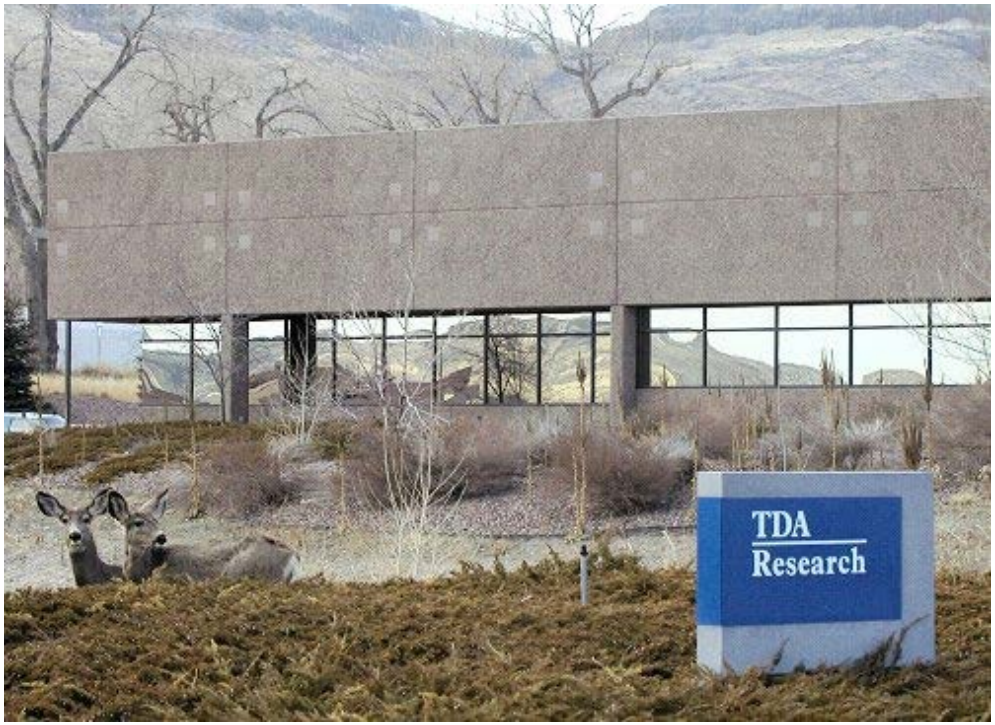
Post-Combustion CO_2 Capture System for Existing Coal-fired Power Plant

Contract No. DE-FE-0007580



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DOE/NETL Carbon Capture Meeting

Pittsburgh, PA

July 29, 2014

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

TDA Research, Inc.

- Privately Owned/Began operations in 1987
- 78 full-time technical staff
  - Primarily chemists and engineers, more than half with advanced degrees (26 PhDs)
- 50,000 ft^2 office and lab spaces
- Core competency in advanced material development
- Successful commercialization of several technologies in a wide range of applications

Direct H_2S Oxidation

Synthesis of Advanced Carbons

SulfaTrap™ Purifiers

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Project Summary

- **The objective is to develop a post-combustion carbon capture process for existing coal-fired power plants**
  - **Demonstrate techno-economic viability of the new concept at the bench-scale and via small slipstream evaluation**
- **A new carbon adsorbent is used to selectively remove CO_2 from the flue gas**

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**

Budget Period 3

- **Fabrication of the Prototype Test Unit**
- **Proof-of concept Evaluation with Actual Flue Gas**
- **High Fidelity Process Optimization/Design and Economic Analysis**

Project Partners

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B&W thebabcock&wilcoxcompany

UNIVERSITY of CALIFORNIA • IRVINE

gti

icci

Project Duration

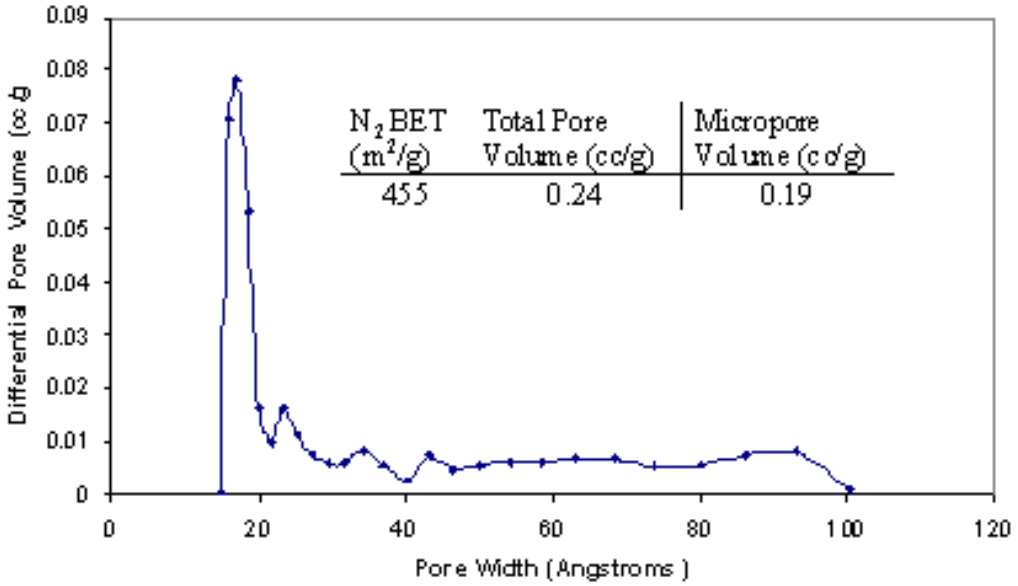
- **Start Date = October 1, 2011**
- **End Date = December 31, 2014**

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 (60-80°C)**
  - **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 3.9-4.8 kcal/mol for TDA sorbent**
  - **The net energy loss in sorbent regeneration is expected to be much lower than amine scrubbers**



- **Sorbent Features**
  - **Mesopores eliminate diffusion limitations and allow rapid cycling/short cycle times**
  - **Moderately high surface area for high CO_2 capacity**
  - **Thermal stability already demonstrated**

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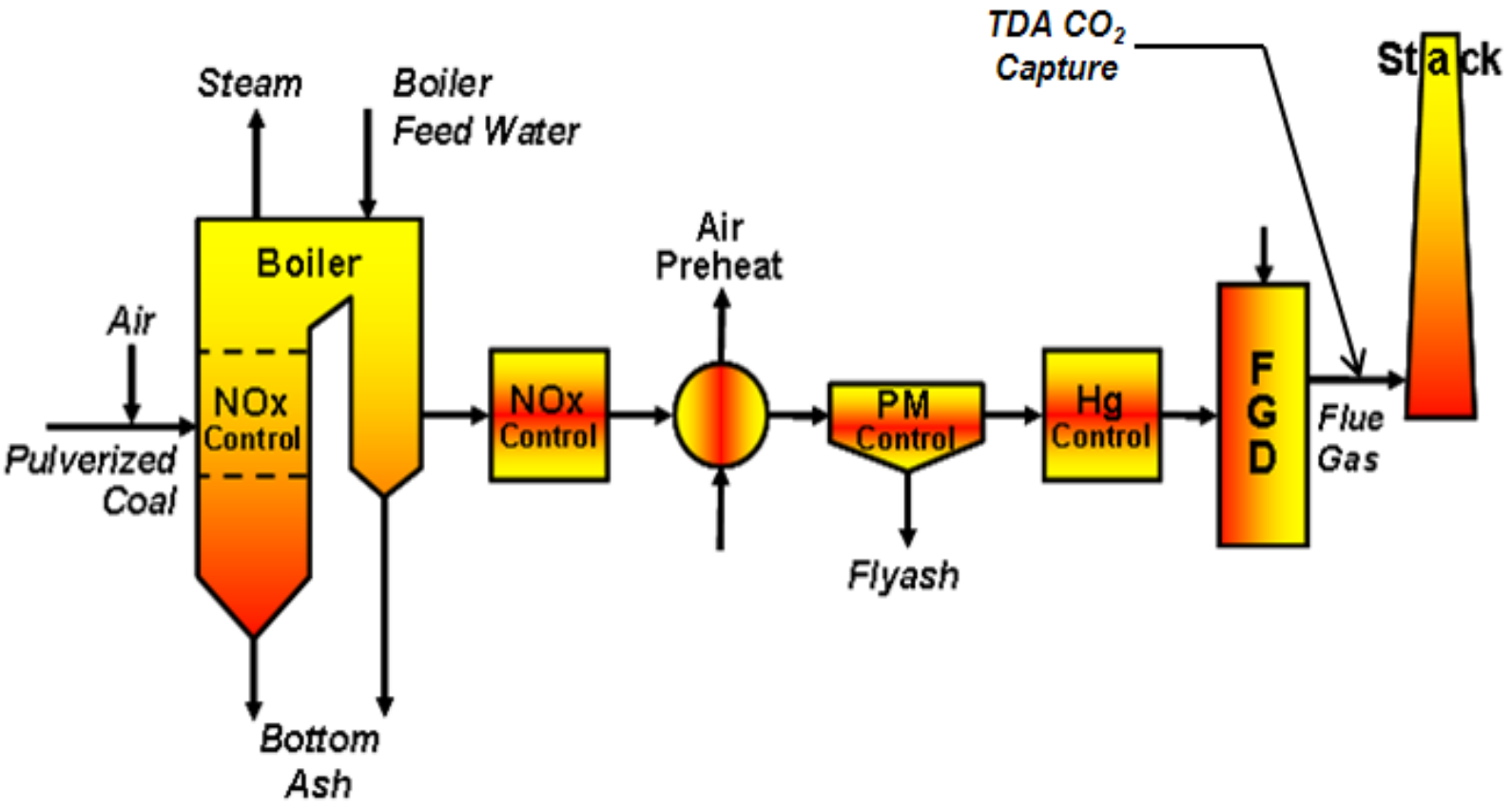
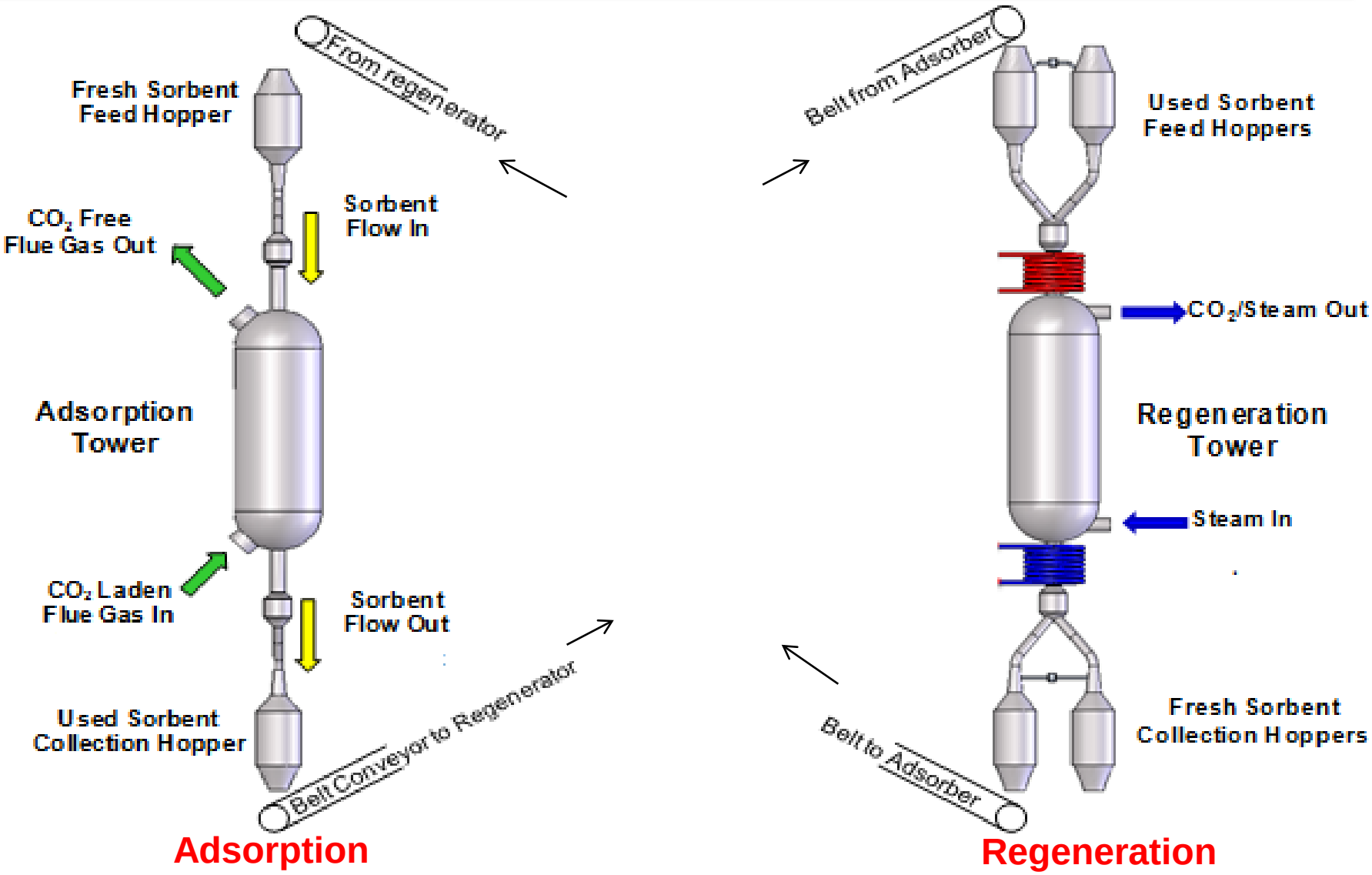
Integrated CO_2 Capture System

