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THE UNIVERSITY OF NORTH DAKOTA

Evaluation of Carbon Dioxide Capture From Existing Coal Fired Plants by Hybrid Sorption Using Solid Sorbents (CACHYS^{TM})

NETL CO_2 Capture Technology Meeting
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Steve Benson, Dan Laudal, Harry Feilen, Kirtipal Barse, Scott Johnson
University of North Dakota – Institute for Energy Studies

Srivats Srinivasachar
Envergex LLC

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Presentation Overview

- Project Overview
- Technology Fundamentals
- Progress and Current Status
- Future Plans

Funding

- Initial Funding – STTR project – Envergex and UND
- Project Funding
  - U.S. Department of Energy Carbon Dioxide Capture RD&D program
  - Bench-scale testing
  - October 2011 to September 2014 (No-cost extension through Dec. 2014)
- Total Project Funding: $3,690,000
  - DOE Share: $2,952,000
  - Cost Share: $738,000

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Project Participants

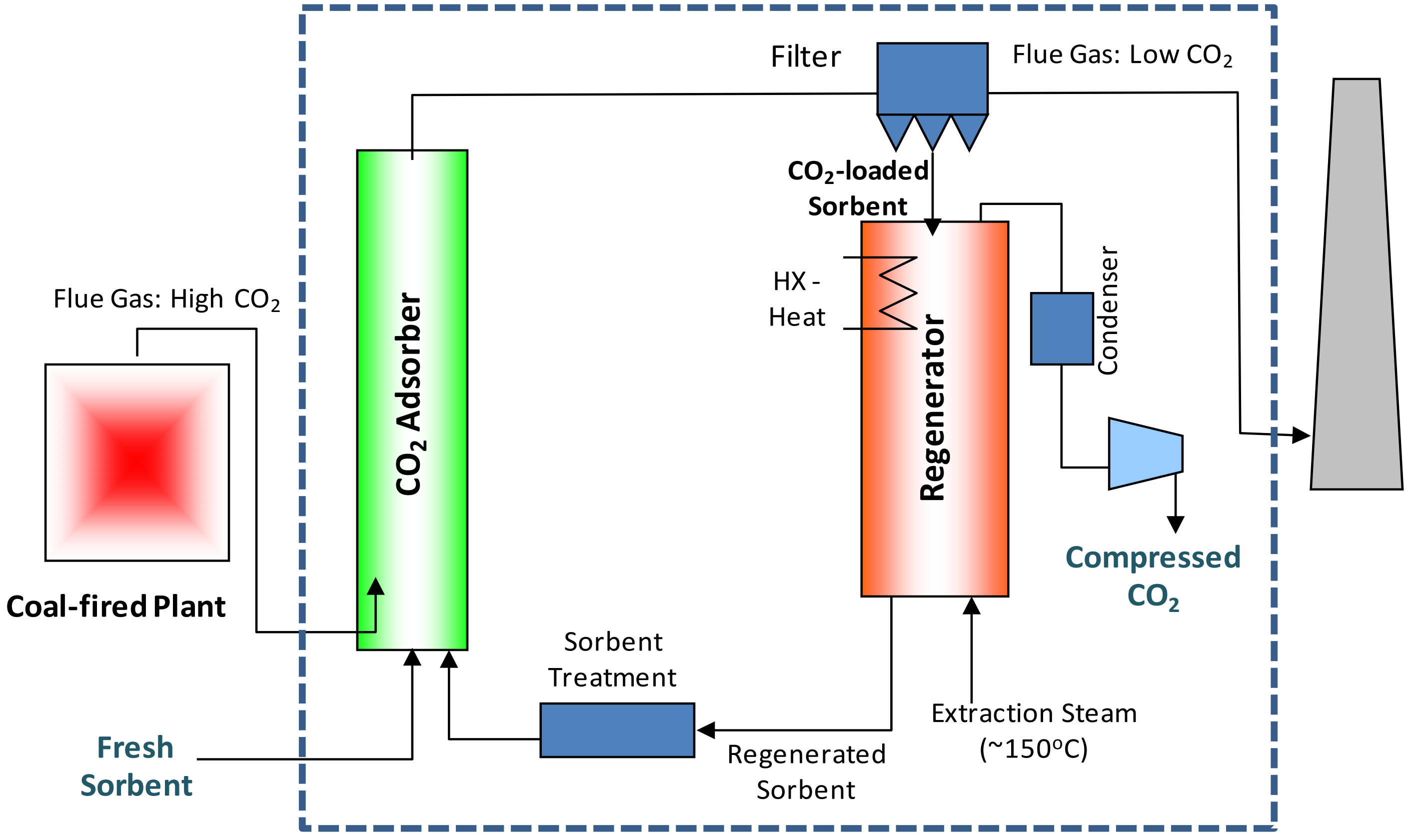
- US Department of Energy - NETL
- UND Institute for Energy Studies
- Envergex LLC
- Lignite Energy Council/NDIC
- ALLETE Group
    - Minnesota Power
    - BNI Coal
- SaskPower
- Barr Engineering
- Solex Thermal Science

Project Objectives

- Overall Project Objectives
  - Improve current state-of-the-art (amine scrubbing) by developing a novel sorbent-based, post-combustion CO_2 capture technology
  - Achieve at least 90% CO_2 removal from coal combustion flue gas
  - Demonstrate progress toward DOE target of less that 35% increase in levelized cost of electricity (LCOE) for plant with CO_2 capture
  - Demonstrate at bench-scale level a sorbent-based technology for capture of CO_2 by hybrid sorption (CACHYS™) from coal combustion flue gas
  - Develop key information on sorbent and technology effectiveness

Technology Background and Fundamentals

CACHYS™ Hybrid Sorption Process



- Key component – metal carbonate salt
- Reacts with CO_2 to form adduct. Reversible with heat addition
- Additive/process conditions - enhance adsorption kinetics + reduce adsorption/regeneration energy

