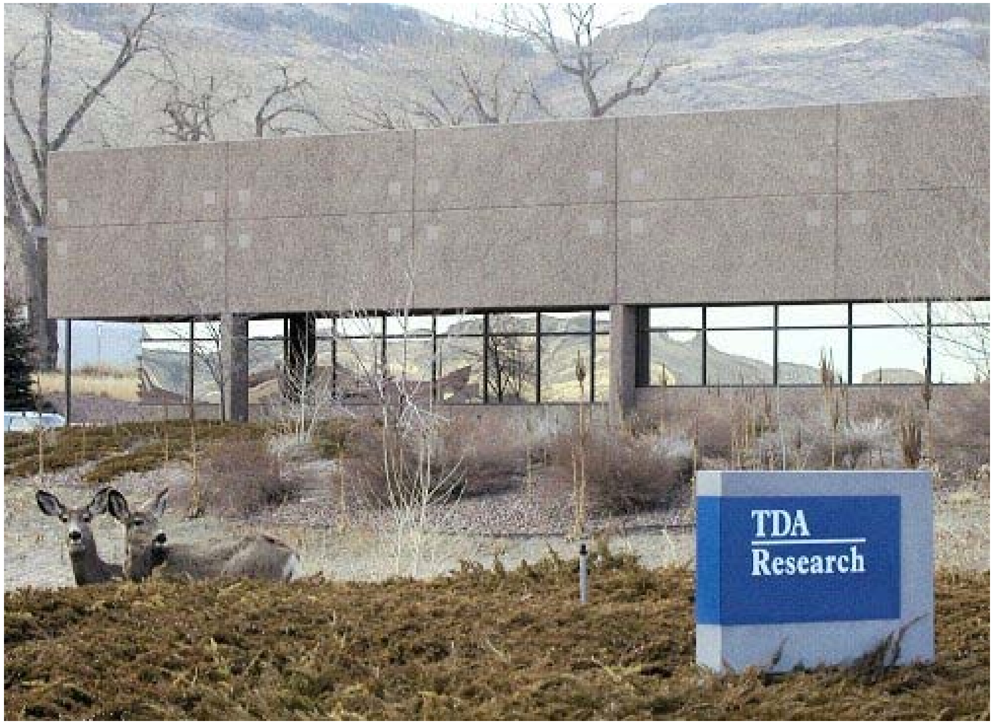
Post-Combustion CO_2 Capture System for Existing Coal-fired Power Plant

Project Review (DE-FE-0007580)



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DOE/NETL CO_2 Capture Technology Meeting Meeting

Pittsburgh, PA

July 8, 2013

Project Summary

- **The objective is to develop a post-combustion capture process for coal-fired power plants and demonstrate technical feasibility (at bench-scale) and economic viability of the new concept**
- **A mesoporous carbon adsorbent is used to selectively remove CO_2 from the flue gas, regenerating under very mild conditions**

Budget Period 1

- **Sorbent Optimization/scale-up and Laboratory Evaluations**
- **Process Design and System Analysis**

Budget Period 2

- **Long-term Sorbent Cycling**
- **Design of a Breadboard Prototype Test Unit**
- **High Fidelity Process Optimization and Design**

Budget Period 3

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

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Project Partners

Project Duration

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

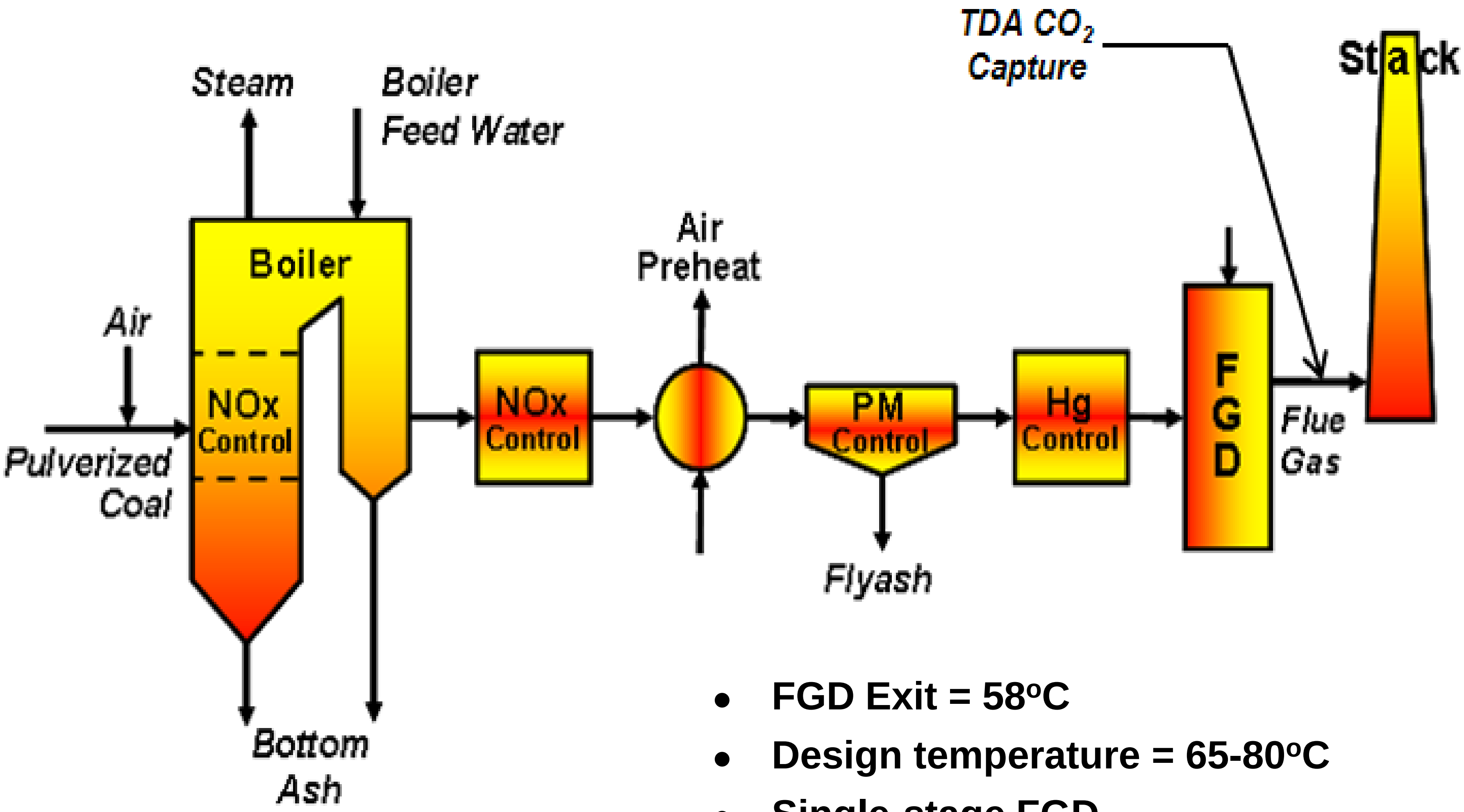
Budget

- **Project Budget = $3,375,000**
- **DOE Share = $2,700,000**
- **TDA/Partners Share = $675,000**

TDA's Approach

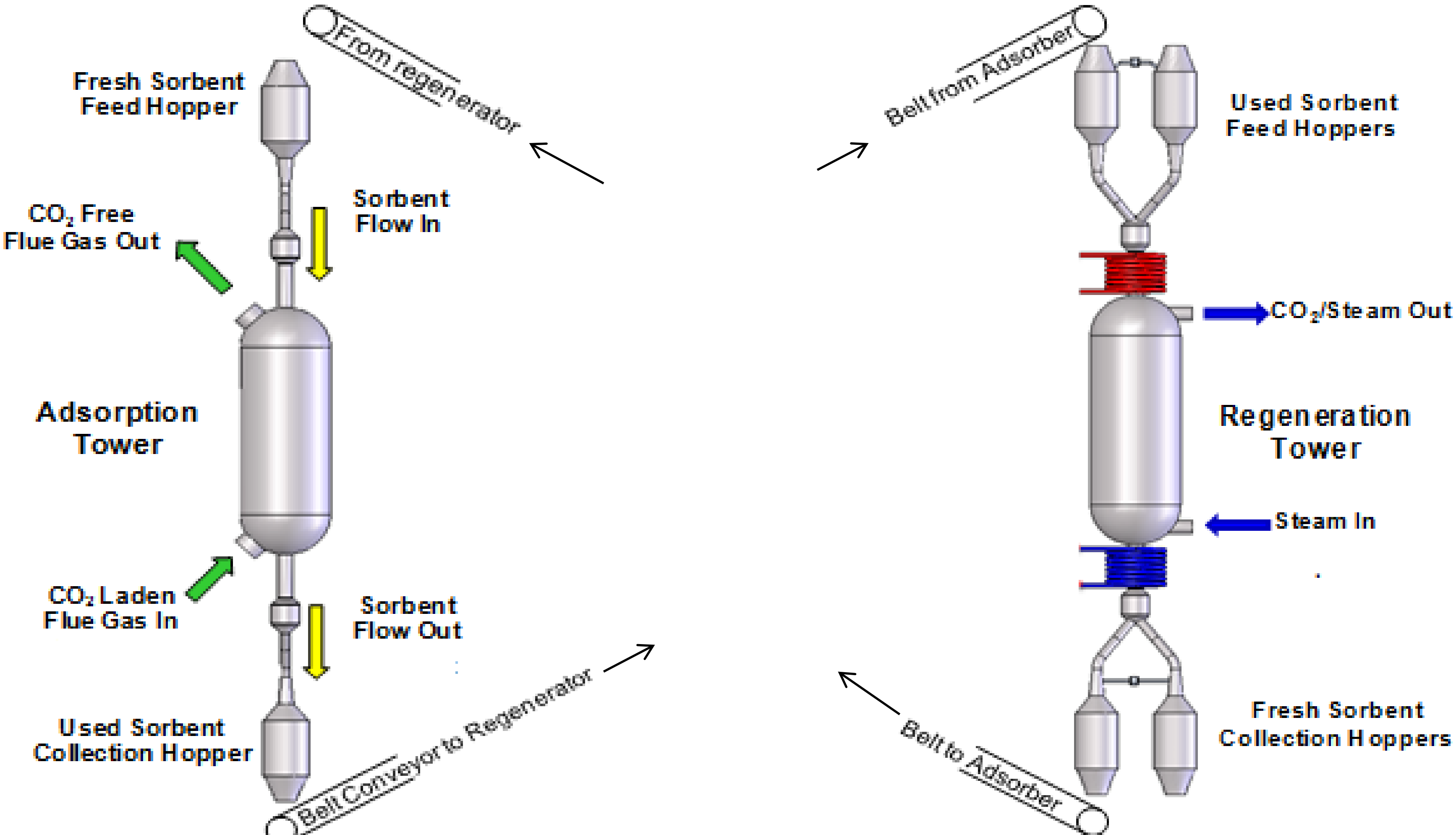
- **The sorbent consists of a carbon material modified with surface functional groups that remove CO_2 via physical adsorption**
  - CO_2-surface interaction is strong enough to allow operation at target temperature range
  - Because CO_2 does not covalently bond to the surface, the energy input for the regeneration process is low
- **Heat of adsorption of CO_2 is measured as 3.9-4.8 kcal/mol for TDA sorbent**
  - Selexol ~4 kcal/mol
  - Amine solvents ~14.4 kcal/mol
  - Chemical absorbents 20-40 kcal/mol
    - $Na_2CO_3 + CO_{2(g)} + H_2O_{(g)} \rightarrow 2NaHCO_3$ ($\Delta H = -30$ kcal/mol)
- **The net energy loss in sorbent regeneration is expected to be much lower than amine scrubbers**
  - Higher process efficiency

