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

Karl Amo, Zhenjie He, Ivy Huang, Jurgen Kaschemekat,

Tim Merkel, Saurabh Pande, Xiaotong Wei, Steve White (MTR)

Prasanna Seshadri and Hamid Farzan (B&W)

NETL CO_2 Capture Technology Meeting

Thursday, July 31, 2014

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

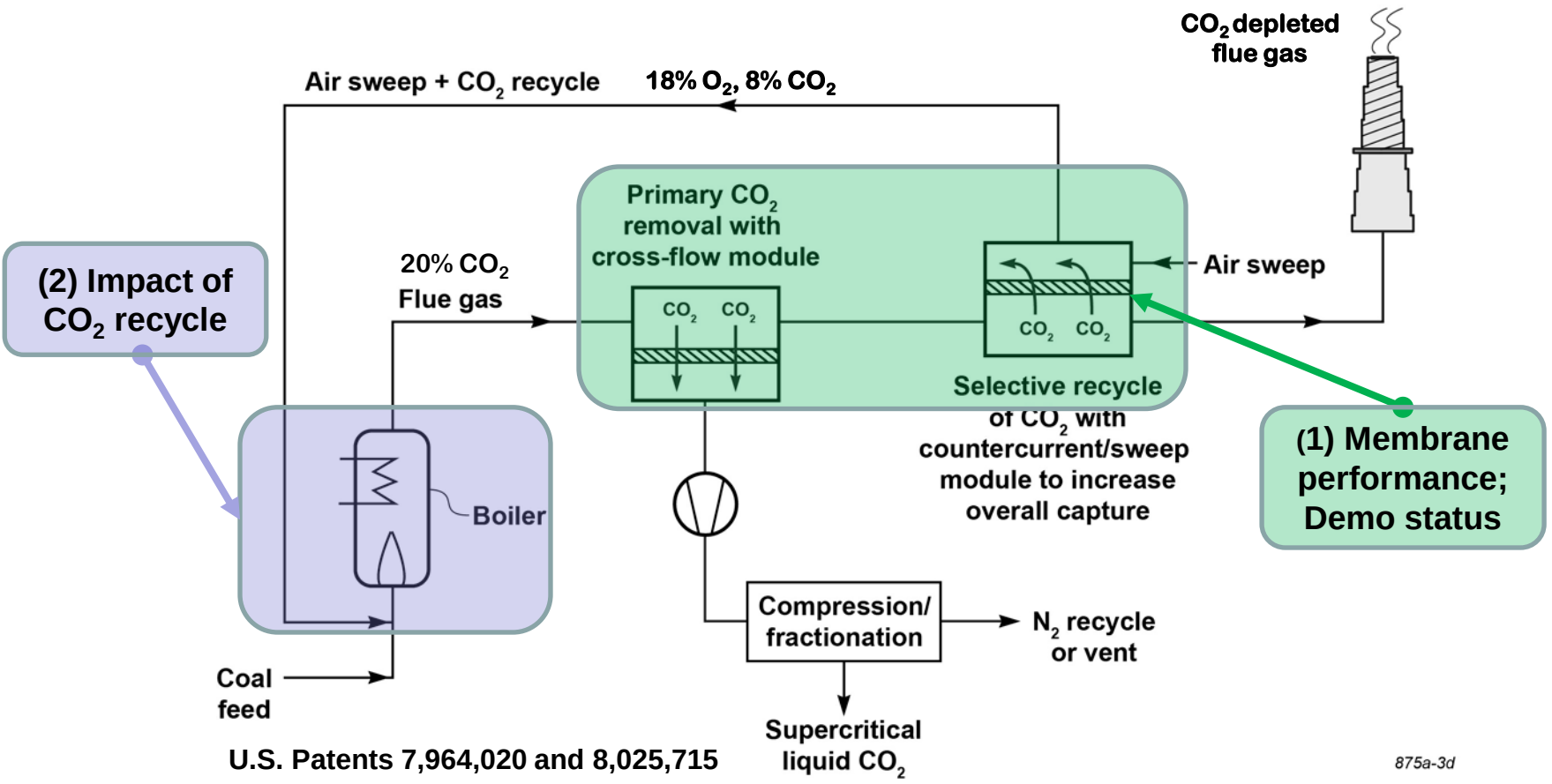
Project scope: Demonstrate a membrane process to capture 20 tons of CO_2/day (TPD) from a flue gas slipstream of a coal-fired power plant.

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; case study at 20 MW-scale

MTR

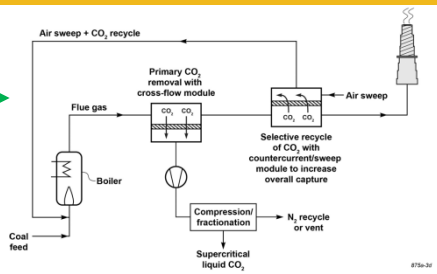
MTR CO_2 Capture Process



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

MTR CO_2 Capture Development Timeline

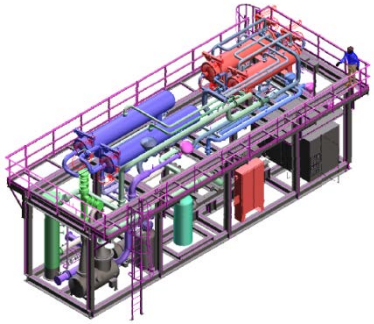
Feasibility study (DE-NT43085)
- Sweep concept proposed
- Polaris membrane conceived



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)