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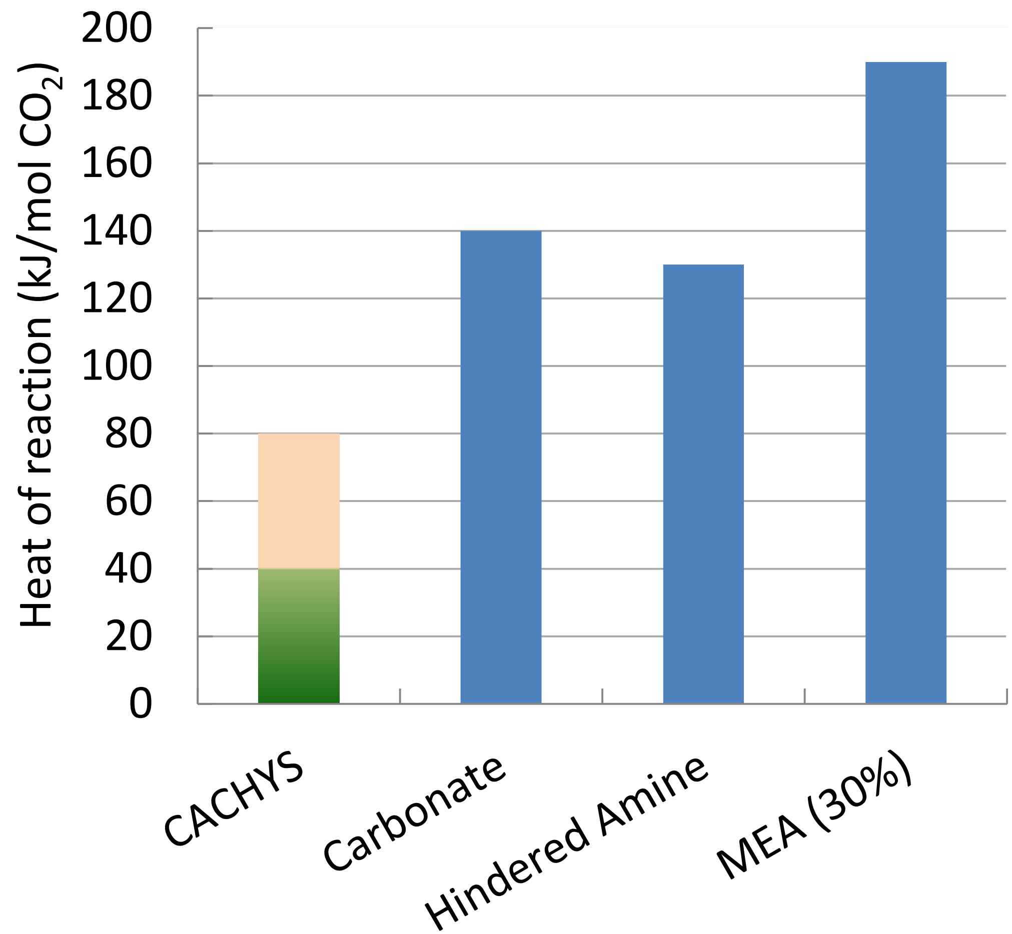
CACHYS™ Process Advantages

Advantages

- ✓ Low reaction heat ~ 40-80 kJ/mol CO_2 (novel chemistry and process conditions)
- ✓ High sorbent capacity (> 7 g CO_2/100 gm sorbent)
- ✓ Increased sorption kinetics (smaller–sized equipment)
- ✓ Use of low cost, abundantly available materials for sorbent
- ✓ Use of commercially-demonstrated equipment design/configuration
- ✓ Reduced capital and operating costs



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CACHYS^{TM} Process Testing Objectives

- Confirmation of energetics
- Confirmation of sorbent capacity
- Confirmation of reaction kinetics
- Sorbent integrity
- Sorbent handling

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Progress and Current Status

Technical Approach and Project Scope

- Scope of work includes eight main tasks

  Task 1: Project Management and Planning

  Task 2: Initial Technology and Economic Feasibility Study

  Task 3: Determination of Hybrid Sorbent Performance Metrics

  Task 4: Bench-Scale Process Design

  Task 5: Bench-Scale Process Procurement and Construction

  Task 6: Initial Operation of the Bench-Scale Unit

  ➡ Task 7: Bench-Scale Process Testing

  ➡ Task 8: Final Process Assessment

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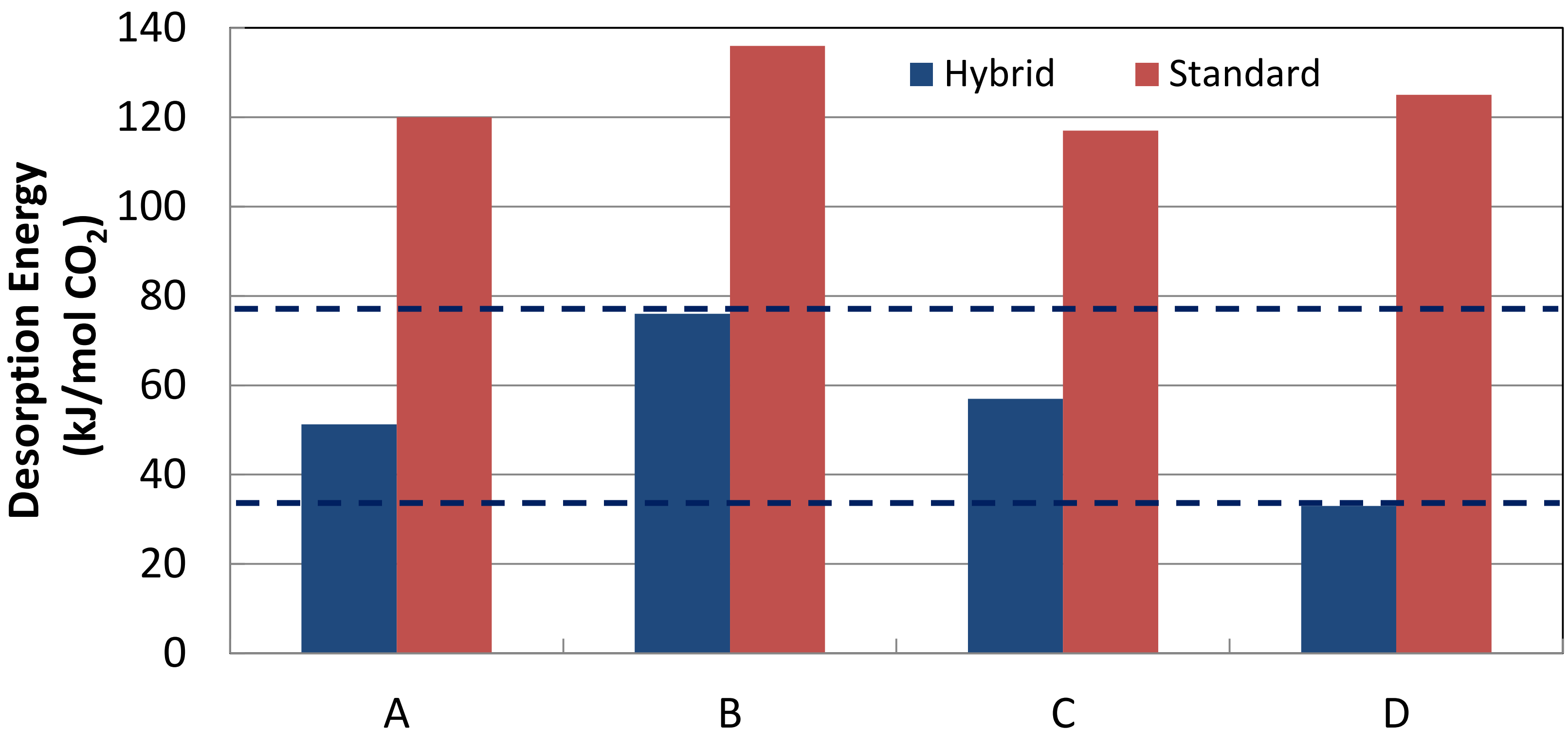
Significant Accomplishments