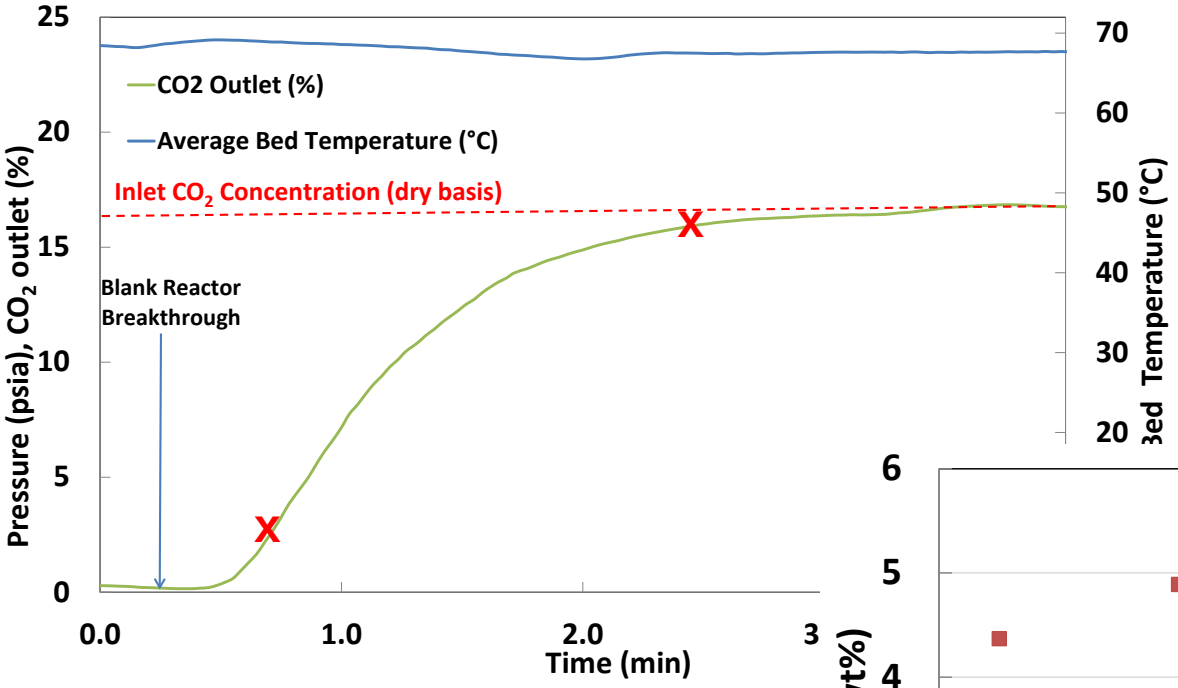


- Design operating temperature = 58-80°C
- High tolerance to SO_2 and NO_x reduces flue gas purification needs
  - Stable performance in presence of up to 70 ppmv SO_2 and 300 ppmv NO_x
  - Single-stage FGD

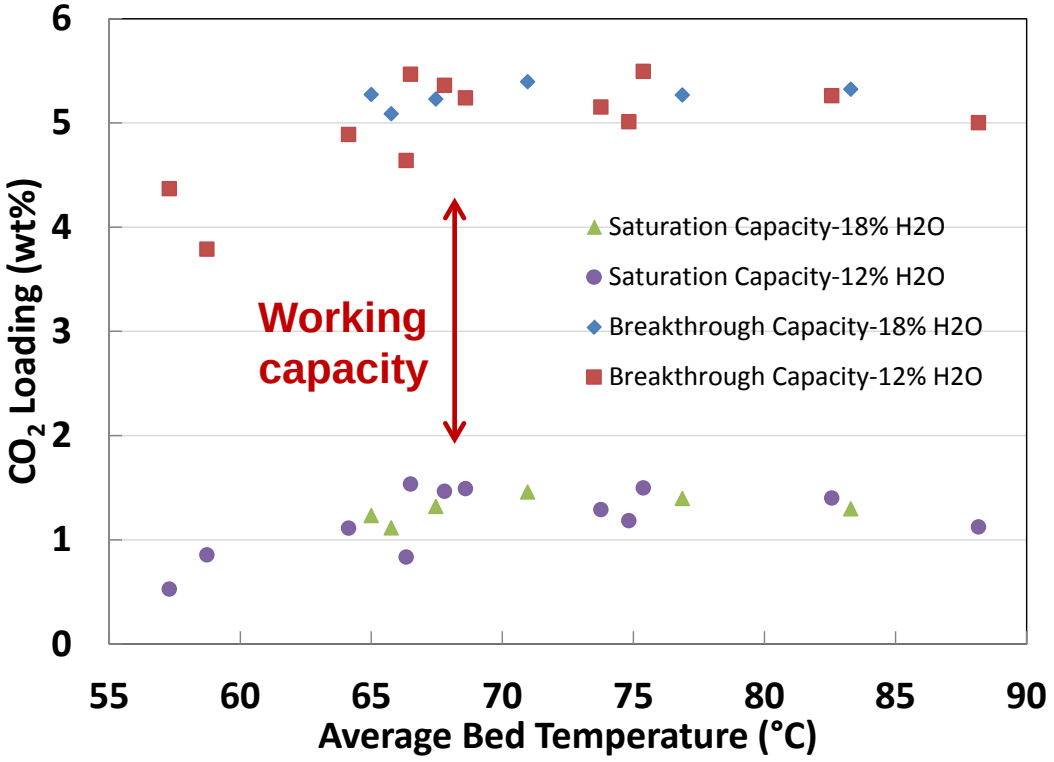
TDA's CO_2 Capture System



CO_2 Breakthrough Profile/Capacity

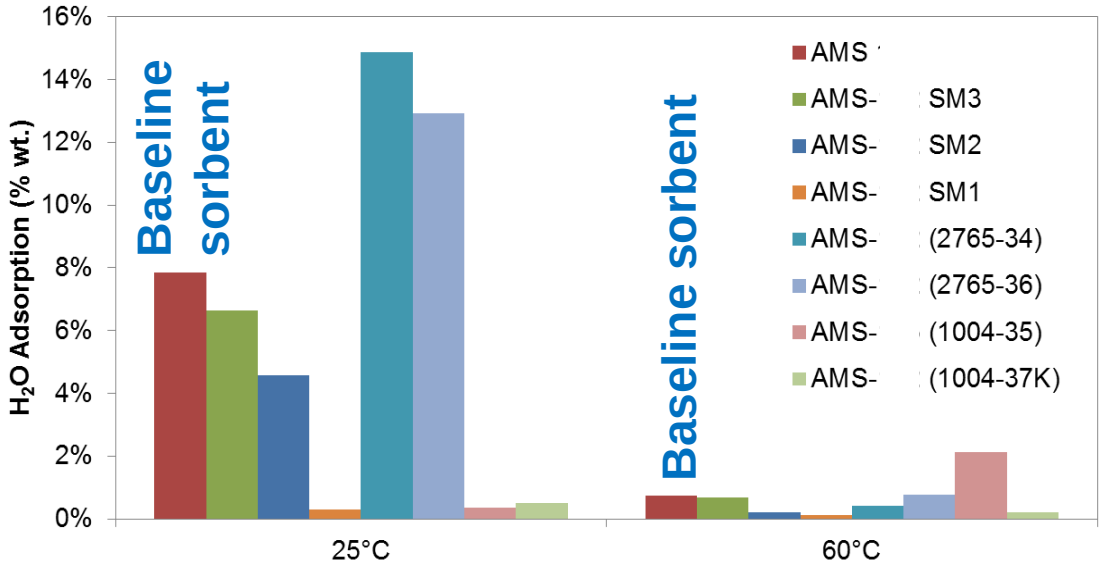


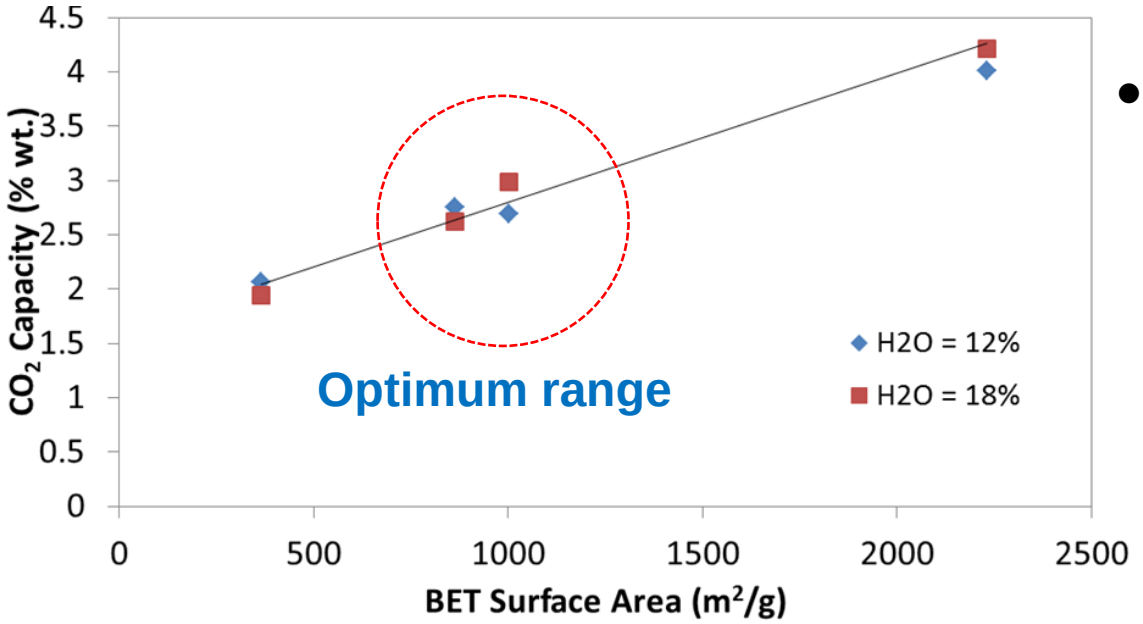
T=68°C, P=16 psia, GHSV= 2,000h^{-1}, 16% CO_2, 12-18% H_2O, simulated flue gas



