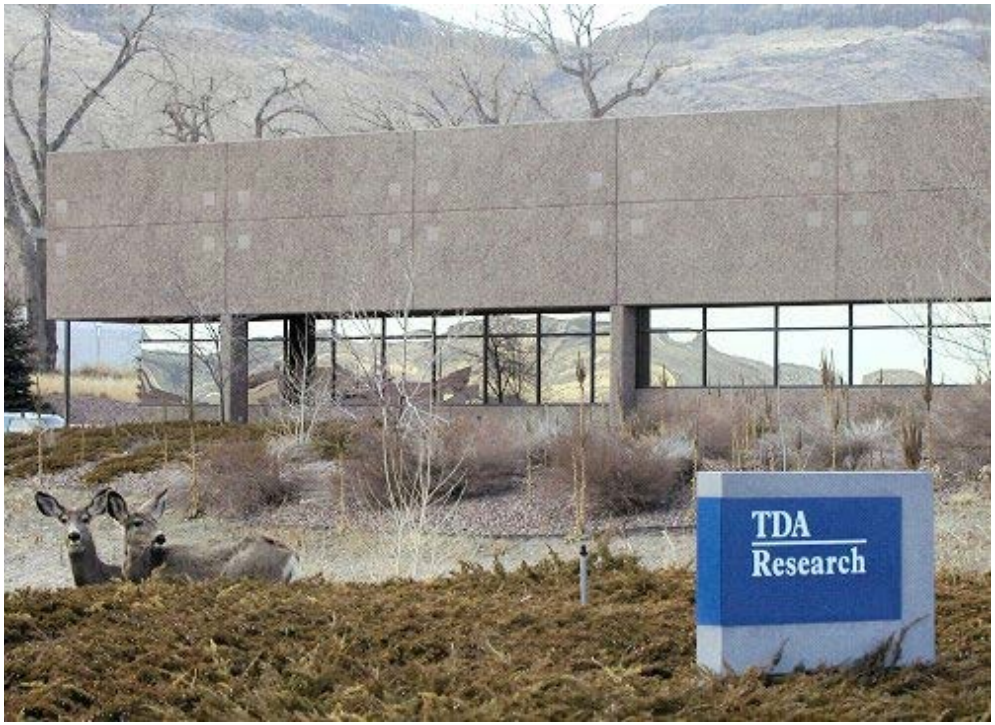
Post-Combustion CO_2 Capture System for Existing Coal-fired Power Plant

Contract No. DE-FE-0007580



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Robert Copeland, PhD

DOE/NETL Carbon Capture Meeting

Pittsburgh, PA

June 25, 2015

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

Project Summary

- **The objective is to develop a post-combustion carbon capture process for new and 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

TDA Research

B&W thebabcock&wilcoxcompany

UNIVERSITY of CALIFORNIA • IRVINE

gti

icci

Project Duration

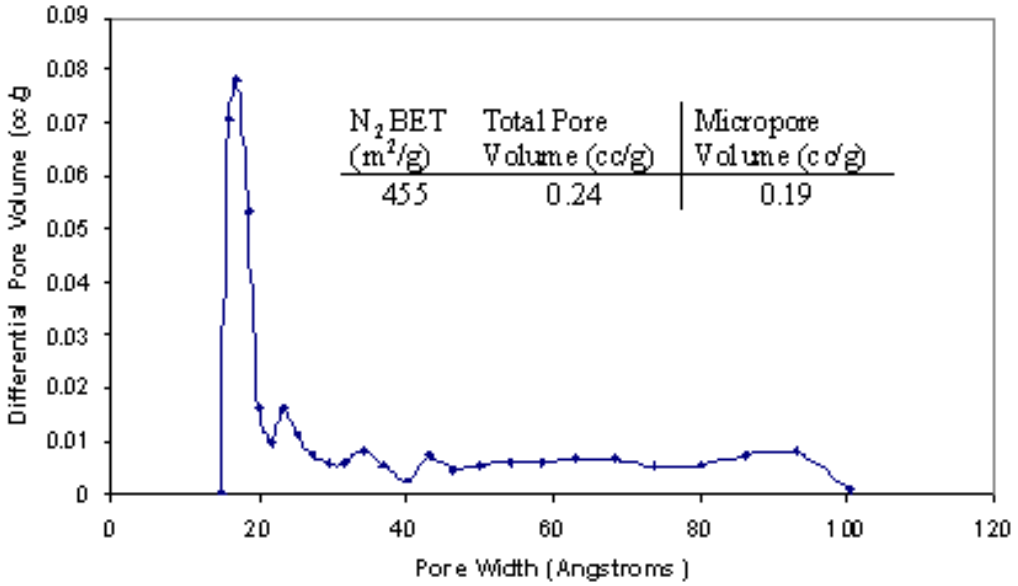
- **Start Date = October 1, 2011**
- **End Date = September 30, 2015**

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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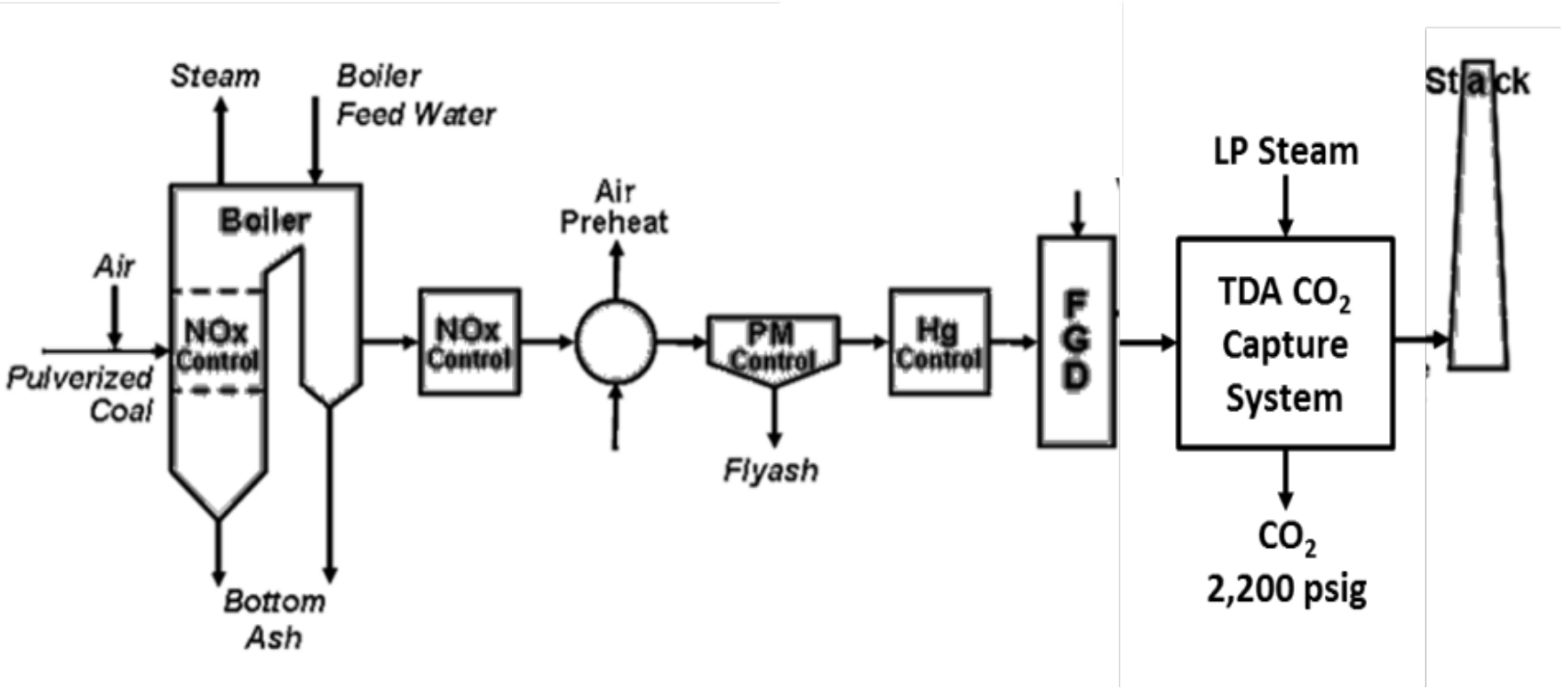
Integrated CO_2 Capture System



- 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 400 ppmv NO_x
  - Single-stage FGD

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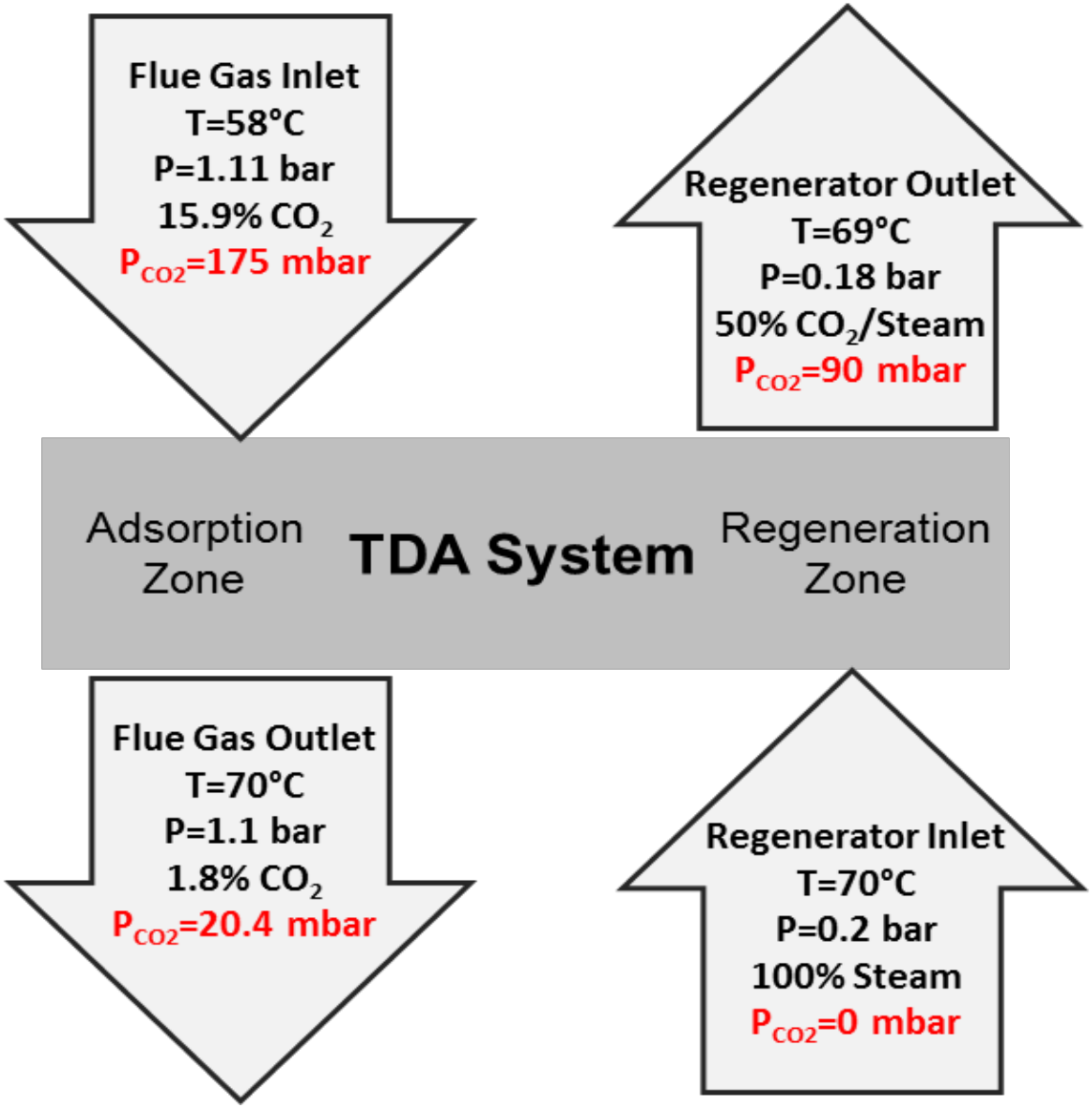
TDA's CO_2 Capture System



