Membranes: An Emerging CO_2 Capture Technology

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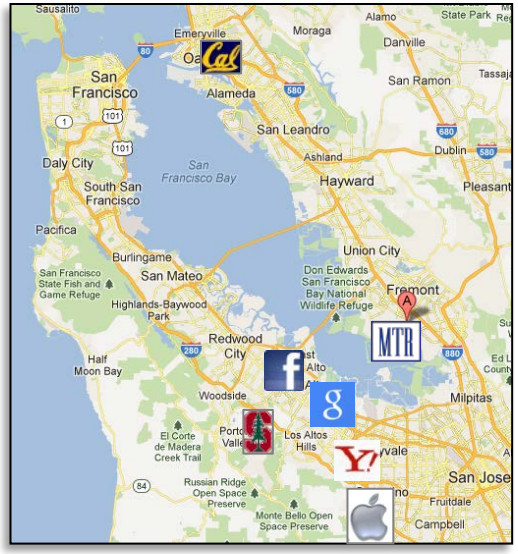
Outline

- Introduction and membrane background
- CO_2 capture with membranes
- Field tests and current status of technology
- Summary thoughts

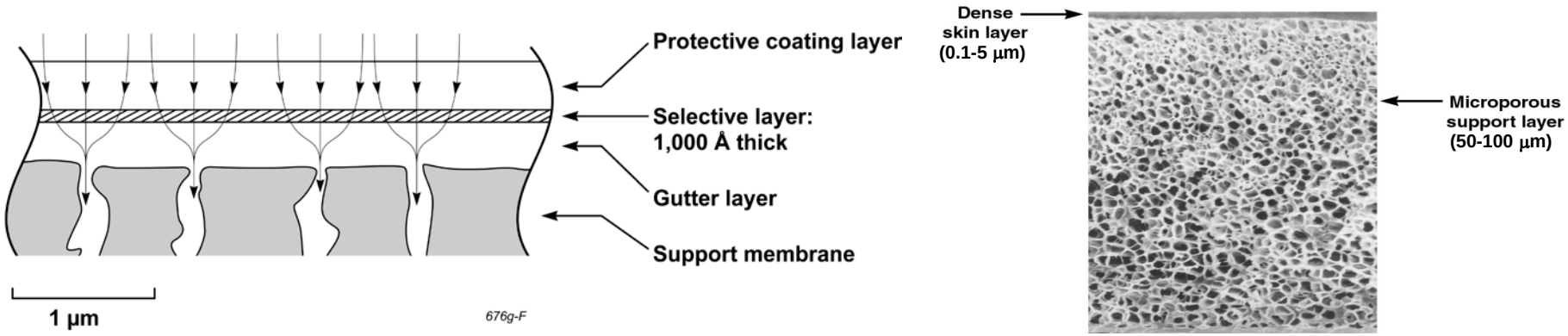
Introduction to MTR



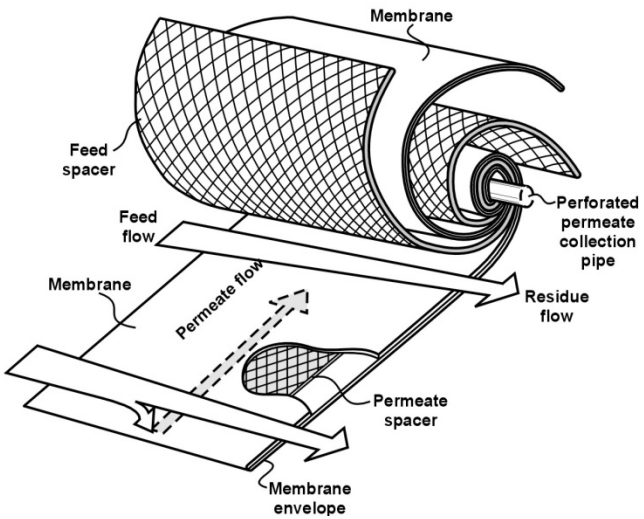
- Privately-held, 60 employees mostly located in Newark, California
- Sell gas separation systems into petrochemical, natural gas, and refinery industries worldwide
- Technology originally developed through DOE, NSF, and EPA SBIR grants
- Have worked with DOE for the past 8 years on development of CO_2 capture membranes

