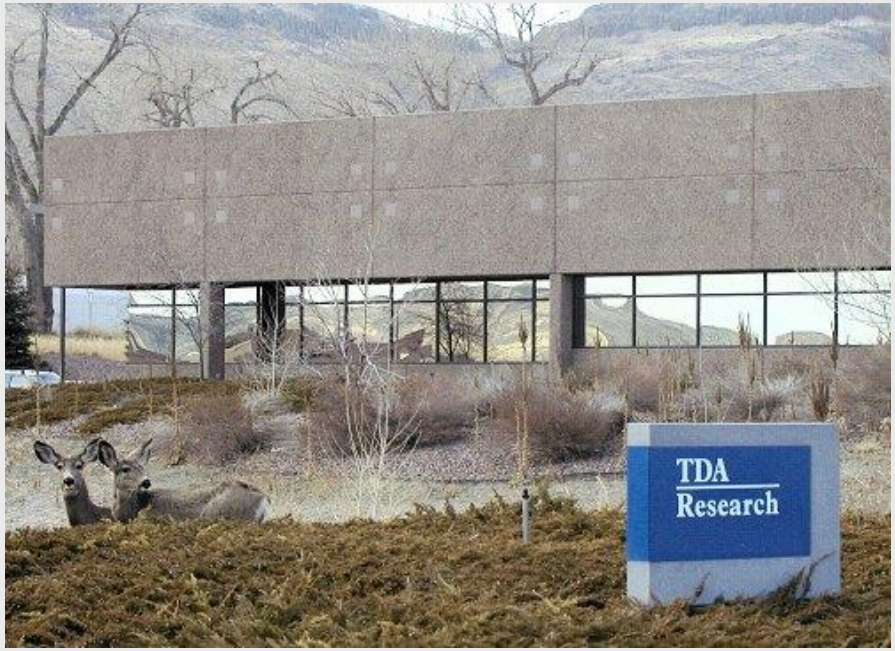
Sorbent Based Post- Combustion CO_2 Slipstream Testing

Project # DE-FE0012870



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May 20, 2014

Kick-off Meeting

Project Overview

DoE Project DE-FE0012870

Funding - Total Project $5,880,378

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

Project Performance Dates

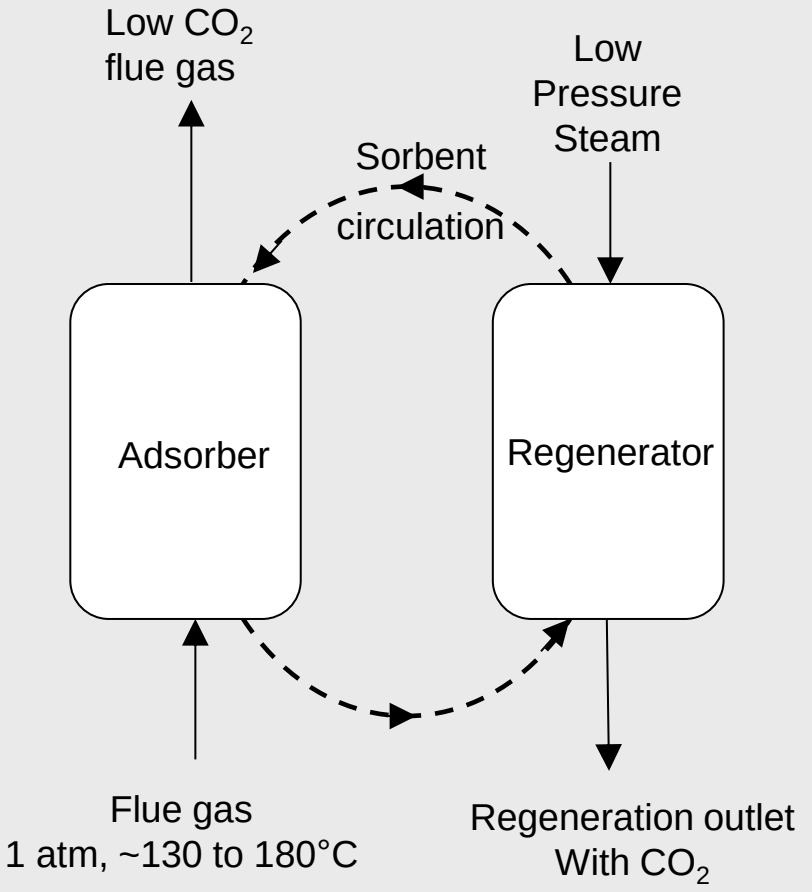
- February 3, 2014 to December 31, 2017

Technical work started April 1, 2014 when we received a large batch of sorbent from our industry partner.