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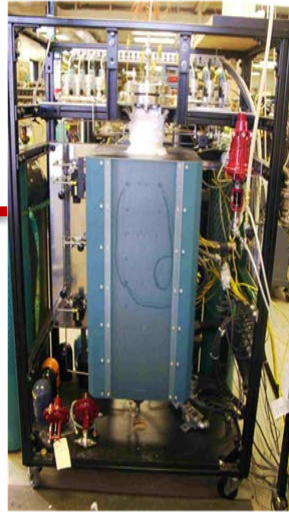
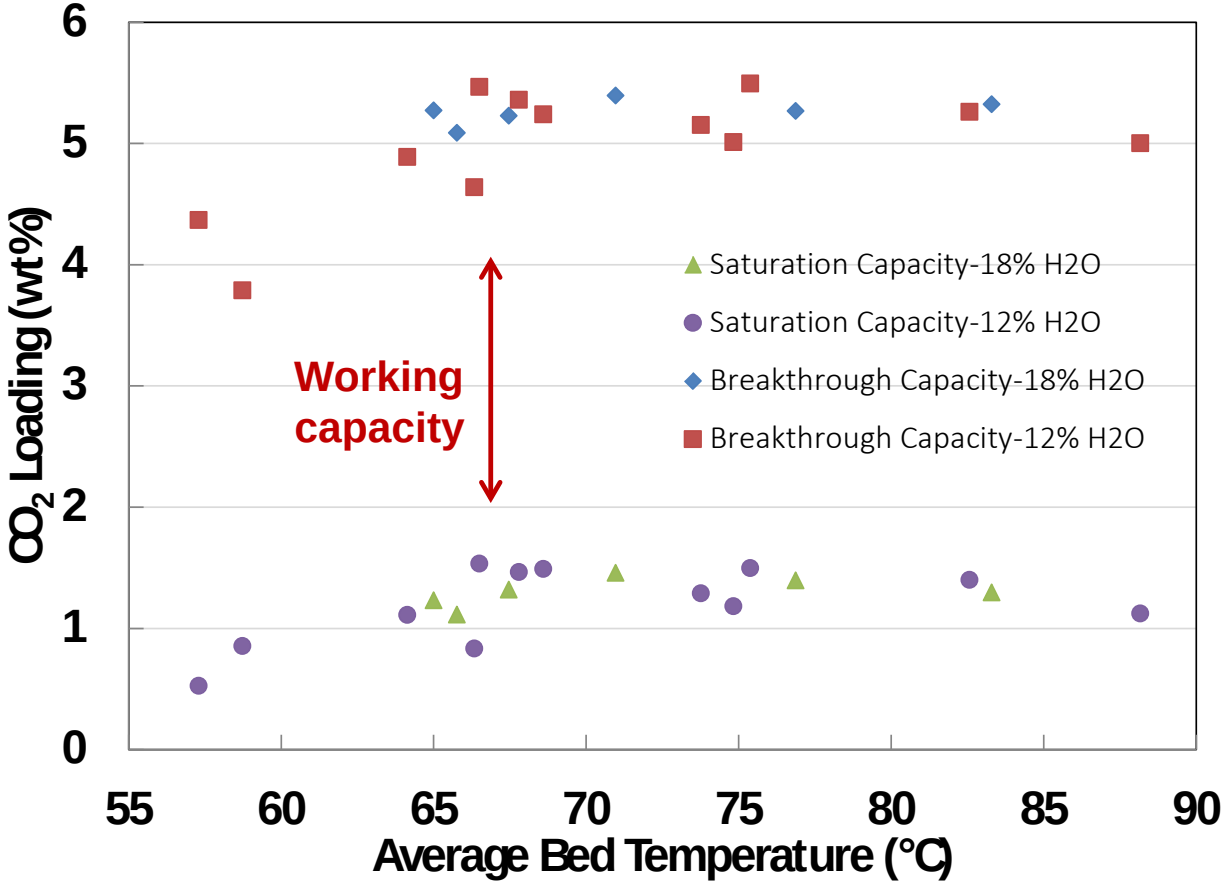
CO_2 Breakthrough Profile/Capacity



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)

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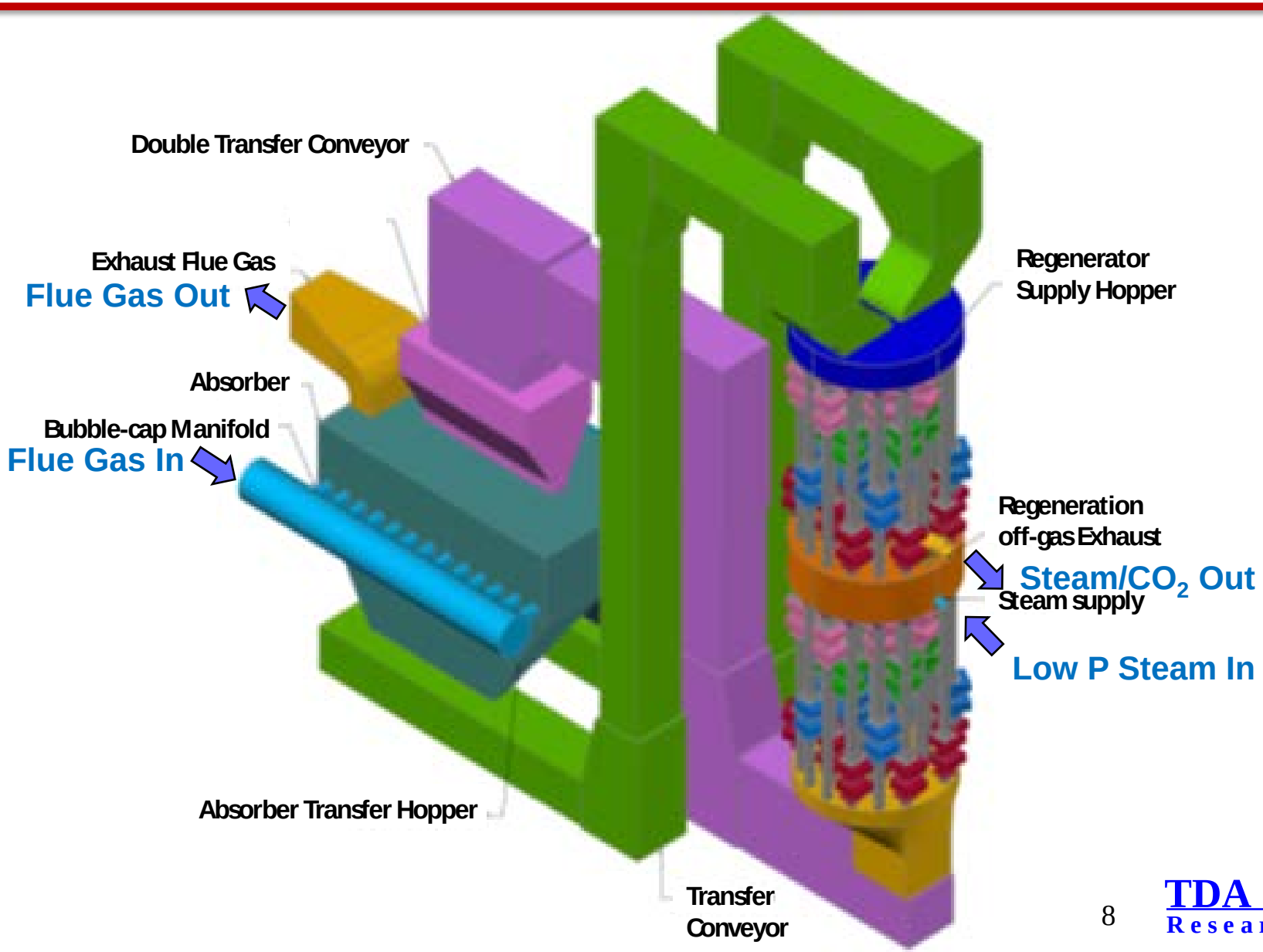
Design of the Moving-Bed System



