Membranes: An Emerging CO₂ Capture Technology

Tim Merkel and Brice Freeman
Membrane Technology and Research, Inc. (MTR)

U.S. Energy Association
June 29, 2017
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\textsubscript{2} capture membranes
Membranes and Modules

- Composite membranes provide high gas fluxes

Typically, 500-1000 m²/m³

- Membranes are packaged in modules for industrial separations
Membrane Systems Can Be Very Large

Dow Filmtec reverse osmosis system, 1.5 million m² area, Ashkelon, Israel

Schlumberger Cameron CO₂/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 CO₂ capture at a 550 MWₑ coal-fired power plant
- However, current membranes are not suited for CO₂ capture; development needed
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 H₂O 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
MTR/DOE CO₂ 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 CO₂ used for algae farm

APS Cholla Demo (DE-FE5312)
- First Polaris coal flue gas test
- 1 TPD CO₂ captured (50 kWₑ)

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

Low Pressure Mega Module (DE-FE7553)
- Design and build a 500 m² optimized module

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

B&W Integrated Test

10 MWₑ Large Pilot

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8
DOE Support has Produced Process and Material Innovations

Selective Exhaust Gas Recycle Design

To achieve high capture rates, MTR uses selective CO₂ recycle to reduce the cost of capture.

Polaris™ Membranes

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

U.S. Patents 7,964,020 and 8,025,715
Importance of Continued Development to Reduce Costs

- All calculations are for 90% CO₂ 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 CO₂ 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
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

Membranes are simple and compact
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
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 CO₂ on boiler performance
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 CO₂; NOx reduced
- No modifications to boiler required; retrofits are possible
- Boiler performance with CO₂ recycle is consistent with prior simulations
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 MWₑ) 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
Membrane Process Can Also Be Used For Natural Gas Capture

- Selectively recycle CO₂ by using sweep membranes
- Pre-concentrates CO₂ with almost no energy input → reduces minimum work of capture
• 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
Acknowledgements

- U.S. Department of Energy, National Energy Technology Laboratory
  - Jose Figueroa
  - Mike Mosser

- Southern Company Services (NCCC)
  - Tony Wu
  - Frank Morton

- Babcock & Wilcox
  - Hamid Farzan
  - Andrew Mackrory

Questions? Tim.merkel@mtrinc.com