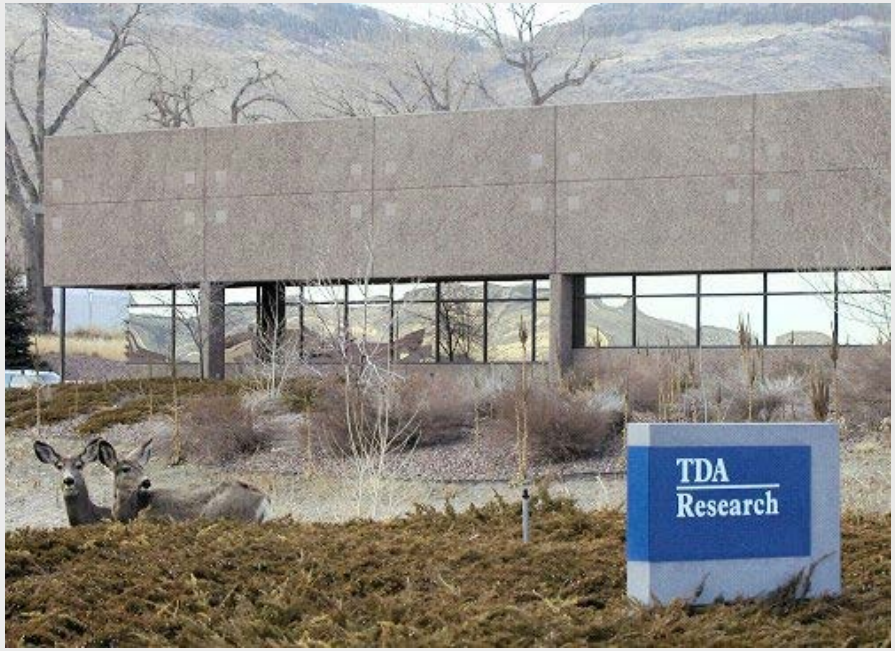
Sorbent Based Post-Combustion CO_2 Slipstream Testing

Project # DE-FE0012870



Dr. Jeannine Elliott

Dr. Bob Copeland

2015 NETL CO_2 Capture Technology Meeting

June 25, 2015

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

Project Objectives

- The objective is to develop a new post-combustion capture technology that captures CO_2 at less than $40 per tonne (DOE's near term cost target)
- Demonstrate TDA's sorbent technology under realistic conditions at the 0.5 MW_e (~10 tpd) scale to collect data necessary for scale up to the next level plant
- Major Project Tasks
  - Design, construction, and operation of slipstream test unit to capture CO_2 from flue gas at the National Carbon Capture Center (NCCC)
- Successful project completion will move the technology along the commercialization road map towards slipstream demonstrations and multi MW installations by 2020-2025

National Carbon Capture Center

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Project Overview

DoE Project DE-FE0012870

Funding - Total Project $5,880,378

- DOE: $4,704,509
- Cost Share: $1,175,868

Project Dates

- April 1, 2014 to May 31, 2018

- **Budget Period 1: Optimization & Design**
  - $1,542,398
- **Budget Period 2: Construction & Installation**
  - $2,946,991
- **Budget Period 3: Operation**
  - $1,390,989

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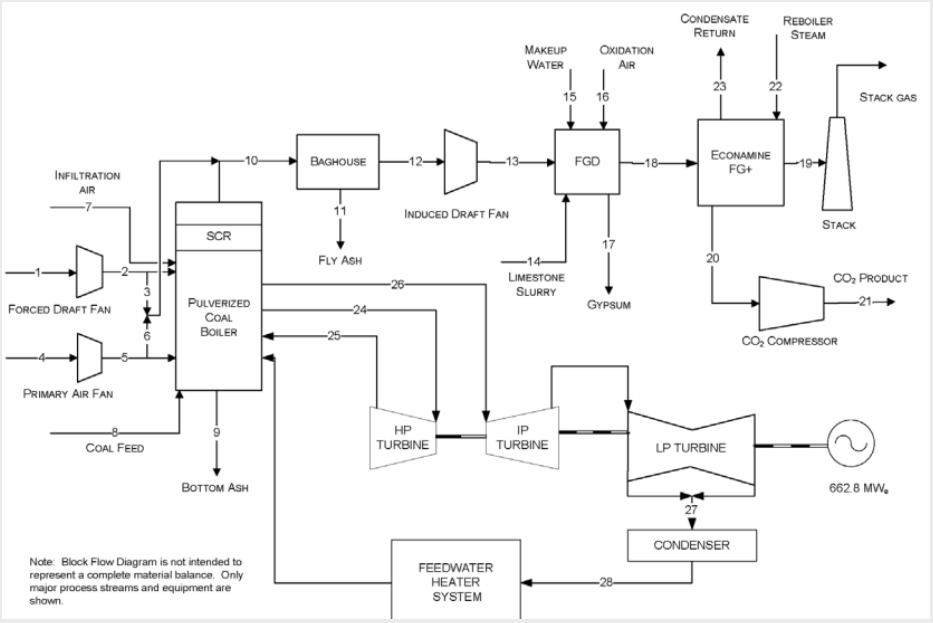
Technology Background & Approach