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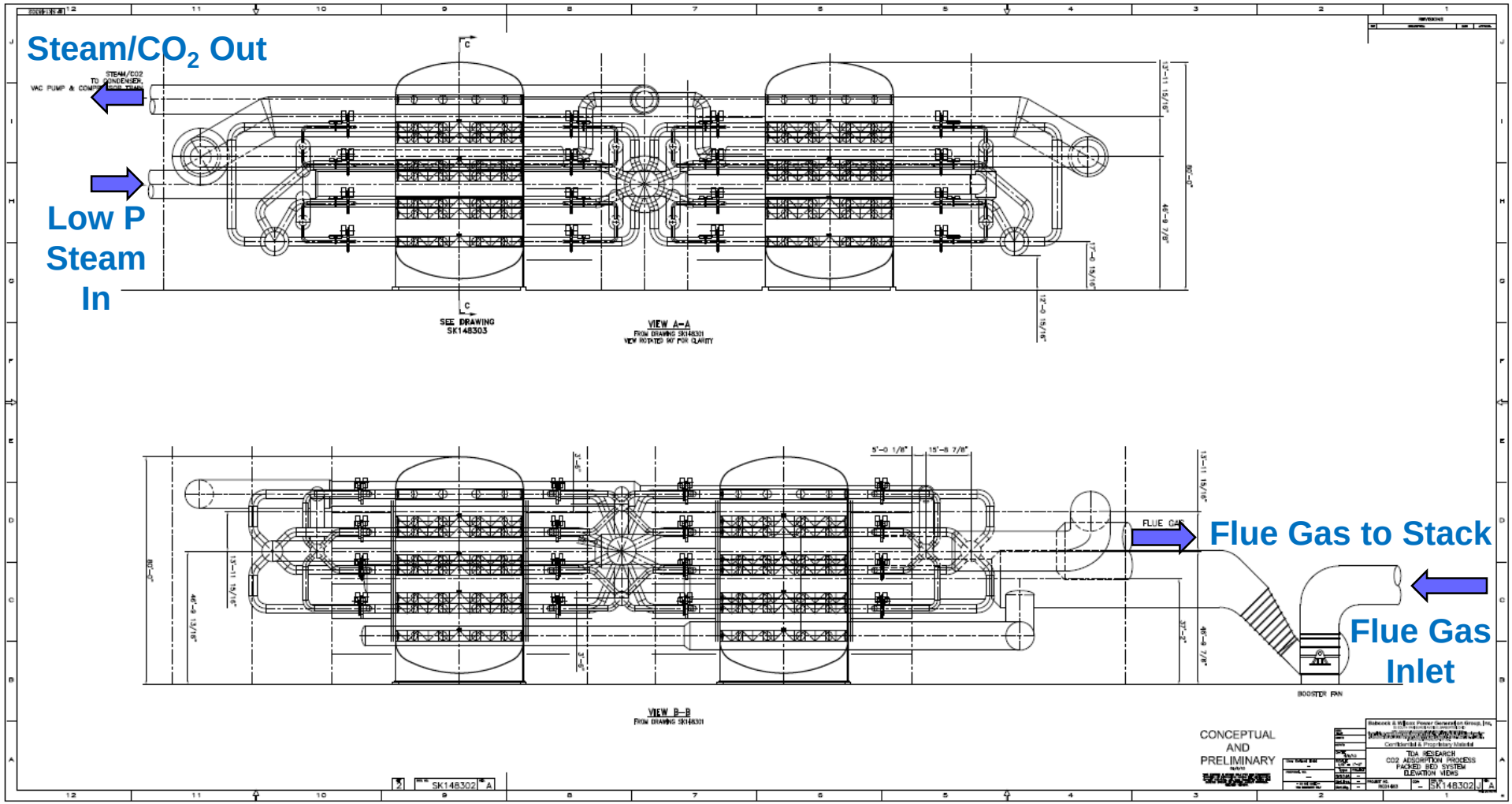
System Design/Packed Beds



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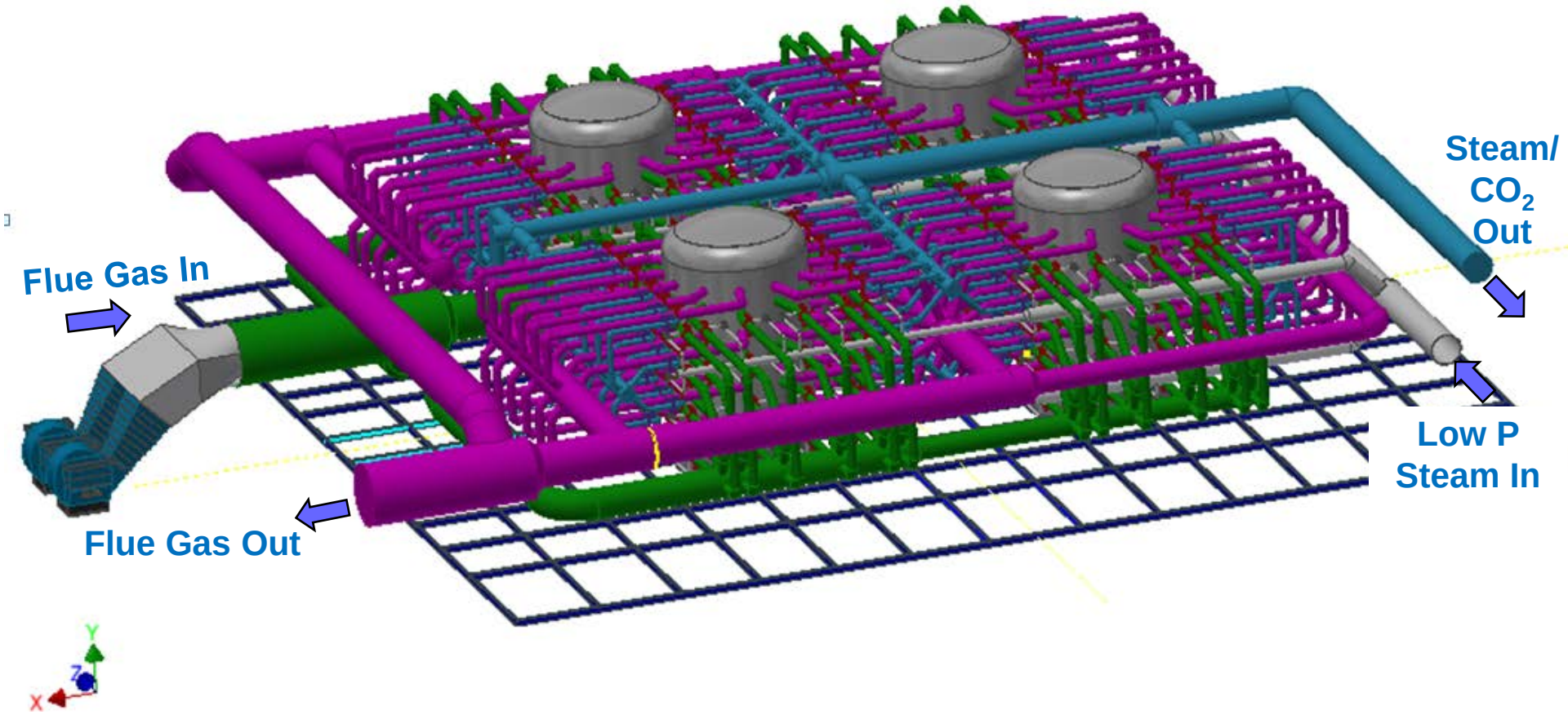
Design of the Fixed-Bed System



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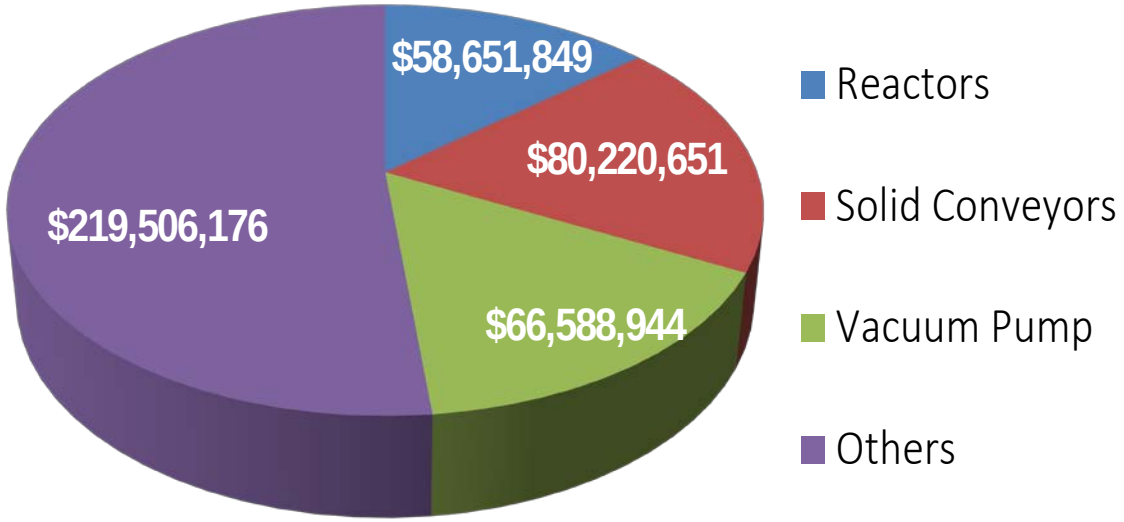
Comparison of System Costs

- **B&W estimated the total plant cost for the moving-bed system as ~$424 million (2011 basis)**
  - **The use of off-the-shelf components generated redundancy and increased cost**



- **The total plant cost for fixed-bed system was estimated as $276 MM (2011 basis)**

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.

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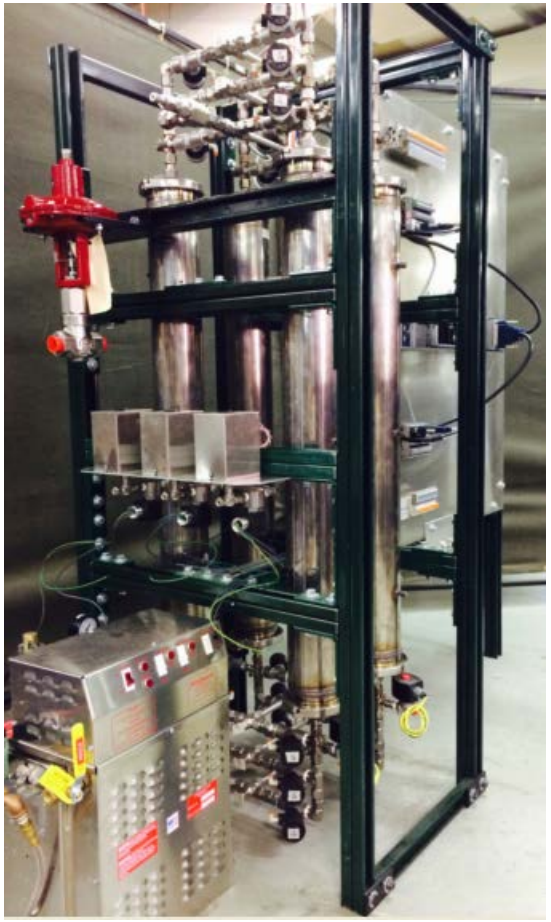
Proof-of-Concept Demonstrations

