Thirteenth Annual Conference on Carbon Capture, Utilization & Storage

Post Combustion Capture Systems Solid Sorbents

CO_2 Capture Using Hybrid Sorption with Solid Sorbents (CACHYS™)

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Presentation Overview

- Project Overview
- Technology Fundamentals
- Significant Accomplishments
- Plans for Future Testing

Project Overview

- Project Funding
  - U.S. Department of Energy Carbon Dioxide Capture RD&D program
  - Bench-scale testing
  - October 2011 to October 2014
  - Initial concept testing conducted by Envergex and UND under DOE STTR program

Project Participants

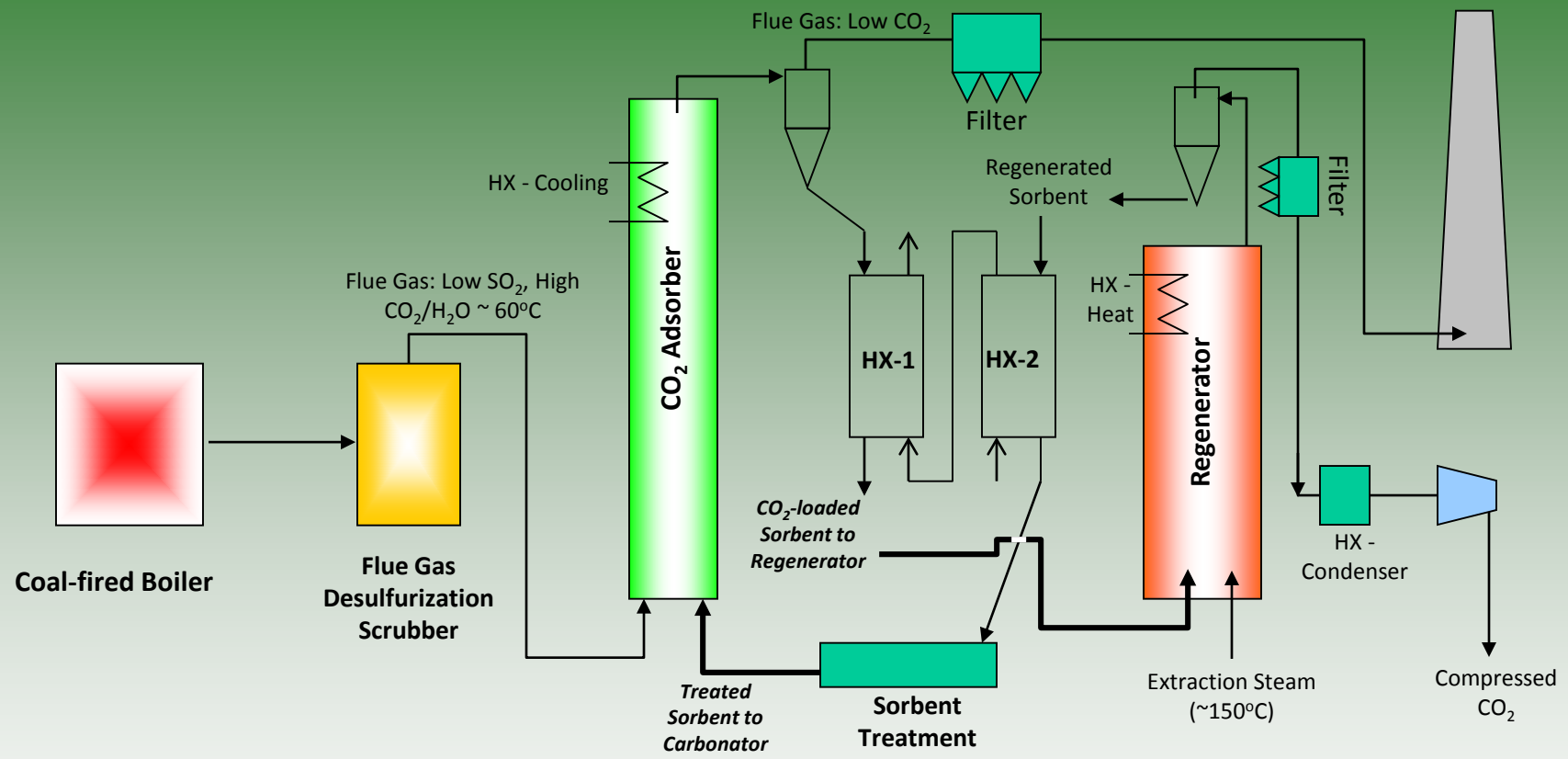
- US Department of Energy - NETL
- UND Institute for Energy Studies
- Envergex LLC
- Lignite Energy Council/NDIC
- ALLETE Group
  - Minnesota Power
  - BNI Coal
- SaskPower
- Barr Engineering
- Solex Thermal Science