Approach

The Basic Idea

- **TDA Research has developed:**
  - **A solid alkalized alumina adsorbent, and**
  - **An optimized CO_2 capture process**



TDA Research

TDA's Post Combustion CO_2 Capture

- **Process advantages:**
  - An inexpensive, durable sorbent
  - Regenerates with low pressure (17 psi) steam
  - Operates at near isothermal conditions
  - Does not require heat recovery from solids
  - Extremely low heat of adsorption
  - Uses counter-current operation to:
    - Maximize capture efficiency
    - Maximize sorbent loading
  - The result, excellent economics

Previous Research

- **This slipstream project builds on previous DoE funded research**
  - Contract #DE-NT0005497
  - $1,714,846 Project
- **Investigated process in single fixed bed reactor**
- **Demonstrated continuous CO_2 capture in 8 bed bench-scale unit**

Previous Field Testing

- **Completed field testing with coal gas at Western Research Institute**
- **Powder River Basin Decker Coal**
  - **Flue gas**
  - ~17 psi
  - 11-14% CO_2
  - ~6% H_2O
  - 5-145 ppm NO
  - 2-11 ppm NO_2
  - 0-15 ppm SO_2
- **> 90% Capture**

Additional Optimization

- **TDA and our industrial partner carried out extensive process optimization**
  - New designs with equal performance, 1/9th the pressure drop and lower steam usage
- **New sorbents developed with better kinetics and loadings**

Current Project:
Slipstream Demonstration Test

- **Project Goal:** Demonstrate TDA's sorbent bed technology under realistic conditions at 0.5 MW_e (~10 tpd) scale to collected data necessary for scale up to next level plant.

- Design, construction, and operation of slipstream test unit to capture CO_2 from flue gas at the National Carbon Capture Center (NCCC)

TDA Research

Project Scope

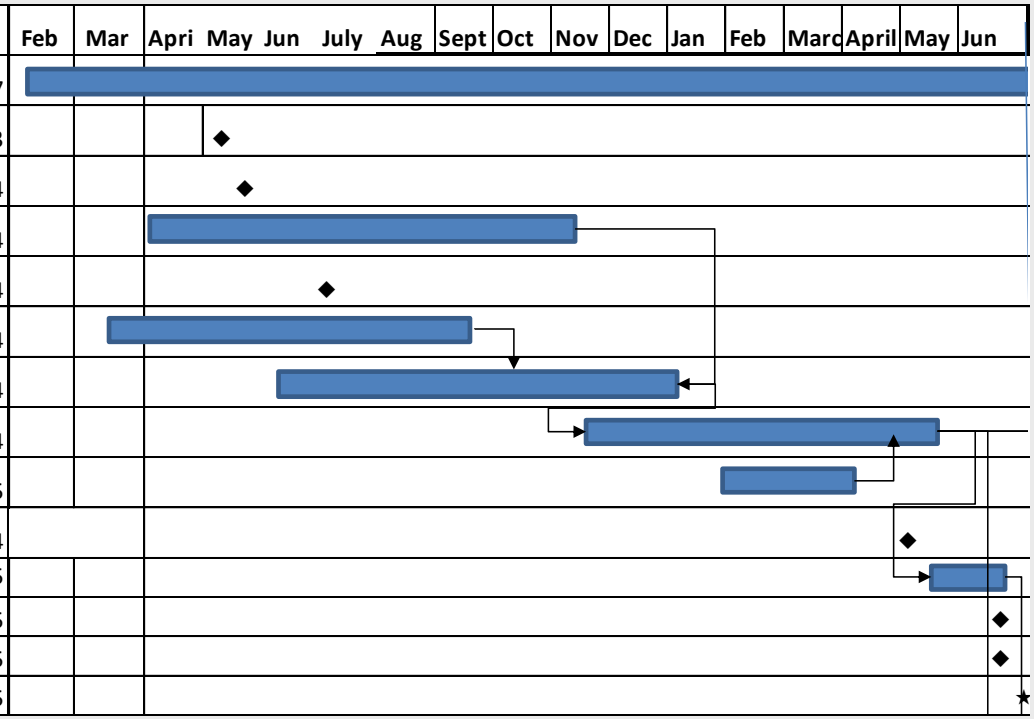
Project Schedule

- **Budget Period 1: Design**
  - April 2014 to June 2015
- **Budget Period 2: Construction & Installation**
  - July 2015 to Sept 2016
- **Budget Period 3: Operation**
  - Oct 2016 to Dec 2017

