Slipstream Testing of a Membrane CO_2 Capture Process

DE-FE0005795

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Membrane Technology and Research, Inc.

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, Southern Company (NCCC), Babcock & Wilcox, 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 optimization and durability testing; new module (including plate-and-frame) testing
- BP3 – 6-month pilot test of the 20 ton/day system; comparative economic analysis; Vectren case study at 20 MW-scale; industrial 1 TPD field test

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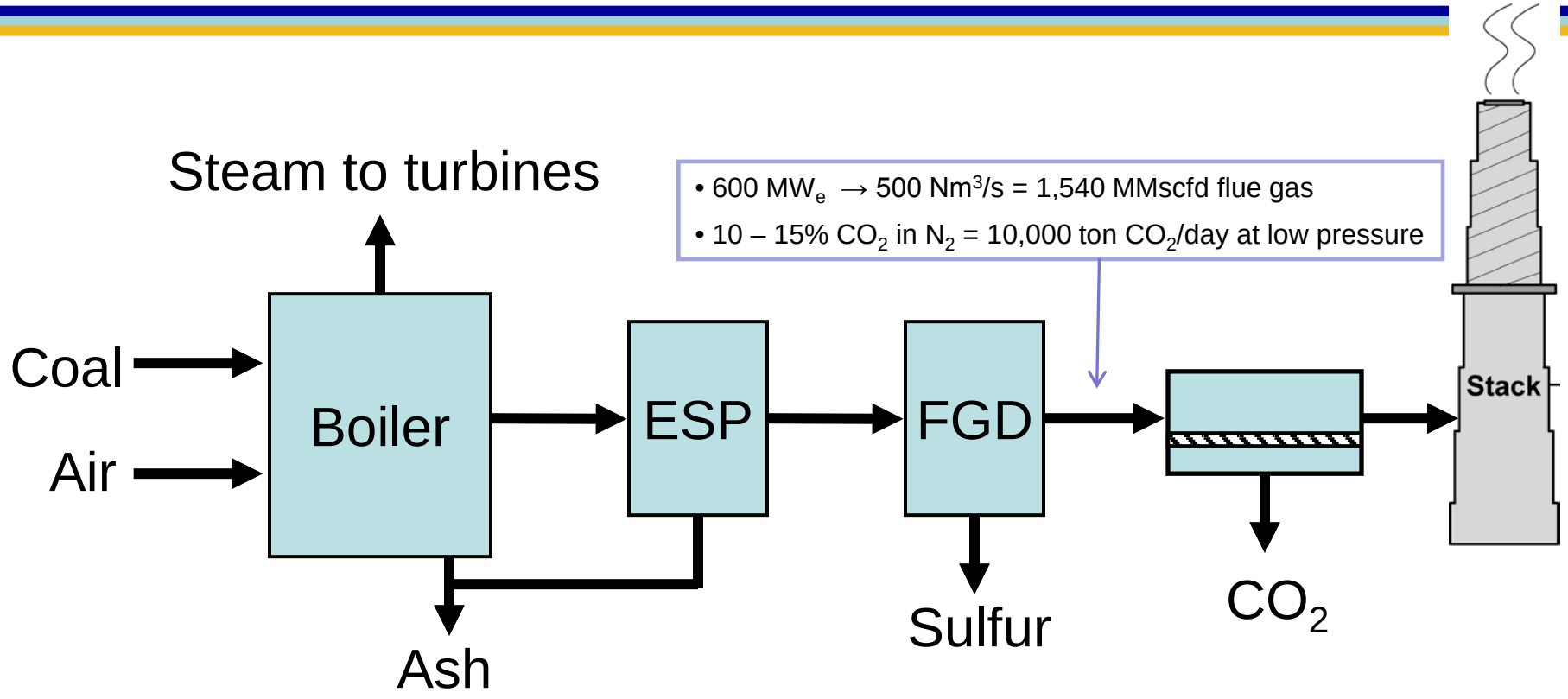
Post-Combustion CO_2 Capture with Membranes



Benefits of a membrane capture process:

- No hazardous chemical handling, emissions, or disposal issues
- Not affected by 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

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Challenges for Membrane Post-Combustion CO_2 Capture

- How to generate a pressure driving force in an affordable manner?
- Large flue gas flow rate (10,000 ton CO_2/day) will require very permeable membranes
- Unknown impact of particulate matter on membrane-module lifetime and module pressure drop
- Materials and performance challenges for rotating equipment used (blowers, compressors, vacuum pumps)
- Gas flow distribution and pressure drops
- Scale-up and cost reduction