Integrated CO_2 Capture System



- FGD Exit = 58ºC
- Design temperature = 65-80ºC
- Single-stage FGD

TDA's CO_2 Capture System



Adsorption Regeneration

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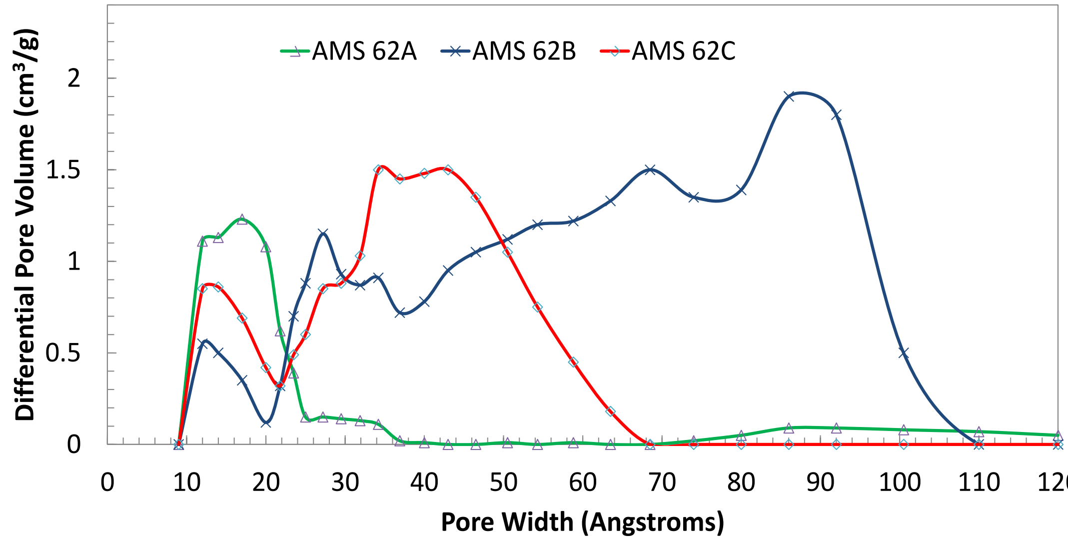
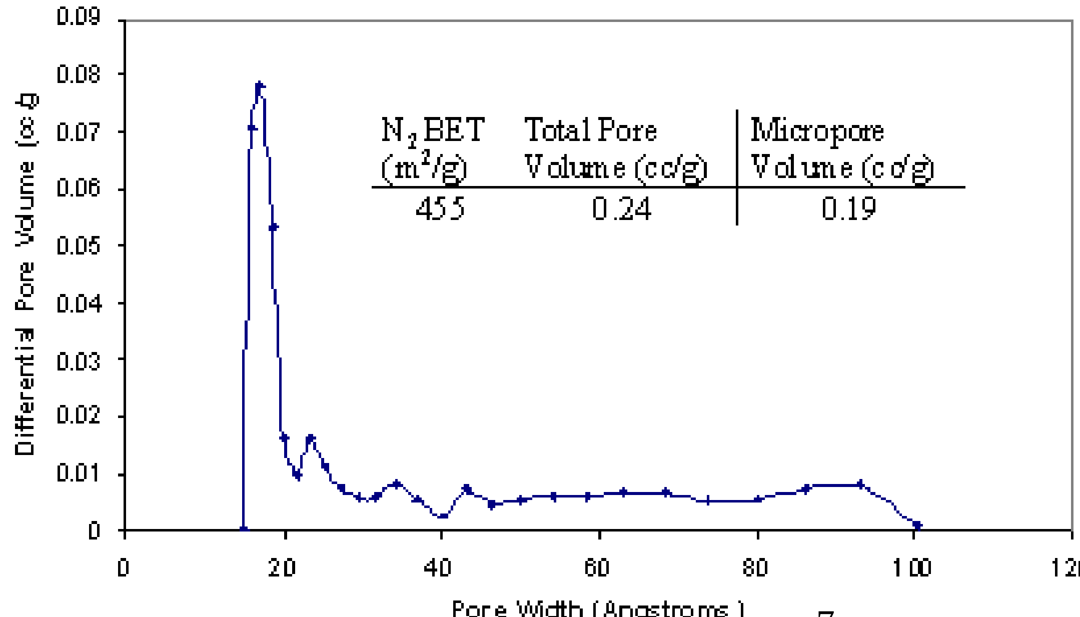
TDA's Sorbent

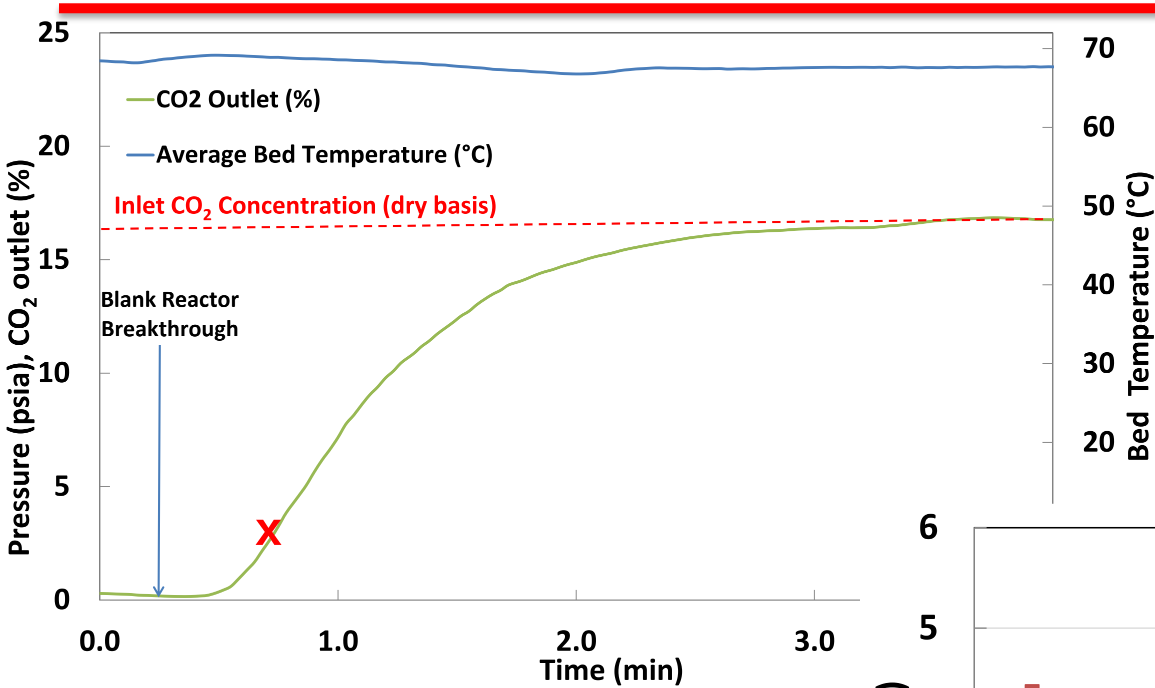
- **A mesoporous carbon is used to disperse the active sorbent phase**
  - **The synthesis process enables us to introduce surface groups active for CO_2 removal**
- **The carbon support is previously developed for ultra-capacitors, large pores to facilitate liquid transport**
  - **Successfully demonstrated for pre-combustion carbon capture (DE-FE0000469)**
  - **T= 260ºC, 12,000+ cycles in lab, 2,500+ cycles in the field**



