Advancing Cleaner Energy

Evaluation of Solid Sorbents as a Retrofit Technology for CO_2 Capture

June 25, 2015

ADA-ES, Inc.

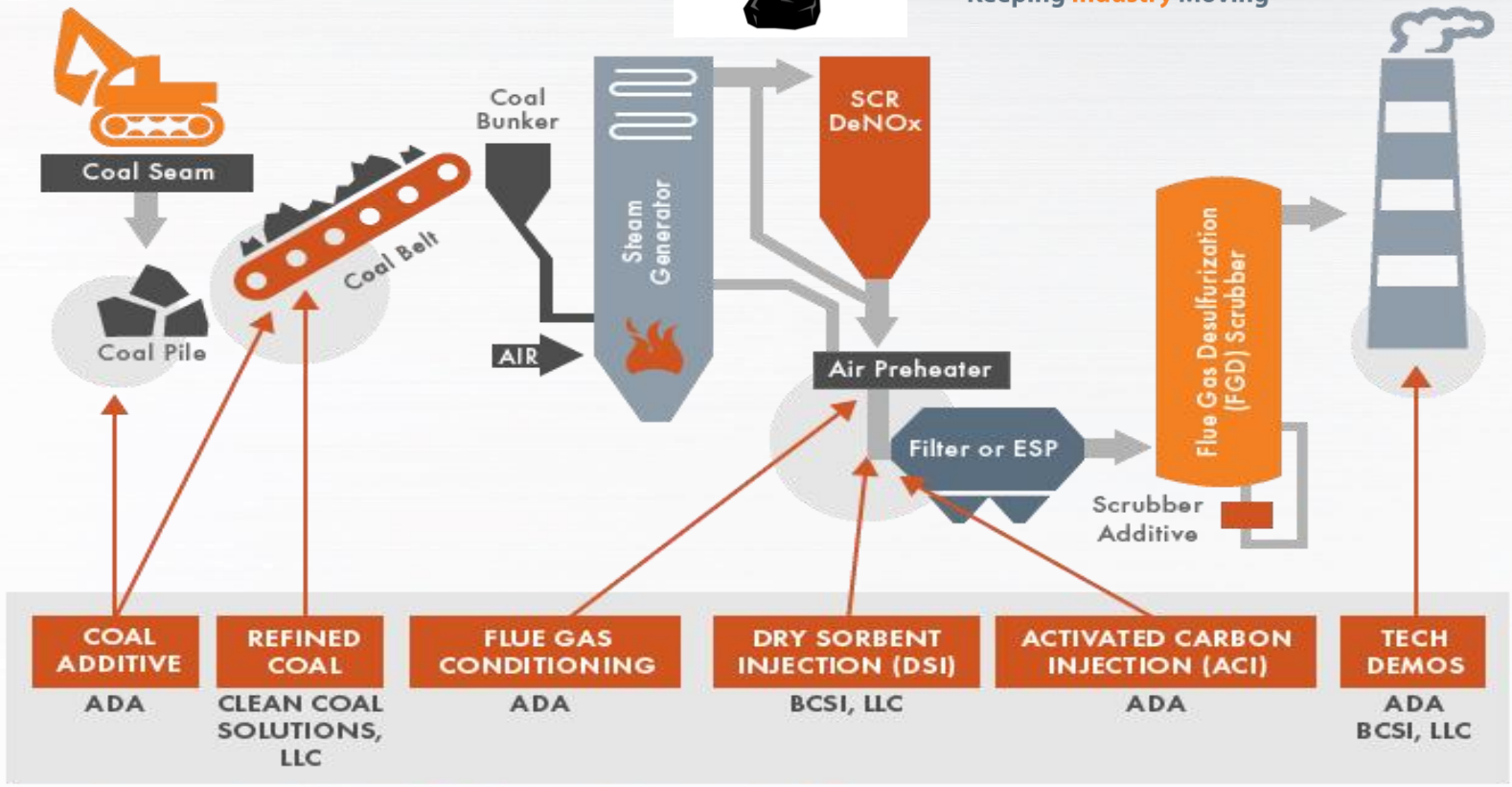
DE-FE0004343

Advanced Emissions Solutions, Inc.

Advancing Cleaner Energy

CLEAN COAL SOLUTIONS LLC.