Membranes and Modules

- Composite membranes provide high gas fluxes



- Membranes are packaged in modules for industrial separations



Typically, 500-1000 m^2/m^3

Membrane Systems Can Be Very Large

Dow Filmtec reverse osmosis system, 1.5 million m^2 area, Ashkelon, Israel

Schlumberger Cameron CO_2/natural gas system, 700 MMscfd, Gulf of Thailand

- Membranes are widely used for water desalination and natural gas sweetening
- The largest existing systems are similar in scale to that required for CO_2 capture at a 550 MW_e coal-fired power plant
- However, current membranes are not suited for CO_2 capture; development needed

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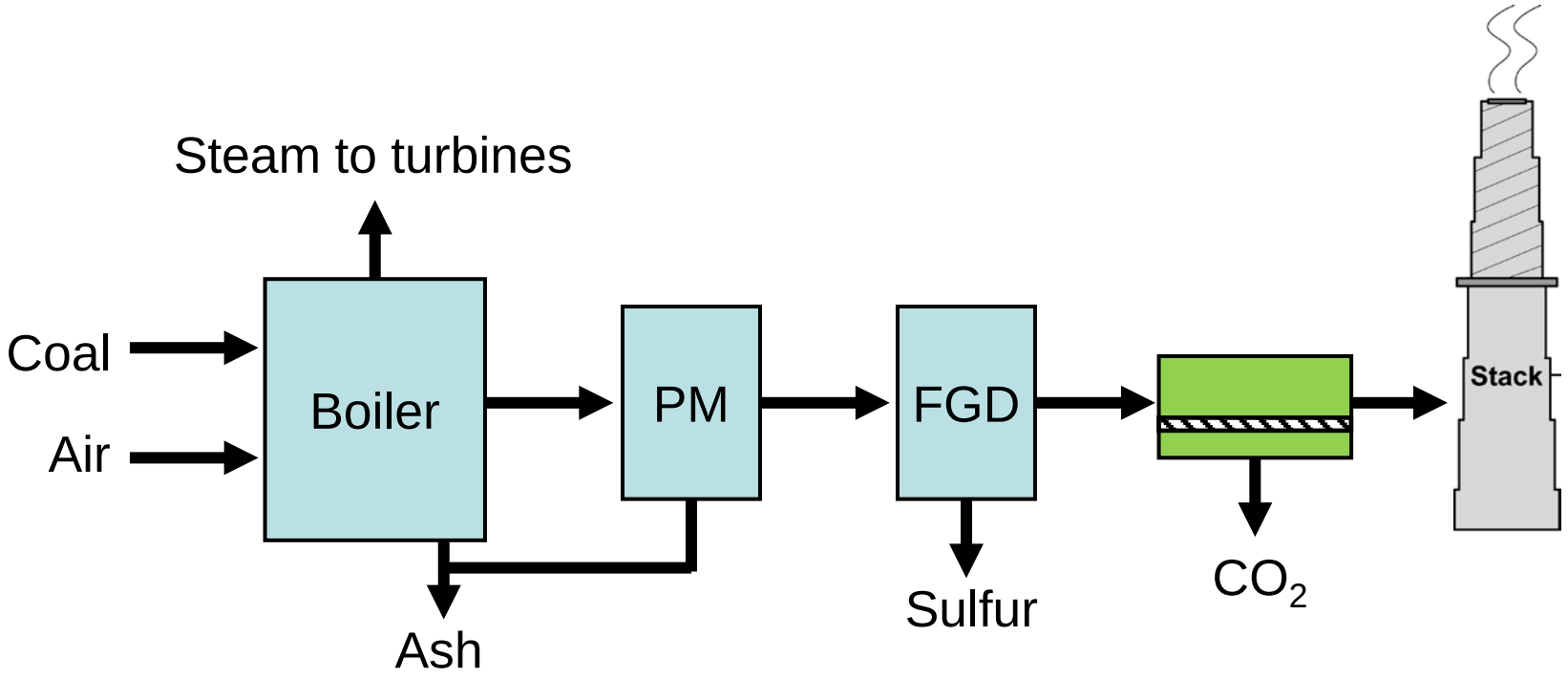
Post-Combustion CO_2 Capture with Membranes



- The key challenges for capture technologies are the low partial pressure of CO_2 and the large scale required for flue gas treatment
- For membranes to be cost-effective, innovations in process design and membrane materials were needed

Advantages of a Membrane Process

- Simple, passive operation with no chemical handling, emissions, or disposal issues
- Relatively low water use (harvests H_2O from gas)
- Modular technology allows advanced manufacturing and economies of volume
- No steam use → no modifications to existing boiler/turbines
- Near instantaneous response; high turndown possible → preserves plant operability
- Particularly efficient for partial capture