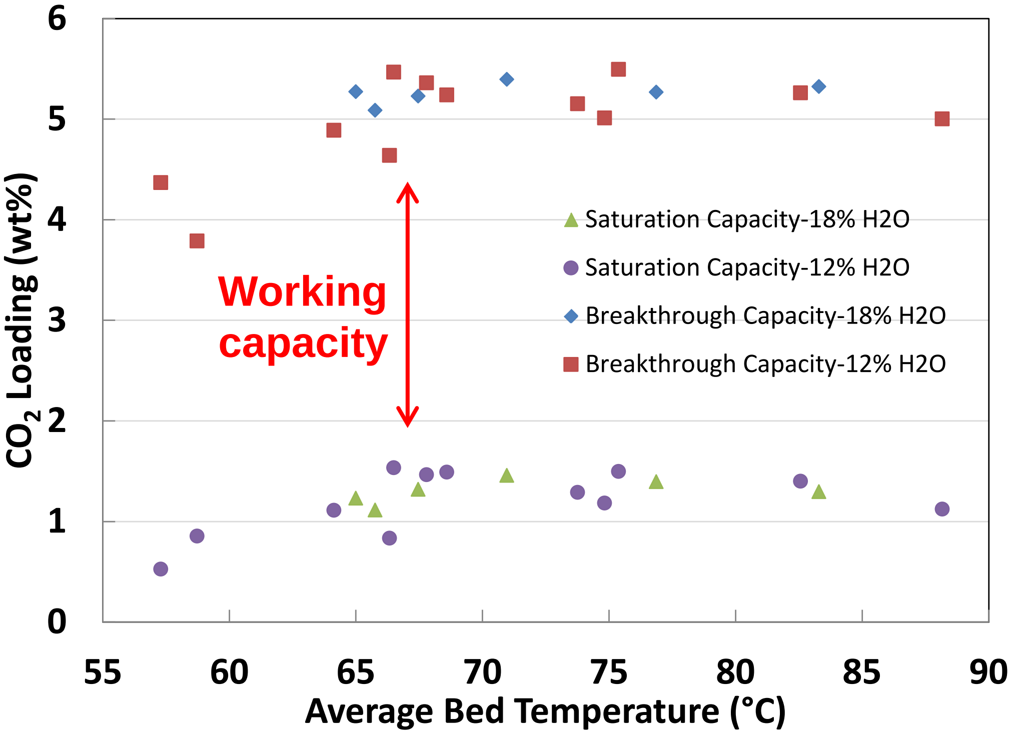


N$_2$ BET (m^2/g)	Total Pore Volume (cc/g)	Micropore Volume (cc/g)
455	0.24	0.19

CO_2 Breakthrough Profile/Capacity

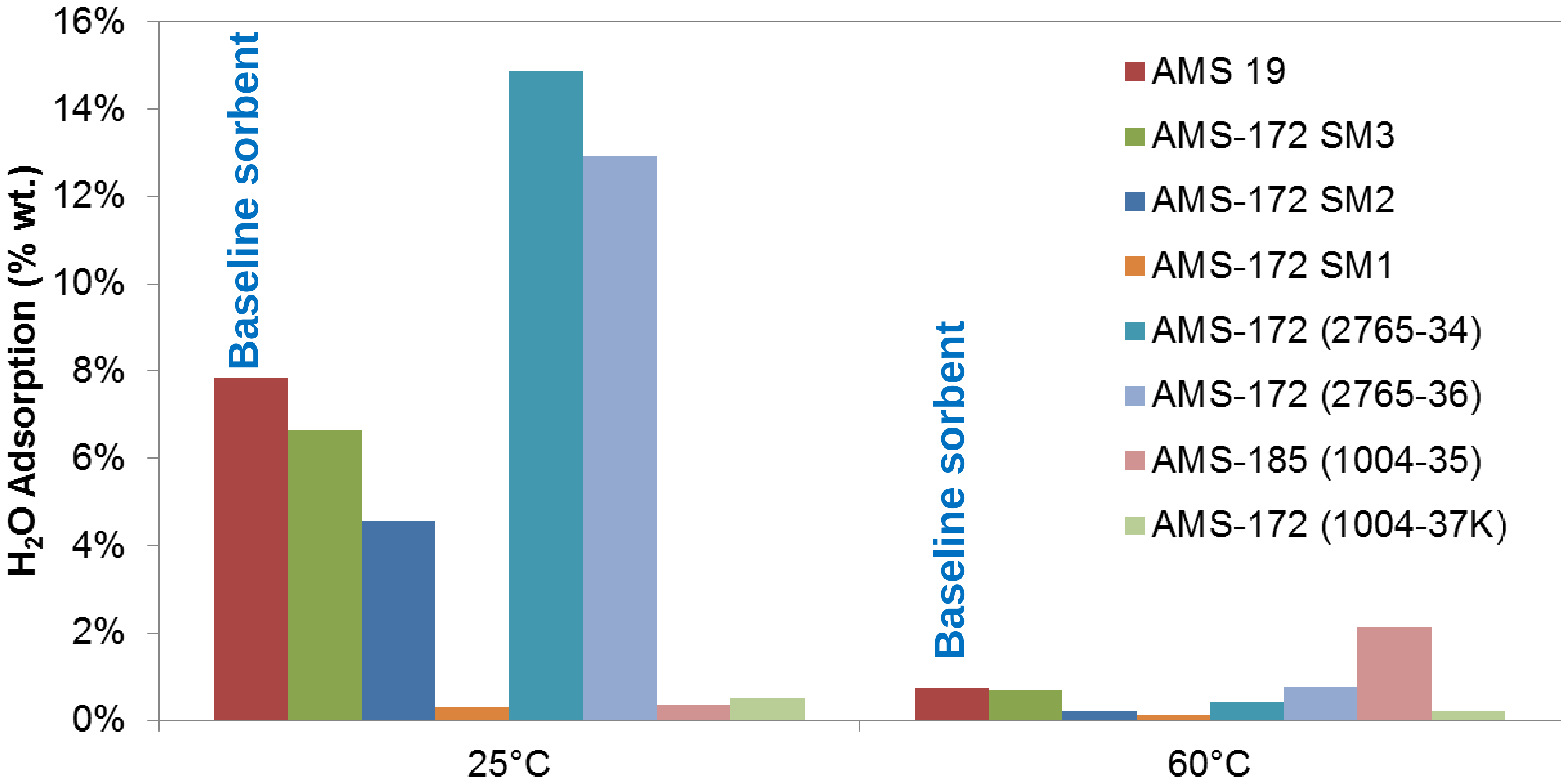


T=68°C, P=16 psia, GHSV= 2,000h^{-1}, 15% CO_2, 12-18% H_2O, simulated flue gas



- **CO_2 capacity = 1.5% wt. at breakthrough (2% vol. CO_2 at the exit)**
- **CO_2 capacity = 5.3% wt. at saturation**

Control of Water Adsorption



- **The carbon surface is modified to reduce water adsorption**
  - **In addition to surface functionality, surface area and pore size are also optimized to reduce the water uptake**

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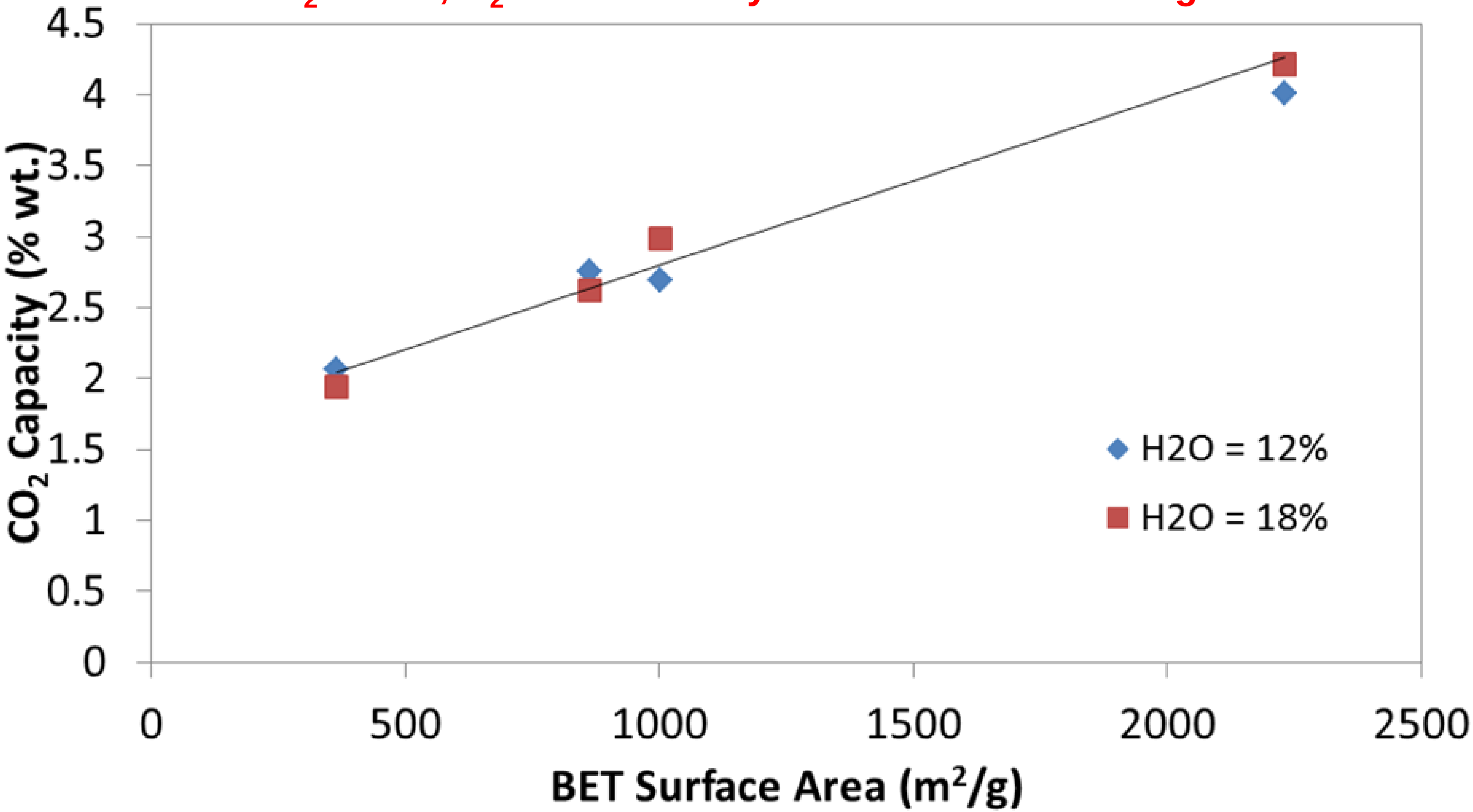
Impact of Surface Area