- CO_2 capacity = 1.5% wt. at breakthrough (2.0% vol. CO_2 at the exit)
- CO_2 capacity = 5.3% wt. at saturation (15.8% vol. CO_2 at the exit)

Control of Water Adsorption





- The carbon surface is modified to reduce water adsorption
  - Surface functionality, surface area and pore size are also optimized to reduce the water uptake
- Surface area has been increased while maintaining mesoporosity
  - Higher capacity due to increased number of active surface sites

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Sorbent Production Scale-up

Continuous rotary kiln

Exhaust gas treatment

Feeder

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

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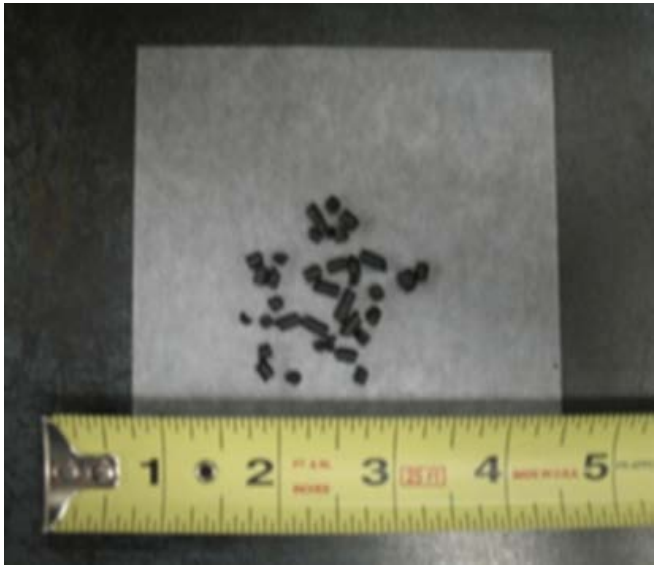
High Mechanical Integrity

- **The crush strength of the pellets are improved to 1.5-2.5 lb_f/mm (in the range of commercial samples)**

2” screw extruder

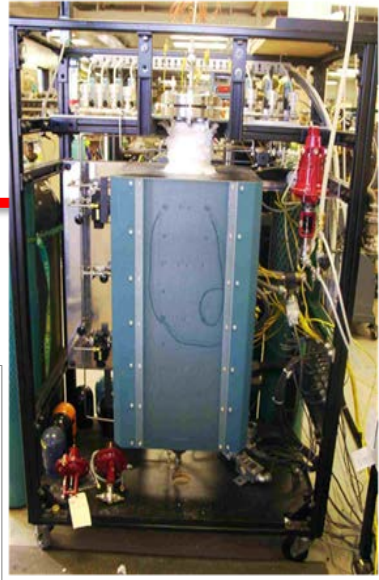
Pellets before treatment

Pellets after treatment

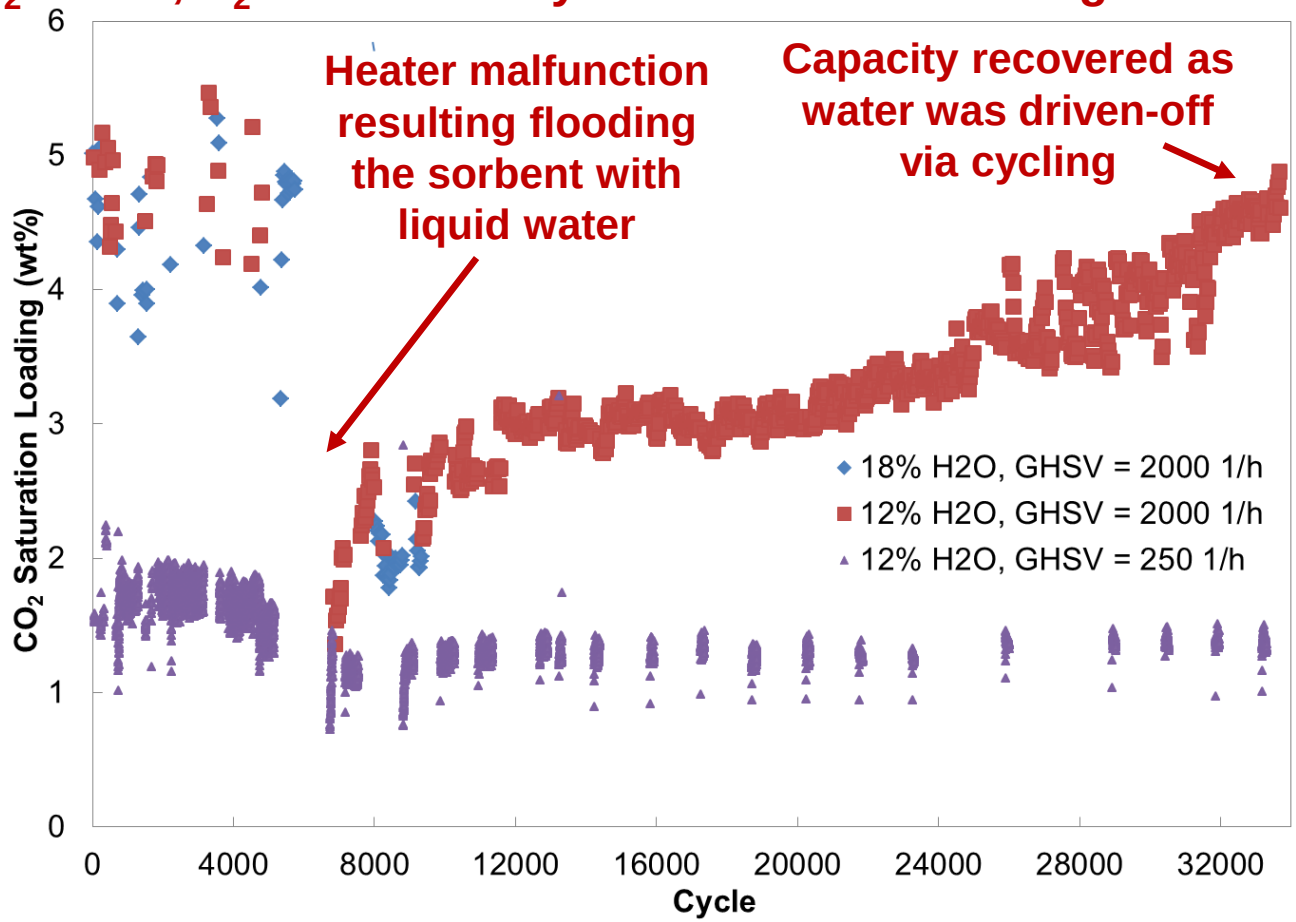


- **Forming the pellets prior to carburization provided the highest strength pellets**
  - **Pre-forming pellets also improved yields**

Multiple VSA Cycles



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



- **Sorbent capacity and removal efficiency recovered following a major upset (stable capacity over 34,000+ cycles)**

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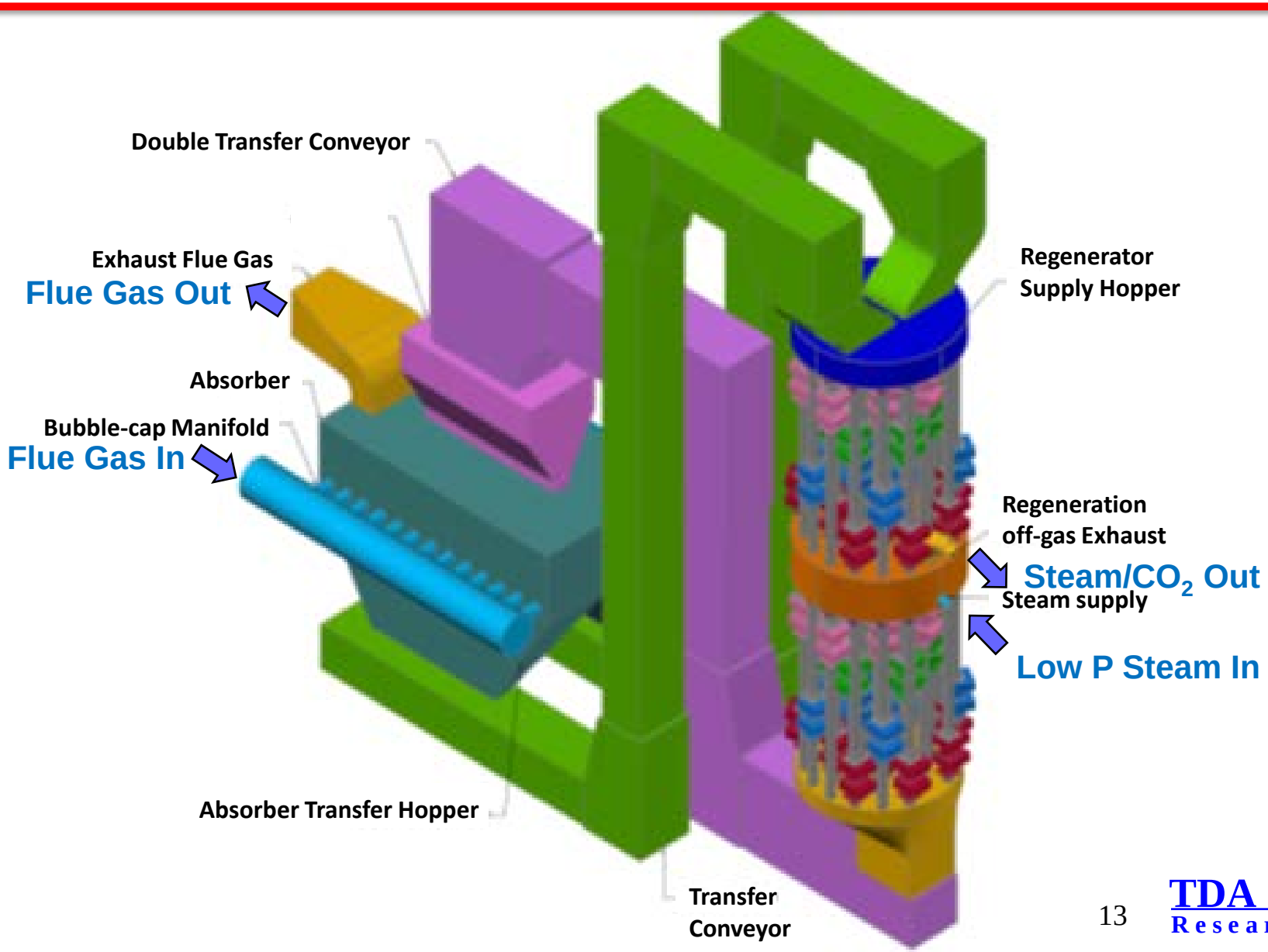
Design of the Moving-Bed System