BCSI
Keeping Industry Moving

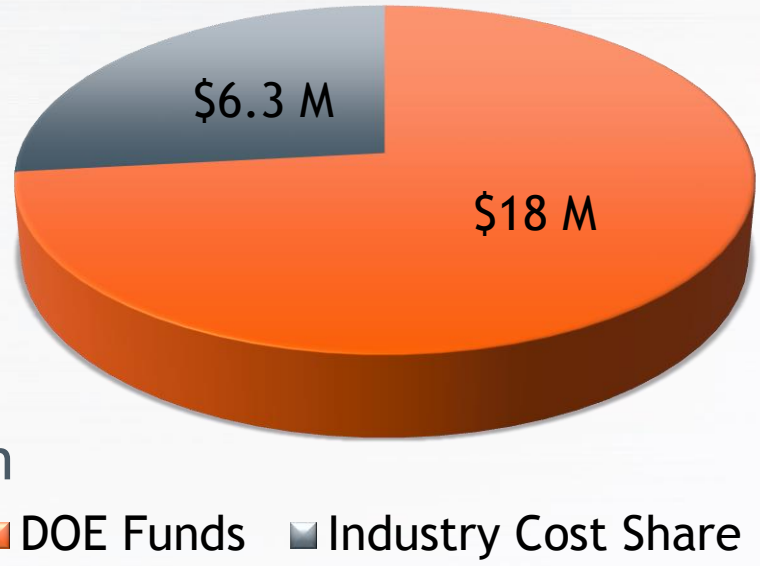






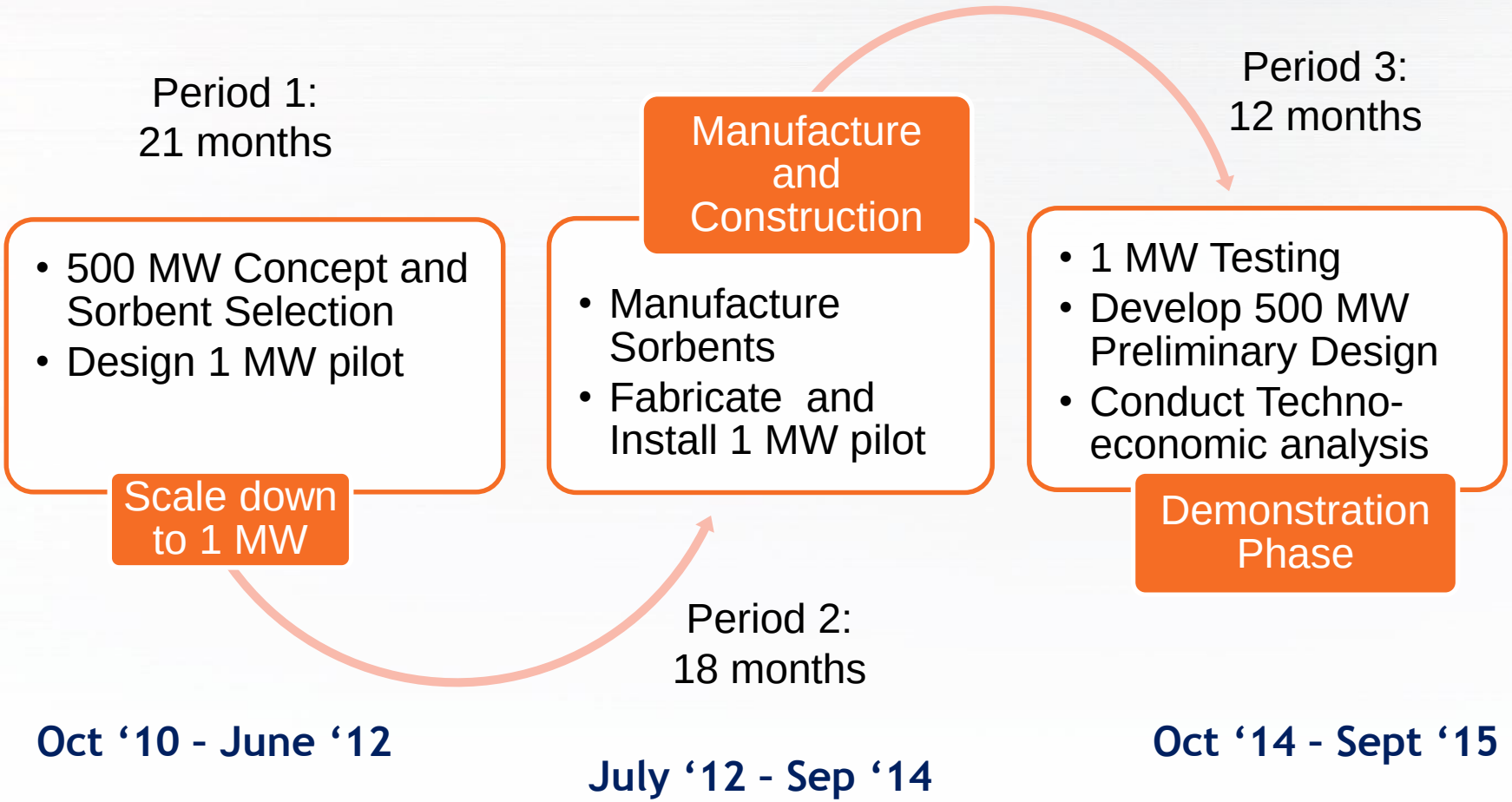

Project Funding and Goals

- The overall objective of this funding stage is to validate solid sorbent-based post combustion CO_2 capture through slipstream pilot testing.
- Project Goals:
  - Achieve 90% CO_2 Capture
  - Reduce costs of carbon capture
    Progress towards <35% LCOE Goal
  - Generate a high purity CO_2 stream
  - Successfully scale sorbents



Cooperative Agreement (Award No. DEFE0004343)
American Recovery and Reinvestment Act of 2009
Administered by DOE-NETL: Project Manager Bruce Lani

Project Overview



Project Team

- DOE – NETL
  - Project Sponsor
- ADA-ES, Inc.
  - Project Management
  - Developed Process Concept
  - Sorbent Eval & Selection
  - Process Validation Testing
  - Techno-Economic Assessment
  - Primary Cost Share
- Technip Stone and Webster Process Technology
  - Detailed Engineering Services

