Membrane Technology & Research

Pilot Testing of a Membrane System for Post-Combustion CO_2 Capture
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NETL CO_2 Capture Technology Meeting

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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

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 – 6-month pilot test of the 20 ton/day system; comparative economic analysis; industrial 1 TPD field test; Vectren case study at 20 MW-scale

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; co-capture possible
- 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
- Very efficient at partial capture (~60%)

Challenges:

- How to generate a pressure driving force in an affordable manner?
- Very permeable/low cost membranes required
- Unknown impact of particulate matter on membrane-module lifetime
- Materials and performance challenges for rotating equipment used (blowers, compressors, vacuum pumps)
- Pressure drop and module flow distribution

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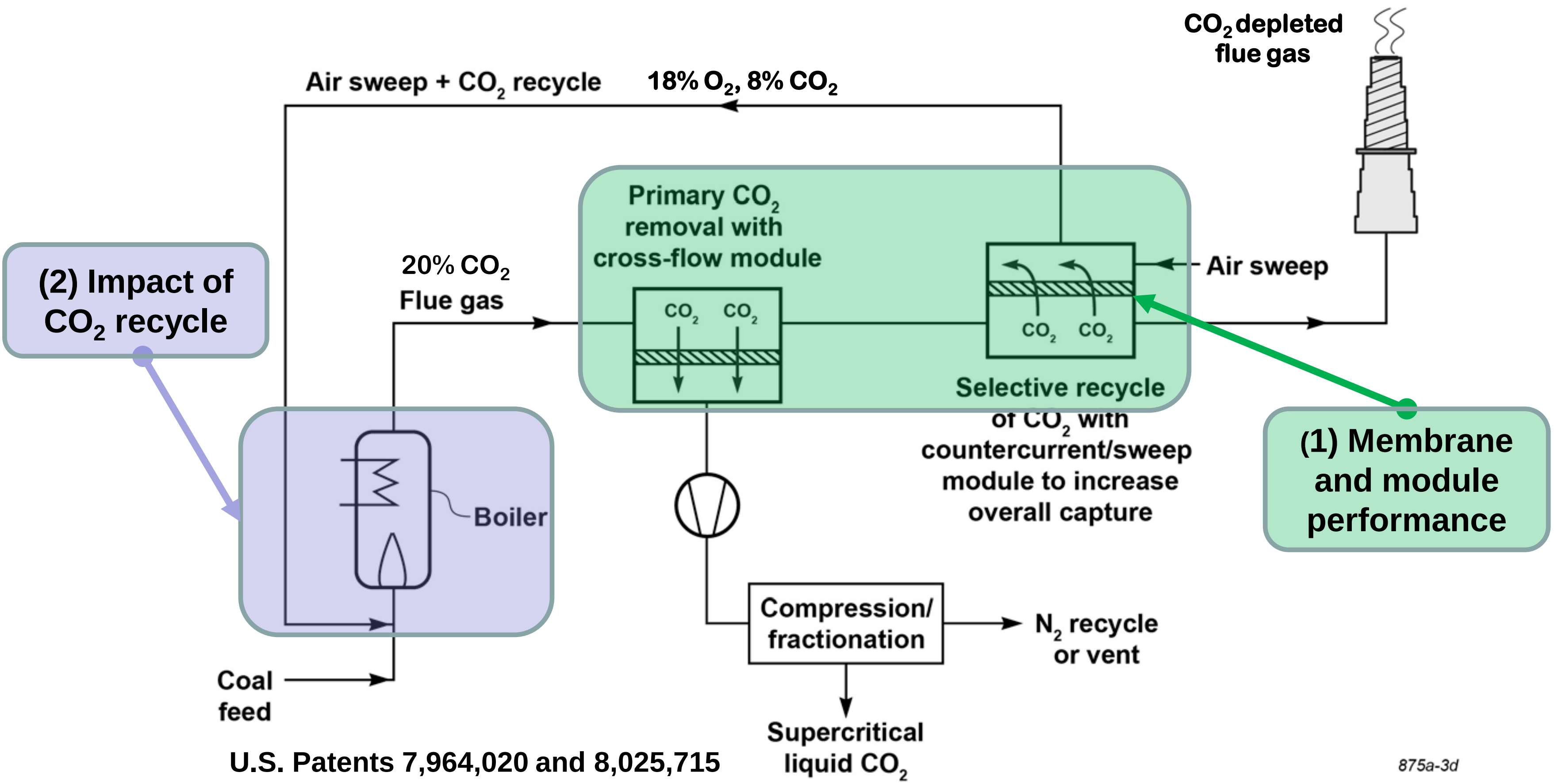
MTR CO_2 Capture Process



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

- Combustion air sweep provides driving force that lowers the capture energy
- Pre-concentrated CO_2 decreases membrane area and power required

Timeline of Major Project Tasks

FY2011	FY2012	FY2013	FY2014	FY2015

BP1 | BP2 | BP3

Optimize Process Design and Complete Systems/Economic Analysis
- In BP1, complete preliminary systems and economic analysis
- In BP2 and 3, evaluate new designs and update economic analysis

