Pilot Unit Testing at NCCC of Sorbent based CO_2 Capture
Project # DE-FE0012870

Dr. Jeannine Elliott and Dr. Fei Yi

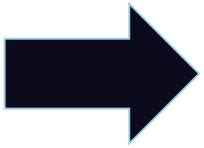
October 6, 2020

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

Program Overview

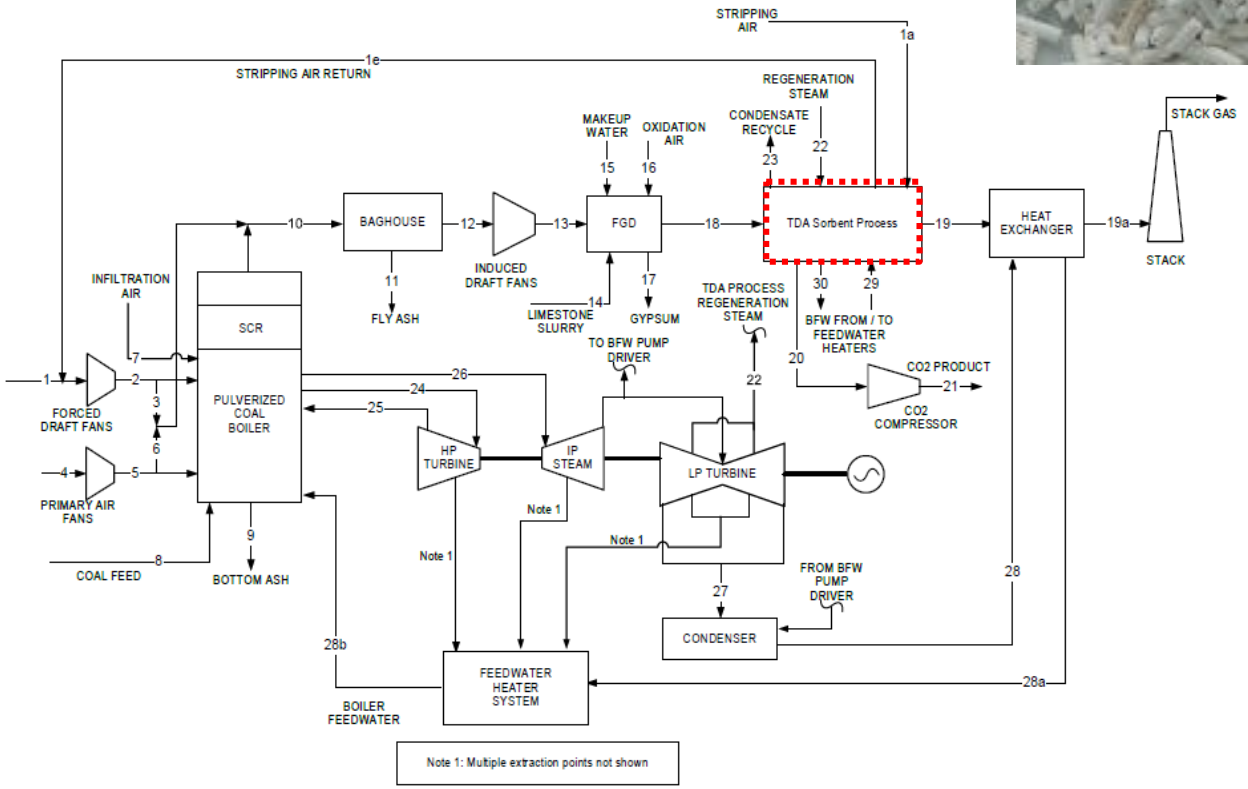
DoE Project DE-FE0012870
Funding - Total Project $6,480,377
DoE $5,204,509
Cost share $1,275,860
Partners: ExxonMobil, UCI, & NCCC

- **Budget Period 1: Optimization & Design**
- **Budget Period 2: Construction & Installation**
  - Pilot Unit Construction
  - Sorbent Production Scale-up and Quality Assurance
  - Pilot Unit Installation
- **Budget Period 3: Shakedown & Operation**



Overall Project Objectives

- The objective is to develop **solid sorbent** capture technology that captures CO_2 at less than $40 per tonne not including TS&M.