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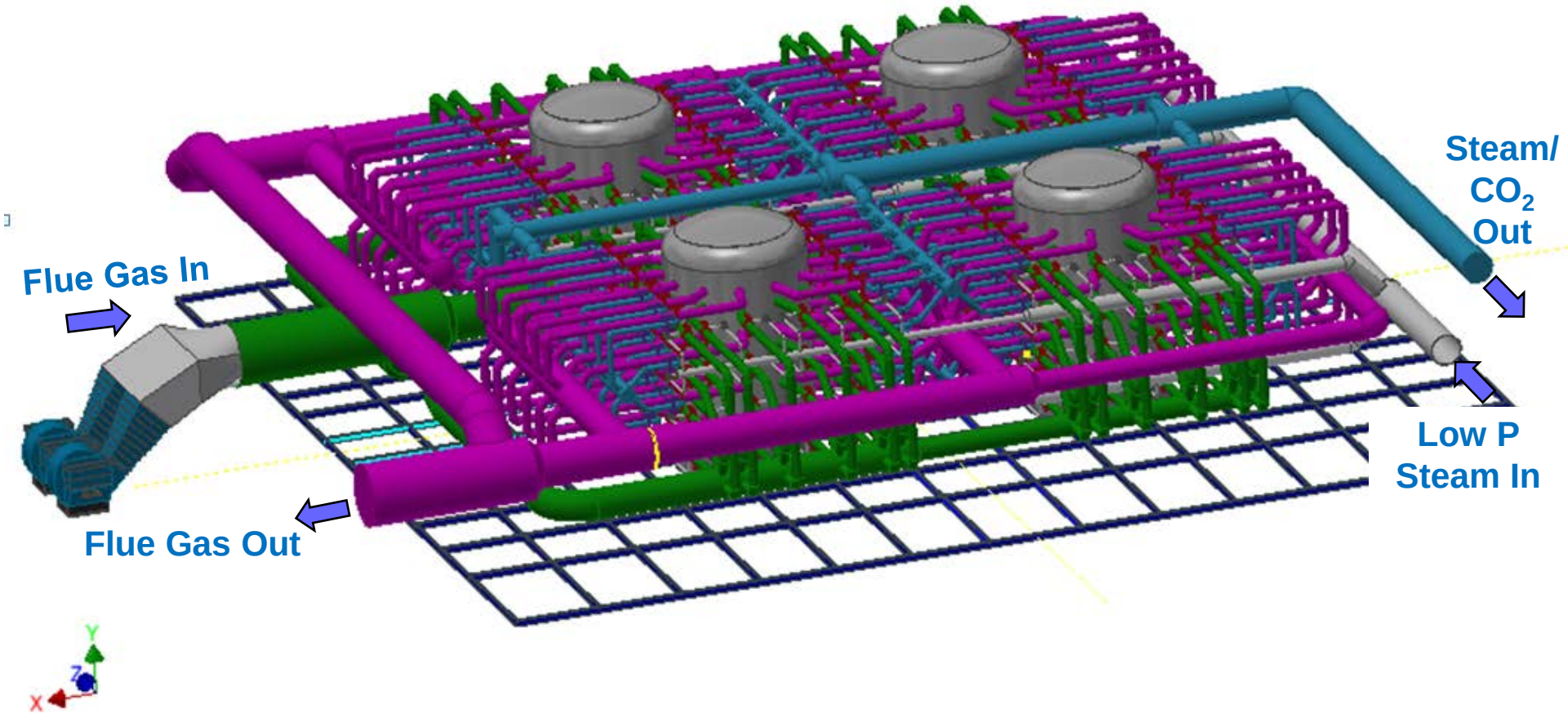
Design of the Fixed-Bed System



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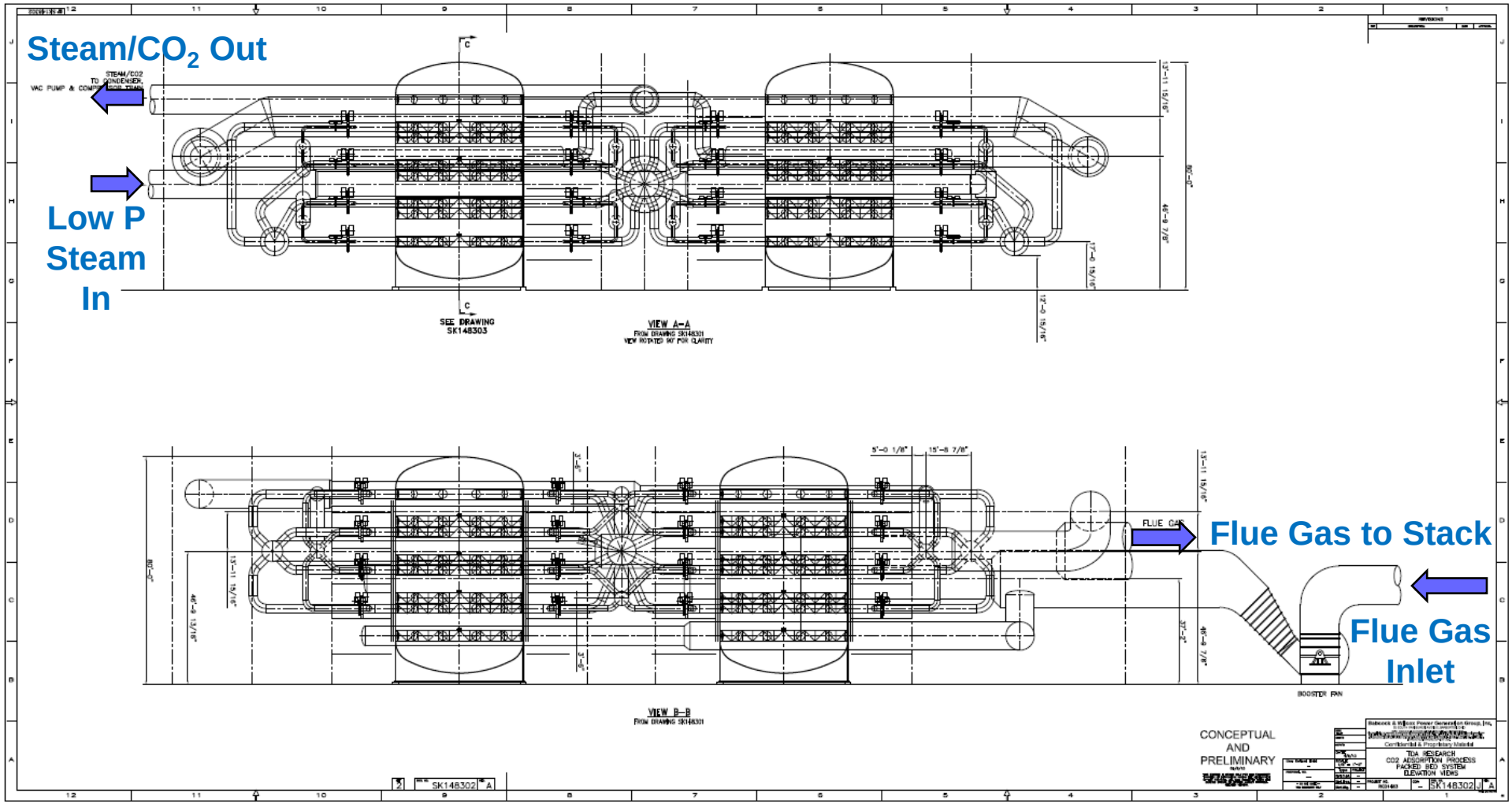
System Design/Packed Beds



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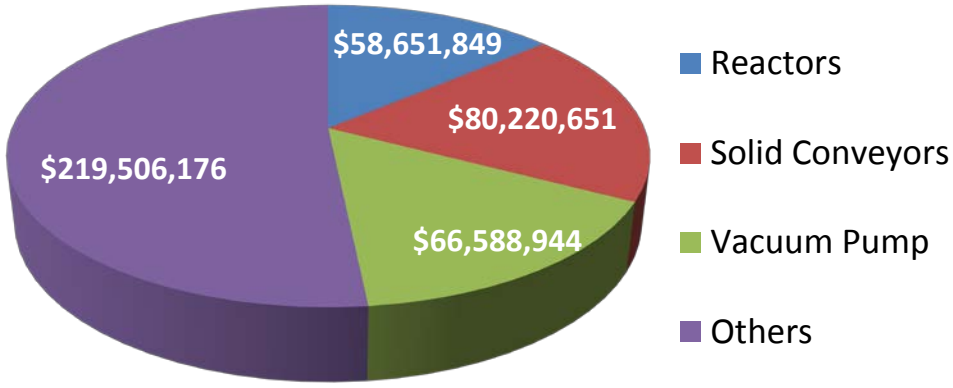
Total Plant Cost

- **B&W estimated the total plant cost for the moving-bed system as ~$424 million (2011 basis)**
  - The use of off-the-shelf components increased redundancy and cost
  - The solid movers/vacuum pump constituted ~35% of the cost



- **The total plant cost for fixed-bed system was estimated as $372 MM based on 1.4% wt. CO_2 working capacity**
  - B&W is analyzing a design with 4% wt. CO_2 working capacity (initial estimates shows that the plant cost will be reduced to $276 MM)

Quality Guidelines for Energy System Studies, Cost Estimation Methodology for NETL Assessments of Power Plant Performance, DOE/NETL_2011/1455, April 2011.
Cost Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, DOE/NETL_2010/1397, Revision 2, November 2010.
Carbon Capture and Sequestration System Analysis Guidelines, DOE/NETL, April 2005.