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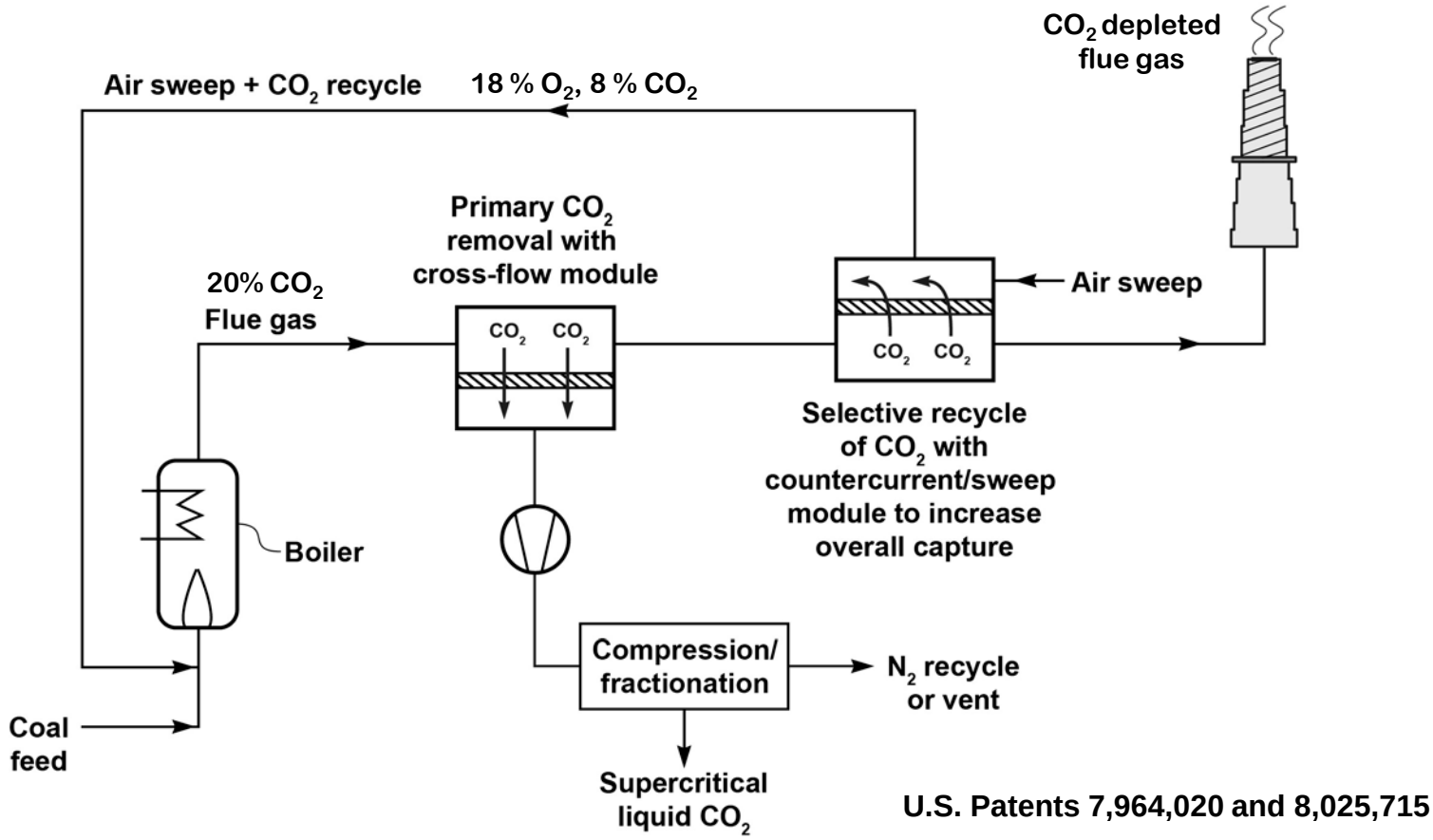
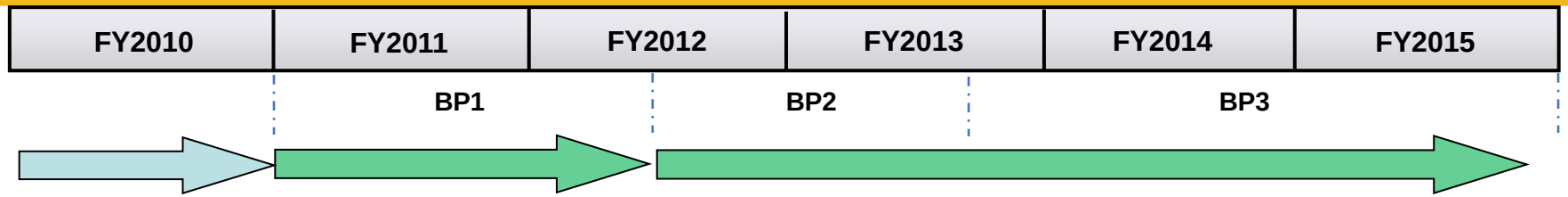
The MTR CO_2 Capture Process



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

- Combustion air sweep provides driving force w/o compression or vacuum
- Pre-concentrated CO_2 decreases membrane area and power required

Major Project Tasks and Timeline



Cholla (1 TPD)
- DOE project NT0005312 (completed 3/31/11)
- Collaboration with APS and EPRI
- Slipstream testing at Cholla plant

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
- Investigate low-fouling module geometries

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
- Demo refinery CO_2 capture at 1 TPD
- Conduct economic analysis based on test results