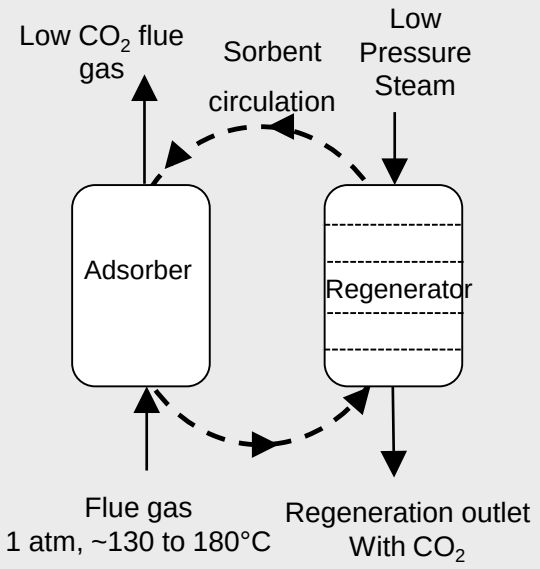
TDA's Approach

TDA Research has developed:

- A solid alkalized alumina adsorbent, and
- A CO_2 capture process designed around this process



TDA CO_2 Capture on Supercritical 550 MW plant



- Moving bed had expensive conveyors, although the beds would be smaller
- New multiple fixed bed design
  - Low cost construction
  - Simple bed design
  - Eliminates power lost to moving sorbent
- Lower overall cost that moving bed

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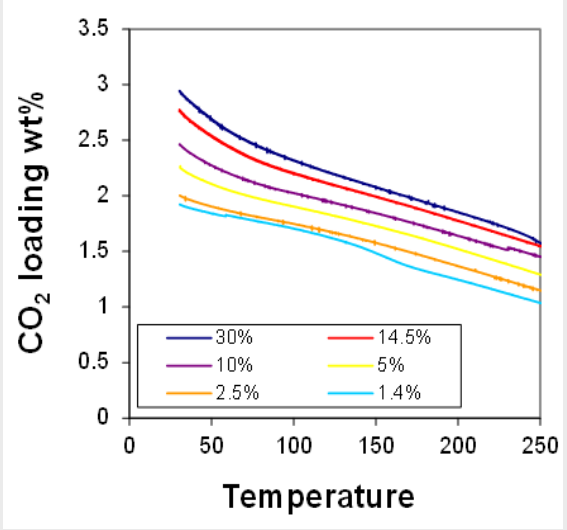
Sorbent-based
Post Combustion CO_2 Capture

- **Process advantages:**
  - An inexpensive, durable sorbent
  - Regenerates with low pressure steam
  - Operates at near isothermal conditions, ambient pressure
  - Does not require heat recovery from solids
  - Extremely low heat of adsorption
  - Uses counter-current operation to:
    - Maximize capture efficiency
    - Maximize sorbent loading