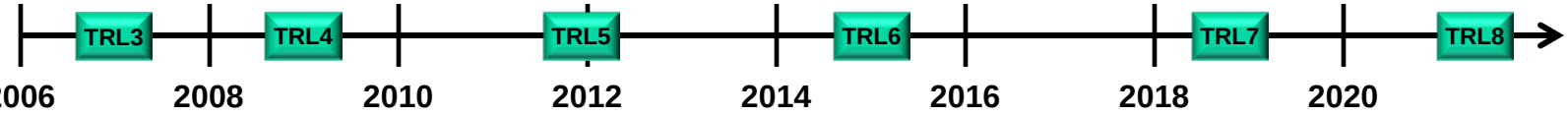
NCCC 1 MW_e Demo (DE-NT5795)
- 8,000 hours of 1 TPD system operation
- 1 MW_e (20 TPD) system to run 6 months



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

Future 10-25 MW_e Demo



Pros and Cons of a Membrane Post-Combustion Capture Process

Benefits:

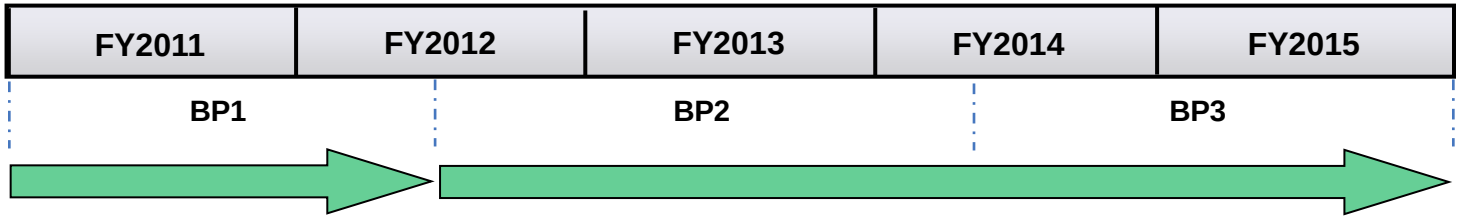
- No hazardous chemical handling, emissions, or disposal issues
- Not affected by oxygen, SO_x or NO_x; co-capture possible
- Water use lower than other technologies (recovers H_2O from flue gas)
- No steam use → no modifications to existing boiler/turbines
- Near instantaneous response; high turndown possible
- Very efficient at partial capture (40-60%)

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

MTR

Timeline of Major Project Tasks



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

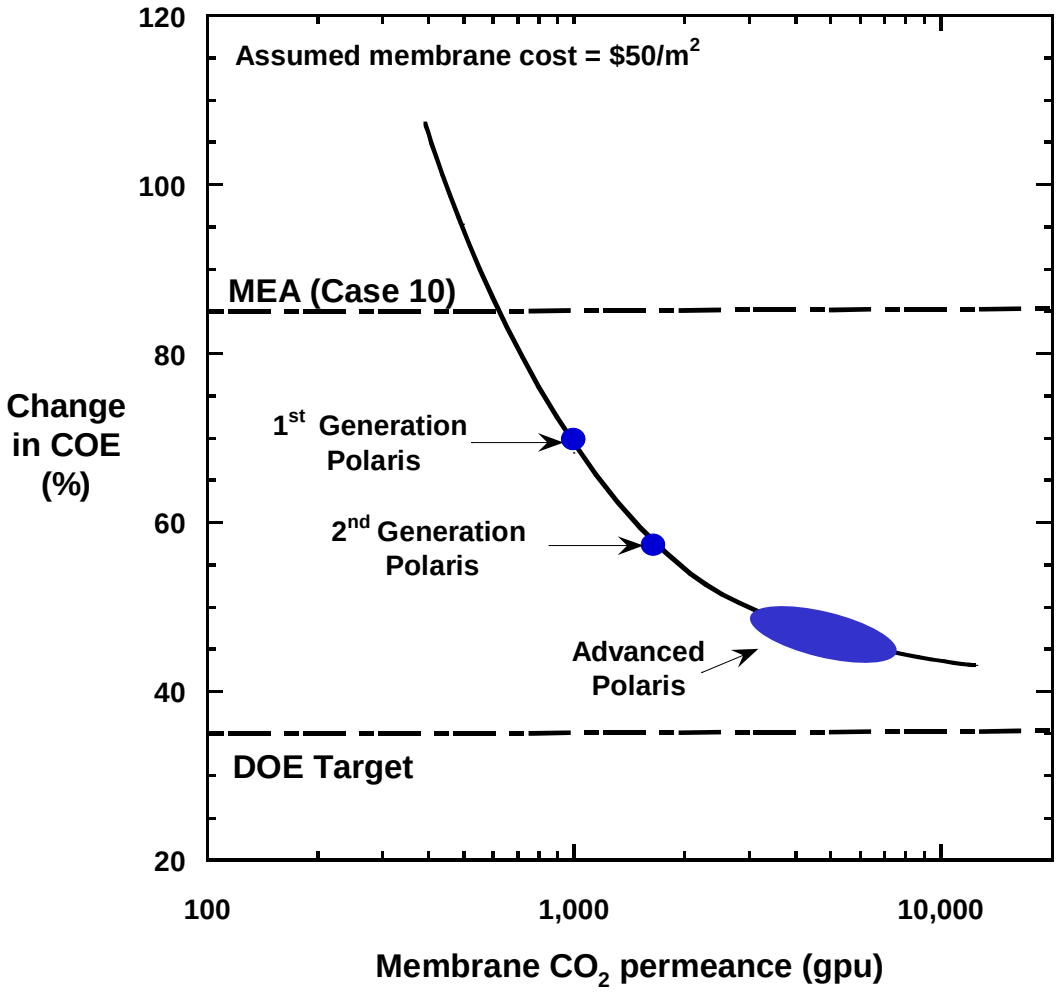
Design/Install/Operate 1 MW Demo (20 TPD)
- Design, build, and install the 20 TPD system at NCCC in BP2
- Run 6 month test in BP3, including P&F sweep module developed in project 7553