Continue Membrane Optimization on 1 TPD System
- Run continuous tests at NCCC
- Improve membrane/module performance
- Collect membrane lifetime data

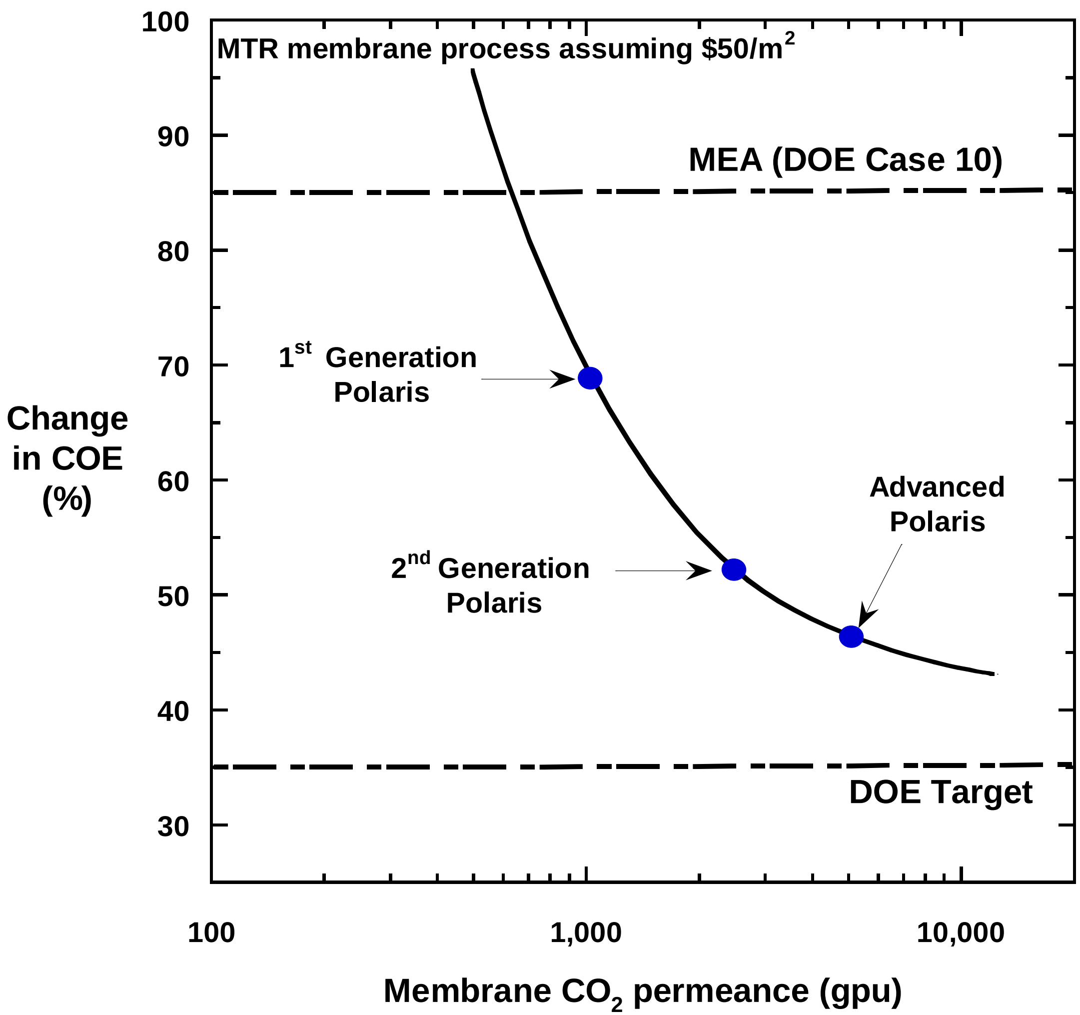
Boiler Recycle Study
- Evaluate CO_2 recycle with B&W
- Computer modeling in BP1; boiler testing in BP2

Design/Install/Operate 1 MW Demo (20 TPD)
- Design, build, and install the 20 TPD system at NCCC in BP2
- Run 6+ month test (parametric and SS) in BP3

Industrial CO_2 Capture Test
- Field test CO_2 capture from syngas
- Conduct economic analysis based on test results