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
  - Target 90% CO_2 removal from coal combustion flue gas
  - Demonstrate at bench-scale (slipstream/sub-pilot) 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

Technology Background and Fundamentals

CACHYS™ Hybrid Sorption Process

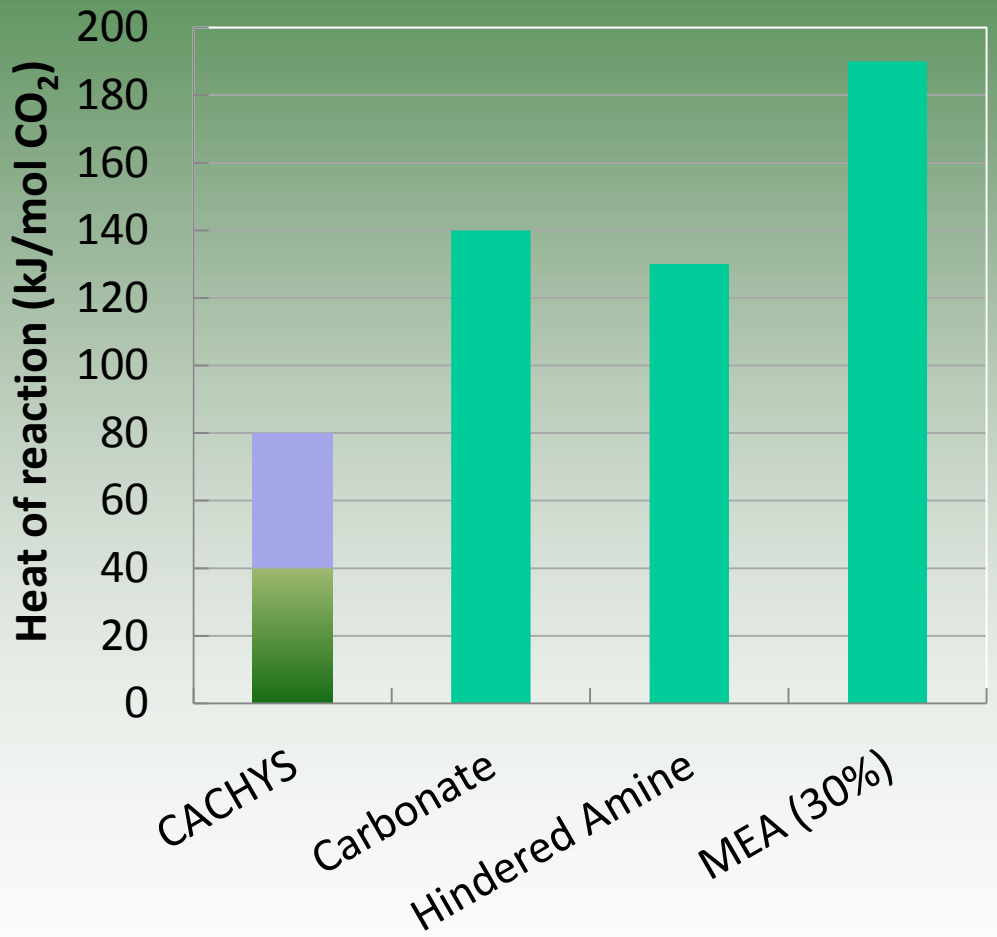


- Key component – metal carbonate salt
- Reacts with CO_2 to form adduct. Reversible with heat addition
- Additive/process conditions - enhance adsorption kinetics + reduce adsorption/regeneration energy