Budget Period 1

Budget Period 1 Schedule

ID	Task Name	Start	Finish
1	Task 1. Project Management	2/3/2014	6/1/2017
2	Milestone 1-1: PMP	5/1/2013	5/15/2013
3	Milestone 1-2: Kick-off Meeting	5/20/2014	5/20/2014
4	Task 2. Preliminary TEA Case 1-4	4/1/2013	11/15/2014
5	Milestone 2-1: Preliminary TEA Case 1	7/1/2014	7/1/2014
6	Task 3.1. Determine Optimal Flow Pattern	3/15/2013	9/15/2014
7	Task 3.2. Basic Process Specific. & Design	5/1/2013	11/1/2014
8	Task 4.1 Pilot Plant Detailed Engineering	11/15/2014	5/1/2014
9	Task 4.2 EH&S Assessment	1/1/2015	3/31/2015
10	Milestone 4-1: Pilot Unit design	5/15/2015	5/15/2014
11	Task 5. Determine Construction Cost	5/2/2015	6/15/2015
12	Milestone 5-1: Submit Design Package	6/30/2015	6/30/2015
13	Milestone 5-2: Year 1 Annual Review	6/30/2015	6/30/2015
14	**Go/No go Decision Point**		7/1/2015



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Budget Period 1 Tasks

- **Task 1: Project Management**
- **Task 2: Preliminary Techno-Economic Analysis**
  - based on integration with a nominal 550 MW_e greenfield supercritical plant
- **Task 3. Pilot Plant Design Optimization and Basis Design**
  - Process experiments to finalize process design
  - Basic process specification and design
- **Task 4. Pilot Plant Detailed Design and Engineering**
  - Design a 0.5 MW_e pilot plant to capture 10 tons per day of CO_2,
  - Perform an initial Environmental, Health and Safety (EH&S) study
  - Hazard Review with NCCC
- **Task 5. Determine Slipstream Unit Construction Cost**
  - Develop a firm cost estimate for the slipstream unit

Preliminary Techno-Economic Analysis

- Integration with greenfield supercritical 550 MW coal fired power plant
  - Cost and Performance Baseline for Fossil Energy Plants (Black 2010) Case 12
- Analysis will follow DoE guidelines
- Work to be performed with University of California at Irvine (UCI)
- Previous TEA's showed cost savings with TDA's process with the use of lower pressure (17.5 psi) steam

Design Optimization

- Collect experimental data need to properly design pilot plant unit
- Characterize breakthrough performance and pressure drop
- Conduct process optimization in bench-scale unit to determine optimum flow/cycling logic for pilot plant
  - Plan to modify existing bench-scale unit to mimic design to be constructed

Slipstream Unit Design

- Sorbent is regenerated by direct contact with steam
- Adsorber/Regenerator operates near isothermal (adiabatically) at 40 to 160°C with about 17 psia steam
- Pressure is about at atmospheric pressure
- Adsorber/Regeneration is a multiple fixed bed unit
  - Bed switch between adsorption, regeneration, purge operations
- Slipstream unit includes adsorber/regeneration beds, heat exchangers, blower