T = 60°C, P = 19 psia, GHSV = 2,000 h^{-1}
CO_2 = 15%, H_2O = 12-18% by vol. in simulated flue gas



- **Higher surface area resulted in higher capacities due to increased number of active surface sites**

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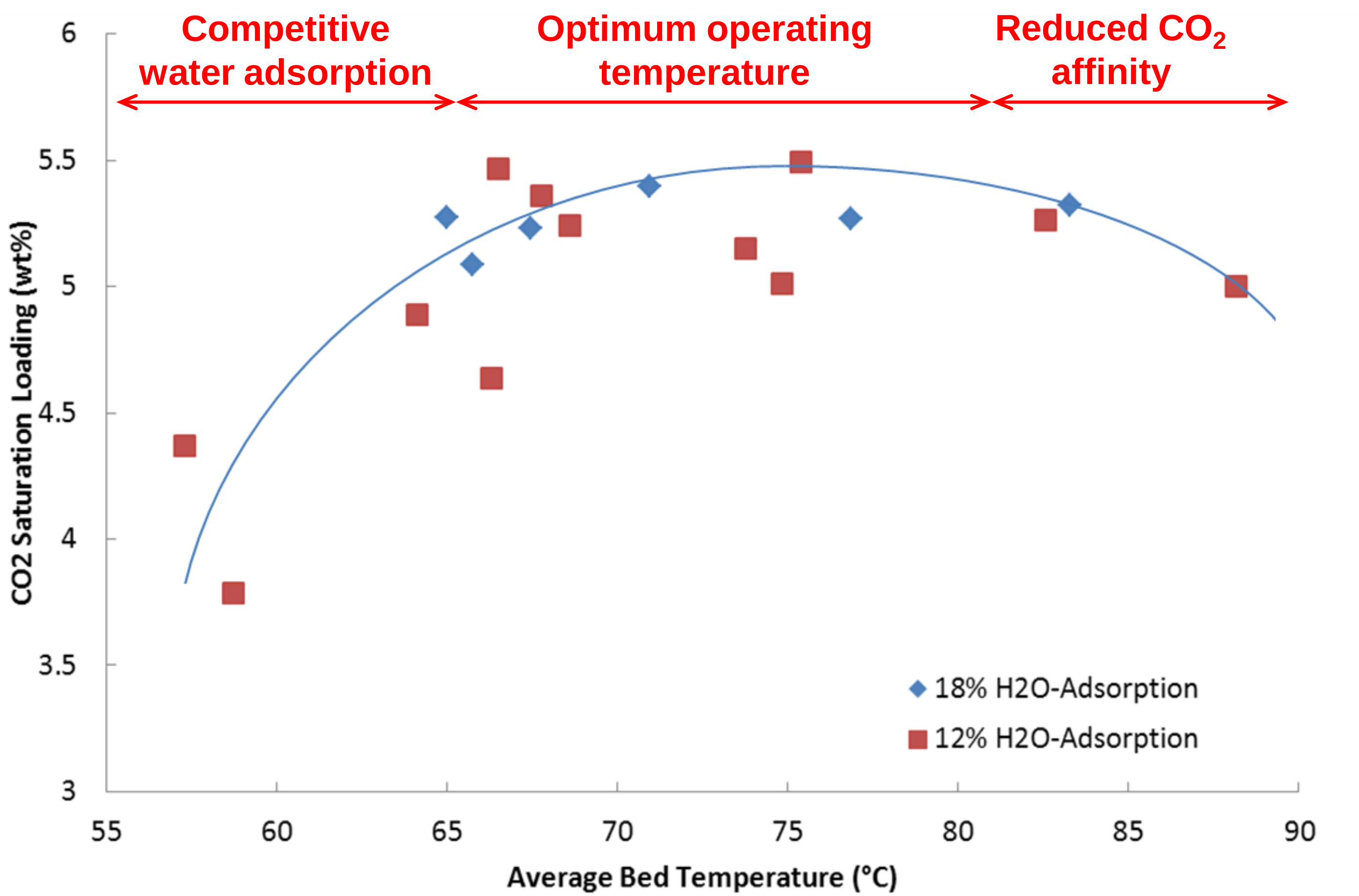
Effect of Temperature



- **Better sorbent performance was observed at 65-80ºC range**
  - **Competitive adsorption of water at lower temperatures**
  - **Lower CO_2 affinity to the surface at higher temperatures**

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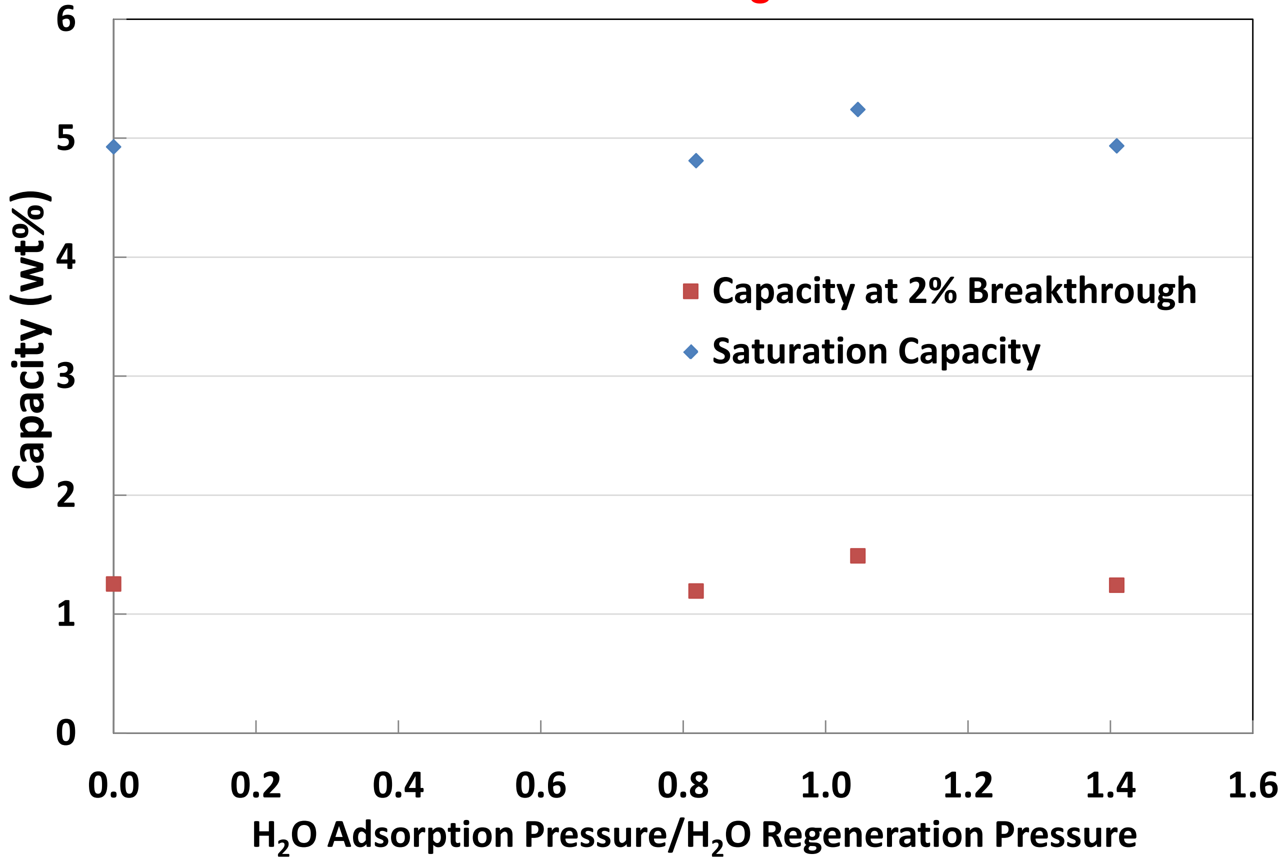
Impact of Water Concentration During Regeneration

T = 60°C, P =18 psia (adsorption), P= 4.8 psia (regeneration), CO_2 = 15%, H_2O = 18% in simulated flue gas



- **Water concentration (partial pressure) has shown to have little impact on the CO_2 capacity of the sorbent**