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

As of 6/30/14, project is 75% complete

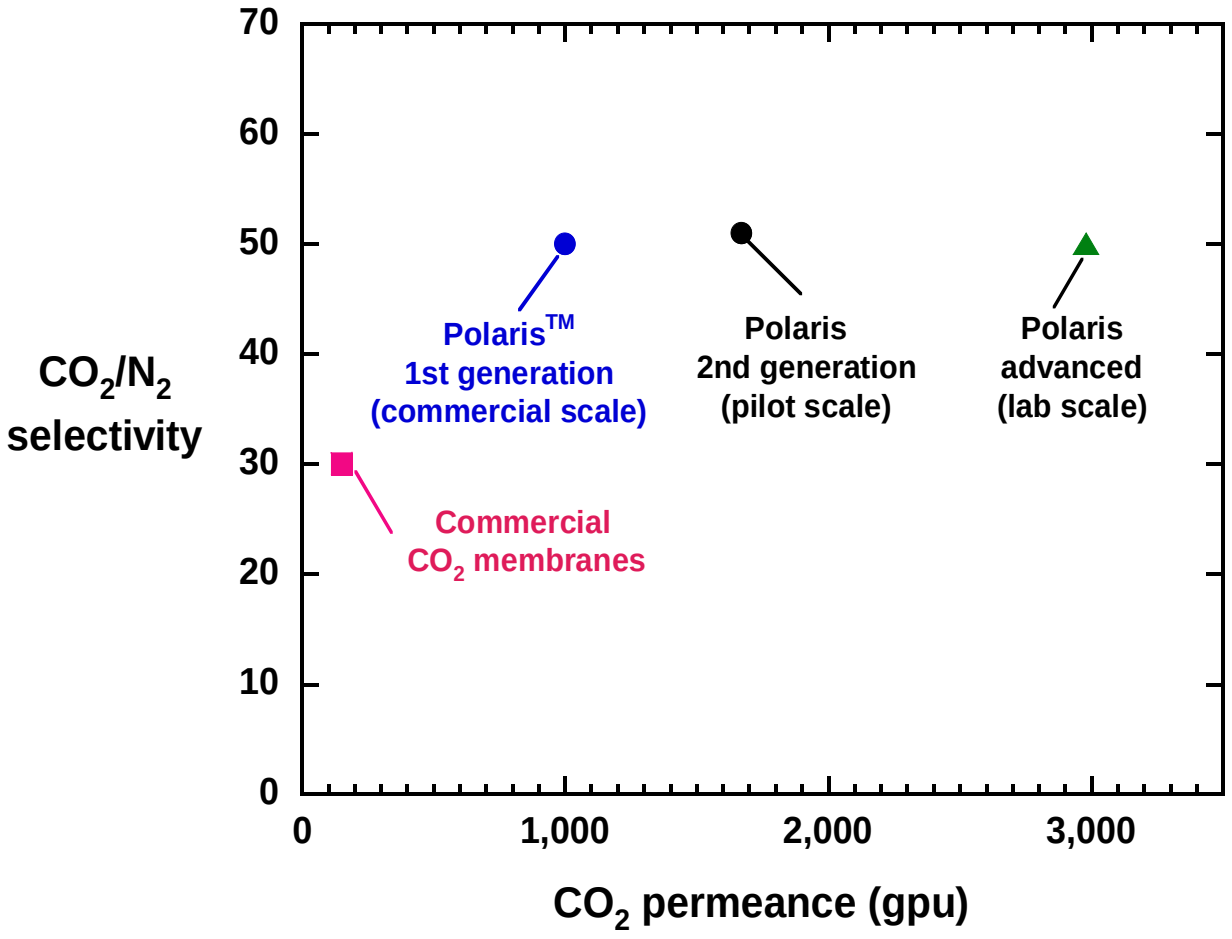
MTR

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 consistent with DOE report “Current and Future Technologies for Power Generation with Post-Combustion Carbon Capture” (DOE/NETL-2012/1557)

Polaris Membranes Continue to Improve

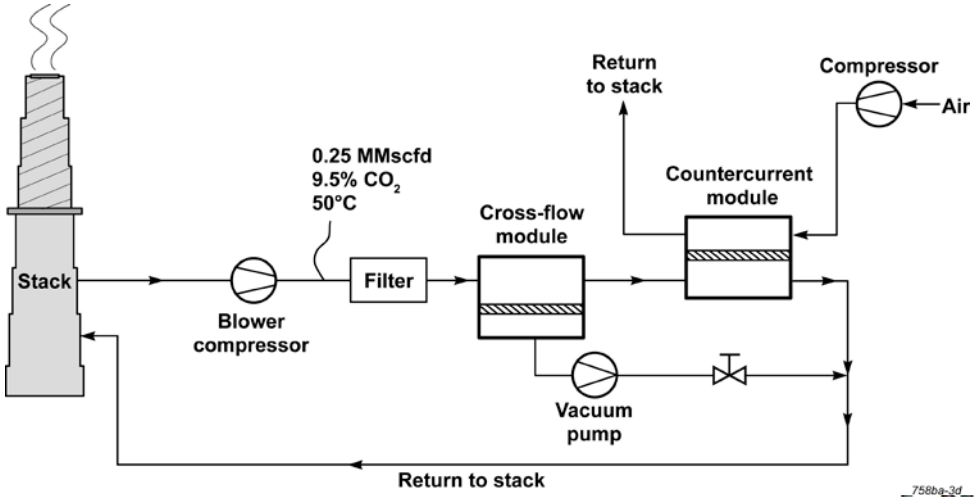


1 gpu = 10^{-6} $cm^3(STP)/(cm^2\ s\ cmHg)$= 3.35 x 10^{-10} $mol/(m^2\ s\ Pa)$

- In addition to lowering costs, these improvements are important to shrink the size of the capture system

