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

NETL CO_2 Capture Technology Meeting
Pittsburgh, Pennsylvania
July 8-11, 2013

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Project Overview

- Project Overview
- Technology Fundamentals
- Progress and Current Status
- Significant Accomplishments
- Plans for Future Testing

Presentation Overview

- Project Funding
  - U.S. Department of Energy Carbon Dioxide Capture RD&D program
  - Bench-scale testing
  - October 2011 to September 2014
  - Initial concept testing conducted by Envergex and UND under DOE STTR program
- Total Project Funding: $3,690,000
  - DOE Share: $2,952,000
  - Cost Share: $738,000

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
    - Energy Requirements
    - Physical Properties
    - Process Integration
    - Equipment sizing, capital and operating costs

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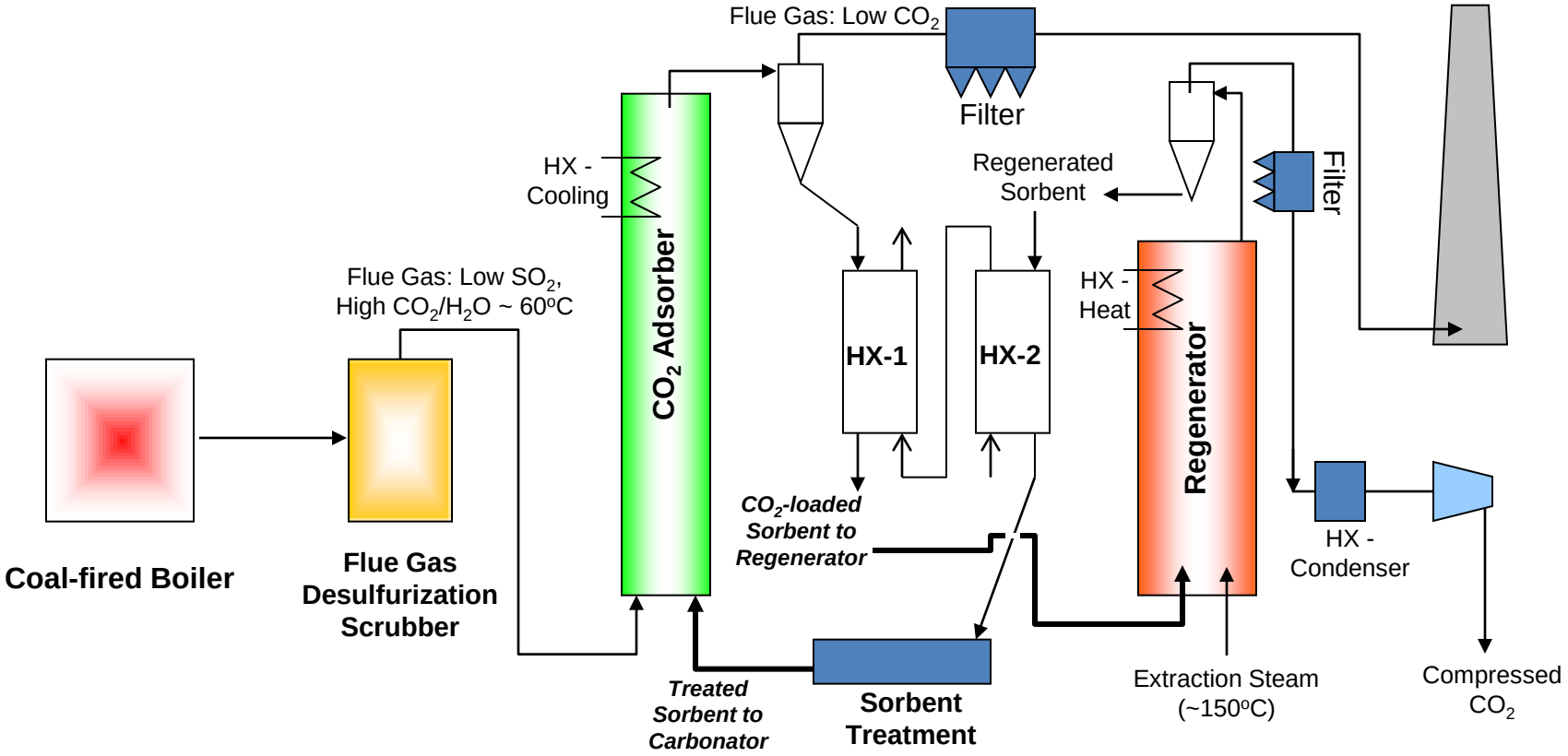
Technology Background and Fundamentals

