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

DE-FE0026414

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NETL CO2 Capture Technology Review Meeting

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Project Overview

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

Project period: 7/1/15 to 6/30/17

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 (Q1-Q4)
- **Phase 2** – Commissioning, testing, and data analysis (Q5-Q6)
- **Phase 3** – Decommissioning and reporting (Q7-Q8)

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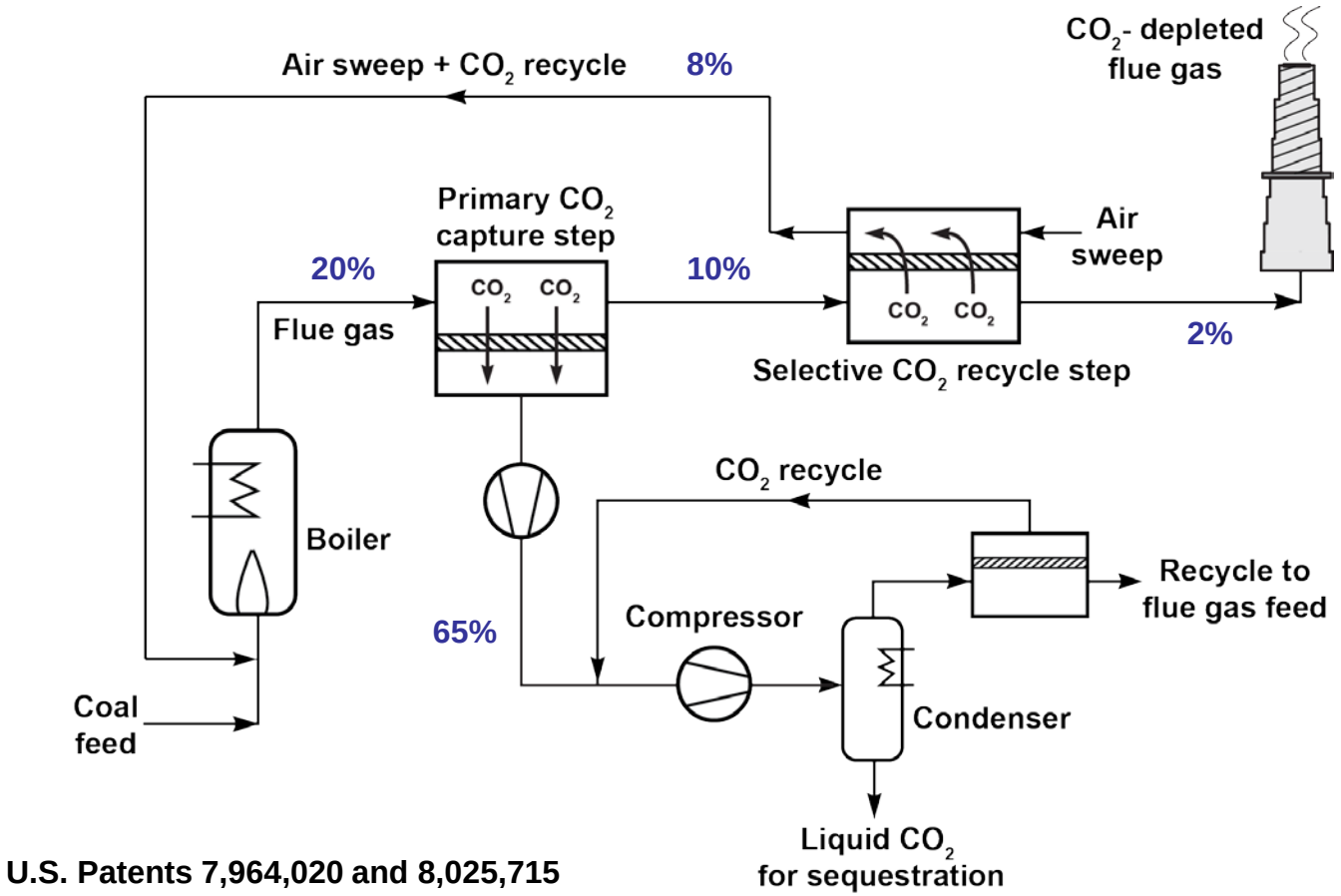
Background: MTR CO_2 Capture Process