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



CACHYS™ Process Challenges

Challenges

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

Significant Accomplishments

Technical Approach and Project Scope

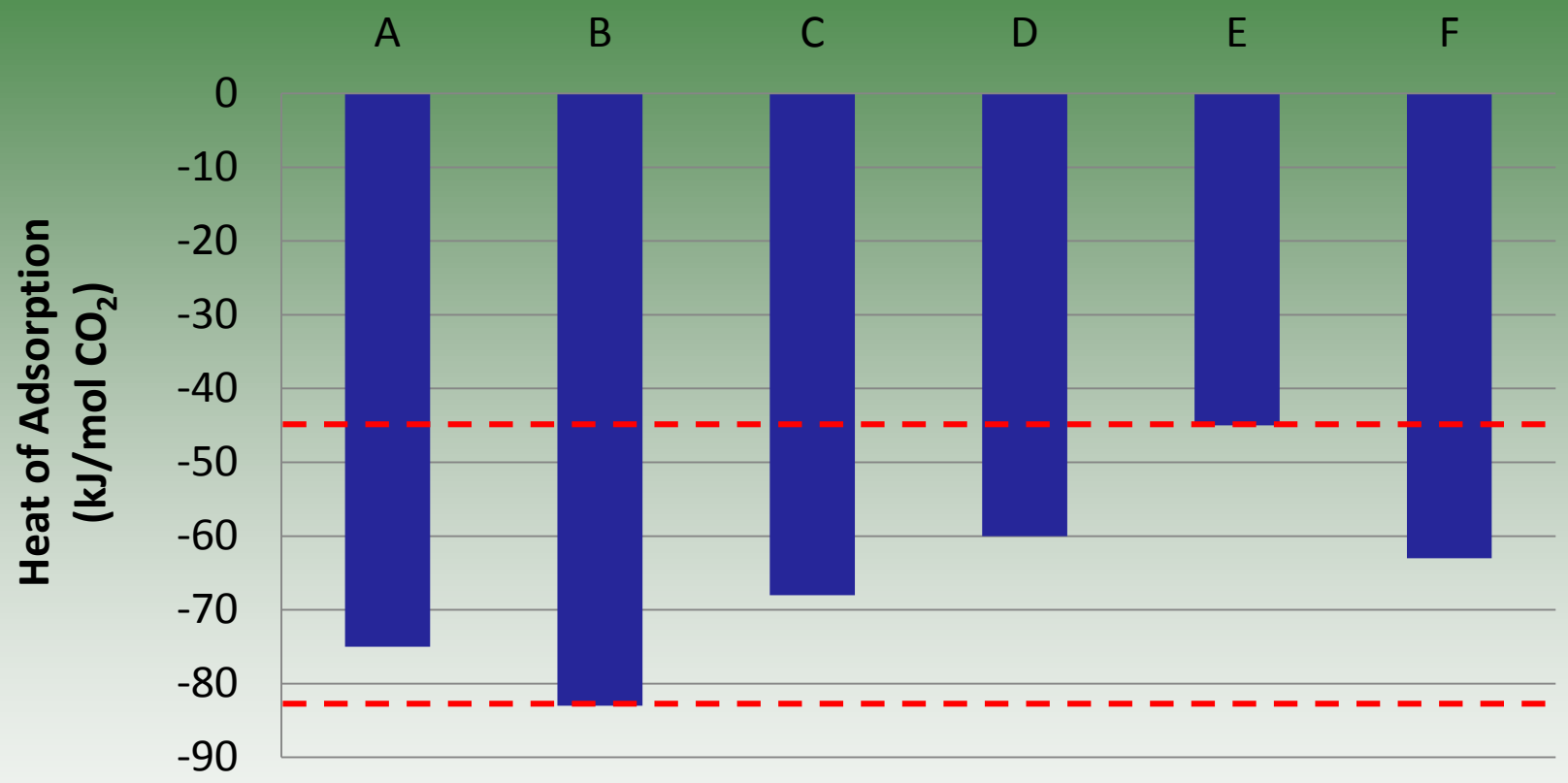
Scope of work includes eight main tasks:

