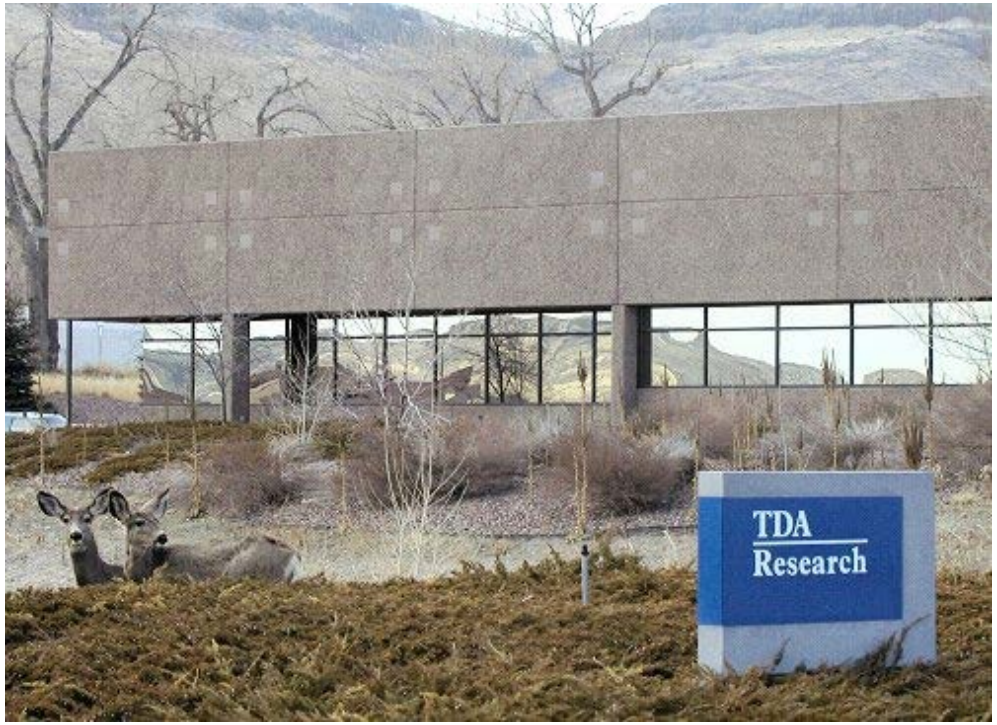
Post-Combustion CO_2 Capture System for Existing Coal-fired Power Plant

DOE Contract No. DE-FE0007580



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Prepared for DOE/NETL

Pittsburgh, PA

December 2, 2011

TDA Research Inc. • Wheat Ridge, CO 80033 • www.tda.com

Outline

- Company Background
- Previous Work
- Post Combustion Carbon Capture System
- Preliminary Performance Data
- Project Work Plan
- Team Members
- Budget

TDA Research, Inc.

- **Privately Owned / Began operations in 1987**
- **~14 million revenue in 2010**
- **86 full-time technical staff**
  - Primarily chemists and engineers, more than half with advanced degrees (29 PhDs)

12345-12355 W 52nd Avenue

22,000 ft^2 offices and labs

Synthetic Chemistry, Catalyst/Sorbent Synthesis and Testing, Machine and Electronics Shops, SEM, TOF Mass Spec

4663 Table Mountain Drive

27,000 ft^2 offices and labs

27 fume hoods, Synthetic Chemistry, Catalytic Process Development

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Project Summary

- The objective is to develop a new post-combustion carbon capture process for existing coal-fired power plants and demonstrate its technical (at the bench-scale) and economic viability
- The system uses a proprietary adsorbent to selectively remove CO_2 from the flue gas and regenerate under mild conditions

Year 1

- Sorbent optimization and laboratory scale evaluations
- Process and system design and modeling

Year 2

- Long-term Sorbent Cycling
- Design of the Sorbent and Key Processing Equipment
- Design of a Breadboard Prototype Test Unit
- High Fidelity Process Optimization and Design

Year 3

- Fabrication of the Prototype Test Unit
- Concept Demonstration
- System Analysis, Economic Evaluation and EH&S Assessment

Project Partners

Project Duration

- **Start Date = October 1, 2011**
- **End Date = September 30, 2014**

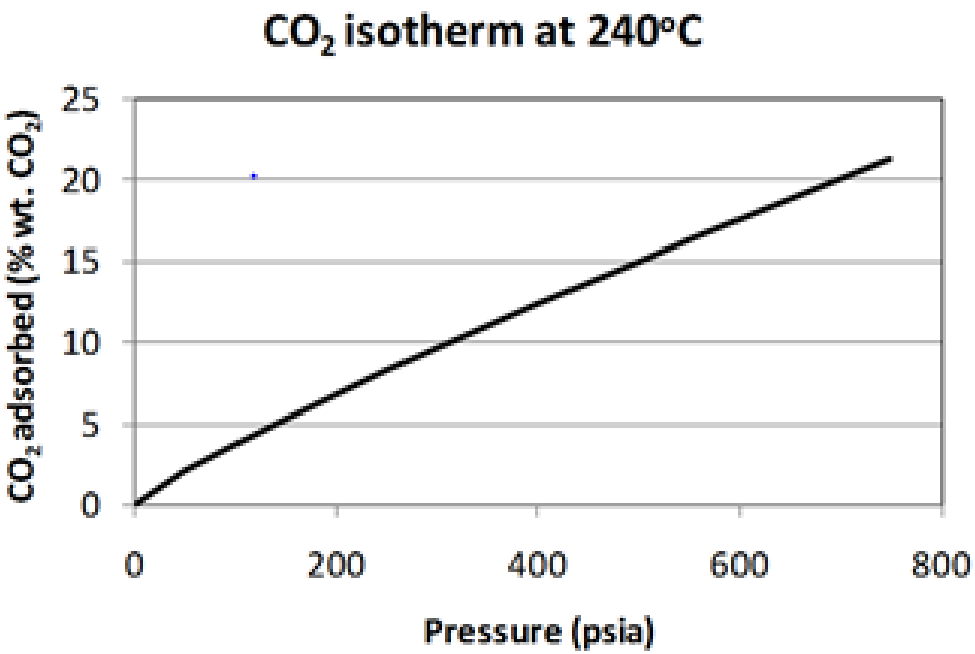
Budget

- **Project Cost = $3,375,000**
- **DOE Share = $2,700,000**
- **TDA and its partners = $675,000**