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

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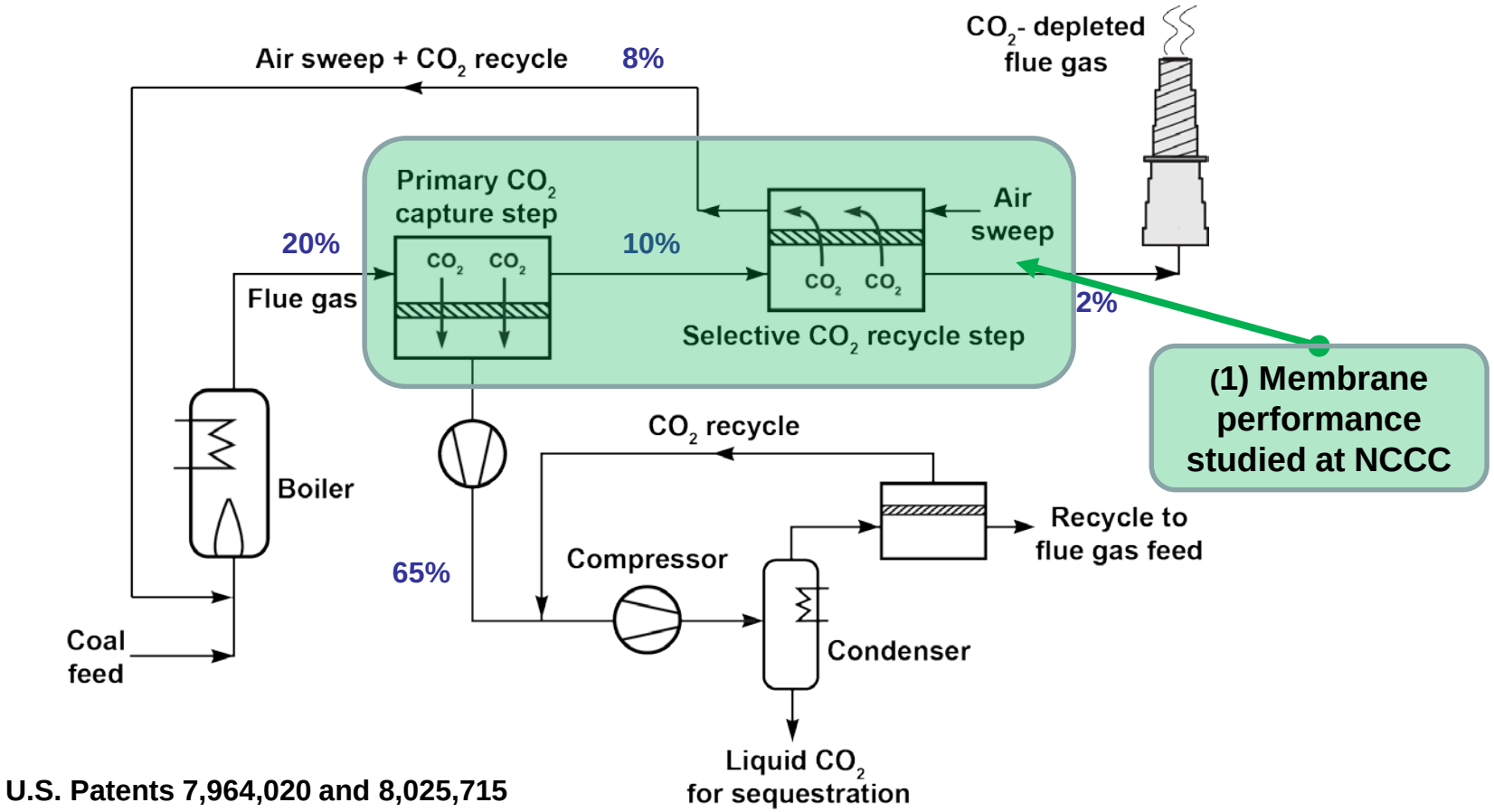