TGA/DSC Desorption Energy Data



- Desorption energy ~ 30-80 kJ/mol CO_2
- Below target of 80kJ/mol CO_2 and significantly lower than standard carbonate process (130 kJ/mol CO_2)

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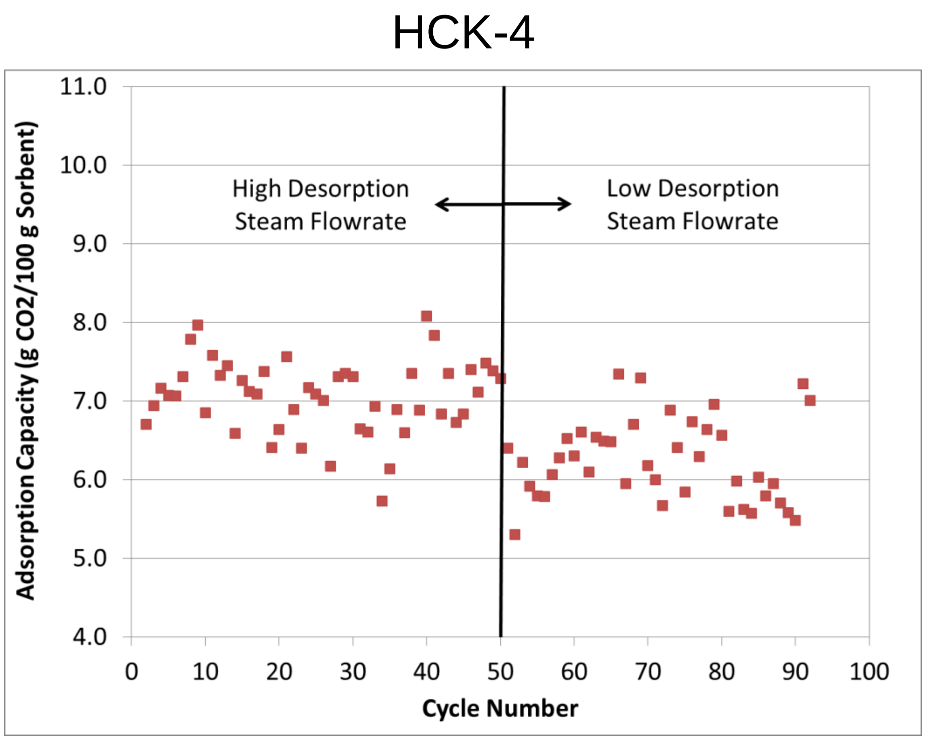
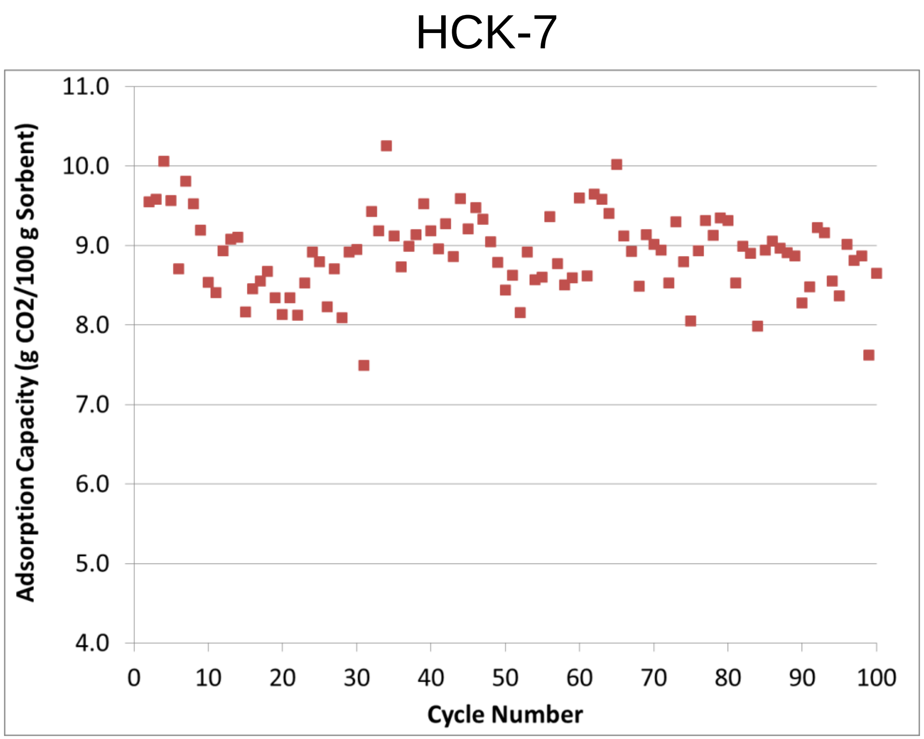
Fixed/Bubbling Bed Reactor: Multi-cycle Sorbent Testing





- Both sorbents exceeded goal of 7.0 g CO_2/100g of sorbent and maintained capacity over the 100 cycle tests

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Technical and Economic Feasibility Study

- Initial Technical and Economic Feasibility (550MW$_e$)
  - Total O&M $28,290,000
  - Capital Charge $102,504,000
  - Total Cost $130,794,000
  - CO_2 Captured 3,614,000 Tons
  - Cost of CO_2 Capture $36.19/ton
  - Cost of Electricity Increase 40%