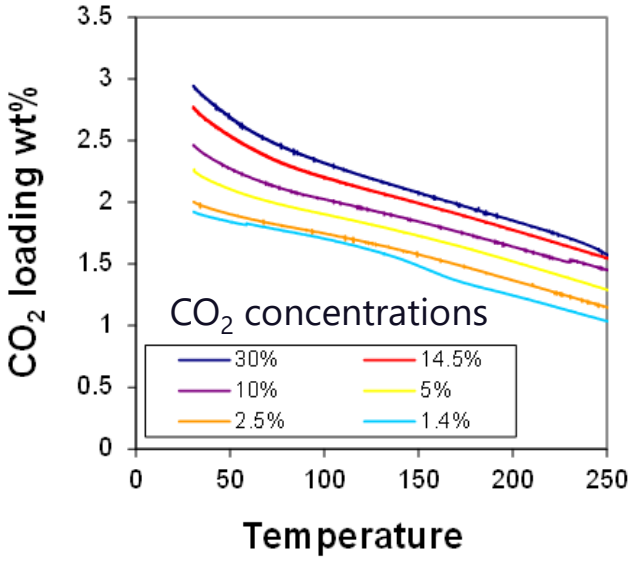


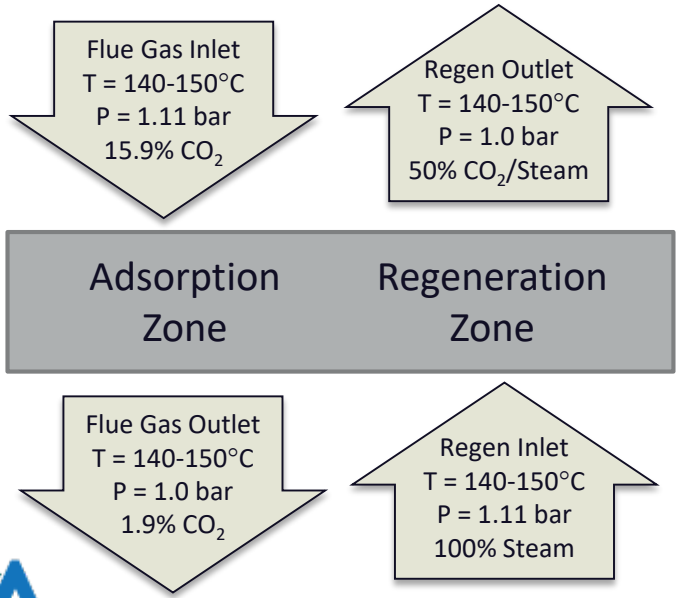
TDA CO_2 Capture on Supercritical 550 MW plant

Technology Background

TDA Research has developed:

- A low-cost, alkalized alumina adsorbent
- A CO_2 capture process designed specifically for this sorbent
- A unique CO_2 capture process to run adsorption and regeneration at near isothermal conditions