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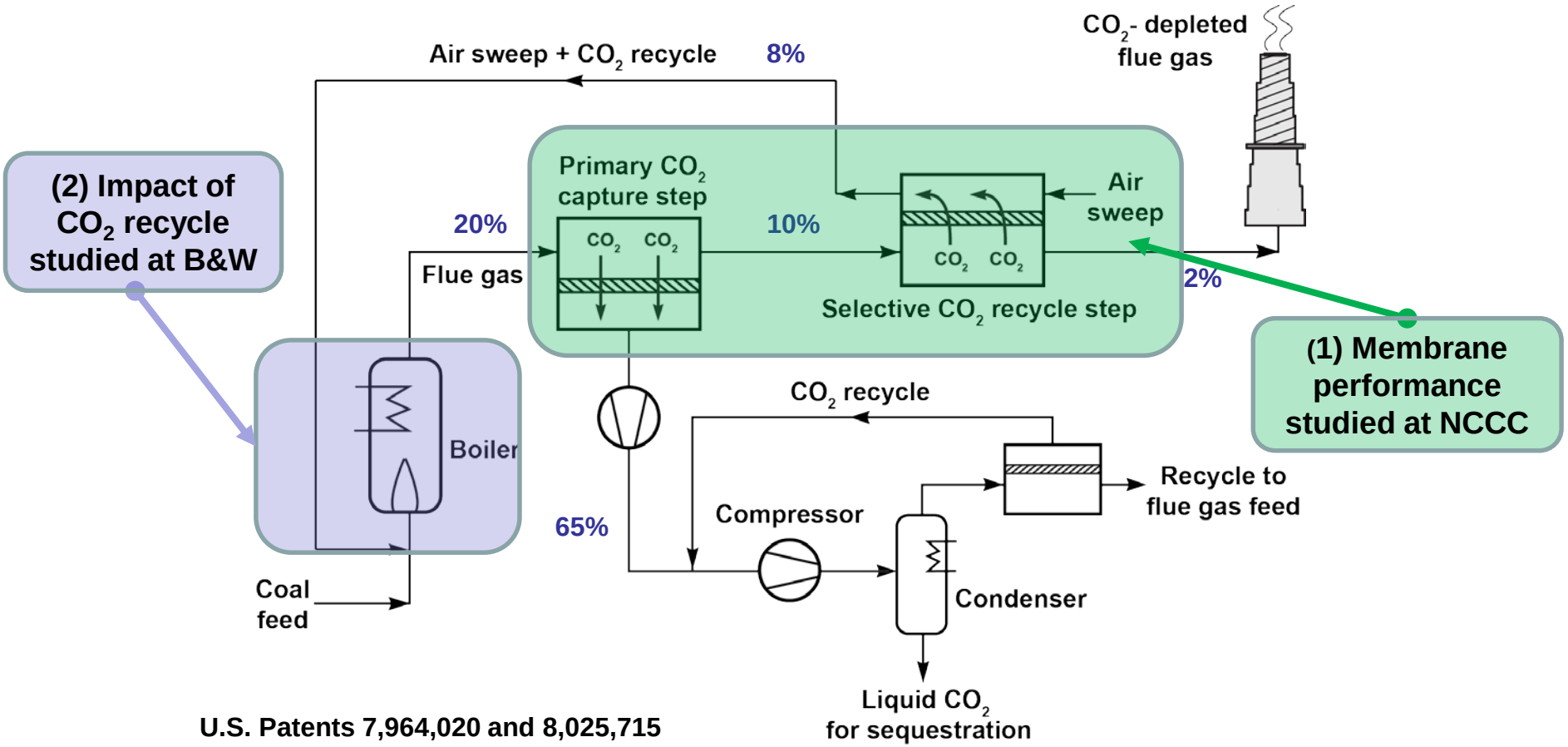

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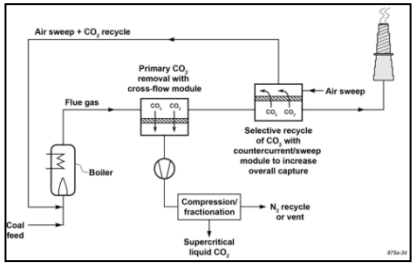
MTR CO_2 Capture Development Timeline

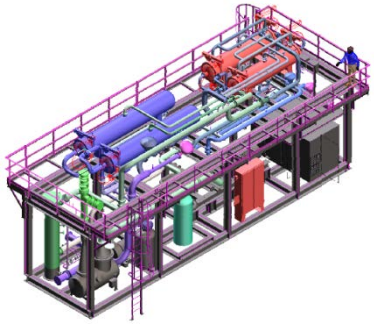
Feasibility study (DE-NT43085)
- Sweep concept proposed
- Polaris membrane conceived



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

Integrated Test (DE-FE26414)