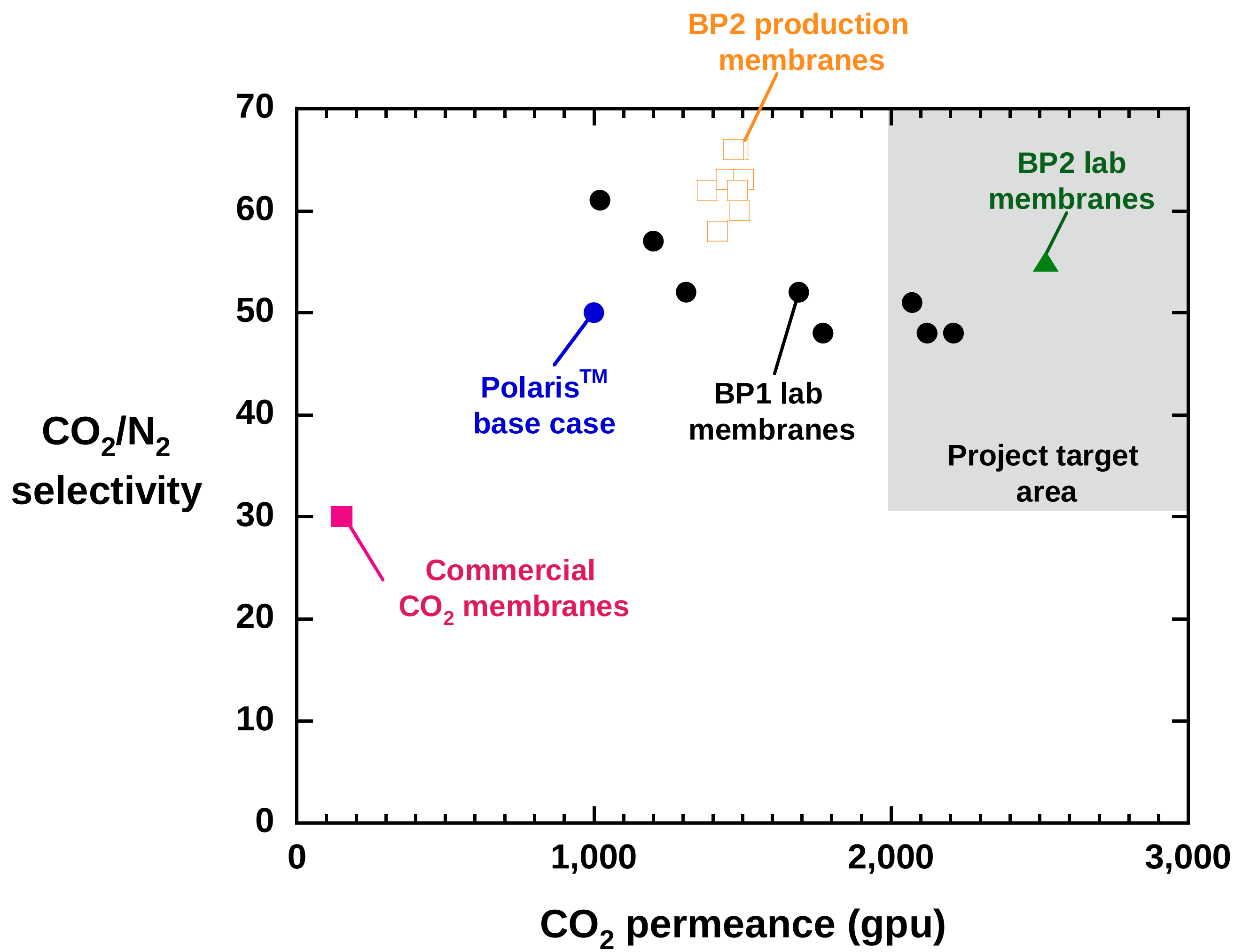
As of 6/30/13, project 45% complete

Systems Analysis: Importance of Membrane Improvements



- Study completed in BP1 to meet a project milestone
- 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 generally consistent with independent findings reported in DOE report "Current and Future Technologies for Power Generation with Post-Combustion Carbon Capture" (DOE/NETL-2012/1557)