Bench-Scale Facility

- Sorbent manufacturing
- Sorbent drying system – rotary tube dryer

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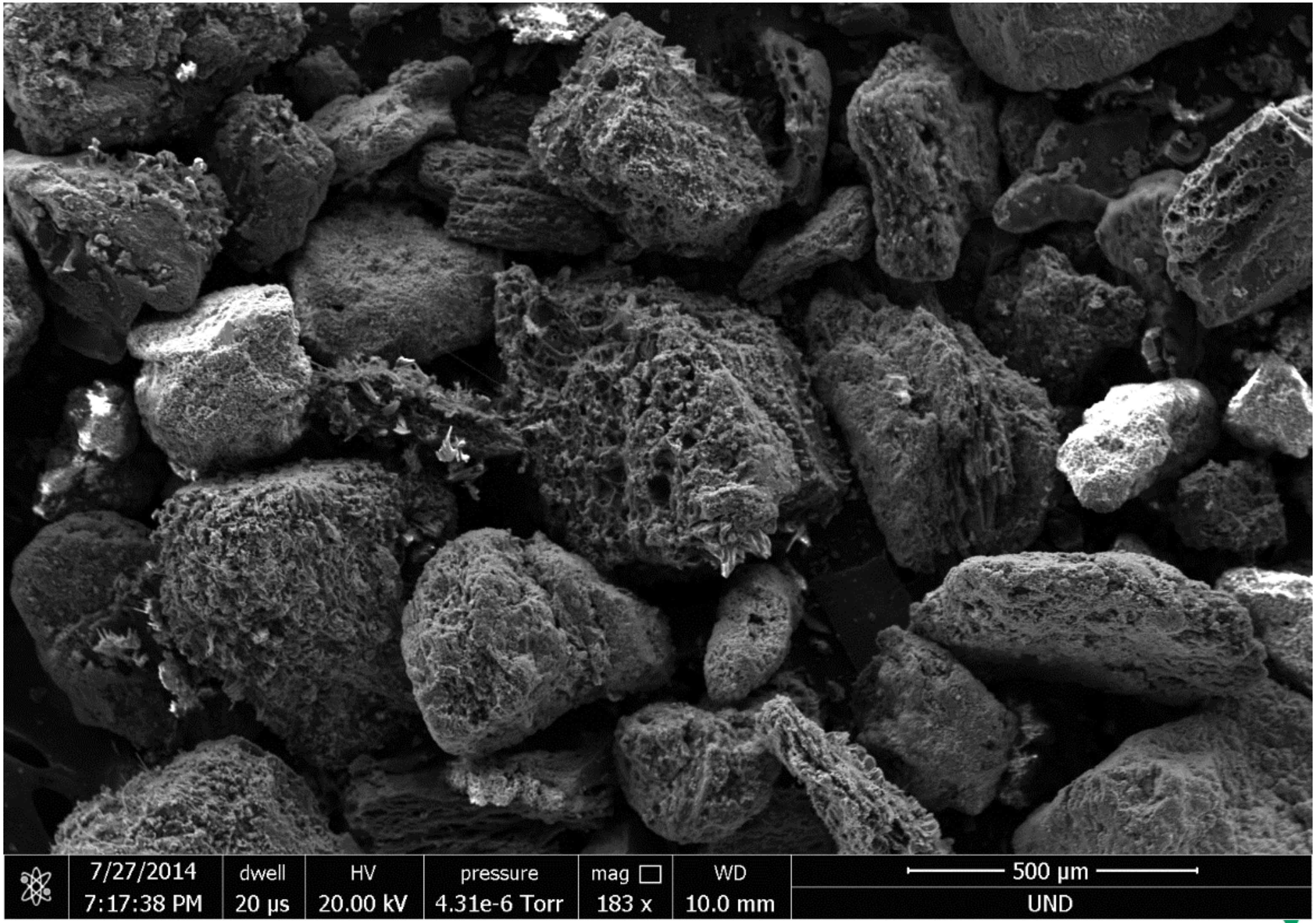
SEM Image – CO_2 Loaded



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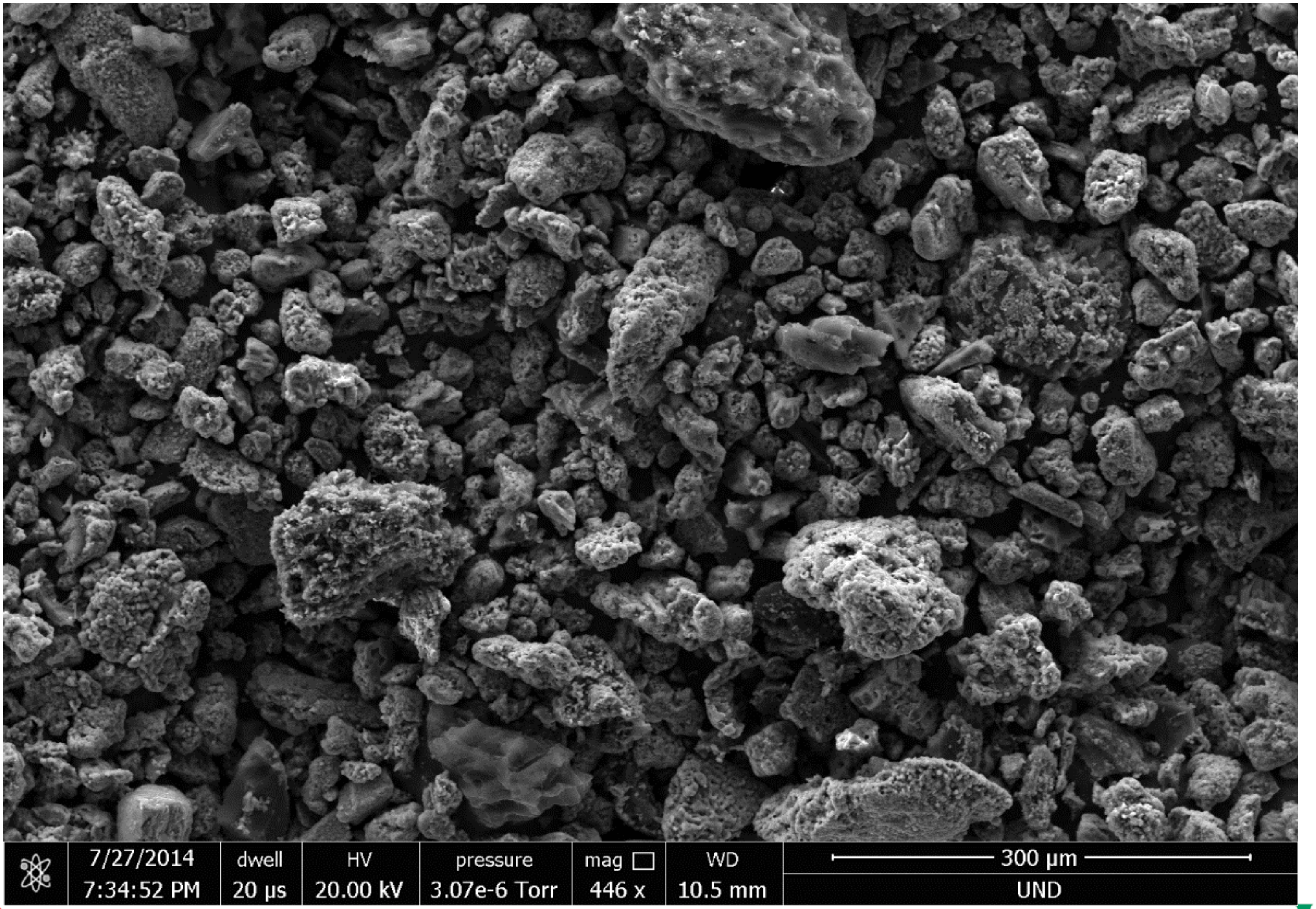
SEM Image – Regenerated