Blue arrow = DE-NT0005312
Green arrows = DE-FE0005795

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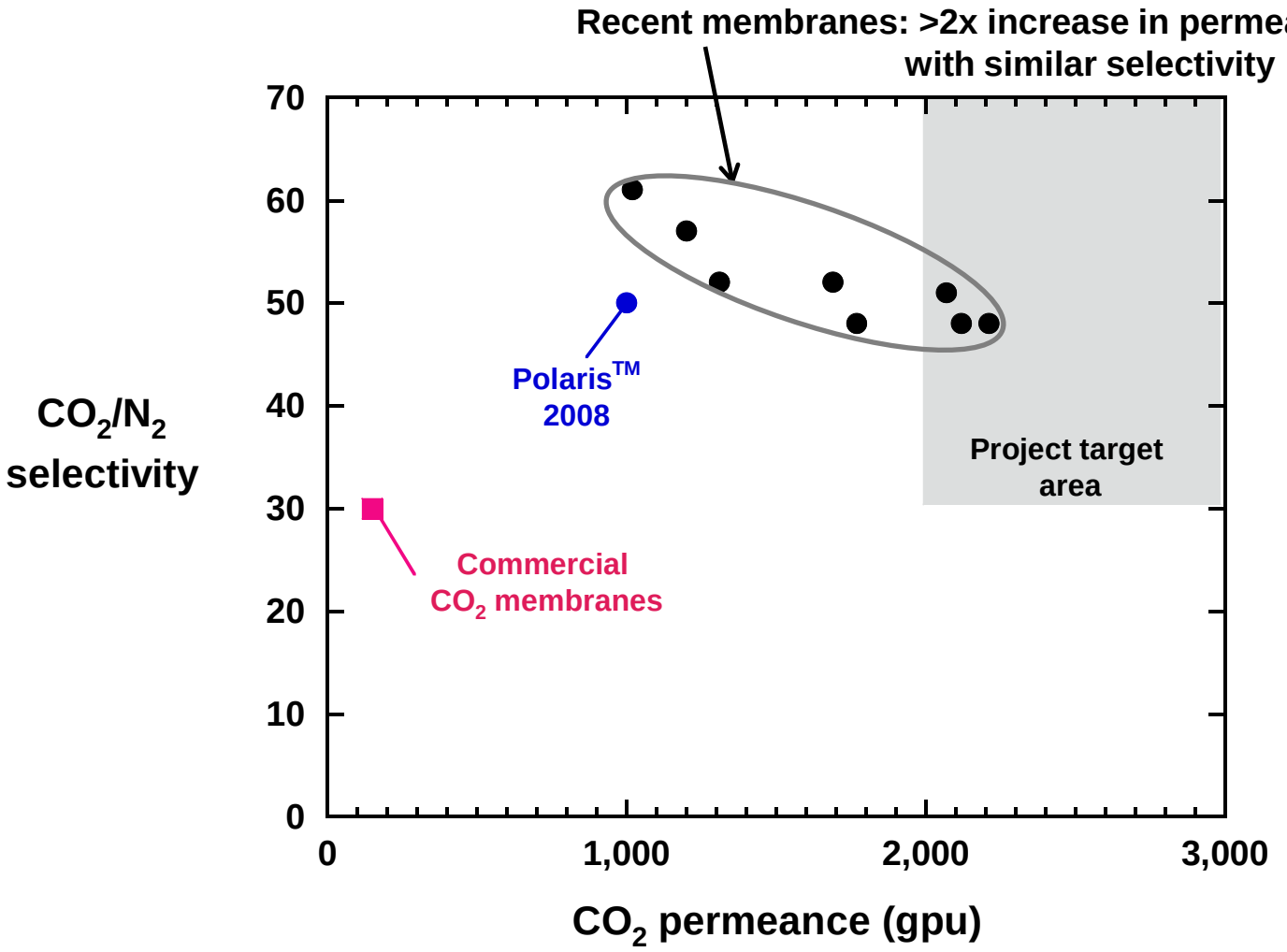
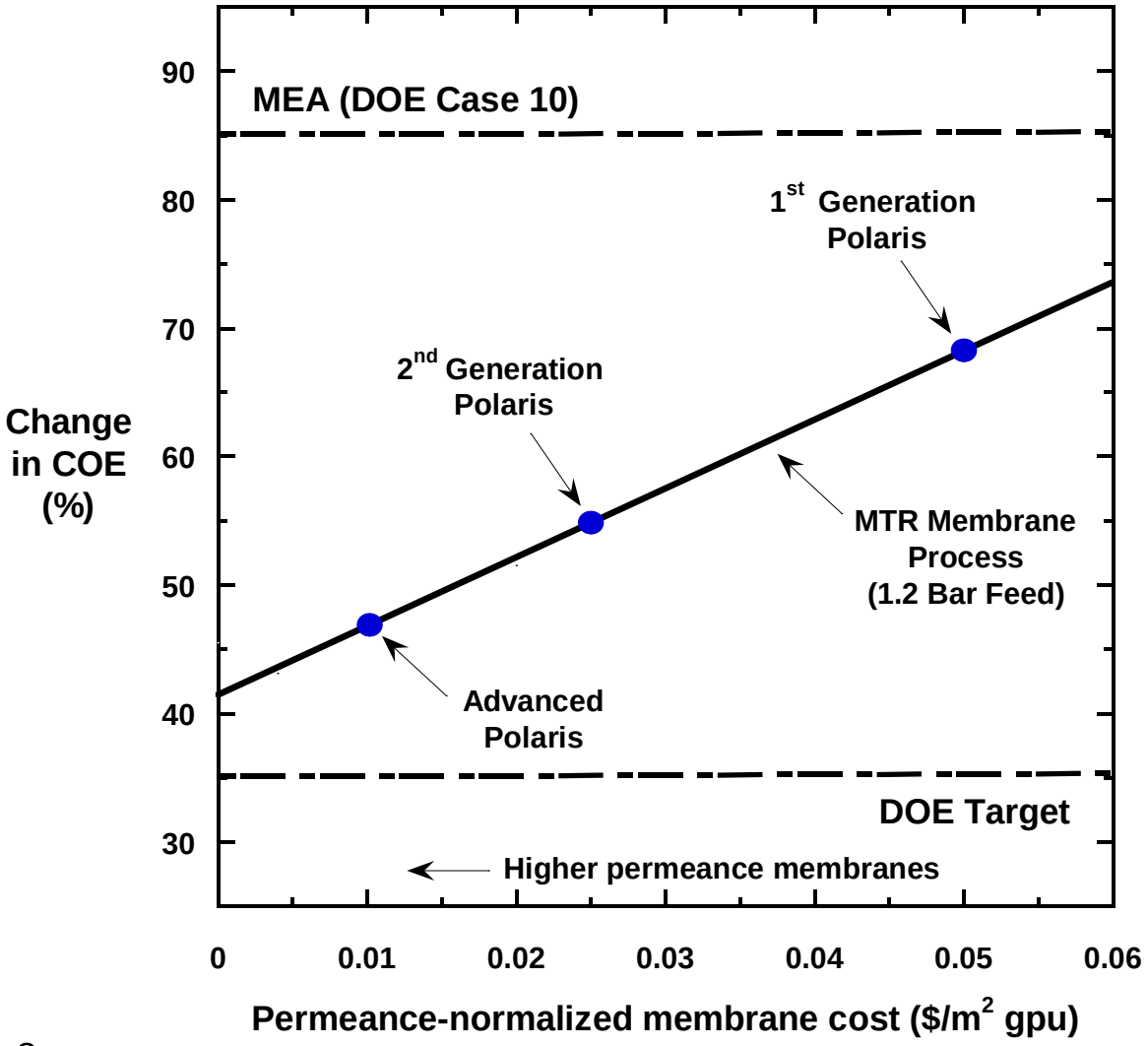
Polaris™ Membranes Continue to Improve