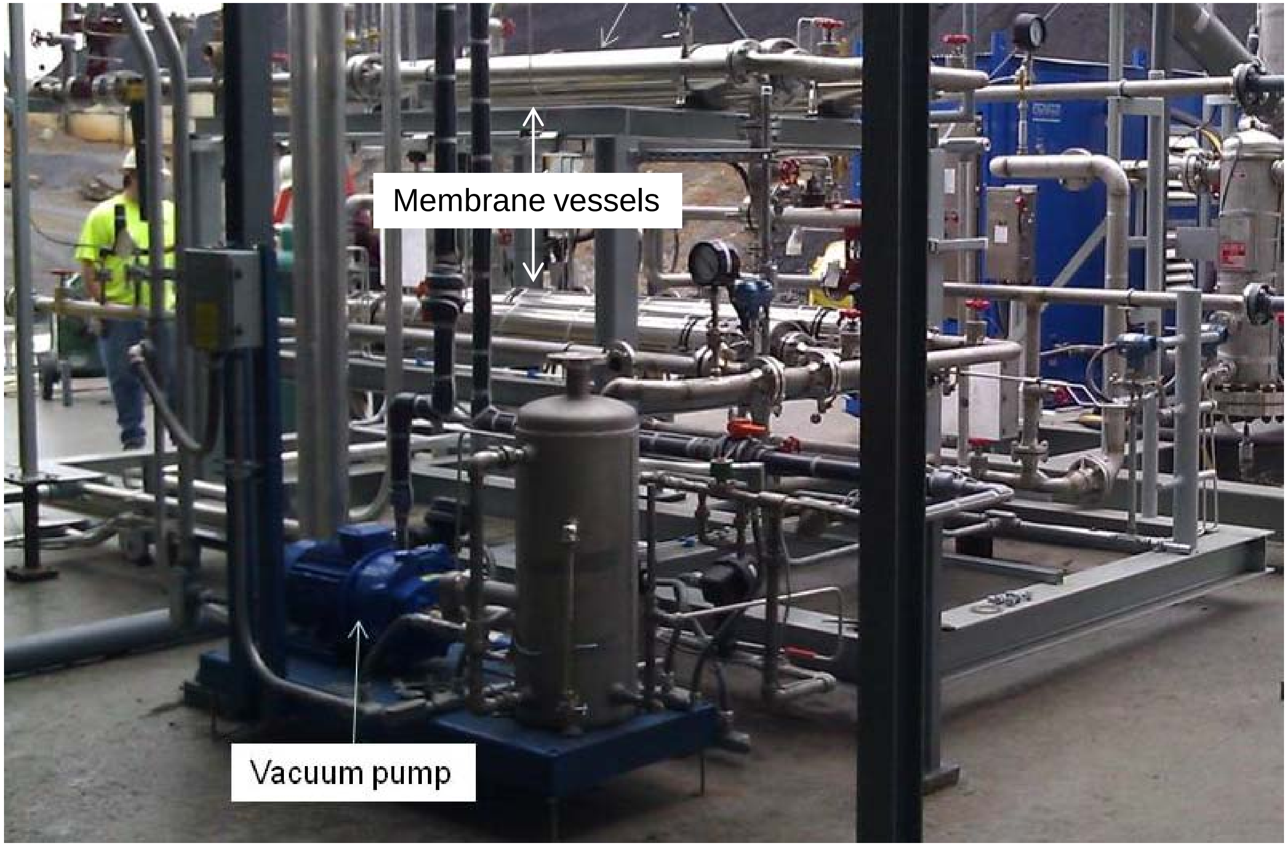
Membrane Performance Improvements



- Membranes continue to improve
- In addition to lower cost, these improvements are important to shrink the size of the capture system

Pure-gas data at 25°C and 50 psig feed pressure; 1 gpu = 10^{-6} $cm^3(STP)/(cm^2\ s\ cmHg)$

1 TPD System at NCCC