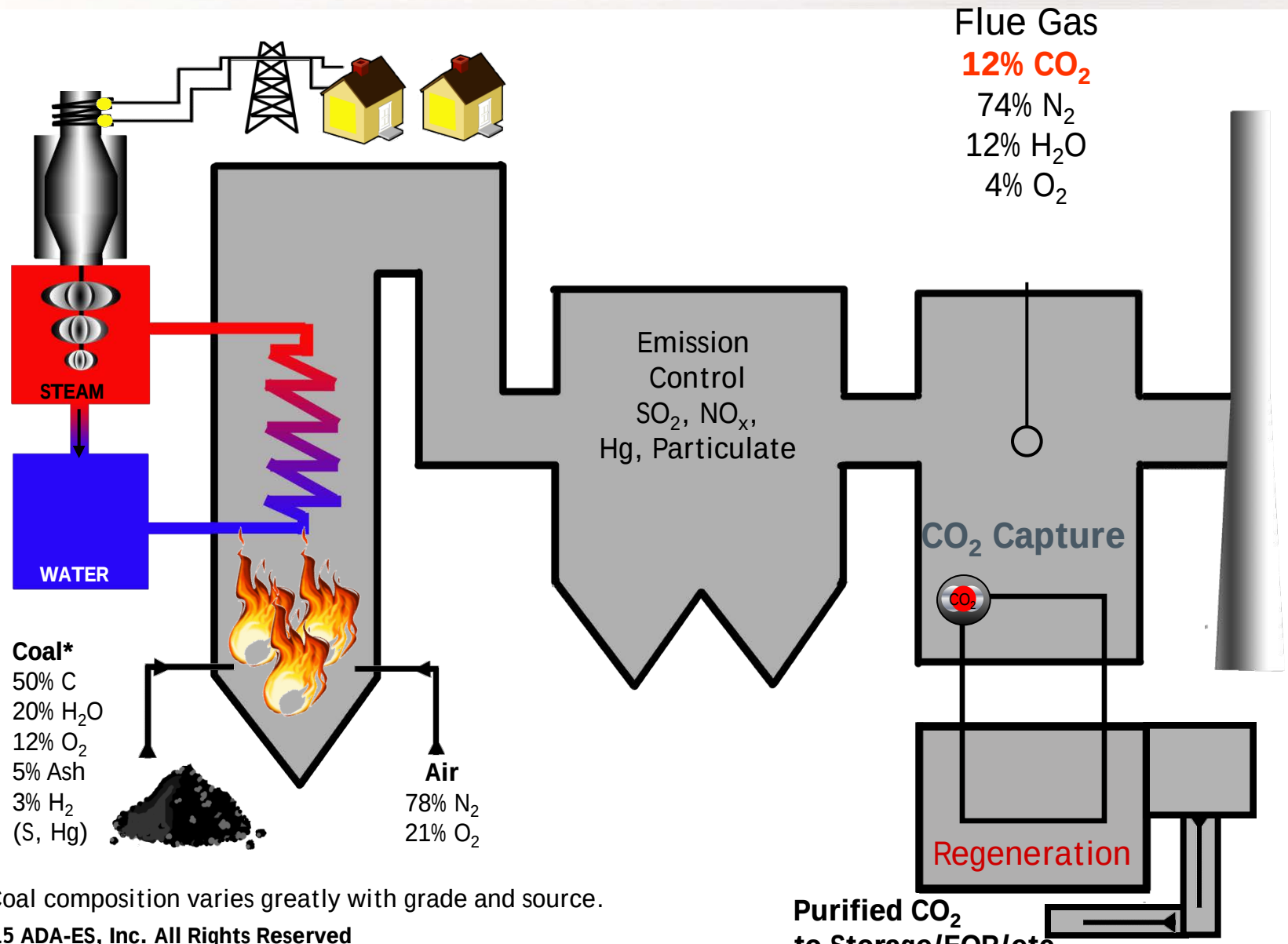
Significant Experience with Fluidized Bed Reactor Design

- Stantec Consulting, Ltd.
  - Cost Analysis, Plant Integration

Owners Engineer Perspective

- McAbee Construction
  - Pilot fab and installation
- EPRI
  - Technical Advisor
  - Cost Share
  - Independent Performance Evaluation and Techno-Economic Assessme
- Southern Company
  - Host Site, Cost Share
- Luminant
  - Cost Share

Post-Combustion CO_2 Capture



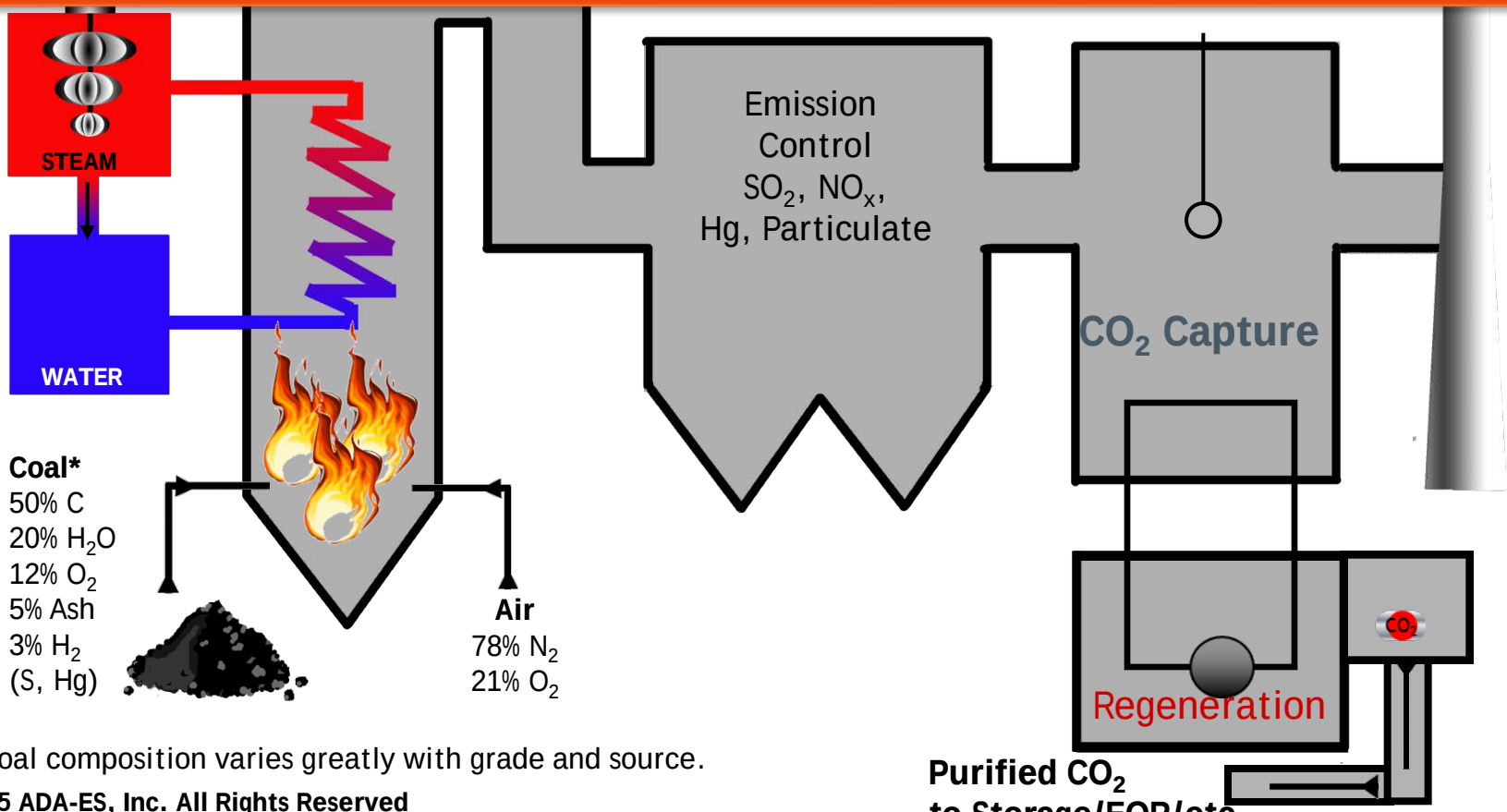
*Coal composition varies greatly with grade and source.