Pure-gas data at 25°C and 50 psig feed pressure

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

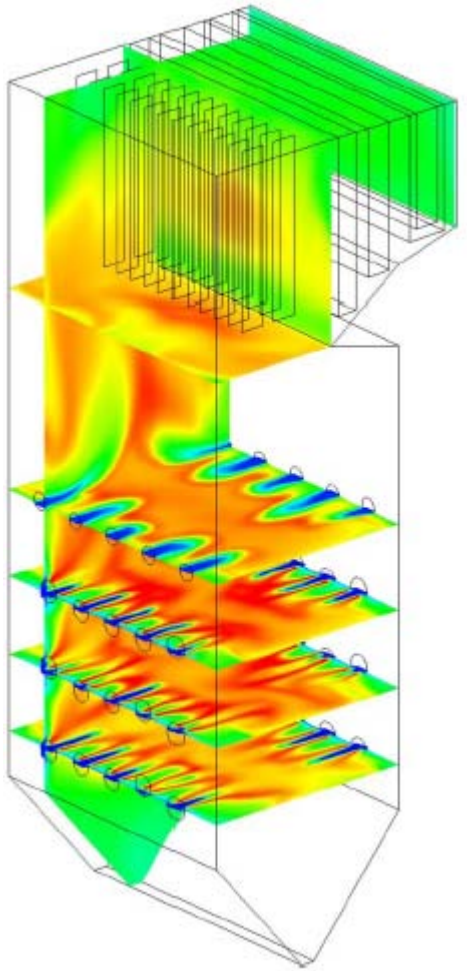
Effect of Membrane Properties on COE



- All calculations for 90% CO_2 capture
- Design uses minimal feed compression (booster fan only)
- Higher permeance (lower cost) membranes are key to approaching DOE goals

Impact of CO_2-Enriched Secondary Air on Boiler Performance: Computer Modeling Results

- B&W examined 2 boiler configurations (radiant boiler firing bituminous coal and SWUP firing PRB coal)
- 2 membrane sweep recycle cases (constant secondary air flow or constant stoichiometry)
- Both boilers perform well in terms of combustion efficiency and FEGT when stoichiometry is fixed
- When secondary air flow is fixed, unburned carbon and CO concentration are high at furnace exit
- For fixed stoichiometry, higher flue gas flow rate results in ~6% increase in heat absorption in superheater tube banks
- Secondary air laden with CO_2 appears feasible as a retrofit in either of the boiler configurations examined
- Boiler testing in BP2 will seek to confirm modeling findings



Modeling conducted by Z. Chen[1], R.A. Wessel[1] and H. Farzan[2]

