MTR Membrane Technology & Research

Pilot Testing of a Membrane System for Post-Combustion CO_2 Capture
DE-FE0005795

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NETL CO_2 Capture Technology Meeting

Tuesday, June 23, 2015

Project Overview

Award name: Pilot testing of a membrane system for post-combustion CO_2 capture

Project period: 10/1/10 to 9/30/15

Funding: $15 million DOE; $3.75 million MTR

DOE program manager: Jose Figueroa

Participants: MTR, Babcock & Wilcox, SCS/NCCC, EPRI, Vectren, ISTC

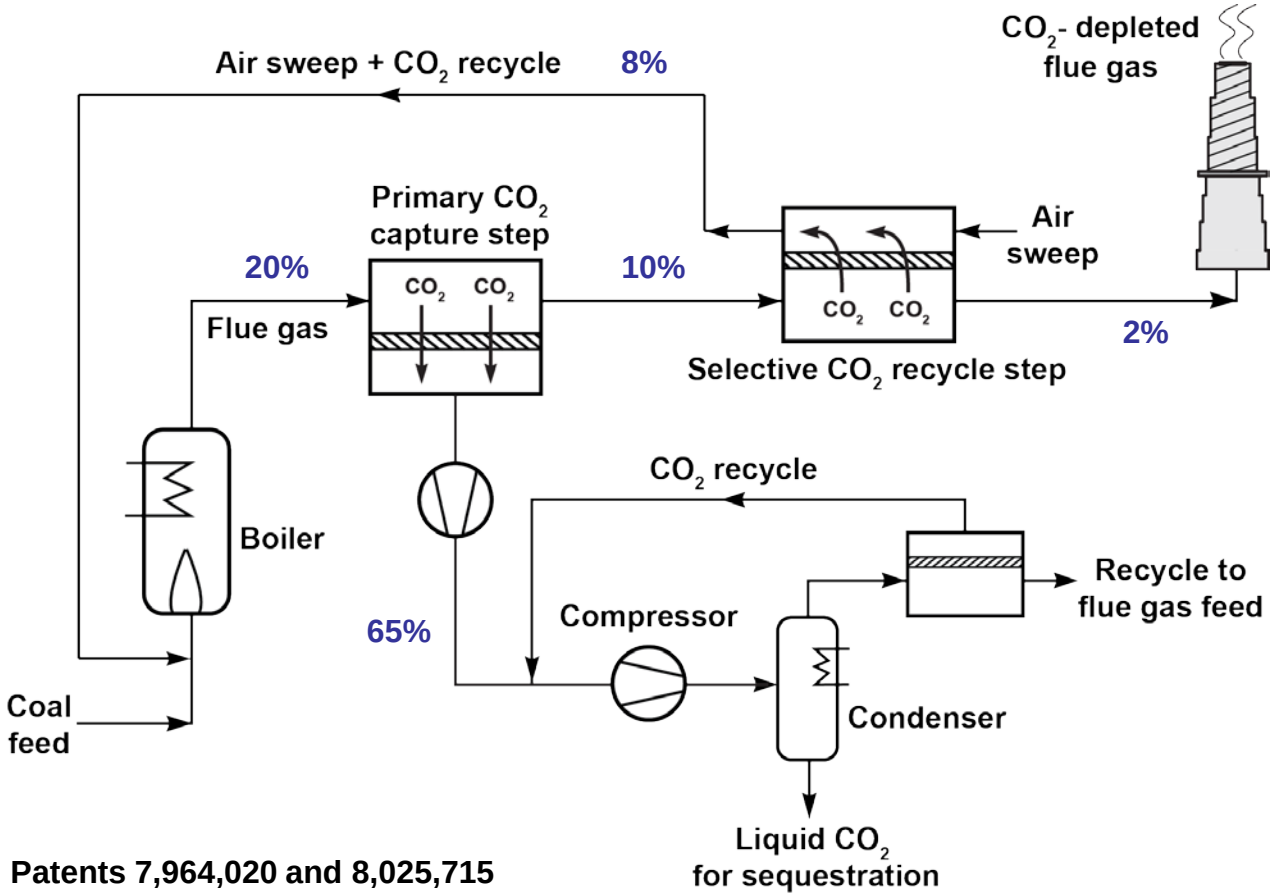
Project scope: Demonstrate a membrane process to capture 20 tons of CO_2/day (TPD) from a flue gas slipstream of a coal-fired power plant.

Project plan: The key project work organized by budget period is as follows:

- **BP1** – Membrane optimization though continued slipstream testing on the 1 TPD system and computational evaluation of sweep recycle with B&W
- **BP2** – Design and construction of the 20 ton/day system, boiler testing at B&W with CO_2-laden air; membrane/module optimization and durability testing through continued testing on 1 TPD system
- **BP3** – Field test of the 20 ton/day system; comparative economic analysis; industrial 1 TPD field test; case study at 20 MW-scale

As of 5/31/15, project is 95% complete

MTR CO_2 Capture Process



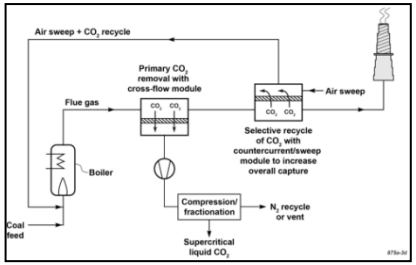
U.S. Patents 7,964,020 and 8,025,715

Benefits of selective recycle:

- Increases CO_2 concentration going to the capture step, and
- Reduces the fractional CO_2 removal required by the capture step