- **Patents filed July 2014**
  - Pending U.S. and PCT applications

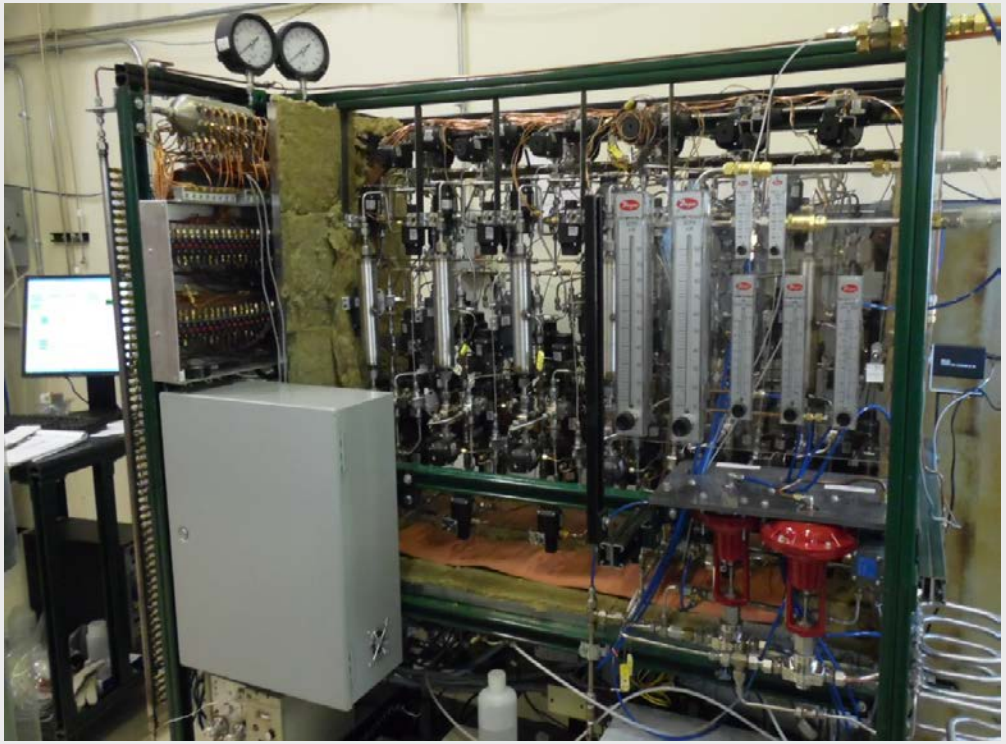


Heat of adsorption

Heat of adsorption ranges from 3 kcal/mole at higher CO_2 concentrations of 10-14%, to 10.3 kcal/mole at CO_2 concentrations of 1-5%

Process Design

- Multiple Fixed Bed Contactor
  - Provides counter-flow contact between the solids and gases
- Beds cycle between adsorption and regeneration functions
- Gas flows in series across regeneration beds
- Multiple fixed beds are flexible and can allow demonstration of multiple process design configurations
- Slipstream unit is being designed as multiple fixed bed unit



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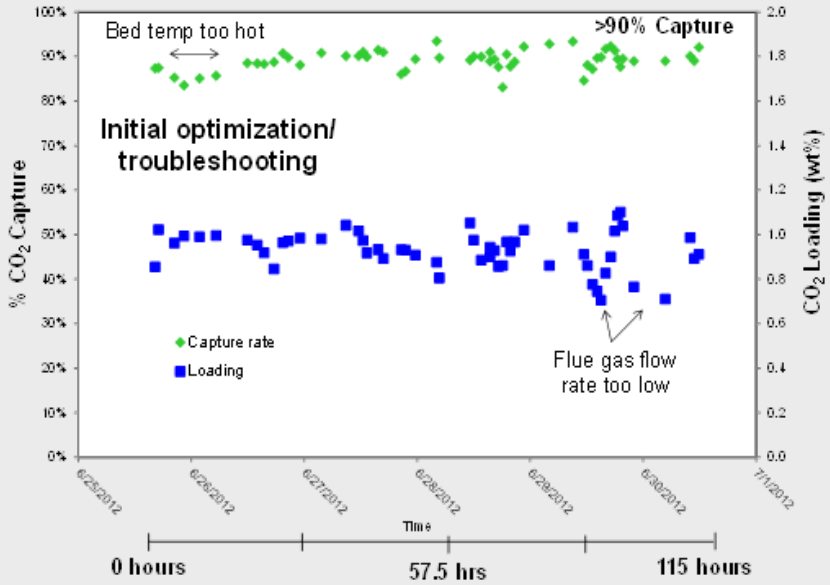
Earlier Demonstration Testing
at Western Research Institute

- Slipstream project builds on previous DoE funded research
  - Contract #DE-NT0005497
- Demonstrated continuous CO_2 capture in 8 bed bench-scale unit in field testing with coal flue gas at Western Research Institute (Laramie, WY)