Post-Combustion CO_2 Capture

Solids functionalized with amines react with CO_2 at "low" temperatures

Solids are heated to reverse reaction with CO_2

Temperature swing adsorption (TSA)



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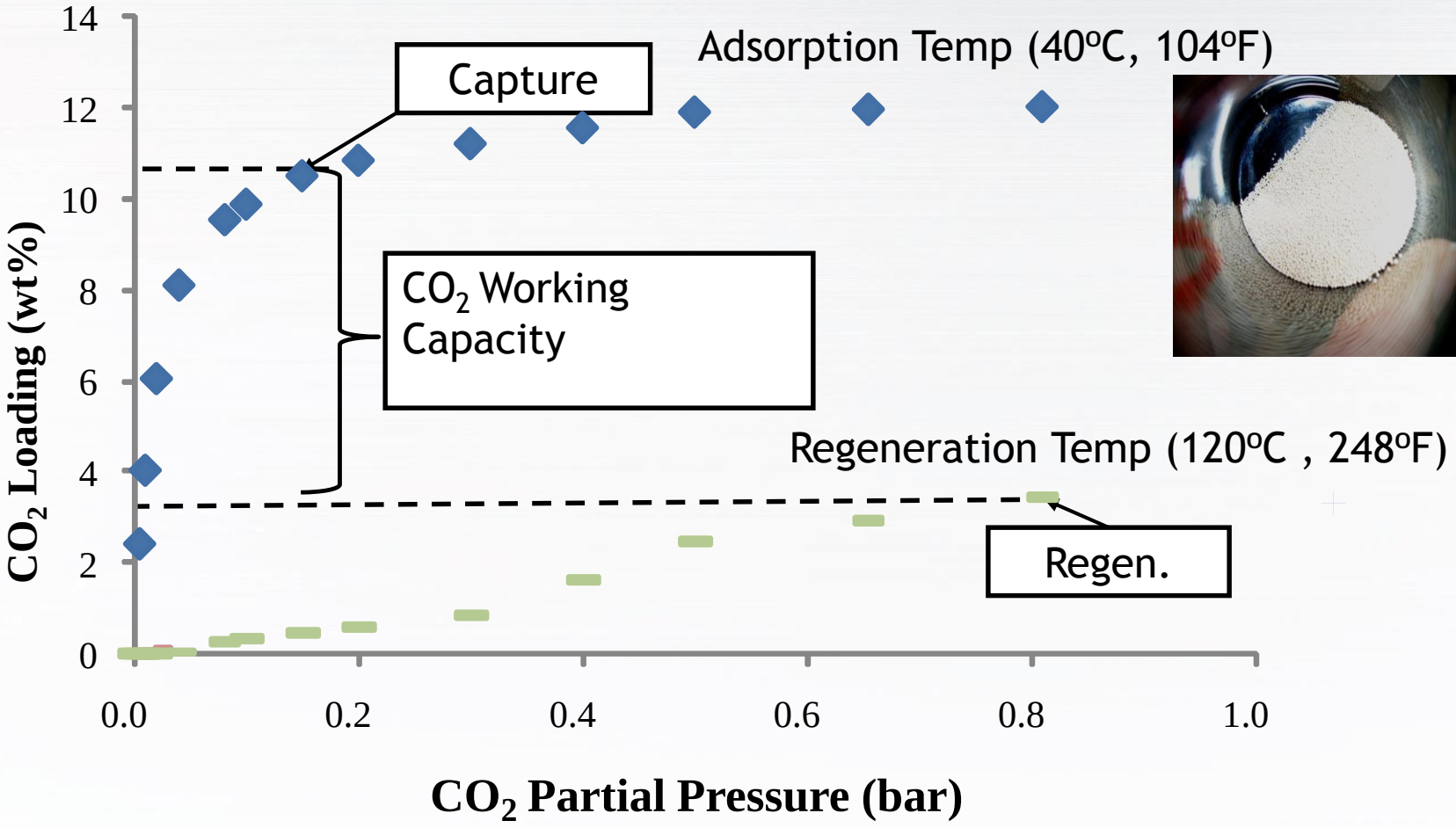
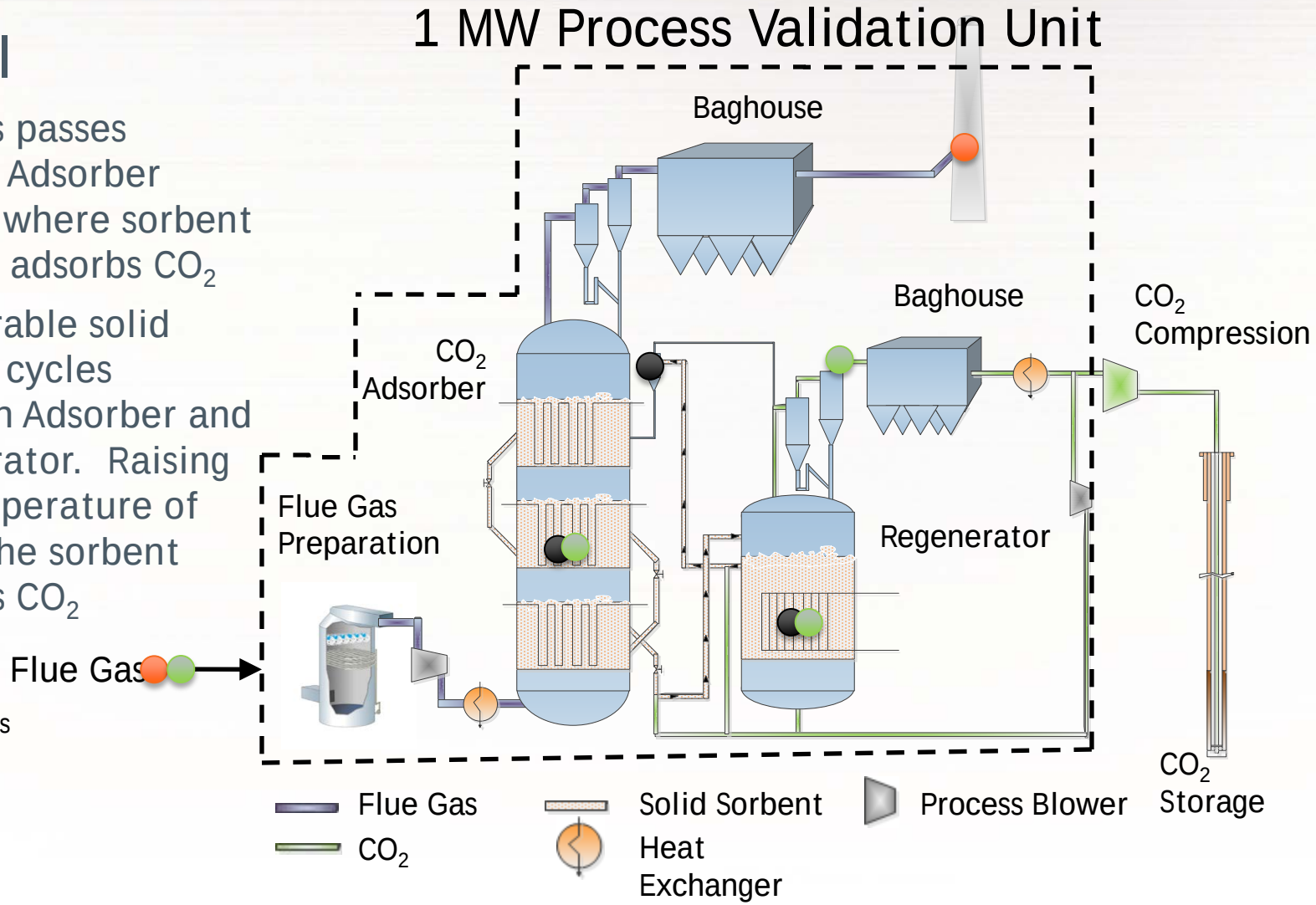
Sorbent Isotherms