System Analysis

CO_2 CAPTURE TECHNOLOGY	UNITs	Amine	VSA-Moving Bed	VSA-Fixed Bed	VSA-Fixed Bed
CASE DESCRIPTION		Booster fan to meet higher ΔP	LP purge Steam generated	LP Purge Steam generated	LP Purge Steam from ST cycle
CARBON CAPTURED	%	90.0	90.0	90.0	90.0
GROSS POWER GENERATED (AT GENERATOR TERMINALS), kWe					
STEAM TURBINE POWER	**kWe**	**669,880**	**806,985**	**806,985**	**798,903**
TOTAL AUXILIARY CONSUMPTION	kWe	140,501	195,637	189,759	178,065
AUXILIARY LOAD SUMMARY					
FLUE GAS BOOSTER	kWe	11,690	9,647	10,677	10,677
CO2 REMOVAL UNIT	kWe	22,084	18,596	11,661	-
CO2 COMPRESSION	kWe	54,882	115,675	115,675	115,675
PUMPING & COOLING TOWER	kWe	19,041	18,354	18,380	18,382
OTHER LOADS	kWe	32,804	33,365	33,365	33,332
NET POWER OUTPUT	**kWe**	**529,379**	**611,348**	**617,226**	**620,837**
% NET PLANT EFFICIENCY, HHV	**%**	**25.18**	**29.08**	**29.36**	**29.53**
CONSUMABLES					
AS-RECEIVED FEED	KG/H	278,957	278,957	278,957	278,957
RAW WATER USAGE	GPM	10,759	10,027	10,036	10,037

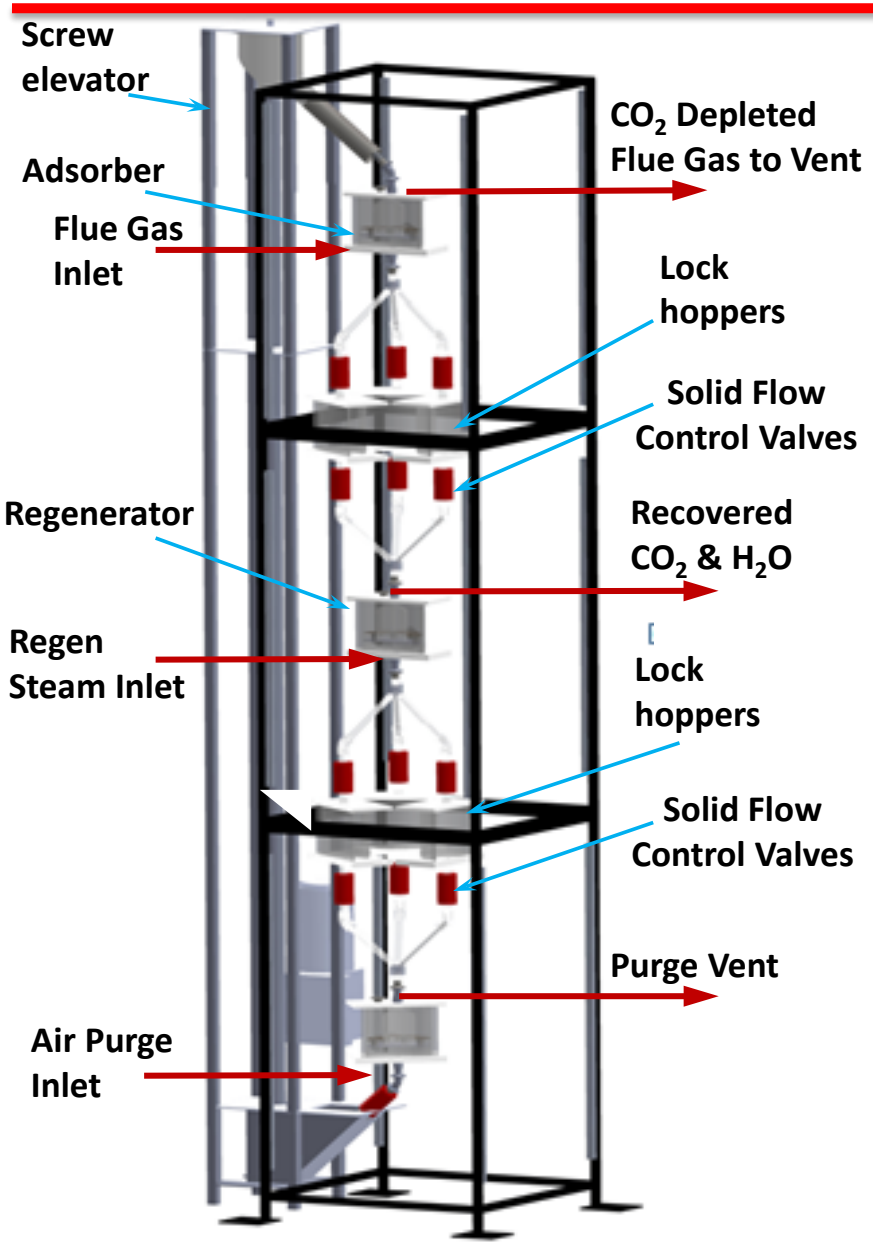
- **TDA's CO_2 capture system achieves 29.5% efficiency in comparison to 25.2% with amine scrubbers (17.3% higher efficiency)**

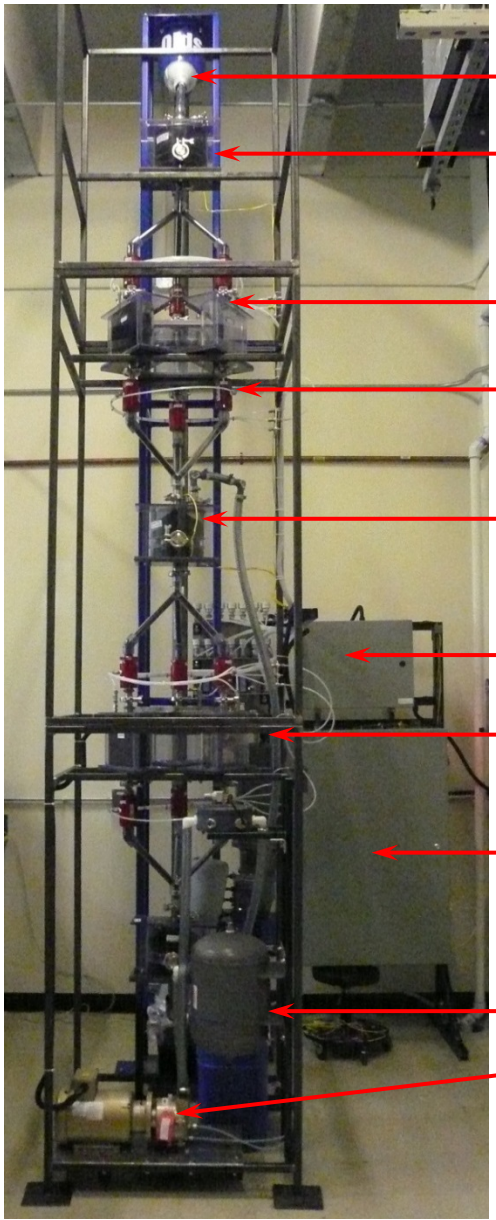
Cost of CO_2 Capture

CO_2 CAPTURE TECHNOLOGY	Amine	VSA-Moving Bed	VSA-Fixed Bed	VSA-Fixed Bed
CASE DESCRIPTION	Booster fan to meet higher ΔP	LP purge Steam generated	LP Purge Steam generated	LP Purge Steam from ST cycle
Net power, MW	**529.38**	**611.35**	**617.23**	**620.84**
Capacity factor (CF), %	85	85	85	85
Total plant cost (TPC), $	1,653,521,816	1,732,257,957	1,654,271,376	1,654,165,943
Total plant cost (TPC), $/kWe	**3,124**	**2,834**	**2,680**	**2,641**
Initial catalyst & chemicals cost, $	2,673,187	17,961,441	8,638,361	8,586,597
Total overnight cost (TOC), $	2,029,584,945	2,143,947,190	2,038,150,311	2,020,608,218
Cost of electricity (COE) w/o CO2 TS&M, $/MWh	**111.1**	**103.0**	**96.8**	**95.6**
Cost of electricity (COE), $/MWh	**117.9**	**108.9**	**102.6**	**101.4**
CO_2 in Fluegas, ST/h	**730.0**	**730.0**	**730.0**	**730.0**
Cost of CO_2 Capture				
$/ST	47.14	46.06	40.59	39.69
$/tonne	51.96	50.77	44.74	43.75
Cost of CO_2 Avoided				
$/ton	61.98	52.44	45.77	44.50
$/tonne	68.32	57.81	50.45	49.05

- **TDA's VSA Fixed-bed/LP steam purge (withdrawn from ST cycle) provided the lowest 1st year COE of $101.4/MWh (vs. $117.9/MWh for amine scrubbers)**
- **Cost of CO_2 avoided is $49.05/tonne (28.2% improvement over amines)**

Prototype Unit Design





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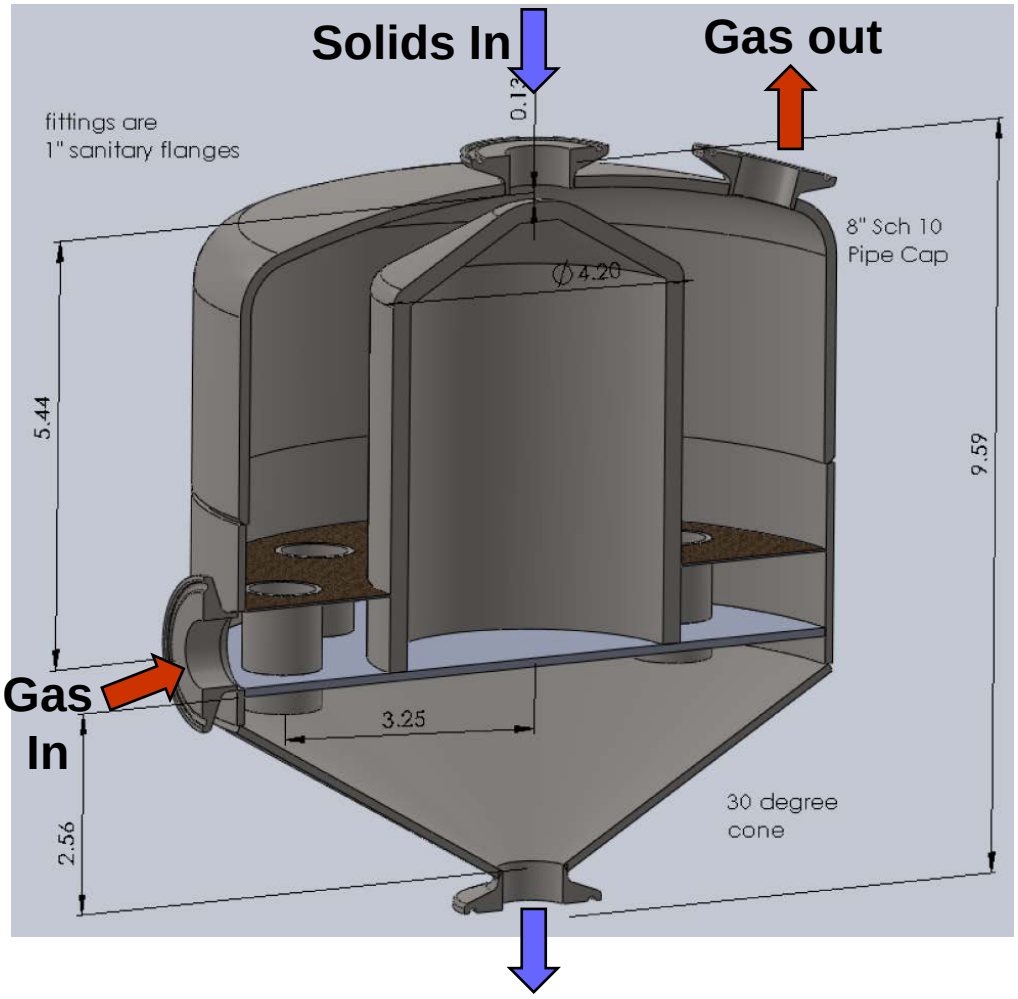
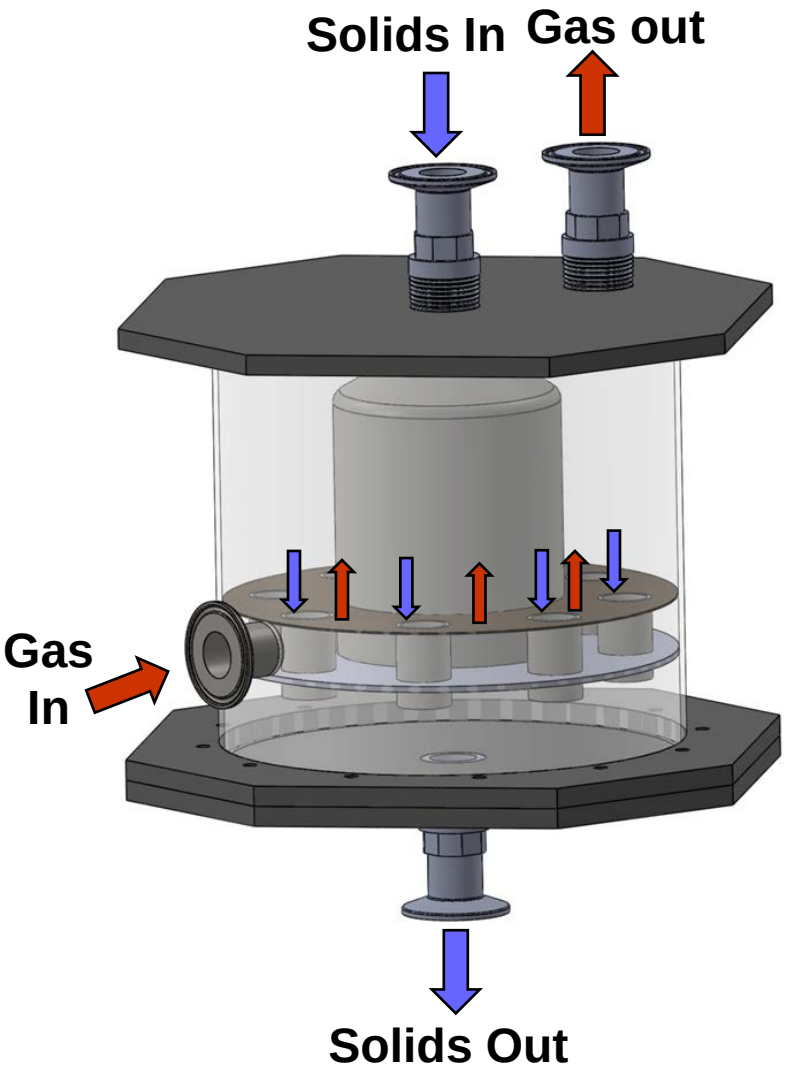
Gas-Solid Contactors