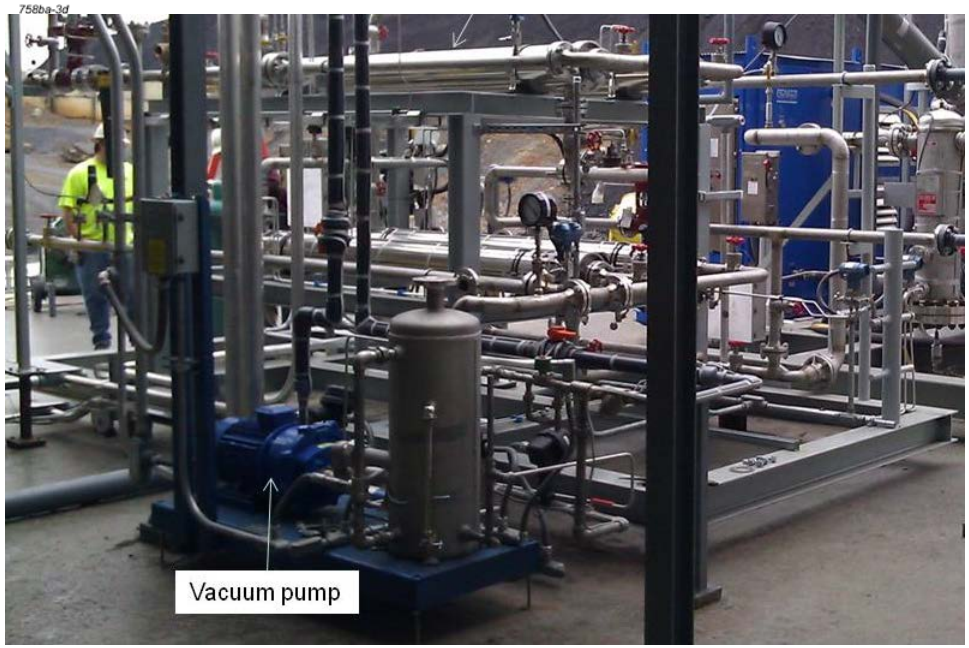
MTR

1 TPD Testing at NCCC

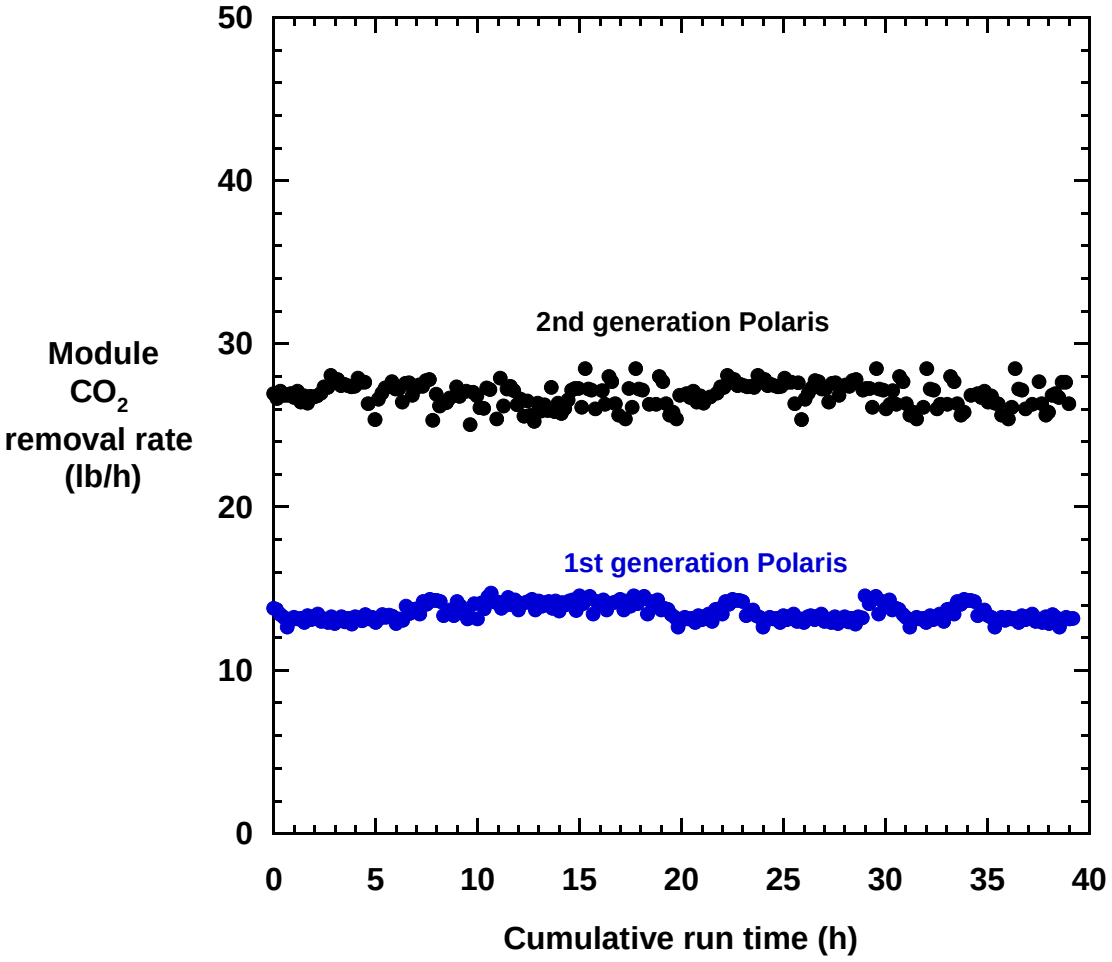


- Field laboratory that allows lifetime evaluation (>6,000 hours cumulative), and validation testing of new membranes
- Many lessons learned (i.e., ammonium sulfate deposition) applied to scale up