10 MW_e Large Pilot

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

2006 2008 2010 2012 2014 2016 2018 2020

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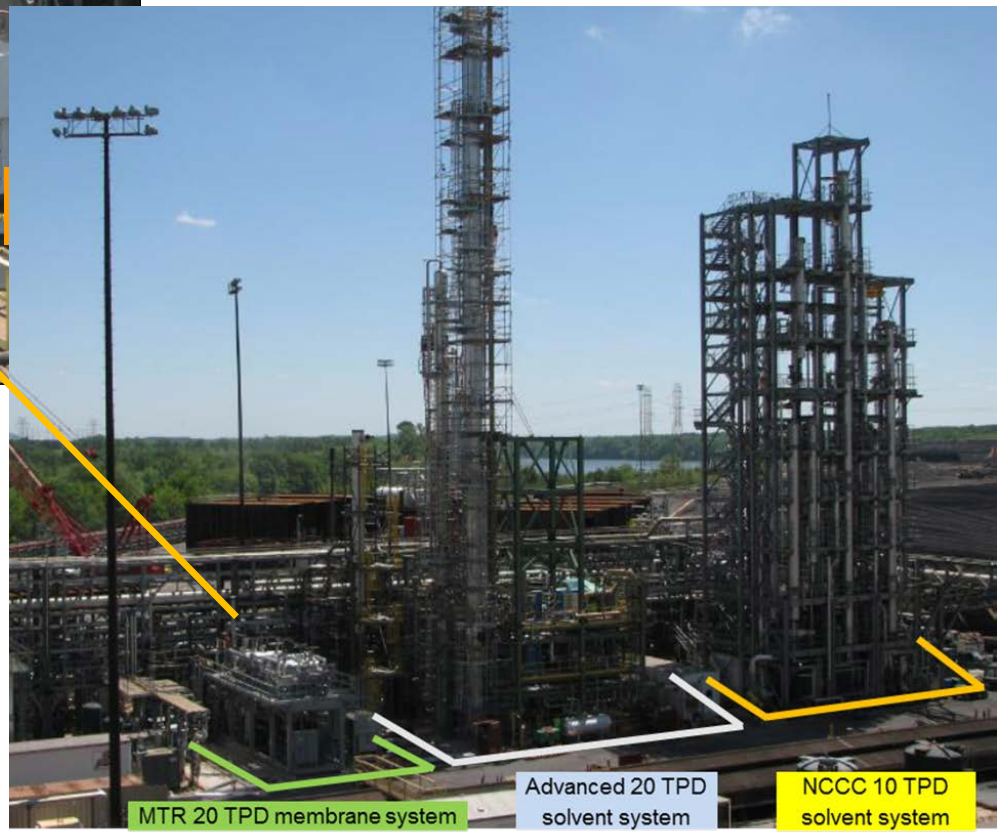
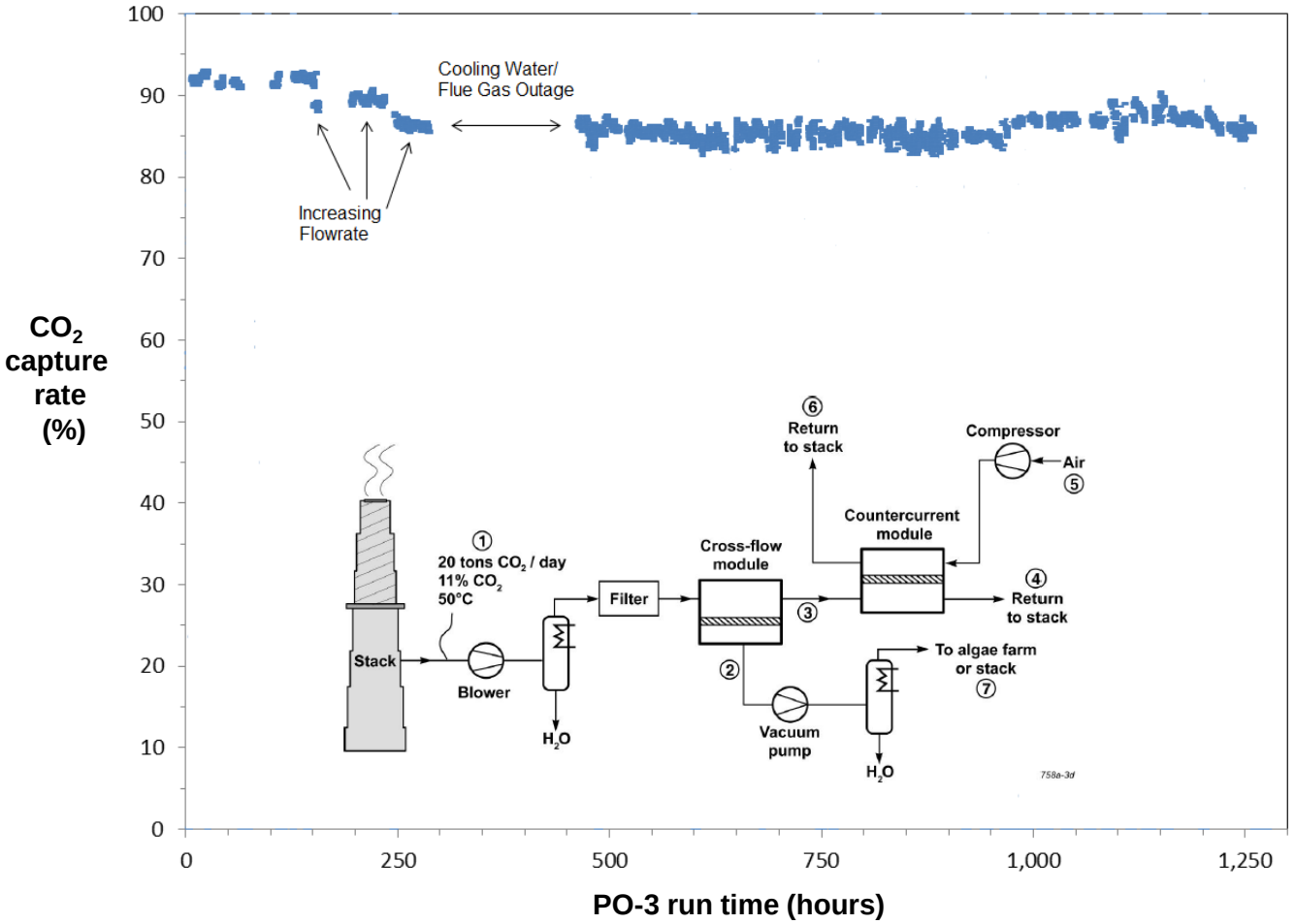
20 TPD System at NCCC