Testing of 8 bed apparatus at Western Research Institute

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Project Scope

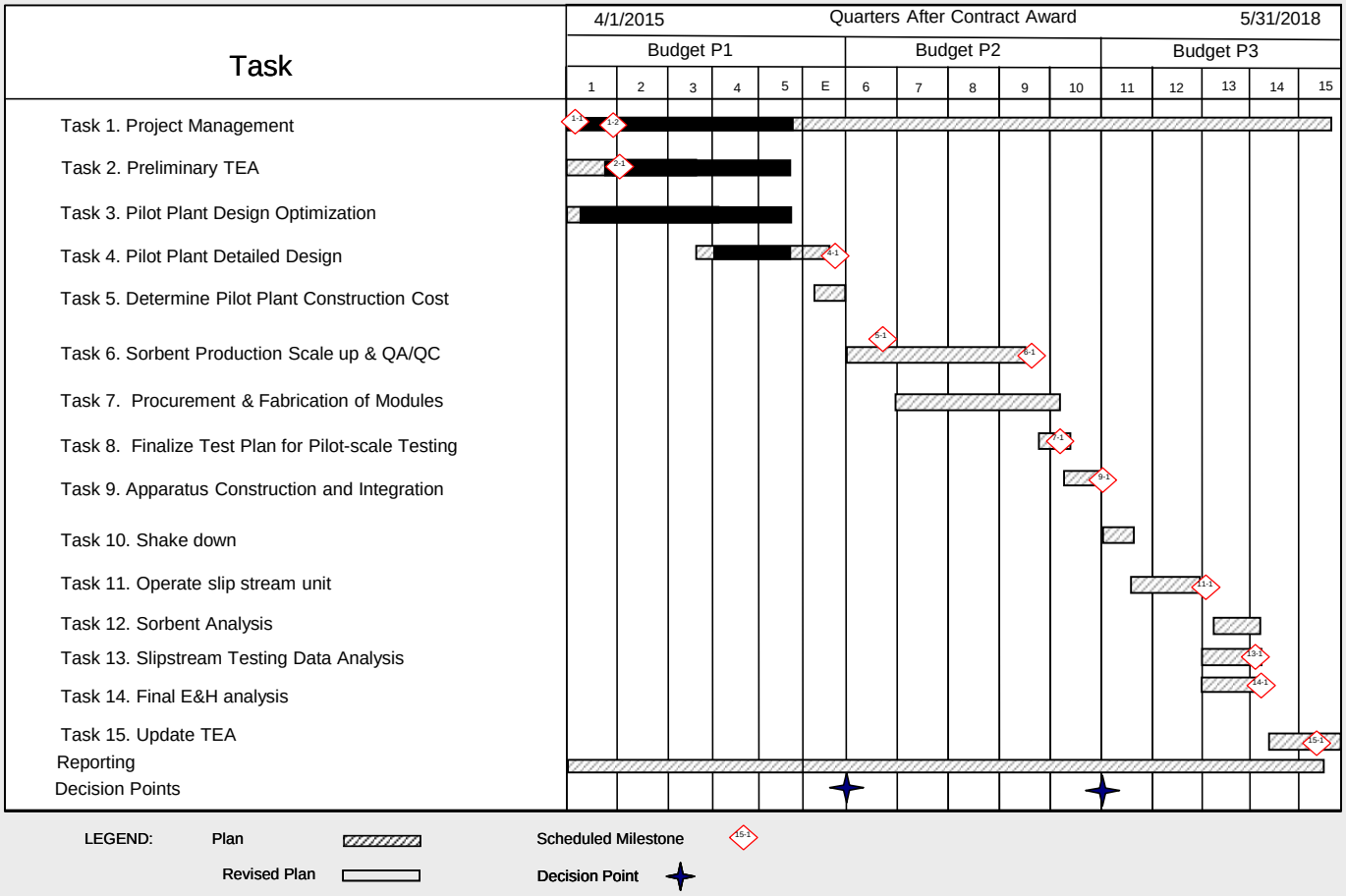
Project Schedule

- **Budget Period 1: Optimization & Design**
  - April 2014 to November 2015
- **Budget Period 2: Construction & Installation**
  - December 2015 to Feb 2017
- **Budget Period 3: Operation**
  - March 2017 to May 2018

Major Project Tasks

- **Preliminary Techno-Economic Analysis**
  - Based on integration with a nominal 550 MW_e greenfield supercritical plant, Case 12
- **Pilot Plant Design Optimization and Basis Design**
  - Process experiments to finalize process design
  - Basic process specification and design
- **Pilot Plant Detailed Design and Engineering**
  - Design a 0.5 MW_e pilot plant to capture 10 tons per day of CO_2,
  - Hazard Review with NCCC and Initial Environmental, Health and Safety (EH&S) study
- **Scale-up production of the sorbent**
  - QA/QC testing of sorbent at TDA
- **Fabricate slip stream unit and install at NCCC**
- **Demonstrate this process in slipstream testing**
  - Under parametric and steady state conditions
- **Update the Techno-Economic Analysis and finalize the EH&S assessment**

