:

- Large membrane area needed • high CO_2 permeance is a must!
- How to generate driving force w/o using large compression or vacuum power
- How to handle contaminants

Lessons from the Current Industry

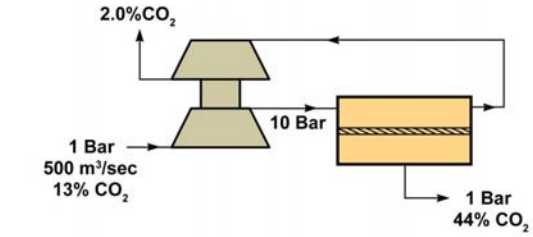
Membrane plant design as drawn by a plant purchaser



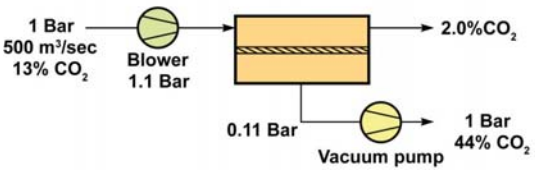
- Compressor electricity cost is significantly more than the annualized module replacement cost.
- A two megawatt (2,000 kW) compressor costs $1,000,000 and uses $1,200,000 electricity/y

Compression or Vacuum Operation

Pressure ratio = 10, α = 50, P/ℓ = 1,000 gpu, efficiency = 0.8
90% CO_2 recovery



Compressor	239.6 MW
Turboexpander	(-79.1 MW)
Total energy	160.5 MW
Membrane area	0.56 x 10^6 m^2



Blower	7.2 MW
Vacuum pump	55.1 MW
Total energy	62.3 MW
Membrane area	4.7 x 10^5 m^2

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Vacuum operation uses

- Ten times the membrane area
- Only 40% of the compression power

Preliminary Conclusions

- Power consumption is the key issue
- The maximum affordable pressure ratio is about 10
- A single-stage process is not going to work
- Vacuum operation is likely the lowest energy design
- Membrane areas will be big – millions of square meters
- A selectivity of 30 to 50 seems optimum

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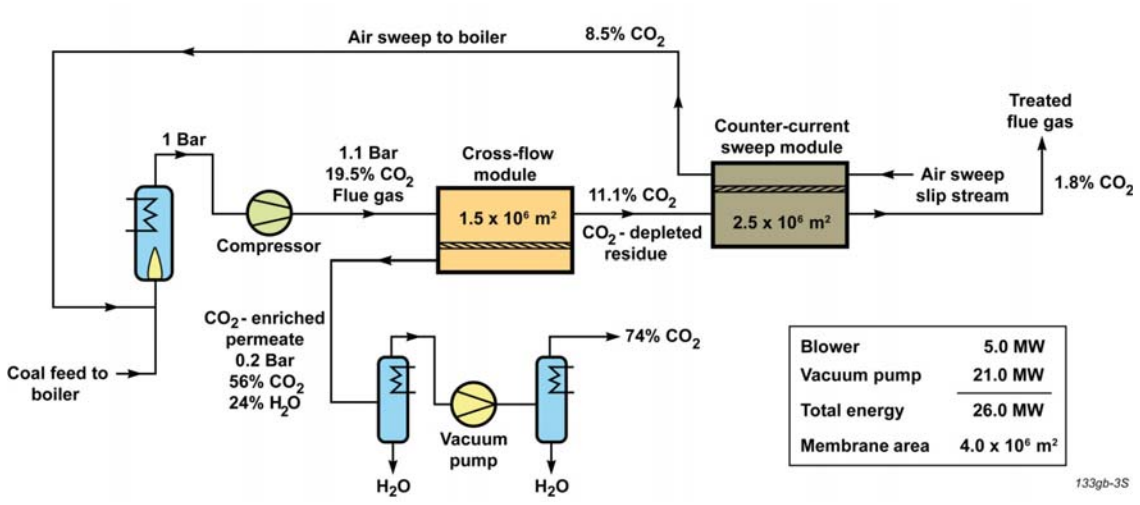
The MTR Process



- Countercurrent sweep with combustion air provides “free” driving force → lower energy required.
- CO_2 recycled in the combustion air stream decreases membrane area required.
- Water in the flue gas helps