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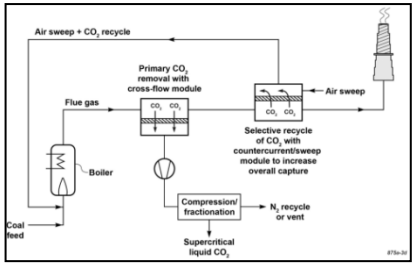
MTR/DOE CO_2 Capture Development Timeline

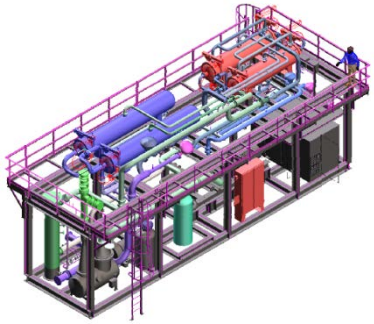
Feasibility study (DE-NT43085)
- Sweep concept proposed
- Polaris membrane conceived



APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO_2 used for algae farm

APS Cholla Demo (DE-FE5312)
- First Polaris coal flue gas test
- 1 TPD CO_2 captured (50 kW_e)

NCCC 1 MW_e Demo (DE-FE5795)
- 11,000 hours of 1 TPD system operation
- 1 MW_e (20 TPD) system operation



Low Pressure Mega Module (DE-FE7553)
- Design and build a 500 m^2 optimized module

Hybrid Capture (DE-FE13118)
- Membrane-solvent hybrids with UT, Austin

B&W Integrated Test **10 MW_e Large Pilot**

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

2006 2008 2010 2012 2014 2016 2018 2020

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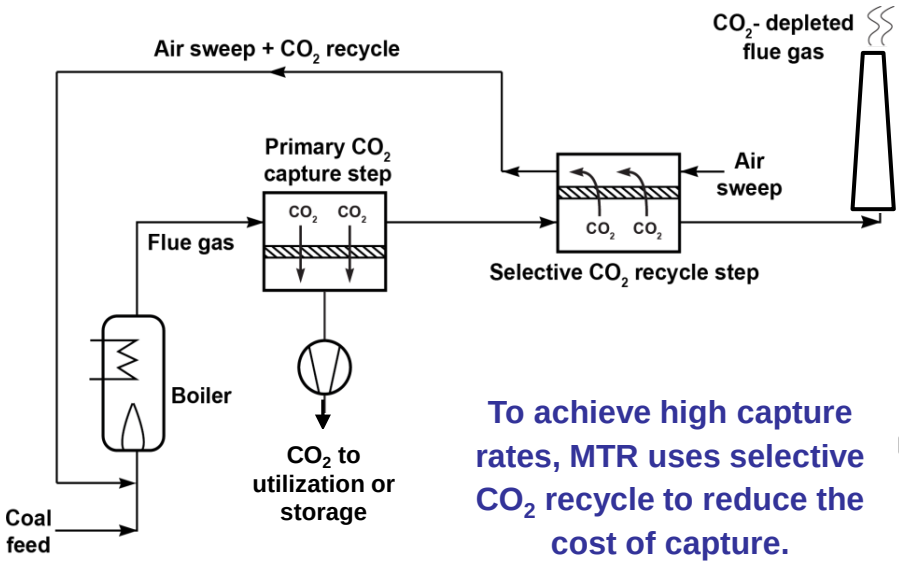
DOE Support has Produced Process and Material Innovations