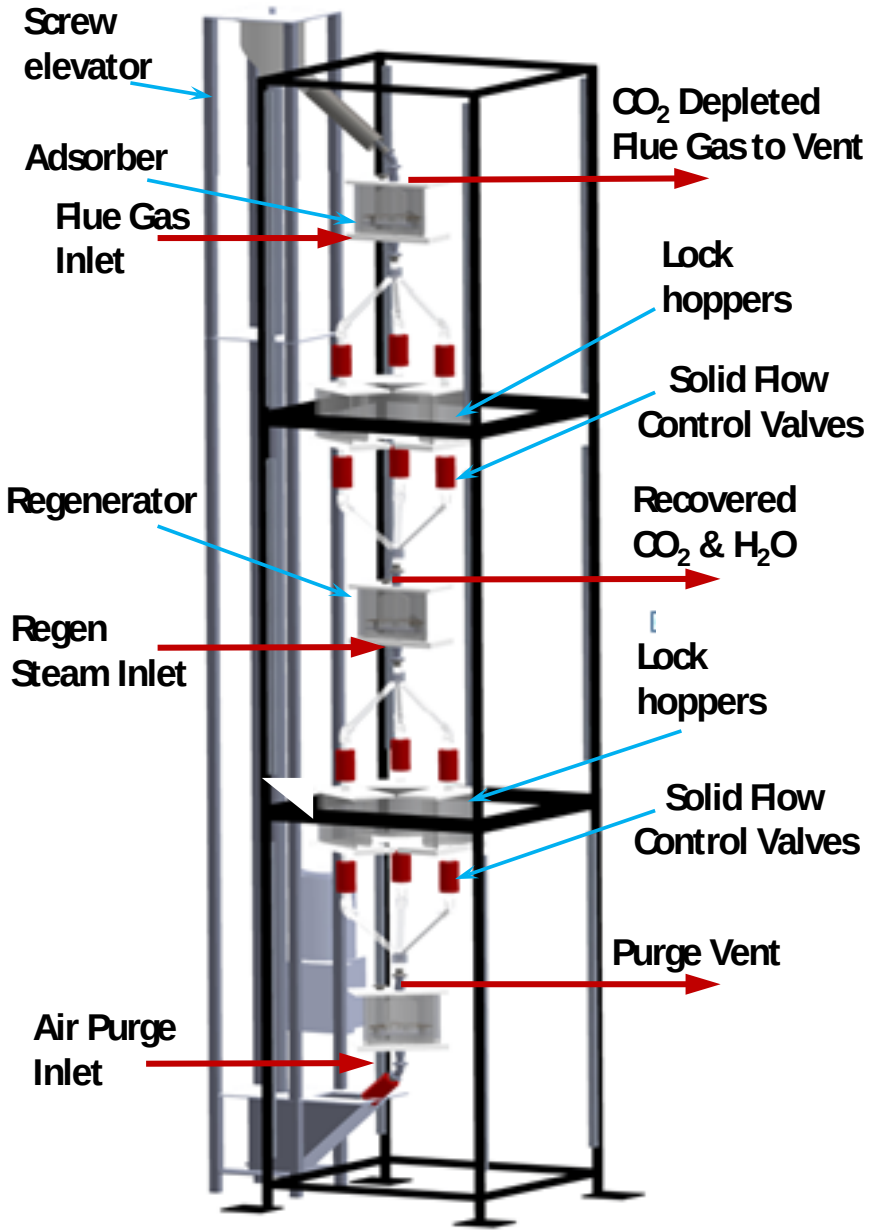
- TDA designed both a moving-bed and a fixed-bed VSA unit to carry out the proof-of-concept demonstrations
- 2 SCFM flue gas
- Same amount of sorbent inventory were used in both systems to provide a direct comparison on the contactor performance
- Identical operating conditions (e.g., inlet T, regeneration vacuum)

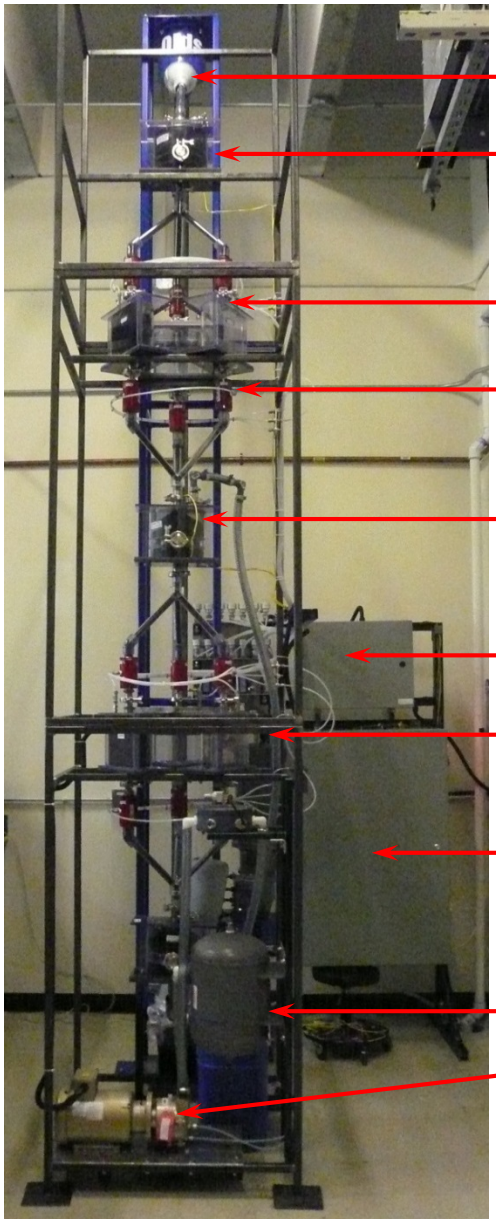
Moving-bed VSA Unit



Fixed-bed VSA Unit

Prototype Unit Design





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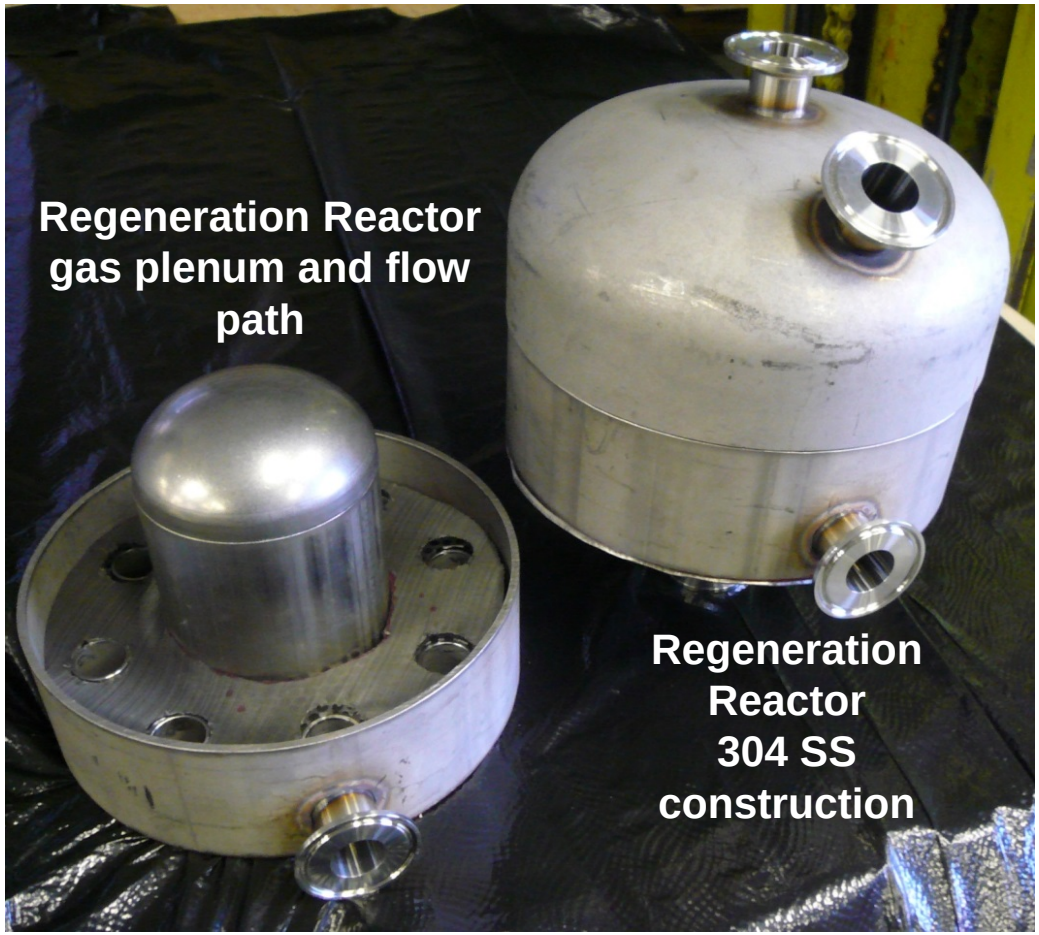
Moving-bed Reactors



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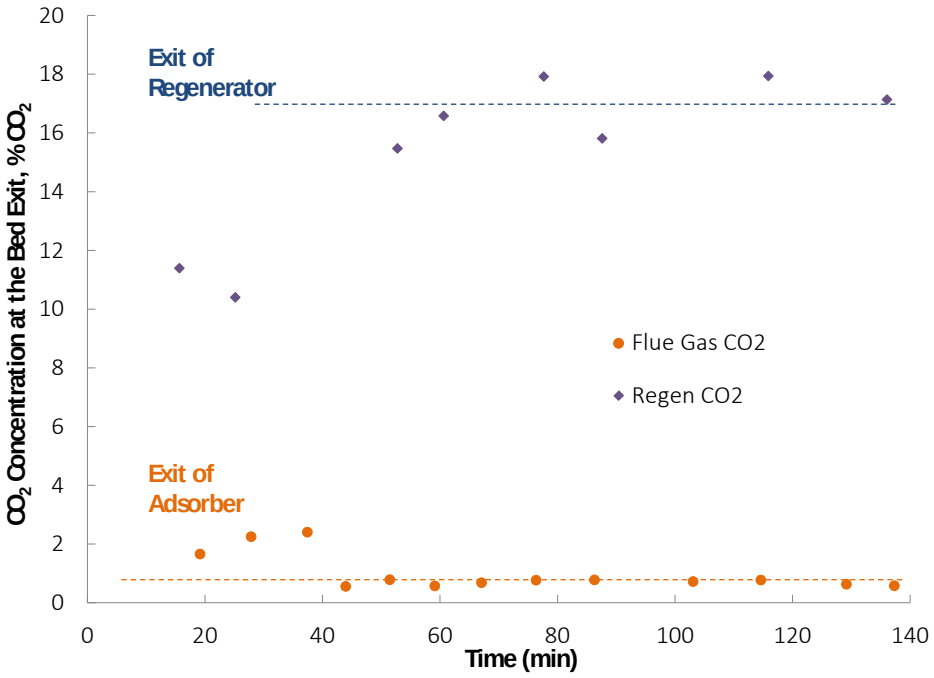
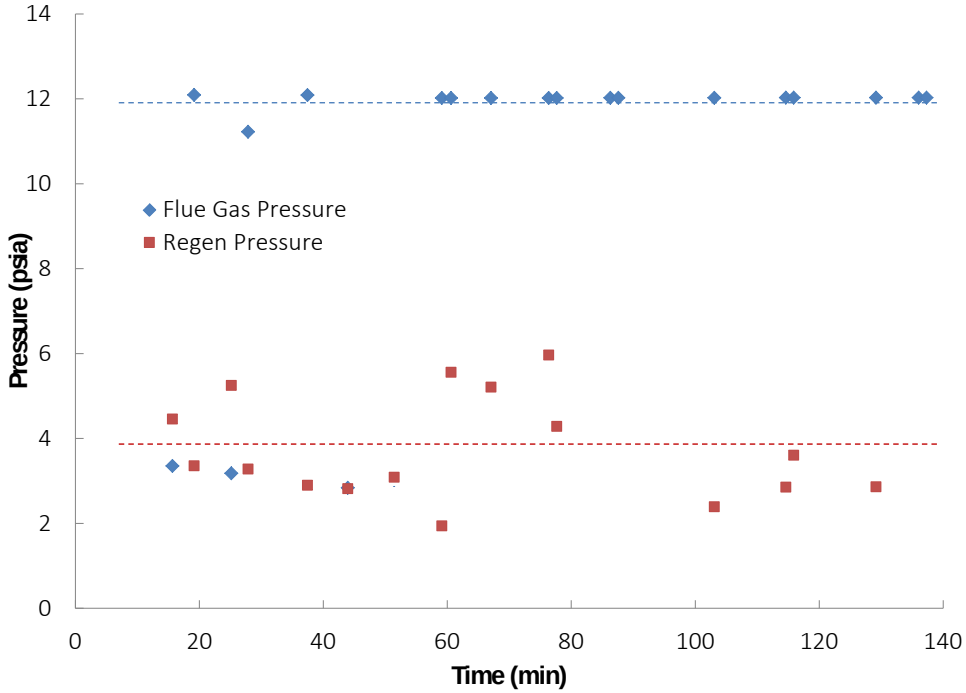
Sorbent Performance in Moving-Bed Unit