MTR CO_2 Capture Development Timeline

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

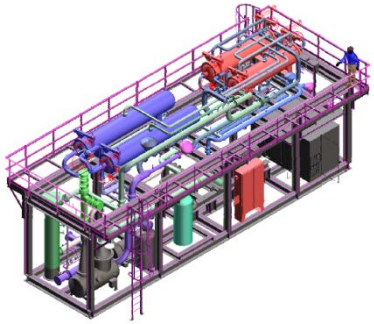


APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO_2 used for algae farm

APS Cholla Demo (DE-NT5312)
- First Polaris coal flue gas test
- 1 TPD CO_2 captured (50 kW_e)

NCCC 1 MW_e Demo ($18.7 MM)
- 10,000 hours of 1 TPD system operation
- 1 MW_e (20 TPD) system operation

Low Pressure Mega Module (DE-NT7553)
- Design and build a 500 m^2 optimized module



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

B&W Integrated Test

Future 10 MW_e Large Pilot

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

2006 2008 2010 2012 2014 2016 2018 2020

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Pros and Cons of a Membrane Post-Combustion Capture Process

Benefits:

- No hazardous chemical handling, emissions, or disposal issues
- Not affected by oxygen, SO_x or NO_x
- Water use lower than other technologies (recovers H_2O from flue gas)
- No steam use → no modifications to existing boiler/turbines
- Near instantaneous response; high turndown possible
- Modular and compact; relatively simple installation/operation
- Particularly well-suited for partial capture (40-60%)

Challenges:

- Very low partial pressure driving force favors high permeance membranes
- Unknown impact of real flue gas on membrane-module lifetime
- Module pressure drop and flow distribution issues

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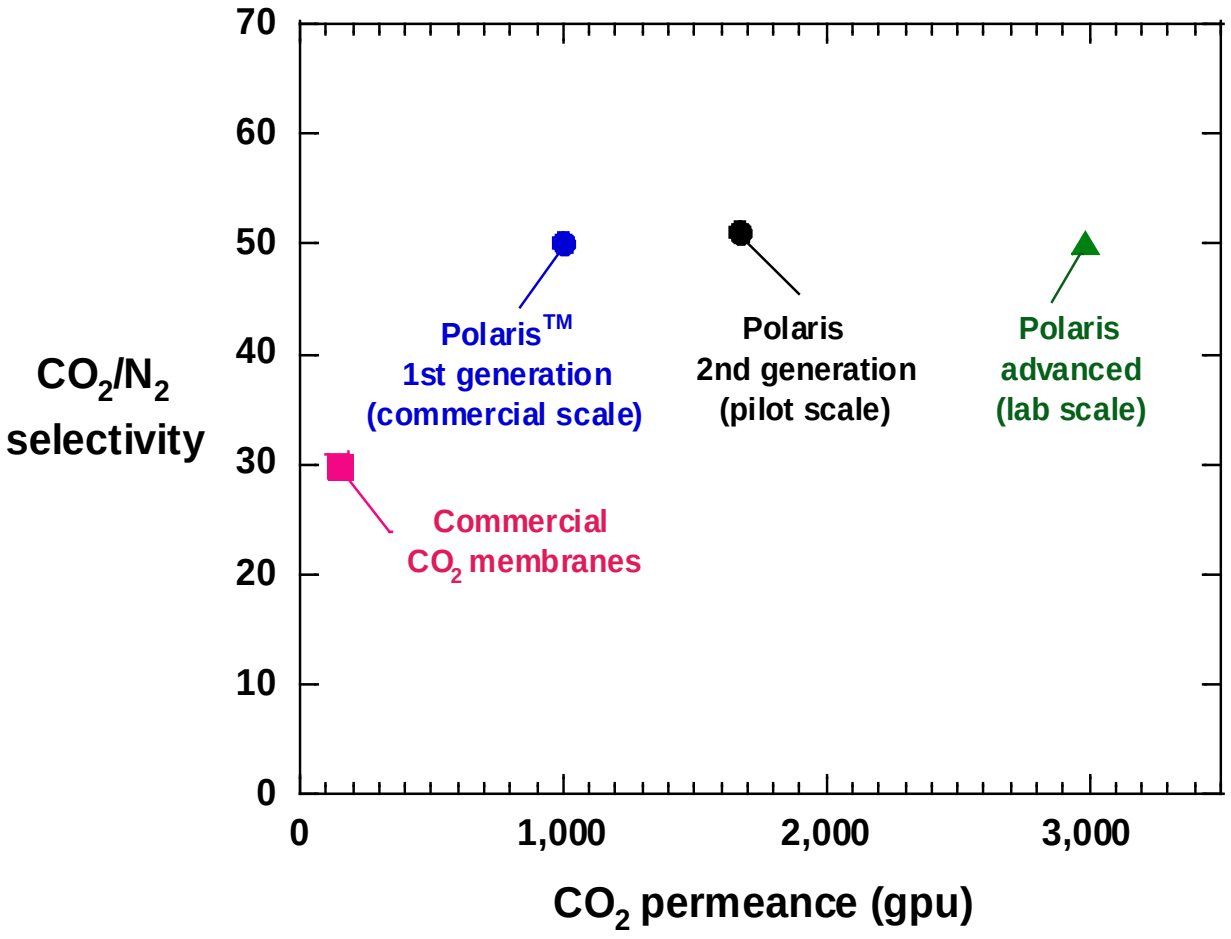
Polaris Membrane Improvements



- During this project, 75% increase in commercial membrane CO_2 permeance; route to 3X increase
- In addition to lowering costs, these improvements are important to shrink the size of the capture system