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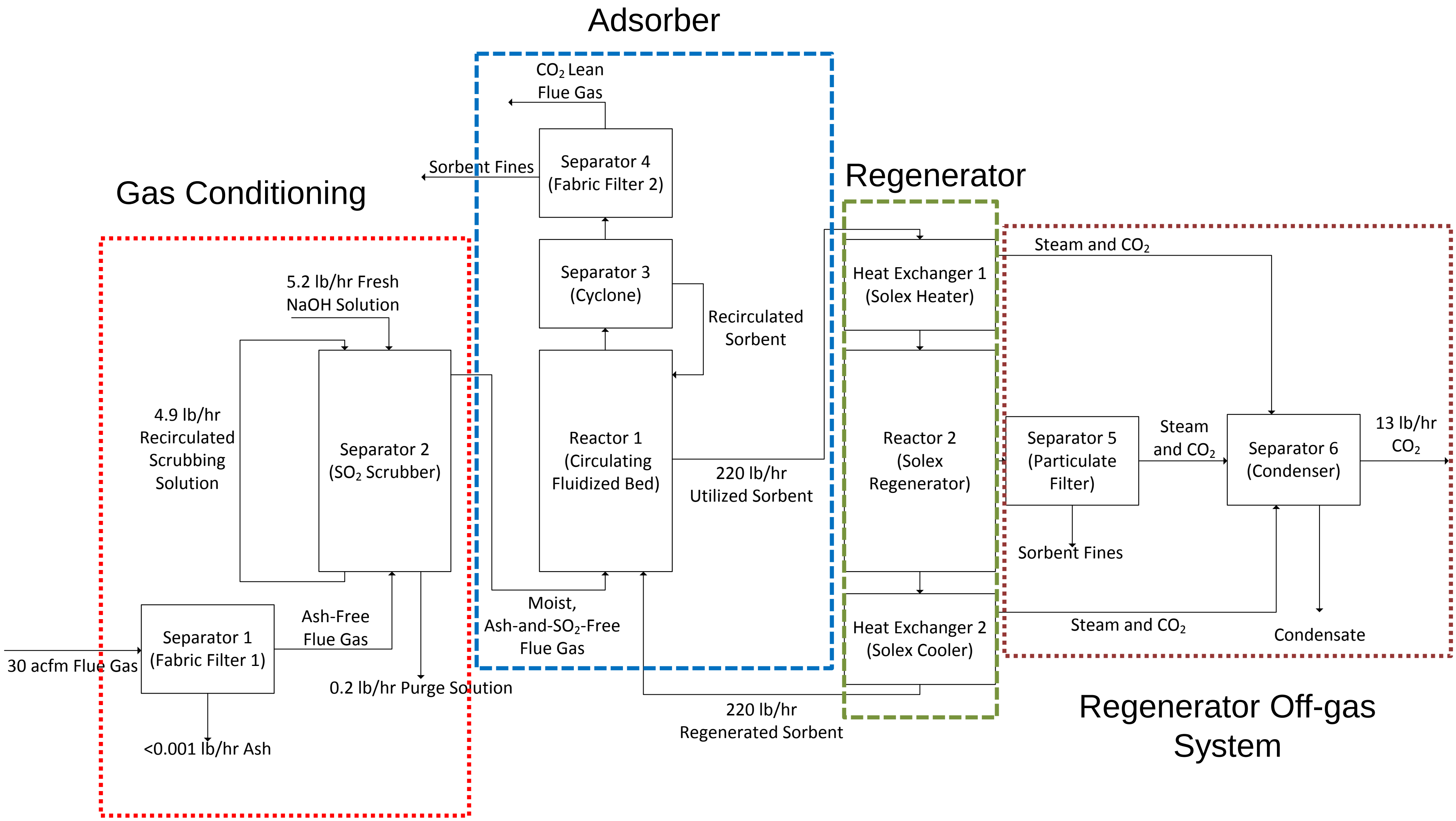
Bench-Scale System Design – Block Flow Diagram



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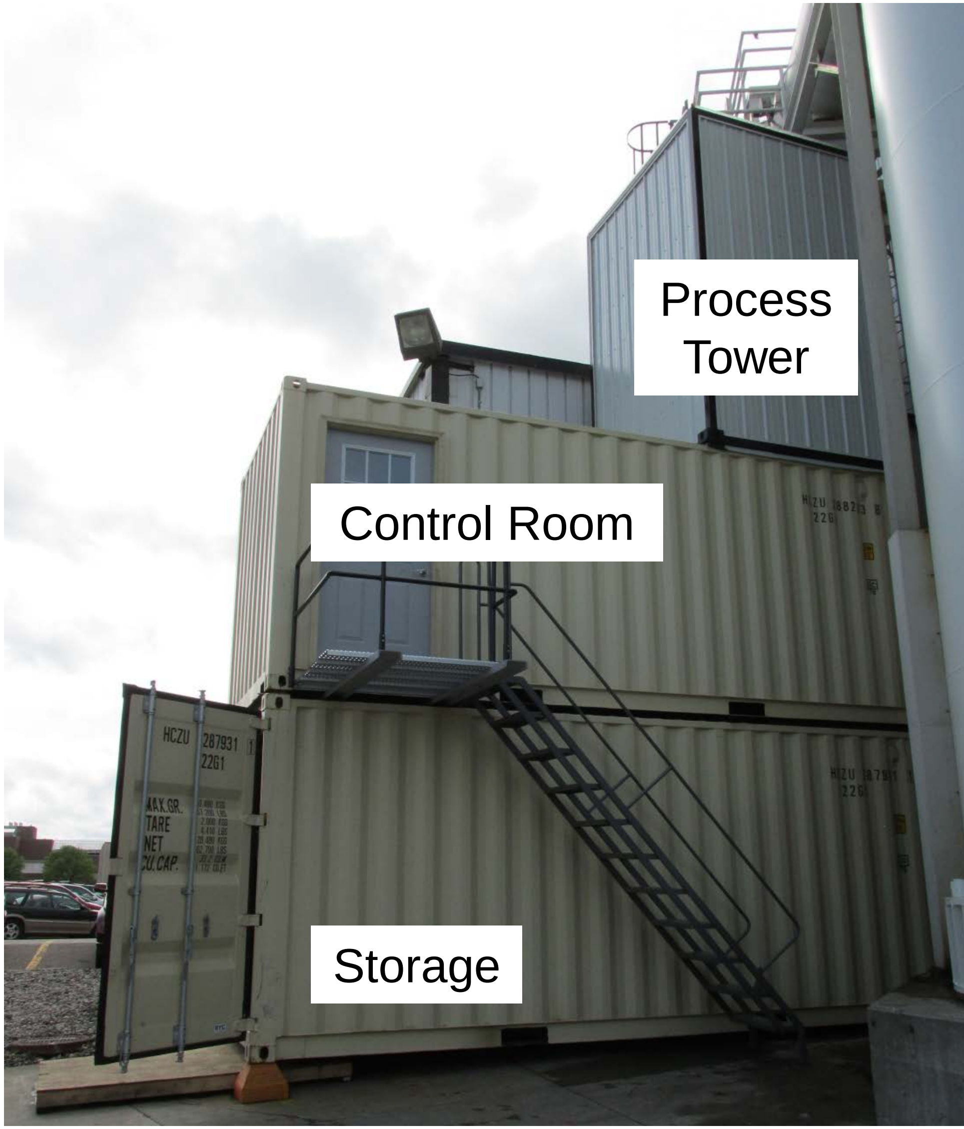
Bench-Scale Facility