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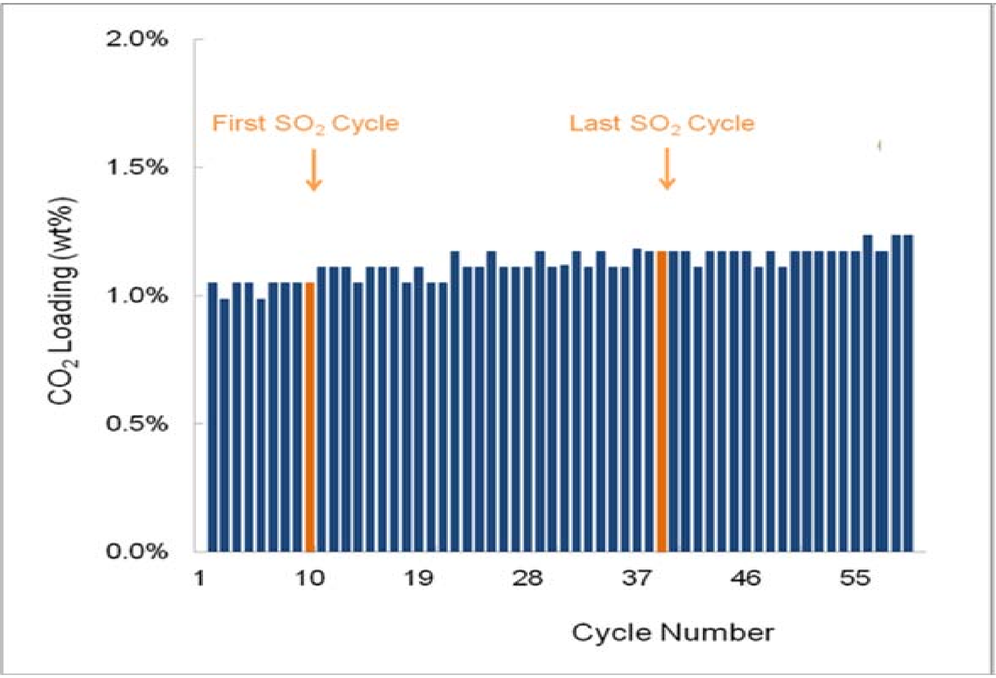
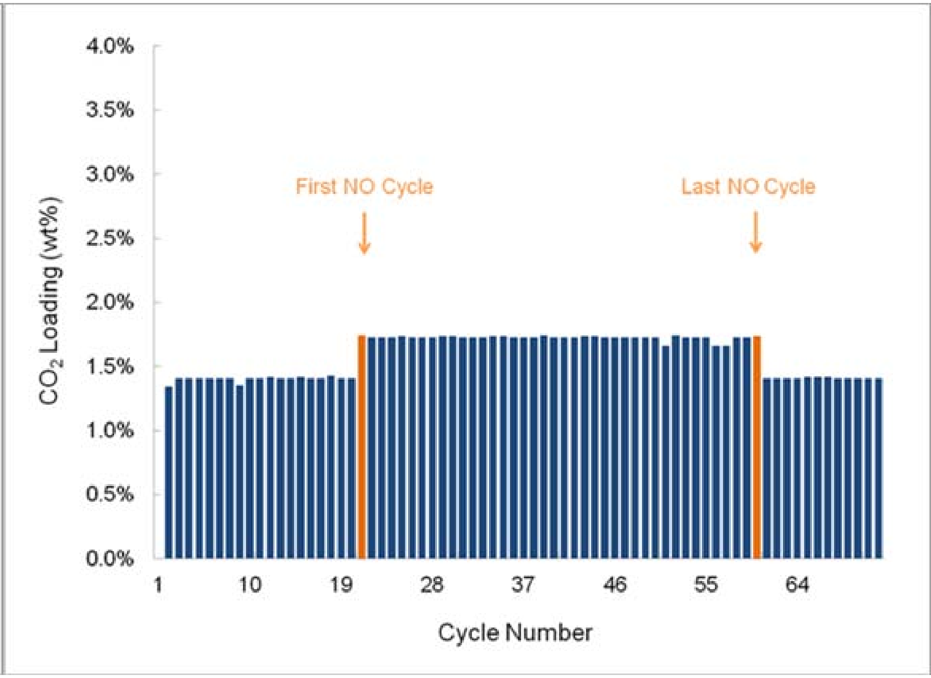
Impact of Contaminants

Adsorption - 62ºC, 300h^{-1}, 1 psig (15.2% CO_2, 2.8%O_2, bal N_2, or 300 ppm SO_2 or 70ppm NO)

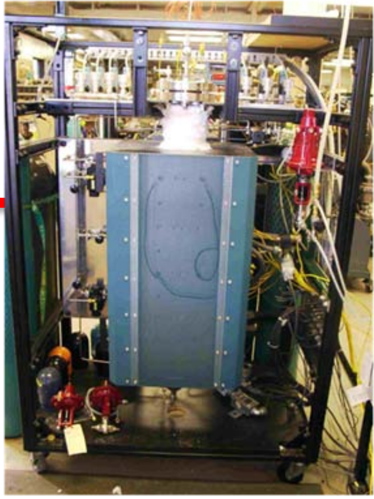
Regeneration = 300h^{-1}, 1psig, N_2 Only, 62ºC



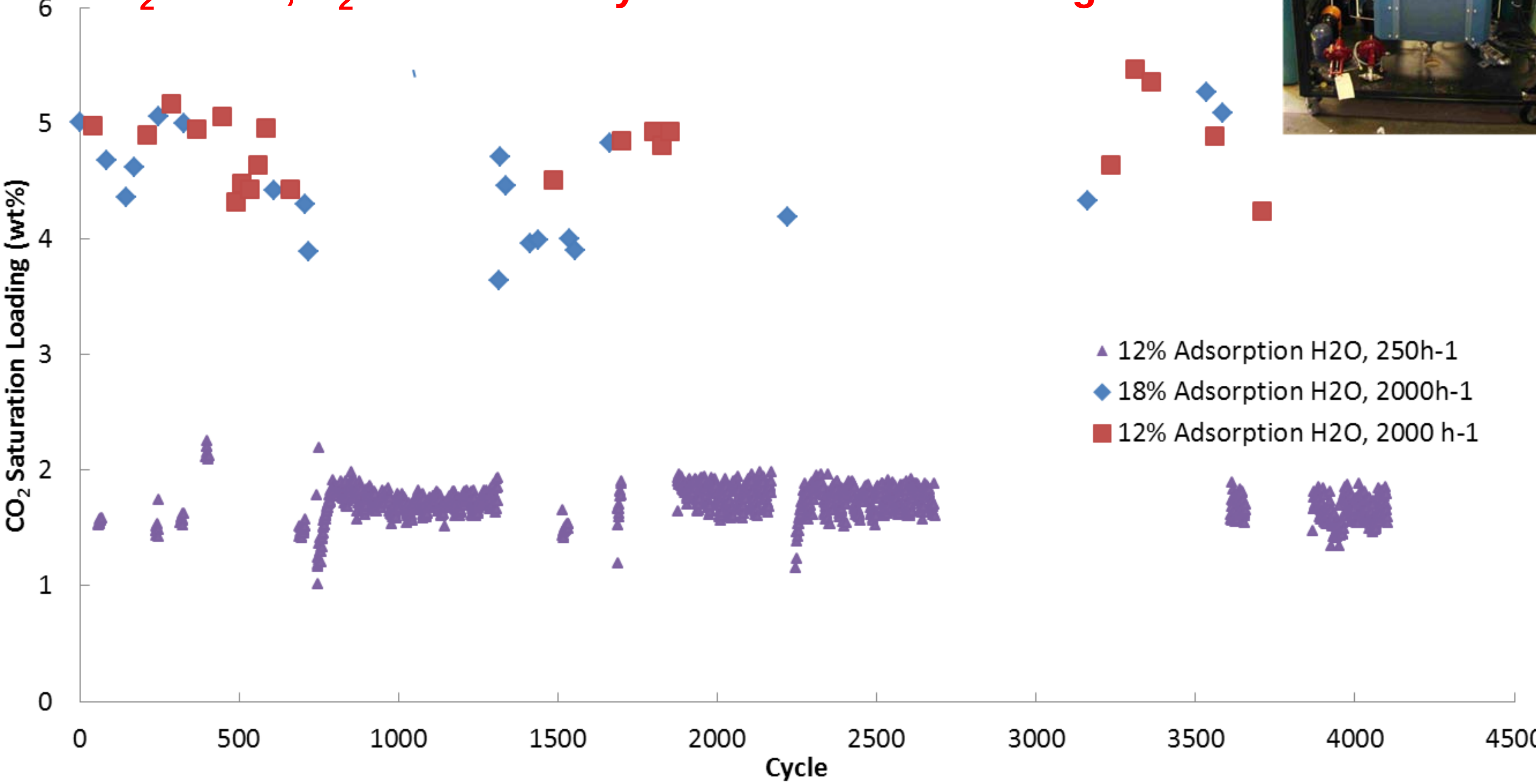


- **Sorbent maintained a stable working capacity at 62ºC cycling in the presence of 70 ppmv NO and up to 300 ppmv of SO_2**

Multiple VSA Cycles

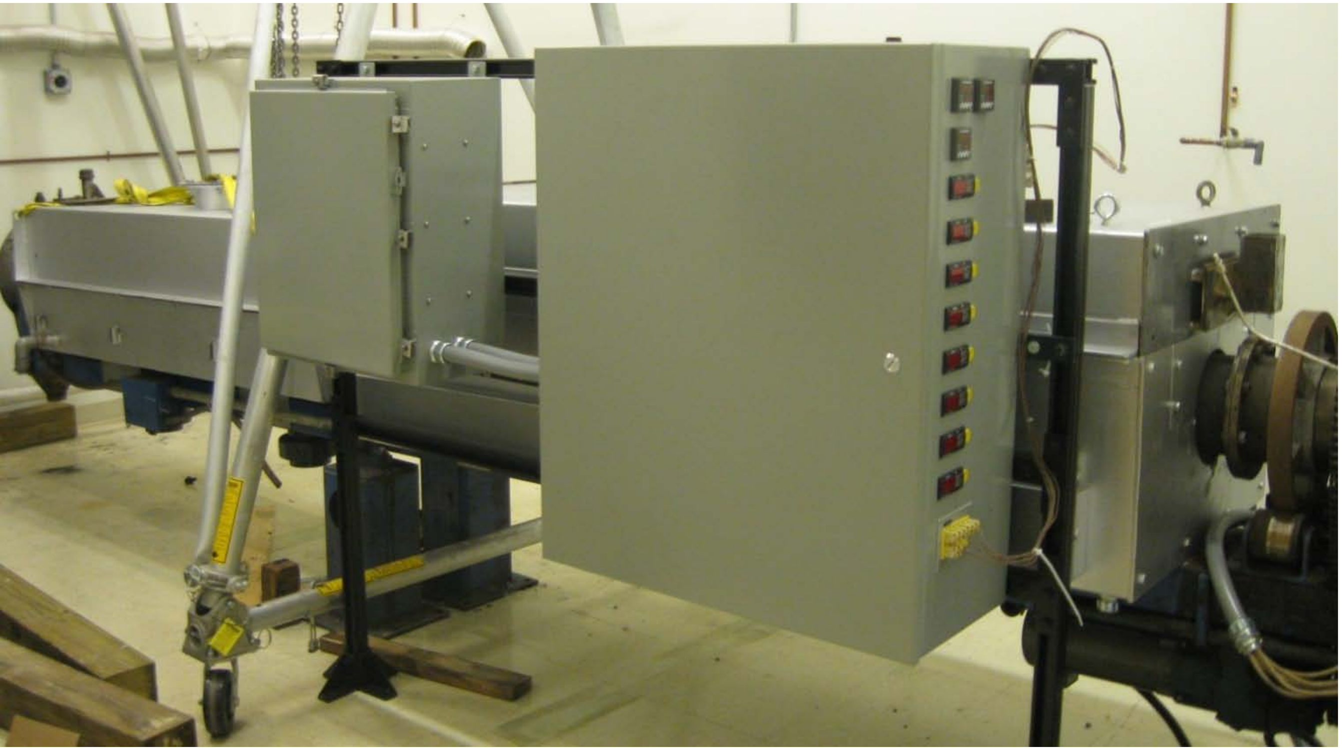


T = 58-70°C, P_{ads} = 14-18 psia, P_{des} = 3 psia, GHSV = 250 or 2,000 h^{-1}
CO_2 = 15%, H_2O = 12-18% by vol. in simulated flue gas