- 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

Sorbent Screening and Energetics Determination

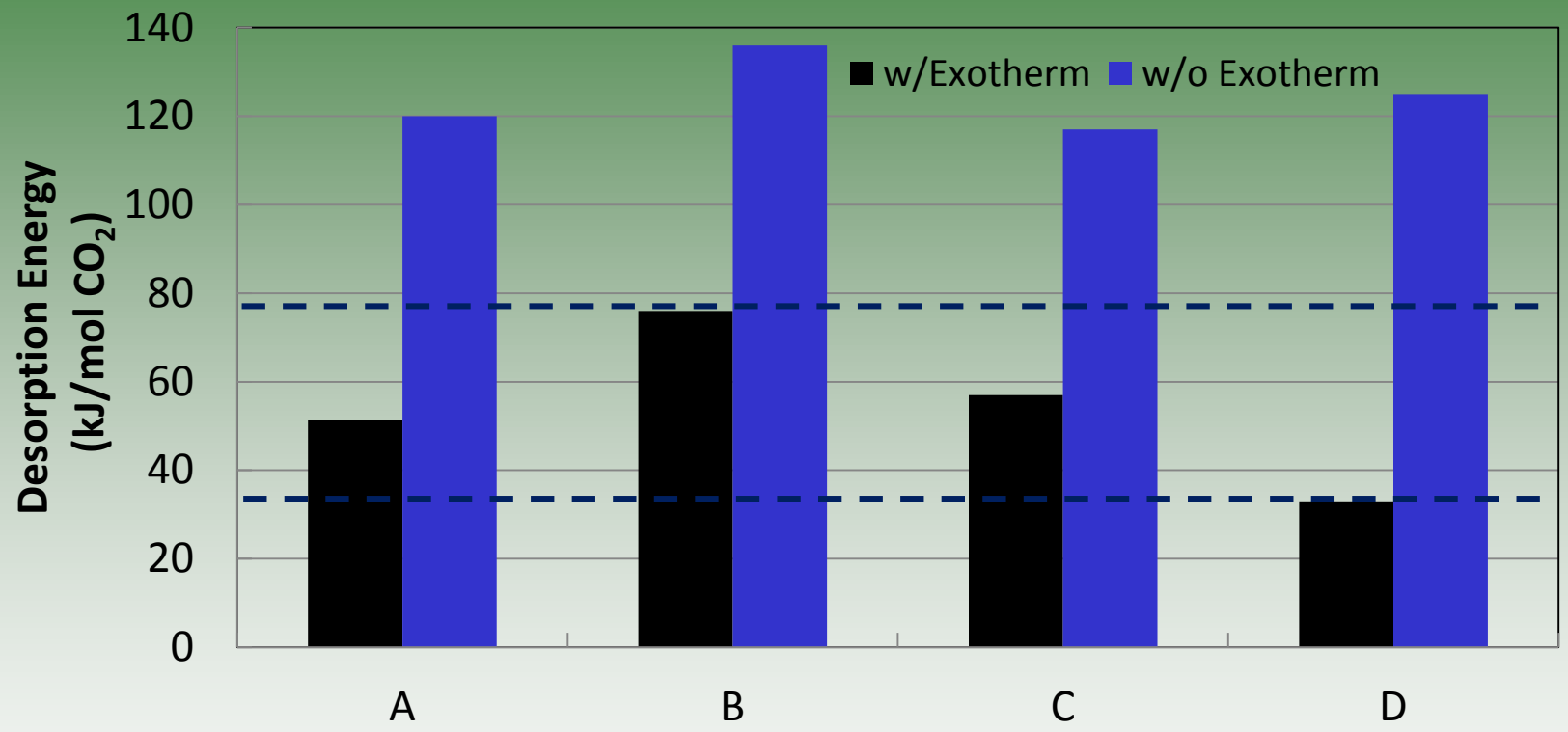
- Sorbent formulation and selection
- Thermogravimetric analyzer/differential scanning calorimeter (TGA/DSC) used to determine sorbent capacity, kinetics and sorption energetics