(1) B&W Computational Analysis Team and (2) B&W Power Generation Group

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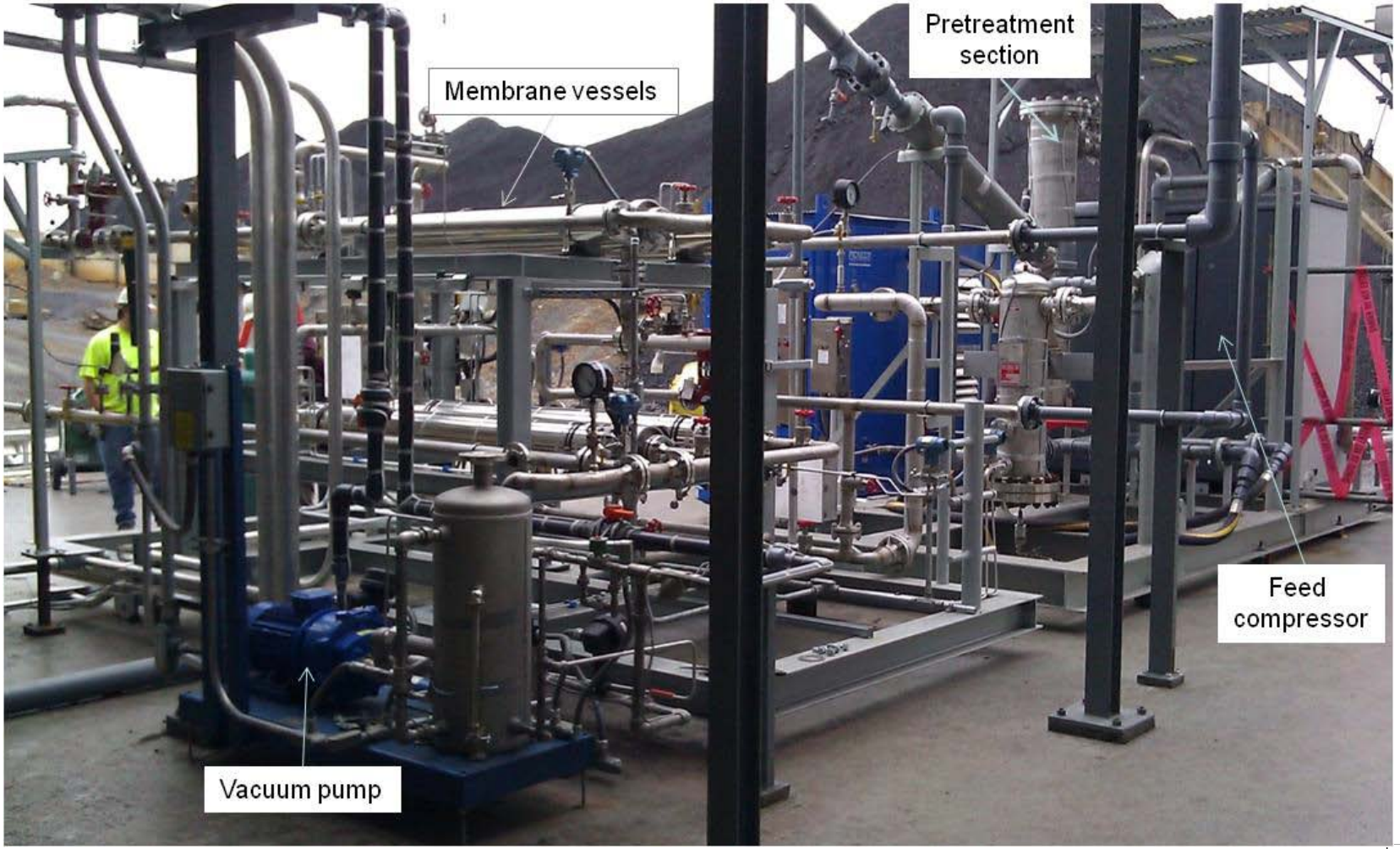
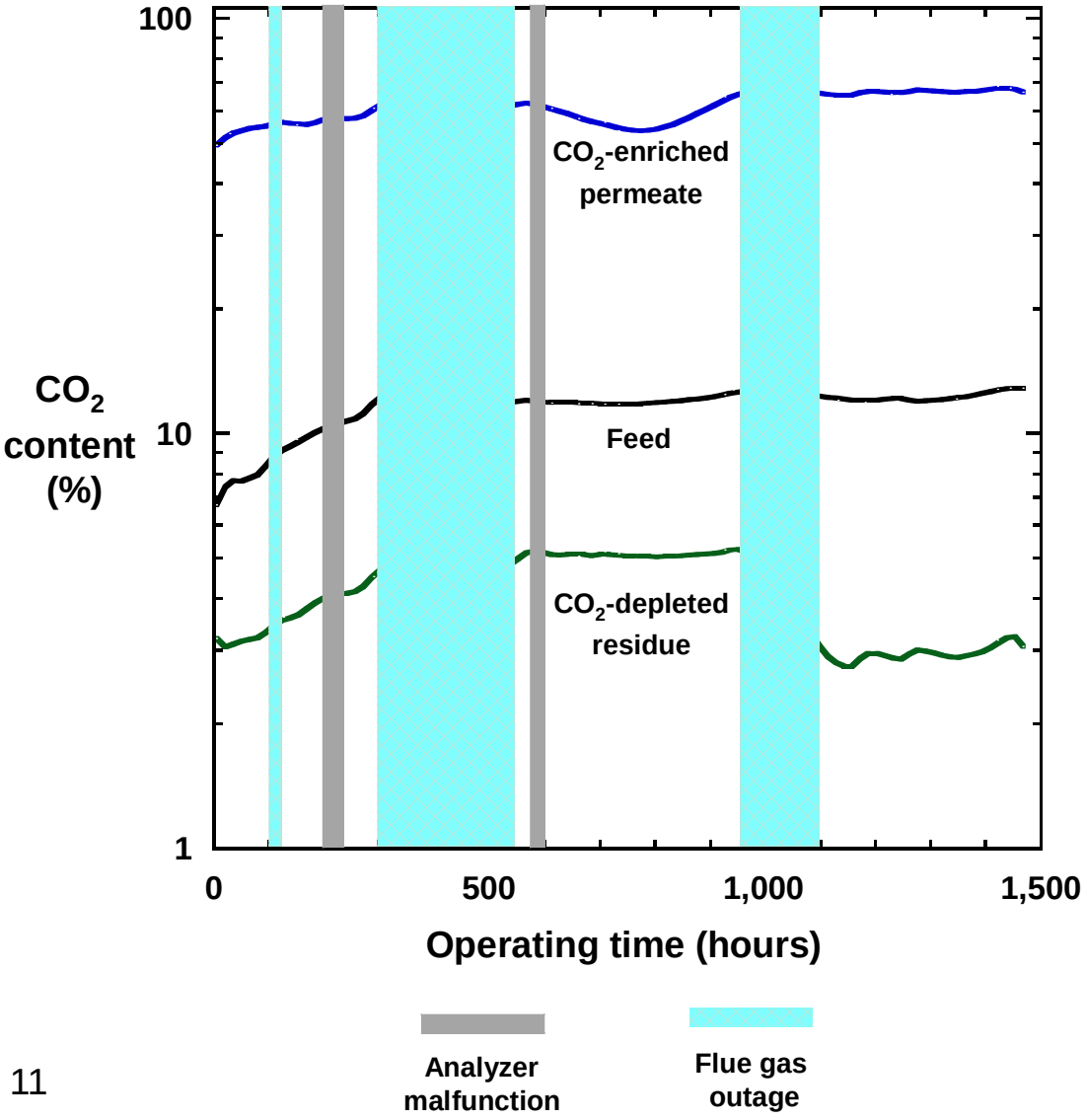
1 TPD Test System at NCCC