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

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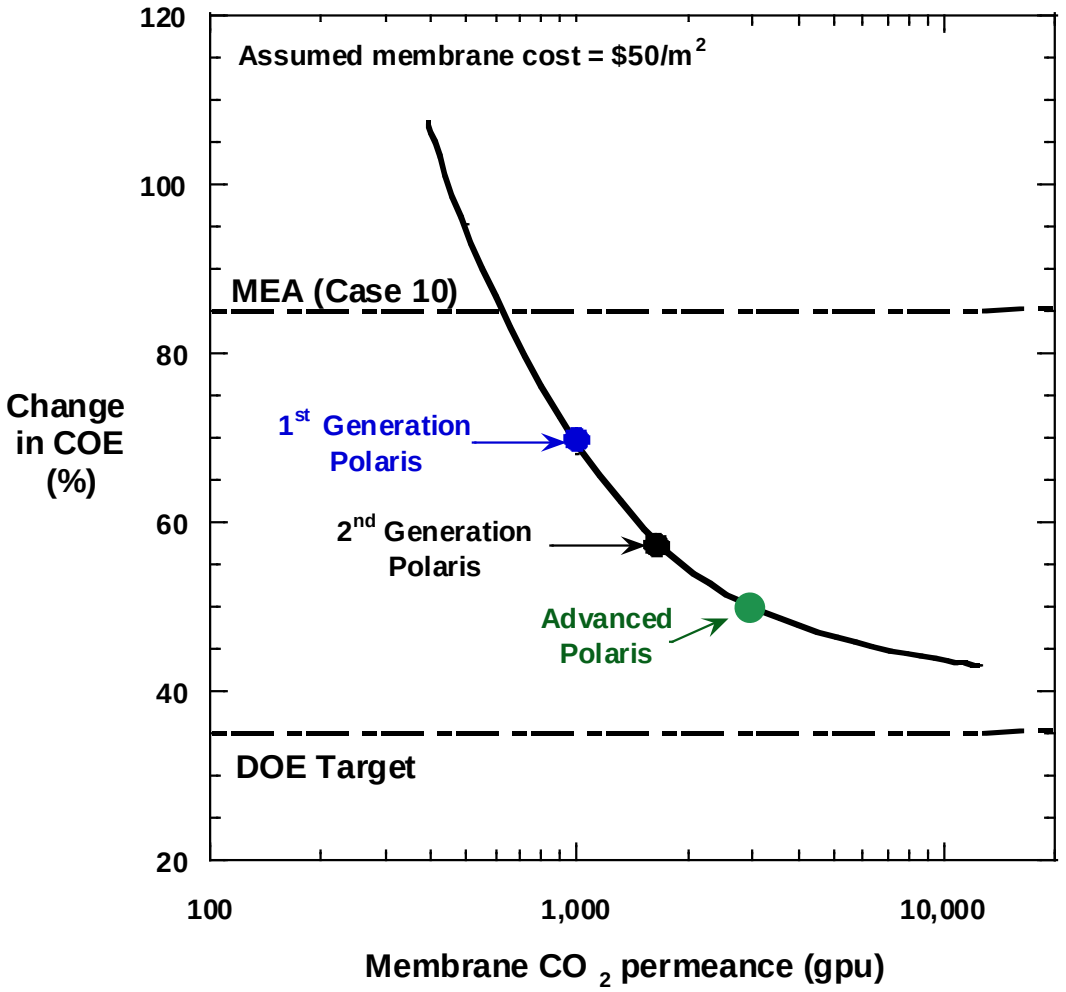
Systems Analysis: Importance of Membrane Improvements



- Study completed in BP1 to meet a project milestone; currently being updated by EPRI/WP
- All calculations for 90% CO_2 capture use Bituminous Baseline report methodology
- Higher permeance (lower cost) membranes are key to approaching DOE goals
- Results are consistent with DOE report "Current and Future Technologies for Power Generation with Post-Combustion Carbon Capture" (DOE/NETL-2012/1557)

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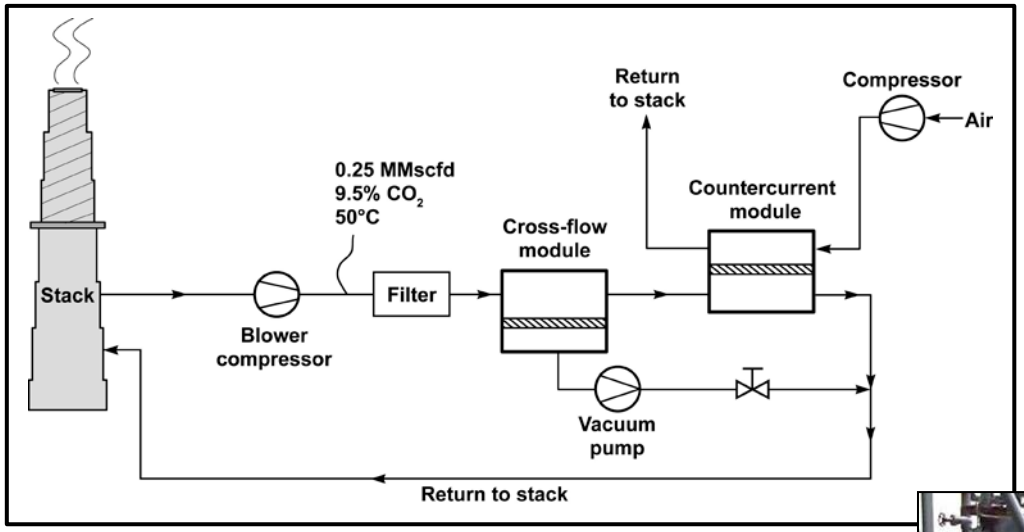
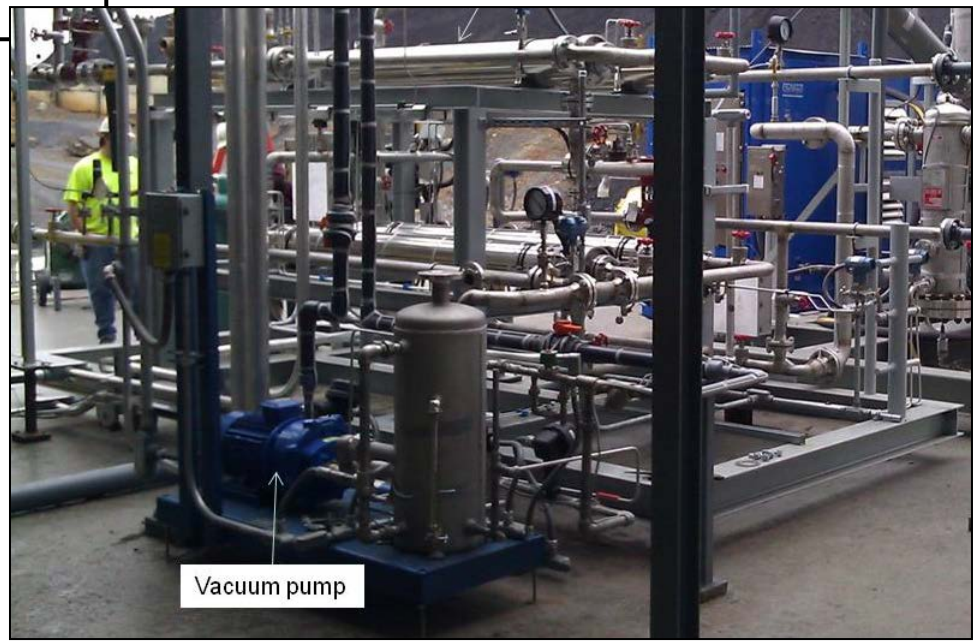
1 TPD Testing at NCCC