- 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 is currently being installed at B&W 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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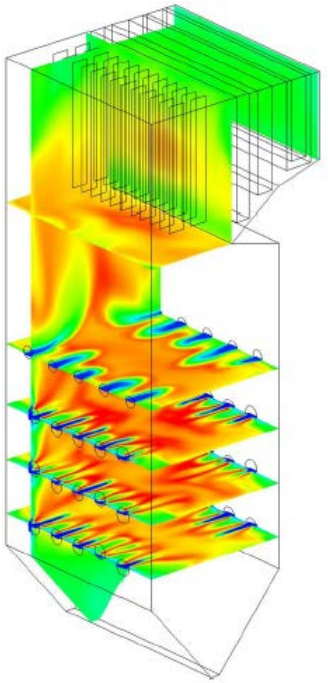
B&W Studies of CO_2 Recycle Impact on Boiler Performance

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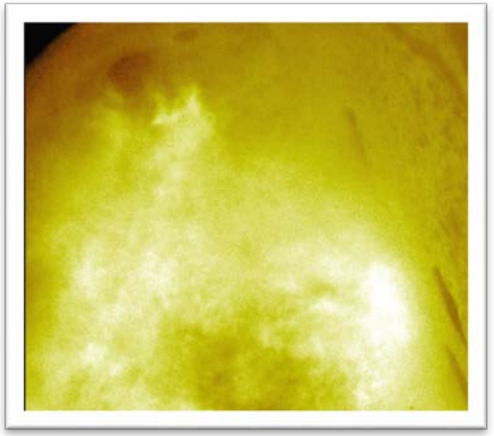
Highlights from Testing with CO_2-laden Air on B&W Boiler