Process Conceptual Design

Principal

- Flue gas passes through Adsorber module where sorbent particle adsorbs CO_2
- Regenerable solid sorbent cycles between Adsorber and Regenerator. Raising the temperature of the of the sorbent releases CO_2



ADAsorb™ CO_2 Capture Process

Advantages

- Heat transfer
  - Isothermal operation
- Mass transfer favorable
- Proven at the industrial scale
- Approaches counter-current gas/solids contacting
- Process Flexibility
  - Can be applied to cycling plant “load following”

Challenges

- Pressure drop
- Solids circulation
- Sorbent attrition
- Water adsorption
- Heat recovery

Project Status

BP1

- Detailed characterization of sorbent
- 500 MW concept completed
- Design of 1 MW pilot completed

✓

BP2

- Detailed engineering of pilot complete
- Sorbent has been manufactured
- Fabrication of pilot is complete
- Installation of pilot is complete
- Commissioning of pilot has begun

✓

BP3

- 1 MW Testing is nearly complete
- Develop 500 MW Preliminary Design
- Conduct Techno-economic analysis

BP 3: Pilot Testing

- Host Site:
  Southern Company Plant
  - PRB Coal
  - WFGD
- Pilot Designed for
  - 90% CO_2 Capture
  - ~2,300 lb CO_2/hr
  - Flue Gas Flow Rate ~ 2,600 SCFM
  - Operation above freezing