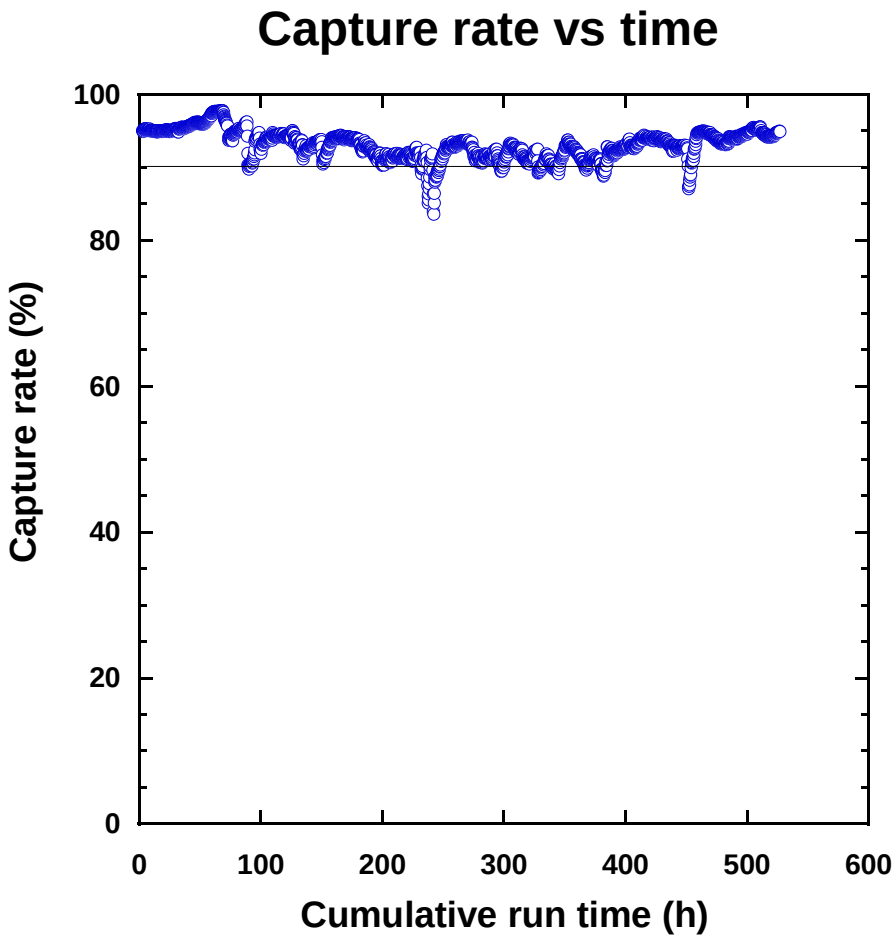


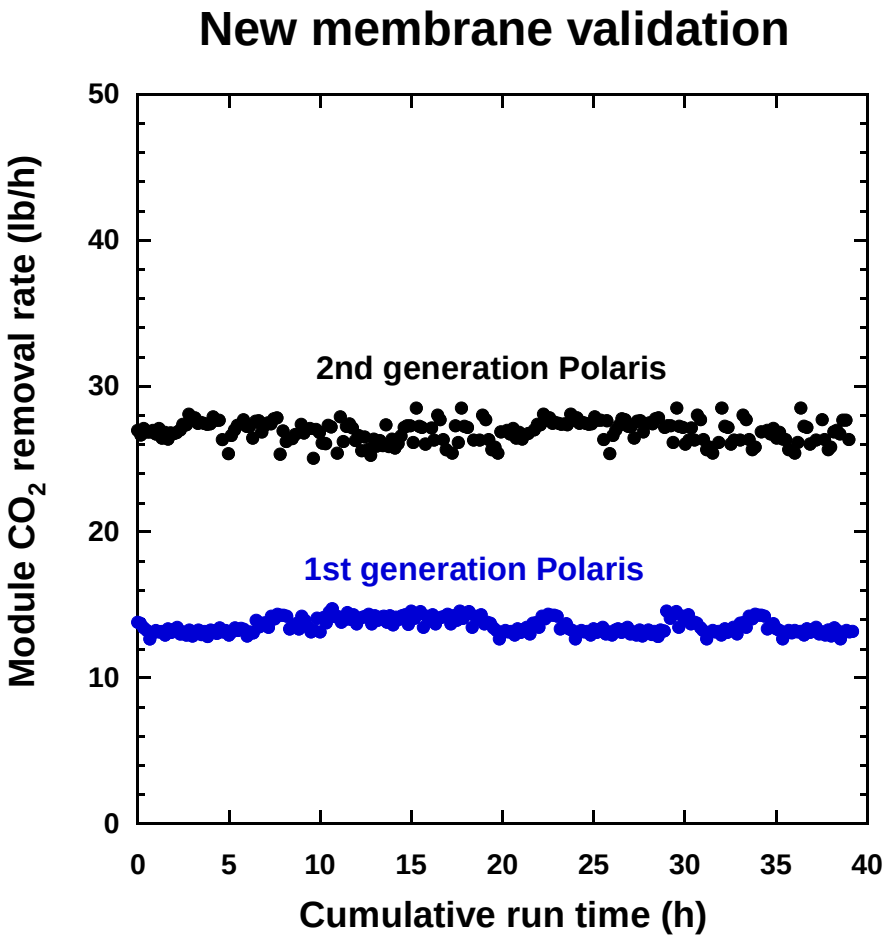
- Field laboratory that allows lifetime evaluation (>10,000 hours cumulative), and validation testing of new membranes
- Many lessons learned (i.e., ammonium sulfate deposition) applied to scale up

- System is testing vacuum and air sweep membrane steps
- Sized to capture 1 ton CO_2/day using commercial sized module
- System started operation in spring 2012