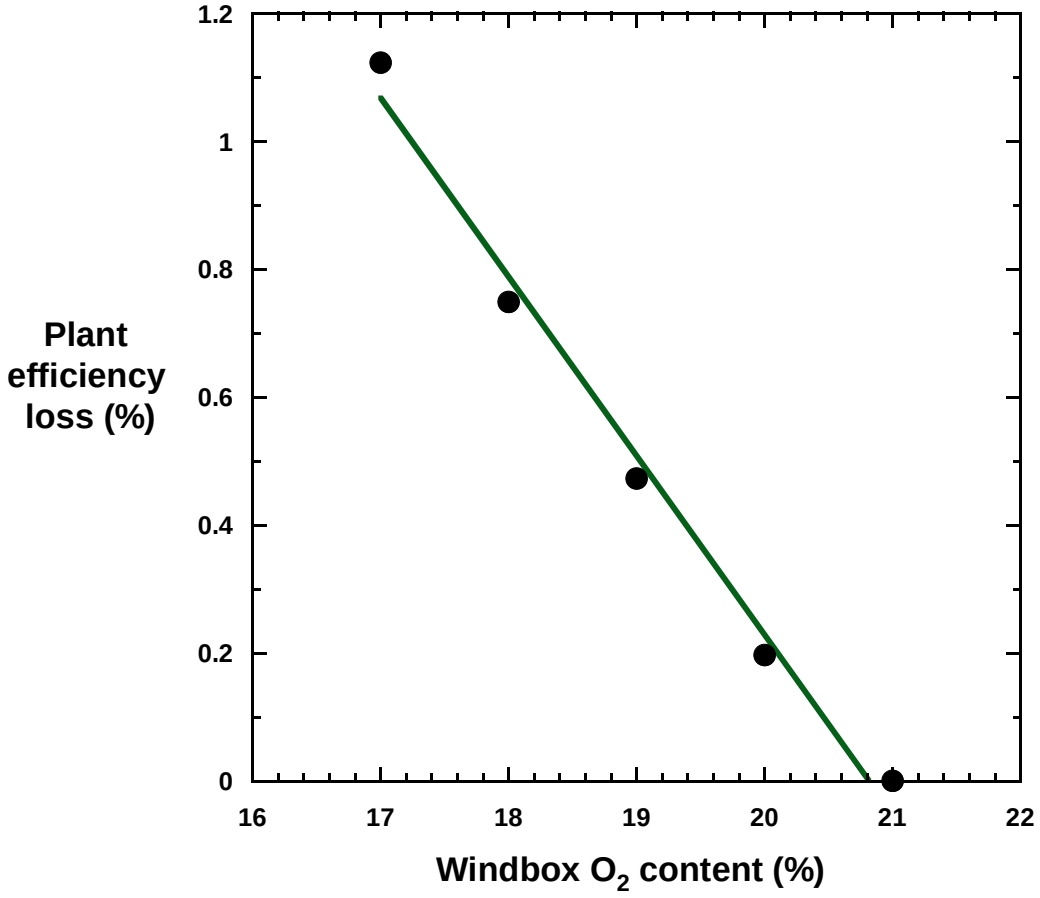
- Stable and attached flames with air (21% O_2) and CO_2-enriched air (16-18% O_2)
- CO_2-enriched flame was less luminous than air-fired case
- Lower furnace heat absorption but higher convection pass/air heater heat transfer for CO_2-enriched operation relative to air