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)

TGA/DSC Desorption Energy Data



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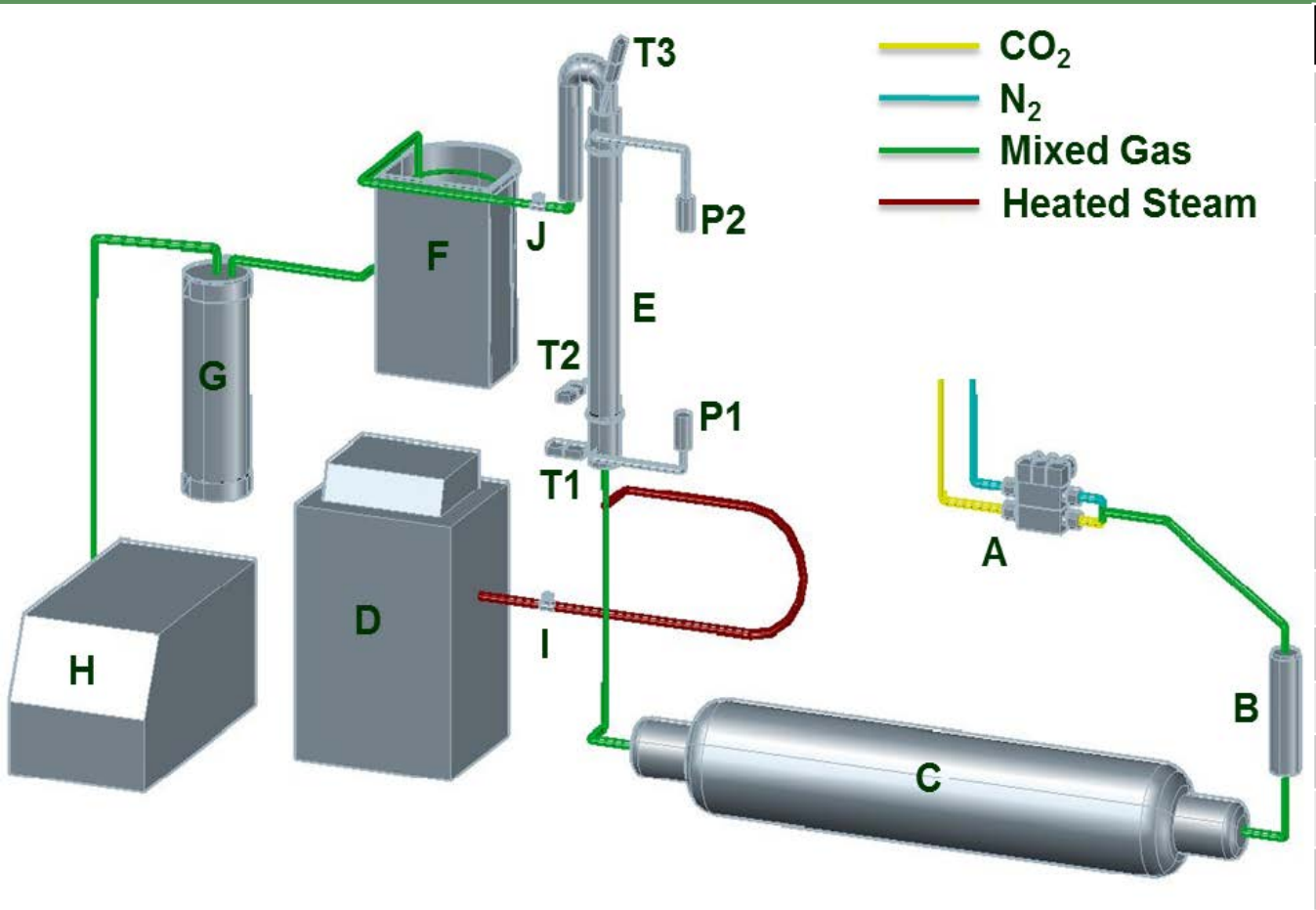
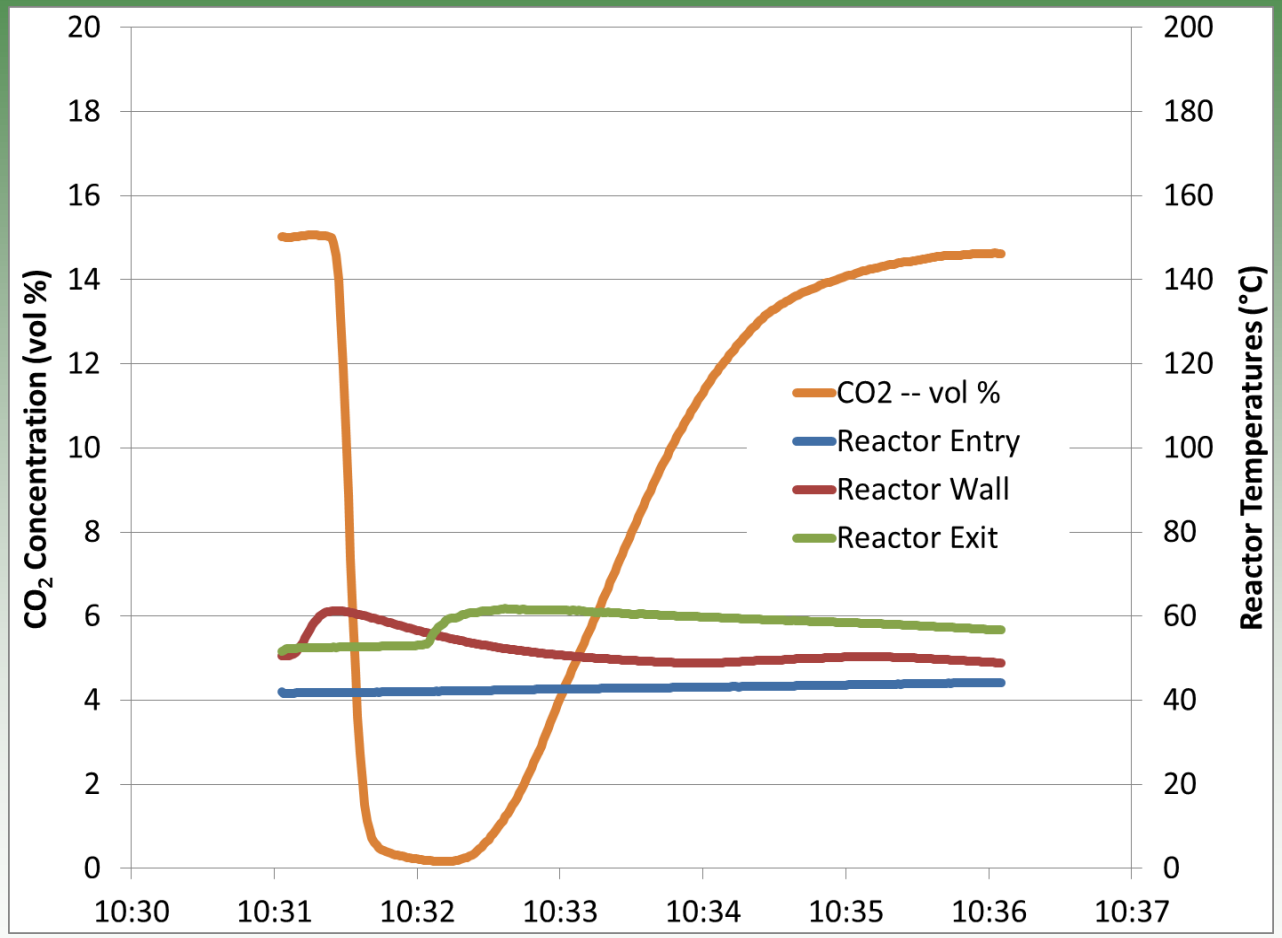
Fixed/Bubbling Bed Reactor Testing