1 TPD system installed Oct/Nov 2011; continuous operation spring 2012

1 TPD NCCC Results: Stream Compositions



- System in continuous operation since April 19
- As expected, membrane enriches CO_2 by about 6 times in the permeate
- Initial low feed CO_2 content due to air ingress
- Most variation in compositions due to daily temperature swings
- Overall, membrane module performance is stable

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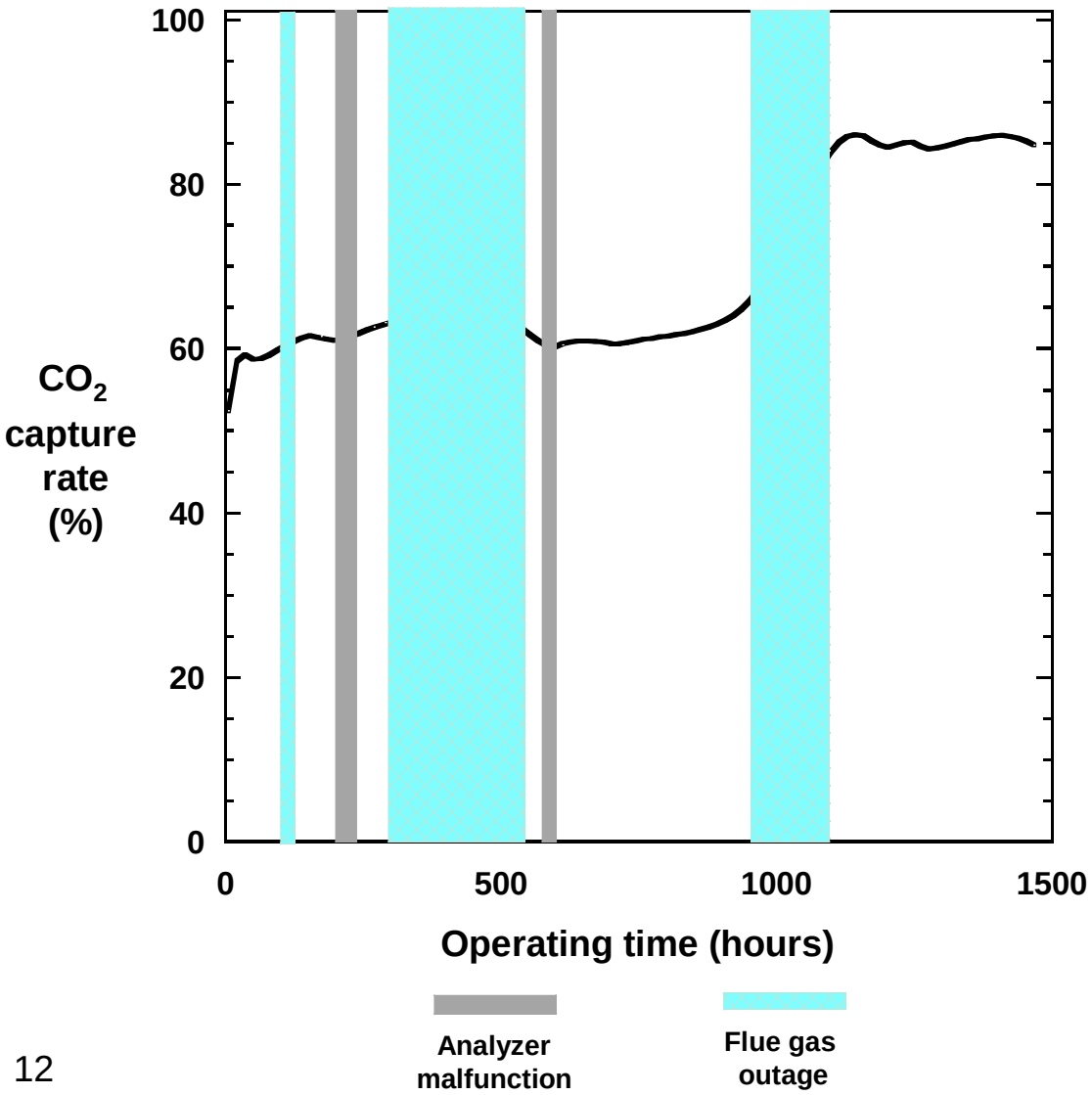
1 TPD NCCC Results: CO_2 Capture Rate



- Initially system operating with Cholla modules at ~2/3 capacity
- After 1,000 hours, additional modules loaded to increase capture rate to 85%

1 TPD NCCC Tests: Lessons Learned and Future Work

- Be prepared for unplanned shutdowns; have robust startup/shutdown procedures to limit equipment problems
- Alabama is hot; size cooling equipment appropriately
- Use robust analyzers; field tests are a lot of work to not get reliable data; NCCC engineers have been a great help

- System is a versatile field laboratory that allows rapid evaluation of new membrane and module configurations, yields material lifetime data, and provides valuable operational experience
- In BP2, we will begin to rotate in 2nd generation Polaris modules; old modules will be analyzed to understand effects of flue gas exposure
- As new module configurations become available, we will test for performance comparison