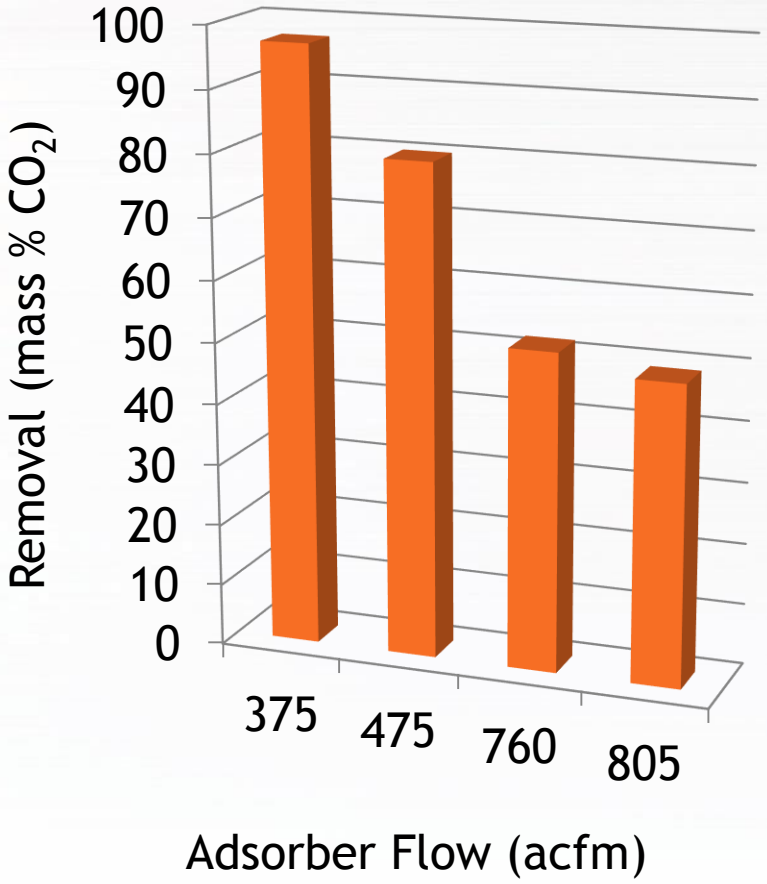
Pilot Schedule

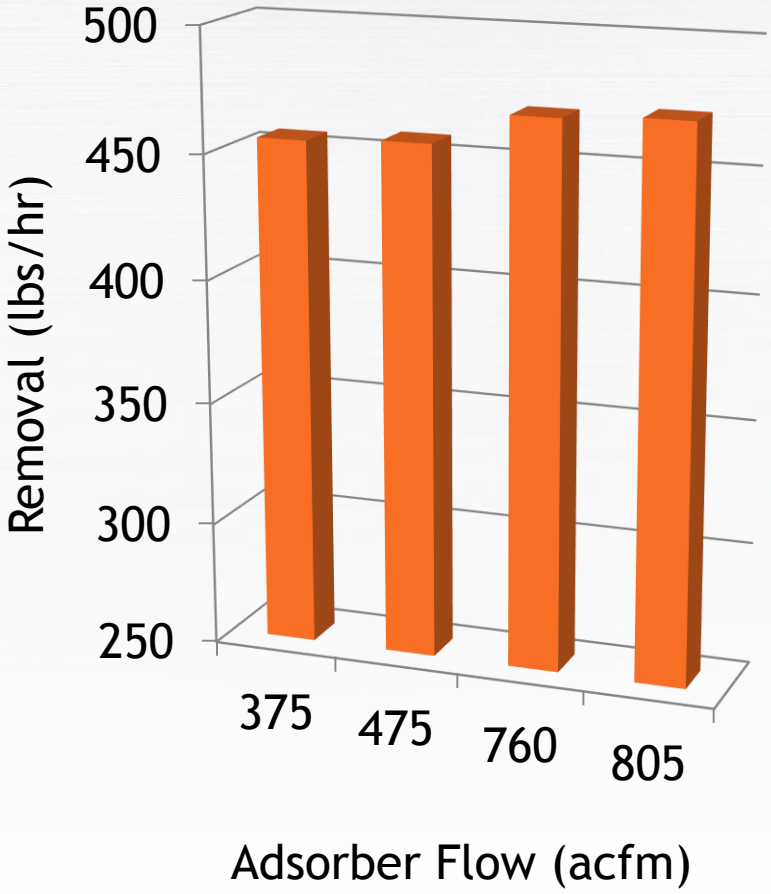
Task	Date
Commissioning/Dry Startup	Aug-Sept ’14
Field Testing Round 1	Oct-Nov ‘14
Field Testing Round 2	April – June ‘15

Key Observations from Pilot Testing

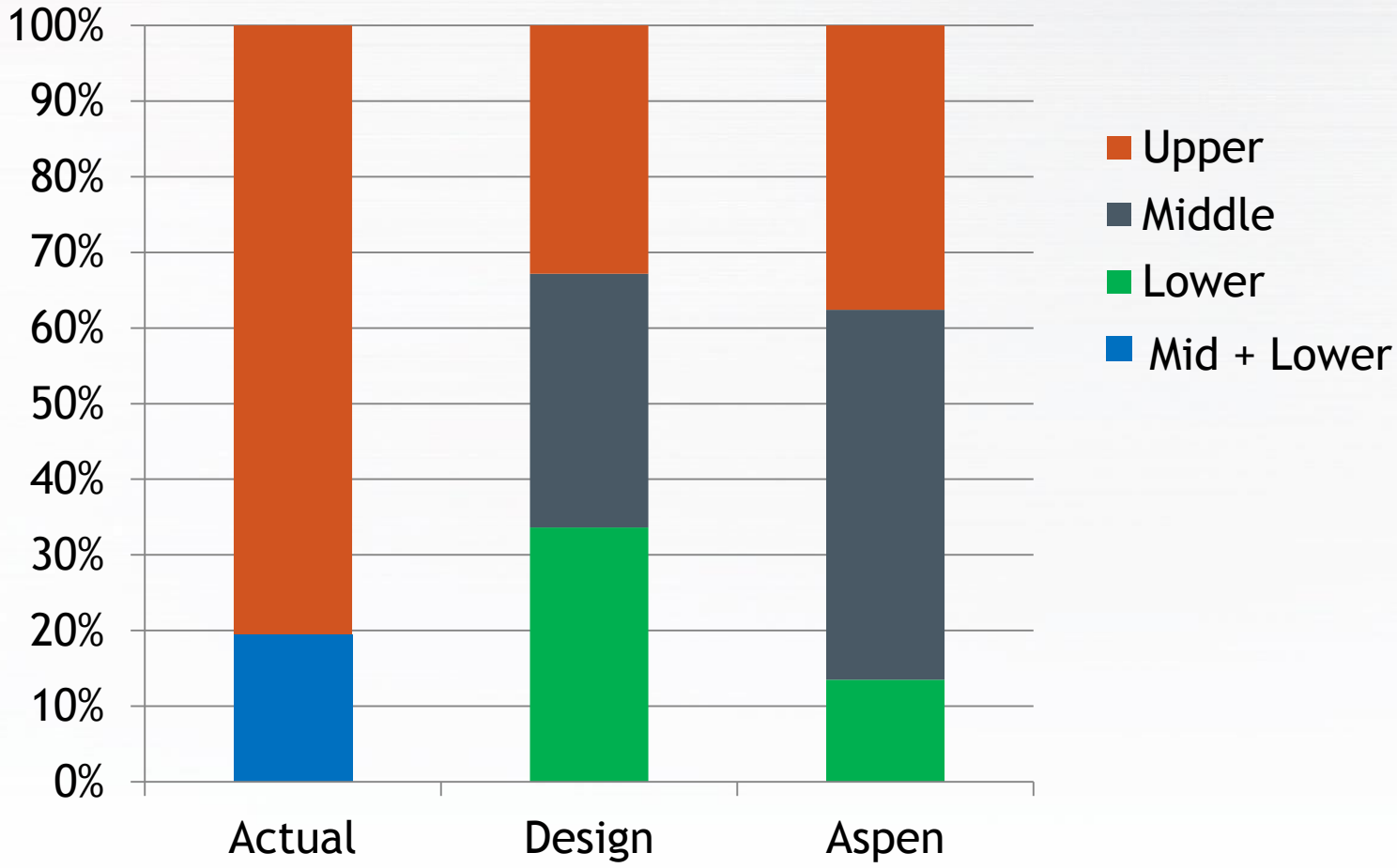
- **90% capture** can be achieved at very low flows but cannot be achieved at high flow rates
  - Capacity limitations
  - Sorbent handling characteristics at full regeneration temperature
- Data suggests relatively **fast adsorption kinetics**
- **Moisture uptake** on the sorbent appears to be higher than predicted from laboratory testing
- It is possible to circulate sorbent in a stable and consistent fashion, but system is sensitive to sorbent particle density, temperature, and CO_2 loading