- **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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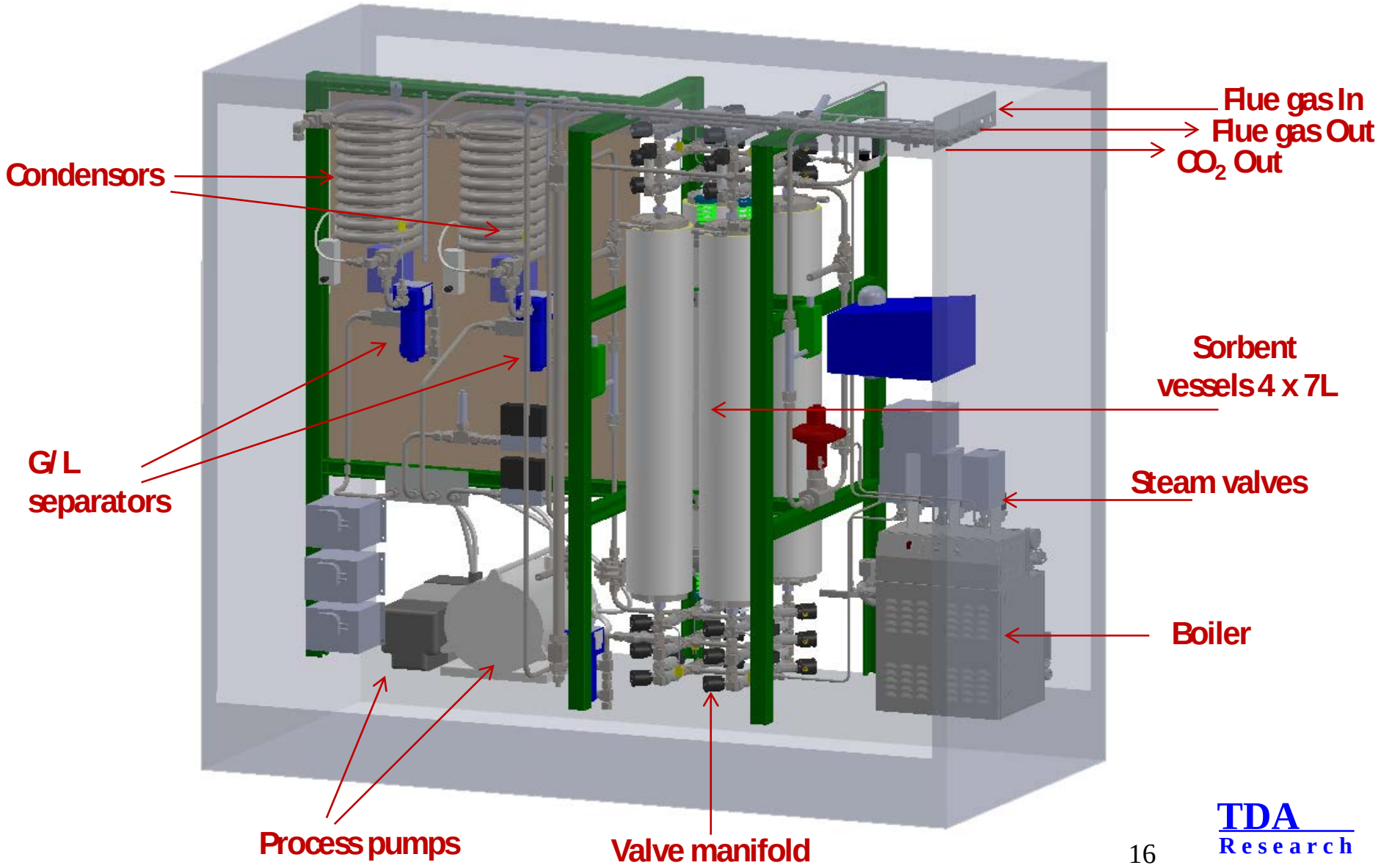
4-Bed VSA System



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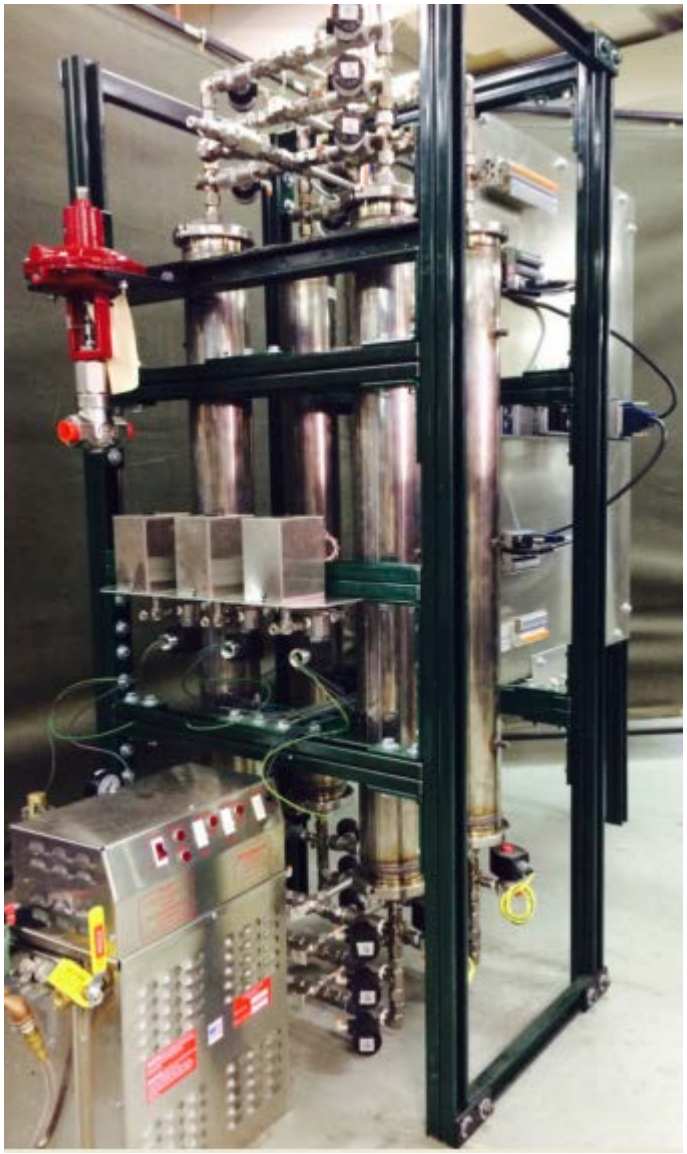
4-Bed VSA System



Dimensions
72” x 24” x 72”