CACHYS™ Hybrid Sorption Process

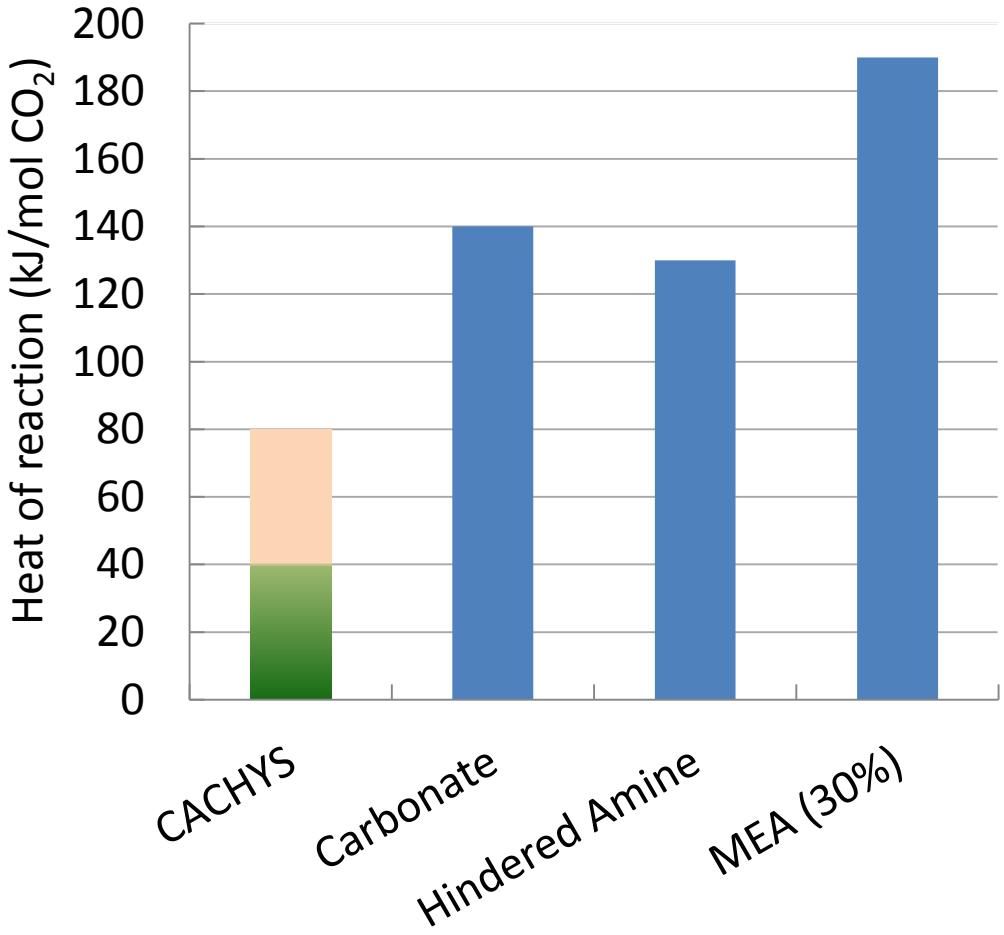


- Key component – metal carbonate salt
- Reacts with CO_2 to form adduct. Reversible with heat addition
- Additive/process conditions - enhance adsorption kinetics + reduce adsorption/regeneration energy

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™ Process Challenges

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

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

Milestone Log – Budget Period 1

ID	Task	Title/Description	Planned Completion Date	Actual Completion Date	Verification Method
a	1	Submit Project Management Plan	10/31/2011	10/28/2011	Project Management Plan file
b	1	Complete Kick-off Meeting	11/21/2011	11/21/2011	Briefing Document & Meeting Results
c	2	Complete Preliminary Technical and Economic Feasibility Study	8/15/2012	8/15/2012	Topical Report file
d	3	Complete thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) testing of 5 sorbent formulations	7/31/2012	7/31/2012	Results reported in the quarterly report
e	3	Down-select to two optimal sorbent formulations for fixed-bed testing	8/15/2012	8/15/2012	Results reported in the quarterly report
f	3	Complete fixed-bed testing of the CACHYS™ process with two optimal sorbent formulations	9/30/2012	9/30/2012	Results reported in the quarterly report
g	3	Determine the optimal process operating conditions of the adsorber and regenerator units, for low energy operation	9/30/2012	9/30/2012	Results reported in the quarterly report

Milestone Log – Budget Period 2

ID	Task	Title/Description	Planned Completion Date	Actual Completion Date	Verification Method
h	4	Complete bench-scale unit column design utilizing a refined mass and energy balance of the CACHYS™ process	12/31/2012	12/17/2012	Results reported in the quarterly report
i	5	Bench-scale unit engineering design package released for bid	1/15/2013	12/31/2012	Bid package is submitted to system integrator/fabricator and submitted to NETL for record
j	5	Complete bench-scale unit construction	7/30/2013		Results reported in the quarterly report
k	6	Complete shakedown testing of the flue gas sampling and conditioning system, as well as the adsorber and regenerator	9/15/2013		Results reported in the quarterly report
l	6	Submit a test matrix for the bench-scale parametric test campaign	9/30/2013		Results reported in the quarterly report

Decision Points & Success Criteria

Decision Point	Basis for Decision/Success Criteria
Completion Budget Period 1 Year 1	1. Successful completion of all work proposed in Budget Period 1
	2. Demonstrate sorbent CO_2 equilibrium capacity of greater than 70 g of CO_2/kg of sorbent - **CACHYS™ sorbents have capacities that range from 70 to 100 g CO_2/kg sorbent.**
	3. Demonstrate a heat of sorption of 80 kJ/mole of CO_2 or less - **Sorption energies ranged from 30 to 80 kJ/mole of CO_2**
	4. Submission of a Topical Report – Preliminary Technical and Economic Feasibility Study - **Completed; Revised report uploaded**
	5. Submission/approval of a Continuation Application to DOE – **Continuing application approved**

Decision Points & Success Criteria

Decision Point	Basis for Decision/Success Criteria
Completion Budget Period 2 Year 2	1. Successful completion of all work proposed in Budget Period 2.
	2. Submission of a bench-scale engineering design package - **CACHYS™ bench-scale system design submitted and approved**
	3. Complete construction of a bench-scale CACHYS™ system
	4. Submission of a test matrix for the bench-scale testing campaign
	5. Submission/approval of a Continuation Application to DOE

Decision Points & Success Criteria

Decision Point	Basis for Decision/Success Criteria
End of Project Year 3	1. Successful completion of all work proposed
	2. Complete continuous testing of integrated bench-scale CACHYS™ process for 1 month
	3. Submission of a Topical Report - Final Technical and Economic Feasibility Study
	4. Submission of a Topical Report – Preliminary EH&S Assessment
	5. Submission of a Final Report

Significant Accomplishments

Sorbent Screening and Energetics Determination

- Sorbent formulation and selection
- Thermogravimetric analyzer/differential scanning calorimeter (TGA/DSC) used to determine sorbent capacity, kinetics and sorption energetics