Selective Exhaust Gas Recycle Design

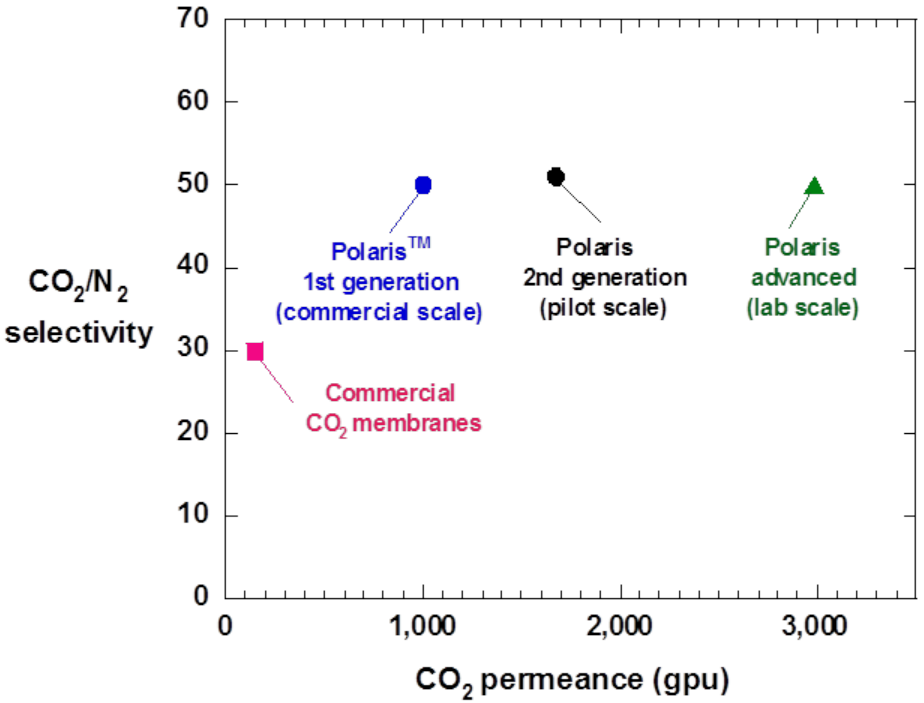


To achieve high capture rates, MTR uses selective CO_2 recycle to reduce the cost of capture.