- For bituminous coal, 30% lower 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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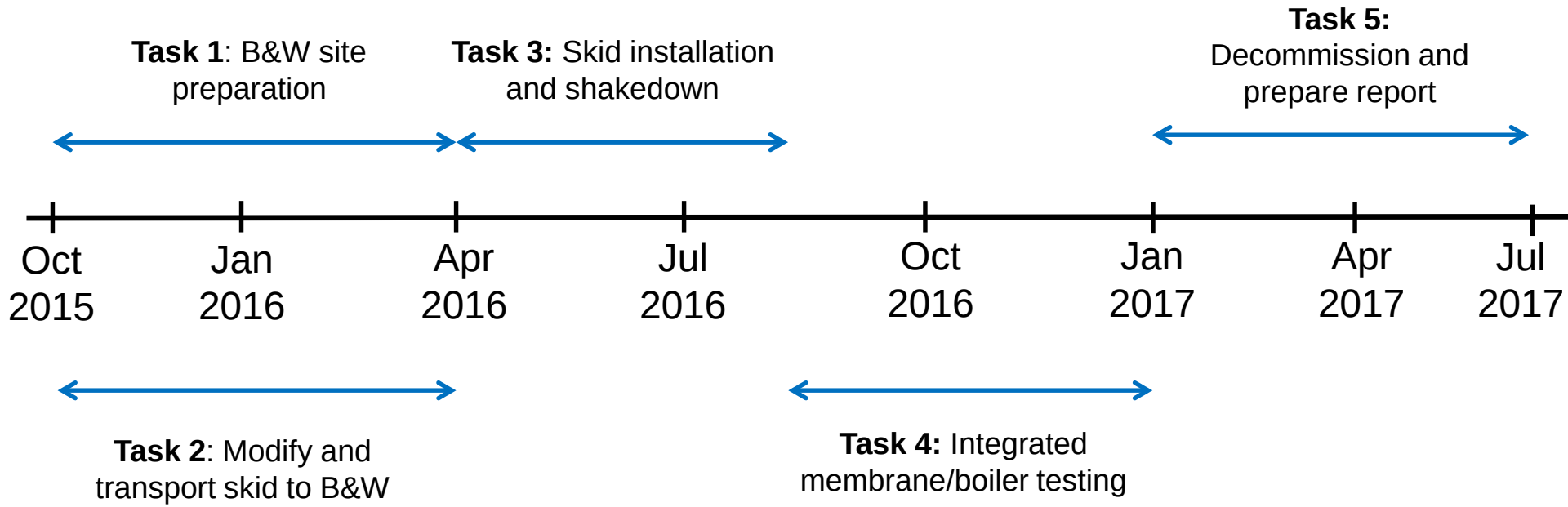
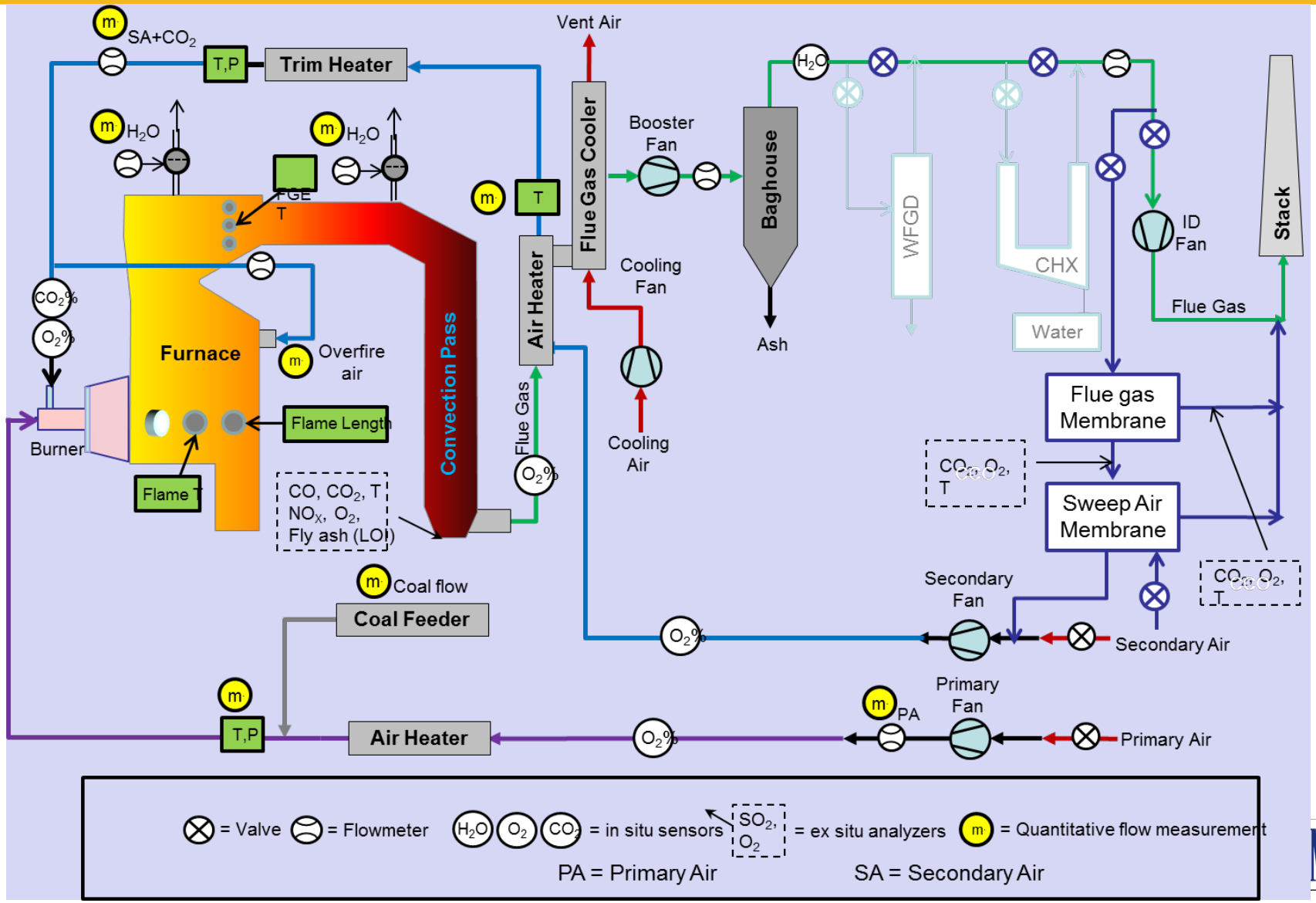
Objectives of Integrated Project (DE-FE0026414)