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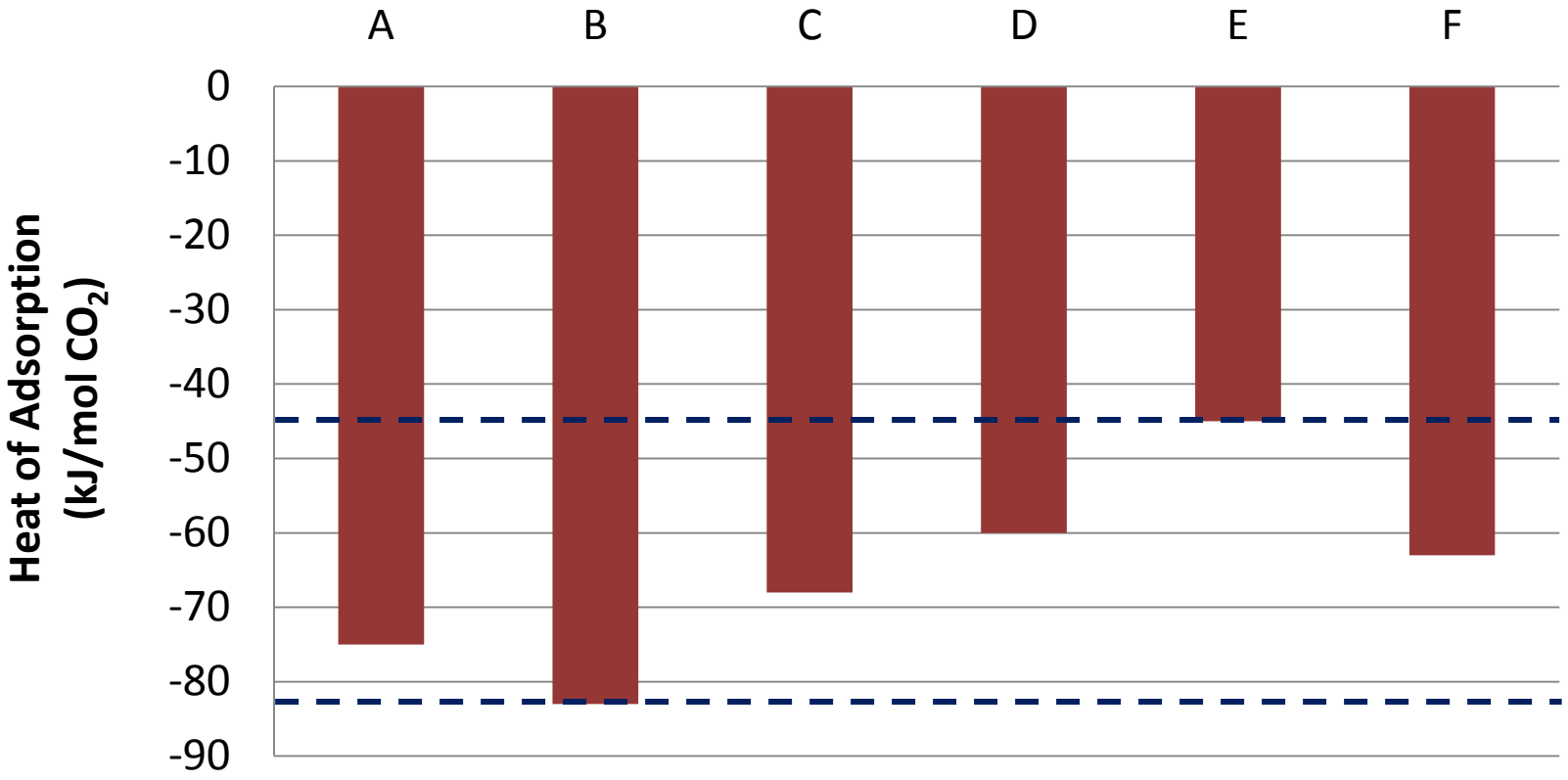
Adsorption Energy Data: TGA/DSC



- Adsorption energy ~ 40-80 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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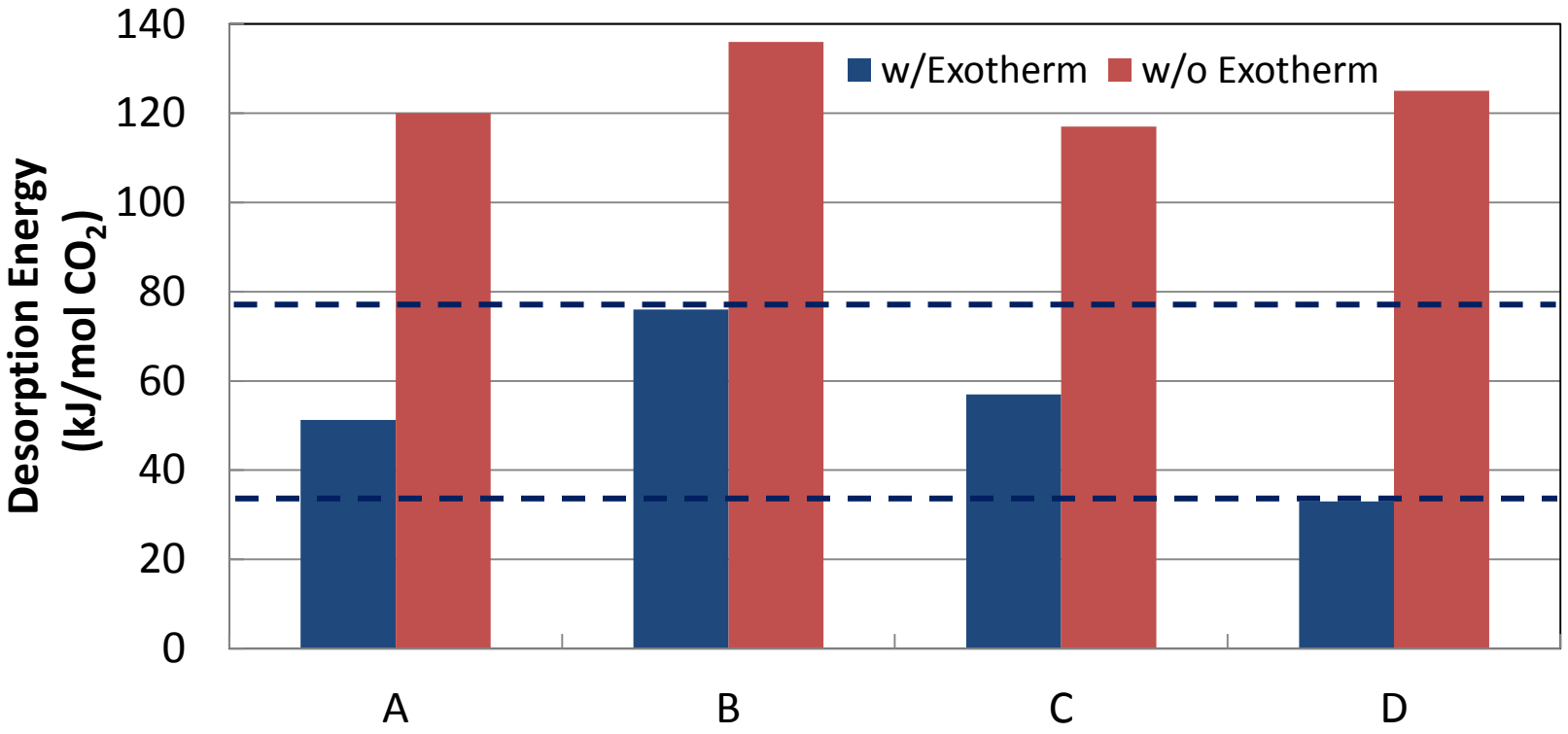
TGA/DSC Desorption Energy Data