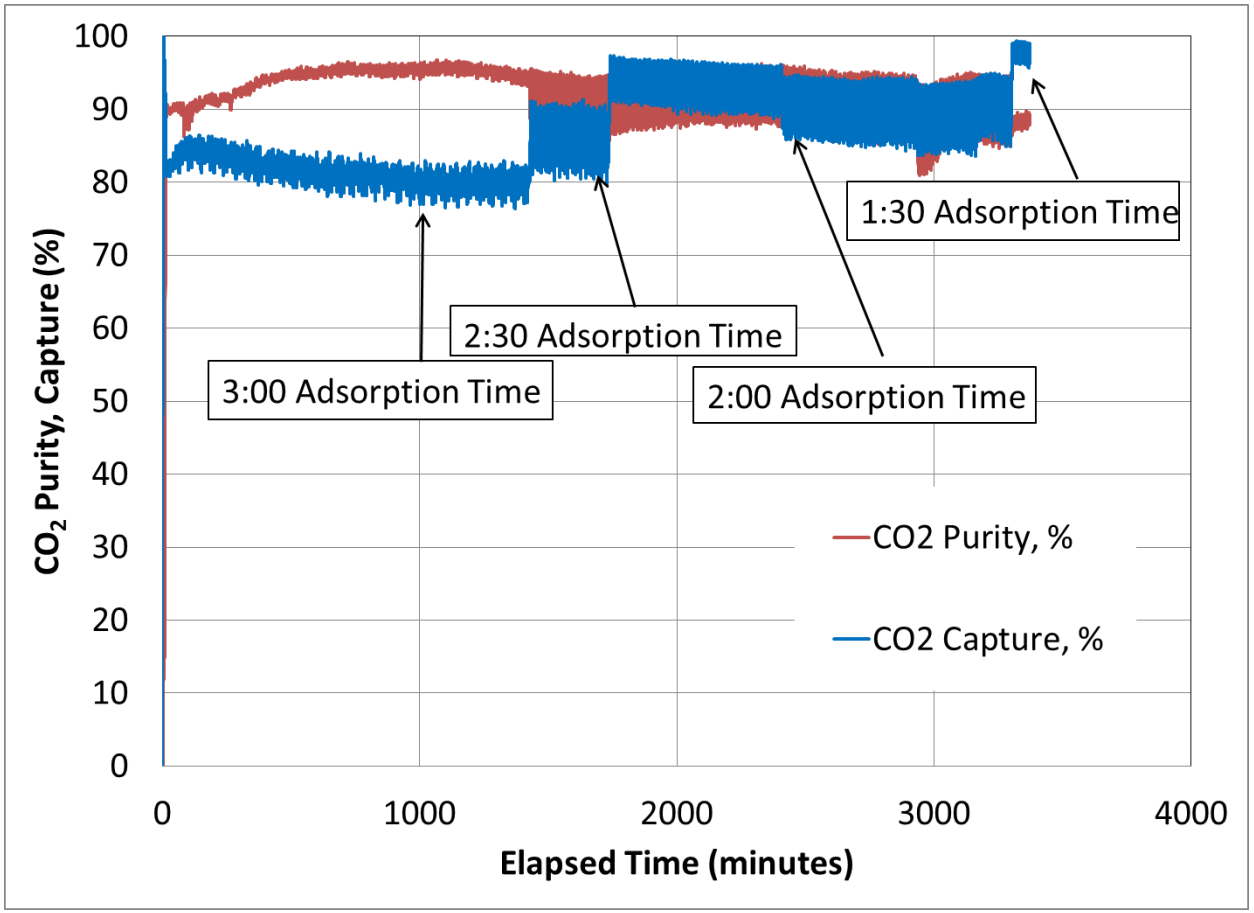
Feed rate
2 SCFM flue gas

Baseline Operating Conditions
70°C, 3 – 17 psia

4-Bed VSA System

Sorbent Performance in Fixed-Bed Unit

Flue gas flow = 28 SLPM; CO_2 Inlet = 13.2% vol., Adsorption pressure = 14 psia



- **98+% CO_2 capture efficiency at 1:30 min adsorption time**
- **Recovered CO_2 purity 90-95% vol. (wet basis)**

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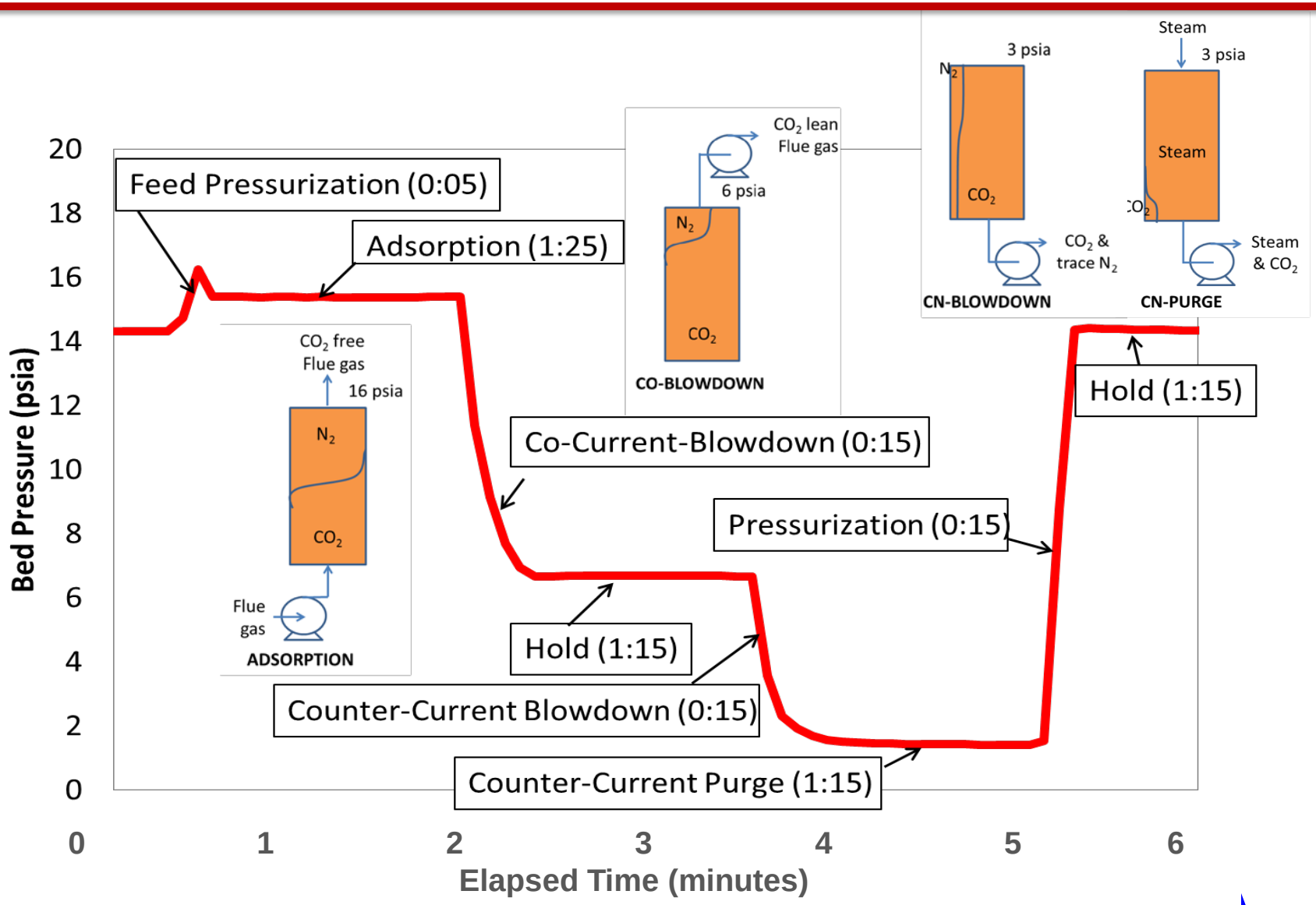
VSA Cycle Pressure Profile



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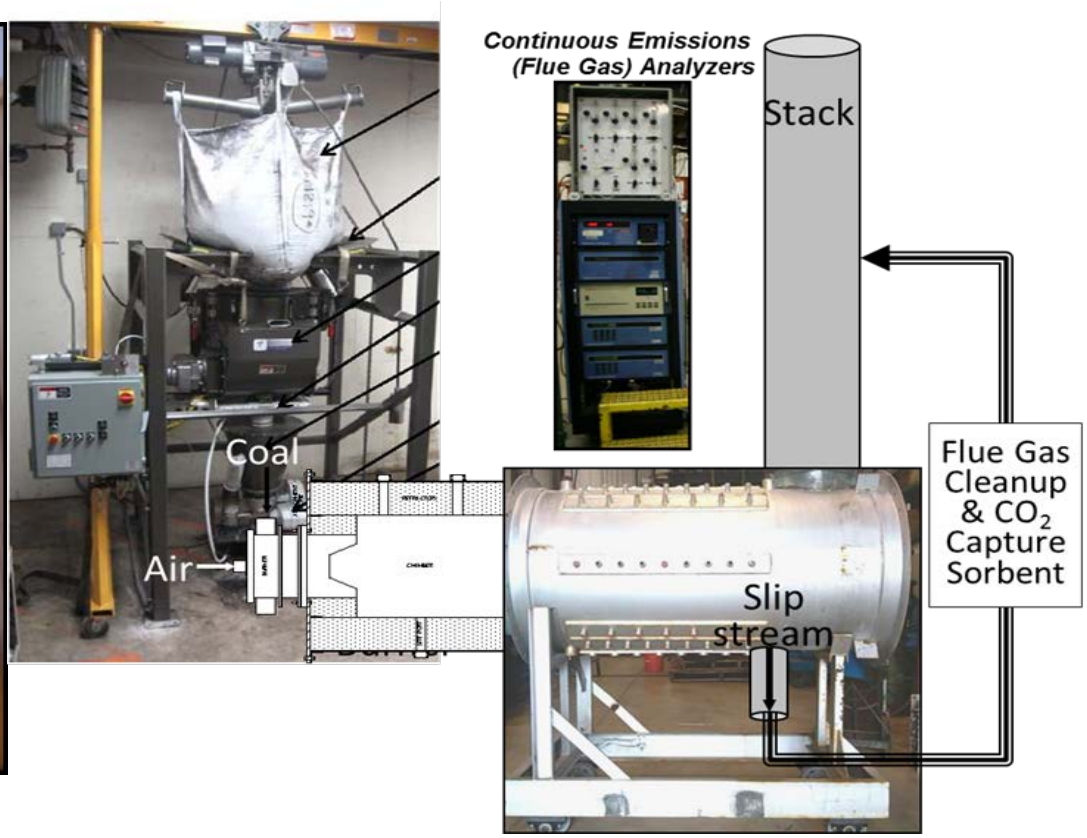
Slipstream Testing



- **The slipstream tests were carried out at Gas Technology Institute's Combustion Facility, Des Plains, Illinois**
- **Total flue gas flow = 81 CFM (29 lb/hr coal feed rate)**
- **Slipstream = 4 SCFM**

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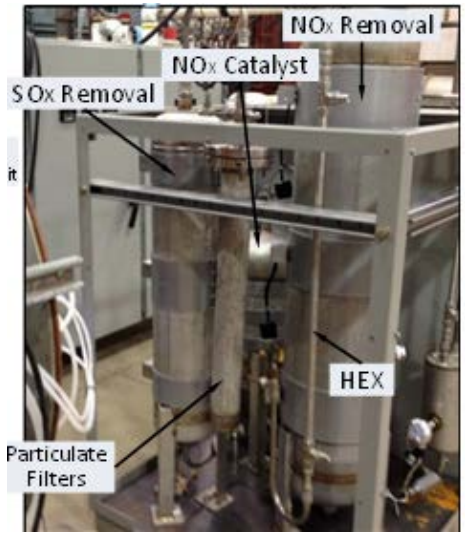
Flue Gas Conditioning



Flue Gas Cleanup System

Gravimetric Coal Feeder

Swirl Type Burner

Combustion Air

Thermal Load

Furnace

Thermal Load

Water

Stack

ID Fan

TDA CO_2 Capture System

Moisture Control

Trace Contaminant Control

Heat Exchanger Temperature Control

Water

NOx Control

Partial Bypass for Fine Control

SO_2 Control

Slipstream (4 SCFM)

Water

PM Control (Cyclones)

Heat Exchanger Temperature Control

PM Control (Metal Filter)