361-Pres062215

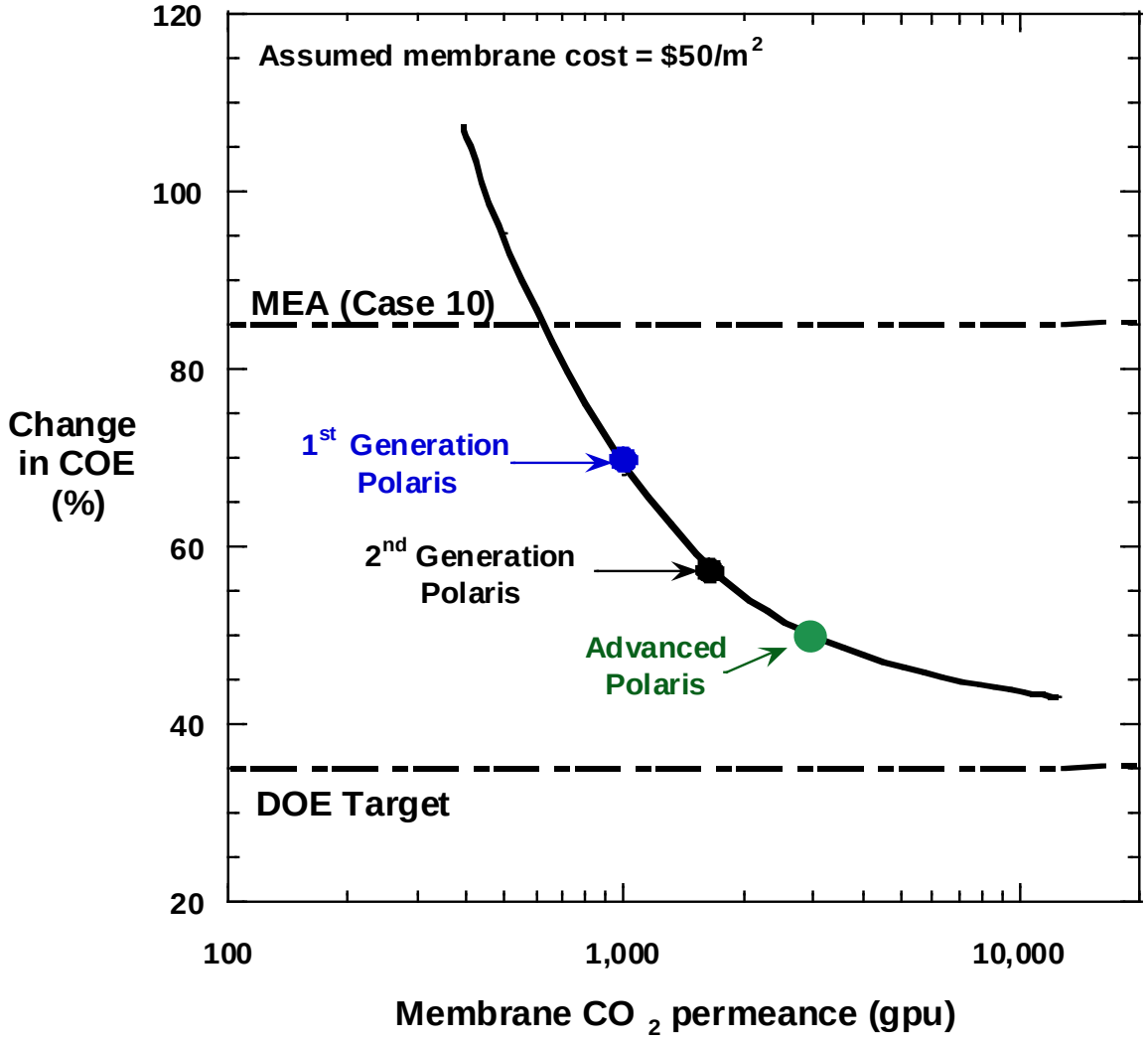
U.S. Patents 7,964,020 and 8,025,715

Polaris™ Membranes



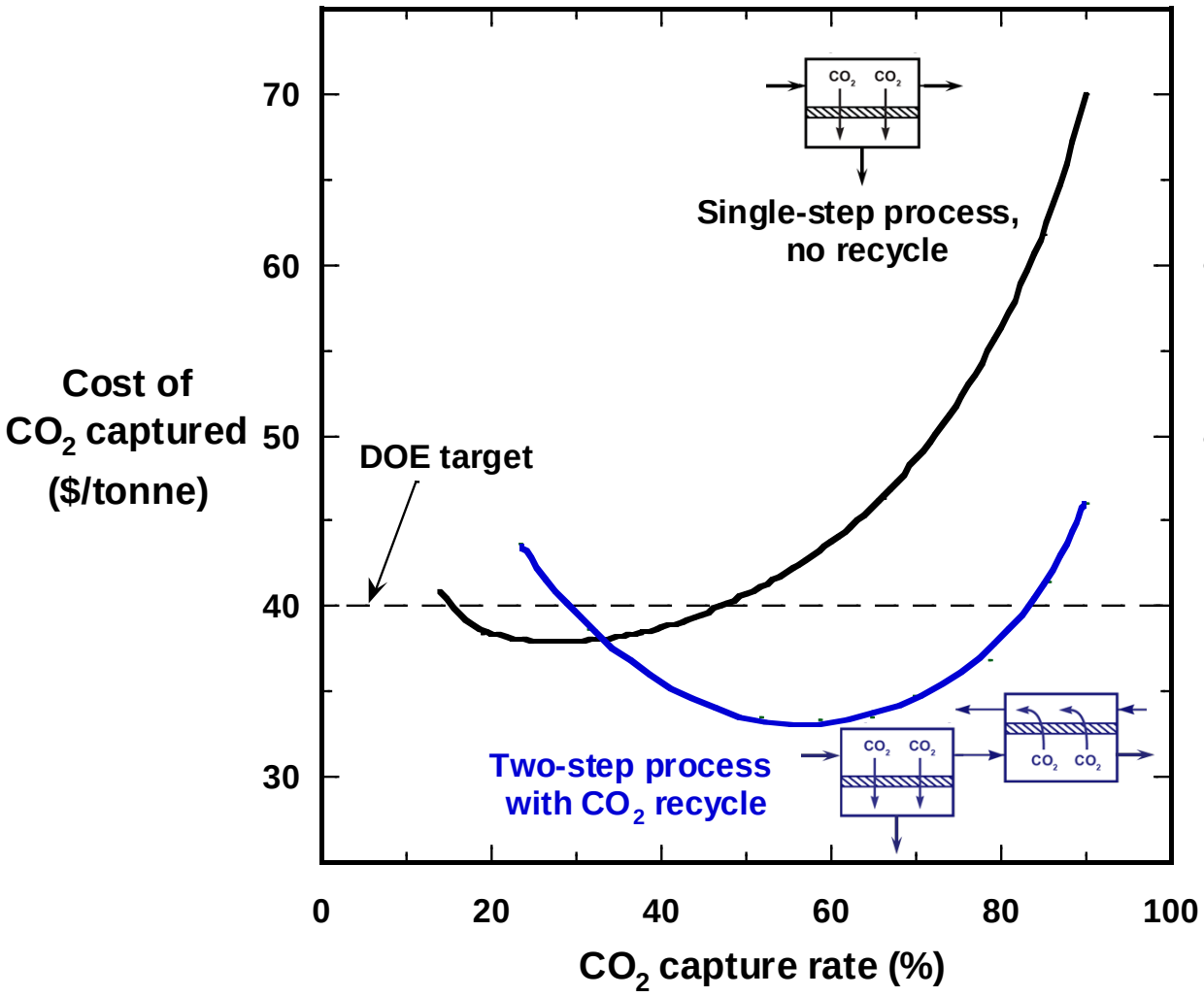
Developments include a patented process design and the Polaris membrane, which has found commercial use in shale gas treatment

