Integrated Testing of a Membrane CO_2 Capture Process with a Coal-Fired Boiler

DE-FE0026414

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NETL CO_2 Capture Technology Review Meeting

August 22, 2017

Project Overview

Award name: Integrated Testing of a Membrane CO_2 Capture Process with a Coal-Fired Boiler

Project period: 7/1/15 to 3/31/18

Funding: $3.6 million DOE; $0.9 million cost share ($4.5 million total)

DOE program manager: José Figueroa

Participants: MTR and Babcock & Wilcox

Project scope: Demonstrate integrated operation of the MTR small pilot capture system with B&W's SBS-II pilot coal boiler.

Project plan: The project is organized in three phases:

- **Phase 1** – Site preparation and system modification/installation
- **Phase 2** – Commissioning, testing, and data analysis
- **Phase 3** – Decommissioning and reporting

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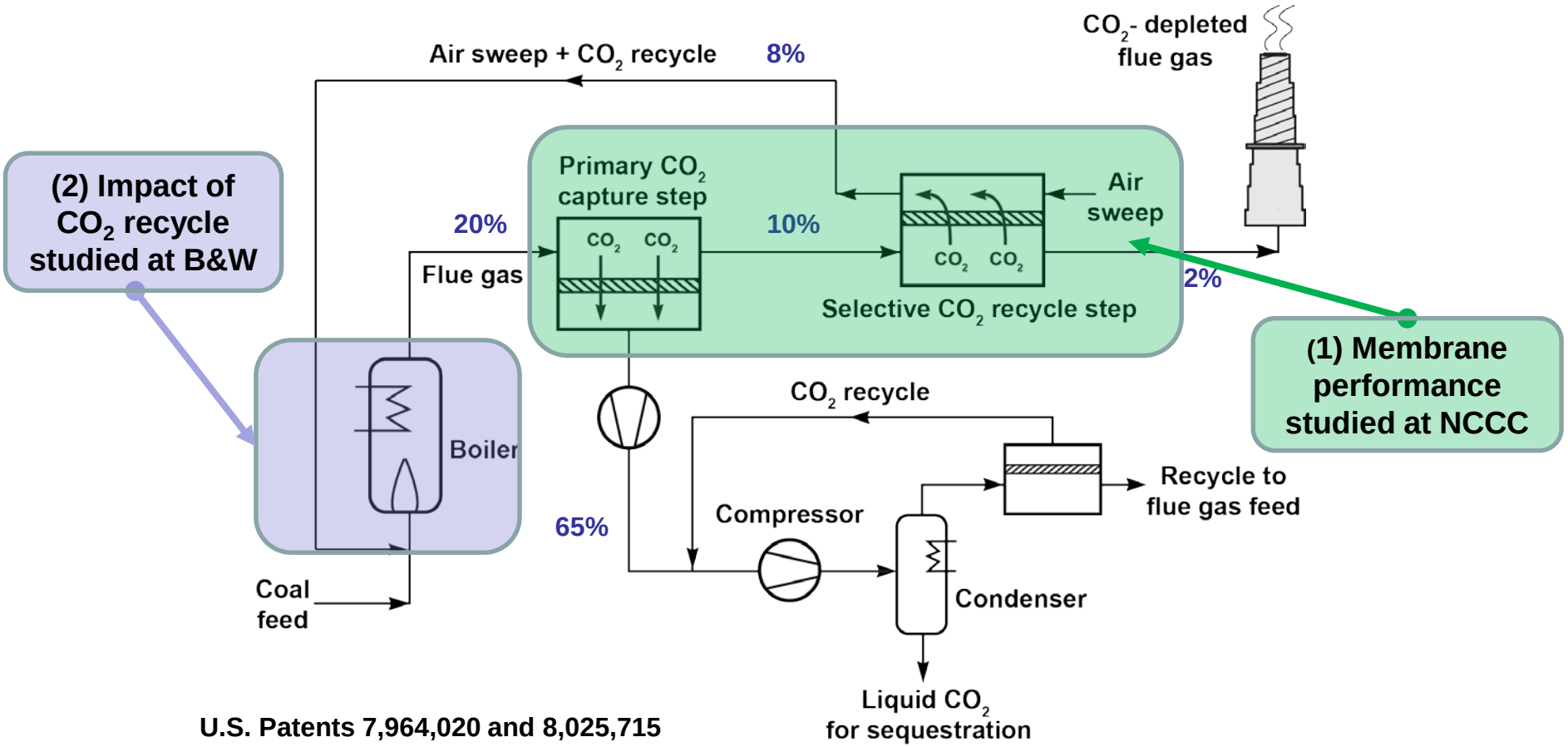
Background: MTR CO_2 Capture Process



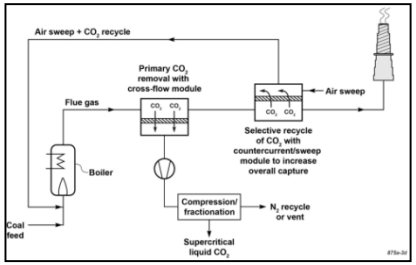
U.S. Patents 7,964,020 and 8,025,715

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

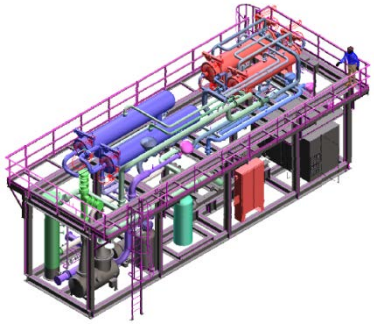


APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO_2 used for algae farm

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

NCCC 1 MW_e Demo (DE-FE5795)
- 11,000 hours of 1 TPD system operation
- 1,500 hours of 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 (DE-FE26414)