Prototype Adsorber Reactor





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

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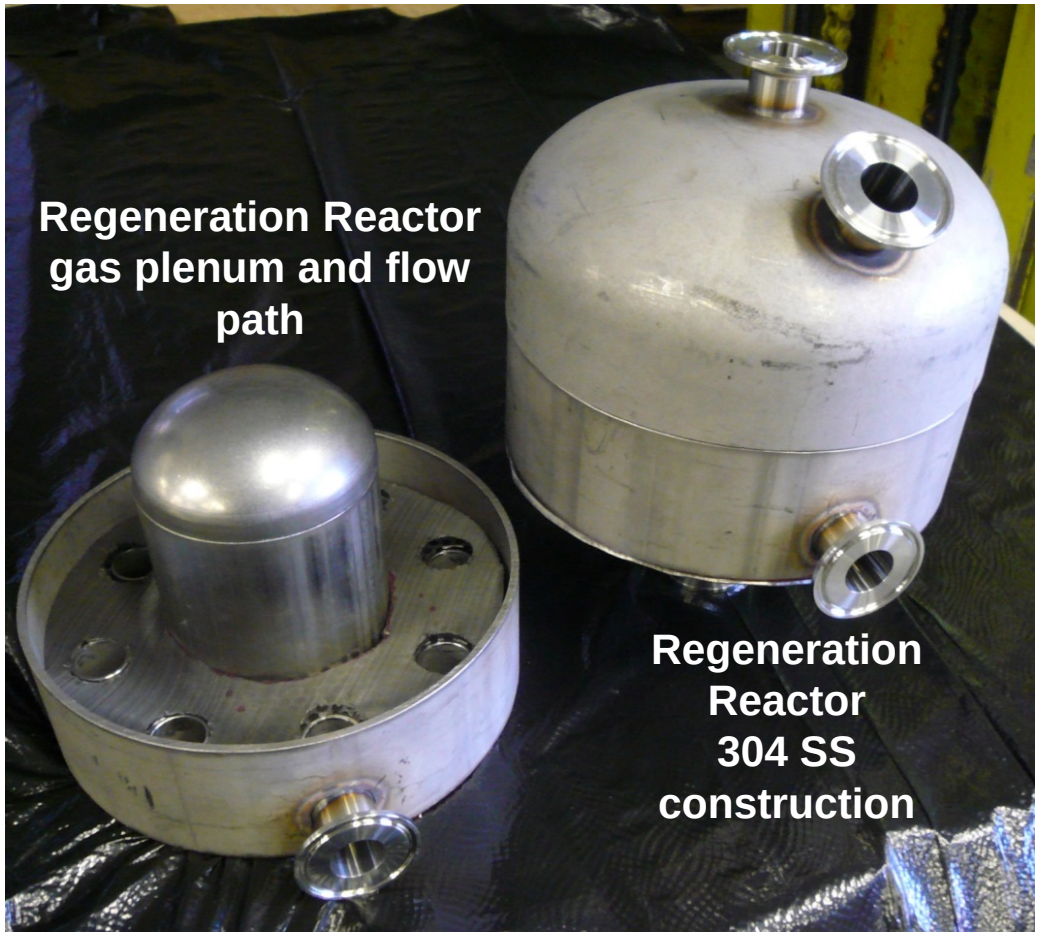
Circulating Bed System



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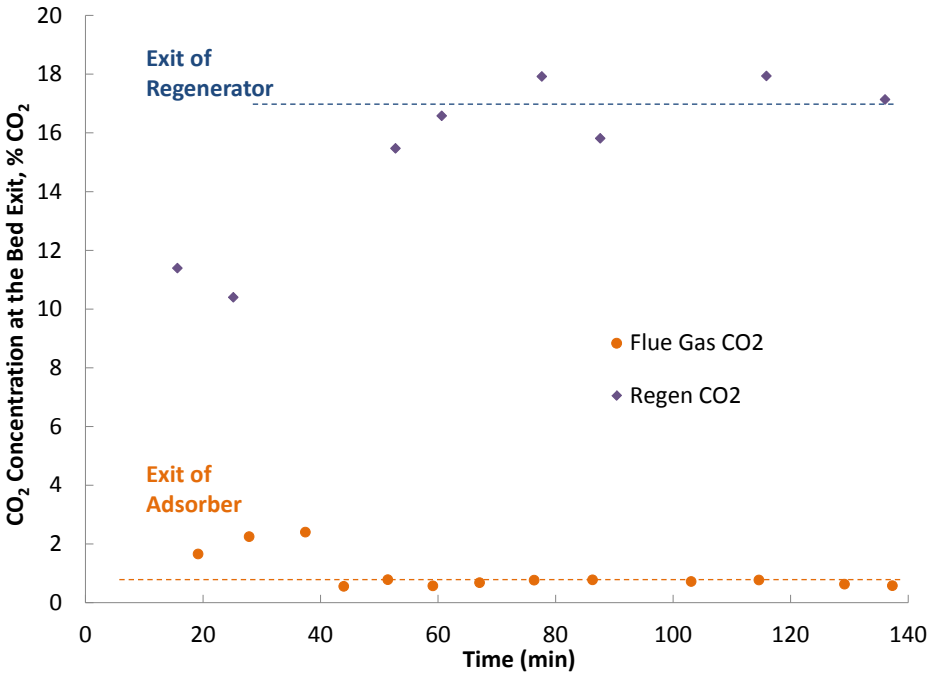
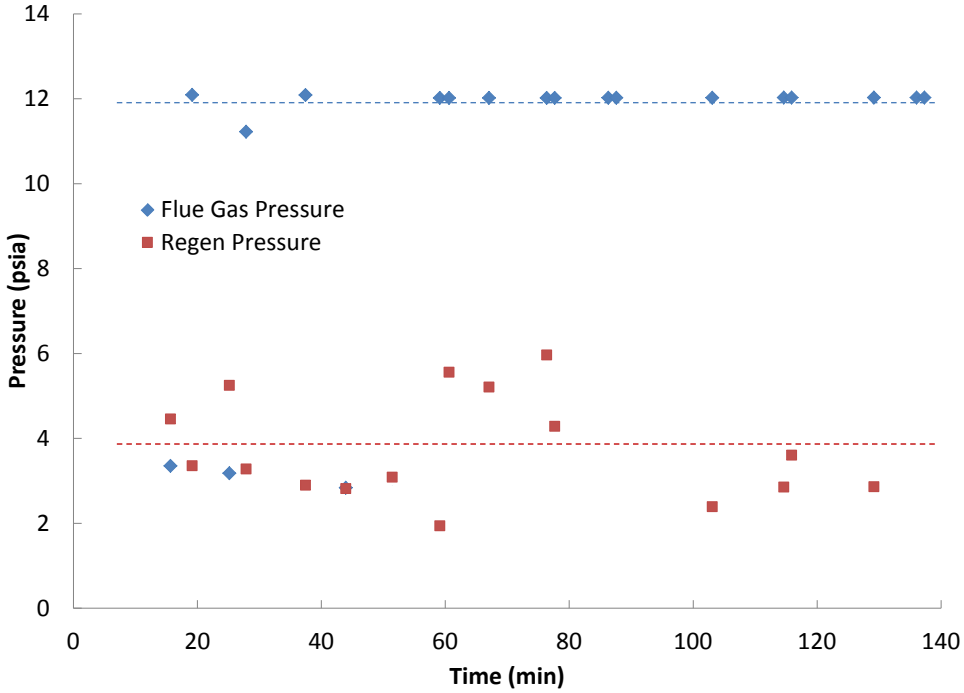
Sorbent Performance in Moving-Bed Unit





- **Flue gas flow rate 40 SLPM (1.4 SCFM)**
- **Inlet CO_2 Concentration = 13.2% vol.**
- **Adsorption pressure = 12.2 psia**
- **Regeneration pressure = 3.5 to 4 psia**
- **Sorbent circulation rate of 98.3 g/min**
- **CO_2 Removal Efficiency = 94+%**