- 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

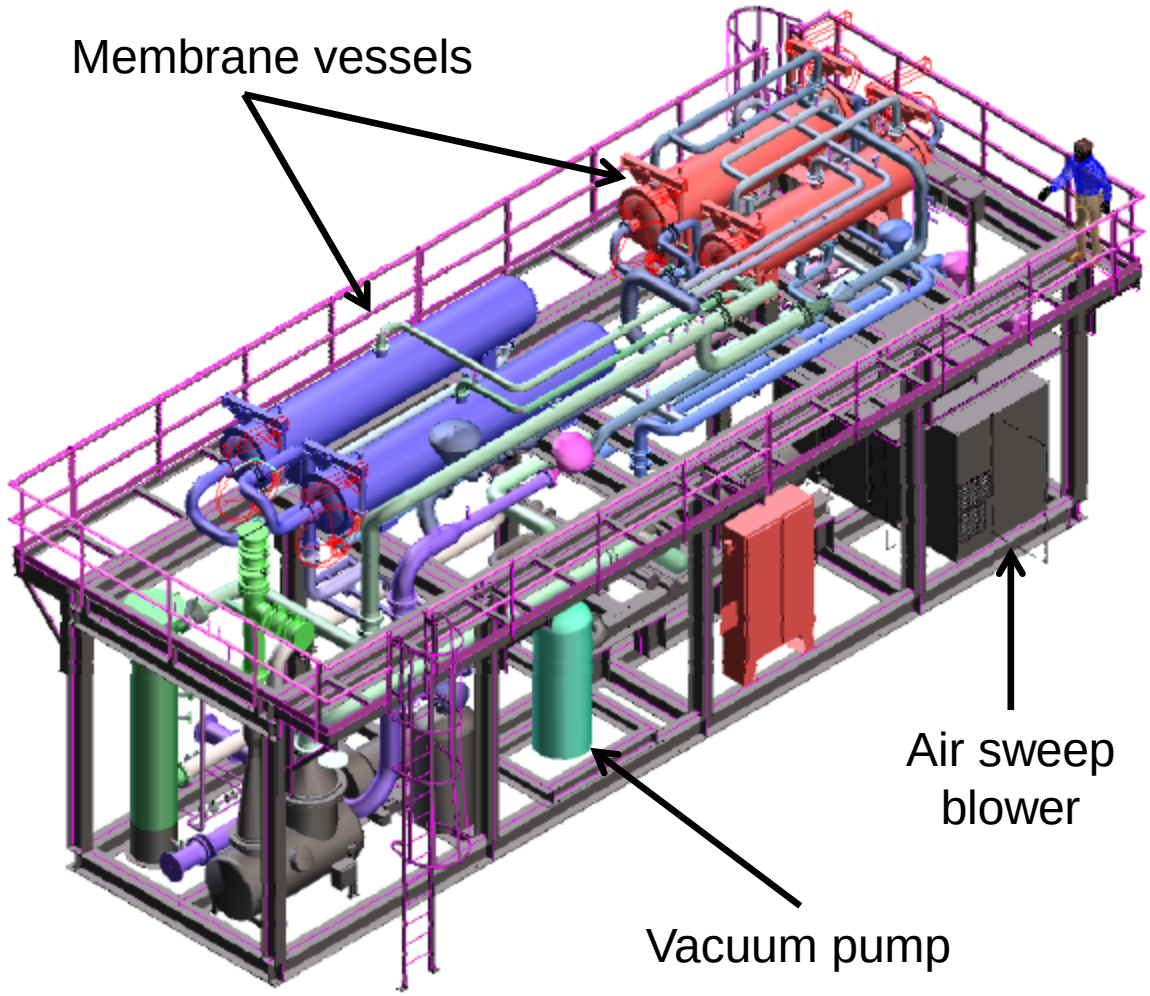


Higher CO_2 Removal Rate by Second Generation Polaris



- Both modules show stable performance
- The 2nd generation Polaris membrane shows 60%-70% more CO_2 removal capacity than that of the 1st generation

20 TPD System Update



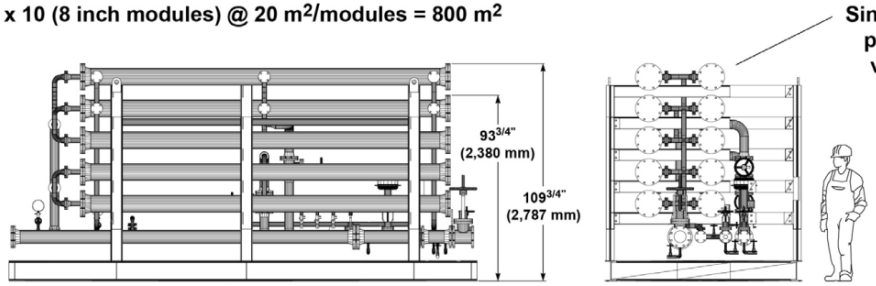
- 20 TPD skid (1 MW_e) is installed at NCCC
- Commissioning underway; will run through end of year
- Objective is 3 months steady state operation at 90% capture, and validation of advanced modules (multi tube and plate-and-frame) designed for low pressure drop and small footprint