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

2006 2008 2010 2012 2014 2016 2018 2020

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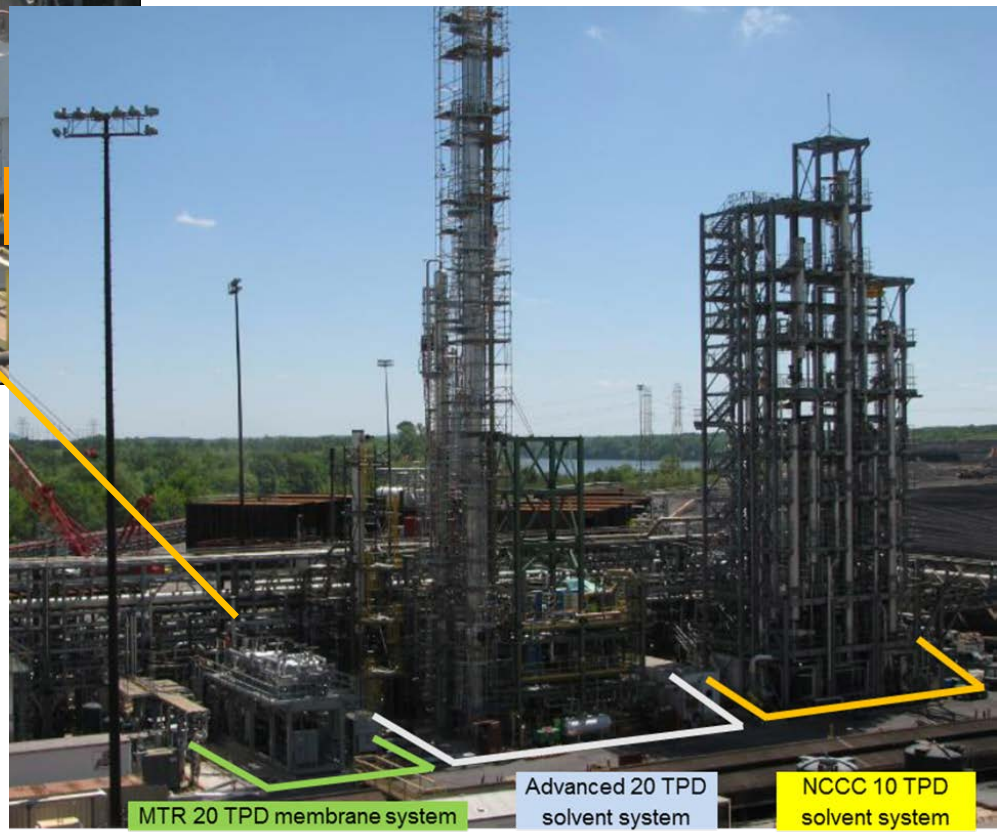
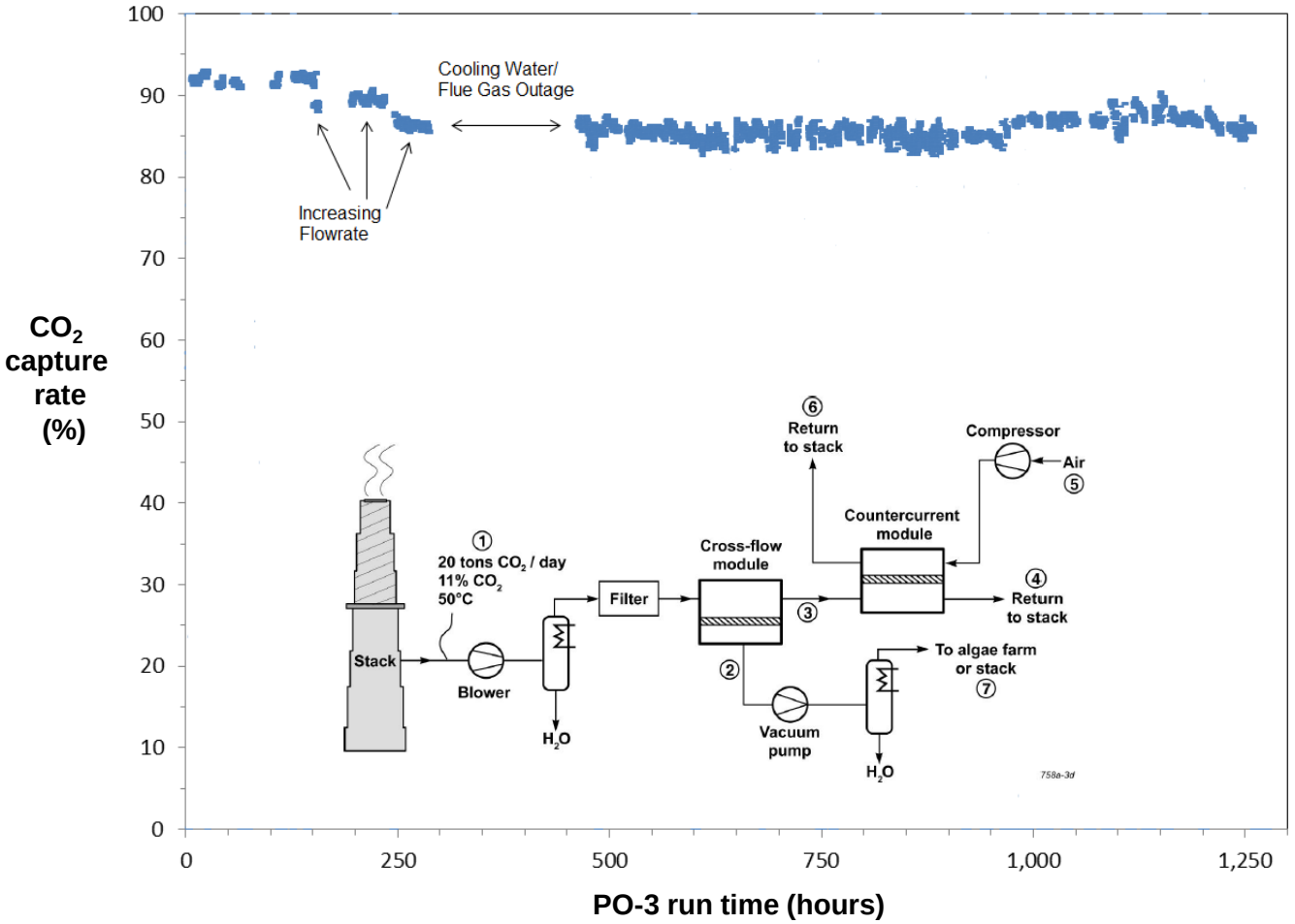
Prior Testing of 20 TPD System at NCCC