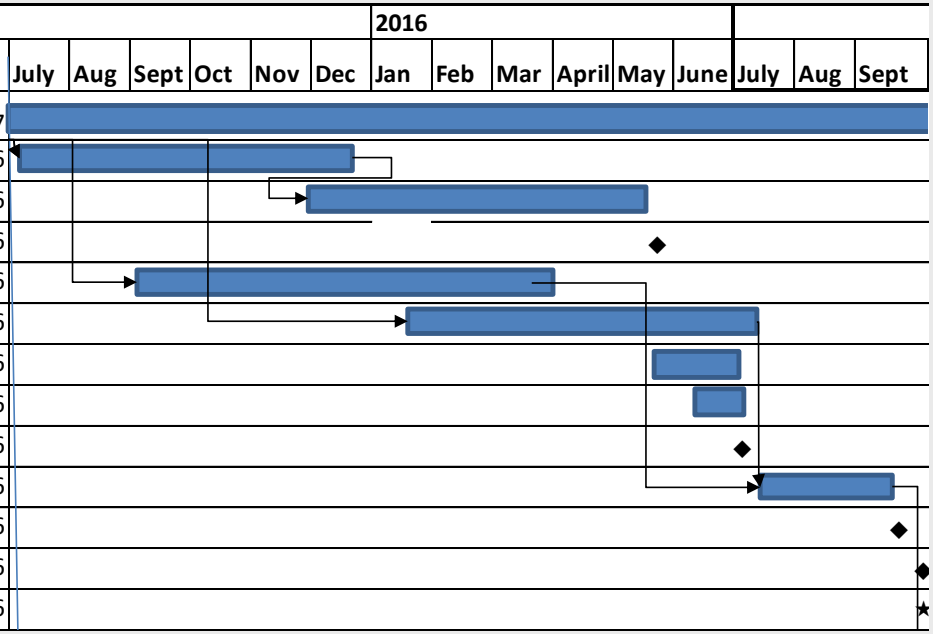
Pilot Plant Engineering Design Package

- Pilot Plant Design with Cost to Build
- Final Process Flow Diagram, General Arrangement Sketch, Elevation Sketch
- Pilot plant electricity, heat, and water consumption, waster generation, and management ties at NCCC
- Estimated CO_2 delivery conditions: pressure, temperature, flow rate, and gas composition
- Startup, steady-state operation, and shut-down procedures
- Sorbent disposal plan
  - to be disposed of by NCCC

Budget Period 2

Budget Period 2 Schedule

ID	Task Name	Start	Finish
1	Task 1. Project Management	2/3/2014	6/1/2017
15	Task 6.1 Sorbent Production	7/1/2015	1/1/2016
16	Task 6.2 Sorbent QA/QC Testing	12/1/2015	5/15/2016
17	Milestone 6-1: Sorbent scale-up QA/QC		5/15/2016
18	Task 7.1 Fabrication of Adsorber Unit	9/1/2015	4/15/2016
18	Task 7.2 Fabrication of other Modules	1/15/2016	6/30/2016
19	Task 8.1 Finalize Slip stream Test Plan	5/1/2017	7/1/2016
20	Task 8.2 Operator Training	6/1/2016	7/1/2016
21	Milestone 8-1: Finalize Test Plan	7/1/2106	7/1/2016
22	Task 9. Appartus Integration at host site	7/1/2016	9/15/2016
23	Milestone 9-1: Installation of Pilot Unit	9/15/2016	9/15/2016
24	Milestone 9-2: Year 1 Annual Review	9/30/2016	9/30/2016
25	**Go/No go Decision Point**		9/30/2016



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Budget Period 2 Tasks

- **Task 6. Sorbent Production Scale-up and Quality Assurance**
  - Scale-up production of the sorbent
  - Sorbent is alkalized alumina - not exotic material
  - Sorbent QA/QC testing at TDA in bench-scale unit
  - Sorbent will be tested under proposed test conditions
  - Evaluation of optimum steady state conditions
- **Task 7. Procurement and Fabrication of Modules**
  - Fabricate the adsorber/regeneration sorbent vessels for the pilot plant
  - Procure/fabricate of heat exchangers and blower
  - Skid mounted units