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)

Fixed/Bubbling Bed Testing: Typical Adsorption Cycle



Adsorption Loadings for Sorbents Tested

Test 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-6	6	7.3	8.4
7	HCK-7	6	6.6	8.3
8	HCK-7	7	7.7	9.1

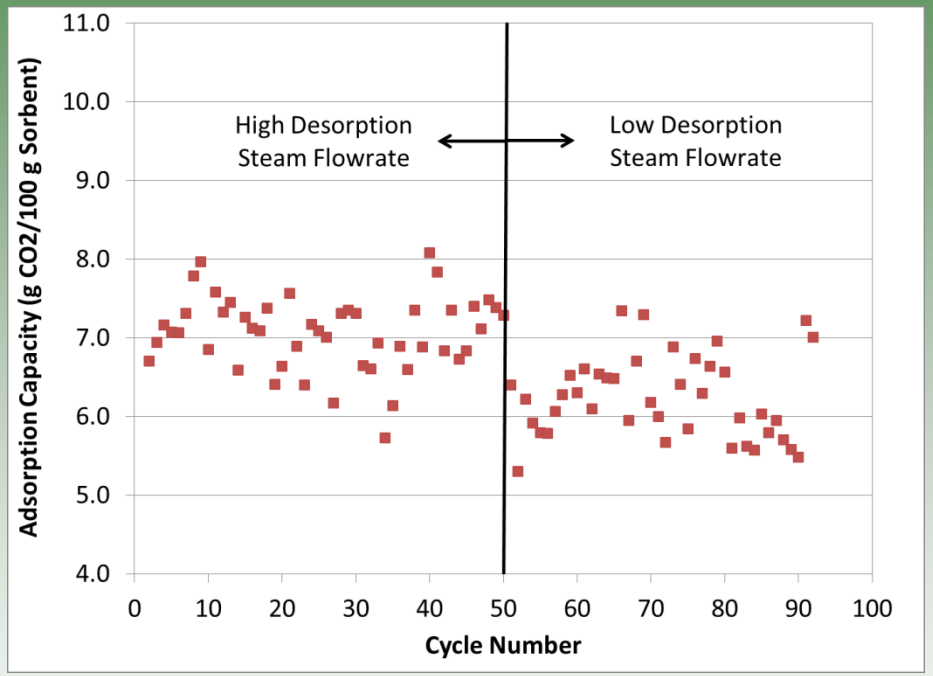
* Does not include the first cycle
** Calculated using TGA/DSC analyses

Sorbent Selection For Continued Evaluation

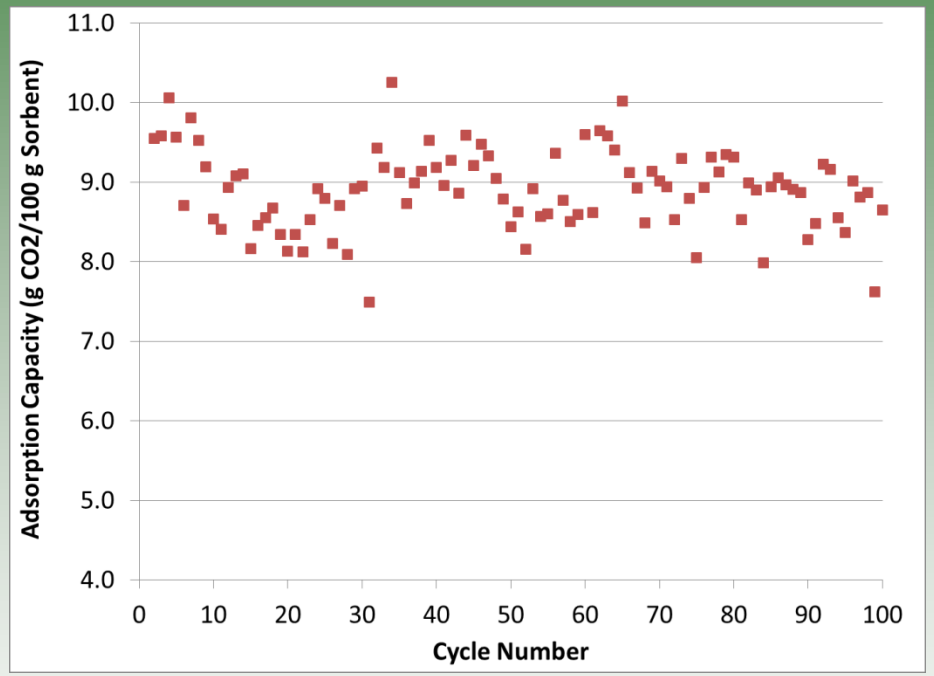
- HCK-4 sorbent averaged 7.1 g CO_2 and was consistently in the range of 6.8-7.4 g CO_2 per 100 grams of sorbent.
- HCK-7 sorbent averaged 9.1 g CO_2 (capacities as high as 10.0 g CO_2) per 100 grams of sorbent.
- Exceeds project goal of capacity of 7.0 g CO_2 per 100 grams of sorbent.