- Membranes are simple and compact compared to competing technologies
- In previous 1 TPD testing, Polaris modules completed ~11,000 hours of operation at NCCC



- In June 2015, MTR pilot system completed 1,500 hours of successful operation at NCCC
- System was then moved to B&W in Spring 2016 for integrated boiler testing

20 TPD System Shows Stable Performance



- System operated in slipstream mode (no recycle to boiler)
- Stable performance, reaching up to 90% capture
- System goes from cold start to steady state in ~15 minutes

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

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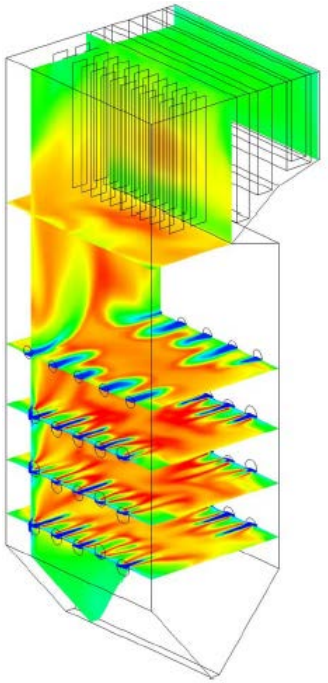
Prior B&W Studies of CO_2 Recycle Impact on Boiler Performance

Phase I – 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 – 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 were determined

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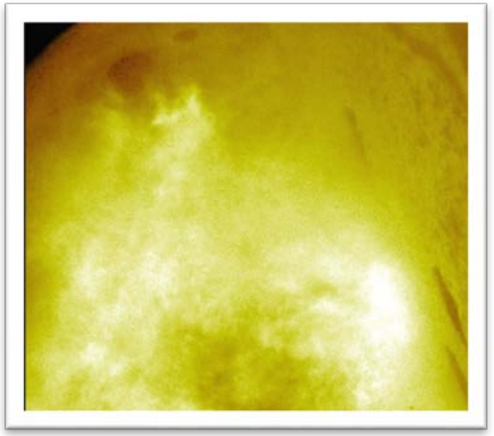
Highlights from Testing with CO_2-laden Air on B&W Boiler

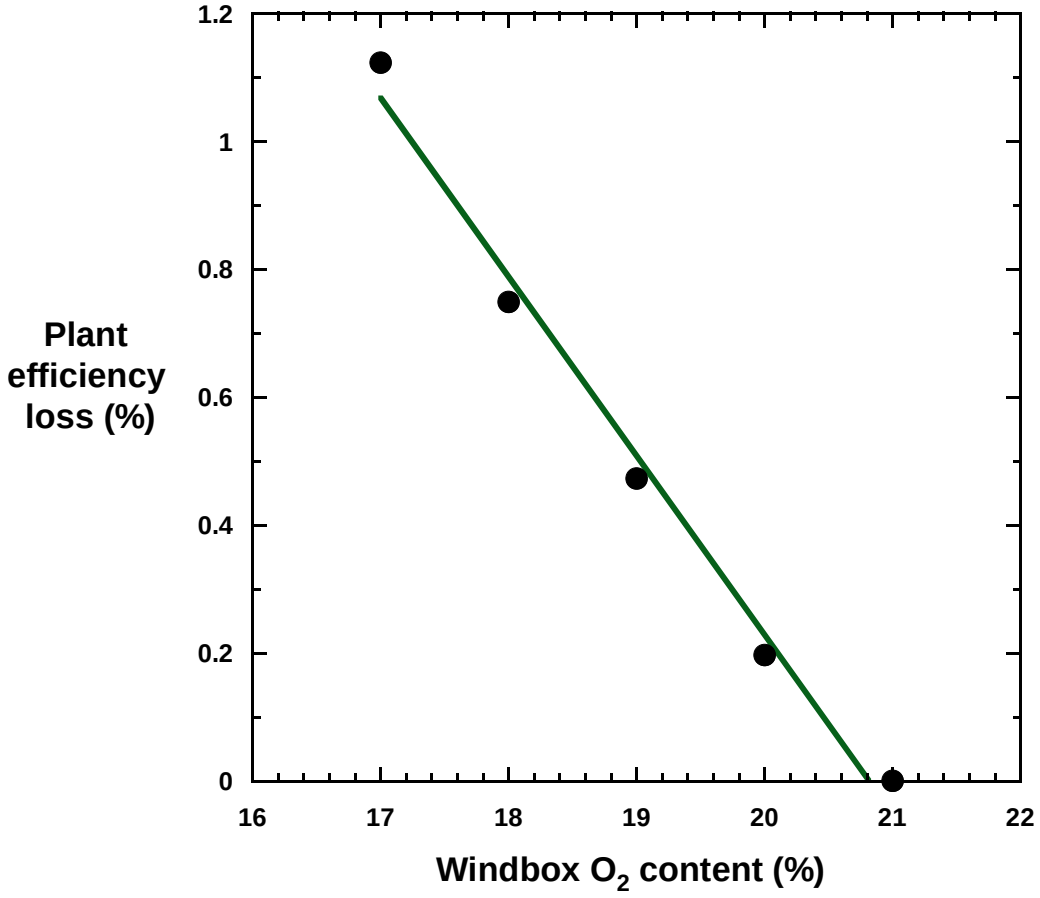
- Stable and attached flames with air (21% O_2) and CO_2-enriched air (16-18% O_2)
- CO_2-enriched flame was less luminous than air-fired case
- Lower furnace heat absorption but higher convection pass/air heater heat transfer for CO_2-enriched operation relative to air
- For bituminous coal, 30% lower 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 may become important
- Because flame is stable to 16% O_2, this level of recycle should be further evaluated for new plants