Project Schedule



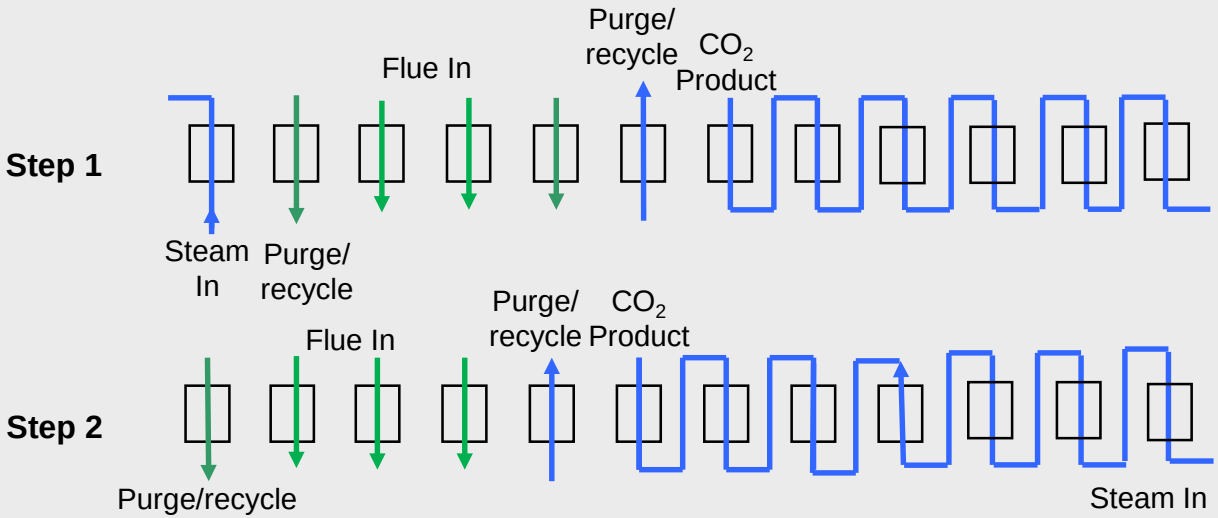
Budget Period 1

Progress to Date

- **Project kick-off meeting held at DoE on May 2014**
- **Several improved process designs developed**
  - New bench-scale unit constructed for optimization testing which mimics slipstream unit
  - Several generations of changes have been made as part of optimization
  - Reconstruction of bench-scale apparatus for optimization experiments delayed project schedule.
- **Engineering and design of 0.5 MW slip stream unit started**
  - Design presented to NCCC for discussion on requirements and logistics
  - Multiple fixed beds design reactor design and layout developed
  - PFD and P&IDs prepared
- **Preliminary Hazard Review with NCCC completed May 2015**
- **EH&S report to be completed June 2015**

Process Design Optimization

- Multiple Fixed Bed Contactor
  - Provides counter-flow contact between the solids and gases
- Beds cycle between adsorption and regeneration functions
- Gas flows in parallel through adsorption beds and in series across regeneration beds



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Features & Benefits of 12 Bed Design

- Previous TDA bench-scale apparatus had 8 beds and limited ability to simulate recycle options
- New 12 bed apparatus is redesigned for improved performance and better simulation of slip stream unit & commercial system

Feature	Advantage	Benefit
12 beds (vs. 8 beds)	Additional regeneration stages	• Additional stripping for same steam usage • Trade-off of adding more beds to be assessed
Steam saver recycle with controlled flow and timing	Steam in wet flue effluent recycled back to regeneration side to rehydrate bed can be optimized in controlled manner	• Steam usage decreased • Steam saver can now be tuned for maximize benefit
Adsorption Breakthrough recycle	Effluent flue in last adsorption bed recycle back to feed to keep capture up	• This recycle option was not available in previous bench-scale apparatus

- TDA is collecting data to evaluate optimized process conditions and performance of recycles/purge steps

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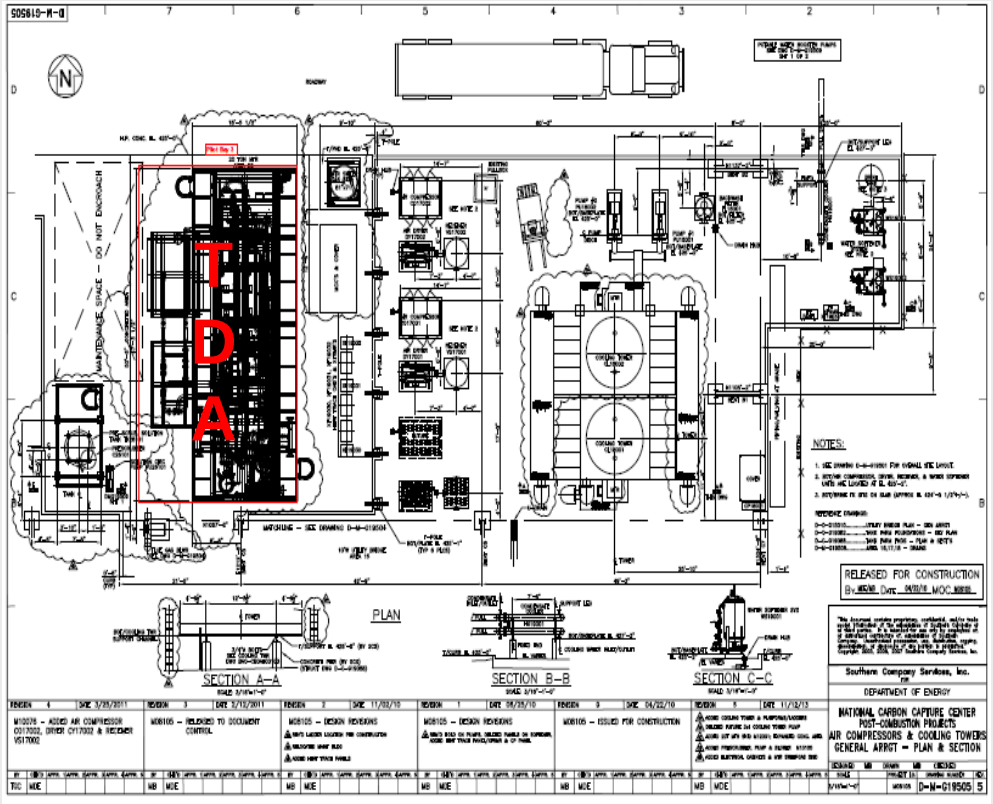
Slipstream Unit at NCCC

- 0.5 MW_e Skid mounted system
- Adsorber/Regeneration Contractor is a multiple fixed bed unit
- Sorbent is regenerated by steam
- Adsorber/Regenerator operates near isothermal (adiabatically) at 120 to 140°C with about 17 psia steam
- Operation pressure is near atmospheric pressure



System to be located at NCCC Pilot Bay #3 47” x30”