- Two 20 ft. shipping containers
- 30 ft. tall process tower fabricated by UND
- Flue gas sampled from either of two coal-fired boilers

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Summary of Bench-scale Results to Date

- Parametric Testing:
  - Short duration tests aimed at optimizing specific parameters
  - Tests to date have focused on operation of individual process components
  - Longer term, integrated tests are currently underway
- Adsorber:
  - Demonstration of hybrid sorption benefits – large increases in capture and kinetics
  - Capture as high as 85% has been achieved to date
  - Working capacity of > 6 wt% (75% utilization after adsorption, 20% after regeneration)
  - Identified optimal process conditions and design basis
- Regenerator:
  - Demonstration of hybrid sorption benefits – reduction of the regeneration energy
  - CO_2 purity ~99%
  - Demonstrated positive impact of direct steam on desorption rate and energetics

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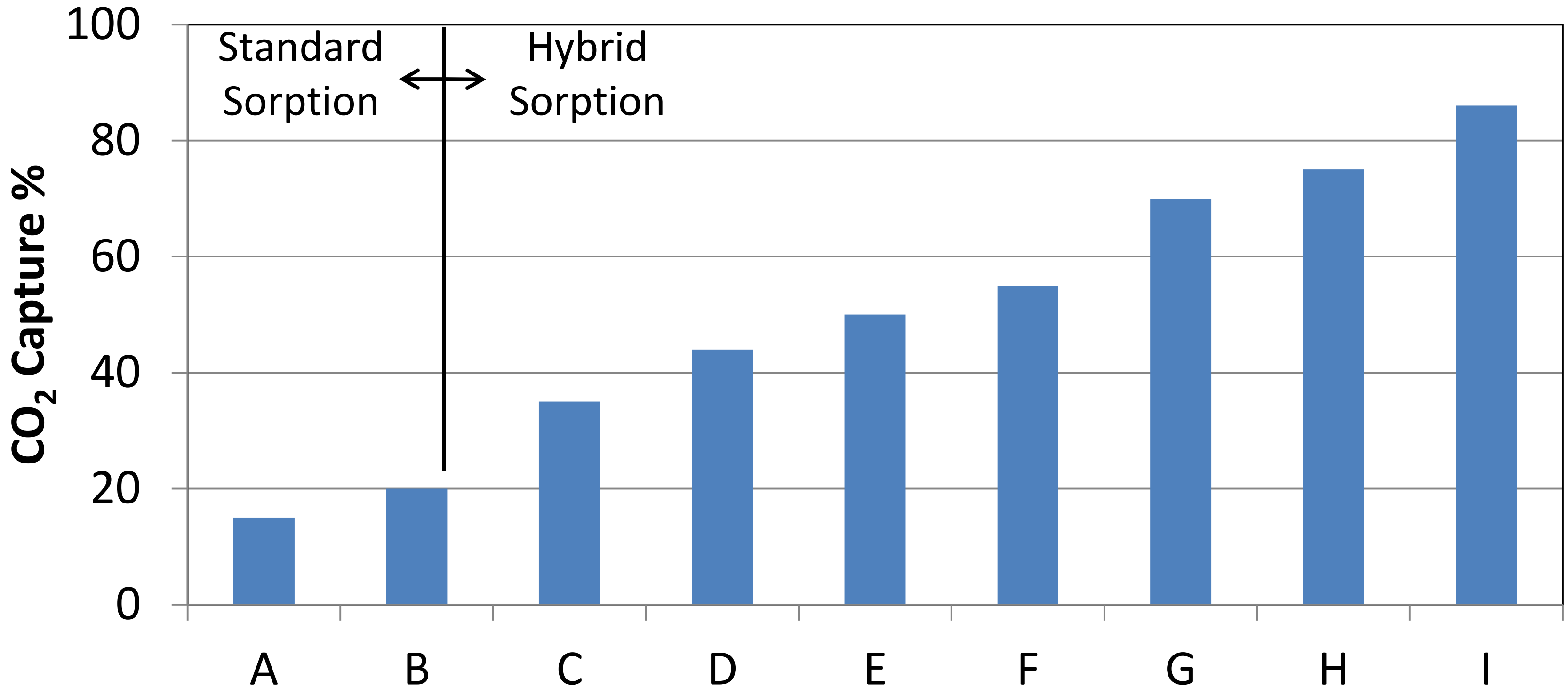
Adsorber Testing – Data Summary



A	Zero Additive	F	Increased Fresh Feed
B	Sorbent Recirculation	G	Increased Gas Res. Time
C	Sorbent with Additive	H	Decreased Flue Gas CO2
D	Sorbent Recirculation	I	Increased Gas Res. Time
E	Increased Additive Loading		