- System is testing vacuum and air sweep membrane steps
- Sized to capture 1 ton CO_2/day using commercial 40-inch-long modules
- System installed Nov 2011; operation started Spring 2012

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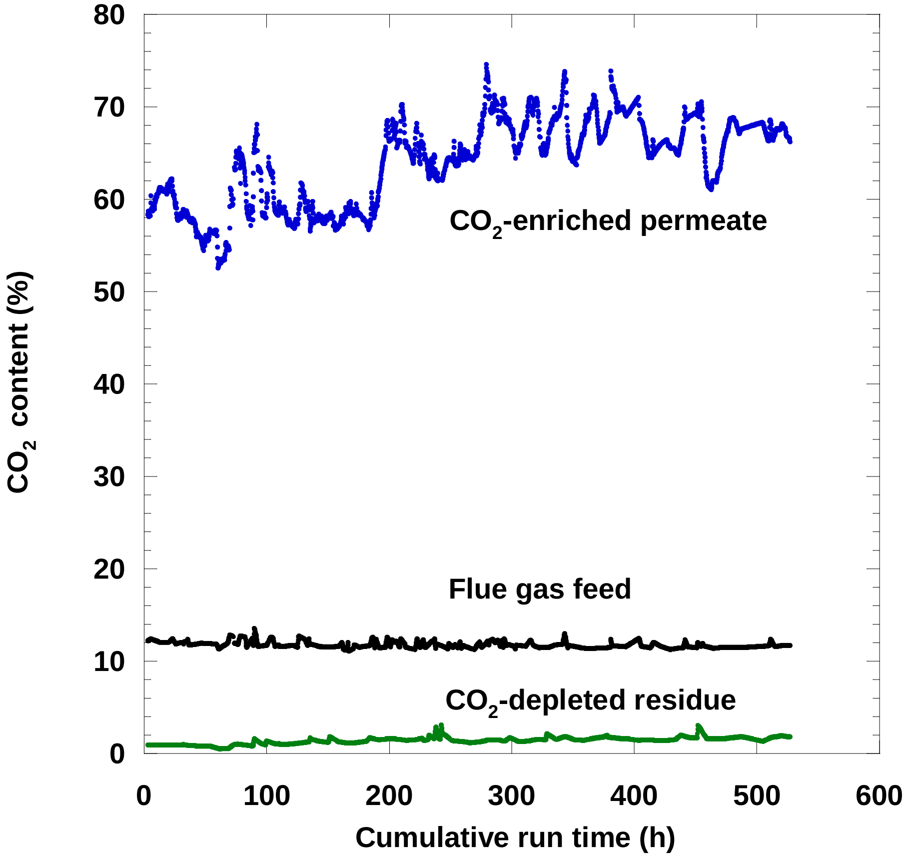
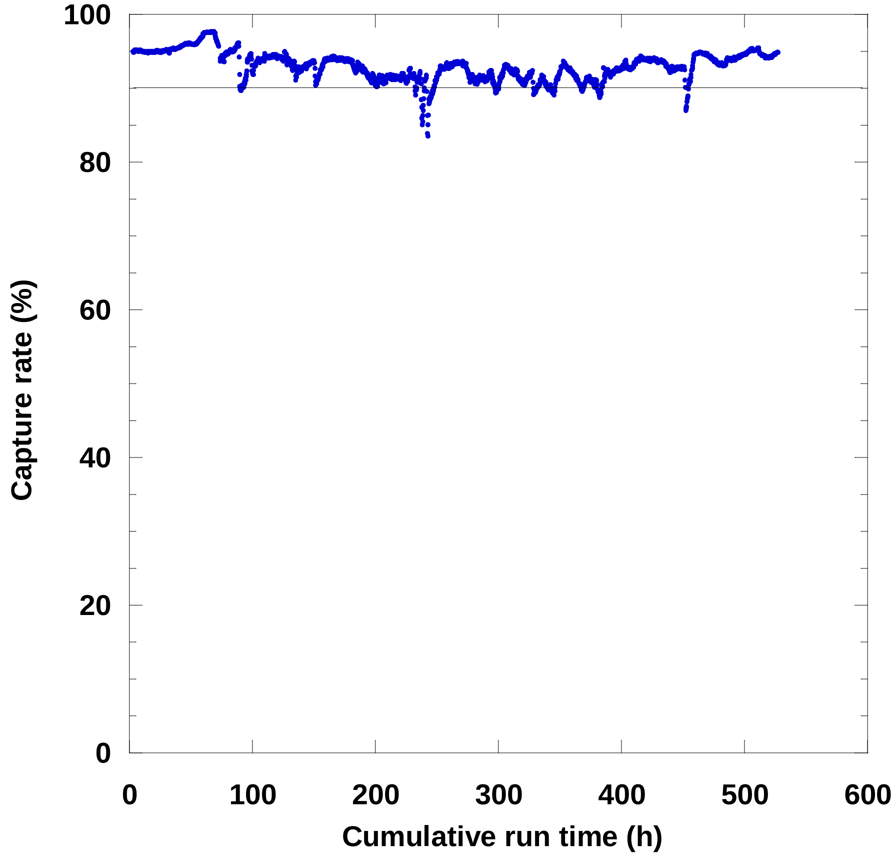
Sample Results at NCCC