Fixed/Bubbling Bed Reactor: Multi-cycle Sorbent Testing

HCK-4



HCK-7



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

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

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

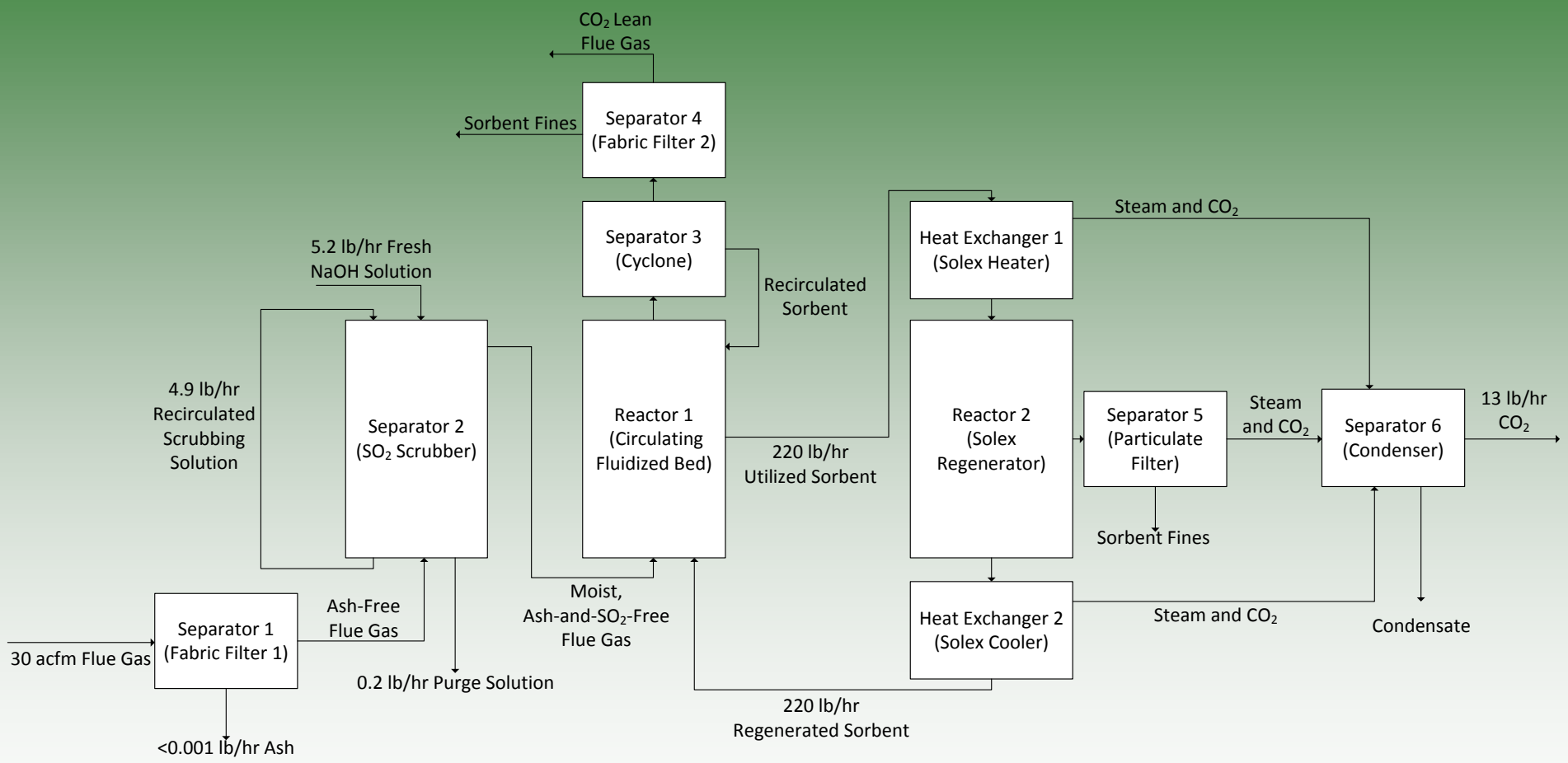
Technical and Economic Feasibility Study: (550 MW_e Net Output)