TDA's Approach

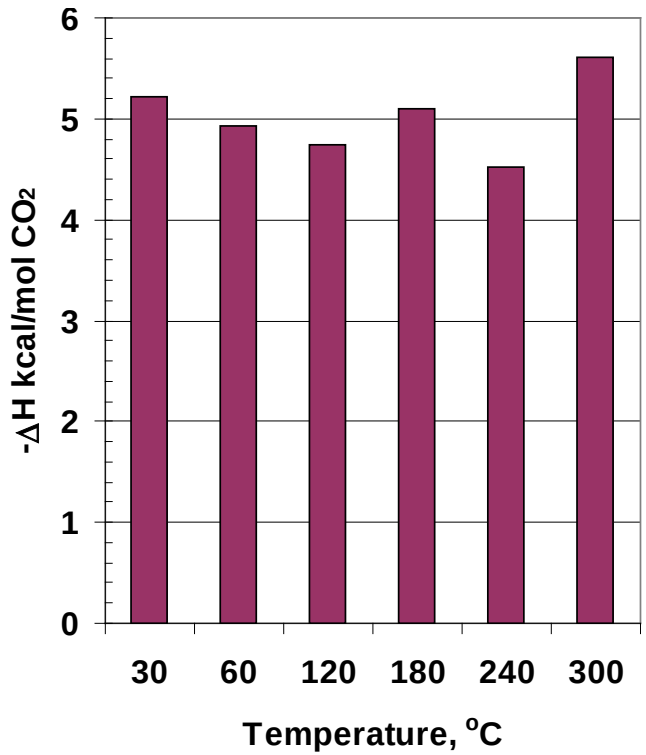
- The sorbent contains surface functional groups that remove CO_2 via strong physical adsorption
  - CO_2-surface interaction is strong enough to allow operation at elevated temperatures
  - Because CO_2 is not bonded via a covalent bond, the energy input for regeneration is low
- Heat of adsorption of CO_2 is measured as 4.9 kcal mol per mole for TDA sorbent
  - Selexol ~4 kcal/mol
  - Amine solvents ~14.4 kcal/mol
  - Chemical absorbents 20-40 kcal/mol ($Na_2CO_3 \rightarrow NaHCO_3$ 30 kcal/mol)
- Net energy loss in sorbent regeneration is much lower than amine scrubbers leading to higher process efficiency

CO_2 Isotherm and Heat of Adsorption



Langmuir Coefficient (q_s)	386.4 mmol/g
Langmuir Coefficient (B)	4.15E-04 1/atm
Langmuir Coefficient (n)	0.869
Diffusion Coefficient (D/R^2)	1.32E-03 1/s
Reference Temperature for B	240 °C
Heat of Adsorption (ΔH)	4.8 kcal/mol

Calorimetry Measurements



$-\Delta H_{ads}$ = 4.9 ± 0.4 kcal/mol

- **Isosteric heat of adsorption calculations and DSC experiments confirm the low heat of adsorption**

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Previous Work on CO_2 Removal

- **Pre-combustion CO_2 Capture**
  - **DOE/NETL Project**
  - **Slipstream demonstrations at Wabash River IGCC Plant and NCCC**
  - **Pressure-swing**
- **Methane Separation from Biogas**
  - **EPA (SBIR Phase I) and Private Funding**
  - **Pilot-scale demonstrations at Air Force Academy Colorado Springs, CO and Metawater, Japan**
  - **Vacuum-swing**
- **Mars Portable Life Support**
  - **NASA Project (SBIR Phase II)**
  - **Temperature-swing**

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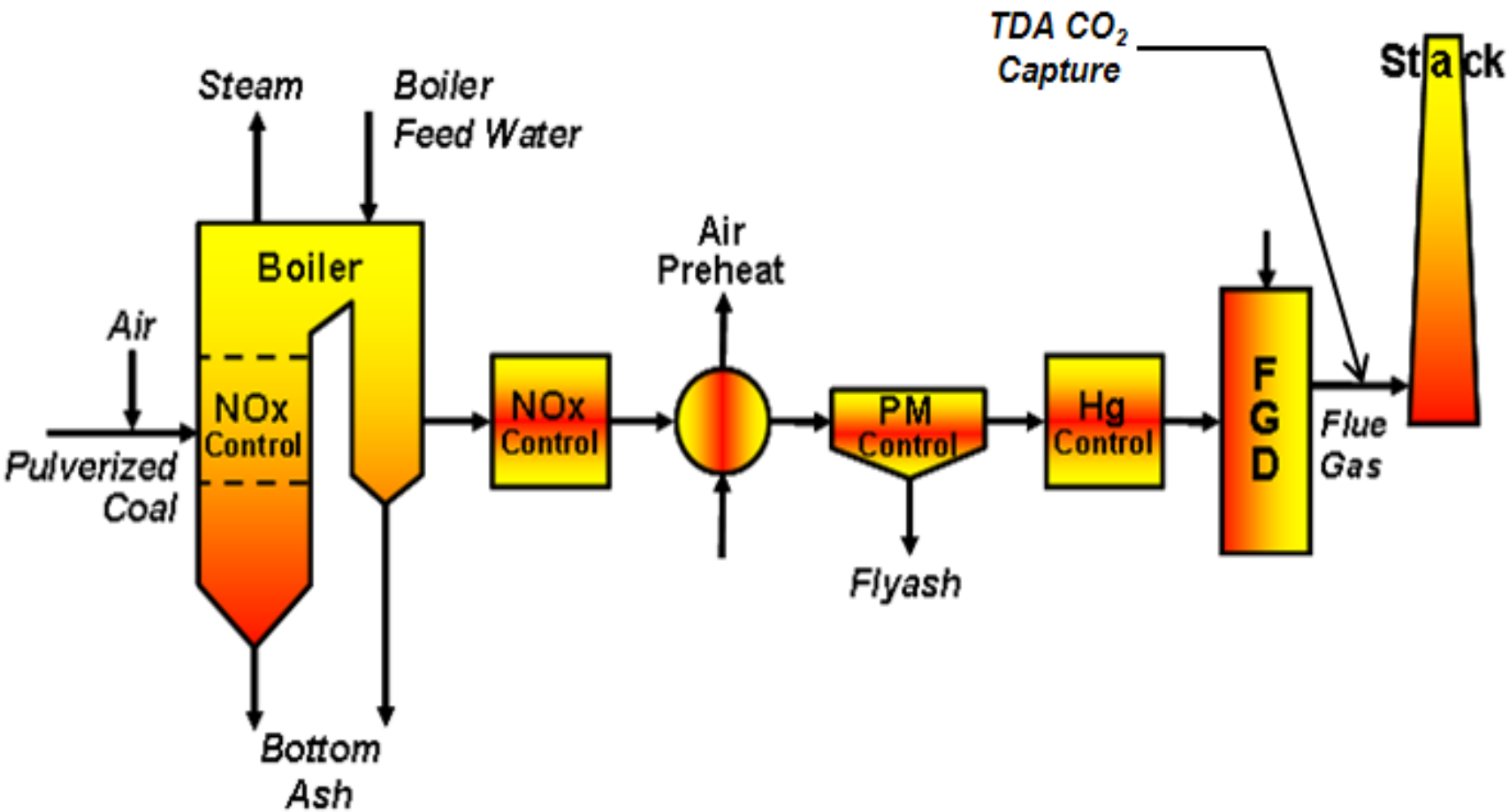
Integrated CO_2 Capture System