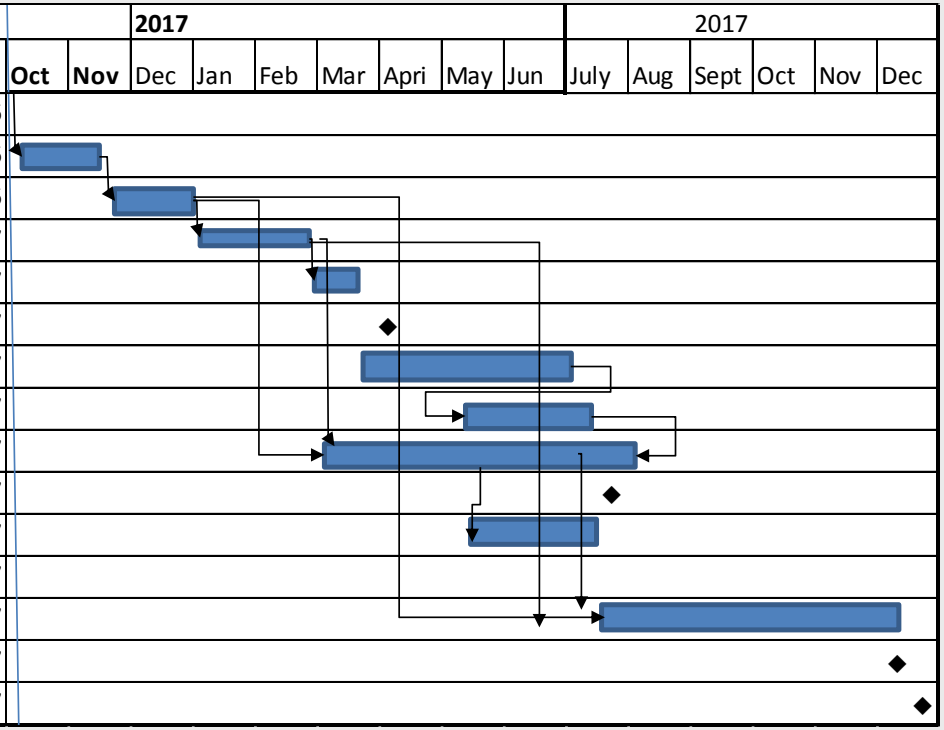
Budget Period 2 Tasks

- **Task 8. Finalize Test Plan**
  - Operating conditions and key parameter parametric conditions selected
  - Operator training
- **Task 9. Pilot Plant Construction at NCCC**
  - Modules transported to NCCC
  - Units assembled and installed
  - Beds filled with sorbent
  - Tie-ins with NCCC

Budget Period 3

Budget Period 3 Schedule

ID	Task Name	Start	Finish
25	**Go/No go Decision Point**		9/30/2016
26	Task 10. Shakedown of Pilot-Unit	10/1/2016	11/15/2016
27	Task 11.1 Parametric Testing	11/15/2016	12/31/2016
28	Task 11.2 Steady State Testing	1/1/2017	3/1/2017
29	Task 11.3 Decommisssioning	3/1/2017	3/30/2017
30	Milestone 11-1: Complete Pilot-scale Test		3/30/2017
31	Task 12.1 Characterization of Sorbent	3/15/2017	7/1/2017
32	Task 12.2 Sorbent Cost & Replacement	5/1/2017	7/15/2017
33	Task 13 Slip Stream Testing Data Analysis	3/3/2017	8/1/2017
34	Milestone 13-1: Update Table of State		7/1/2017
35	Task 14. Final EH&S Study	5/1/2017	7/1/2017
36	Milestone 14-1: Complete EH&S Analysis		7/1/2017
37	Task 15. Update Techno-Economic Analys	7/16/2017	12/15/2017
38	Milestone 15-1: Complete Updated TEA	12/15/2017	12/15/2017
39	Milestone 15-2: Year 3 Annual Review		12/31/2017



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Budget Period 3 Tasks

- **Task 10. Shakedown of slipstream unit.**
  - Series of cold then hot shakedown runs
- **Task 11. Operation Slipstream Unit**
  - Demonstrate this process in slipstream testing at the NCCC under both parametric and steady state conditions using coal derived flue gas.
  - **Parametric Testing**
    - 1.5 months of parametric testing under varying operating conditions
  - **Steady State Testing**
    - 2 months testing under continuous of steady state conditions at optimum conditions
    - Collect data for future scale up
  - **Decommissioning**
    - Sorbent disposed of by NCCC after all testing

Budget Period 3 Tasks

- **Task 12. Post-Testing Sorbent Analysis**
  - Characterize physical and chemical properties of sorbent after testing
  - Determine sorbent cost, useful life and replacement rate
- **Task 13. Slipstream Testing Data Analysis**
  - Review sorbent CO_2 loading and CO_2 capture under test conditions
  - Recommend best operating conditions
  - Update table of state
  - Data from the pilot plant test will be used to develop recommendations for the next level of scale up
- **Task 14. Update EH&S Study**
  - Update based on results of slipstream test
  - Review CO_2 capture process and sorbent manufacturing

Budget Period 3 Tasks

- **Task 15 Update Techno-Economic Analysis**
  - Incorporate performance data from slipstream test into TEA and update results
  - Determine cost of electricity for TDA's sorbent based CO_2 capture process
  - Compare to current state of the art technology
  - Work performed with UCI
- **Final Report**
  - Documentation of pilot-plant results and TEA results
  - Technology benefits and shortcomings
  - Recommendations for future R&D addressing short-comings
  - Proposed-scale up strategy for next stage of technology testing and demonstration both CO_2 capture and compression.

Summary

- **Slipstream testing will assess and demonstrate technical viability of this CO_2 capture approach**
- **0.5 MW slipstream testing at NCCC**
- **Work builds on technical success of previous work**
- **TDA has an ongoing relationship with an industry partner on post-combustion CO_2 capture.**