MTR

Membrane Vessels Redesigned For Low-Pressure Flue Gas

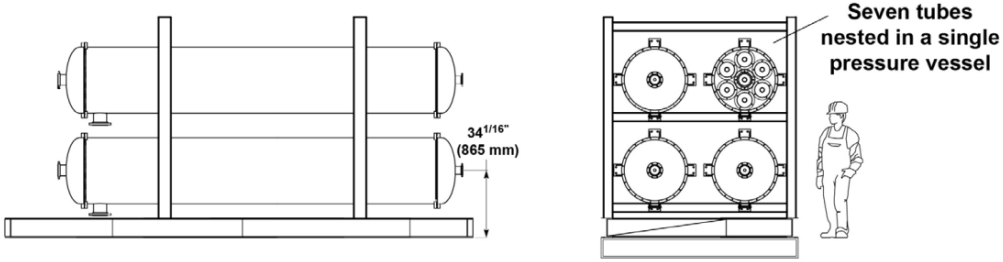
Module type demonstrated on:

Gen 1 (a) 4 x 10 (8 inch modules) @ 20 m^2/modules = 800 m^2



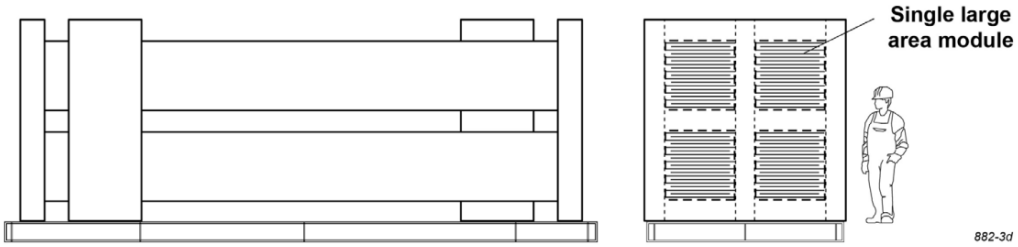
1 TPD

Gen 2 (b) 4 x 8 inch modules) @ 20 m^2/modules = 2,240 m^2



20 TPD

Gen 2b (c) 4 x (1 x 1 x 5 m) modules @ 2,500 m^2/modules = 10,000 m^2



20 TPD

MTR

20 TPD System Arriving at NCCC

Photo courtesy of Tony Wu

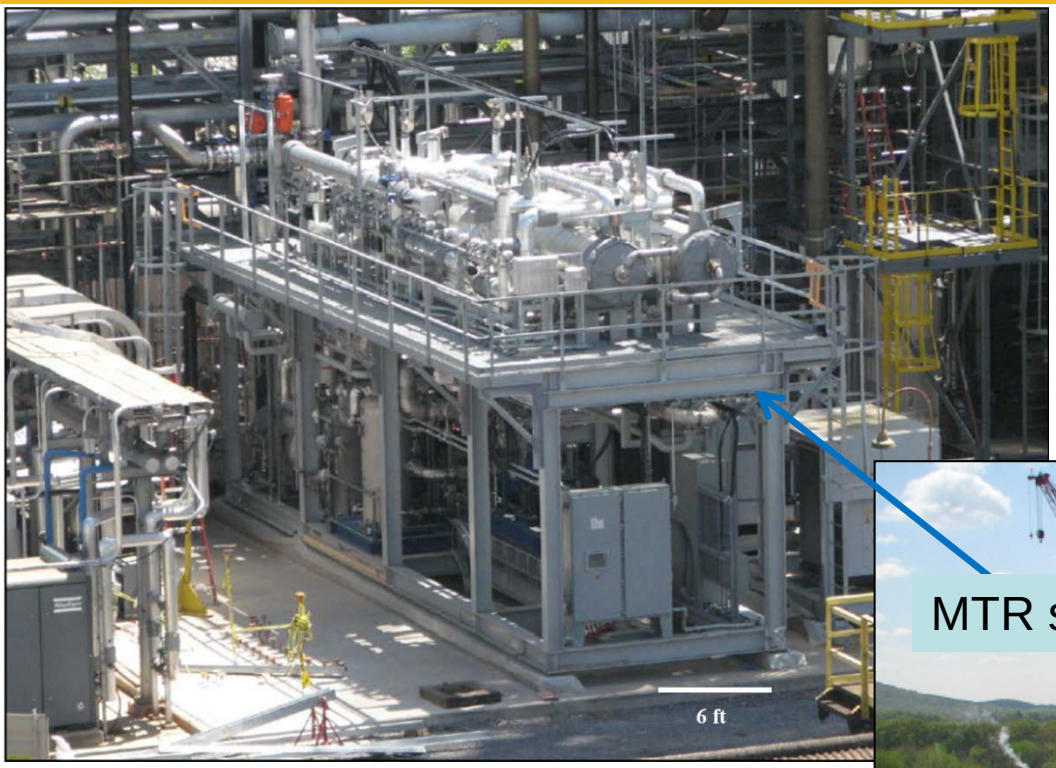
- System shipped from fab shop in Houston to NCCC April 2