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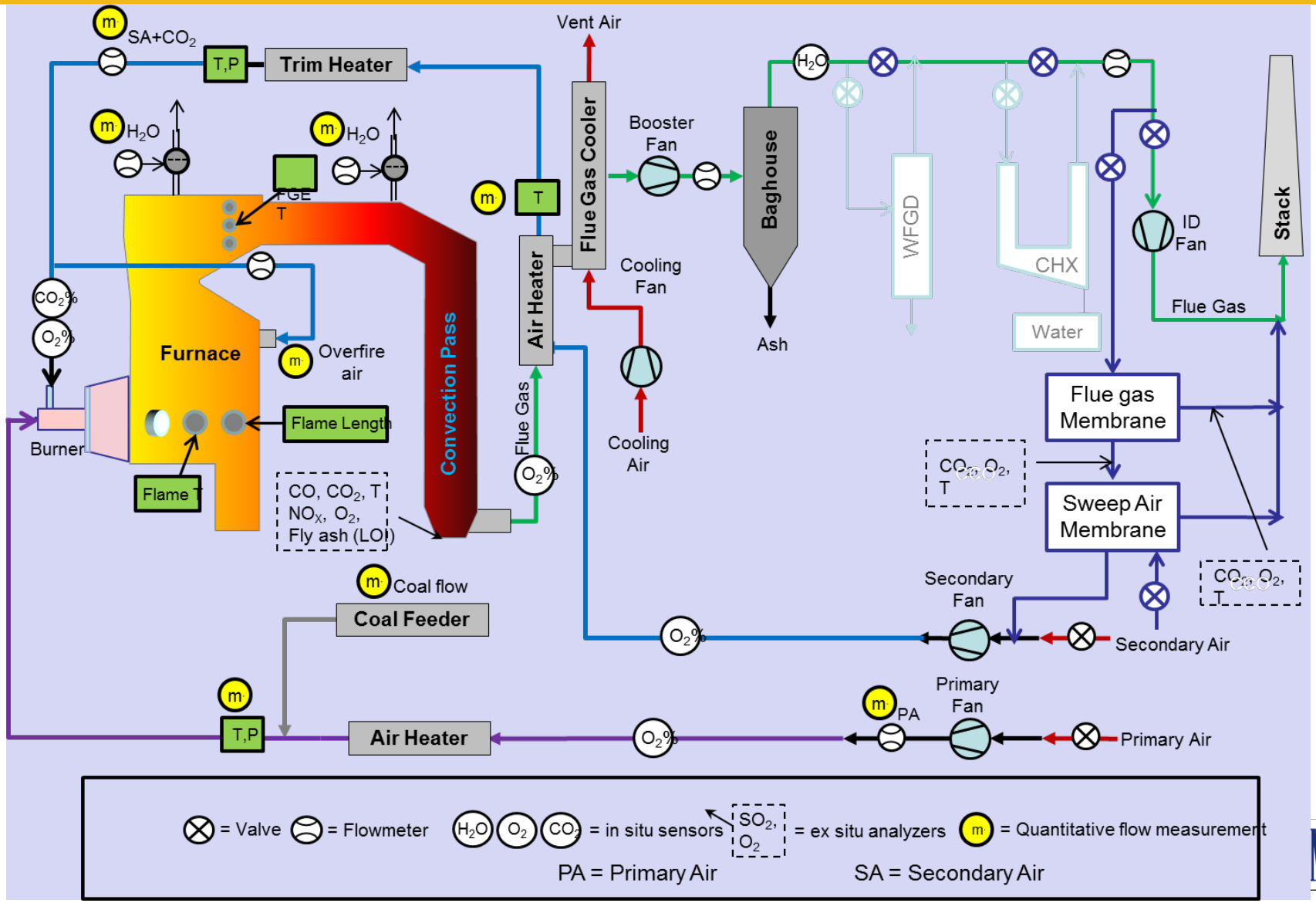
Objectives of Integrated Project (DE-FE0026414)

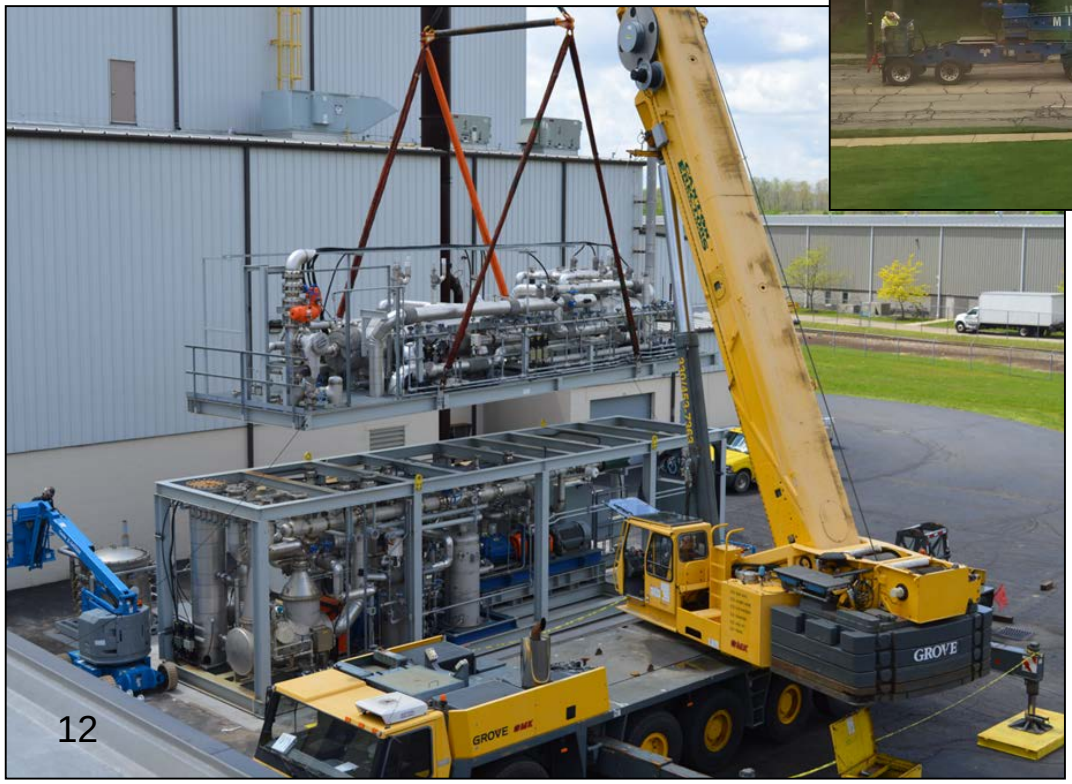
- Use an existing 20 TPD MTR small pilot membrane system to test integrated operation (with CO_2 recycle to boiler) on an appropriately-sized boiler (B&W SBS-II)
- Validate prior B&W modeling and testing showing modest effect of recycled CO_2 on boiler performance
- Understanding how the various membrane parameters impact performance of a dynamic boiler system
- Reduce risk prior to scaling up to larger demos