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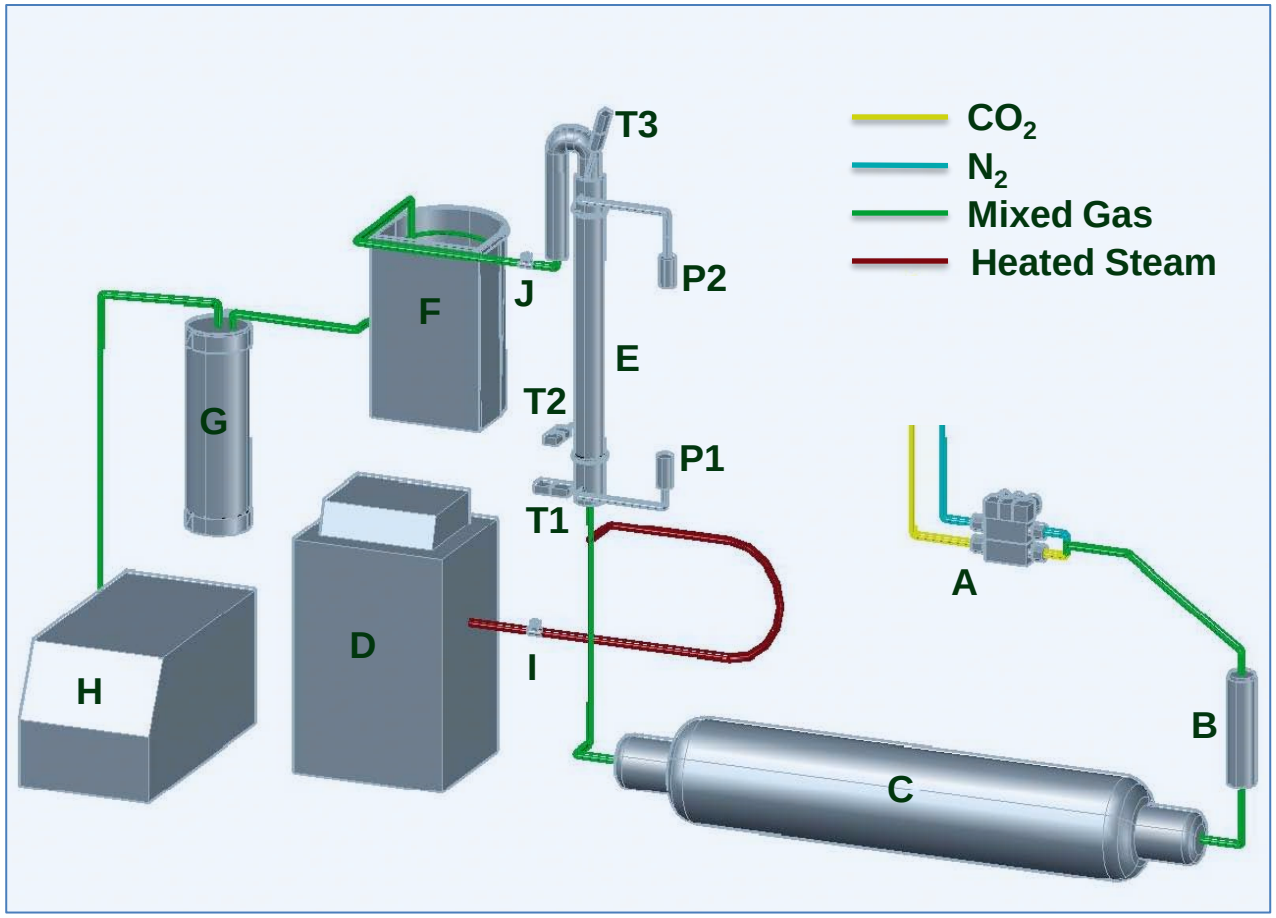
Fixed/Bubbling Bed Reactor Testing



	Components
A	Mass Flow Controllers
B	Bubbler
C	Air Preheater
D	Steam Generator
E	Reactor
F	Condenser
G	Water Knockout Drum
H	5 Gas Analyzer
I	Manual Steam Control #1
J	Manual Steam Control #2
T1	Thermocouple – Air In
T2	Thermocouple – Reactor Wall
T3	Thermocouple – Air Out
P1	Pressure Transducer (Bottom)
P2	Pressure Transducer (Top)