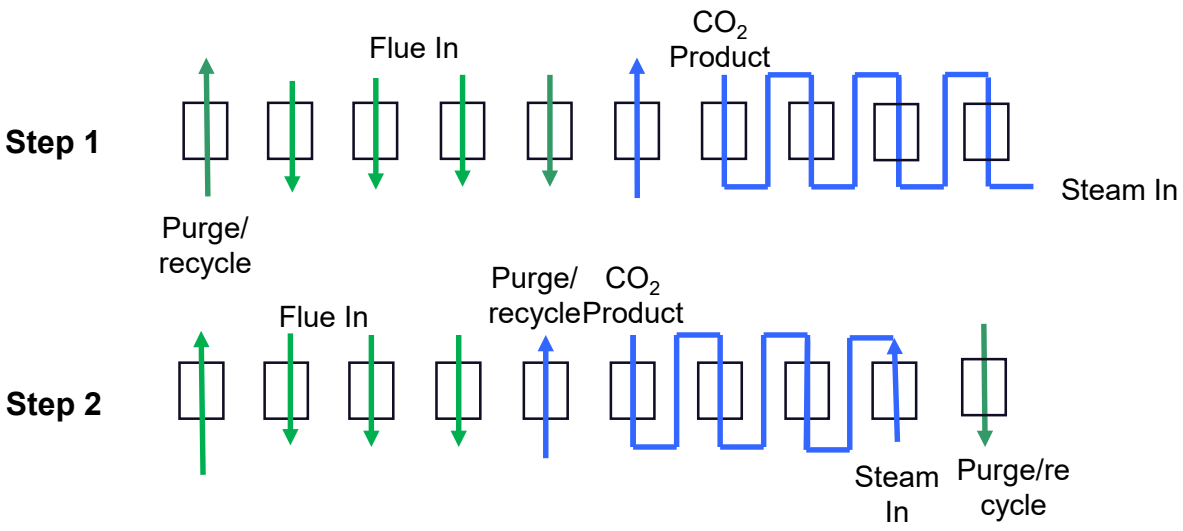




Heat of adsorption ranges from 3 kcal/mole at higher CO_2 concentrations of 10-14%, to 10.3 kcal/mole at CO_2 concentrations of 1-5%

Simulated Moving Bed Process

- 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



Advantages over moving bed

- Moving bed had expensive conveyors, although the beds would be smaller
- Multiple fixed bed design
  - ✓ Basic duct work
  - ✓ Low cost construction
  - ✓ Simple bed design
  - ✓ Eliminates parasitic power needed to move the sorbent
- Lower overall cost than moving beds

Small Scale Testing at TDA

- New sorbents manufactured and characterized in both single bed and 10-bed system
- Process design optimized
- Expanded from 8-bed to 10-bed process and demonstrated in bench-scale unit at TDA
- Based on bench-unit data, the capture cost was $39.7/tonne CO_2 (2011 $)
- Multiple patents on the process: US9539540B2, US9446343B2 US9504955B2, US9527029B2

Single bed system

10-bed system

Schedule and Milestones

- Completed Milestones
  - Process Flow Pattern Optimization
  - System Design and Engineering
  - Pilot Unit Construction
  - Sorbent Production
  - Pilot Unit Installation and Shakedown
- Next Milestones
  - 1.5 Months of Parametric Testing (In Progress)
  - 2 Months of Steady State Testing
  - Update Techno Economics

Pilot Tests Overview

- Goals of NCCC testing
  - Demonstrate alkalized alumina sorbent technology under realistic conditions at 0.5 MW_e (~10 tpd CO_2) scale on coal flue gas) to collect data necessary for scale up to next level plant.
  - Demonstrate sorbent technology on coal fuel gas and diluted flue gas to simulate NG flue gas
- Planned Testing
  - 1.5 month parametric testing and 2 months steady state testing

National Carbon Capture Center located at the E.C. Gaston power plant (Wilsonville, Alabama)