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Units Installed at GTI

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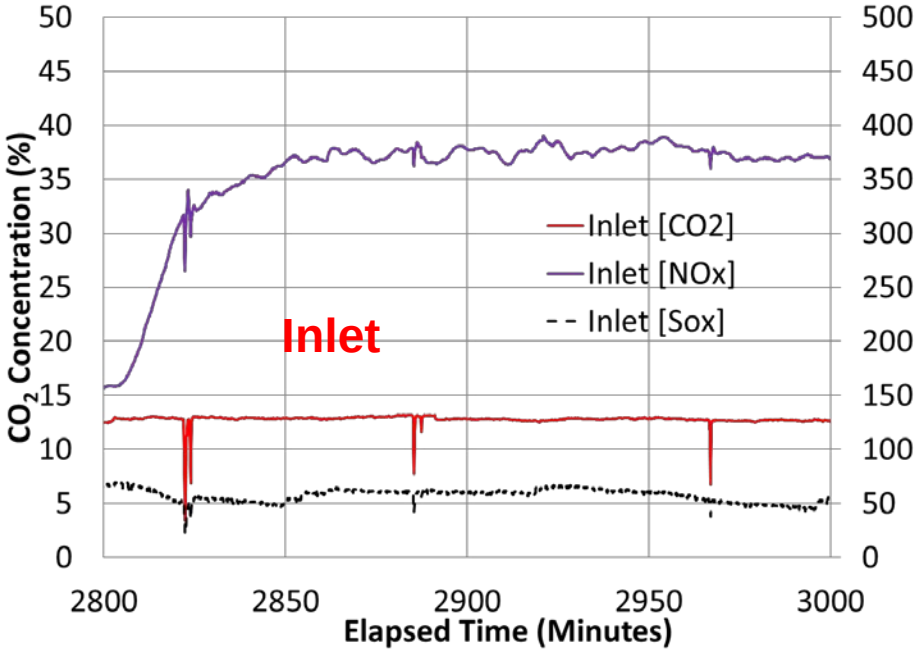
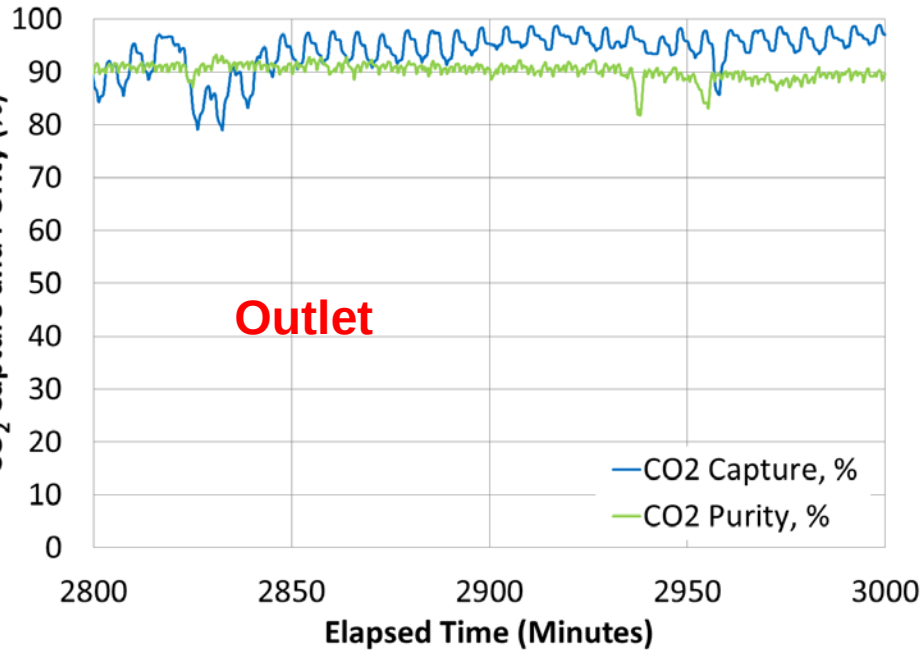
Illinois #6 Coal Derived Flue Gas

Flue gas composition: 13% vol. CO_2, 370 ppm NOx, and 50 ppm SOx





- **4-bed VSA system removed 95+% CO_2 in the flue gas and the CO_2 product purity was above 90%**
- **Sorbent maintained stable performance in the presence of 370 ppmv NOx and 50 ppmv SOx**

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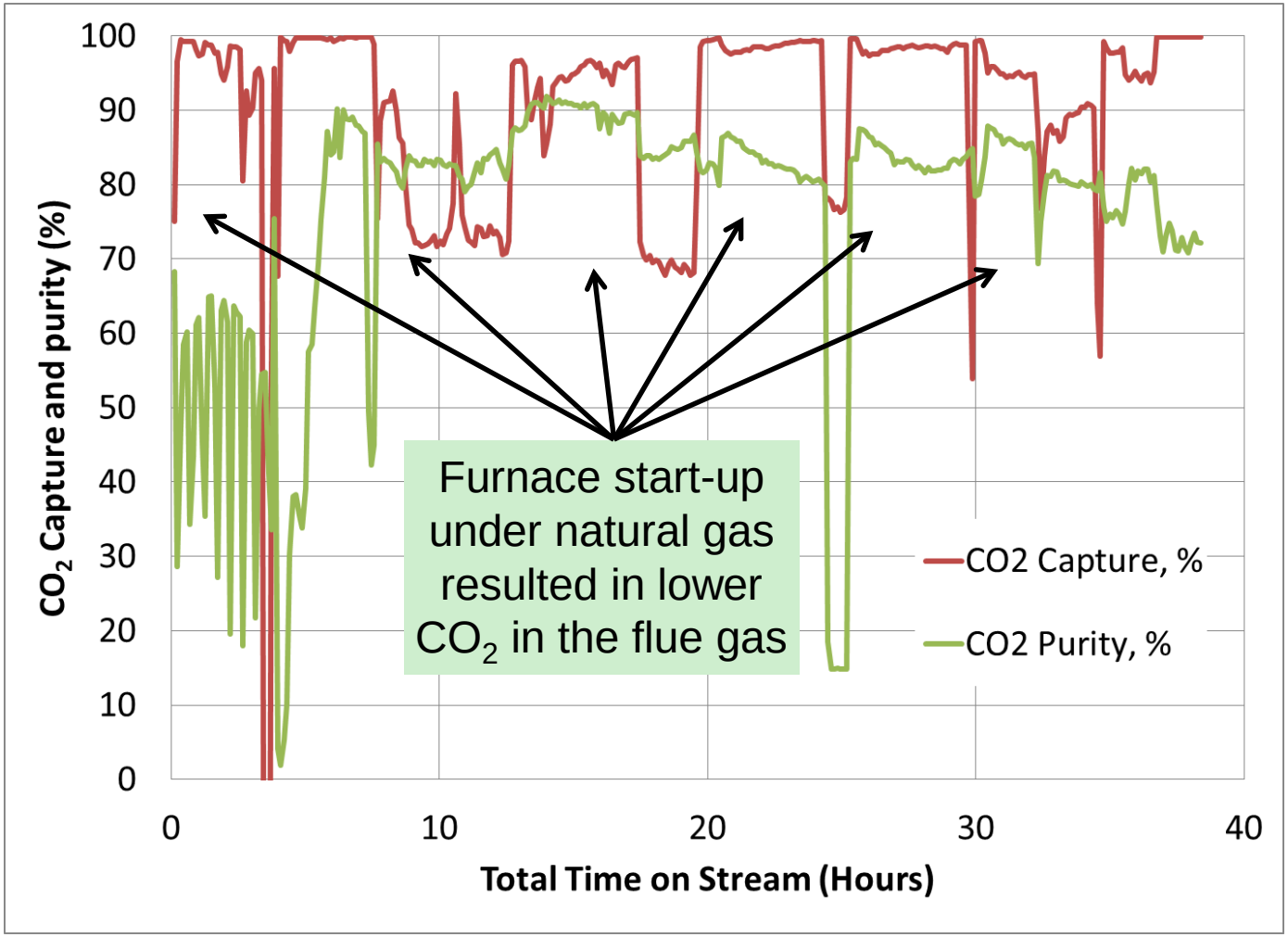
Field Test Data at GTI



- **4-bed VSA system achieved more than 95+% CO_2 capture from real coal derived flue gas**

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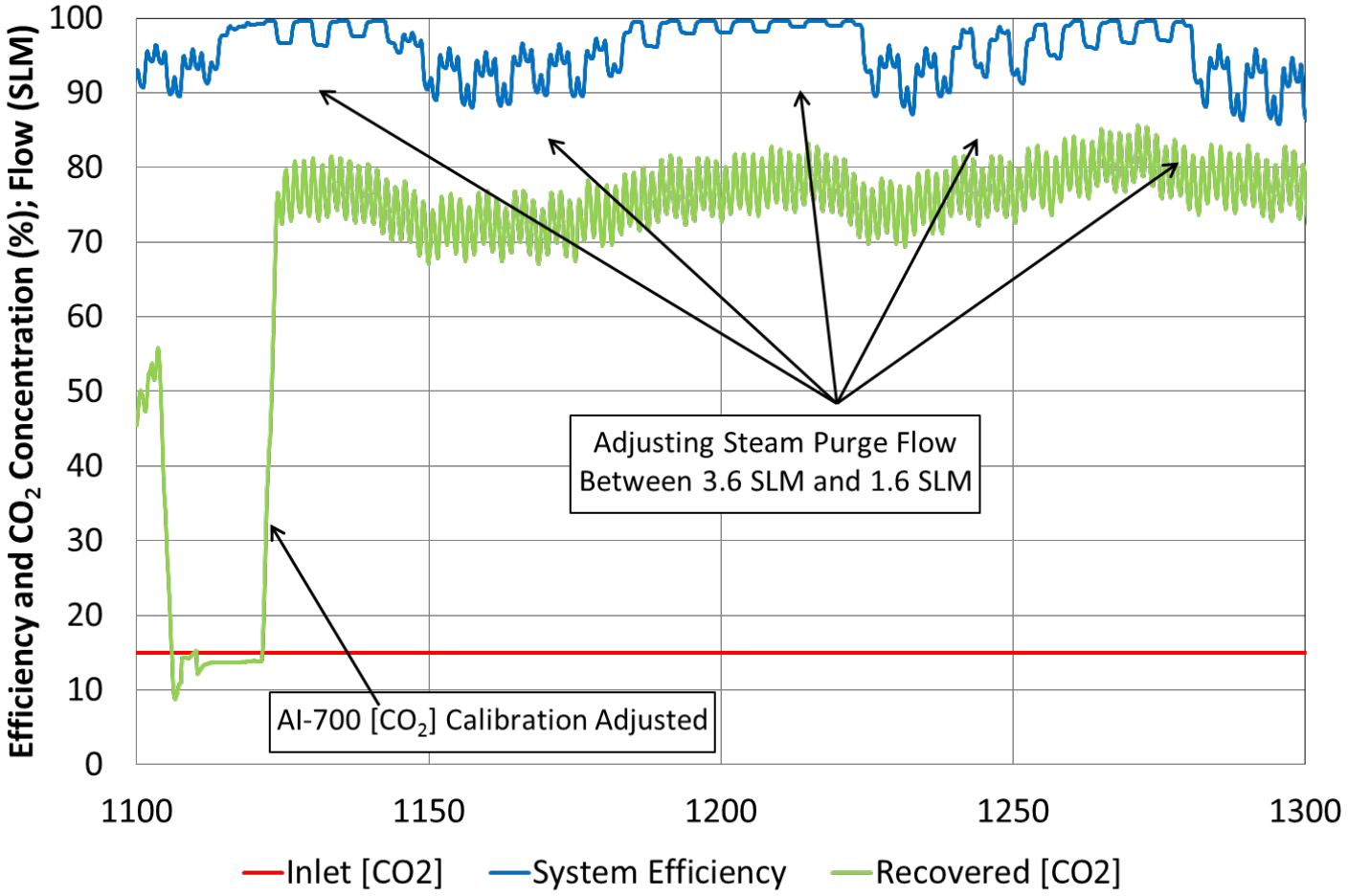
Purge Steam: CO_2 Ratio