CO_2 Concentration



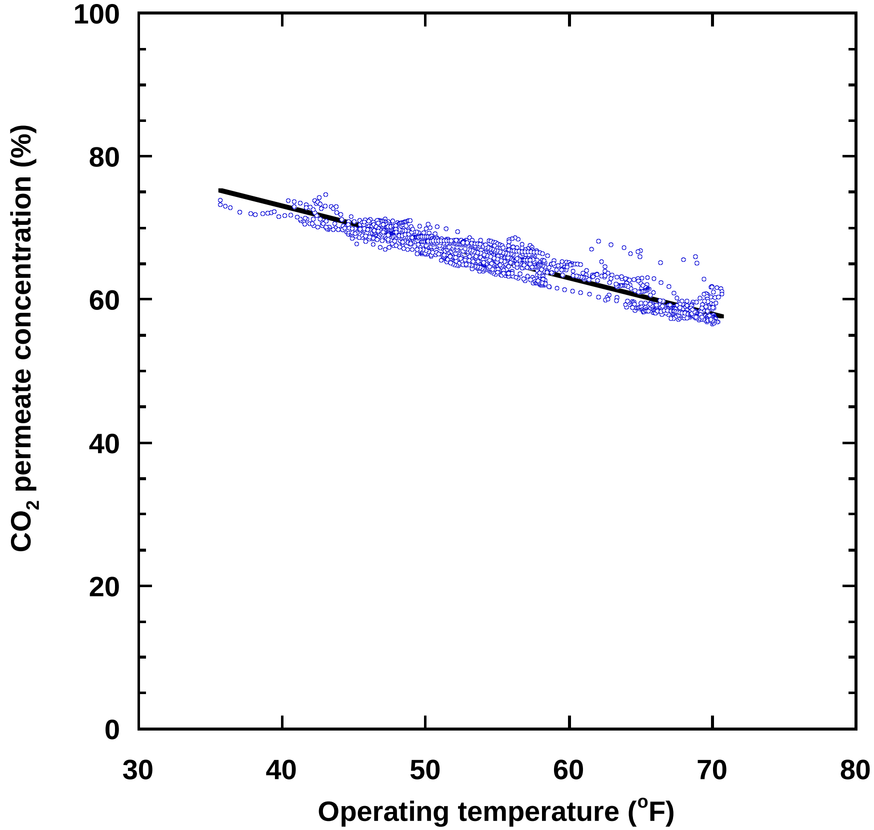
Capture Rate



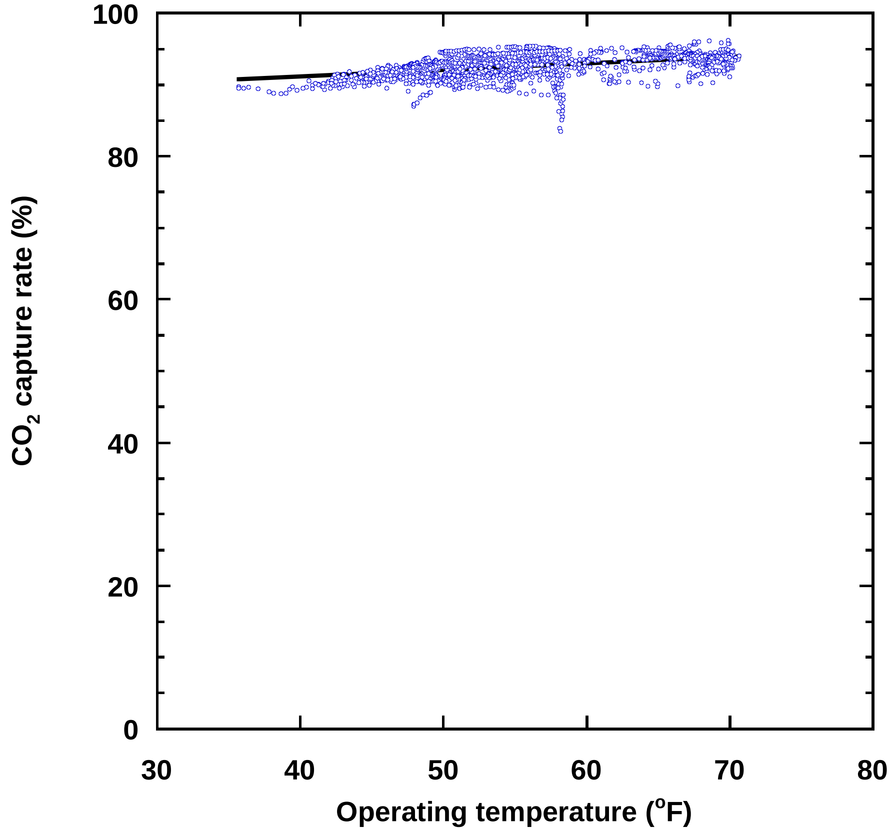
Most concentration fluctuations due to changes in feed gas temperature

Correlation of CO_2 Purity and Capture Rate With Temperature

CO_2 Concentration



Capture Rate



- Higher temperatures yield higher gas permeances, leading to greater CO_2 capture, but at lower purity; could be controlled by switching modules on and offline depending on temperature.

1 TPD System: Lessons Learned

- In July 2012, compressor failed due to extensive deposition of unknown material
- NCCC and MTR analyses indicate presence of water soluble sulfur salts (ammonium sulfate/bisulfate, iron sulfate)
- It is believed these salts were created in SCR/FGD operation upstream of the membrane, and were present as aerosols in the flue gas fed to the system
- A more solids-tolerant liquid ring compressor was installed; appears to effectively remove acidic aerosol in sealing water