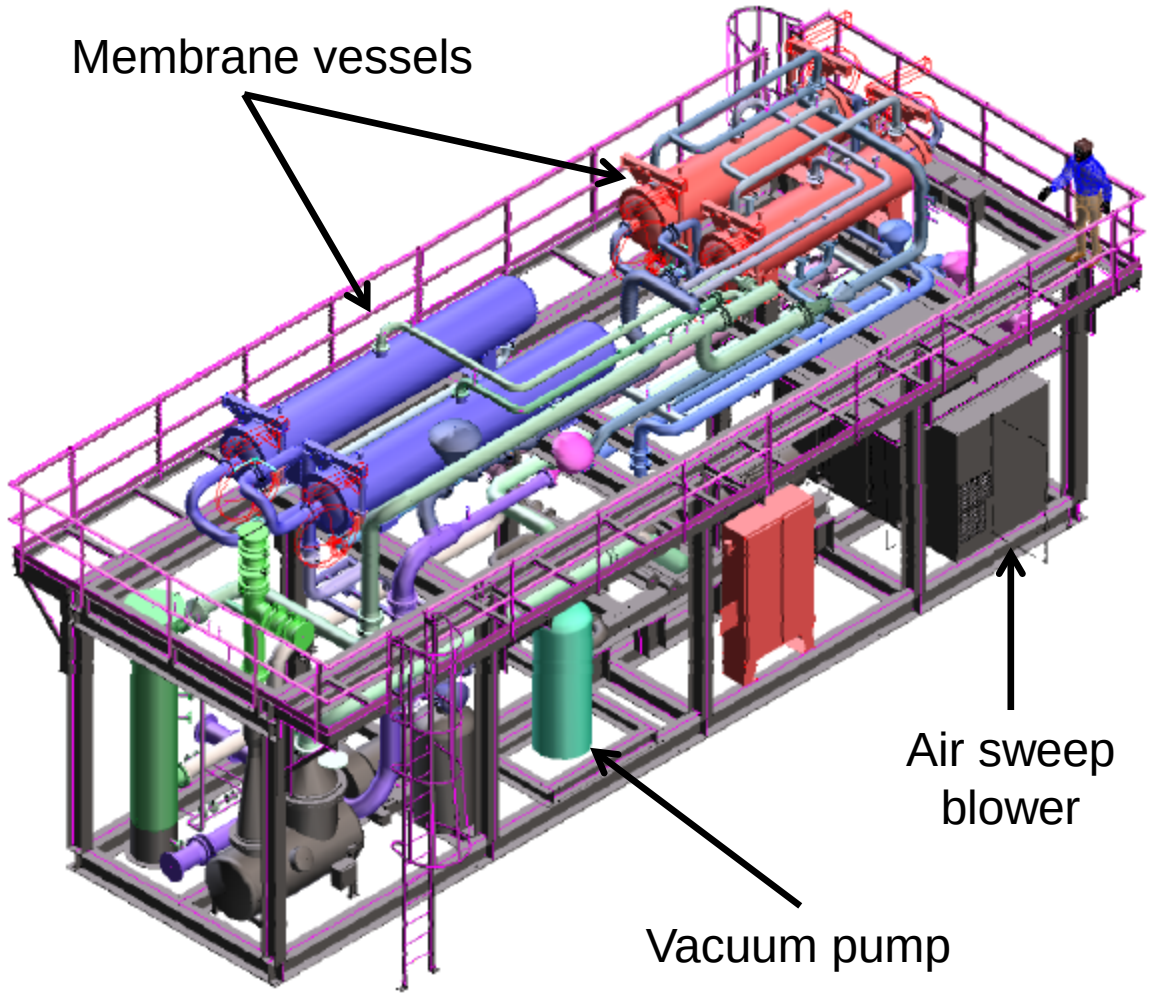
Sample 1 TPD Results from NCCC





System allows more rapid materials optimization through real world testing

Scale up to 20 TPD Small Pilot



- 20 TPD skid (1 MW_e) was installed by NCCC and MTR personnel during summer 2014
- Currently in operation
- Test objective is validation of advanced modules (multi-tube and plate-and-frame) designed for low pressure drop and small footprint