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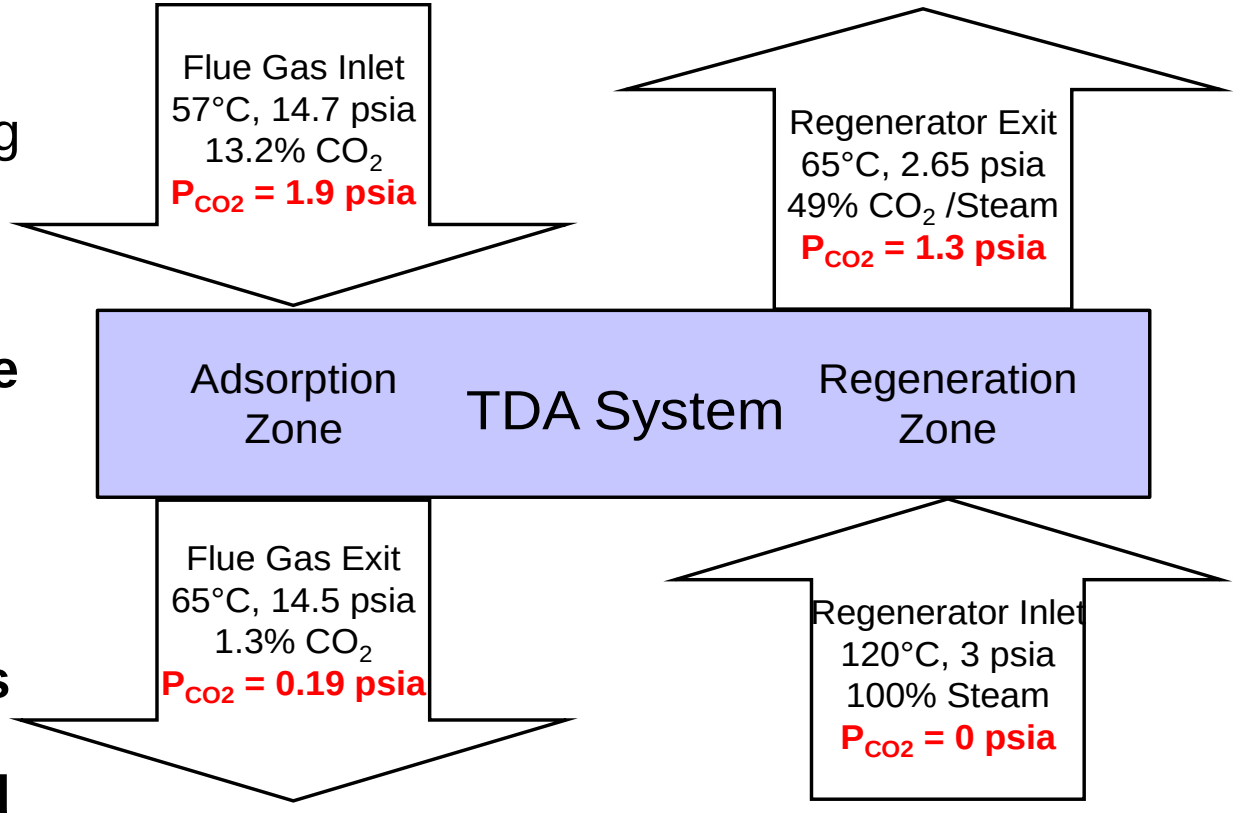
Regeneration Options

- **Physical adsorbent provides flexibility in regeneration**
  - Temperature swing
  - Pressure swing
  - Concentration swing
  - Combinations
- **Isothermal operation has merits to eliminate heat/cool transitions which reduces cycle time and increases sorbent utilization**
- **Steam consumption is greatly reduced if steam purge is carried out at low pressure**



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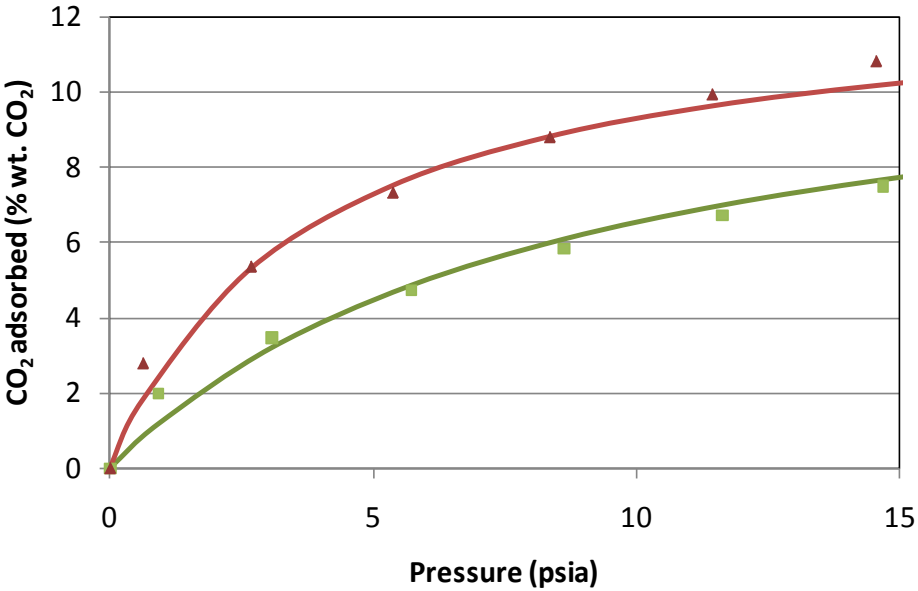
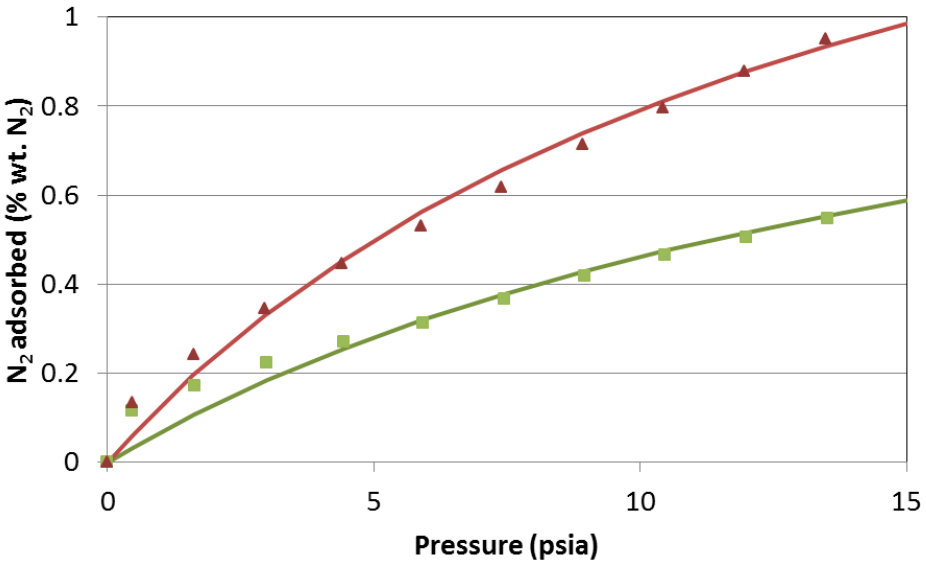
Adsorption Isotherms