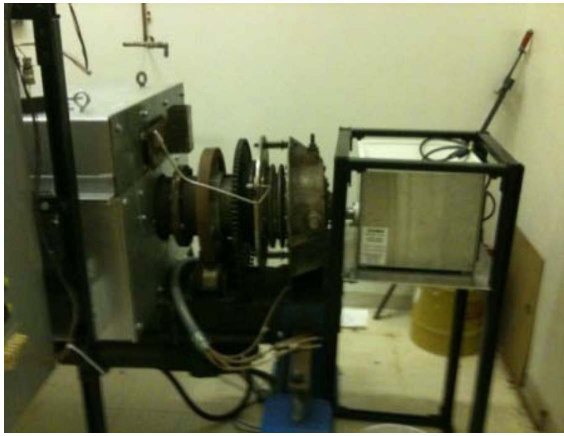
- **Sorbent maintained capacity and removal efficiency over 4,200 cycles**

Production Scale-up



Continuous rotary kiln

Exhaust gas treatment



Feeder

- **A continuous rotary kiln was setup to carry out the carburization and activation processes**
  - **12 lb/hr production capacity (continuous)**

Improvements in Mechanical Integrity

- **The crush strength of the pellets are improved to 2.5-3 lb_f/mm (typical range for the commercial samples)**

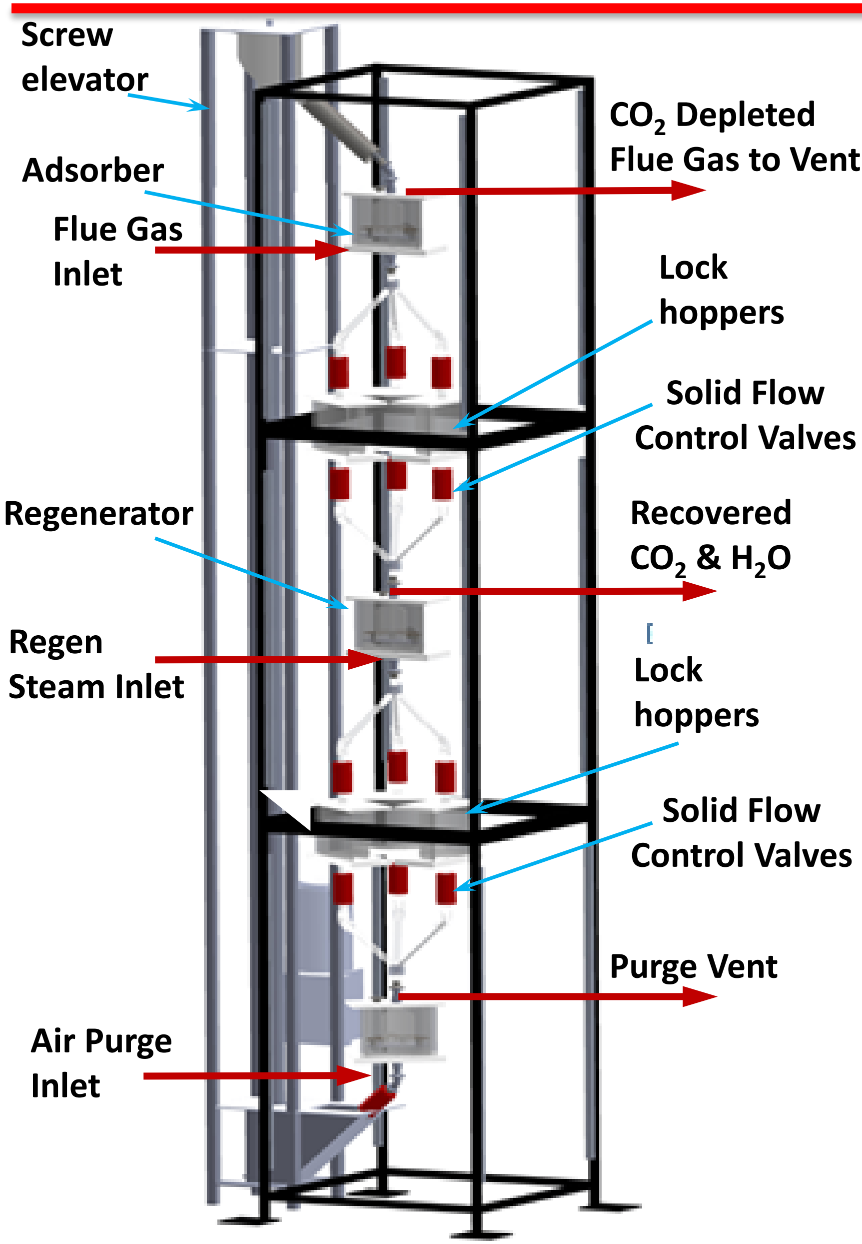
2" screw extruder

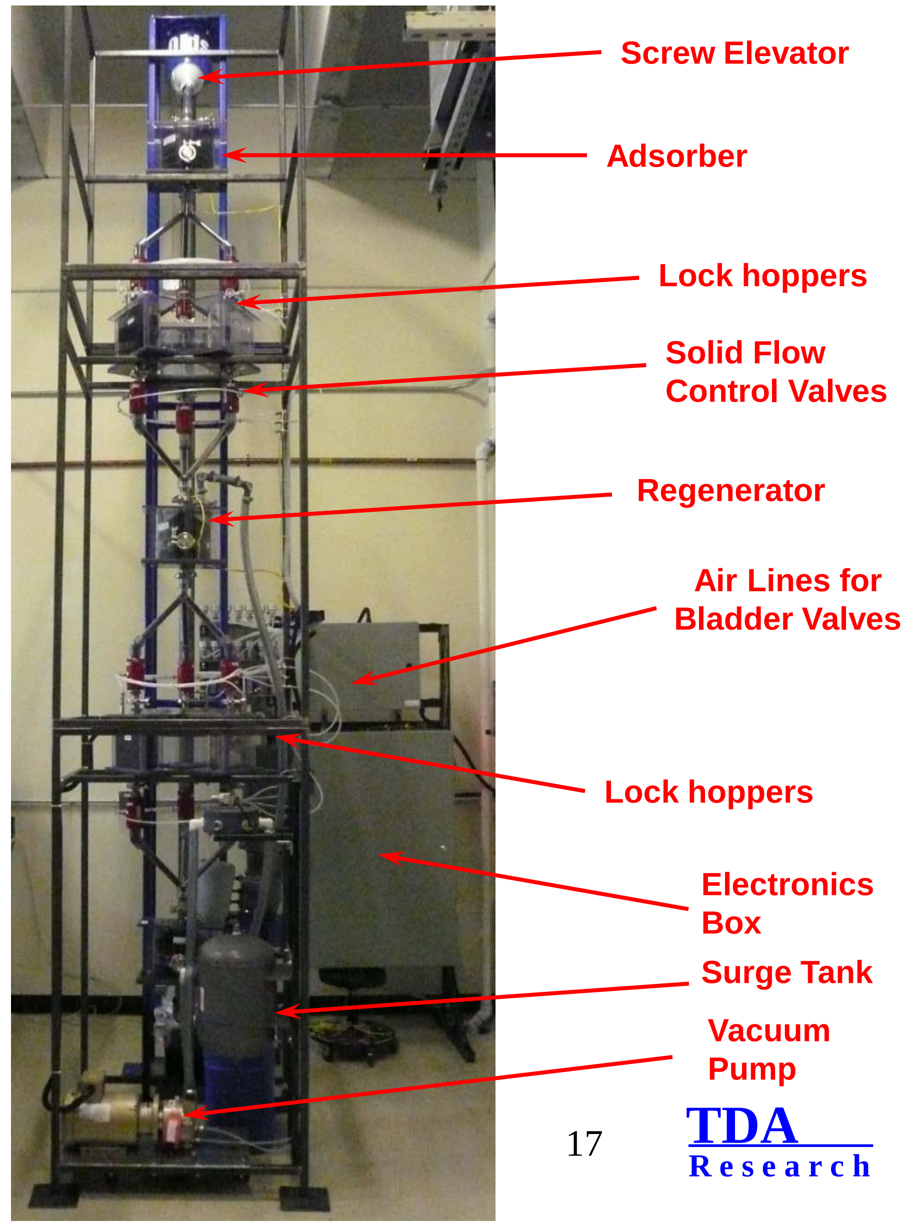
Pellets before treatment

Pellets after treatment

- **Among the various approaches, forming the pellets prior to carburization provided the highest strength pellets**
  - **Also provides high yields**