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Pilot-scale Unit Design

- Engineering design of 0.5 MW of skid mounted slip stream unit with multiple fixed beds (5000 lb/hr flue gas)
- Pilot System includes 4 units
  - Adsorber/Regeneration Contractor
    - 12 Beds switch between adsorption, regeneration, purge operations
  - Support unit (heat exchanger, blower, flow metering, exhaust cooler)
    - Blowers to increase pressure of flue which is provided to the unit from NCCC with virtually no pressure head
    - Steam and resistive heat exchangers to heat flue gas up to the operating temperature and control (fine tune) the regeneration steam temperature
    - Flow metering to measure flue gas and steam flow rates
    - Cooling water heat exchangers to cool exhaust gases to less than 60°C to make it compatible with NCCC exhaust vent system.
  - Instrument/control unit
    - Gas analyzers and control system units
- Engineering issues being addressed related to bed design, flow distribution, valves & manifolding to minimize pressure drop, transportation/weight of units
- SolidWorks models complete on contactor unit

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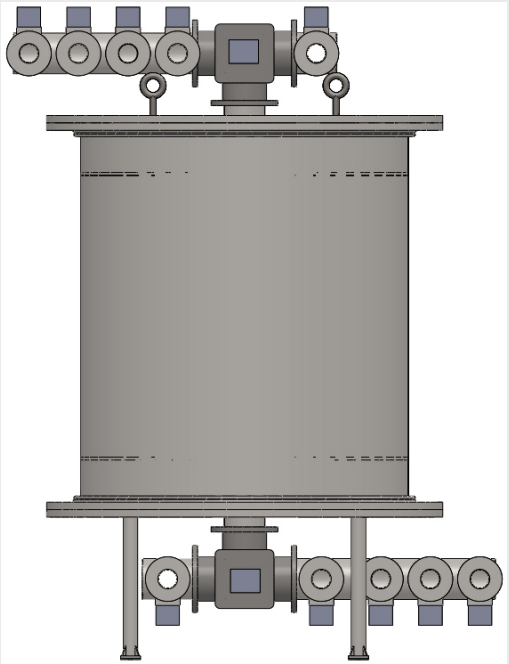
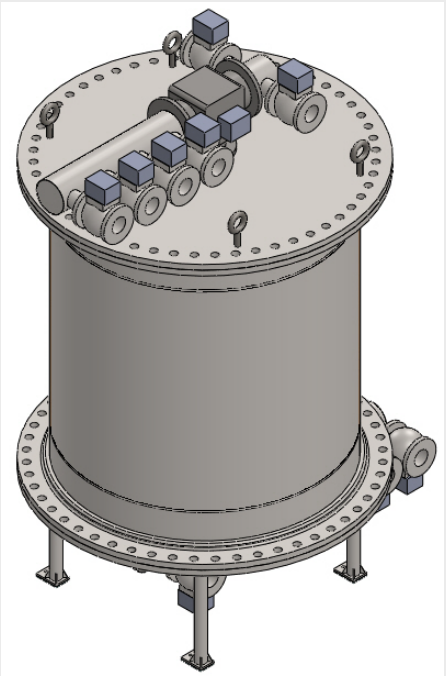
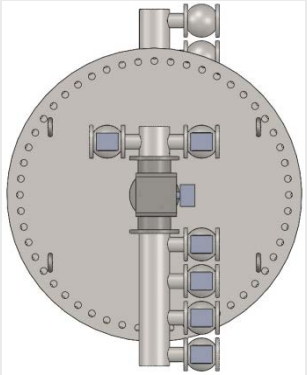
Slipstream Unit Reactor Design





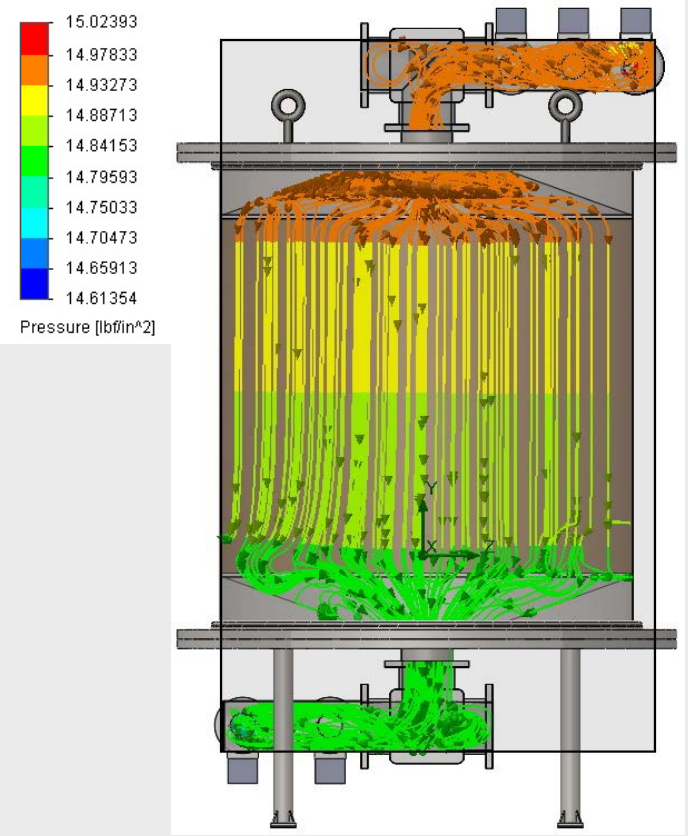
- Beds are cylindrical reactors with carbon steel flanges.
- Top flange is removable to fill sorbent.
- A main 3 way ball valve is the central piece of each valve assembly with a number of 2 way ball valves for each gas stream.
- All valves are pneumatically actuated.