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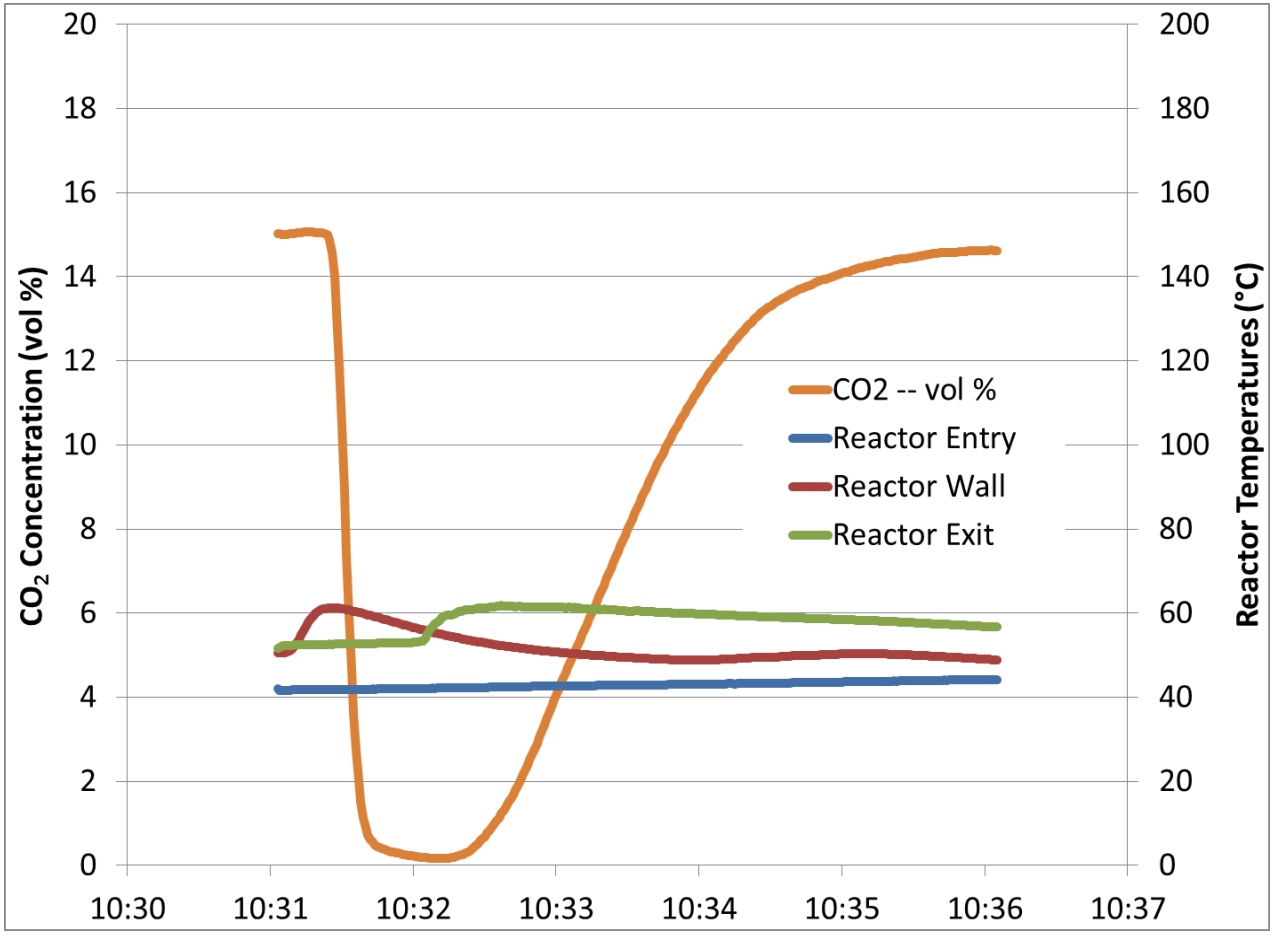
Fixed/Bubbling Bed Testing: Typical Adsorption Cycle



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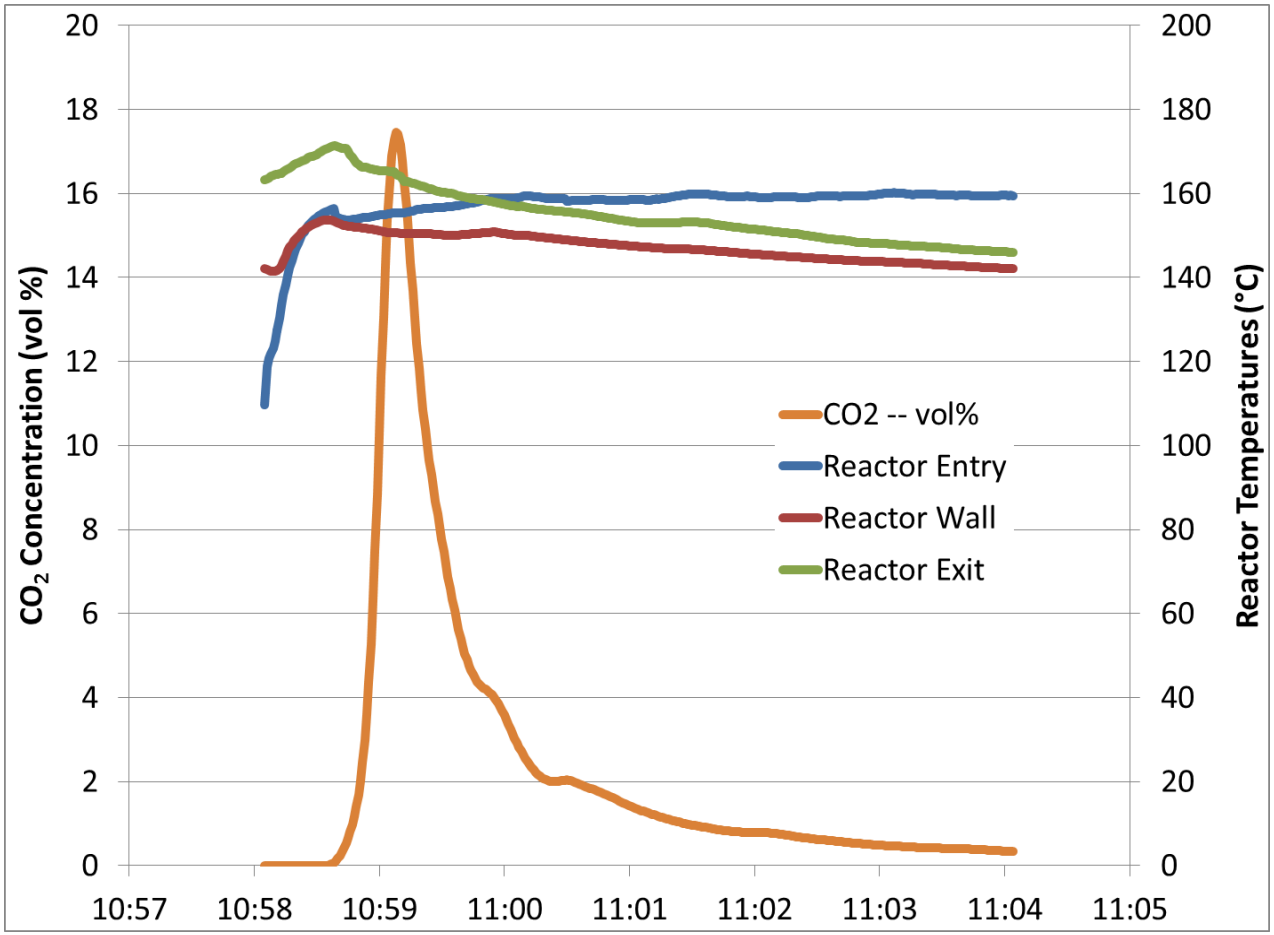
Fixed/Bubbling Bed Testing: Typical Desorption Cycle