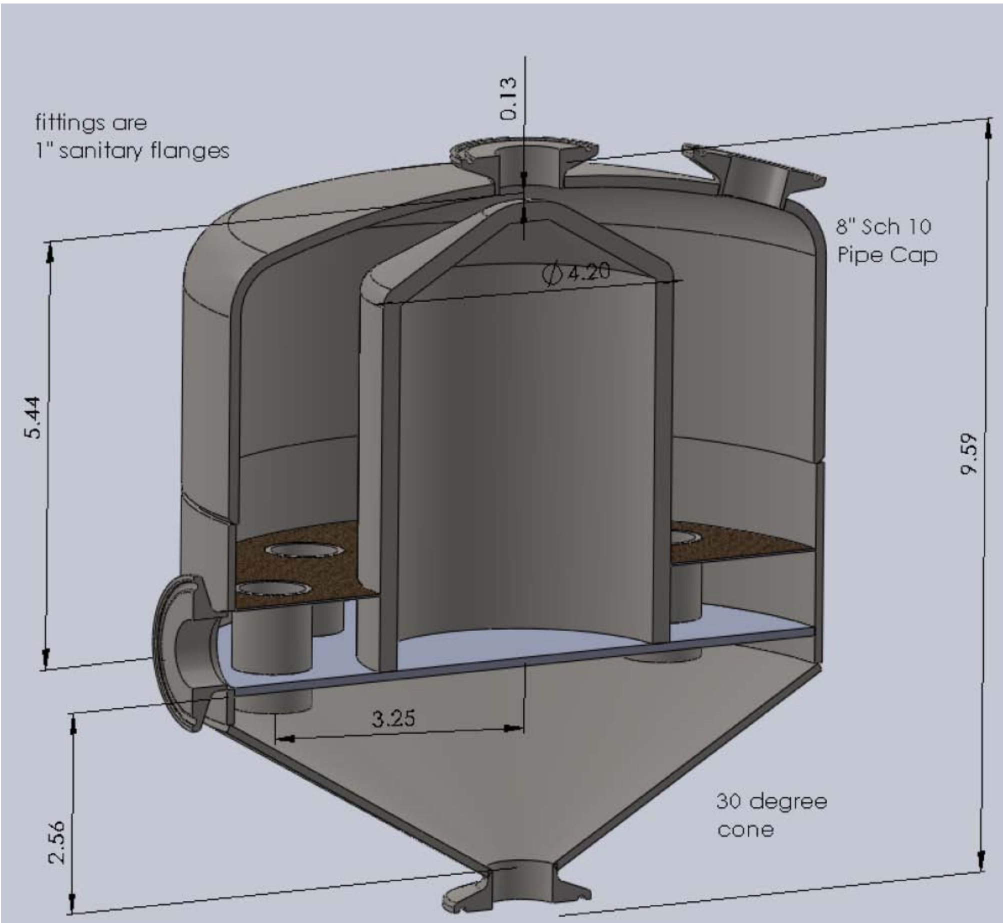
Prototype Unit Design



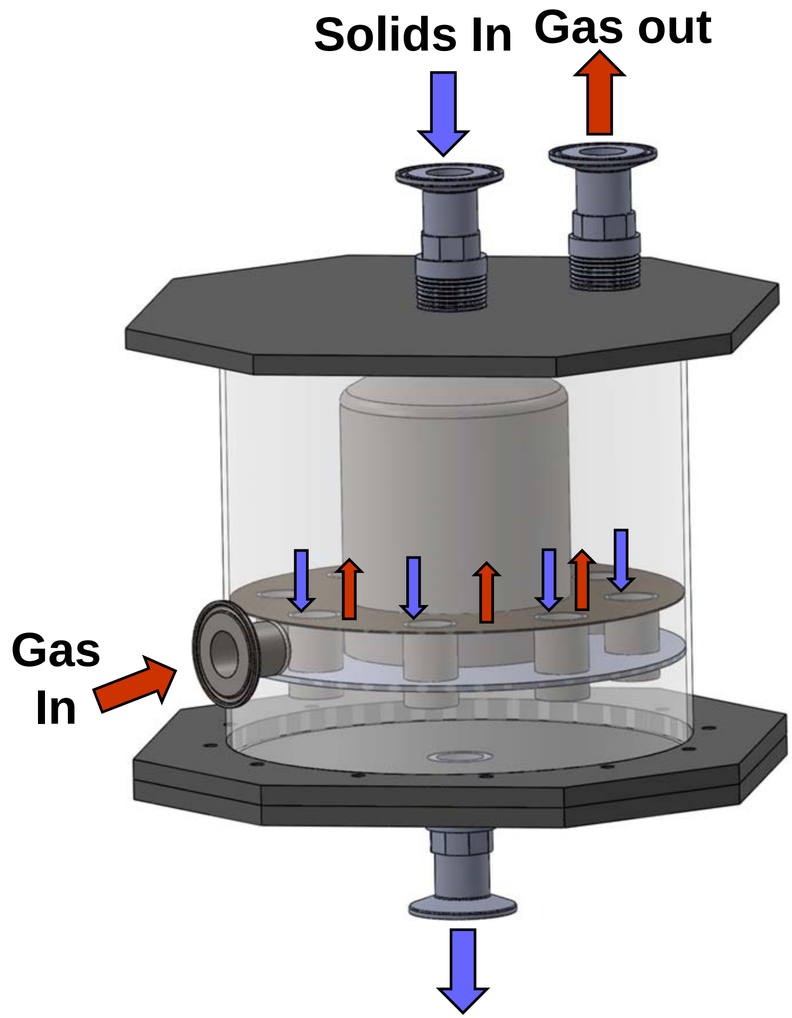


Gas-Solid Contactors

Prototype Adsorber Reactor



2-5 ACFM flue gas flow
7-8 ft^3/h of sorbent circulation



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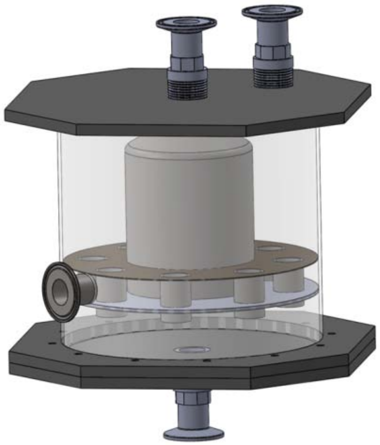
Research

Cold Flow Visualization Unit



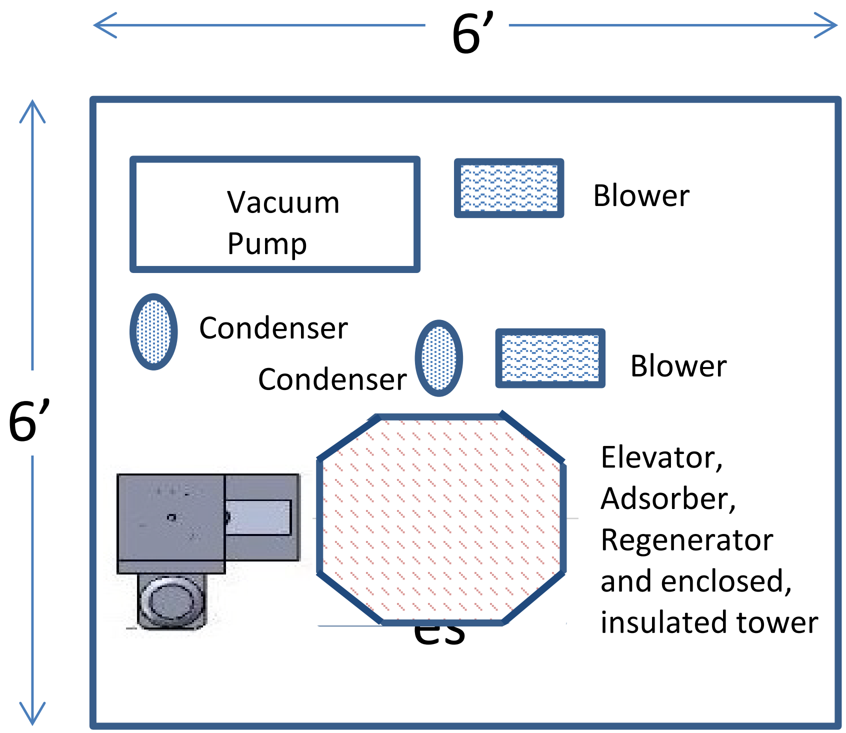
- **A clear cold flow visualization system (absorber, regenerator along with the bladder valves) was assembled**
    - **To monitor desired solids distribution**
    - **To optimize the control of solids flow rate**

Preliminary Flow Tests



- **First, single-reactor flow tests in clear reactors were completed in a dedicated test stand**
- **The operation of bladder valves were optimized**
    - **The air pressure outside of the bladder is adjusted to control the orifice size (thereby control of the solid flow rate)**

Slipstream Testing with the Unit - GTI



- **A slipstream test will be carried out at GTI**
- **All facility requirements are identified**
  - **Skid size/footprint, consumables, analytical needs**
- **A preliminary design review is scheduled by the end of summer**