Schematic of Integrated Test



MTR Skid During Transport and Installation at B&W

Skid arriving at B&W ⟶

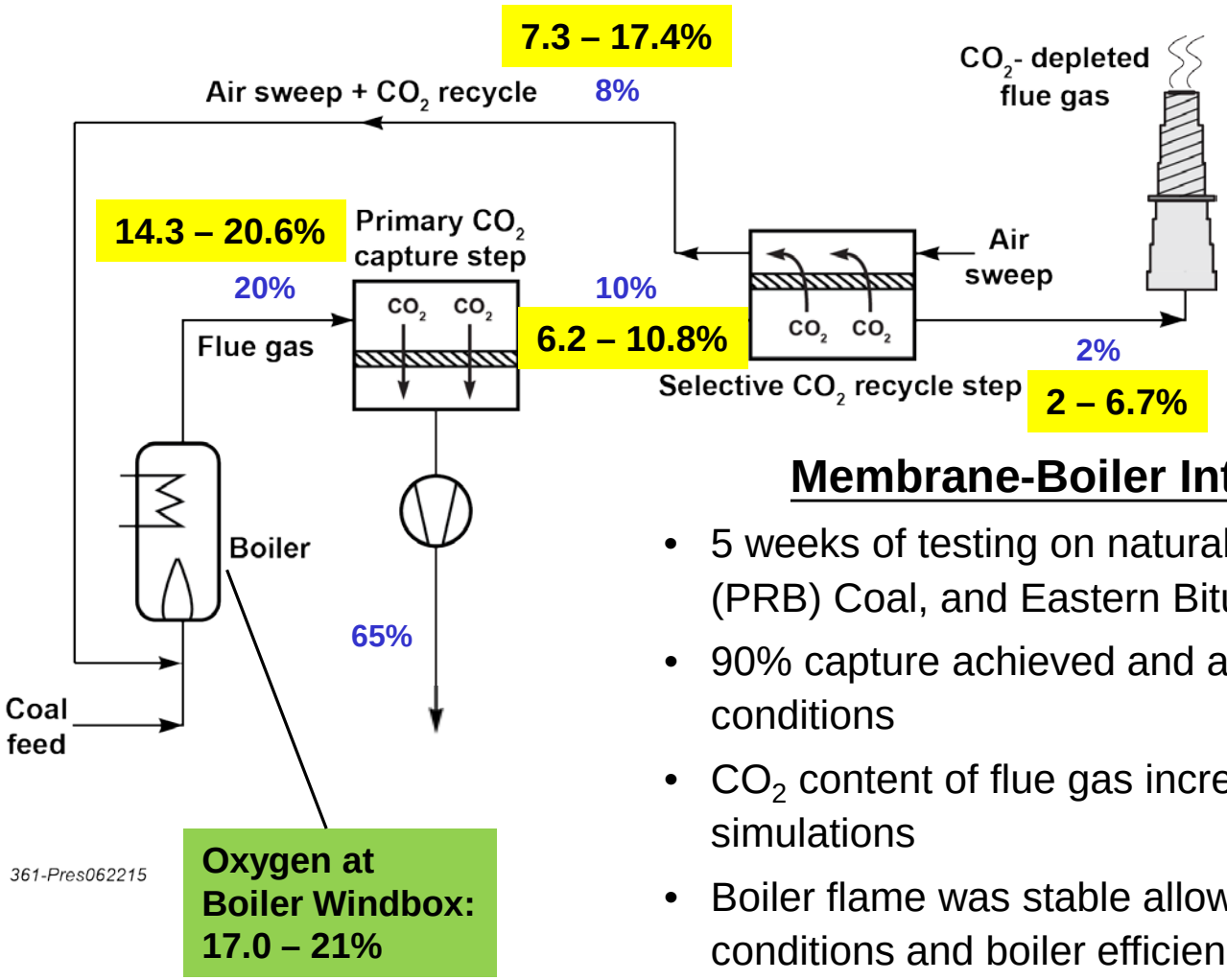


⟵ Installation of 2nd floor

MTR Skids at B&W's SBS-II Research Facility

Main skid and smaller low-pressure drop sweep module anchored to foundation

Sample Results from B&W Integrated Tests



Membrane-Boiler Integrated Test Plan

- 5 weeks of testing on natural gas, Powder River Basin (PRB) Coal, and Eastern Bituminius Coal
- 90% capture achieved and a variety of partial capture conditions
- CO_2 content of flue gas increased as expected in simulations
- Boiler flame was stable allowing a full battery of stream conditions and boiler efficiency measurements to be conducted (analysis is ongoing)