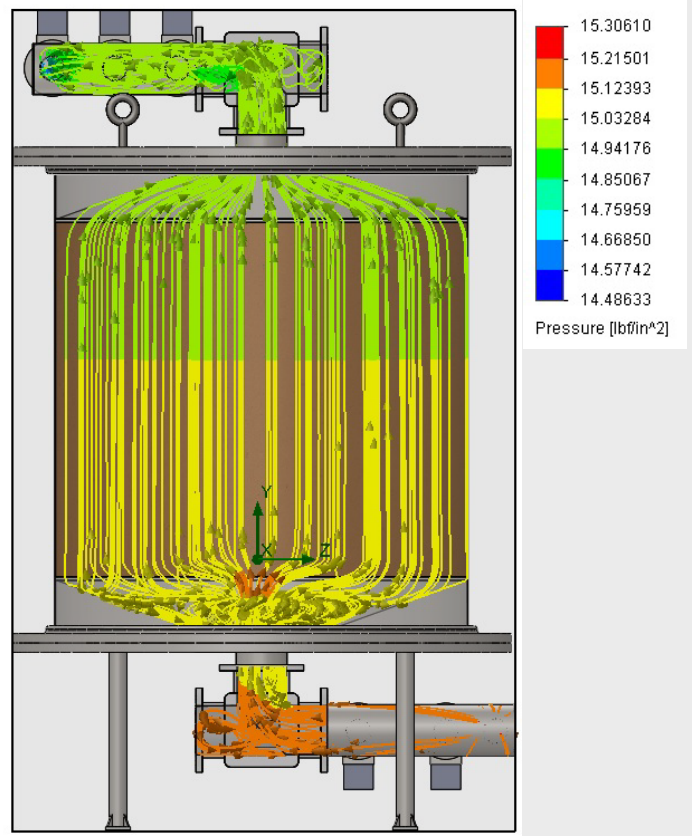


Manifolding & valves to control multiple operation on each bed

Slipstream Unit Bed Design

Flow distribution simulation through reactors





- A 4.5” high plenum above and below the sorbent bed for flow distribution.
- A grated plate/screen is secured at the bottom of the plenum to keep the sorbent in place.
- CFD modeling with the Solids Works flow simulation program on adsorption and regeneration flow distribution.