20 TPD System During Installation

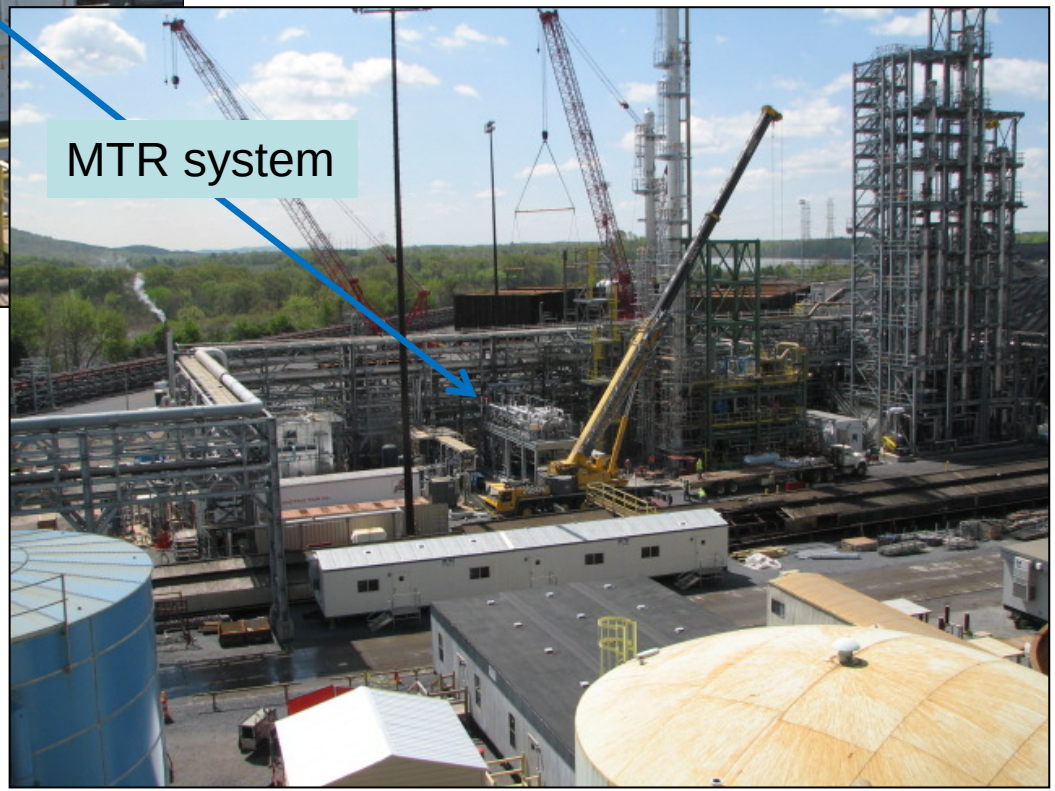
Photo courtesy of Tony Wu

- Crane lowering 2nd floor of system into place at NCCC

20 TPD System at NCCC

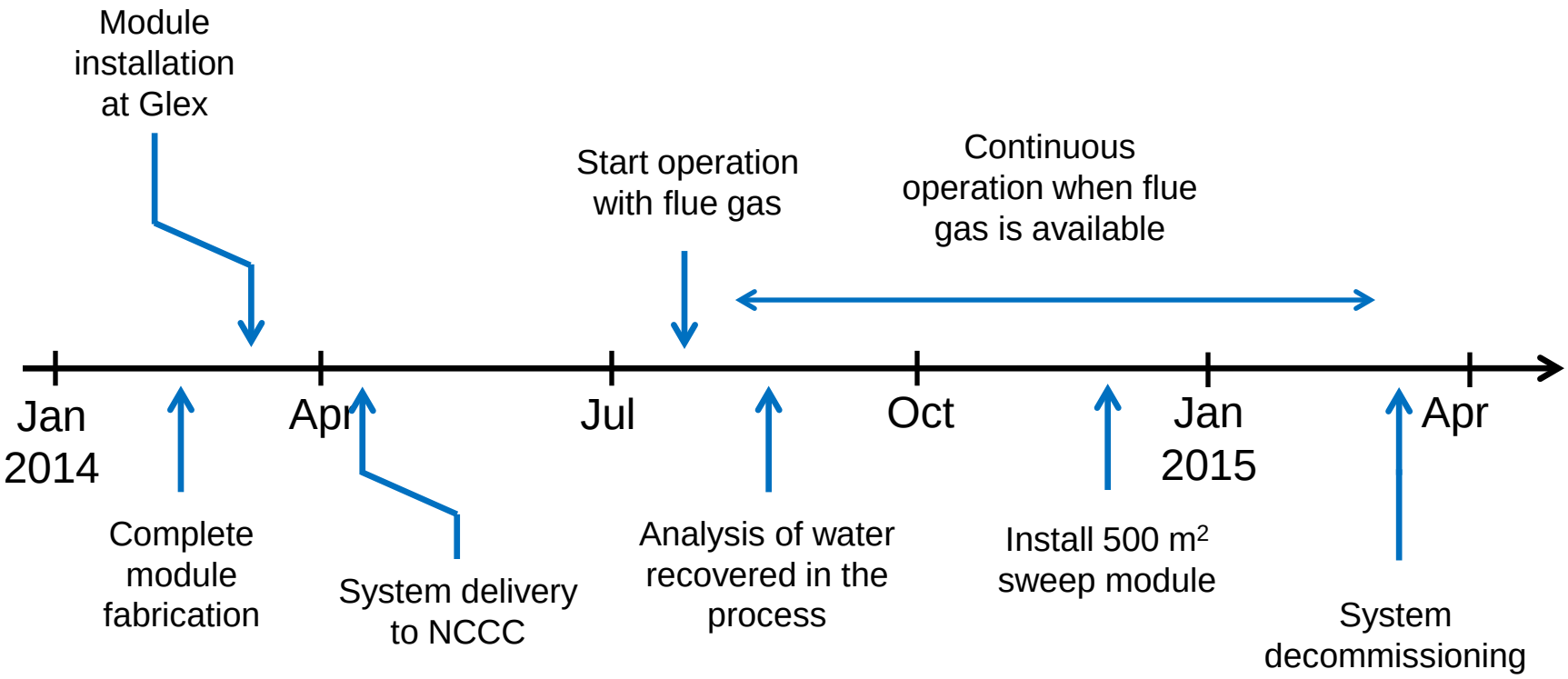


- System installation complete; now in commissioning
- Operation during summer/fall 2014