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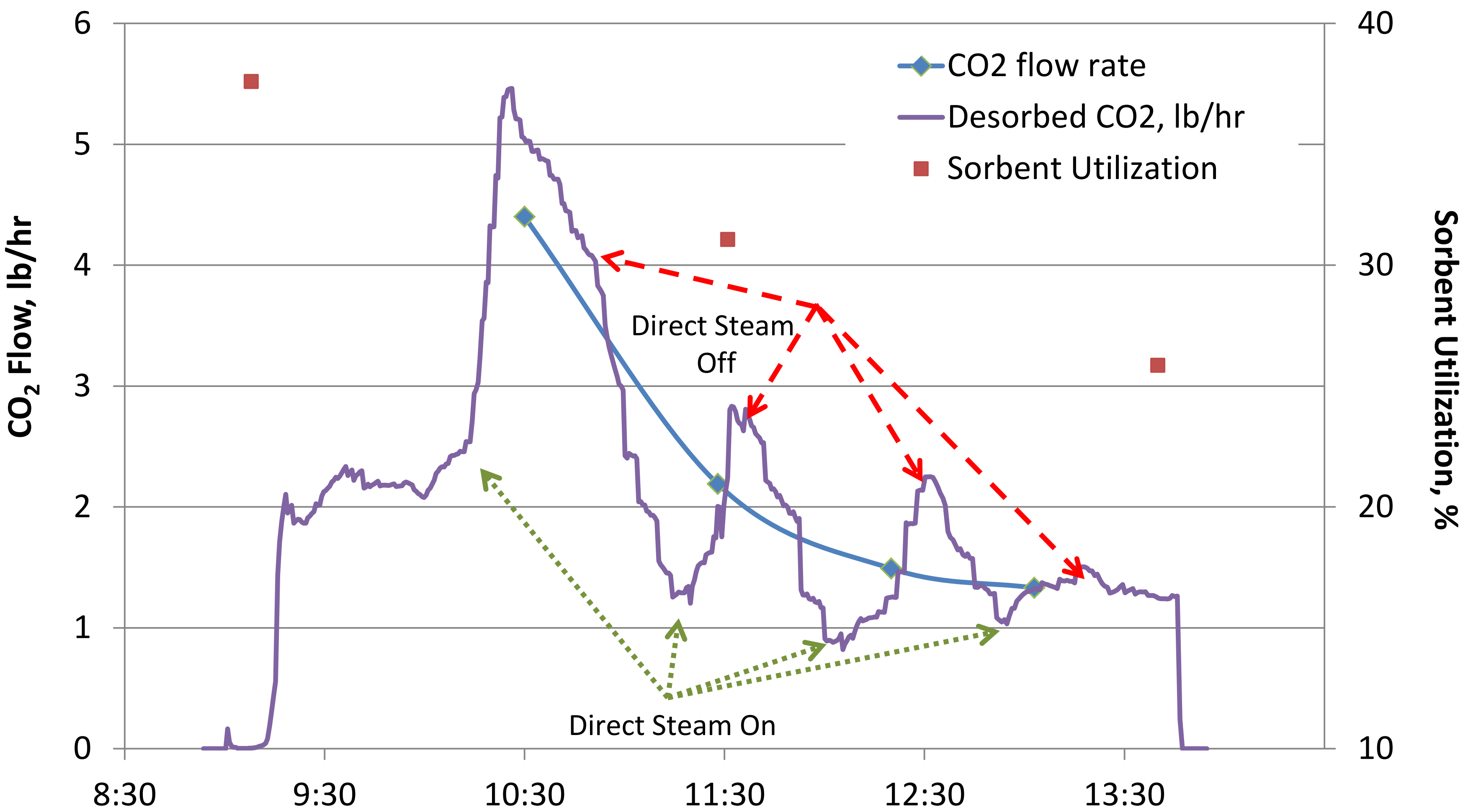
Regenerator Testing



- Use of direct steam facilitates CO_2 desorption

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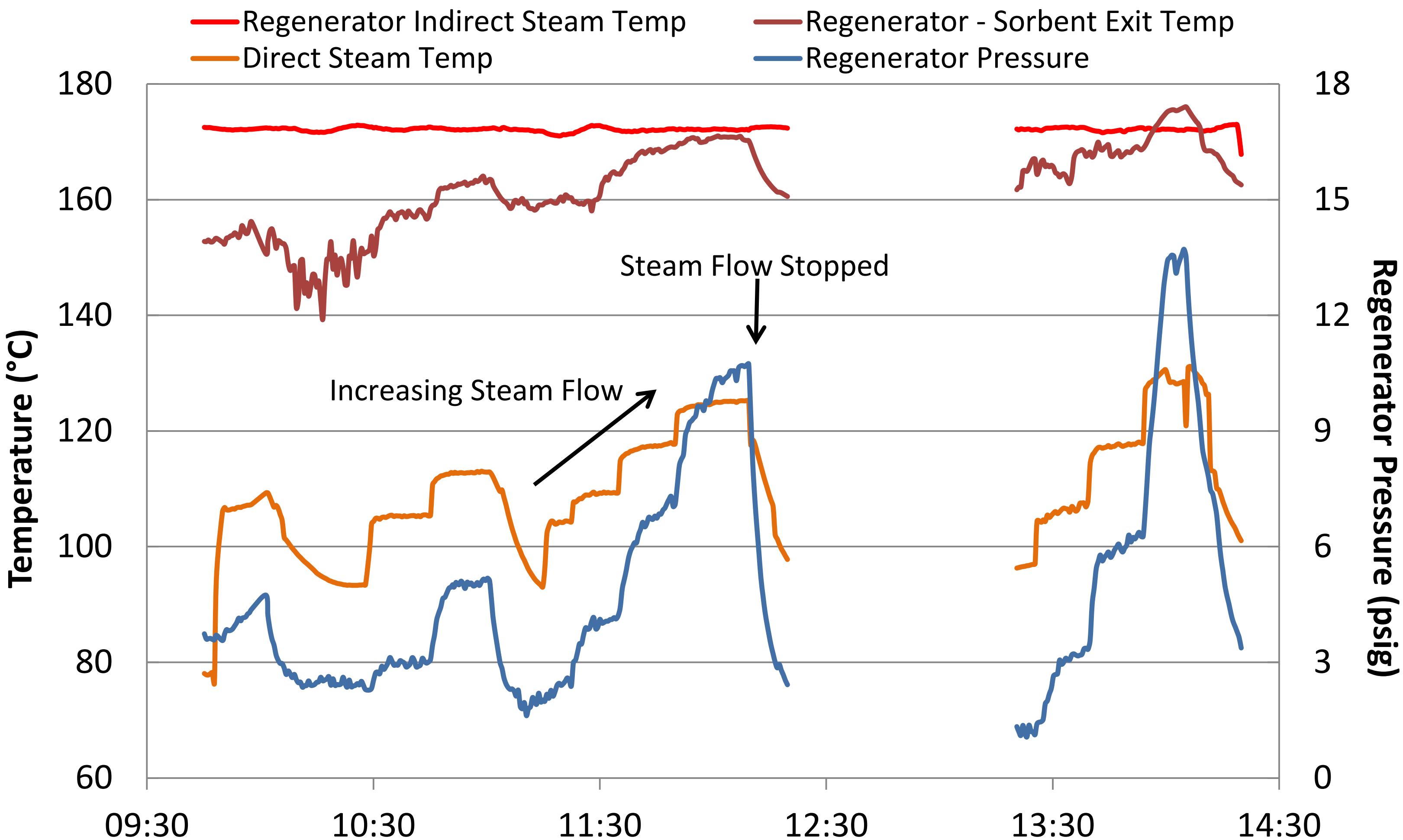
Regenerator Testing



- Use of direct steam increases sorbent temperature via exothermic reaction that reduces regeneration energy – confirms observations during lab-scale work