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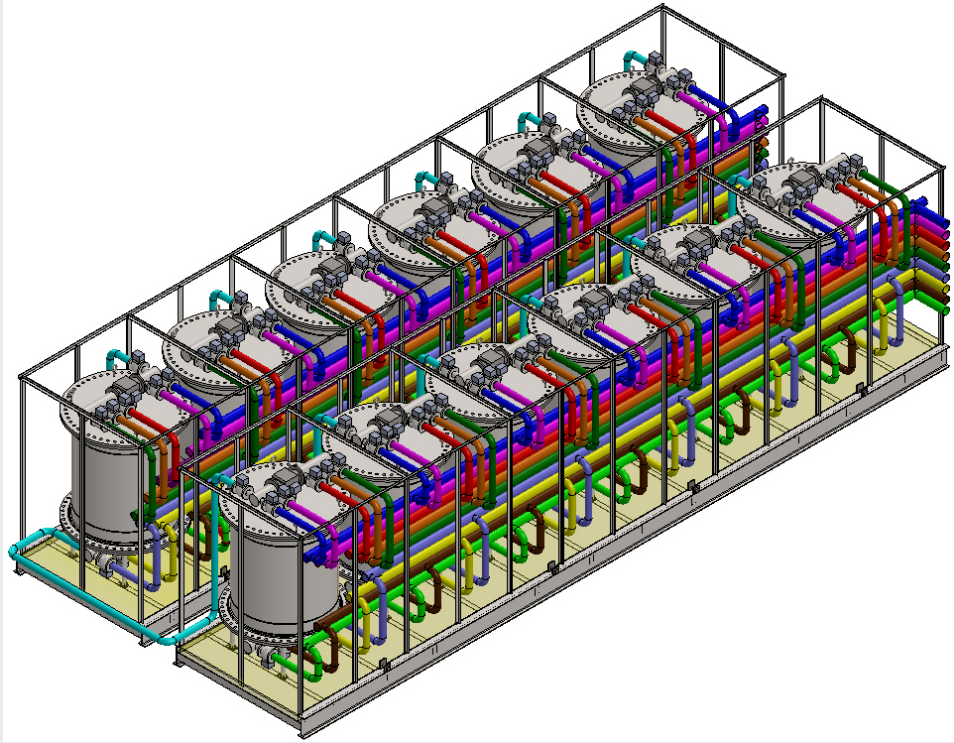
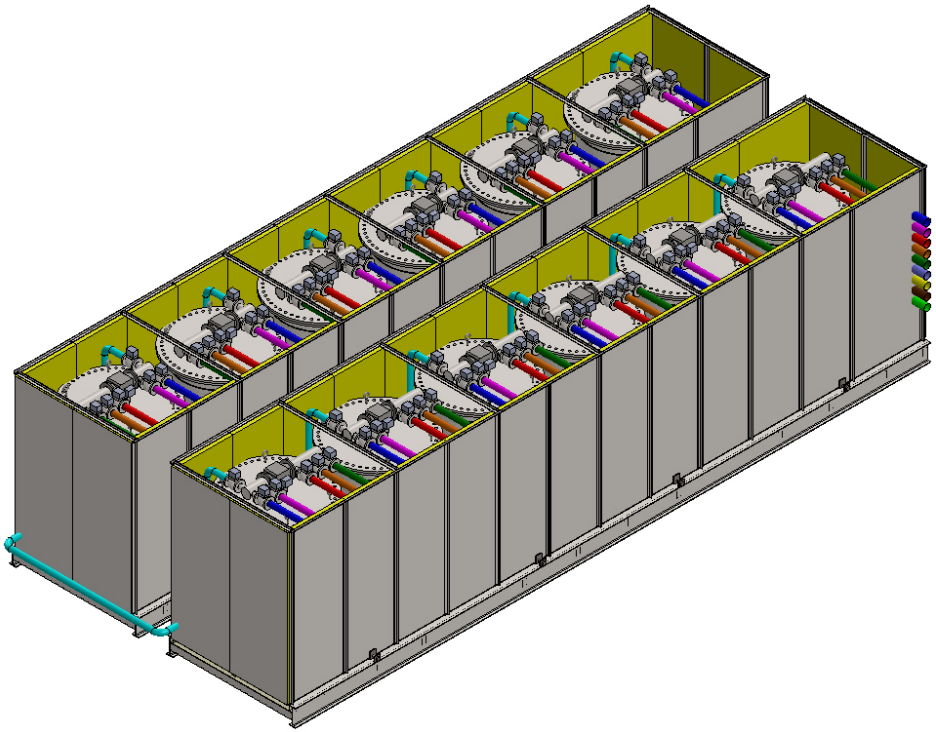
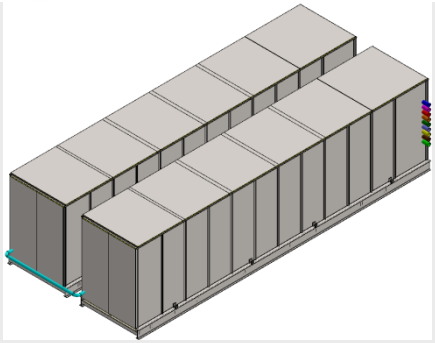
Slipstream Unit Bed Design





- SolidWorks models of the reactors and piping developed
- Sorbents beds are arranged in two rows on two skid mounted units
- 12 beds in internally insulated box, entire trailer at operating temperature, removable panels for maintenance/repair



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Budget Periods 2 & 3

Budget Period 2

BP 2 Tasks December 2015 to February 2017

- Scale-up production of the sorbent
- QA/QC testing of sorbent at TDA
- Fabricate the sorbent bed vessels for the pilot plant and other modules
- Finalize Test Plan
  - Operating conditions and key parameter parametric conditions selected
  - Operator training
- Integrate the unit at the NCCC

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Budget Period 3 Tasks

Budget Period 3 March 2017 to May 2018

- Demonstrate this process in slipstream testing at the NCCC under both parametric and steady state conditions using coal derived flue gas.
- Update the Techno-Economic Analysis and finalize the EH&S assessment
- Data from the pilot plant test will be used to develop recommendations for the next level of scale up

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Summary

- Process design optimization is focused on the flow pattern of the gases (which is controlled by the programming of the system) through the multiple fixed bed system
- We have moved forward with hardware design even as we continue to push of the optimization of the system
- Initial process flow diagrams and P&IDs of the slipstream system have been prepared
- We have completed initial Process Hazard Analysis with NCCC
- We have nearly completed preliminary Environmental, Health and Safety (EH&S) review
- We will complete final process optimization and economic analysis
- By end of Budget Period 1 we will complete engineering design, HAZOP review and submit design package to DoE

TDA Research Inc.

Privately Owned/Began operations in 1987

80 Full-time technical staff

Located just west of Denver, CO

Acknowledgements

- Project funding provided under DoE Contract # DE-FE0012870
- Andy O'Palko
- Lynn Brickett