Flue gas flow = 24 SPLM, Inlet CO_2 Conc. = 15% vol. (Steam:CO_2 = 1 to 0.44)



- **Steam :CO_2 of 0.44 provides high CO_2 capture efficiency of 95+%**

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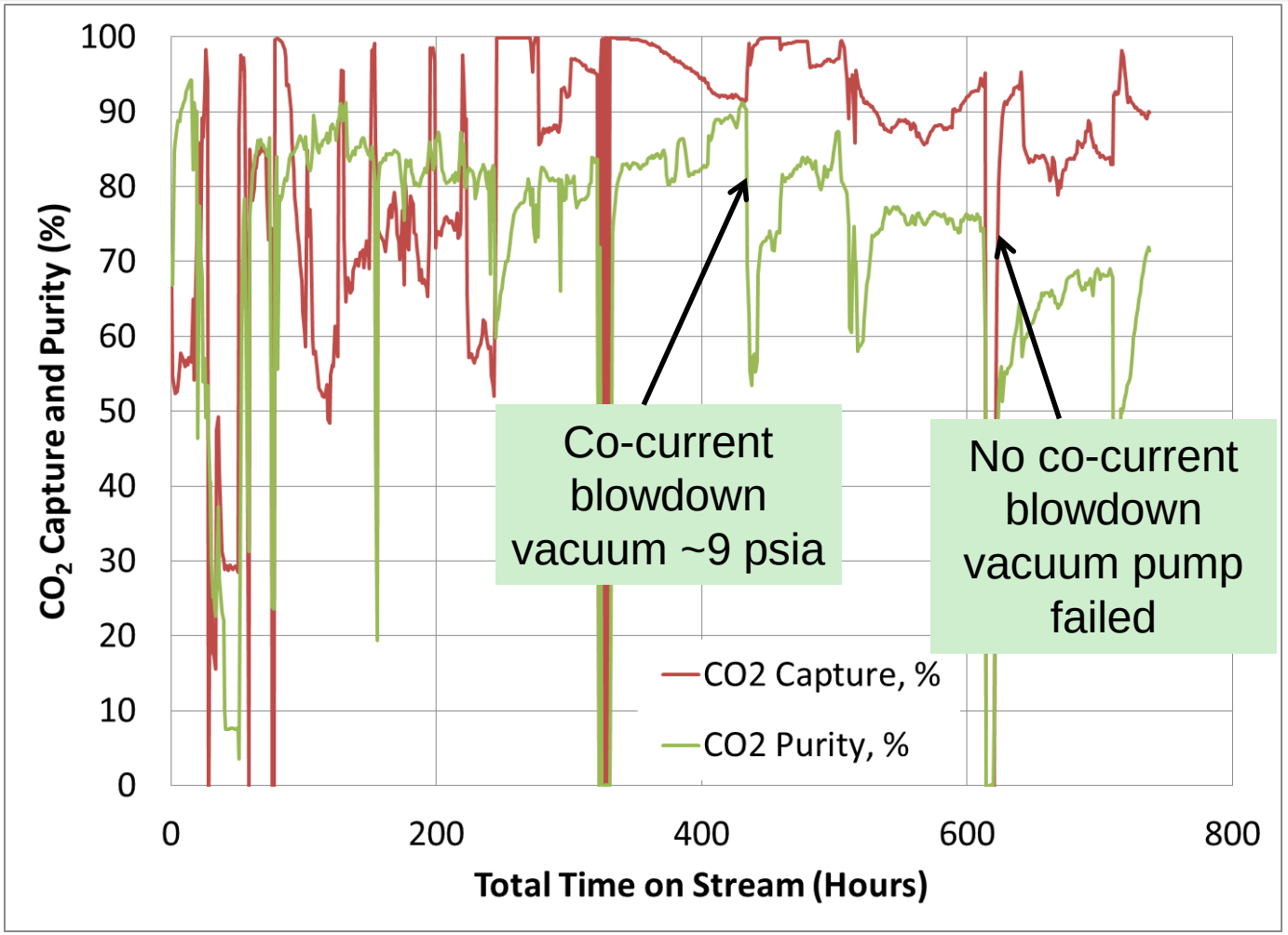
Summary of Tests at GTI



- **4-bed VSA system was tested for more than 750 hours with stable performance achieving 90+% CO_2 capture**

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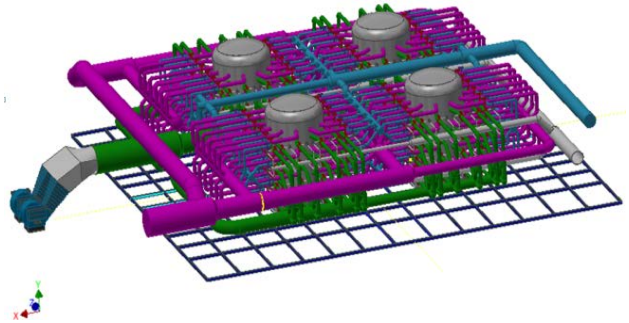
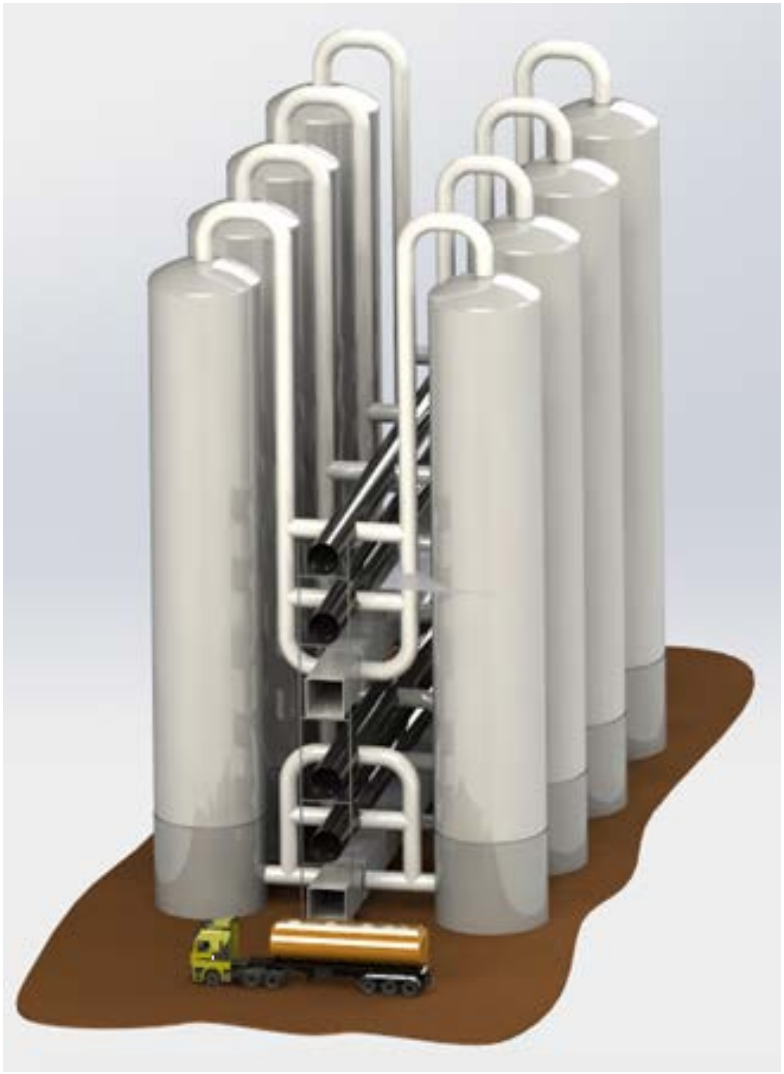
Advanced Packed Bed Design

- **Greatly simplified the B&W design using smart manifolding, cutting down the number of connections, valves etc. and the cost**





- **550 MW net power output**
- **8-beds**
- **7.3 m (24 ft) in diameter and are 33.5 m (110 ft) tall**
- **All piping/ducting is insulated to prevent water condensation**
- **Piping of the vessel manifolds is manufactured from 48” pipe**

Cost of CO_2 Capture

CO_2 Capture Technology	Amine based CO_2 Capture DOE Case 12	TDA's VSA based CO_2 Capture
CO_2 Capture, %	90	90
Gross Power Generated, kWe	662,800	696,195
Auxiliary Load, kWe	112,830	146,195
Net Power, kWe	549,970	550,000
Net Plant Efficiency, % HHV	**28.4**	**31.8**
Coal Feed Rate, kg/h	256,652	229,527
Raw Water Usage, m^3/MWh	4.2	3.3
Total Plant Cost, $/kWe	3,563	2,872
COE without CO_2 TS&M, $/MWh	137.3	113.6
COE with CO_2 TS&M, $/MWh	**147.3**	**122.4**
Cost of CO_2 Capture $/tonne	**66.4**	**47.2**

- **TDA's VSA Fixed-bed/LP steam purge (withdrawn from ST cycle) provided the 1st year COE of $122.4/MWh (vs. $147.3/MWh for amine scrubbers)**
- **Cost of CO_2 capture is $47.2/tonne (vs. $66.4/tonne for amine scrubbers i.e., 29% improvement over amine scrubbing)**

Acknowledgements

- **The funding from DOE/NETL under Contract No. DE-FE-0007580 is greatly acknowledged**
- **Technical Monitor, Andrew O'Palko, NETL**
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- **Dr. Ashok Rao, UCI**
- **Dr. Francois Botha and Dr. Debalina Dasgupta, ICCI**