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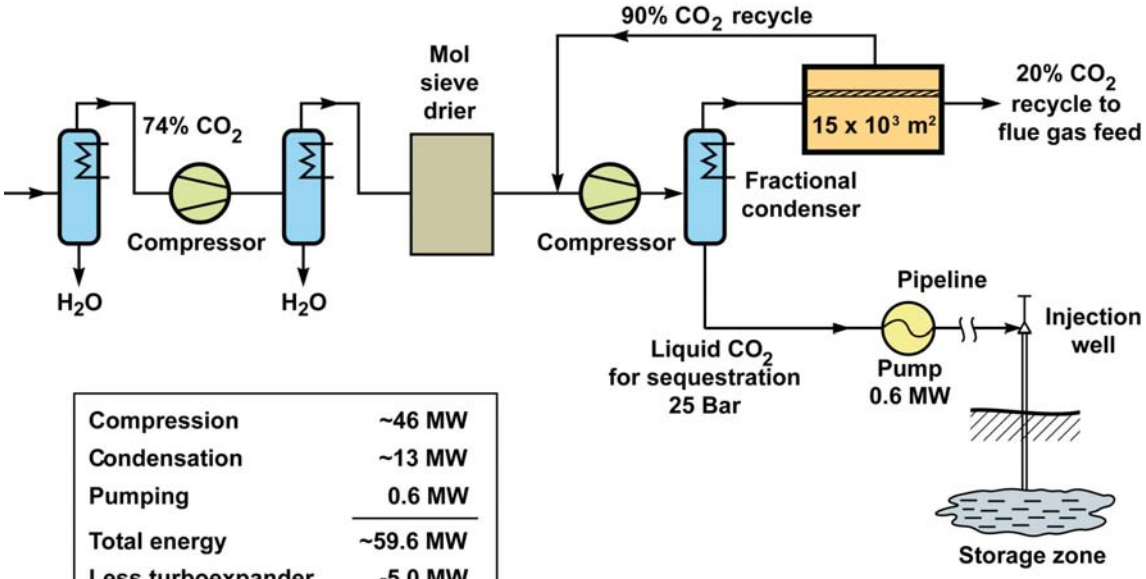
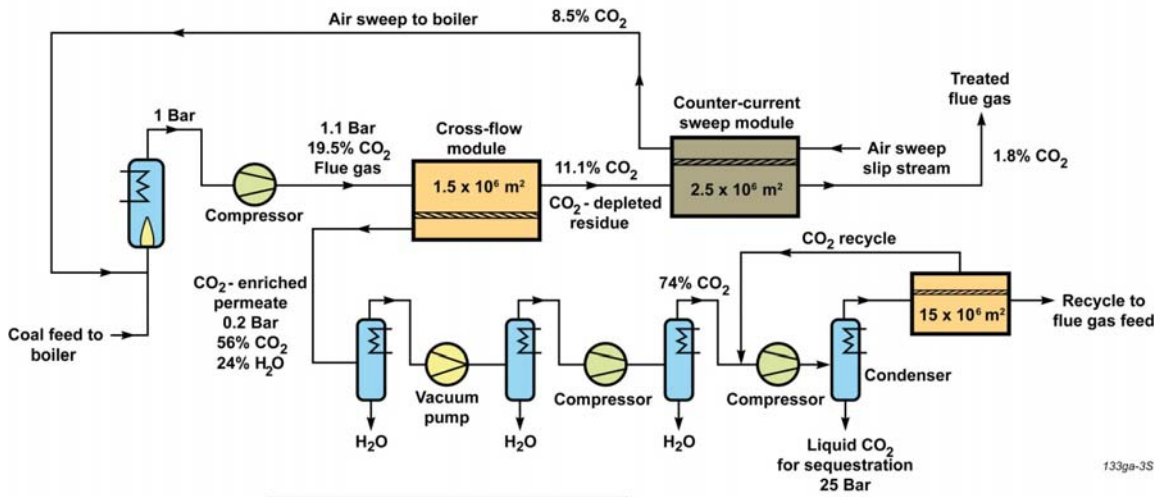
Membrane Assisted CO_2 Liquefaction and Injection



Compression	~46 MW
Condensation	~13 MW
Pumping	0.6 MW
Total energy	~59.6 MW
Less turboexpander	-5.0 MW
Net	~54.6 MW

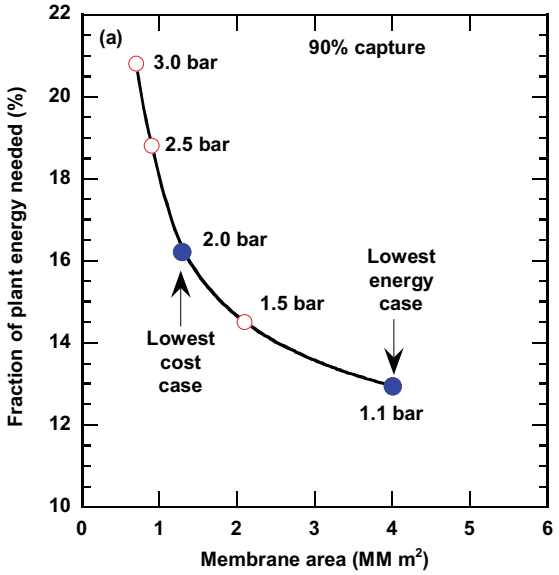
The Total MTR Process – The Lowest Energy Case