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Installation of 20 TPD Small Pilot at NCCC

1st floor of system arriving by truck

Crane lowering 2nd floor of system into place

Photos courtesy of Tony Wu

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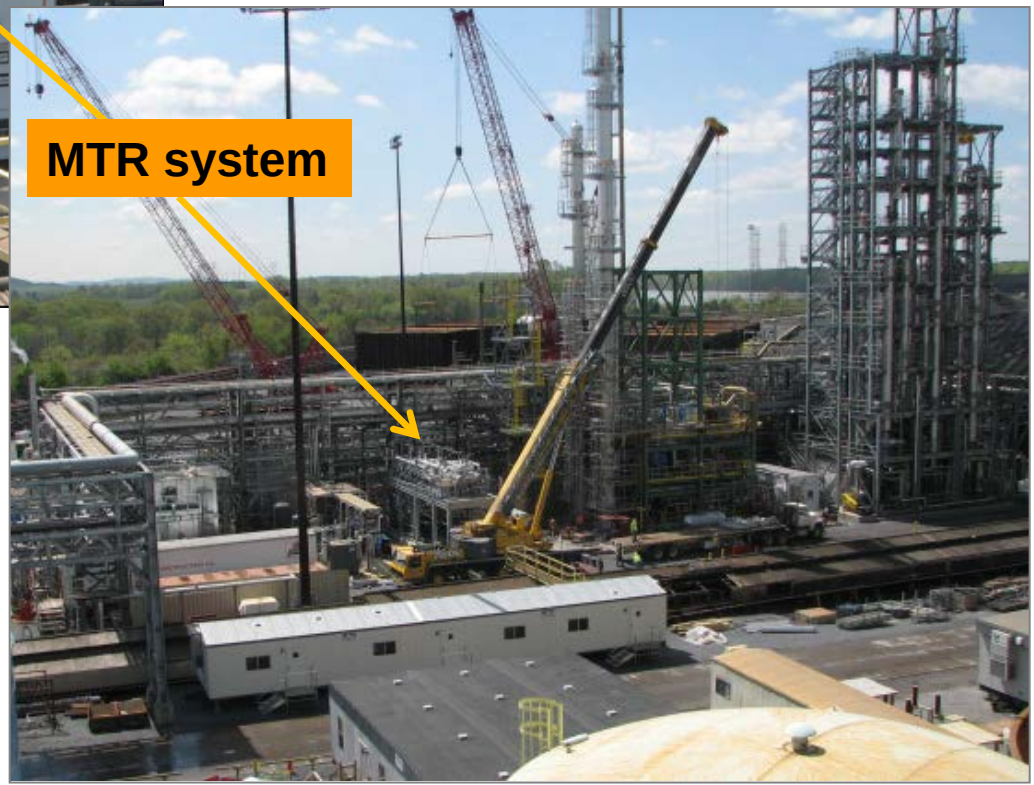
20 TPD System at PC4

- System installation completed Aug 2014
- Operation during Jan – Jun 2015



- Membranes are modular, compact, and require relatively little on-site construction

System Tests Scaled-Up Membrane Modules

Bundled spiral sweep modules

Bundled Polaris spirals

Polaris plate-and-frame (designed in DE-NT7553)