Adsorption Loadings for Sorbents Tested

Number	Sorbent	Total Cycles	Average Adsorption (g CO_2)*	Normalized Average Adsorption** (g CO_2 / 100 g pure sorbent)
1	HCK-1	4	5.5	7.1
2	HCK-2	5	6.5	7.1
3	Used HCK-1	5	8.0	9.0
4	HCK-4	5	6.7	7.1
5	HCK-5	6	7.6	9.2
6	HCK-7	7	7.7	9.1
7	HCK-16	7	7.0	8.2
8	HCK-25	11	5.8	7.2
9	HCK-31	6	7.4	8.8

* Does not include the first cycle
** Calculated using TGA/DSC analyses

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Sorbent Selection For Multi-Cycle Evaluation

- HCK-4 sorbent averaged 7.1 g CO_2 and was consistently in the range of 6.8-7.4 g CO_2 per 100 grams of sorbent.
- HCK-7 sorbent averaged 9.1 g CO_2 (capacities as high as 10.0 g CO_2) per 100 grams of sorbent.
- Exceeds project goal of capacity of 7.0 g CO_2 per 100 grams of sorbent.

Fixed/Bubbling Bed Reactor: Multi-cycle Sorbent Testing

- 100 cycles with down-selected sorbents, HCK-4 & HCK-7
- Gather key information on sorbent performance
  - Attrition resistance
  - Determine capacity with continuous cycling
  - Determine optimal operating conditions

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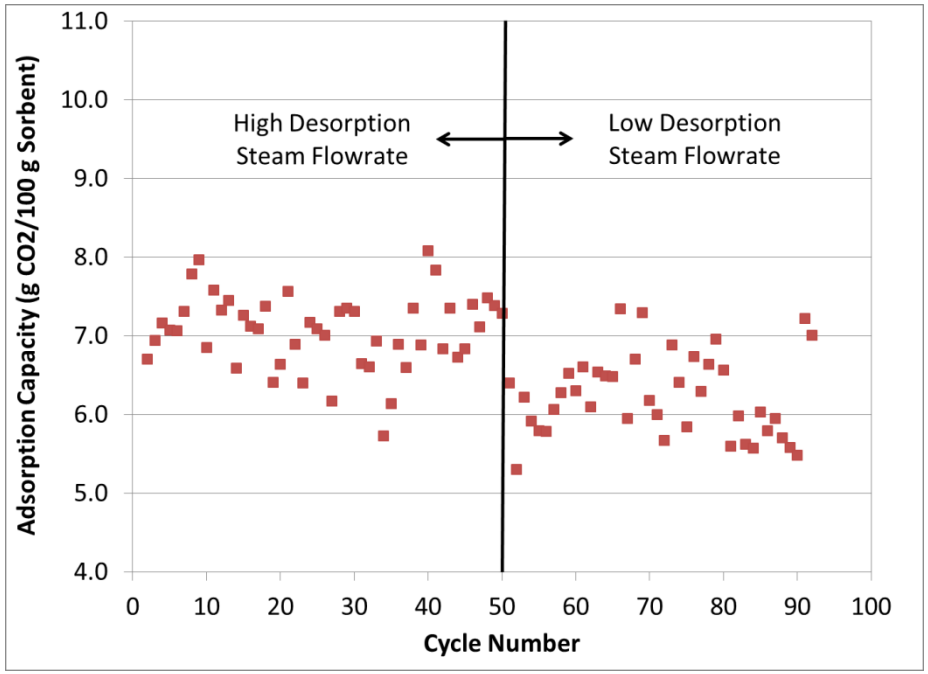
Fixed/Bubbling Bed Reactor: Multi-cycle Sorbent Testing

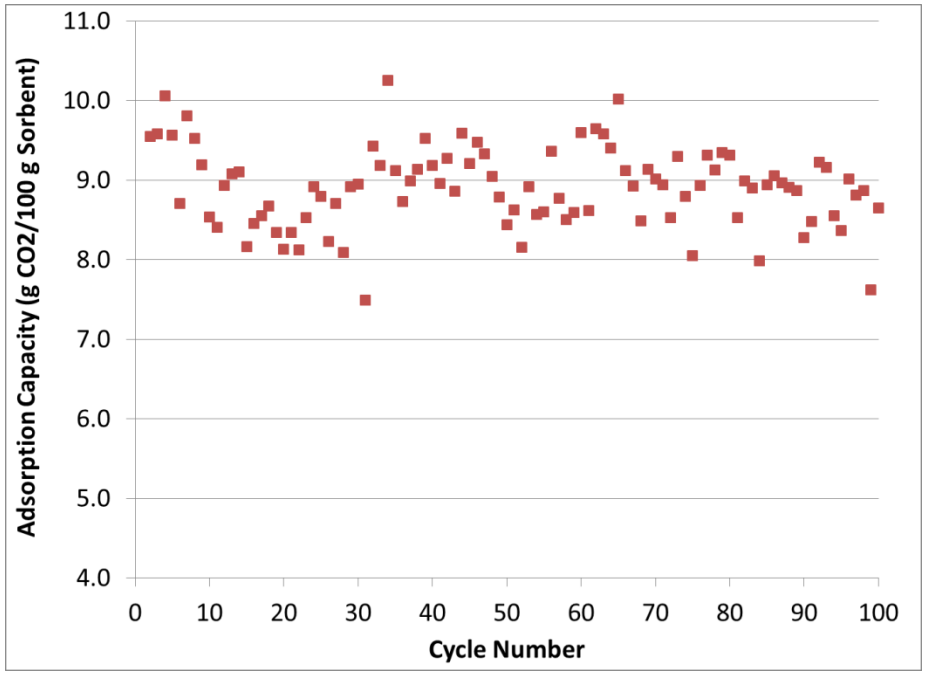
- HCK-4 Results
  - Capacity at optimal process conditions: 8.3 g CO_2/100 g Sorbent
  - No apparent loss in sorbent capacity
  - Little attrition to 75 cycles. Measurable attrition between 75 - 100 cycles
- HCK-7 Results
  - Average capacity: 8.9 g CO_2/100 g Sorbent
  - No apparent loss in sorbent capacity
  - Little attrition through 100 cycles
- HCK-31 Results
  - Average capacity: 8.8 g CO_2/100 g Sorbent
  - Candidate for slipstream bench-scale testing