CO_2



N_2



q (mol CO_2/kg); P (atm); T (K)			
k1	1.82	k3	3.0E-03
k2	138.42	k4	2112.23

$-\Delta H_{CO2} = 4.9$ kcal/mol

q (mol N_2/kg); P (atm); T (K)			
k1	0.022	k3	1.2E-01
k2	1017.01	k4	624.43

$-\Delta H_{N2} = 1.9$ kcal/mol

- **Isotherms measured in a constant volume apparatus**

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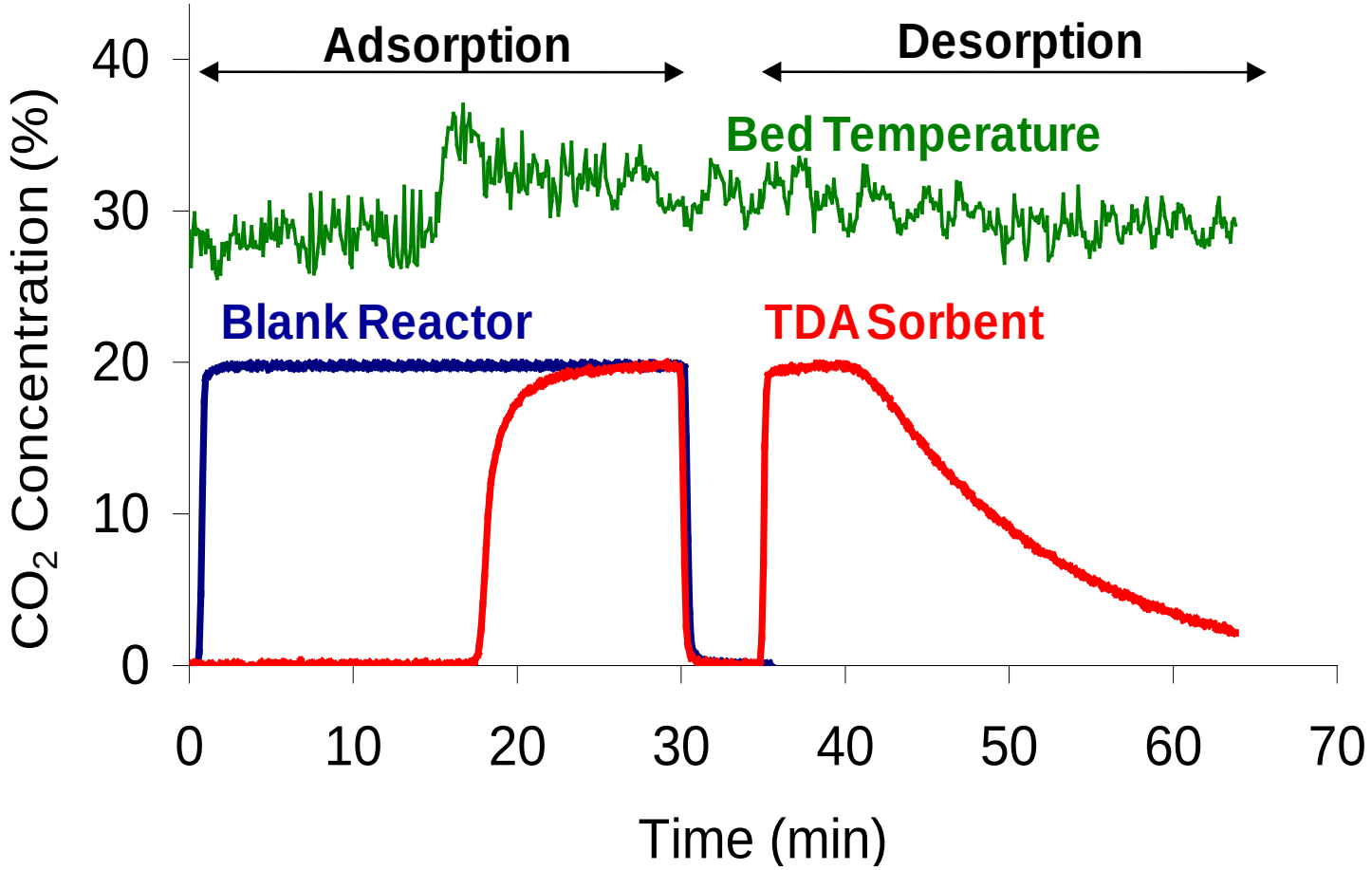
Typical Adsorption/Desorption Profile

T= 30°C, P_{CO2}= 2.5 psia, GHSV= 150 h^{-1}
CO_2 loading= 4.5% wt. at 95% CO_2 removal



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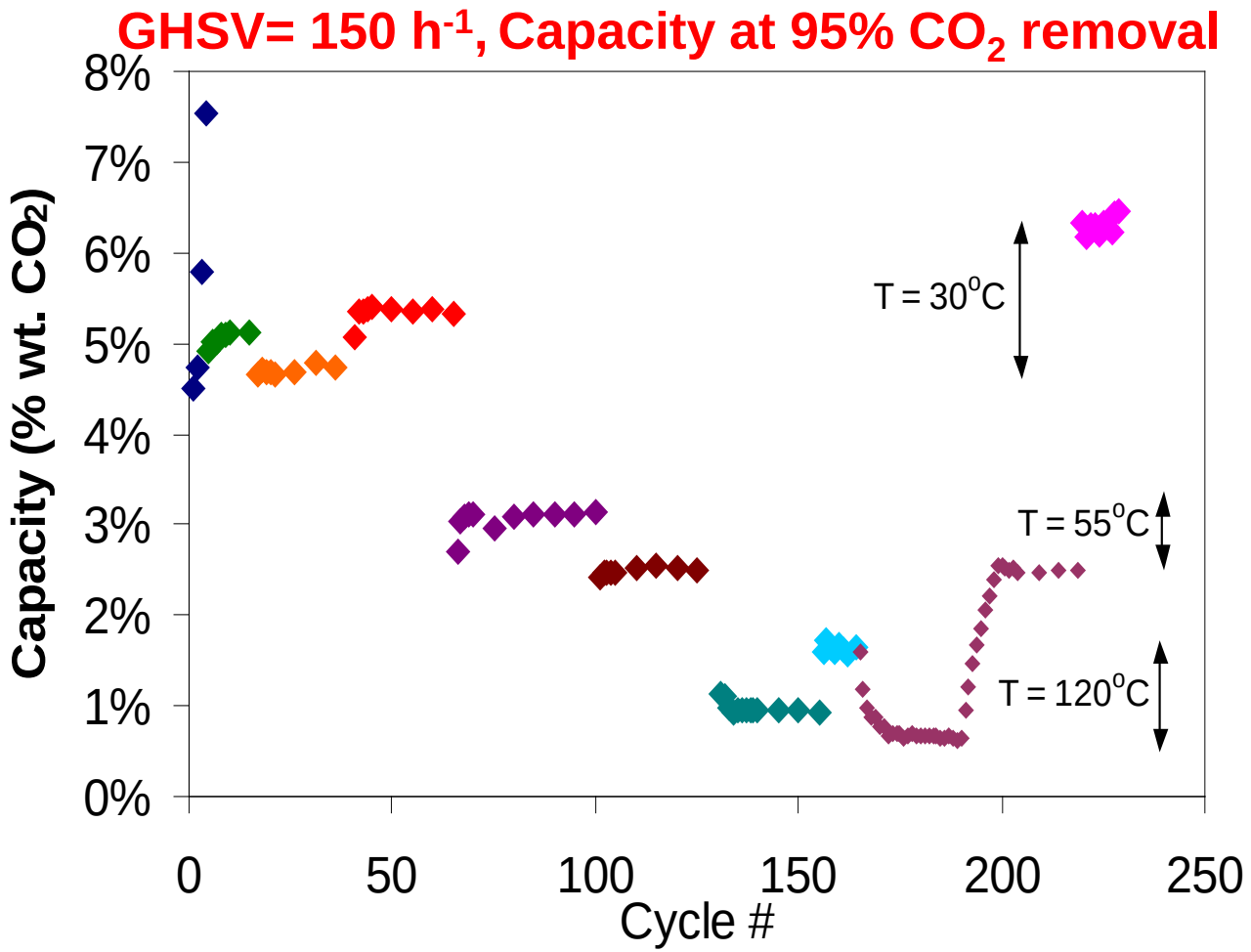
Effect of Temperature