Motor element showing deposition

Material dissolved in water

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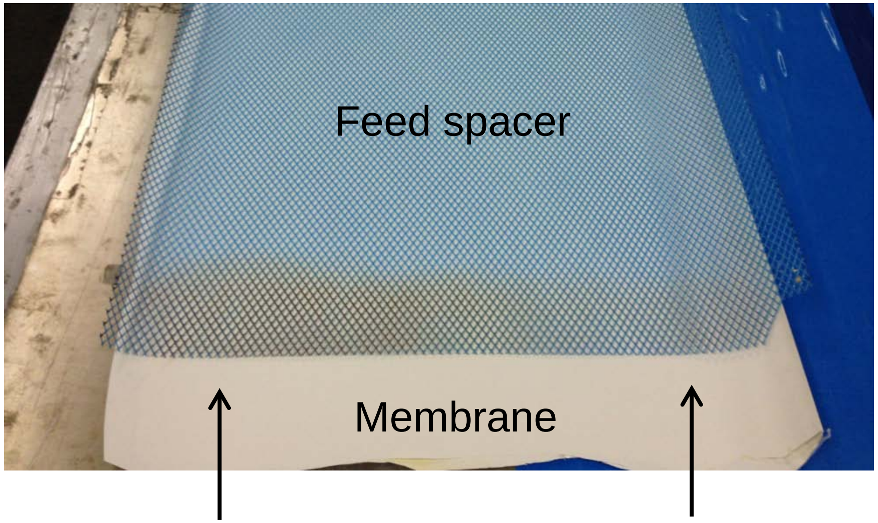
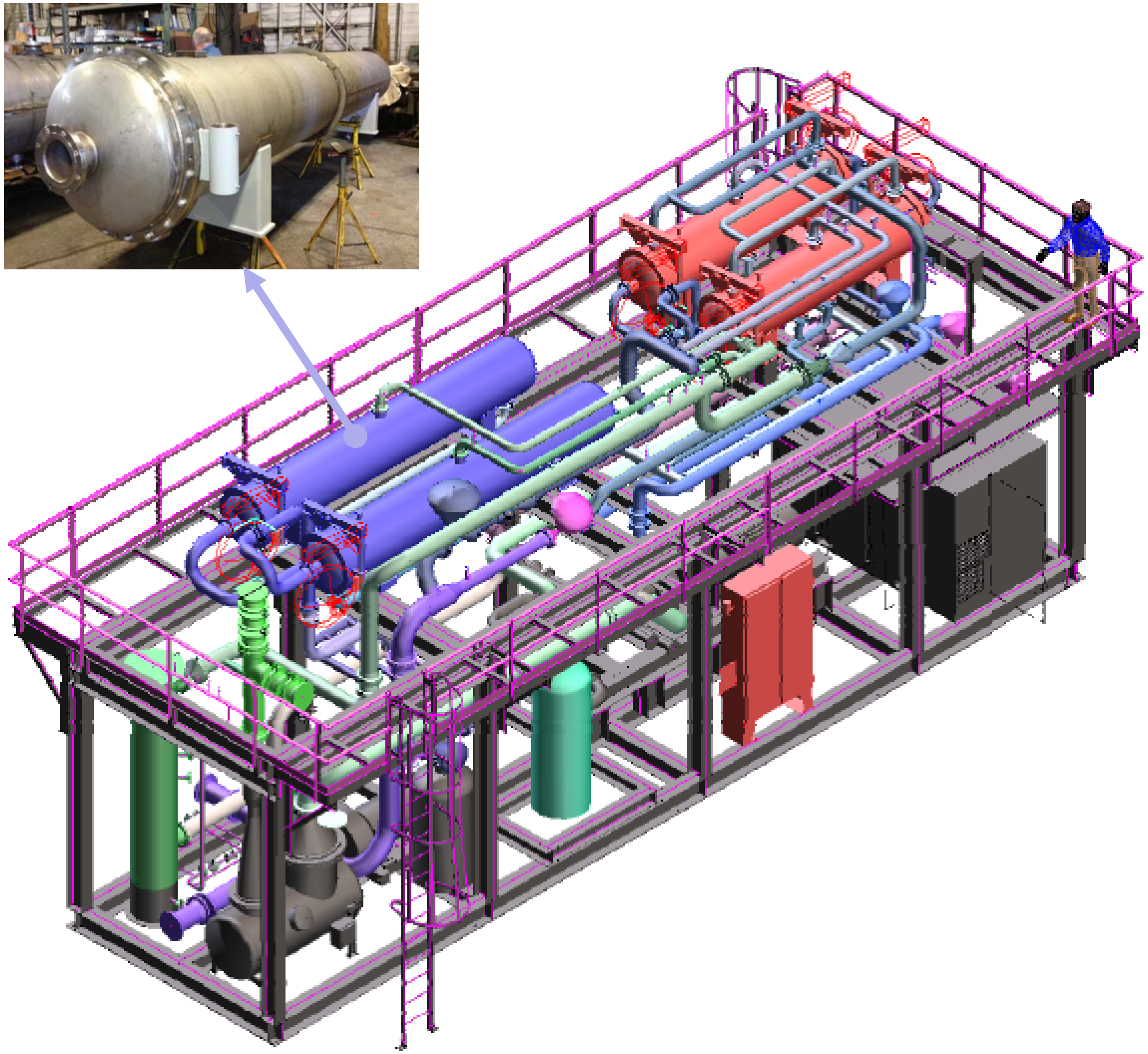
1 TPD System: Lessons Learned



- After compressor failure, system continued operating with vacuum only until Sept 2012
- Membranes showed stable performance during this time
- After shutdown at end of Sept, it was found that condensed water with dissolved sulfate salts collect on surface of membrane, and resulted in low CO_2 flux
- To prevent future occurrence, system shutdown procedure changes, and module material solutions developed
- Several startup/shutdown cycles since these changes show stable membrane performance

20 TPD System Status



- 20 TPD skid (1 MW_e) design is complete; now under construction
- Fabrication and site preparation on schedule
- Planned installation at NCCC in 1Q2014, followed by 6 month demonstration
- Will test 2nd generation modules designed for low pressure drop while minimizing footprint (cost)

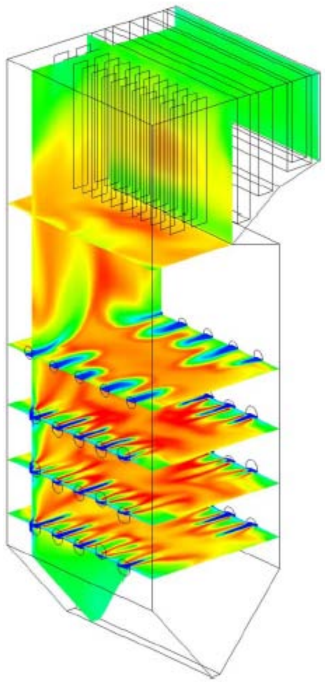
20 TPD System Location at NCCC/PC4

Picture courtesy of Mr. Tony Wu, Southern Company

Impact of CO_2 Recycle on Boiler Performance

Phase I (BP1) – CFD modeling

- B&W modeled 2 boiler configurations (radiant boiler firing bituminous coal and SWUP firing PRB coal) and 2 sweep recycle cases (constant secondary air flow and constant stoichiometry)
- Main conclusion of modeling study: secondary air laden with CO_2 appears feasible as a retrofit in either of the boiler configurations examined if oxygen mass flow to boiler is fixed