Fixed/Bubbling Bed Reactor: Multi-cycle Sorbent Testing

HCK-4



HCK-7



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

Task 2: Initial Technology and Feasibility Study

- Developed detailed process scheme
- Used ASPEN Plus software for CACHYS™ process model
- Identified all process equipment
- Designed, sized, and specified equipment
- Developed detailed plant design and plant arrangement
- Obtained plant component costs
- Determined capital costs for plant installation
- Estimated startup and ongoing operating costs
- Compared performance and costs to benchmarks

Technical and Economic Feasibility Study (550 MW_e Net Output)

- Initial Technical and Economic Feasibility (550MW_e)
  - Total O&M $28,290,000
  - Capital Charge $130,794,000
  - Total Cost $118,577,000
  - CO_2 Captured 3,614,000 Tons
  - Cost of CO_2 Capture $36.19/ton
  - Cost of Electricity Increase 40%

Task 4: Bench-Scale System Design

- Capture CO_2 from UND's Steam Plant
  - 30 acfm slip stream of flue gas from coal-fired boiler
- Gas Conditioning System
  - Fabric filter
  - Wet packed bed SO_2 scrubber
- Adsorber System
  - FD/ID fans
  - Circulating fluidized bed
  - Cyclone for bulk solids separation
  - Fabric filters for fines separation
- Regenerator System
  - Pre-heater unit
  - Regenerator unit
  - Cooler unit
- Regenerator Off-Gas System
  - Particulate filter
  - Steam condensers

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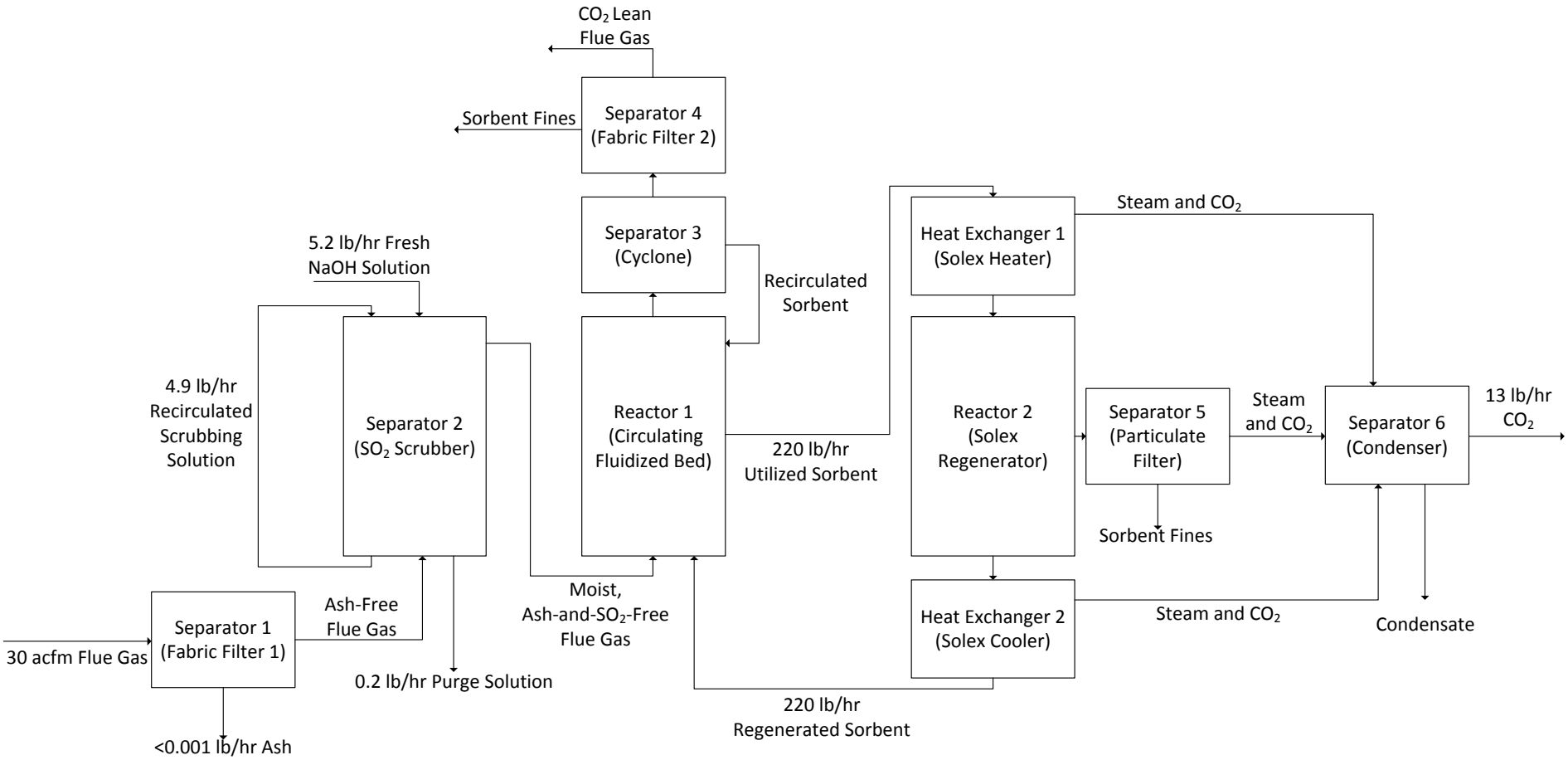
Bench-Scale Design for Slipstream Testing: Block Flow Diagram