- **Higher capacity at lower temperatures**
- **Changes at a temperature are due to variation in CO_2 partial P**

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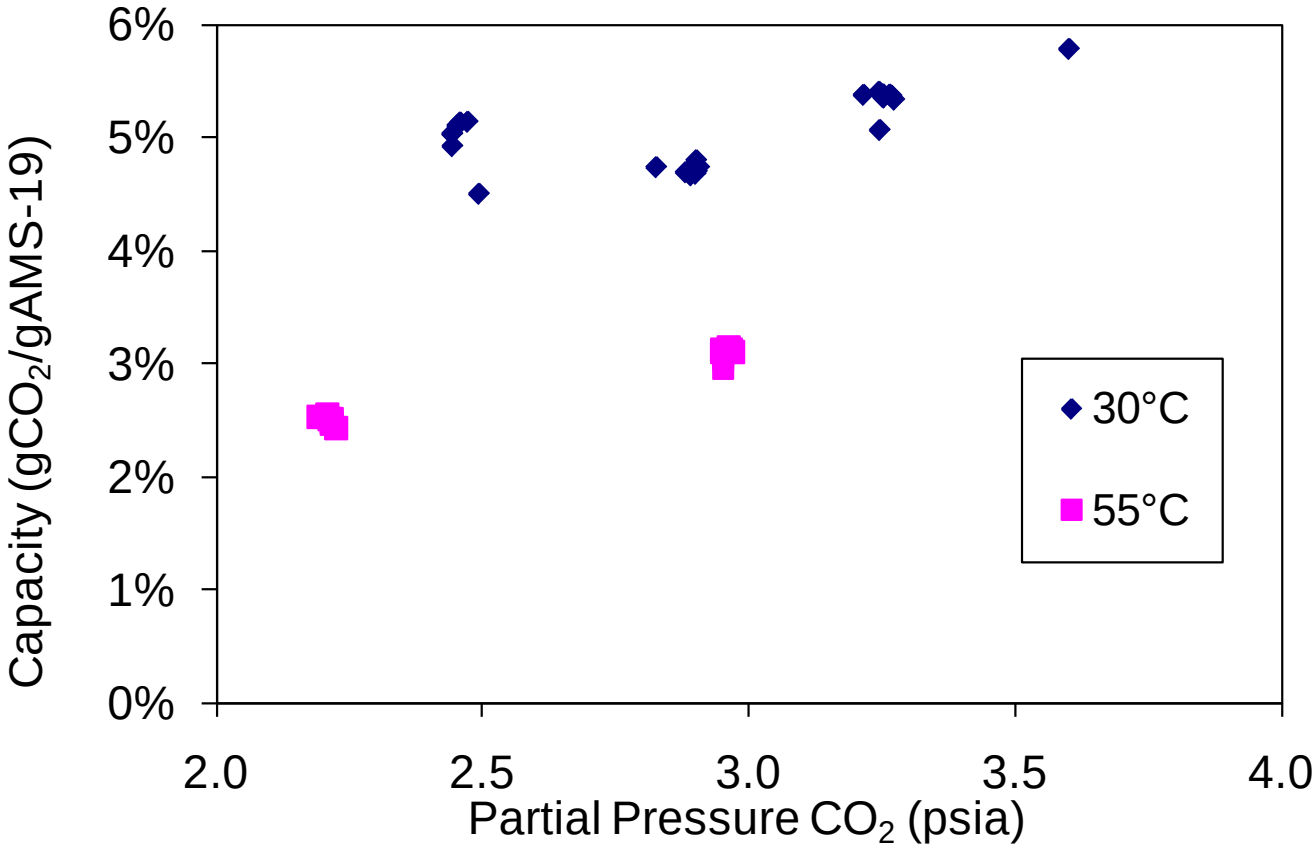
Effect of CO_2 Partial Pressure

GHSV= 150 h^{-1}, CO_2 loading at 95% CO_2 removal



- **Higher capacity at higher CO_2 partial pressure**

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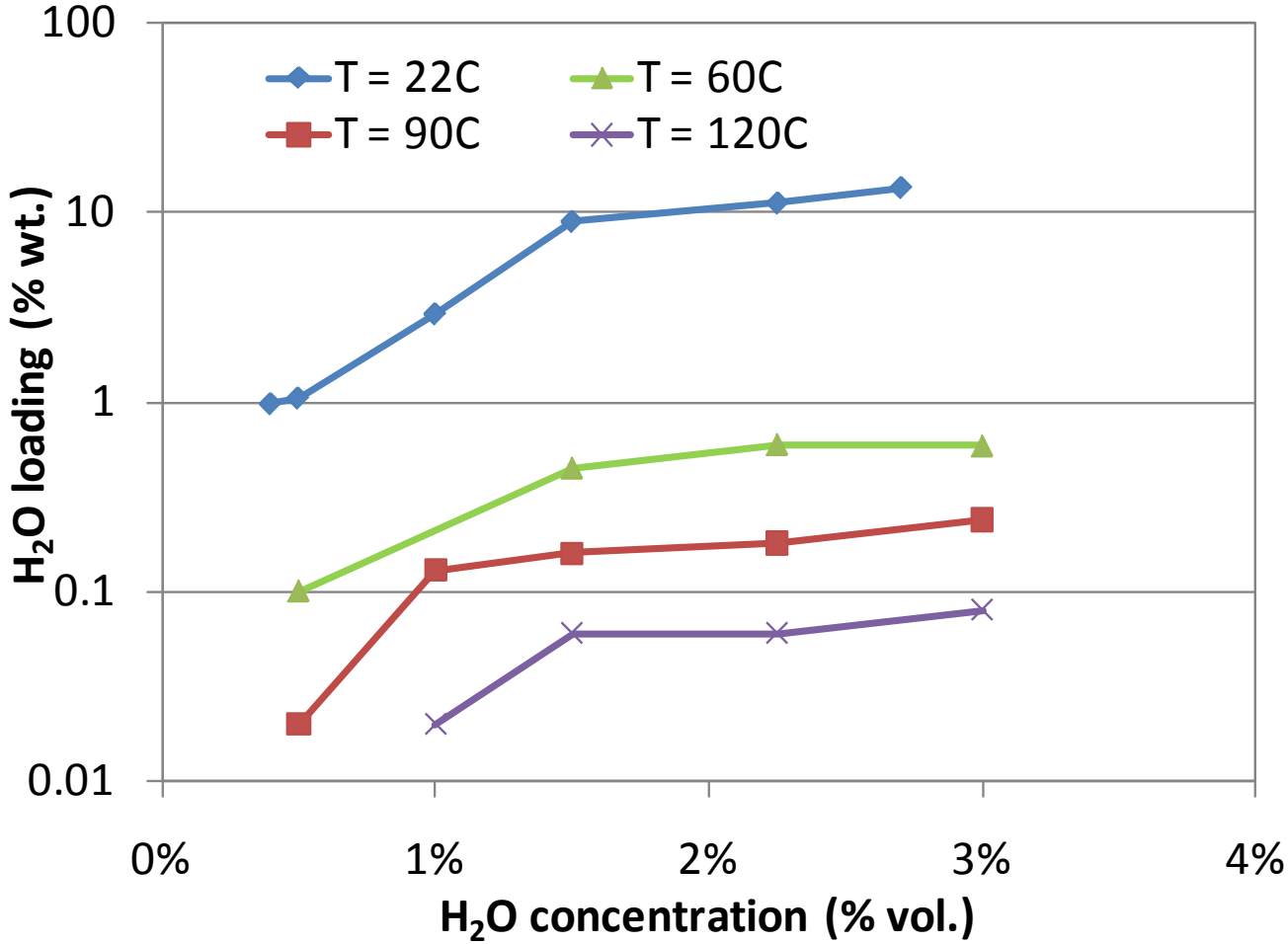
Water Adsorption on the Sorbent