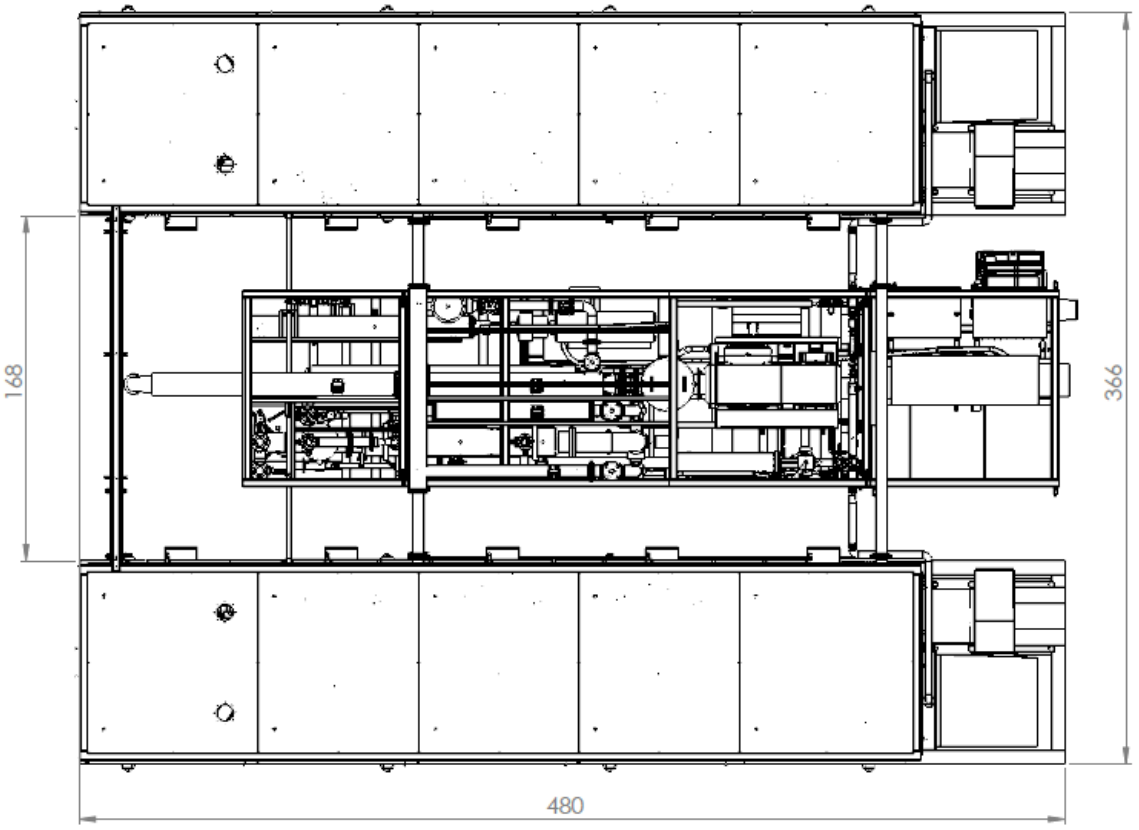
Pilot Unit System
0.5 MW Demonstration

2 Sorbent Bed Trailers

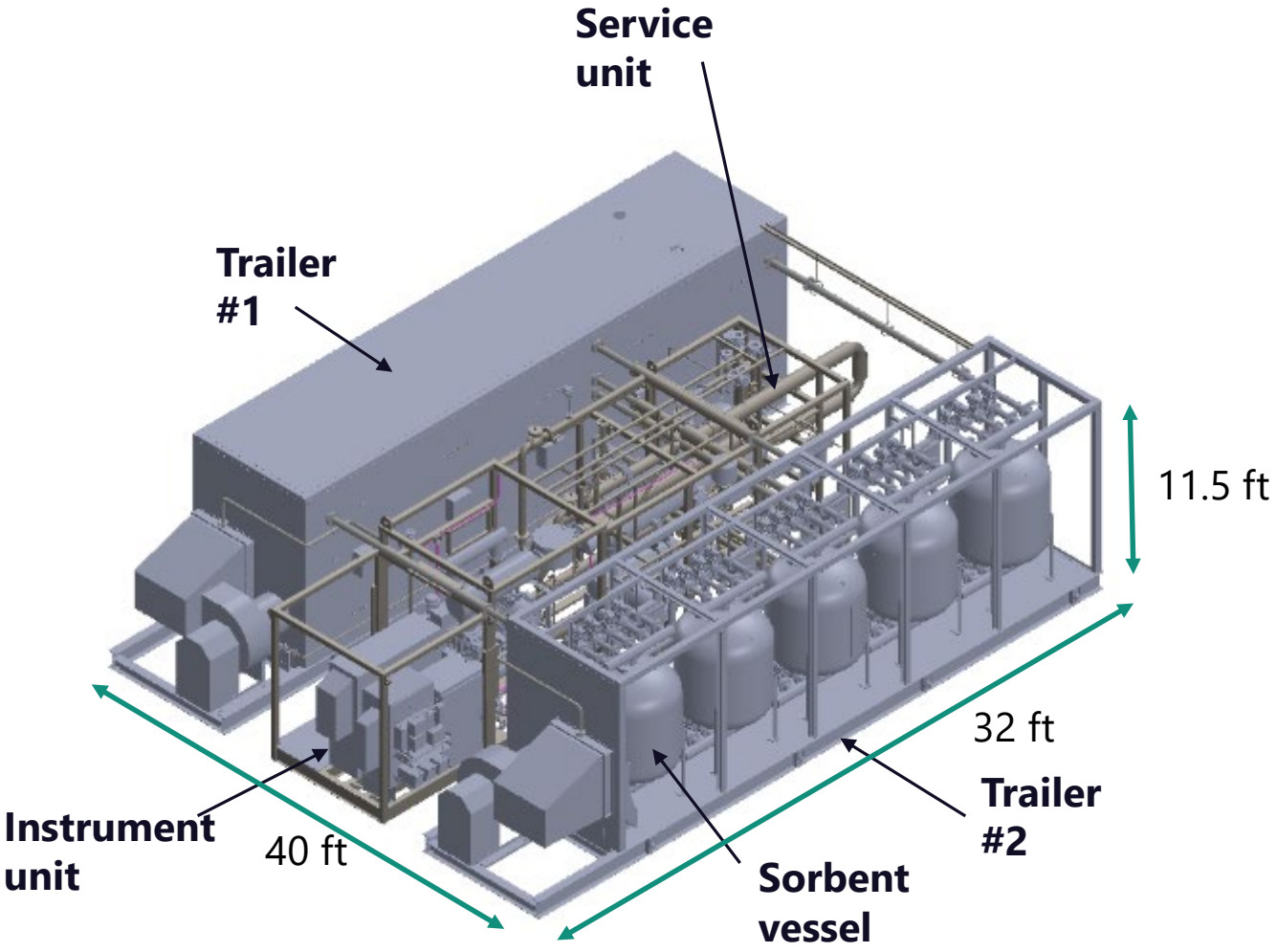
- Sorbent trailers house 10 sorbent beds (5 in each trailer) and manifold piping
- Each trailer is insulated and heated to provide an isothermal environment

Service Unit/Instrument Trailer

- Pressure, temperature and flow control for process gases
- Each process gas routed to both sorbent bed trailers
- Houses the control system and all electrical components for power allocation
- A full suite of on-board analyzers to evaluate system performance



Pilot Unit Skids



TDA Unit at NCCC

- Process operations demonstrated sequentially
- Simple batch mode operation run with each beds in pairs
  - One bed on adsorption and one bed on regeneration
- Additional process step features added one at a time