Advanced modules demonstrate lower cost and pressure drop

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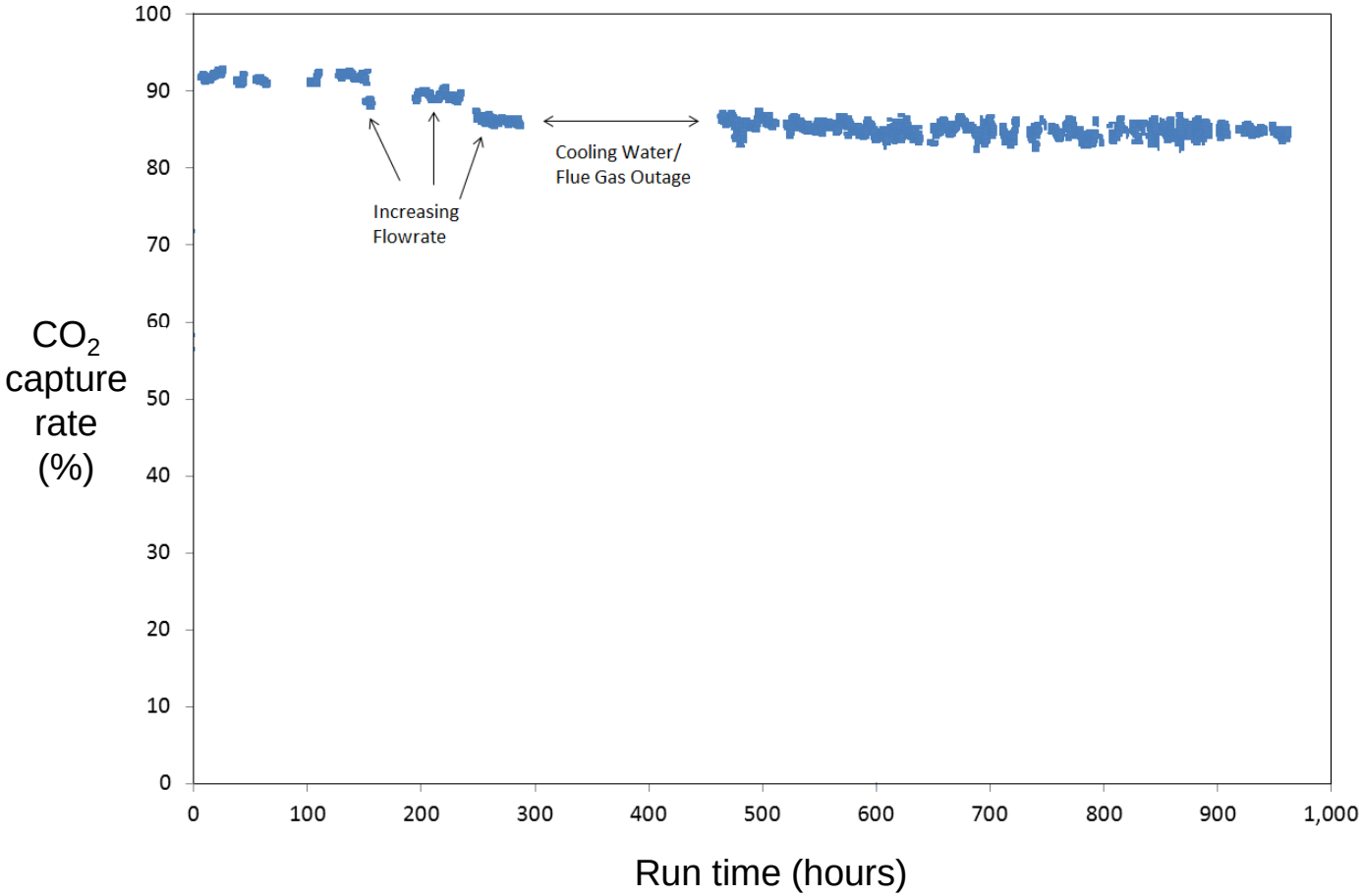
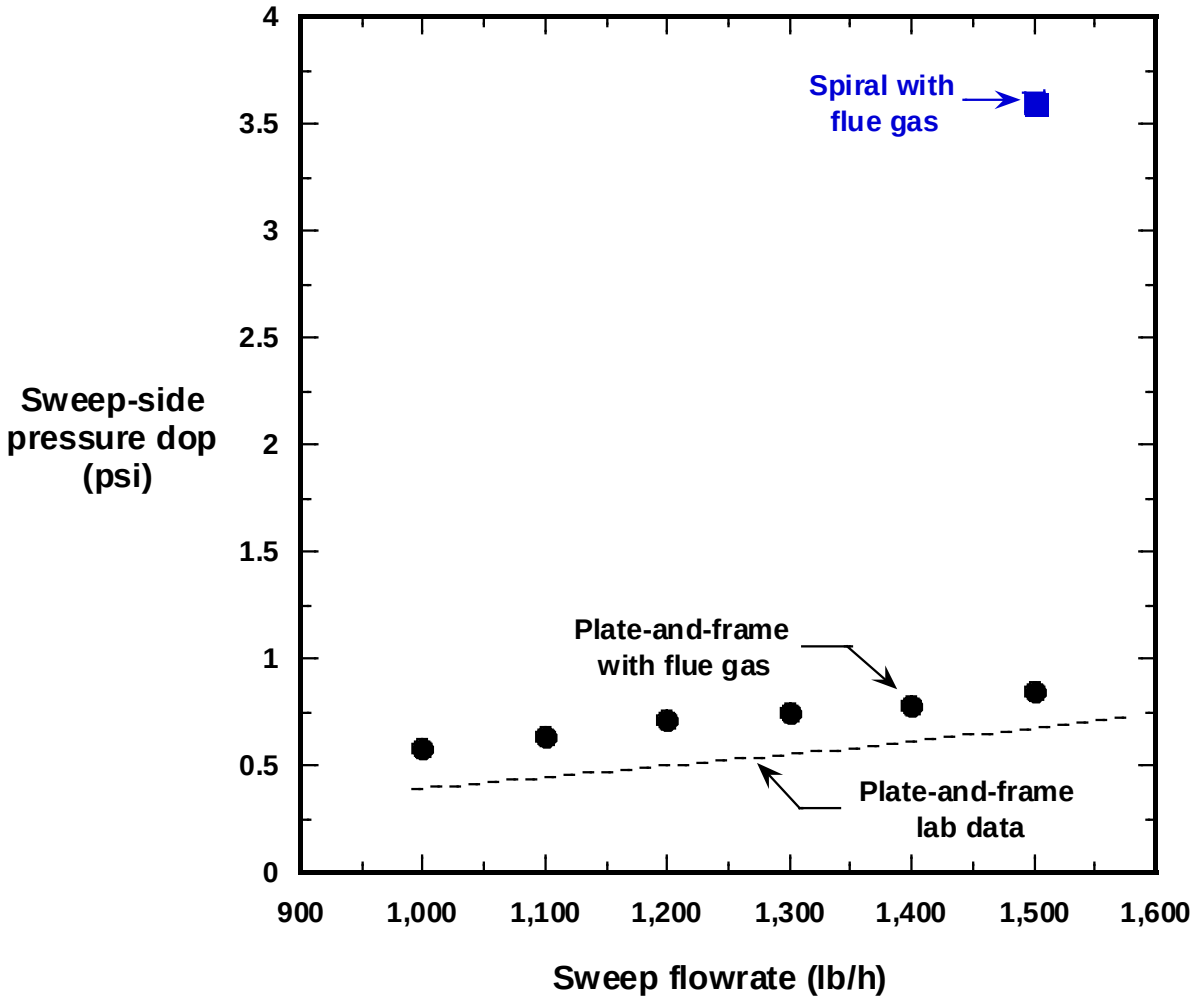
20 TPD System Shows Stable Performance