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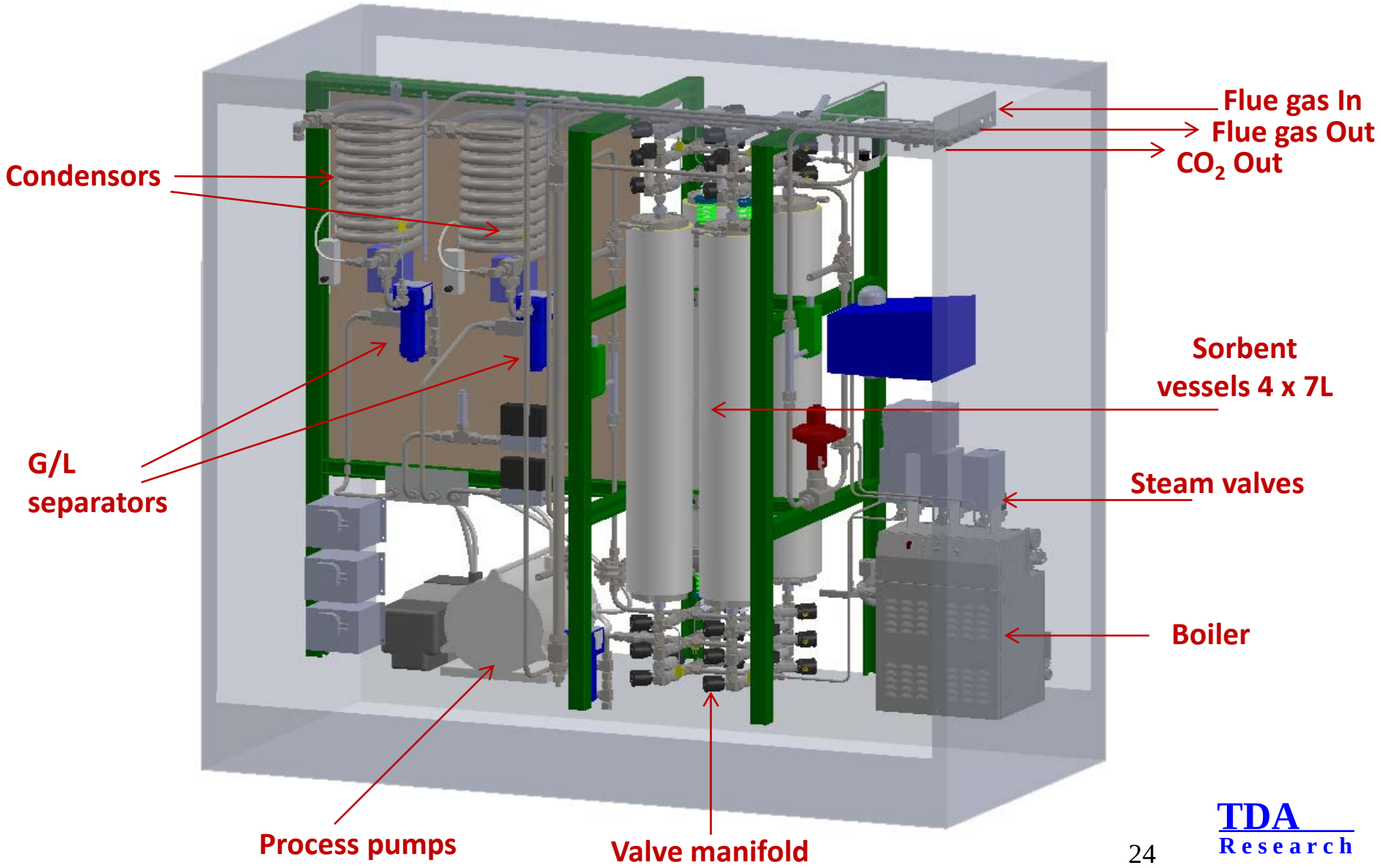
4-Bed VSA System



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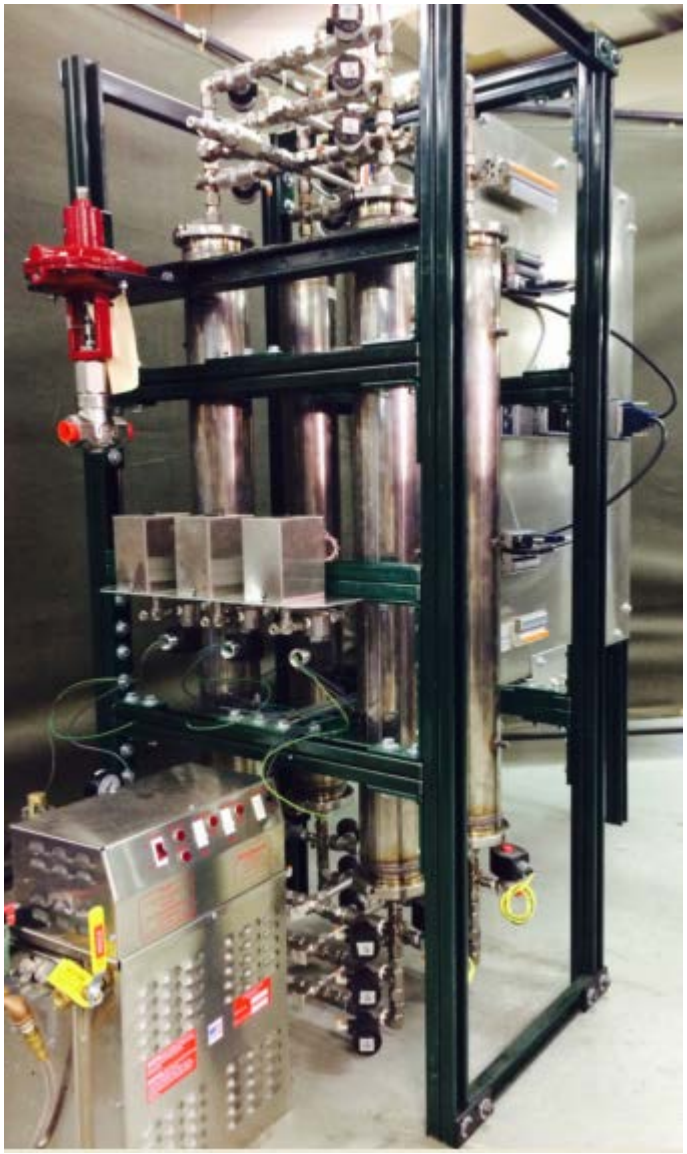
4-Bed VSA System



Dimensions
72” x 24” x 72”

Feed rate
2 SCFM flue gas

Baseline Operating Conditions
70°C, 3 – 17 psia

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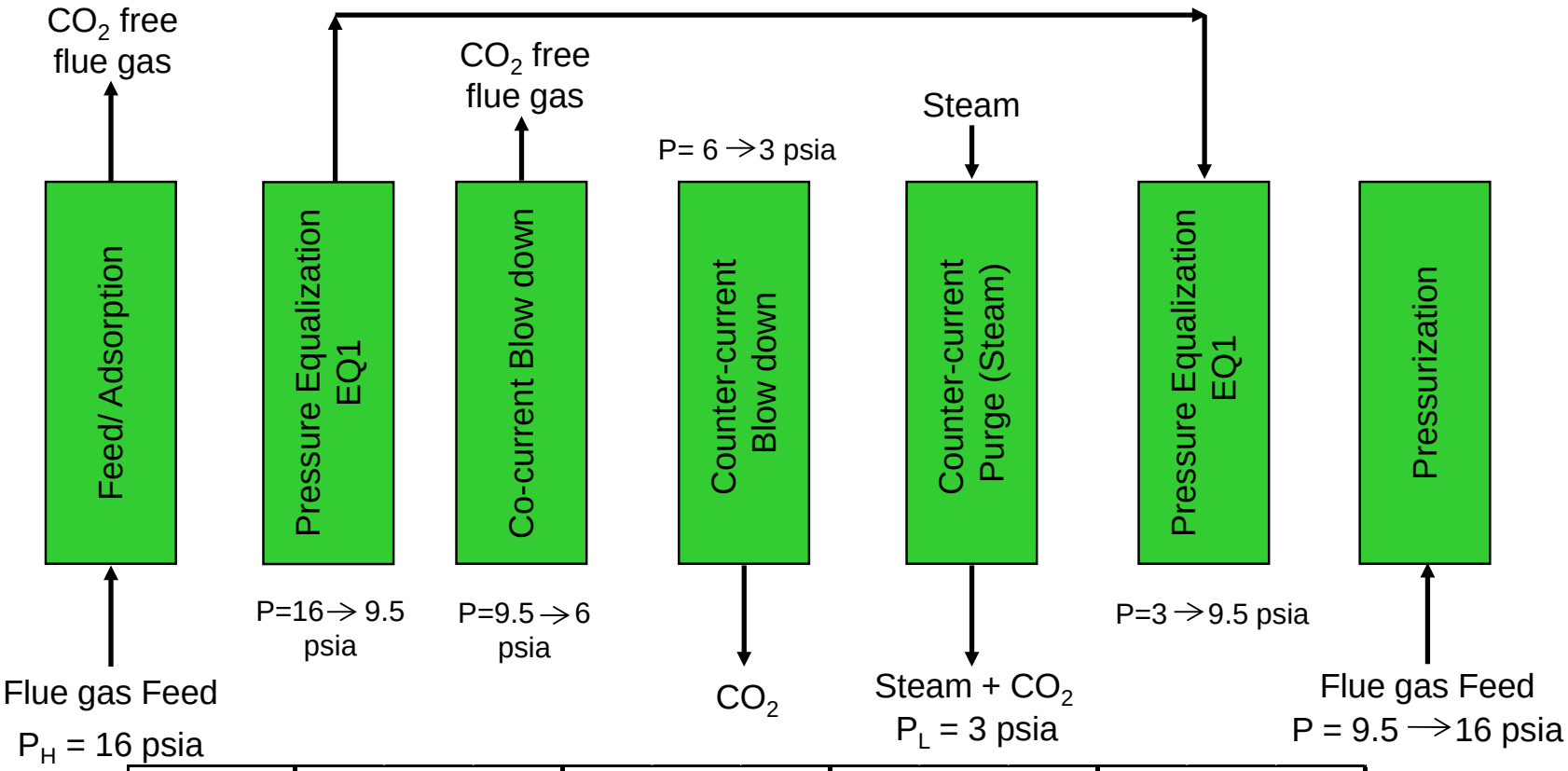
4-bed VSA Fixed Bed Cycles



	Stage 1			Stage 2			Stage 3			Stage 4		
Time (min)	3			1	1	1	3			1	1	1
Bed 1	ADS			EQ1	CoBD	CnBD	PURGE			EQ2	Hold	PRESS
Bed 2	EQ2	Hold	PRESS	ADS			EQ1	CoBD	CnBD	PURGE		
Bed 3	PURGE			EQ2	Hold	PRESS	ADS			EQ1	CoBD	CnBD
Bed 4	EQ1	CoBD	CnBD	PURGE			EQ2	Hold	PRESS	ADS		