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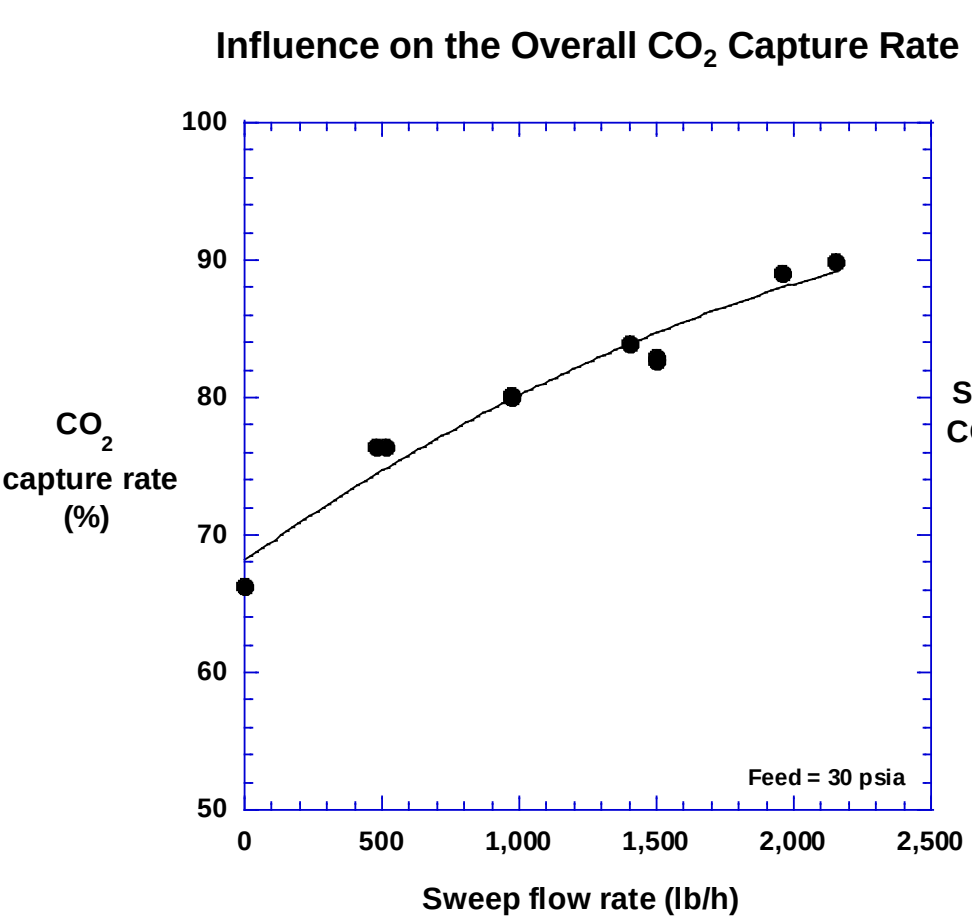
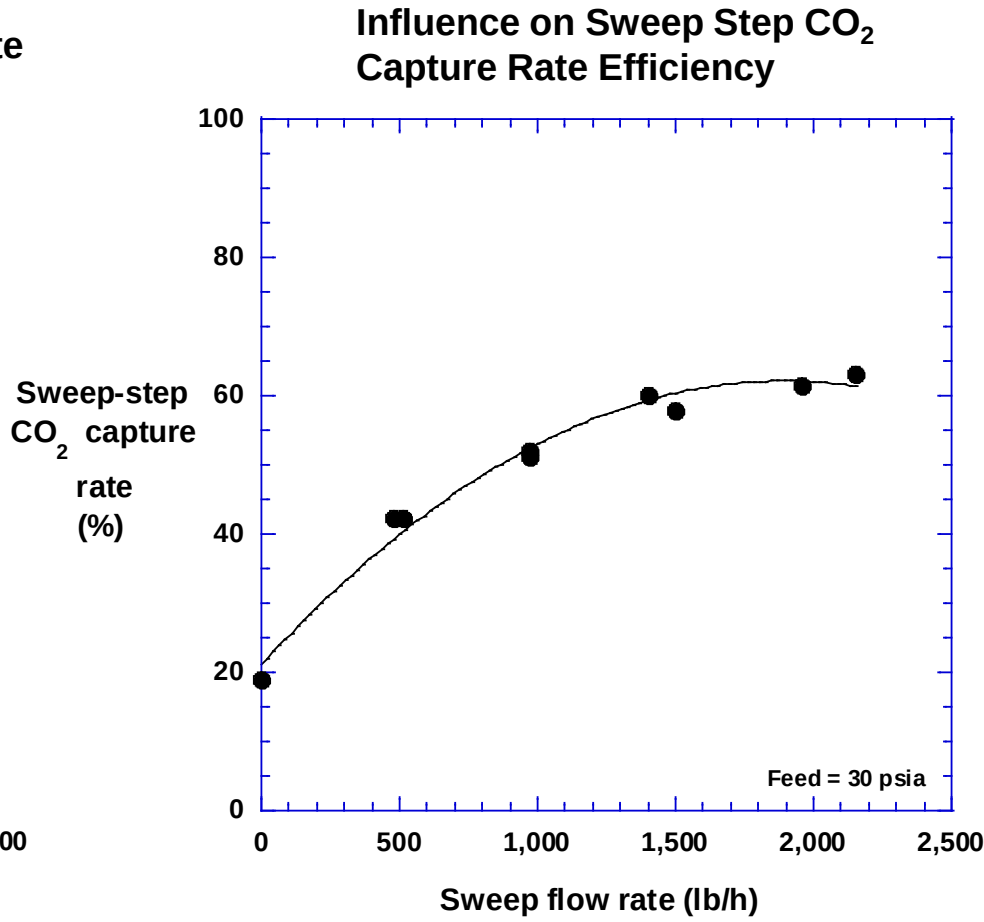
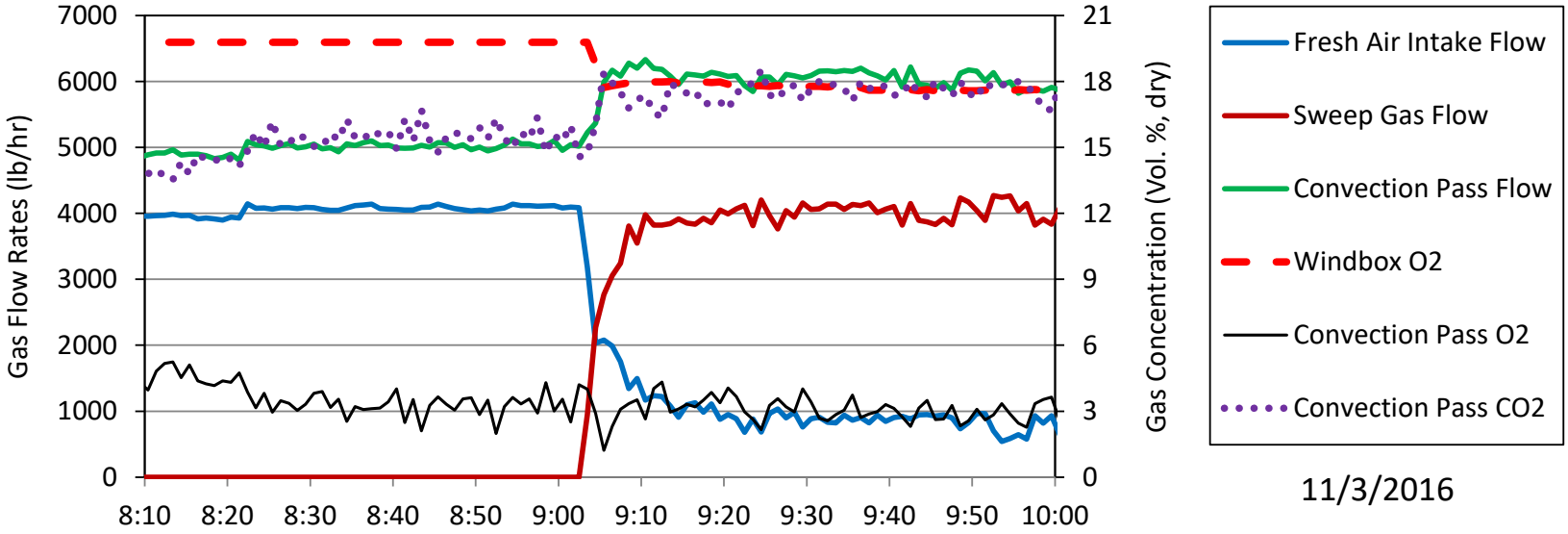
1 MW_e System Sweep Flow Rate Parametric Results from Integrated Tests