CO_2 Removal at Varying Adsorber Flow Rates

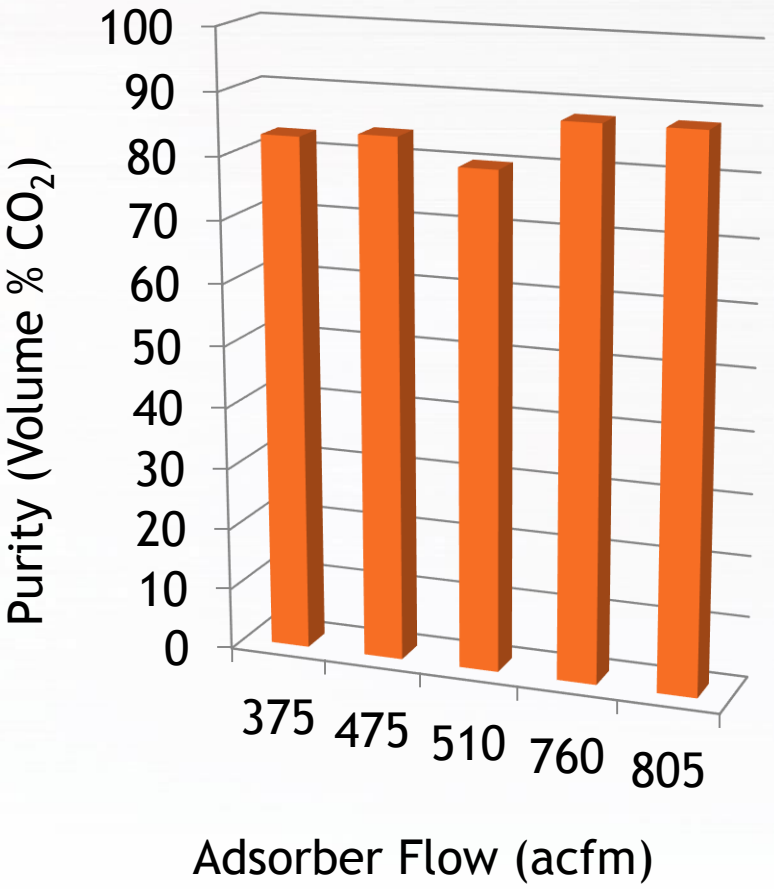




CO_2 Removal in Adsorber

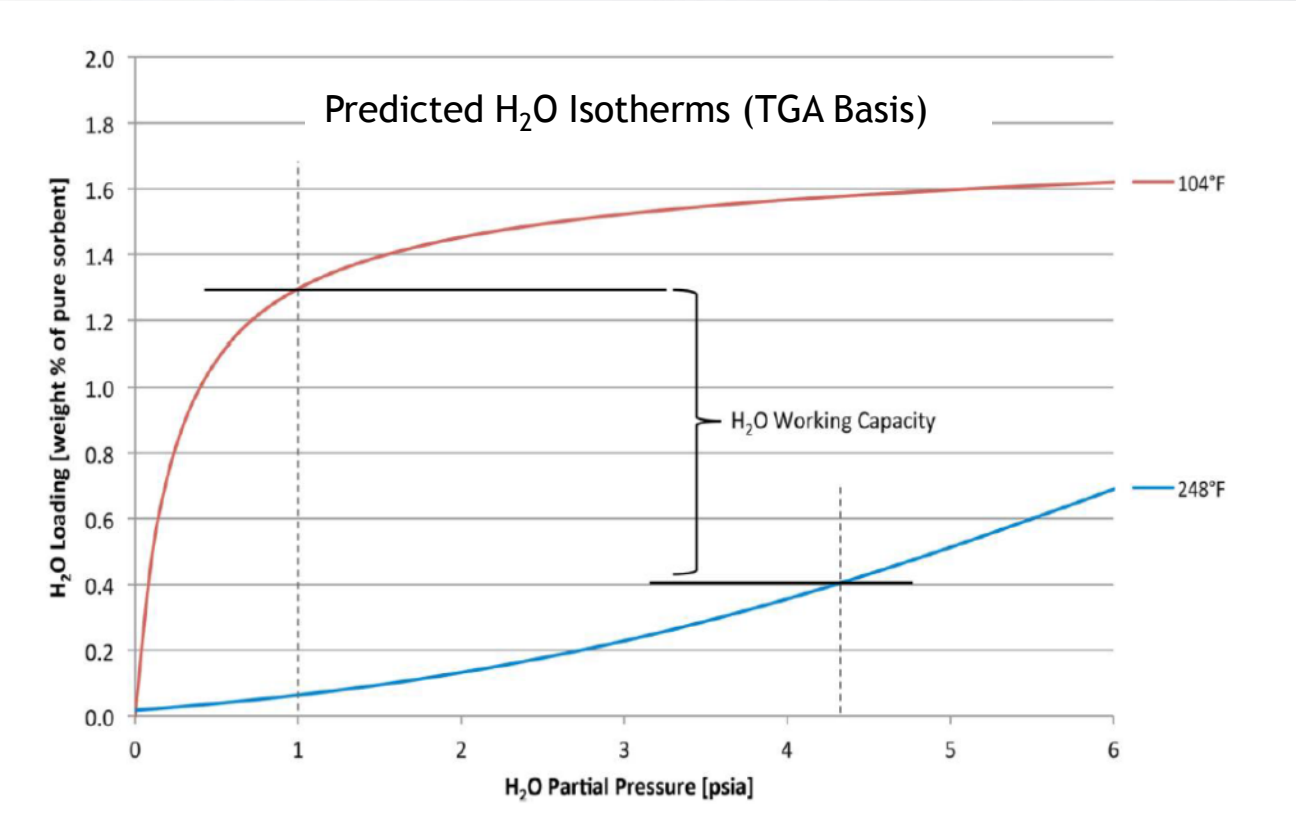


CO_2 Removal at Varying Adsorber Flow Rates



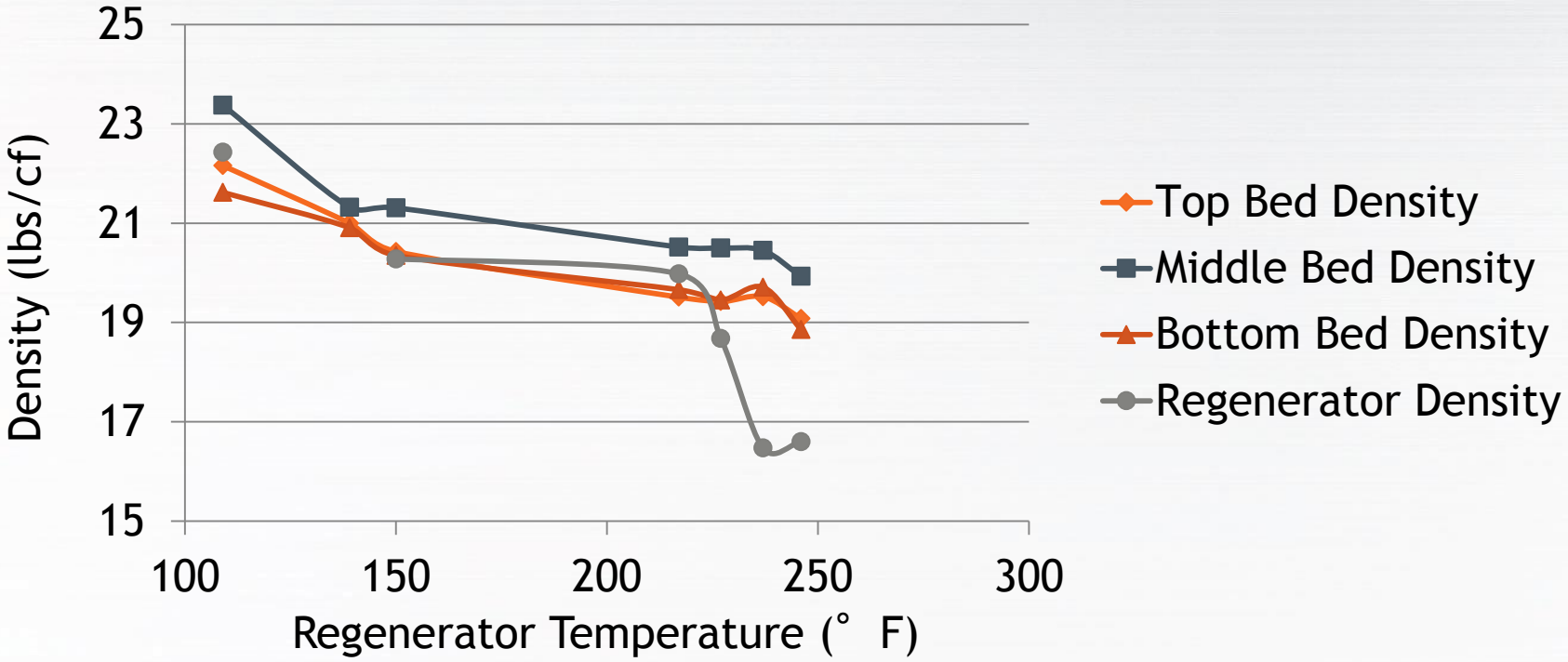
- Product stream purity 80% to 90% CO_2 during prolonged periods of stable pilot operation
- High moisture in CO_2 product

Moisture Uptake



- Pilot results indicate working capacity may be higher than predicted from TGA testing

Sorbent Density



Location At 248F	Design (lbs/cf)	Measured (lbs/cf)
Regenerator	26.0	16.6
Adsorber	15.0	18.9 – 19.9

Environmental Testing

- **Liquid discharge samples**
  all condensate locations
  all discharge points
  - Total suspended solids
  - HEM / “Oil and Grease”
- **Sorbent samples**
  collected bi-weekly from both the regenerator and the adsorber
  - RCRA 8 Metals
- All testing performed has produced results below the recordable limit for the tests

Additional Testing

- TGA results after approximately 3 weeks in the process indicated sorbent had **not** degraded in flue gas

Key Challenges from Testing

- Balance of plant issues
  - SO_2 scrubber operation and subsequent blower issues
  - Electrical grounding issues
  - Unseasonably cold weather and inadequate freeze protection
  - Supply water contamination
  - Analyzer Reliability
- Managing sorbent flow
  - Changes in sorbent behavior at high temperatures
  - Insufficient fluidization
  - Sorbent carryover
- Significant reliance on manual operation

Retrospective on Bench Testing and Modeling

Additional bench-scale testing could improve design and performance expectations in pilot

- Hot sorbent flow characteristics
- Sorbent moisture uptake

Modeling from CCSI efforts have been improving throughout testing program. Confidence in models may allow performance estimates with improved sorbent characteristics

Summary

- **90% CO_2 capture** can be achieved
- **Moisture adsorption by sorbent** will impact sorbent working capacity and overall performance
- Reducing the moisture adsorption of the sorbent and managing sorbent flow at higher temperatures could **significantly improve process results**

Next Steps

- Complete pilot testing and data analysis
- Techno-economic analysis
- Continue evaluating options for post-pilot scale-up
  - Will final regulations and oil prices support large-scale use of fossil-generated CO_2?
  - Today, regulatory drivers alone do not justify continued investment
- Work with DOE to make pilot facility available to other contractors

Questions?

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