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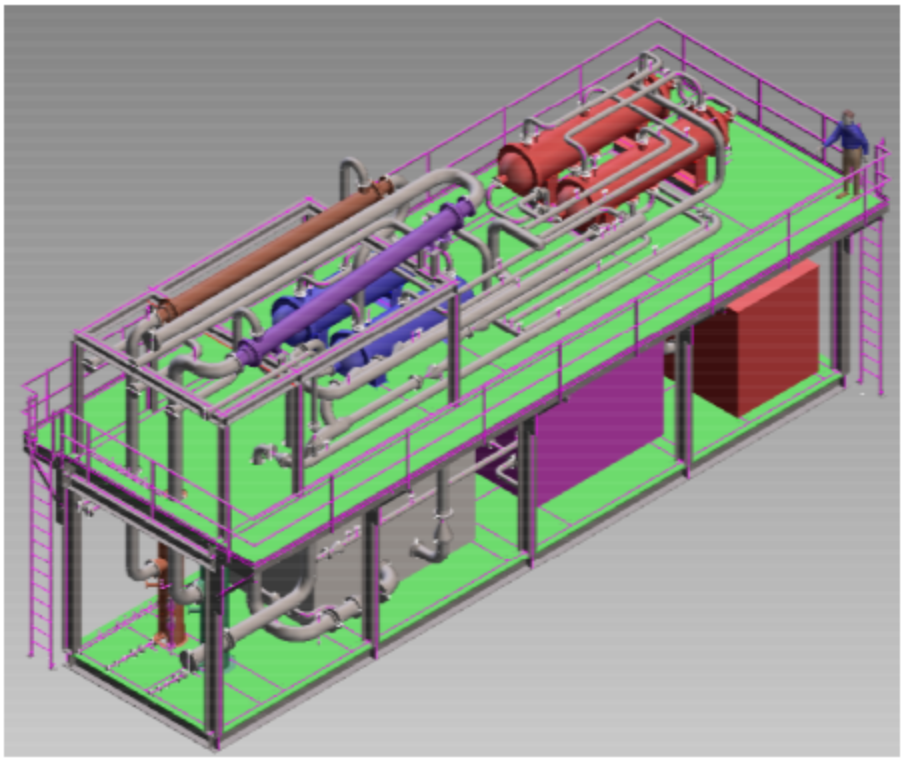
20 TPD System Status

- P&ID, general arrangement drawings, and construction schedule are completed
- Fabrication has started in the past week
- Estimate installation at NCCC in 2nd quarter 2013
- Operate system at NCCC for 6+ months; at least 3 months of continuous SS operation
- System demonstrates bundled spiral-wound modules (Gen 2 modules) and 500 m^2 plate-and-frame prototypes (Gen 3) produced by project DE-FE0007553



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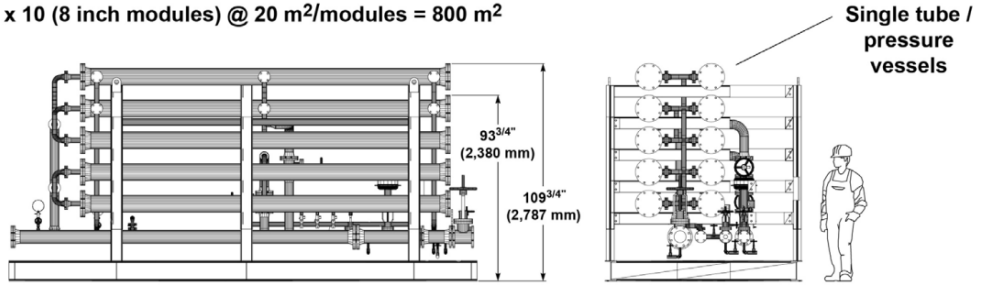
20 TPD System Location at NCCC/PC4