Phase II (BP2) – Pilot testing

- B&W's SBS-II 1.8 MW_{th} pilot boiler operated with CO_2-laden combustion air
- Two coals evaluated: a western sub-bituminous coal and a highly volatile bituminous coal
- O_2 content of windbox air varied from 21% to 16% through CO_2 dilution
- Monitored flame stability, length, and shape; unburned combustibles in fly ash, and furnace exit gas temperature
- Radiant furnace and convective pass heat absorptions were measured
- Boiler efficiencies for air and sweep firing being determined

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Baseline and Sweep Air Flames with a Western Sub-Bituminous Coal

Air-Firing

Sweep Air-Firing

Conditions: 5 MMBtu/h with sub-bituminous coal; deep staged flame, stoichiometry 0.8; sweep air is 18% O_2

Viewpoint is from top of boiler looking down at flame

Boiler Study Preliminary Findings

- Pilot-scale evaluation shows that stable flames can be obtained with sweep air (in fact B&W analysis indicates sweep flame is more stable due to additional combustion air swirl)
- Although flame is stable down to 16% O_2, for existing boilers, 18% is preferred to minimize increased mass through boiler
- Data analysis to determine the effect of sweep air on boiler efficiency and the potential need for additional heat transfer surface area is ongoing
- Findings will be used to update BP1 techno-economic analysis

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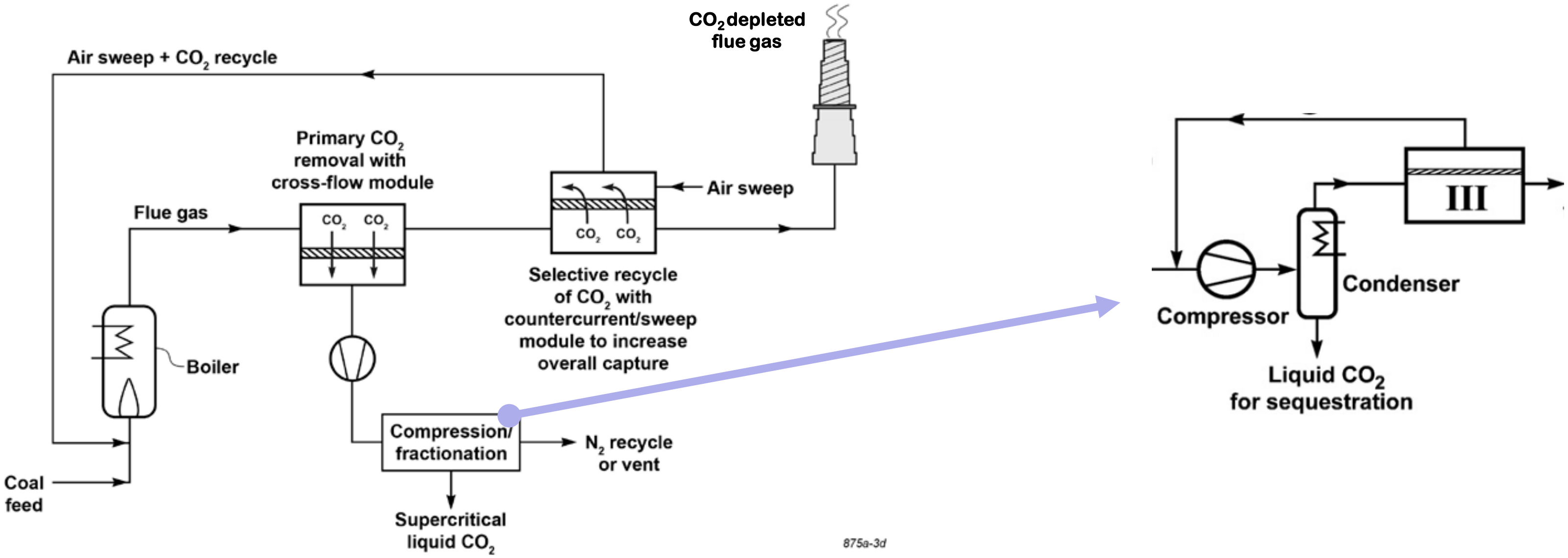
CO_2 Liquefaction and Industrial Capture



- The compression/purification step of the flue gas CO_2 capture process uses a membrane-assisted refrigeration design
- This CO_2 liquefaction process was recently tested at NCCC (in a separate DOE-funded project) using the BP1 Polaris membrane
- In BP3, a similar membrane-assisted refrigeration process will be used to conduct a 1 TPD field test of CO_2 capture from a biowaste-to-methanol facility; the membrane performance will be compared with an existing Rectisol unit

Summary

- Post-combustion capture membrane performance continues to improve
- Bench-scale slipstream tests at NCCC show membrane modules capable of generally stable 90% capture
- Many useful lessons learned from operating with real flue gas; NCCC assistance has been invaluable
- B&W CFD analysis and flame stability tests suggest CO_2 recycle with sweep membrane is feasible; detailed analysis ongoing
- Industrial CO_2 capture membranes have demonstrated liquid CO_2 production; industrial field tests planned
- Key objective of next 12 months is fabrication, installation, and operation of the 20 TPD demonstration unit

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Acknowledgements

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