- 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%

Bench-Scale (Slipstream Sub-pilot) System

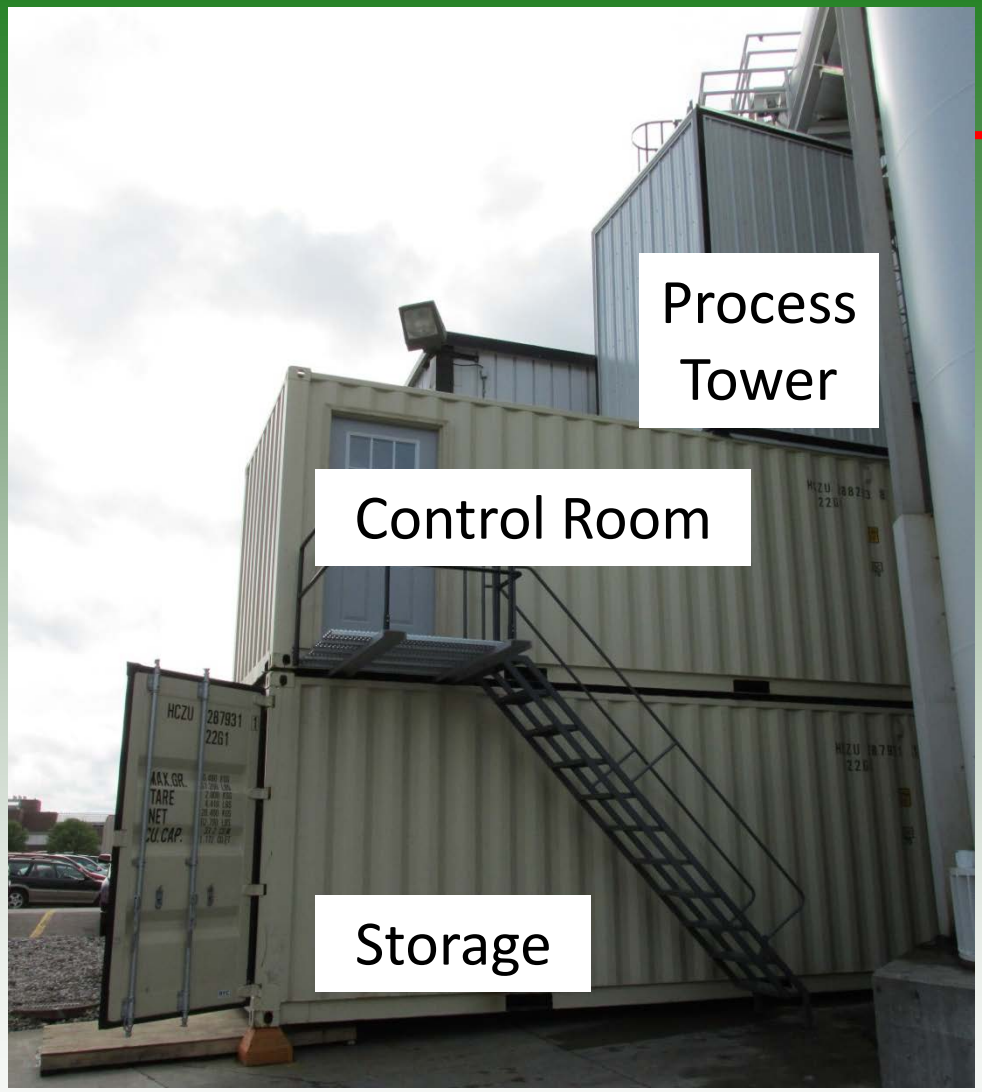
- Capture CO_2 from UND's Steam Plant
  - 30 acfm slip stream of flue gas from coal-fired boiler
- Gas Conditioning System
  - Fabric filter
  - Wet packed bed SO_2 scrubber
- Adsorber System
  - FD/ID fans
  - Circulating fluidized bed
  - Cyclone for bulk solids separation
  - Fabric filters for fines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

Bench-Scale Design for Slipstream Testing: Block Flow Diagram



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

Bench-Scale (Slipstream Sub-pilot)Facility



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

Task 5: Bench-Scale (Sub-pilot)Facility: Sorbent Production

Tasks 6 & 7: Bench-Scale Testing

- Task 6: Initial Testing
  - Confirmed operation of process components
- Task 7: Parametric and Continuous Testing
  - Parametric tests initiated
  - Determine optimum process conditions
  - Continuous tests conducted at optimized conditions to provide longer-term performance data

Future Work

- Complete bench-scale testing campaign
  - Sorbent and process performance
  - Adsorber and regenerator multi-cycle evaluation
  - Obtain data for scale-up and process economics
  - Determine environmental, health and safety concerns
- Task 8: Final Process Assessment
  - Environmental Health & Safety
  - Final Technical and Economic Feasibility Study
- E-CACHYS™
  - Being developed as part of a DOE SBIR/STTR grant
  - Goal to increase sorbent capacity by 2x CACHYS™ sorbents
  - Phase I results have been very promising – capacity targets achieved
  - Phase II application recently submitted to DOE

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 Sciences
  - UND
- DOE-NETL Project Manager – Andrew Jones

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