Work at NCCC to Date

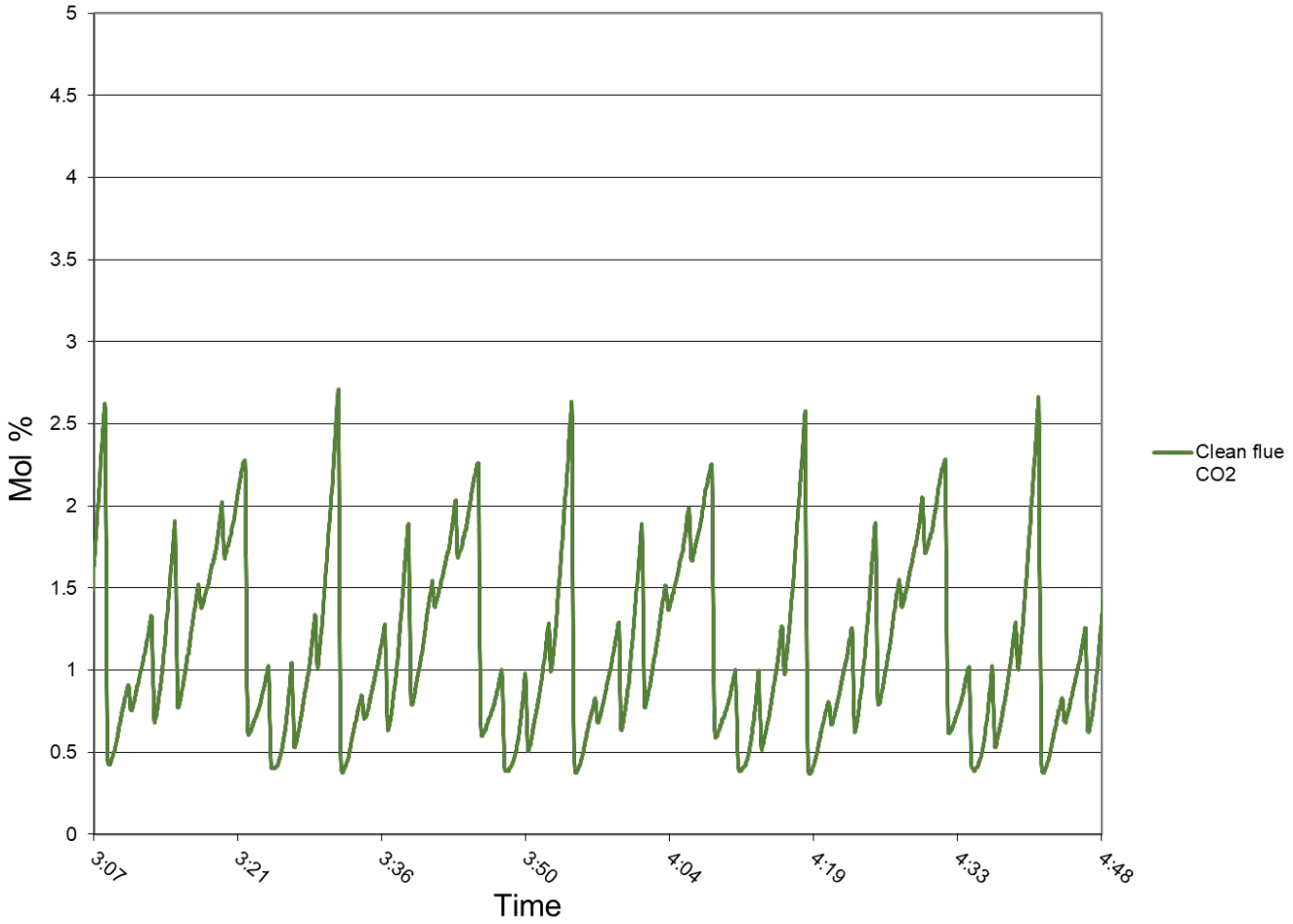
- The unit was installed at NCCC and sorbent was loaded
- The system was checked out in the shakedown
- The modes run included 2-bed, 3-bed, 4-bed, 10-bed 5+5, 10-bed purge and 10-bed purge + steam saver
- Individual beds evaluated
- The parametric tests are nearly complete

Operation in the past year

- Aug. 12 - Sep. 6, 2019
- Sep. 10 - Sep. 17, 2019
- Sep. 23 - Oct. 3, 2019
- Jan. 24 - Feb. 4, 2020