Importance of Continued Development to Reduce Costs



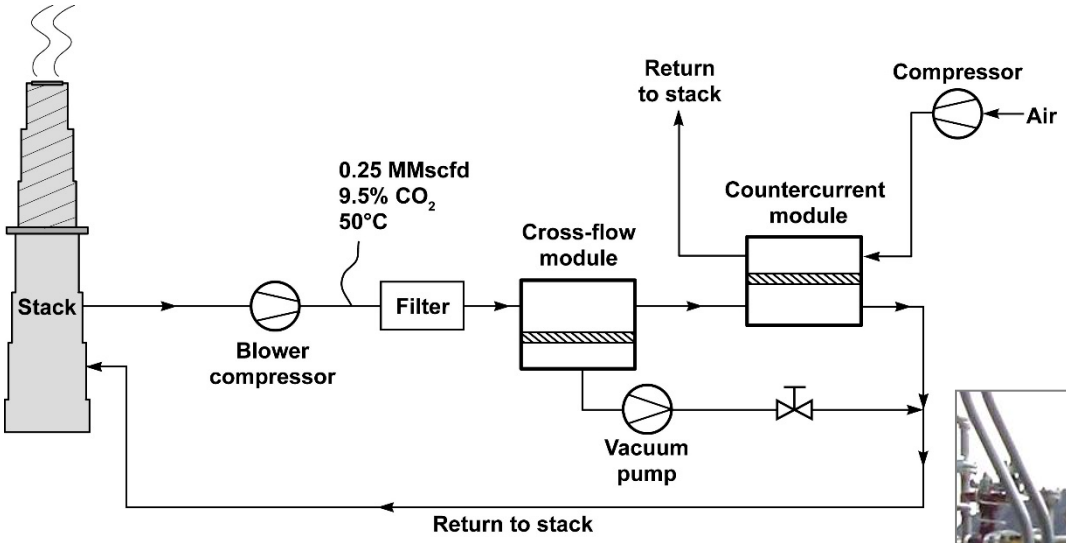
- All calculations are for 90% CO_2 capture using DOE Bituminous Baseline report methodology
- Higher permeance (lower cost) membranes are key to approaching cost targets

Membranes are Particularly Effective at Partial Capture

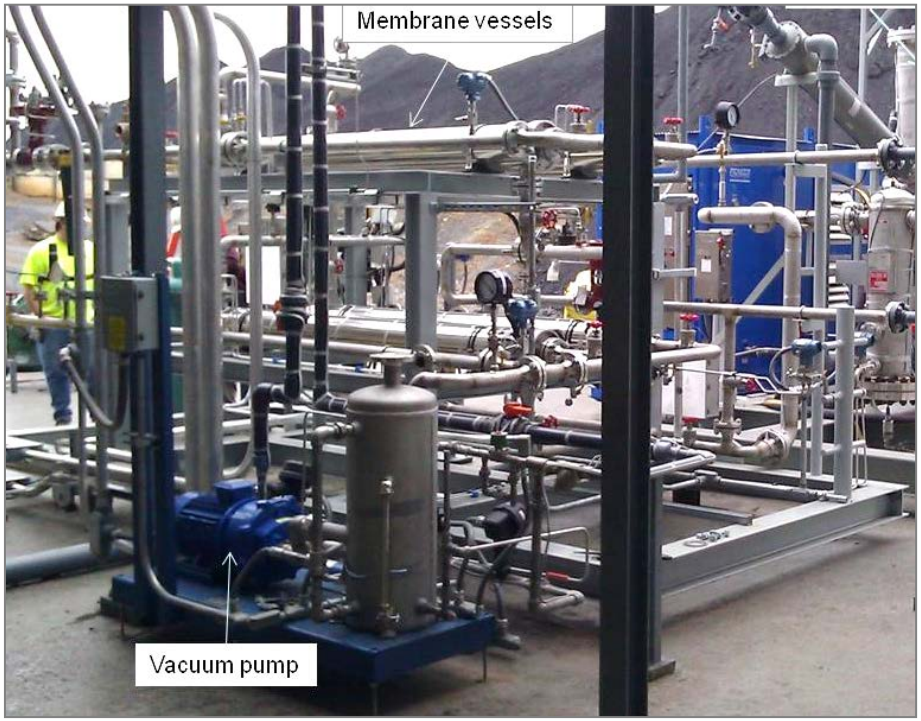


- Membranes show a minimum in capture cost
- To match natural gas CO_2 emissions, capture rates of 40-50% are needed for coal plants