- Stable system performance through various startup / shutdowns and large variations in ambient conditions (sub-freezing in Jan to >95°F now)
- System goes from cold start to steady state in ~15 minutes

Figure data from current NCCC campaign (PO3: May to July 2015)

New Modules Demonstrate Improved Pressure Drop Performance



- Field data is consistent with lab results, and confirms much lower air sweep pressure drop in new modules
- At full scale, the difference in pressure drop amounts to savings of about 10 MW_e

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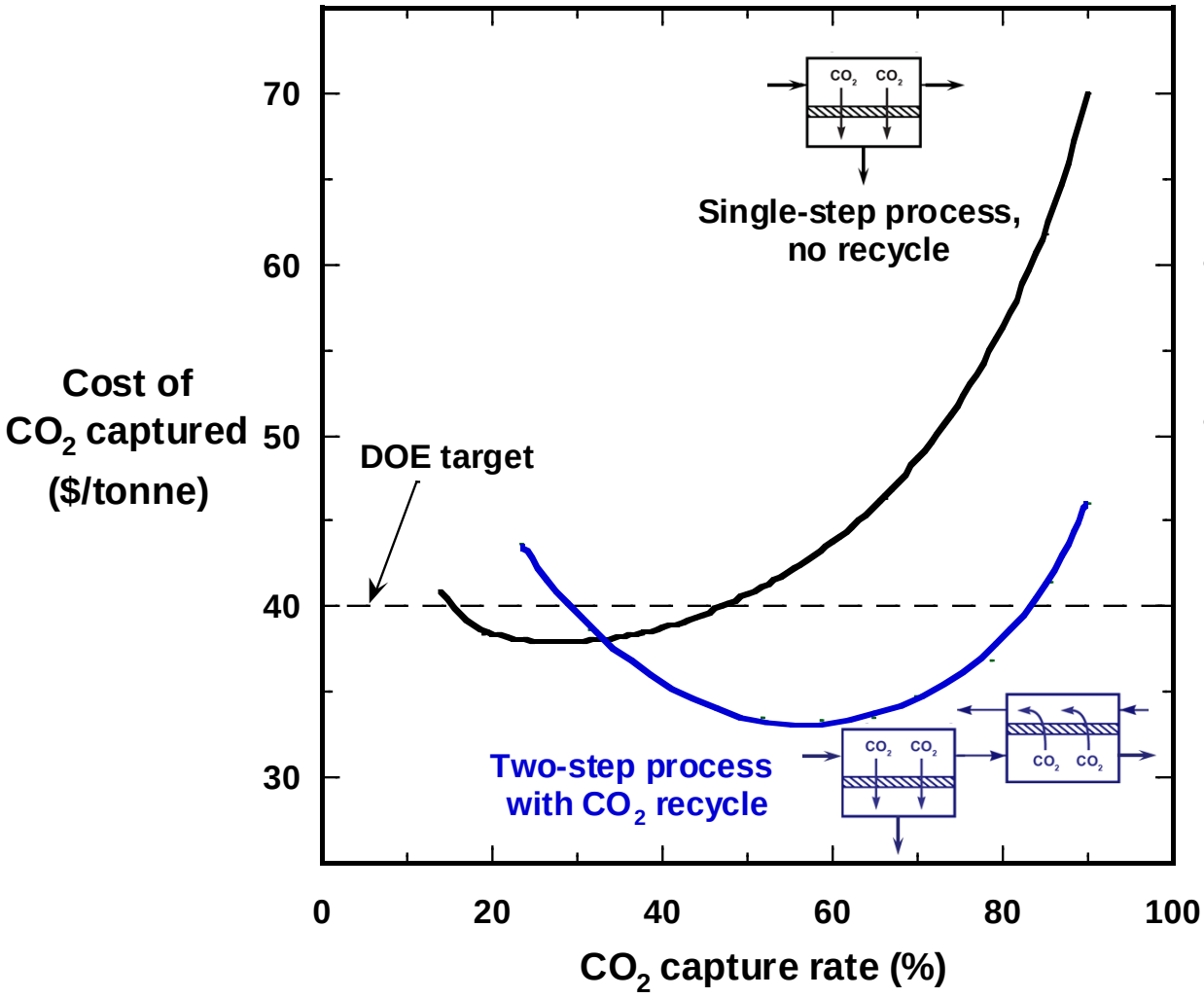
Systems Analysis: Membranes are Particularly Effective at Partial Capture



- Membranes show a minimum in capture cost
- To meet proposed EPA emission limits for coal (~40% capture), a simple system without recycle may be preferable

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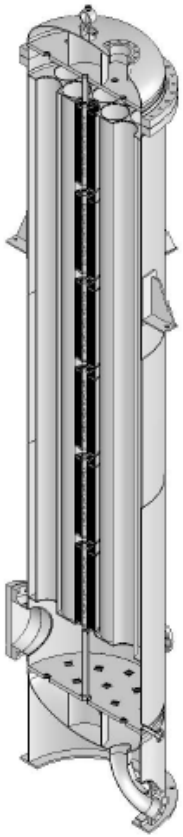
What Would a Large Membrane System Look Like?

Ashkelon desalination plant

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

Flue gas membrane vessels

- ~100 vessels required for 550 MWe plant with today's membranes
- Double permeance → halve the vessels



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Summary

- CO_2 capture membrane performance continues to improve, and has been validated on a 1 TPD slipstream system at NCCC (now ~10,000 hours total run time)
- 20 TPD small pilot operation at NCCC is nearly complete; Testing successfully demonstrated optimized modules (low Δp, low cost)
- Systems analysis shows low-cost “sweet spot” for membranes at 40-60% capture; updated TEA underway

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Acknowledgements

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  - Mike Mosser

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