- Use of real flue gas - coal-fired boiler at the UND steam plant

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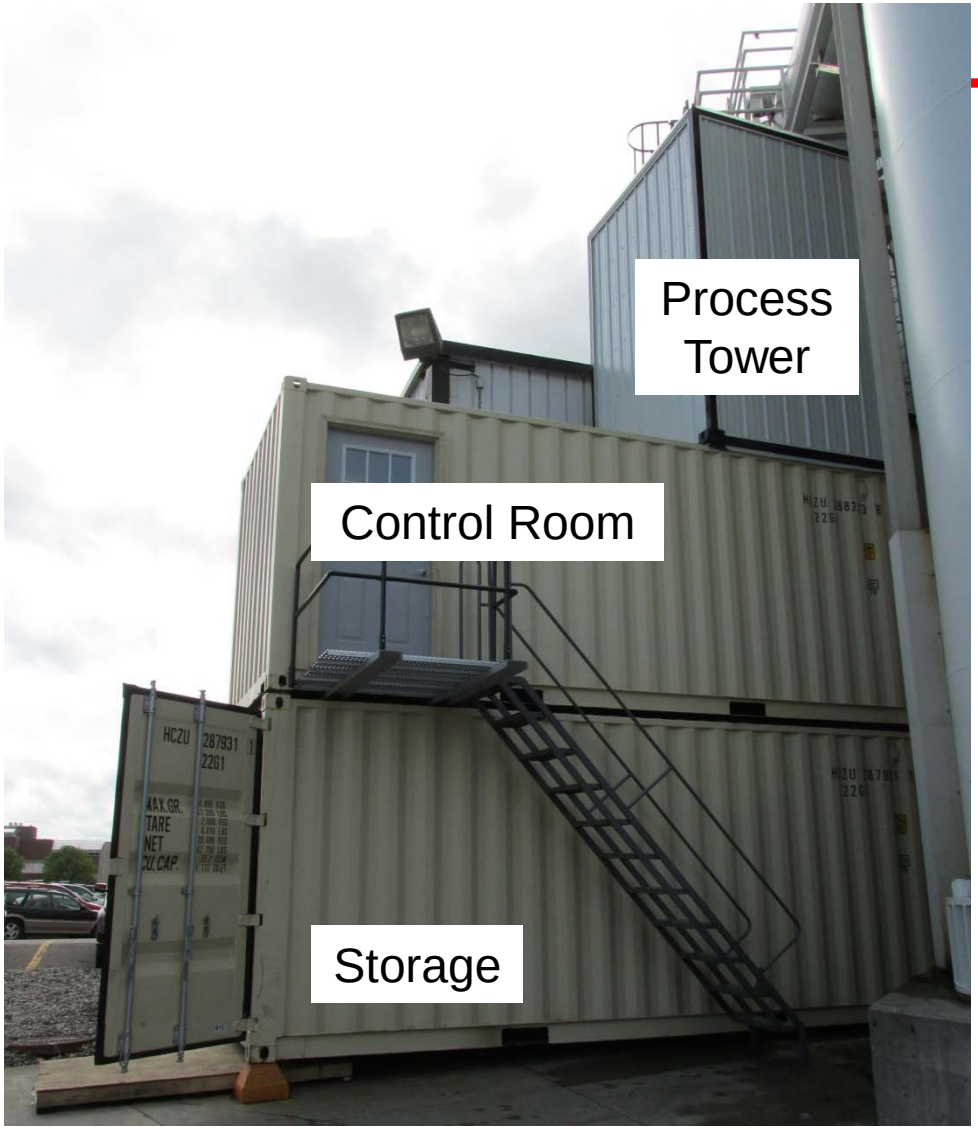
Task 5: Bench-Scale Facility



- 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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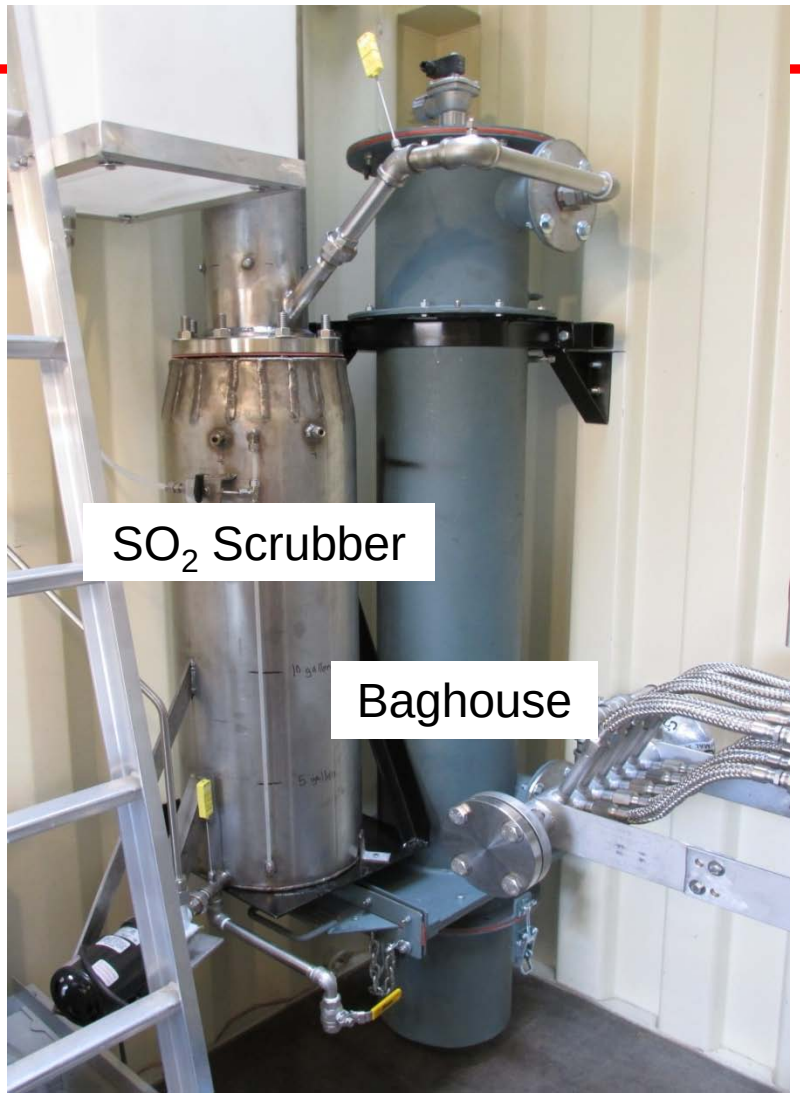
Bench-Scale Facility



- Gas conditioning system completed
- Installation of adsorber and regenerator systems continuing
- Target completion of shakedown testing - September 2013

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Future Plans

- Year 2
  - Complete construction bench-scale CACHYS™ system
  - Complete sorbent substrate optimization
- Year 3
  - Bench-scale testing – Operate bench-scale adsorption and desorption facility (parametric and continuous). Collect data to determine technical feasibility at this scale (30 acfm flue gas).
    - Sorbent and process performance
    - Adsorbent and regenerator multi-cycle testing
    - Data for updating process design and economics
    - Determination of environmental health and safety concerns

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
  - UND

- DOE-NETL Project Manager – Andrew Jones

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