Integrated Boiler/Membrane Systems Transition Response



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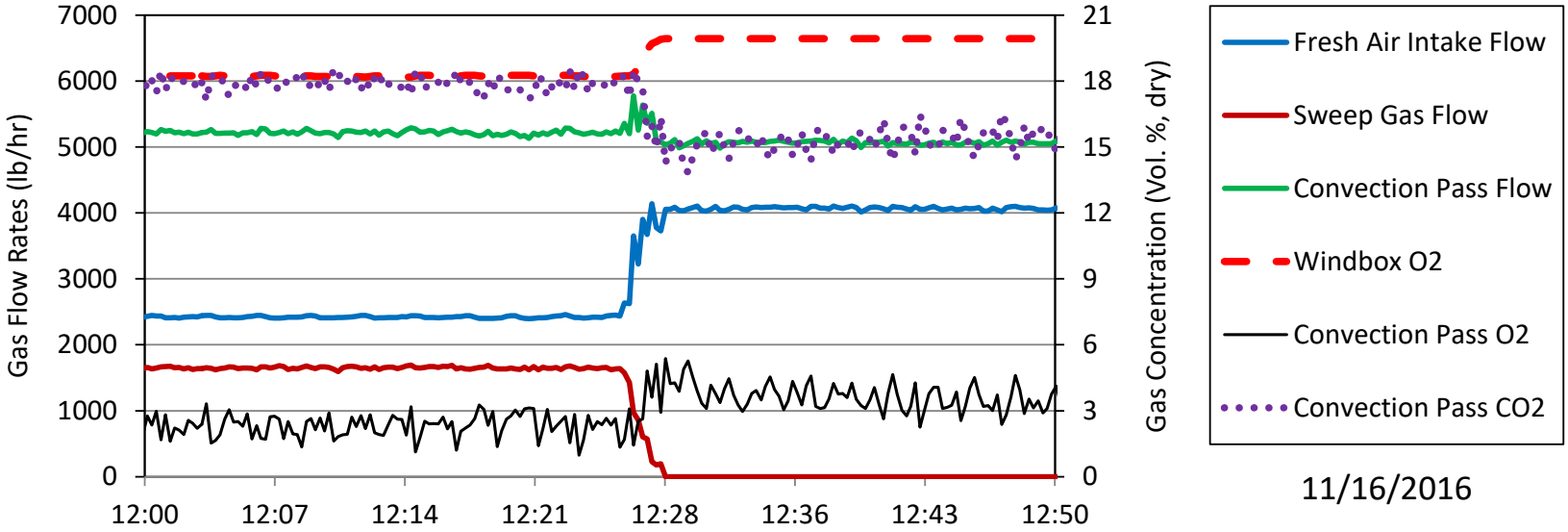