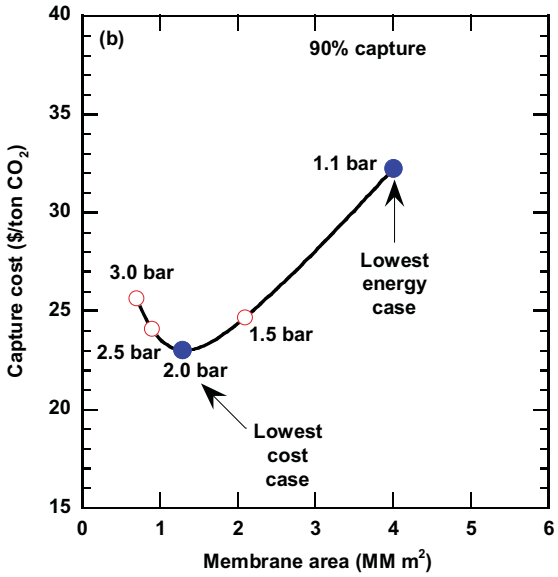


Compressor/blower	5.0 MW
Vacuum pump	21.0 MW
Permeate compressor	46.0 MW
Refrigeration	13.0 MW
Subtotal	85 MW
Less turboexpander	- 5.0 MW
Net	80 MW

Membrane area
4.0 x 10⁶ m²

Predicted Process Costs Look Attractive





But millions square meters of membranes are required

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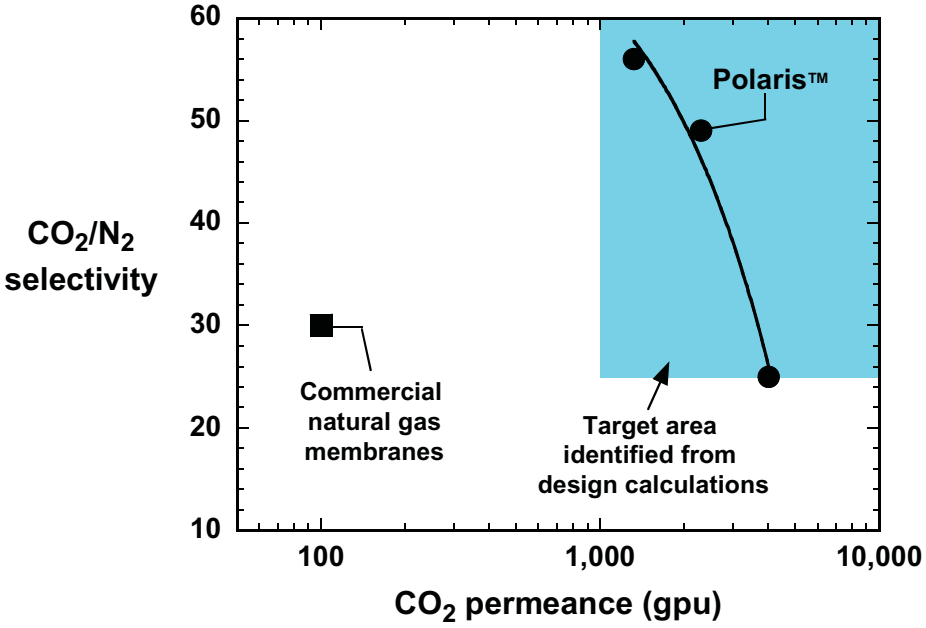
Membrane Plants of The Required Size Exist Today

Ashkelon desalination plant

- 40,000 spiral-wound RO membrane modules (Dow Filmtec®)
- 1.5 million m^2 membrane area