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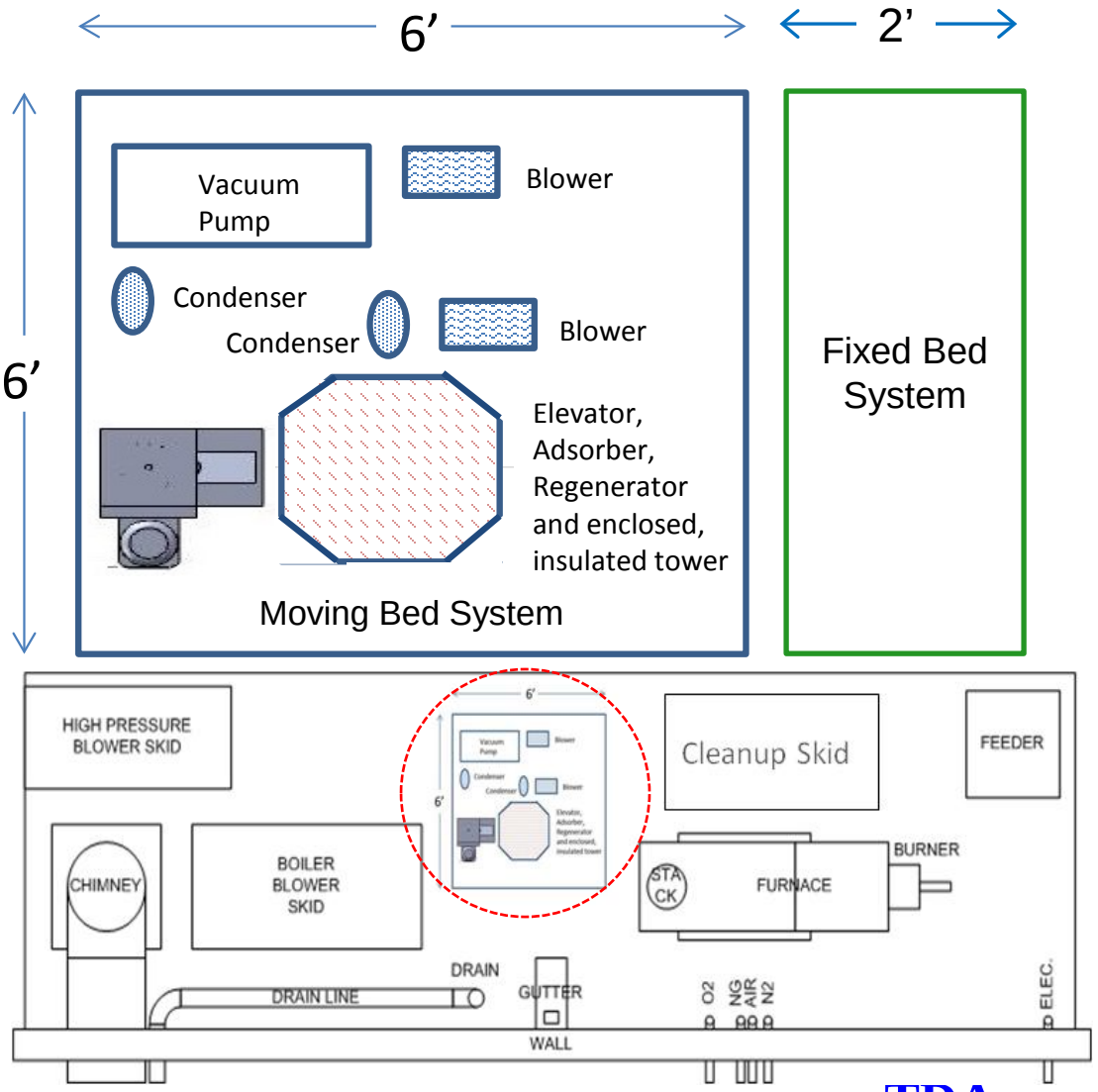
Slipstream Testing with the Unit



- **A slipstream test will be carried out at GTI**
- **All facility modifications are complete**

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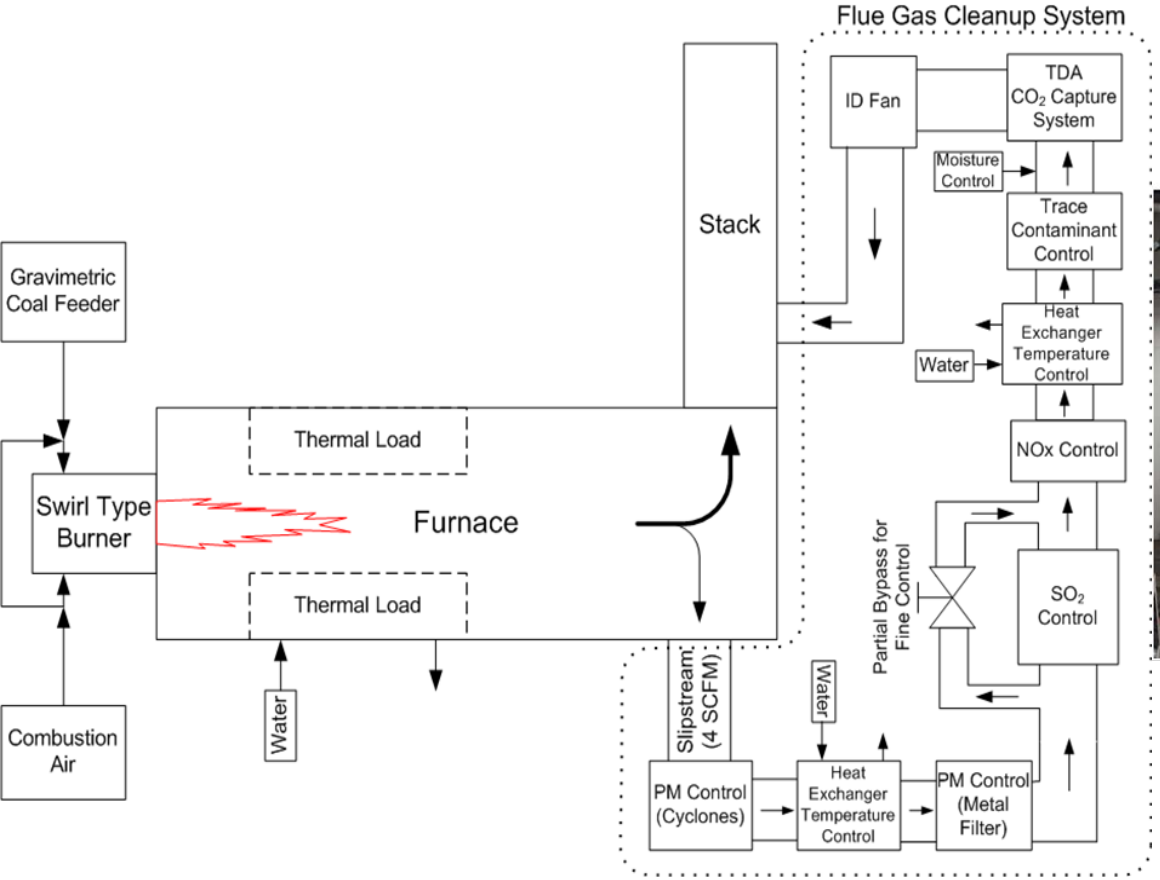
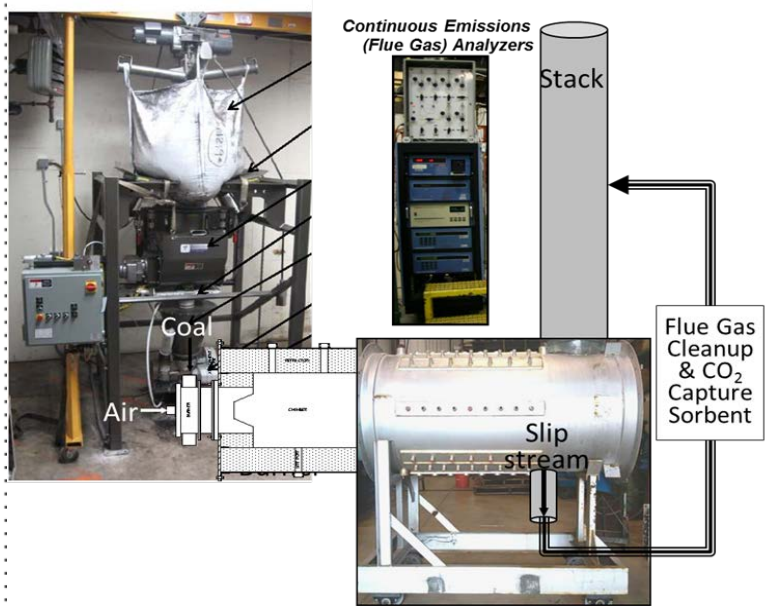
Site Preparation Work





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

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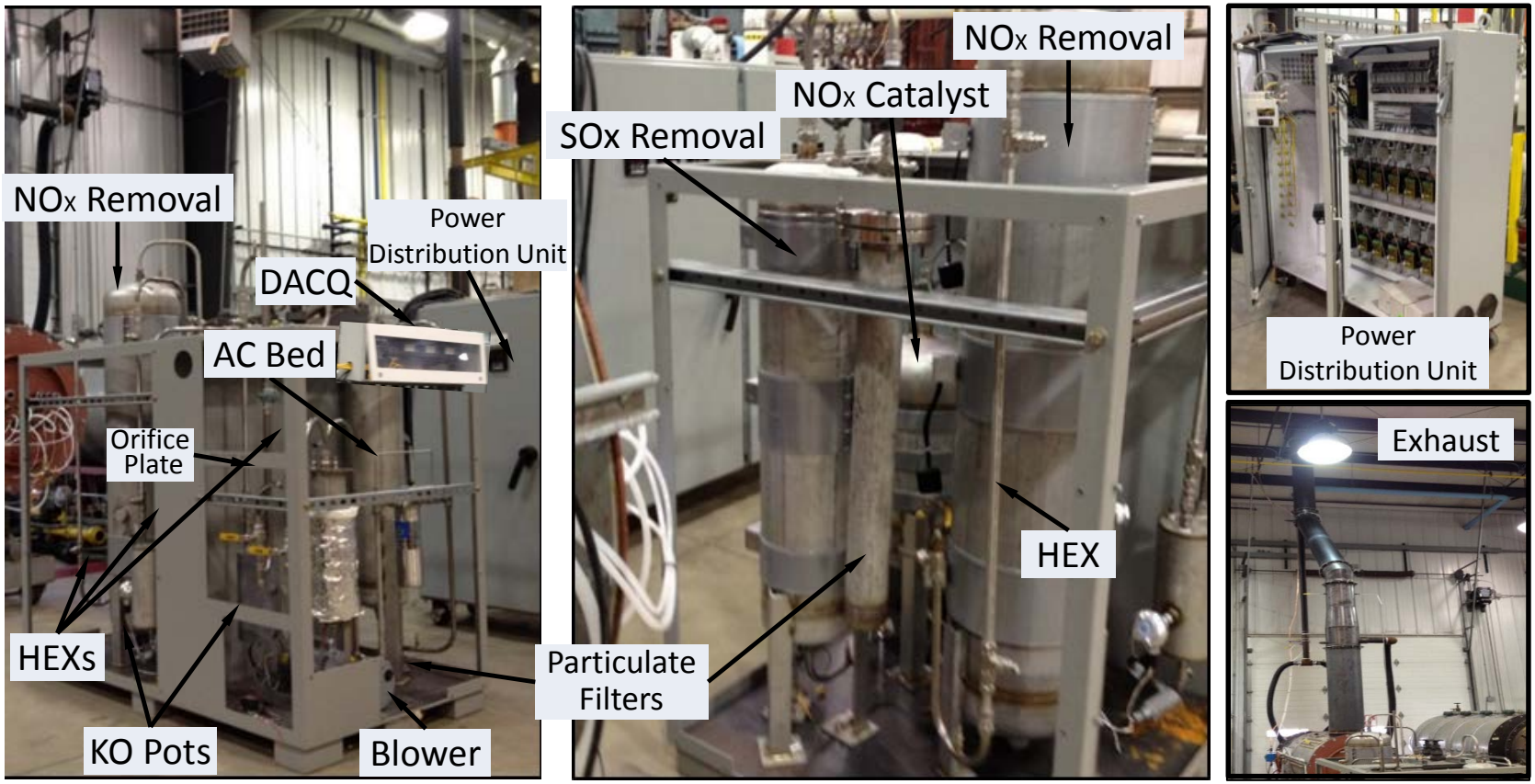
Removal of Contaminants



- **NO_x andSO_2 control will be accomplished by materials provided by TDA**
  - SulfaTrap™-SO for SO_2 scrubbing to sub ppmv concentration
  - NO Oxidation catalyst/NO_2 scrubbing sorbent for NO_x control at sub ppmv concentration

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Acknowledgements

- **The funding from DOE/NETL under Contract No. DE-FE-0007580 is greatly acknowledged**
- **Technical Monitor, Andrew O'Palko, NETL**
- **Dr. Bartev Sakadjian, Doug Devault, Ruyu Zhang, B&W**
- **Dr. Ashok Rao, UCI**
- **Dr. Chuck Shistla and Andy Hill, GTI**
- **Dr. Francois Botha and Dr. Debalina Dasgupta, ICCI**