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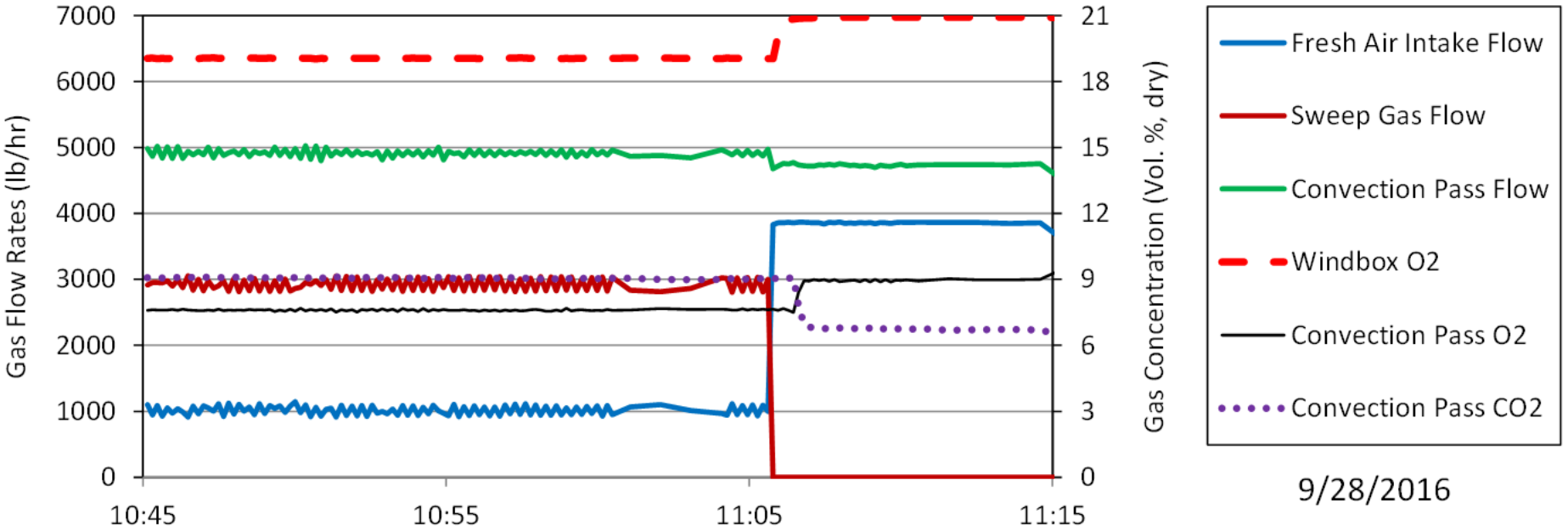
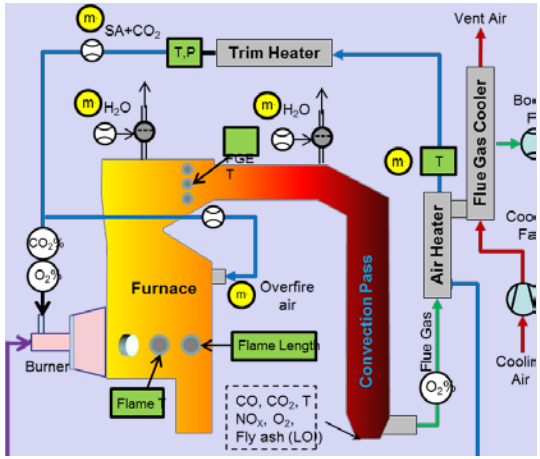
Integrated Boiler/Membrane Systems Transition Response to E-Stop



B&W's Analysis of CO_2 Recycle Impact on Boiler Operation

- Furnace heat absorption is lower
- "Furnace" refers to the radiant heat transfer section of the boiler upstream of the tube banks in the convection pass.
- Convection pass heat absorption is higher
- Convection pass outlet heat flux is higher
- Air heater heat absorption is higher
- Air heater flue gas outlet heat flux is higher
- Total heat absorption is slightly reduced

Test Name		Coal 30P M1 & M2	Coal 27P M2 Only
Date		20-Oct-16	18-Oct-16
Test Duration	(h:mm)	7:00	7:15
Fuel		PRB	PRB
Load	(MW)	1.5	1.4
FEGT	(°C)	1,179	1,259
Convection Pass Exit Temperature	(°C)	397	380
Air Heater Exit Temperature (Flue Gas)	(°C)	217	210
Membrane Secondary Air Ratio		**53%**	**0%**
Furnace Absorption	(MW)	0.52	0.66
Convection Pass Absorption	(MW)	0.96	0.91
Convection Pass Outlet Heat Flux	(MW)	0.50	0.43
Total Heat Absorption	(MW)	1.62	1.68
Air Heater Absorption	(MW)	0.19	0.16
Air Heater Outlet Heat Flux (Flue Gas)	(MW)	0.31	0.27



Decommissioning and Site Restoration Activities Have Been Completed

- All skids decommissioned and removed from site by June 2017

- Site clean-up and smooth-out of concrete foundation has been finished

- Final reporting and analysis is underway

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Summary

- CO_2 capture membrane performance continues to improve and has been validated on the 0.05 MW_e slipstream system with over 11,000 hours of runtime at NCCC
- 1 MW_e small pilot operation at NCCC was completed in 2015. Testing successfully demonstrated optimized modules (low Δp, low cost) with over 1,500 hours of runtime
- 1 MW_e small pilot was successfully integrated with the B&W research boiler for five weeks of integrated testing with CO_2 recycle to the boiler in late 2016
- The integrated membrane-boiler field test experimentally validated simulated system performance
- Boiler flame was stable throughout parametric testing allowing a full battery of stream conditions and boiler efficiency measurements

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Acknowledgements

- **U.S. Department of Energy,**

National Energy Technology Laboratory

  - José Figueroa
  - Mike Mosser
- **Southern Company Services (NCCC)**
  - Tony Wu
- **Babcock & Wilcox**
  - Hamid Farzan
  - Jennifer Sivy
  - Andrew Mackrory