1 TPD Field Testing at NCCC



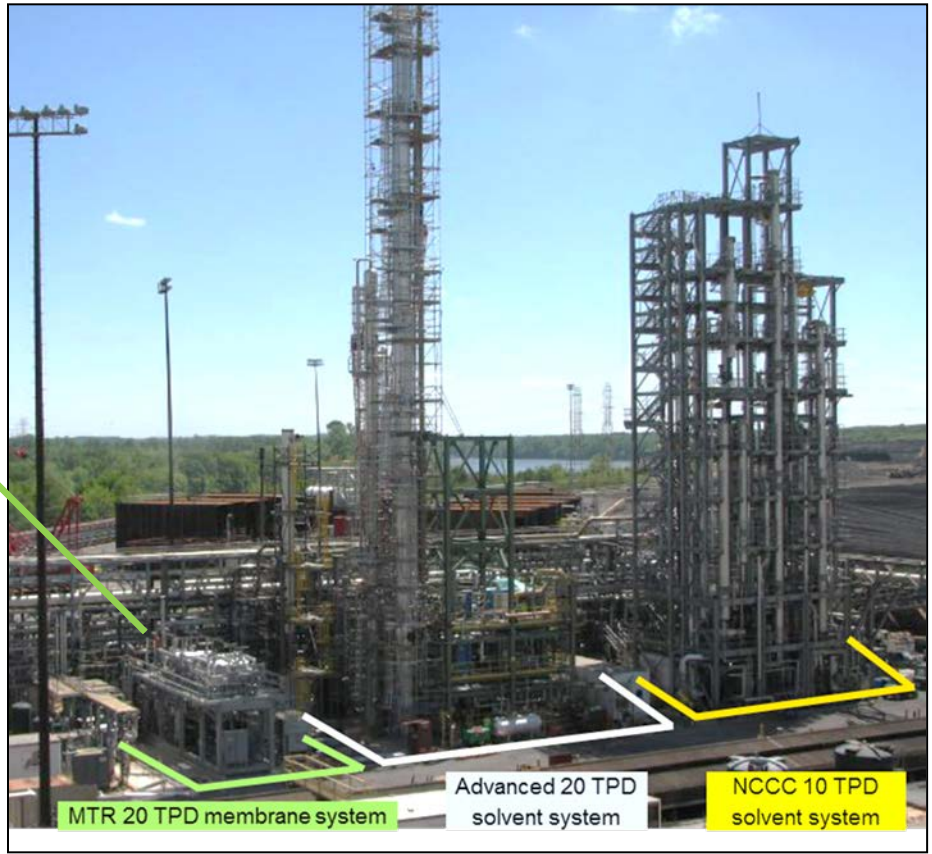
- The National Carbon Capture Center (NCCC) is a valuable field laboratory
- Allows validation testing with real coal flue gas



- MTR system tested vacuum and air sweep membrane steps capturing 1 ton CO_2/day
- Accumulated over 11,000 hours of operation

Scale-Up to 20 TPD Small Pilot

- Membranes are simple and compact



- Recently, MTR pilot system completed 6 months of successful operation at NCCC
- Currently, system is being tested at a Babcock & Wilcox (B&W) boiler facility

Compact, Modular Membrane Systems are Easily Moved and Installed

1st floor of system arriving by truck

Crane lowering 2nd floor of system into place

20 TPD system during installation at NCCC

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Testing Integrated Operation at B&W Boiler Research Facility

- After testing at NCCC, the 20 TPD skid was installed at B&W's Barberton, OH research facility
- Goal was to evaluate impact of recycled CO_2 on boiler performance

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Integrated Operation at B&W

MTR 20 TPD system (foreground) installed at B&W's coal boiler facility (background)

B&W Test Highlights

- Boiler flame is stable with recycled CO_2; NOx reduced
- No modifications to boiler required; retrofits are possible
- Boiler performance with CO_2 recycle is consistent with prior simulations

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Next Step: Large Pilot

- Current status:
  - Successfully tested at small pilot scale at NCCC and B&W
  - A world-leading membrane capture technology that needs a final push for commercialization
- Next step:
  - Large pilot (~10 MW_e) test is a critical scale-up step to demonstrate the final “form factor” for modular membrane technology; MTR cannot do it alone
  - Once proven at this scale, these membrane modules can be repeated for full-scale, commercial systems