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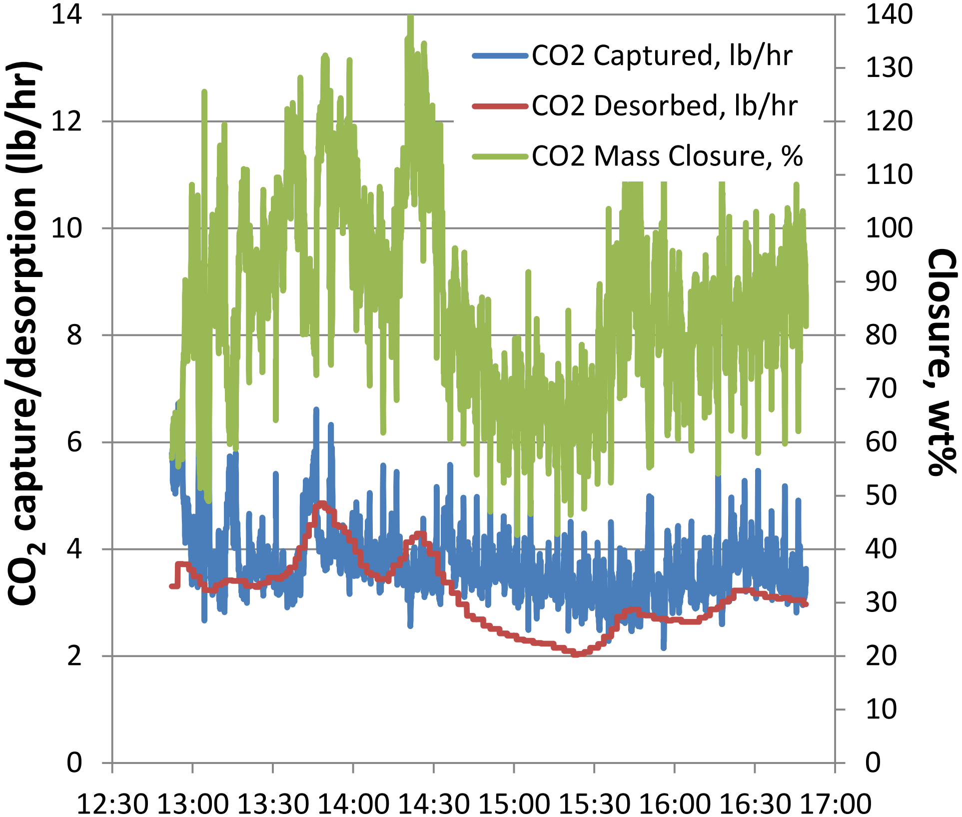
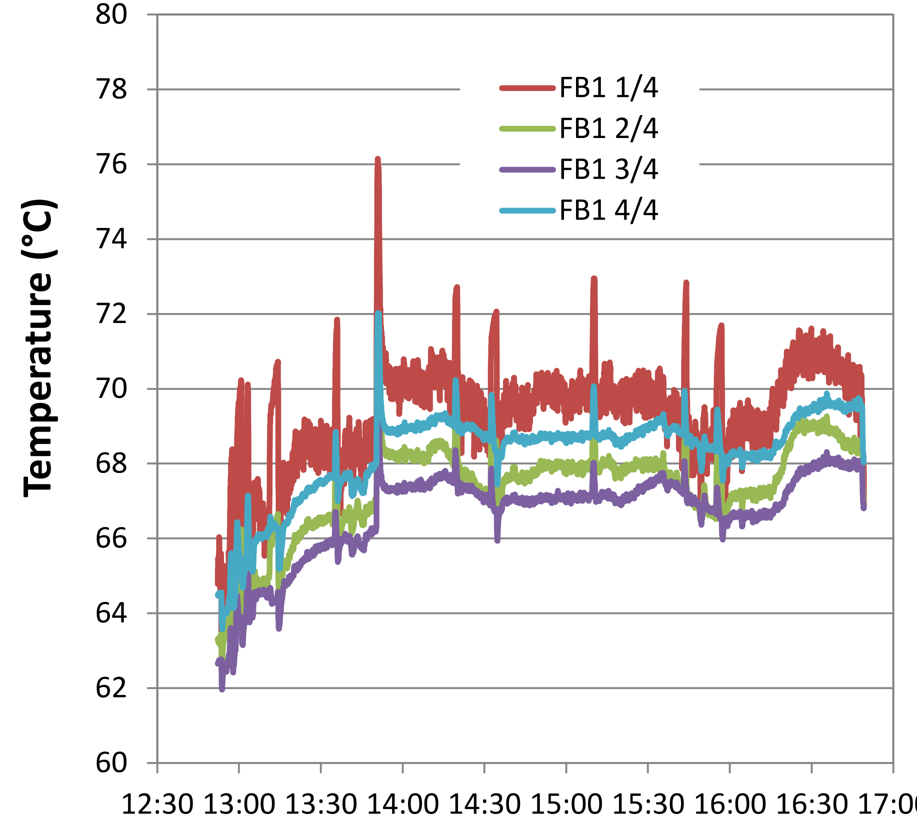
Integrated Testing





- Achieved reasonable CO_2 mass closures over an extended period
- Very good control of the exothermic heat of reaction in the adsorber

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Operational Challenges/Mitigation Strategies

Challenges:

- Adsorber
  - Capture efficiency
  - Reliable sorbent circulation
- Regenerator
  - Condensation and flowability
  - Desorption rate

Mitigation Strategies:

- Adsorber
  - Longer residence time/sorbent recirculation
  - Ensure sufficiently large surge volumes
- Regenerator
  - Identification of stagnant zones
  - Ensure heating of all contact surfaces
  - Use of “soot blowers” and vibration
  - Online cleaning
  - Higher temperature operation

Scale up to larger diameter beds will alleviate many of the challenges experienced during bench scale operation

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Remaining Work

- Complete Bench-scale Testing:
  - Sorbent and process performance
  - Identify attrition rates and performance with SO_2-containing flue gas
  - Adsorber and regenerator multi-cycle evaluation
  - Obtain data for scale-up and process economics
  - Determine environmental, health and safety (EH&S) concerns

- Final Process Assessment:
  - EH&S
  - Final Technical and Economic Feasibility Study

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Future Plans

- E-CACHYS™
  - Developed as part of a DOE SBIR/STTR Phase I grant
  - Goal to increase sorbent capacity by 2x CACHYS™ sorbents
  - Capacity targets were achieved while maintaining other benefits of hybrid sorption
  - Phase II application was submitted to DOE - received notice of intent to award

- Phase II STTR
  - Develop improved sorbent manufacturing methodologies
  - Modification of the existing bench-scale facility to accommodate improved sorbent
  - Demonstrate a new process configuration that greatly reduces the impact of sorbent attrition
  - Develop an improved hybrid sorption technology that will further reduce the cost of CO_2 capture

Acknowledgements

- Project Funding and Cost Share
  - U.S. Department of Energy (DOE-NETL)
  - Lignite Energy Council/NDIC
  - ALLETE (Minnesota Power and BNI Coal)
  - SaskPower
  - Solex Thermal
  - UND
- DOE-NETL Project Manager – Andrew Jones

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Contact Information

Steven A. Benson
Institute for Energy Studies, University of North Dakota
(701) 777-5177; Mobile: (701) 213-7070
steve.benson@engr.und.edu

Dan Laudal
Institute for Energy Studies, University of North Dakota
(701) 777-3456; Mobile: (701) 330-3241
daniel.laudal@engr.und.edu

Harry Feilen
Institute for Energy Studies, University of North Dakota
(701) 777-2730; Mobile: (701) 739-1199
harry.feilen@engr.und.edu

Srivats Srinivasachar
Envergex LLC
(508) 347-2933; Mobile: (508) 479-3784
srivats.srinivasachar@envergex.com

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