- Membranes offer compact, simple operation

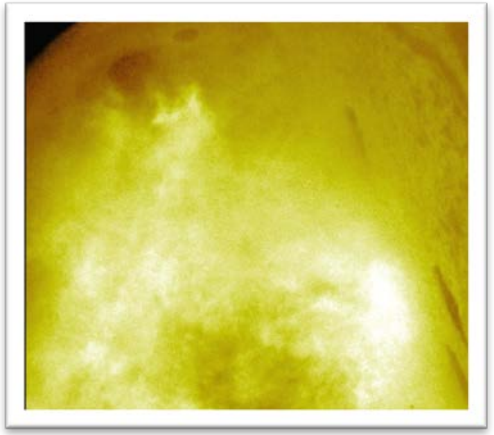
20 TPD Installation and Test Timeline



B&W Boiler Study Highlights

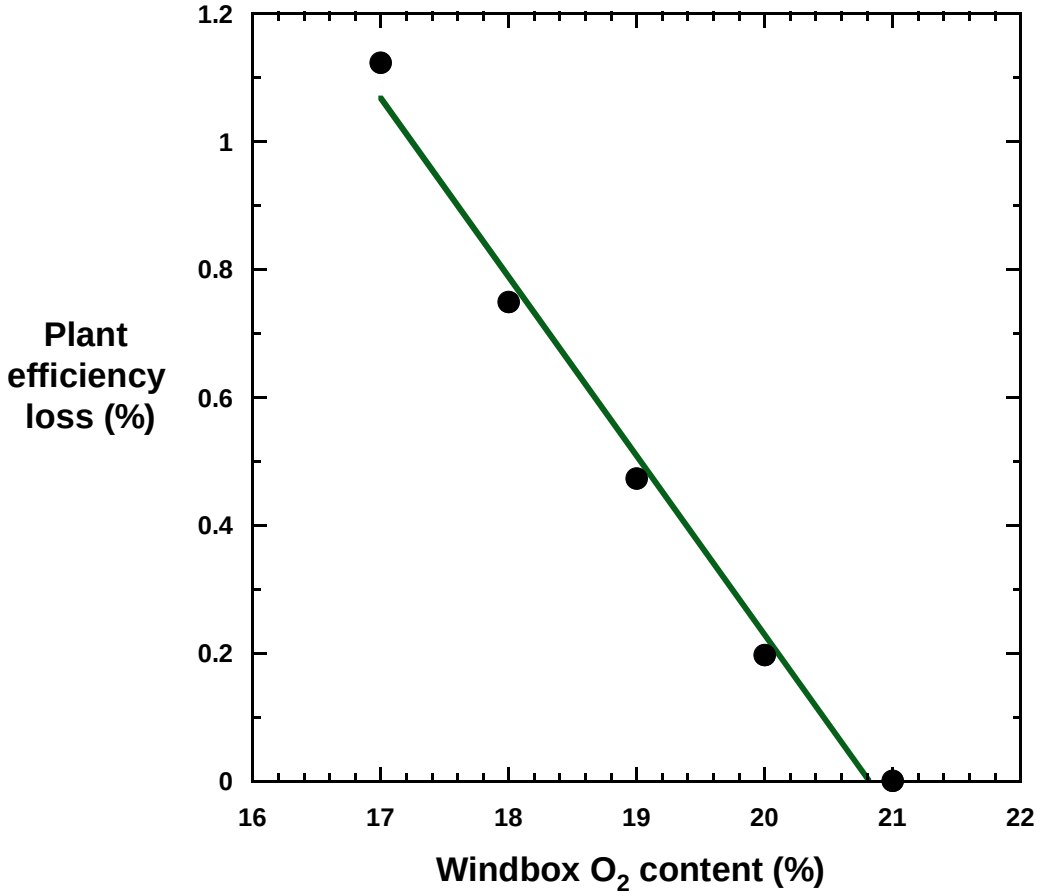
- Stable and attached flames with air (21% O_2) and CO_2-enriched air (16-18% O_2)
- CO_2-enriched flame was less luminous than air-fired case
- Lower furnace heat absorption but higher convection pass/air heater heat transfer for CO_2-enriched operation relative to air
- For bituminous coal, 30% lower NO_x emissions with CO_2-enriched air
- No burner modifications necessary
- Net reduction in plant efficiency of ~0.75% at 18% O_2

Flame image from combustion of PRB coal with air (21% O_2)



Flame image from combustion of PRB coal with CO_2–enriched (18% O_2)

Boiler Efficiency Versus Windbox O_2



- Increased CO_2 recycle reduces windbox O_2 content through dilution, which reduces plant efficiency almost linearly
- However, increased CO_2 recycle reduces capture energy; net benefit
- 18% O_2 appears to be optimum for retrofit; beyond this point tube erosion, abrasion, and slagging become important
- Because flame is stable to 16% O_2, this level of recycle should be further evaluated for new plants

Other Remaining Project Tasks

- Industrial CO_2 capture – 3 month 1 TPD field test of CO_2 capture from a biowaste-to-methanol facility starting in 4QCY2014 (co-funded by Alberta Innovates)
- 20 MW case study – preliminary cost analysis of membrane process applied to a ~20 MW boiler
- Update BP1 techno-economic analysis to include new performance information

MTR

Summary

- CO_2 capture membrane performance continues to improve
- 1 TPD slipstream system at NCCC is valuable for lifetime testing and new membrane performance validation
- 20 TPD demonstration unit fabrication and installation is complete; Testing for remainder of year to validate optimized modules (low Δp, low cost)
- B&W boiler test suggests CO_2 recycle with sweep membrane is feasible; efficiency impact is similar to predictions

MTR

Acknowledgements

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

- **Southern Company Services (NCCC)**

MTR