- **Water adsorption was measured with a thermogravimetric analyzer (TGA) at different temperatures**

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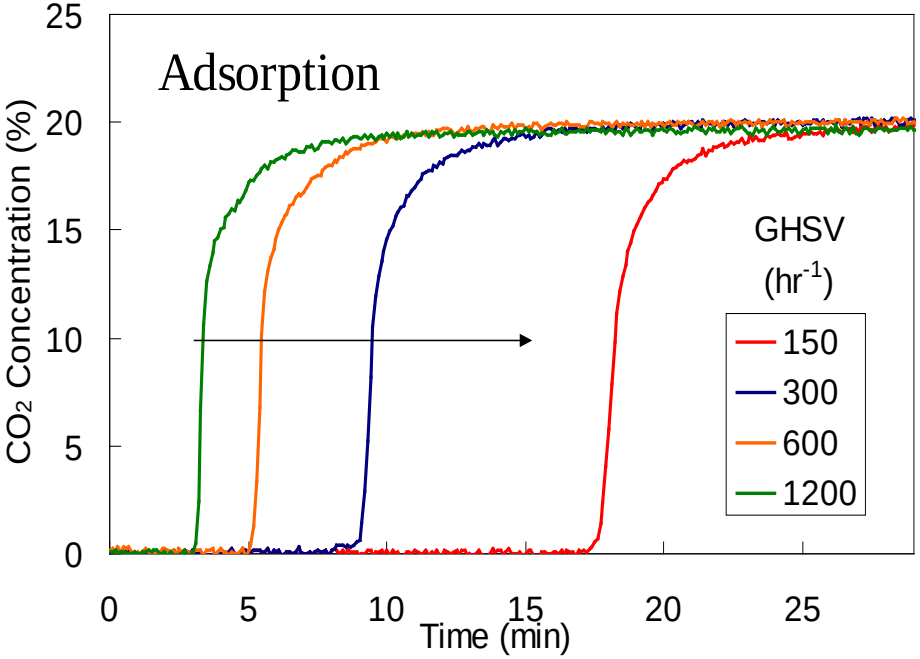
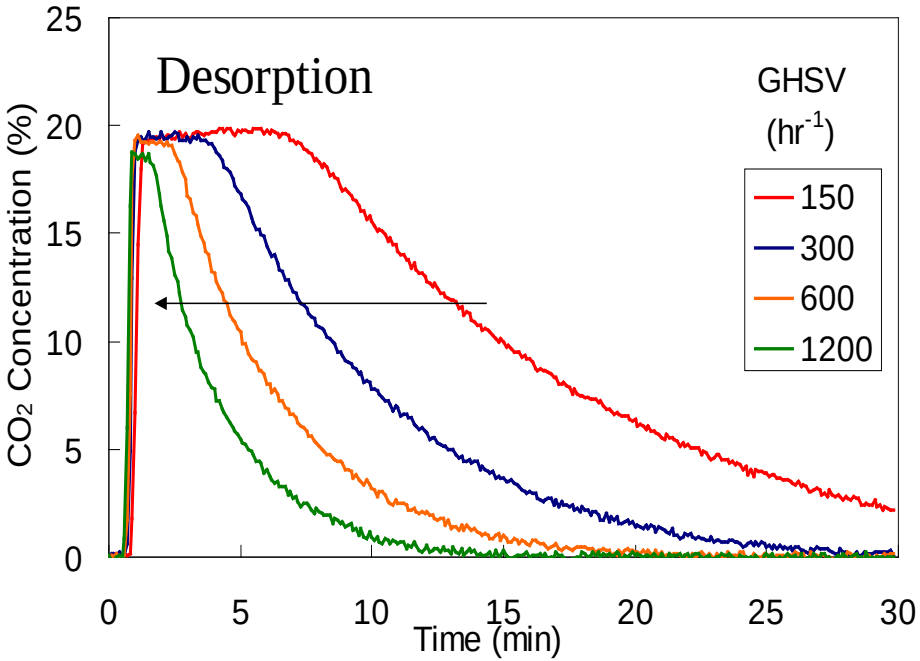
Impact of Space Velocity