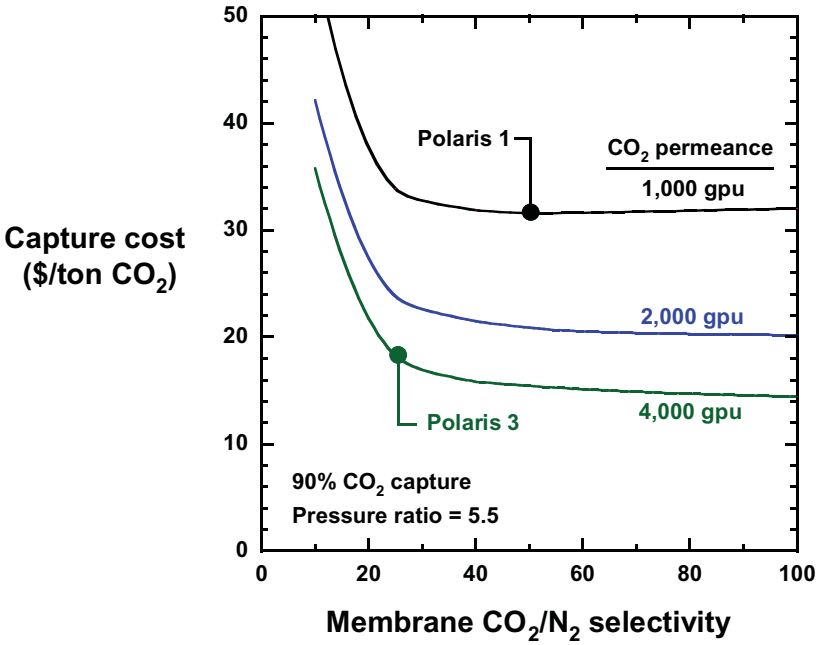
- Total energy use in plant is 56 MW; uses 5.5 MW water pumps
- Plant produces 100 million m^3/yr of fresh water

Polaris™ Membranes are Extremely Permeable to CO_2



Polaris™ membranes are 10 times more permeable to CO_2 than conventional membranes used for natural gas treatment; Pure-gas data at 25 C and 50 psig feed pressure

Higher CO_2 Permeance Reduces Cost More Than Higher Selectivity



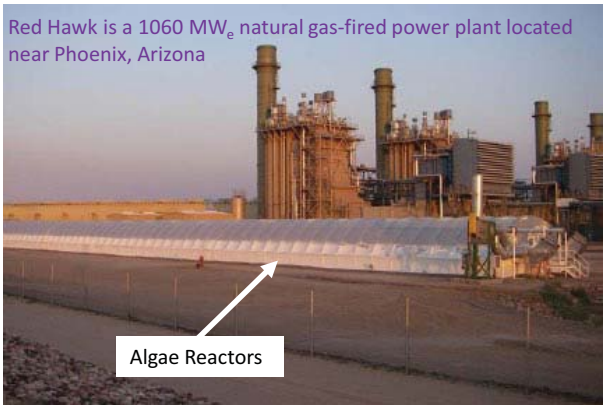
Baseline amine capture cost is >$80/ton CO_2

Where We Are Now

APS Red Hawk Power Plant
Field Test

Red Hawk Module Test Unit

MTR is conducting field demonstrations at Arizona Public Service (APS) power plants



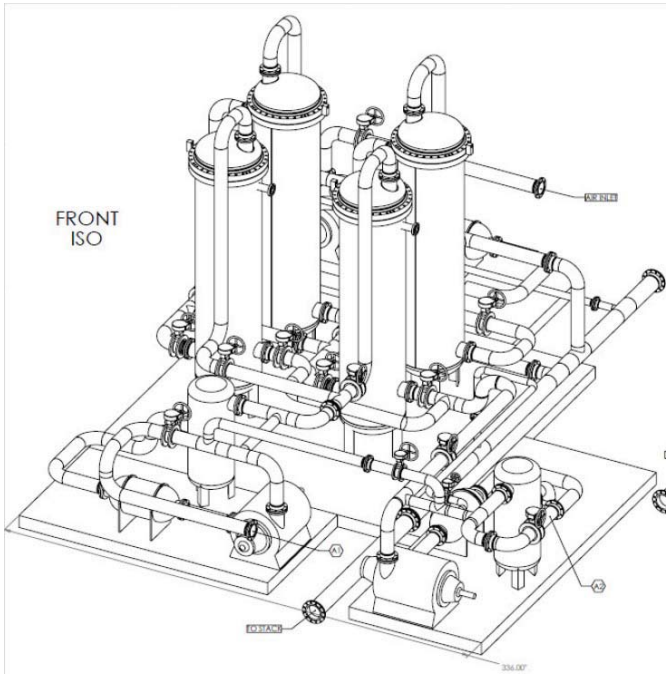
CO_2 from Red Hawk plant is sent to algae reactors for biofuel production