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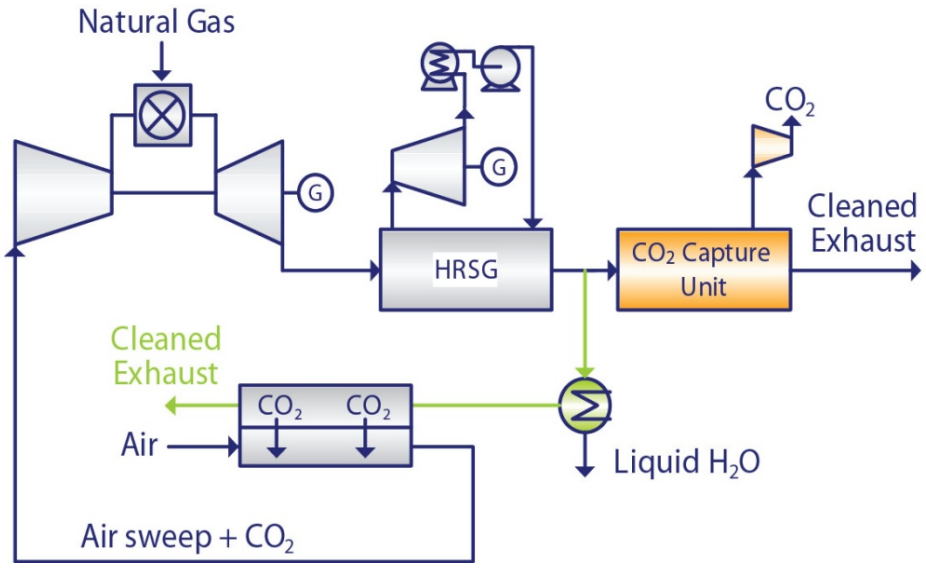
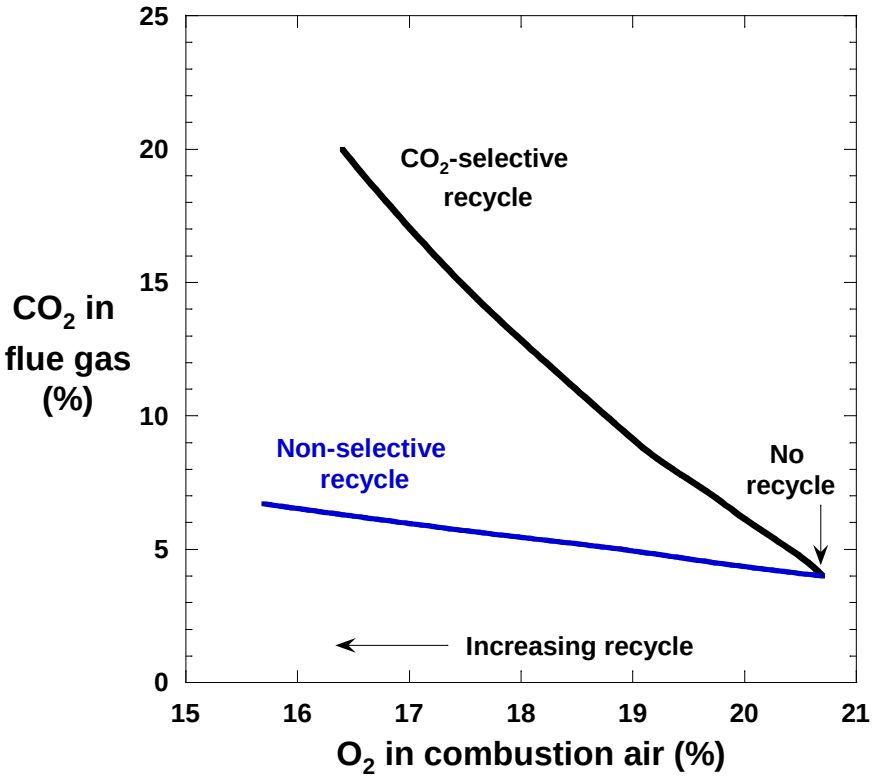
Membrane Process Can Also Be Used For Natural Gas Capture

Membrane Selective Exhaust Gas Recycle





- Selectively recycle CO_2 by using sweep membranes
- Pre-concentrates CO_2 with almost no energy input → reduces minimum work of capture

Summary

- With DOE support, we have taken a novel, advanced membrane capture technology through small pilot testing
- This membrane approach offers many advantages including simplicity, environmental-friendliness, small footprint, and low cost particularly at partial capture
- DOE support of large pilot testing is critical as a final push to commercialization
- While developed for coal, the selective recycle membrane approach can also be used to reduce the energy costs of decarbonizing natural gas power

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Acknowledgements

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