T= 30°C, CO_2 concentration = 20%, P = 12.5 – 26.5 psia, GHSV= 150-1,200 h^{-1}



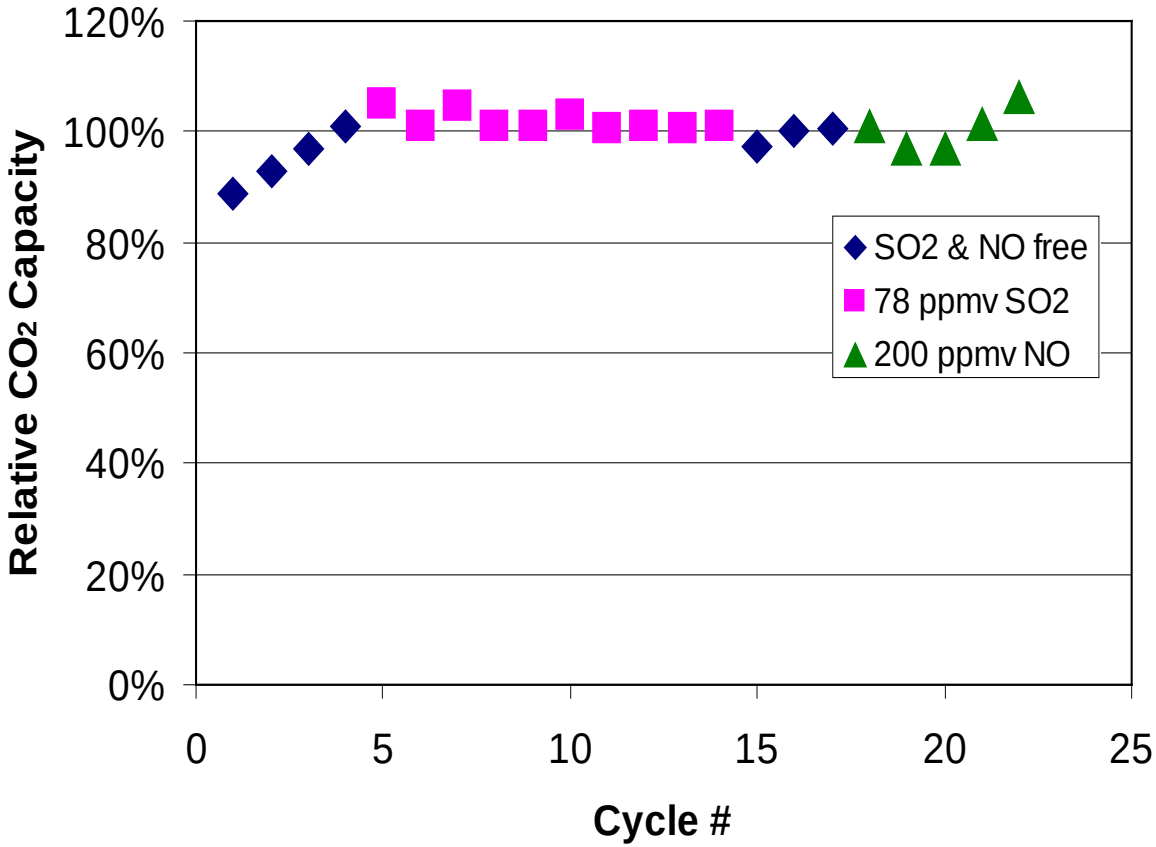


- **CO_2 adsorption is rapid which allows rapid cycling and high sorbent utilization**

TDA Research

Impact of Flue Gas Contaminants

T= 30°C, CO_2 concentration = 20%, P = 12.5 psia, GHSV= 150 h^{-1}



- **Preliminary experiments suggests low impact of SO_2 and NO_2 on CO_2 capacity**

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Project Work Plan

- **Task 1. Project Management and Planning**

Year 1

- **Task 2. Sorbent Optimization**
- **Task 3. Sorbent Evaluations**
- **Task 4. Process Design and Modeling**

Year 2

- **Task 5. Production Scale-up**
- **Task 6. Long-term Sorbent Cycling**
- **Task 7. Design of the Sorbent Reactors and Key Processing Equipment**
- **Task 8. Design of the Prototype Test Unit**
- **Task 9. Process Optimization and Design**

Year 3

- **Task 10. Sorbent Production for Prototype Testing**
- **Task 11. Fabrication of the Prototype Test Unit**
- **Task 12. Concept Demonstration with Coal Flue Gas**
- **Task 13. System Analysis and Process Economic Evaluation**
- **Task 14. Preliminary Technology Environmental, Health and Safety (EH&S) Assessment**

Task 1. Project Management/Planning

- Carry out an initial technical and economic feasibility study
- Initiate and coordinate with the sub-contractors/partners and conduct regular review meetings
- Measure progress against Milestones
- Provide quarterly reports to DOE
- End of Year Review Meetings with DOE

Project Team Members

- **Babcock & Wilcox**
  - Project Lead - Bartev Sakadjian
- **Gas Technology Institute**
  - Project Lead – Chuck Sistla
- **University of California**
  - Project Lead – Ashok Rao

Task 2. Sorbent Optimization

- **Optimize the chemical composition**
- **Optimize the physical properties and mechanical integrity of the sorbent to meet the specific requirements of the process**
- **Explore the use of low cost bulk raw materials**

Task 3. Sorbent Evaluation

- **Physical properties**
  - Surface area, pore volume, crush strength, attrition index
  - Heat of adsorption/desorption (using DSC, TGA)
  - CO_2 isotherms (in automated isotherm measurement unit)
  - Sorbent performance under cycles
    - CO_2 adsorption and desorption breakthroughs
    - Measure dynamic CO_2 capacity, heat and mass transfer
- **Identify optimum operating conditions and process parameters for design calculations**
  - Space velocity, temperature, and cycle time
- **Selected sorbents will be further evaluated in an existing moving-bed setup**
- **Evaluate Impact of Contaminants**
  - SO_2, NOx, HCl
- **Chemical Characterization**
  - Bulk composition by x-ray fluorescence (XRF)

Task 4. Process Design and Modeling

- **In collaboration with UCI and B&W, we will carry out process design and simulations using Aspen-Plus™ software**
- **TDA will develop the adsorption & desorption models and design the CO_2 control system**
  - Multiple design options will be considered
    - Different regeneration procedures i.e., temperature swing, vacuum swing
    - Different reactor systems i.e., fixed bed, moving bed)
  - Design of the CO_2 process will be reviewed with our partners – UCI, B&W and GTI
- **A sensitivity analysis will be carried out to identify the impact of key operating parameters on process efficiency**
- **Major process equipment will be sized and an economic analysis will be performed (~25% accuracy)**
- **Preliminary technology feasibility study as outlined in Attachment 3 of DE-FOA-0000403 will be completed**

Task 5. Production Scale-up

- TDA will increase the batch size for producing the sorbent using scalable production equipment
- We will also explore semi-continuous or continuous preparation approaches in our pilot production facility in Golden, CO
- The production process will be optimized to increase final product yields
- We will carry out extensive physical characterization and performance evaluations at bench-scale to validate the properties of formulations prepared in large batches
- We will also collaborate with MWV to carry out a cost analysis

Task 6. Long-term Sorbent Cycling

- **Test the best sorbent in multiple-cycles to determine if extended use affects the capacity or adsorption/regeneration rates**
- **Minimum 5,000 cycles under representative conditions**
- **The effects of long-term exposure of the sorbent to contaminants will also be investigated**
- **At the end of the multiple-cycles, we will compare the sorbent's mechanical and physical properties to those of the fresh material**

Task 7. Design of the Sorbent Reactors and Key Processing Equipment

- **With input from TDA, B&W will design the sorbent reactors that will best fit the proposed application**
  - TDA will provide B&W with the expected operating conditions and requirements, and sorbent performance parameters
  - B&W will provide TDA with process flow and instrumentation diagrams and 3-dimensional layouts of the proposed reactors
  - This information will be directly used in the system design and cost analysis

Task 8. Design the Prototype Test Unit

- **TDA will design the prototype test unit that will be evaluated at GTI's Des Plains, IL facility using actual flue gas from coal combustor**
  - Detailed description of the design basis and the overall process
  - Preparation of a process flow diagram
  - Carrying out heat and material balances, and establishing utility requirements (electric power, cooling water etc.)
  - Generating process and instrumentation drawings and layouts
  - Identifying instrumentation and data collection requirements
  - Designing process control system
  - Writing an "Operation Manual" and an "Experiment Test Plan".