APS Cholla Power Plant Feasibility Test

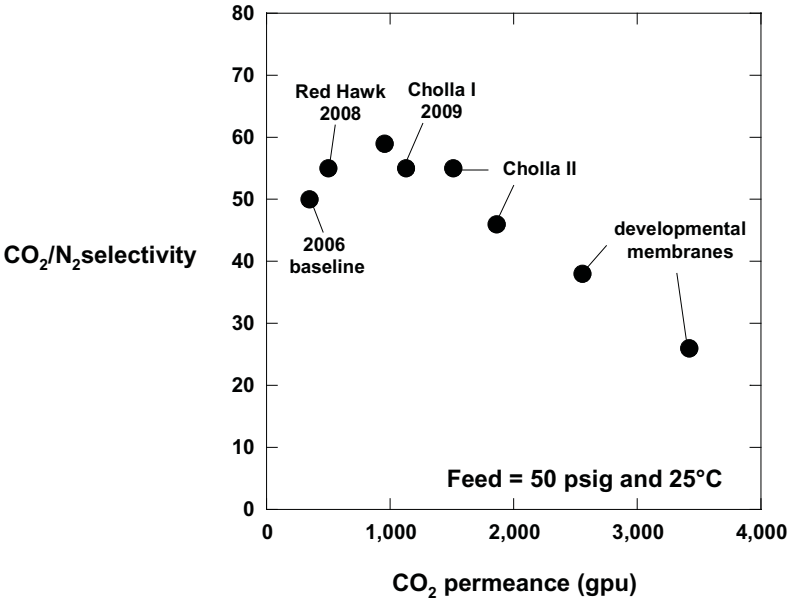
- Six-month test with coal-fired flue gas started in April 2010
- Polaris™ membrane system captures 1 ton CO_2/day

Planned Future Development

Cholla II skid (20 ton CO_2/day or 1 MW_e) is proposed to begin operation in late 2011

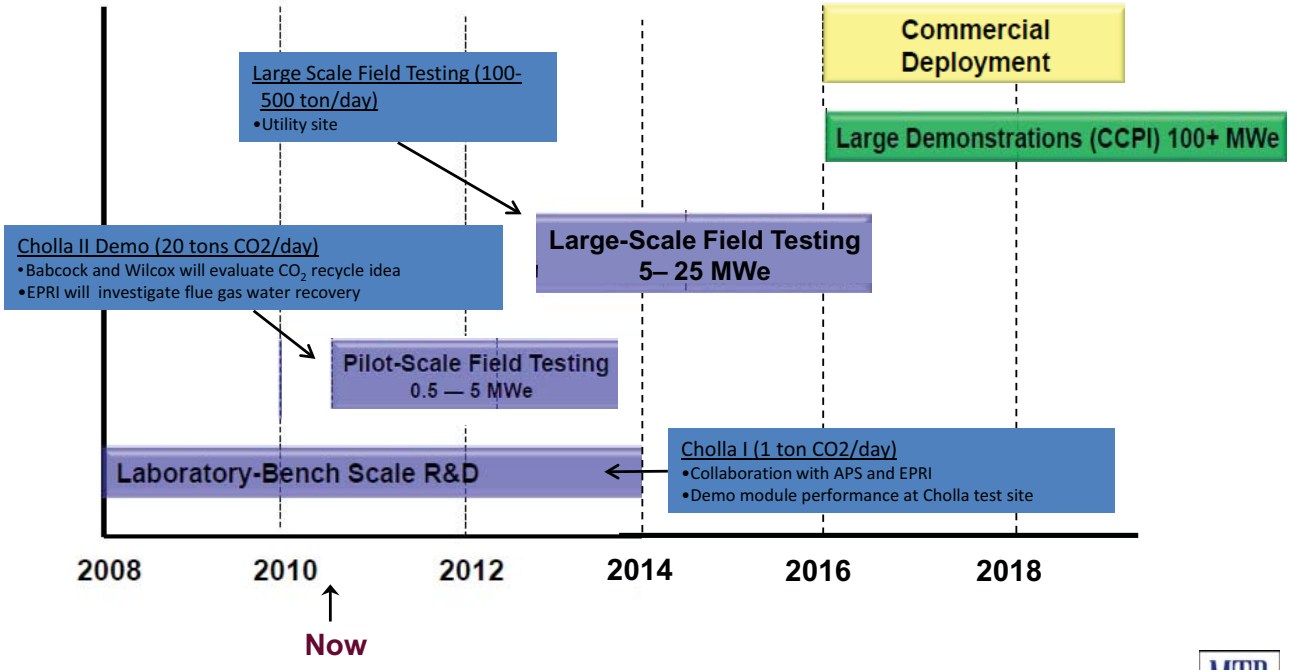


High Permeance Membranes in Low Cost Membrane Modules and Housings are Key



Membranes are getting better

DOE Post-Combustion CO_2 Capture Timeline



Thank You