Picture courtesy of Mr. Tony Wu, Southern Company

Membrane Vessels Redesigned For Low-Pressure Flue Gas

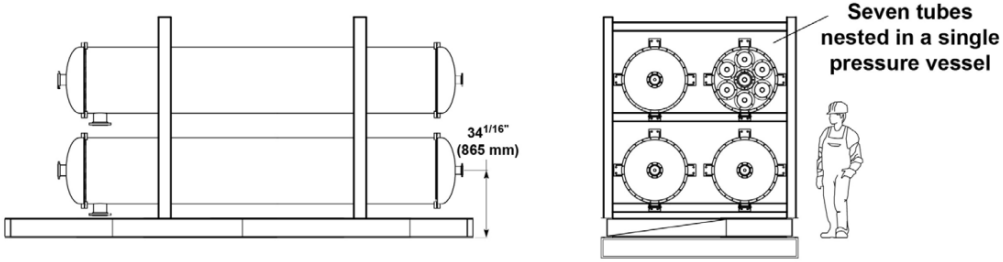
Gen 1

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



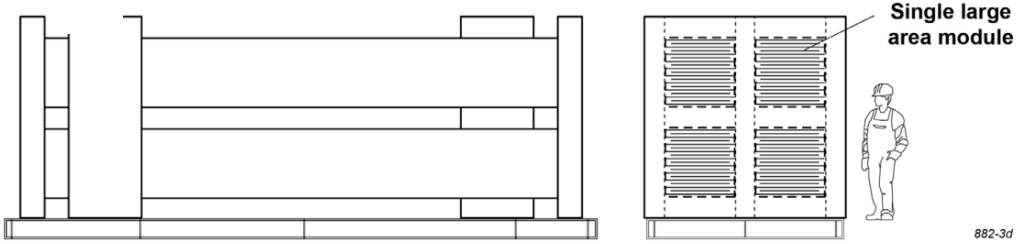
Gen 2

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



Gen 3

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



Module type <u>demonstrated on:</u>

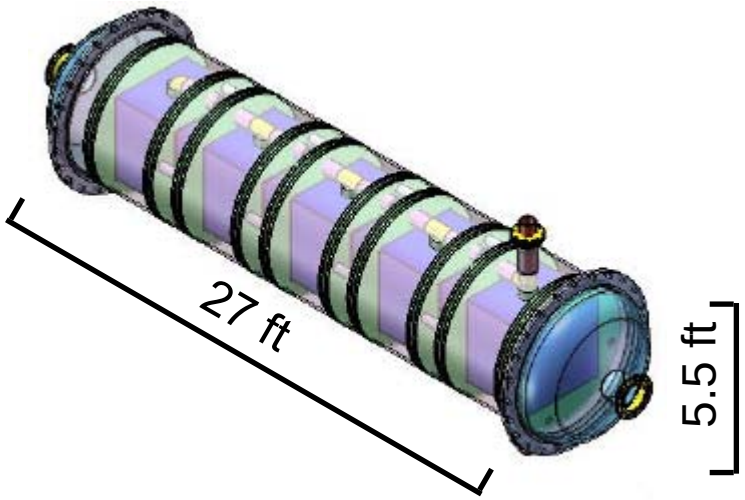
1 TPD

20 TPD

20+ TPD

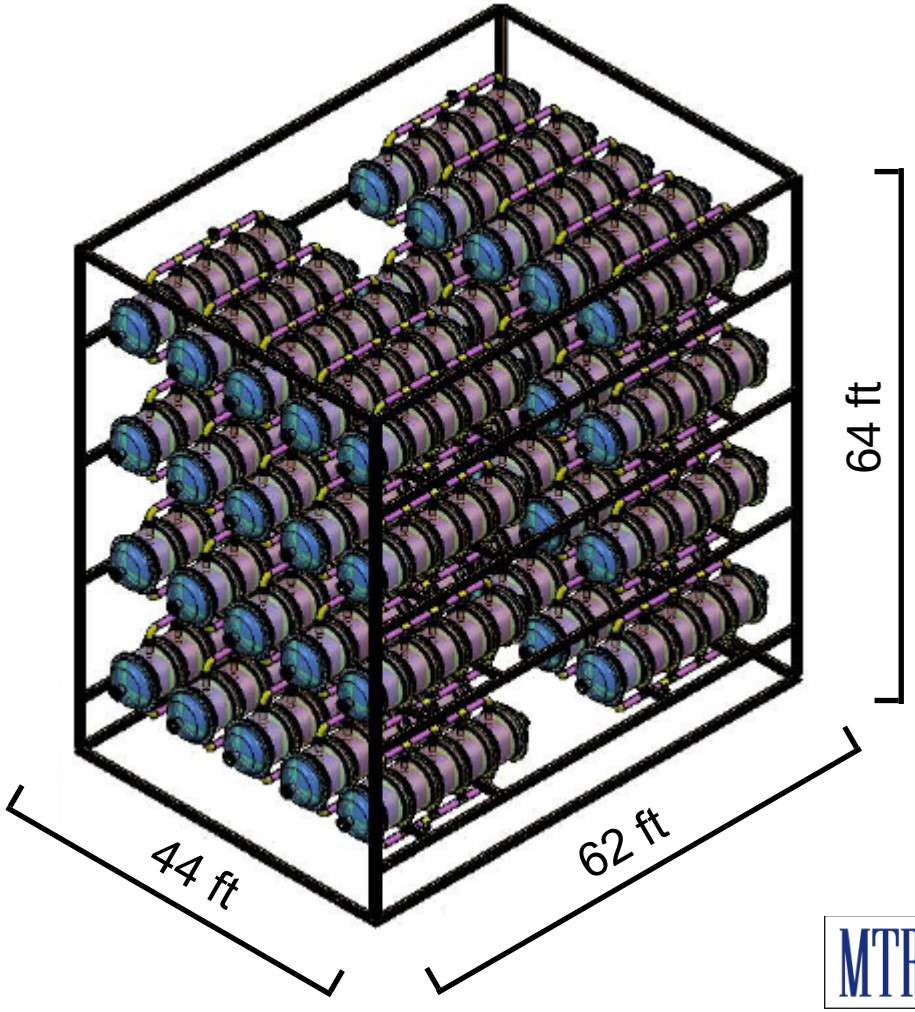
Future Scale-Up

One module skid, 2500 m^2



- Smaller foot print
- Low pressure drop
- Reduced manifolding
- Lower cost

40 modules plant, $100MW_e$



Summary

- Membrane post-combustion capture technology is at the slipstream test stage
- Initial flue gas field tests show stable module performance
- Many challenges for a first-of-a-kind field unit; NCCC assistance has been invaluable
- Computational analysis suggests CO_2 recycle with sweep membrane is feasible as retrofit to existing boilers
- Key objectives of next 12 months:
  - Optimize membrane/module performance on 1 TPD skid
  - Fabricate, install, and operate 20 TPD demonstration unit
- Future work – demo full process on appropriately-sized boiler, examine hybrid options (sweep membrane only)

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Acknowledgements

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  - Jose Figueroa

- **Southern Company (NCCC)**
- **Babcock & Wilcox Power Generation Group**
- **EPRI**