- Use an existing 1 MW_e 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

Integrated Project Tasks Timeline



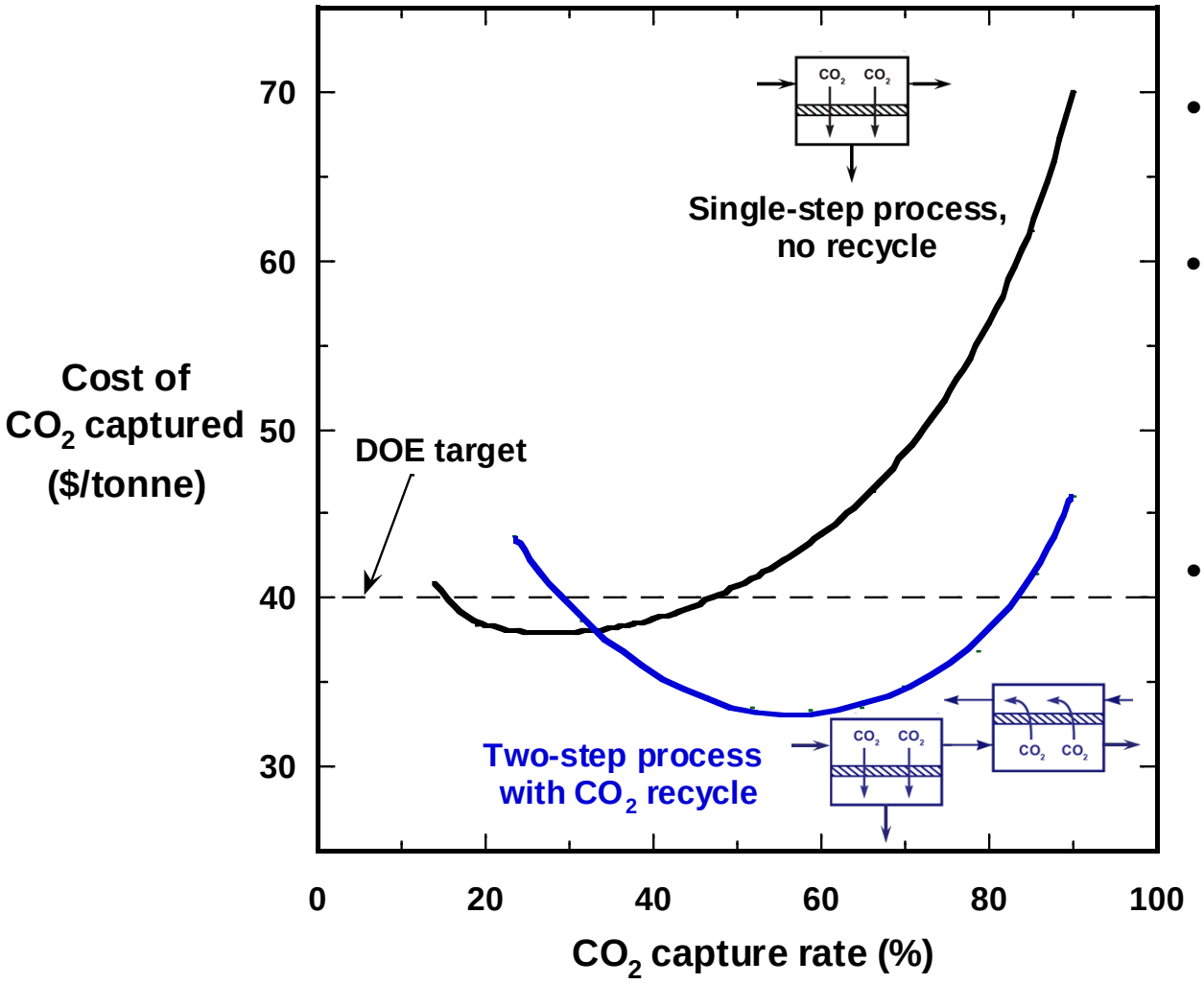
Schematic of Integrated Test



Preliminary Test Plan

- A total of 4 weeks of boiler operation is planned, including time on both PRB and bituminous coal
- Parametric testing will focus on varying air sweep ratio
  - Initially, no air sweep (regular air firing with 1 step membrane capture)
  - Then, slowly increase air sweep to design condition while monitoring boiler performance and CO_2 capture
- Measurements will include flame observation, FEGT, UBC, SOx/NOx, gas composition, temperature profiles, heat transfer (thermal efficiency)
- Optimized conditions will be run in long duration tests (48 h) for both partial (1100 lb CO_2/MWh) and 90% capture

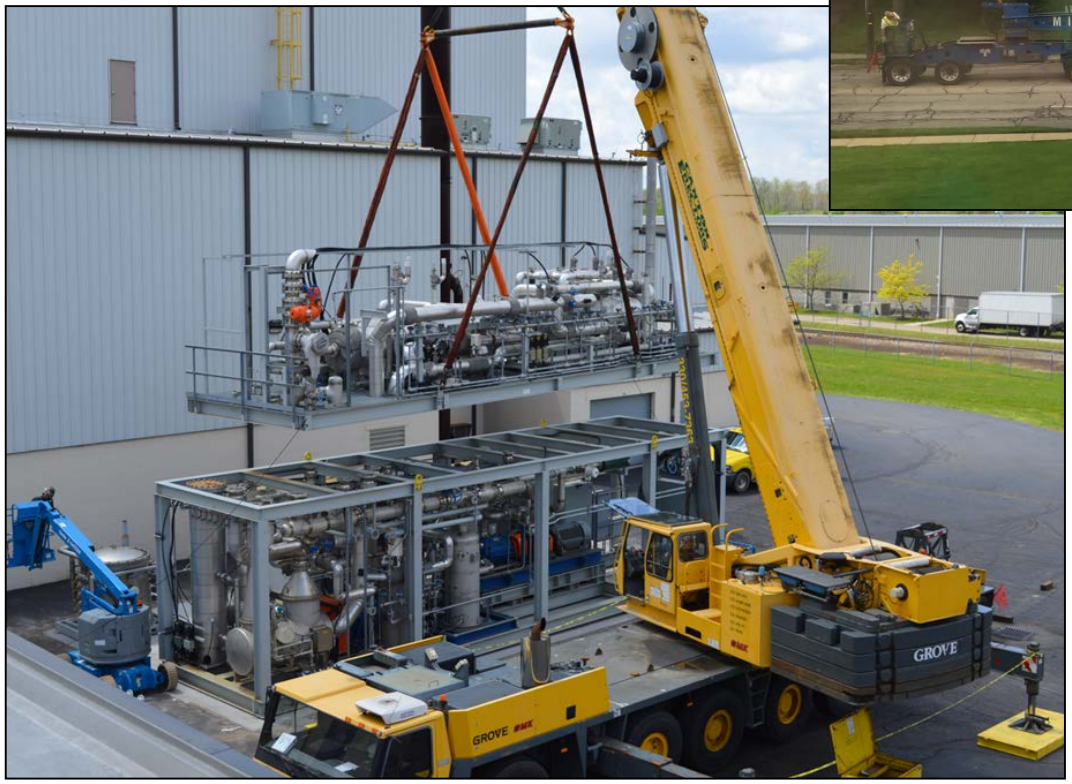
Integrated Test will Help Clarify the Best Design for Partial Capture



- Membranes show a minimum in capture cost
- To meet proposed EPA emission limits for coal (~30% capture), a simple system without recycle may be preferable
- Integrated project will test both 90% capture and 1100 lb CO_2/MWh; these data will be used to update this figure

MTR Skid During Transport and Installation at B&W

Skid arriving at B&W ⟶



⟵ Installation of 2nd floor

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MTR Skids at B&W Research Facility May 2016

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

MTR Skids at B&W Research Facility June 2016

Skid with B&W 0.6 MW_e SBS-II boiler facility in background

MTR Skids at B&W Research Facility July 2016

Process and utility lines connected to and from skid

Summary

- The 1 MW_e MTR small pilot system has been transported from NCCC and is being installed at B&W
- Installation/commissioning to be completed by the end of this month
- Integrated membrane/boiler testing will demonstrate CO_2 recycle to boiler by membrane for the first time
- Parametric testing will clarify the pros/cons of recycle/no-recycle for partial and 90% capture

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Acknowledgements

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  - José Figueroa
- **Southern Company Services (NCCC)**