Task 8.1 Design Review

- **We will carry out detailed design review meetings with GTI and its partner ICCI**
- **Also coordinate site visits to GTI and ICCI to ensure smooth integration of the prototype unit with their systems**

Task 9. Process Optimization & Design

- TDA, UCI and B&W will work together to identify operating conditions and heat/equipment integration opportunities to further lower the cost of the CO_2 capture system when integrated into an existing coal fired power plant
- UCI will update the process model using the information from the second year multiple-cycle tests
- B&W will provide input on reactor designs and heat transfer loops that would provide the energy needed for sorbent regeneration
- TDA will use information from the multiple-cycle tests to determine sorbent makeup and replacement requirements and associated costs
- Major process equipment will be sized and an economic analysis will be performed (~15% accuracy)
- Preliminary technology feasibility study will be updated

Task 10. Sorbent Production for Prototype Testing

- **TDA will produce the sorbent needed for the prototype unit testing at the scaled-up batch size following procedures developed in Year 2**
- **Bench-scale evaluations will be carried out to confirm that the sorbent produced meets performance specifications**
  - extensive physical characterization and performance evaluations will be carried out at bench-scale to validate the properties of the sorbent batches

Task 11. Fabrication of Prototype Unit

- **In collaboration with GTI (the field test facility operators), TDA will perform a final Hazard Analysis**
- **Utility requirements of the unit, and discussions on the Operating Manual and Experimental Test Plan will also take place with plant operators**
- **Once TDA, plant operators and project partners agree upon the requirements, safety features and operating capabilities of the test unit, TDA will complete the fabrication of the prototype**
- **Shakedown and troubleshooting of the test system will be performed at TDA to qualify the unit for field demonstrations**
  - Test unit will undergo thorough in-house testing with simulated gases prior to shipment to the test sites

Task 12. Concept Demonstration with Coal Flue Gas

- **TDA will work with GTI to install the prototype test unit at their pilot-scale demonstration site**
- **During the evaluations at GTI we will use flue gas generated from a pilot-scale coal combustor**
  - The first steps will be a series of shakedown runs (first cold and then hot), to confirm mechanical integrity and the proper functioning of the control systems after the shipment
  - At GTI, we will run extensive tests to optimize the operation of the unit and ensure that it will meet all safety requirements of a potential commercial host site (that may be considered for demonstration) in following work
  - We will perform a series of tests to evaluate sorbent's performance at different operating conditions to establish optimum sorbent performance
- **After completion of tests, the results will be reviewed by all team members and the level of commercial interest will be evaluated**

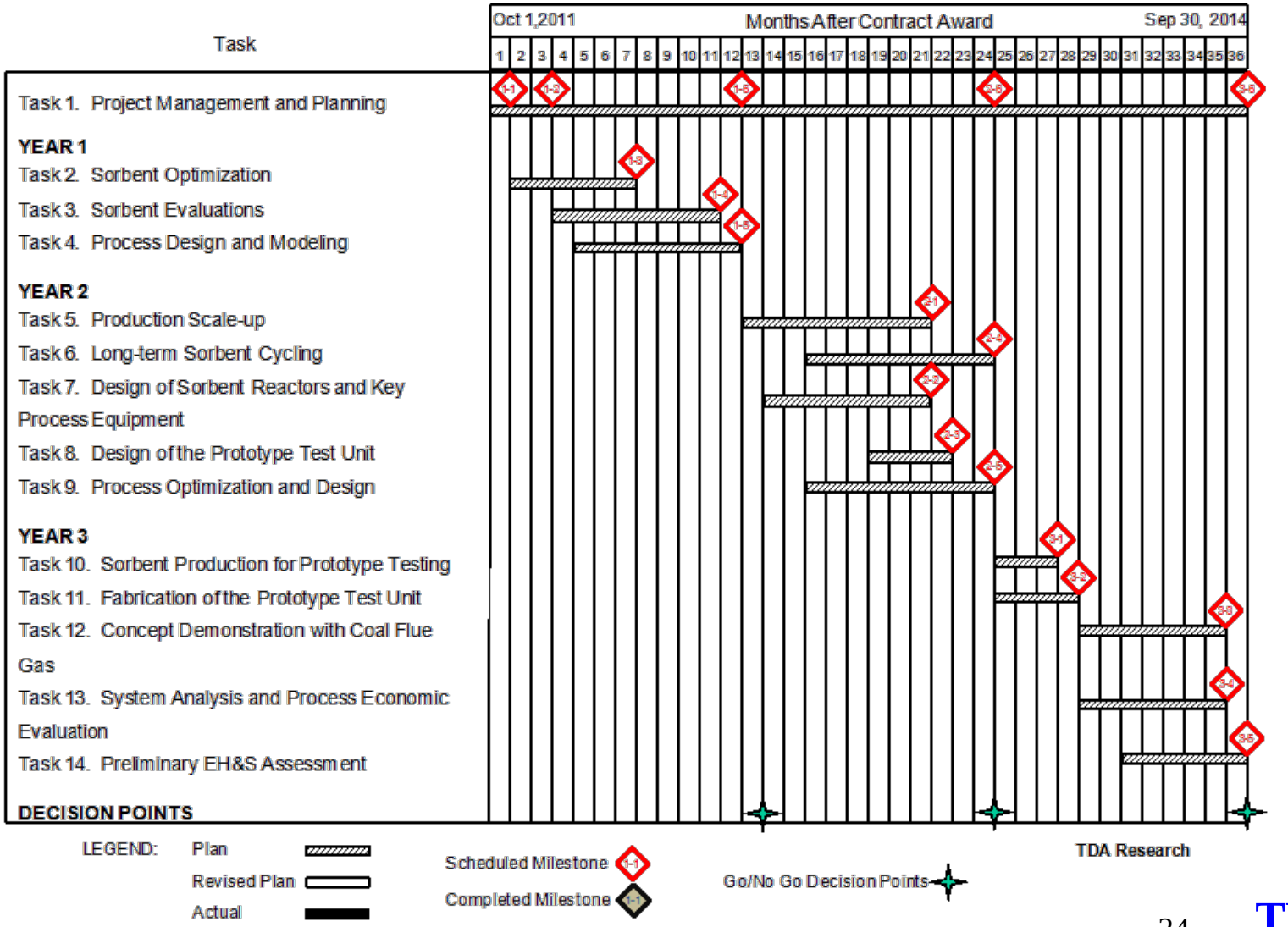
Task 13. System Analysis and Process Economic Evaluation

- **UCI will initially update the Aspen-Plus™ model with the new year testing results**
- **Using the performance data from the field tests, TDA will revise the simulation model**
- **TDA and UCI will carry out a final system analysis based on the results of the test campaigns**
  - TDA will estimate capital and operating cost to determine the overall cost of CO_2 captured and resulting increase in cost of electricity cost, using the NETL guidelines (~15% accuracy)
  - The data will be compared with the currently available CO_2 capture technology
- **A final technology feasibility study will be completed following the guidelines provided in Attachment 3 of the solicitation**
- **B&W will evaluate the results of the final systems and economic analysis to determine the commercial viability of the process and the scale-up potential for future pilot scale test campaigns**

Task 14. Preliminary Technology EH&S Assessment

- TDA and B&W will perform an assessment of environmental, health and safety risks of the process
- The EH&S risk assessments will be conducted following industrial guidelines (and guidelines provided in Attachment 4 of the solicitation)
- This study will identify and quantify all potential ancillary or incidental air and water emissions, and solid wastes produced from the proposed technology, including sorbents used, any by-products, any accumulated waste products, and the ultimate fate of contaminants from the feed flue-gas stream
- A thorough literature search will be conducted to examine potential human health effects and eco-toxicity
- Engineering analysis to minimize hazardous waste and treatment and disposal of waste disposal will be addressed in the EH&S assessment

Project Schedule



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