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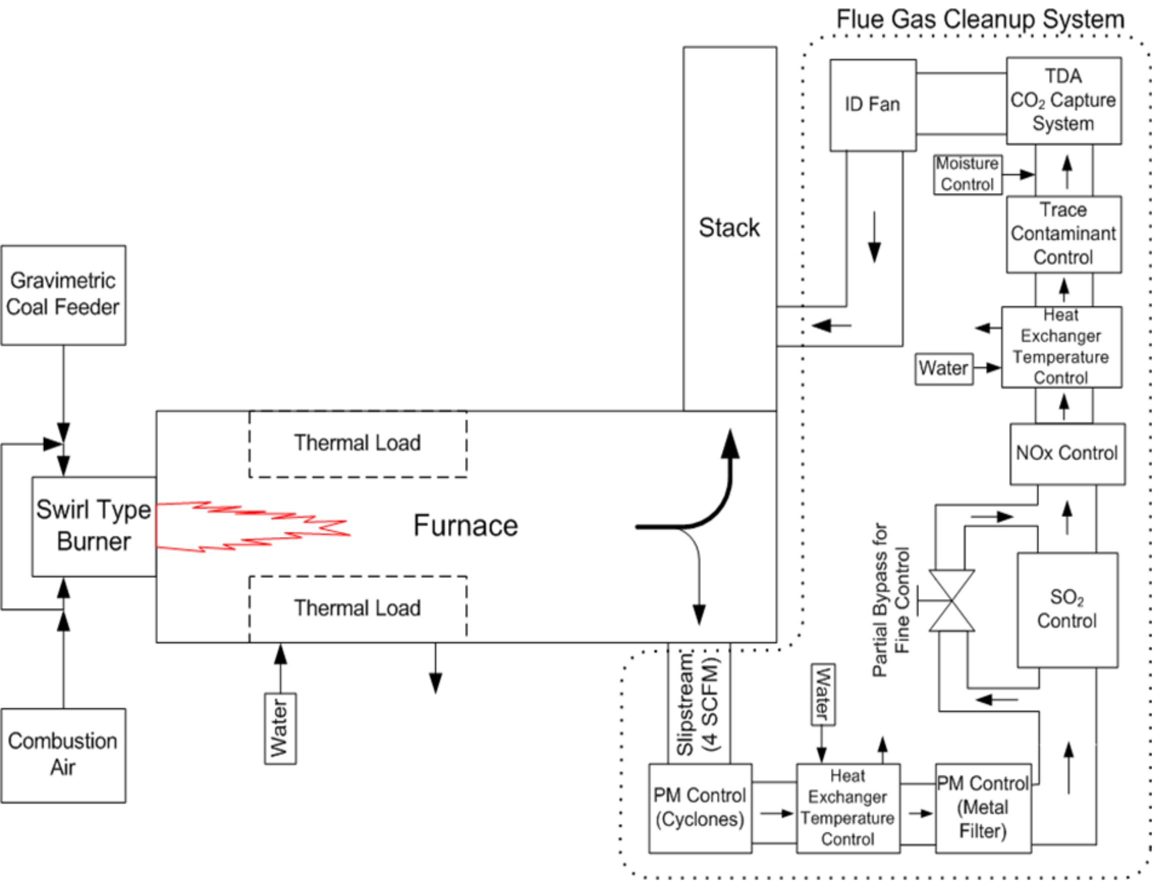
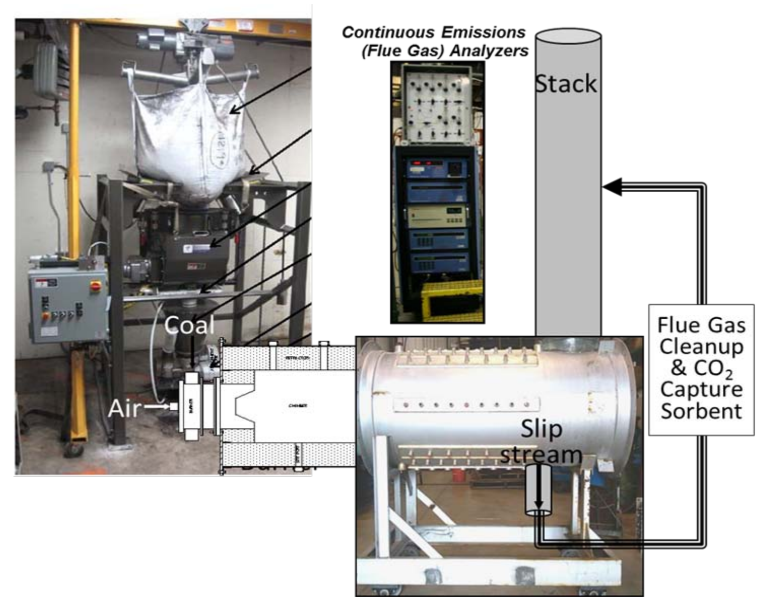
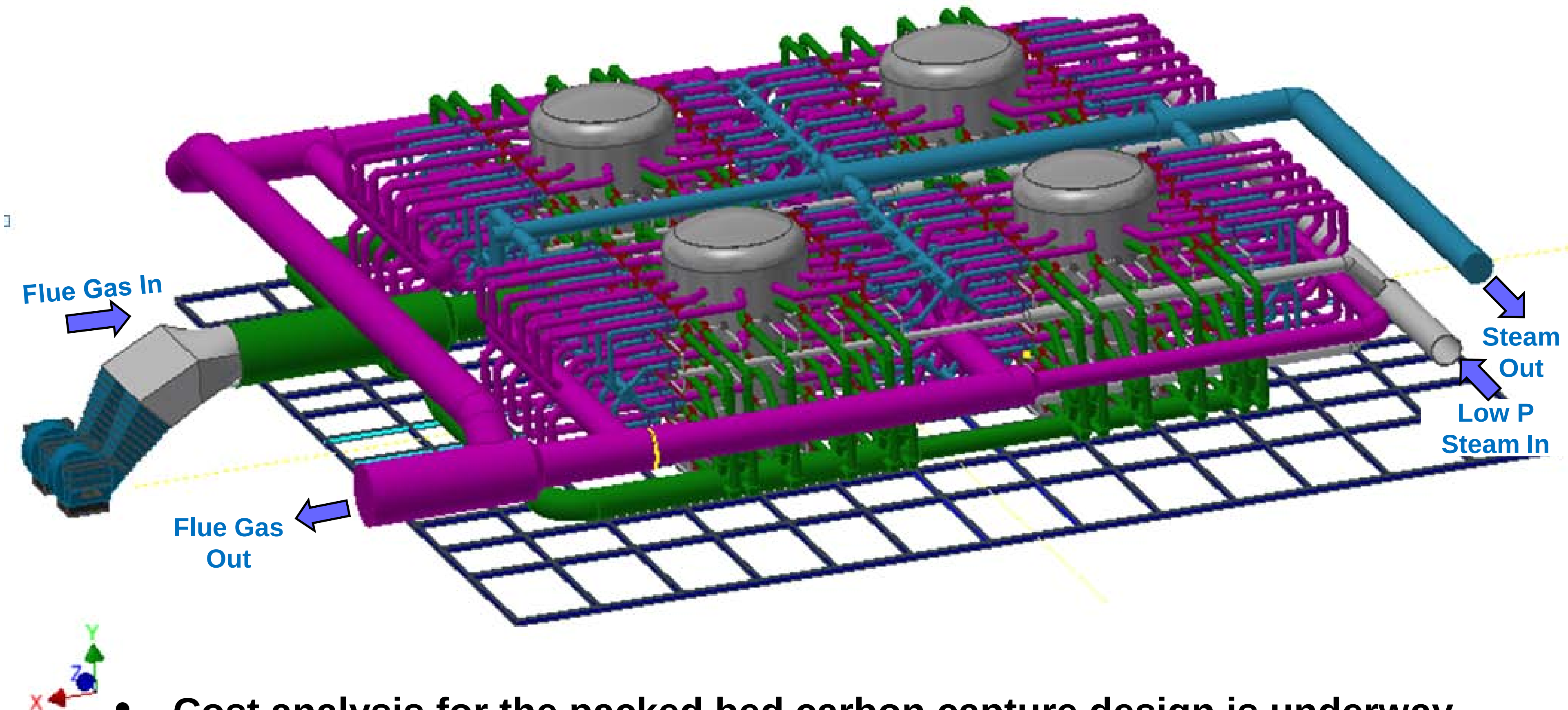
Site Preparation Work - GTI





- **GTI completed all site modifications, including installation of a coal feeder and modifications to an existing boiler**
- **The test system will provide 4 CFM flue gas slipstream at the desired gas composition/purity**

Plant Layout/Packed Beds – B&W



- **Cost analysis for the packed bed carbon capture design is underway**
- **Based on the data from the prototype unit, B&W will also design a moving-bed carbon capture system**

System Analysis Results - UCI

	Case 9 (No-CO_2 Capture, DOE Report Data)	Case 9 (No-CO_2 Capture, Aspen)	Case 10 AMINE (DOE Report Data)	Case 10 AMINE (Aspen)	Case 10A TDA_VSA (Aspen)
CARBON CAPTURED, %	0	0	90	90	90
GROSS POWER GENERATED (AT GENERATOR TERMINALS), KWE					
STEAM TURBINE POWER	**582600**	**582600**	**672700**	**672700**	**814185**
AUXILIARY LOAD SUMMARY, KWE					
CO2 REMOVAL POWER	--	--	**22400**	**22084**	--
SORBENT CONVEYING POWER	--	--	--	--	**9147**
CO2 COMPRESSION POWER	--	--	**48790**	**48791**	**133406**
PUMPING & COOLING TOWER	9390	8899	18730	18559	16809
OTHER LOADS	23190	23185	32820	32816	33394
TOTAL AUXILIARIES, KWE	32580	32084	122740	122250	192756
NET POWER, KWE	550020	550516	549960	550451	621430
% NET PLANT EFFICIENCY, % HHV	**36.8**	**36.81**	**26.2**	**26.18**	**29.56**
CONSUMABLES					
AS-RECEIVED COAL FEED, KG/H	**198391**	**198392**	**278956**	**278957**	**278957**
LIMESTONE SORBENT FEED, KG/H	19691	19944	28404	28831	28831
RAW WATER USAGE, GPM	5896	6541.678	11224	11212	10172

- **TDA's CO_2 capture system achieves 29.6% efficiency in comparison to 26.2% with the amine scrubbers (DOE/NETL-2010/1397)**
  - **19.7% efficiency drop vs. "no CO_2 capture" case**

TDA Research

Acknowledgements

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