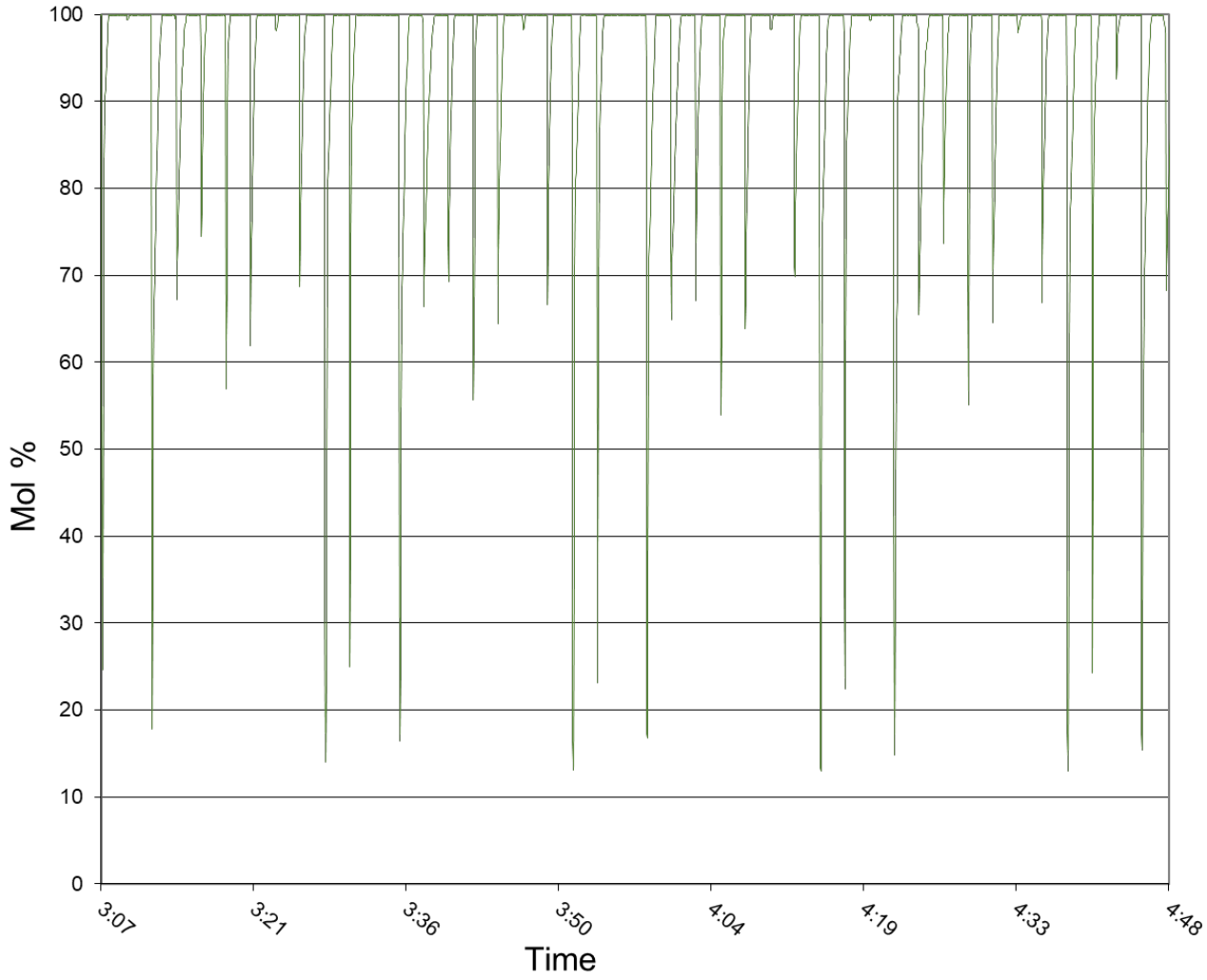
CO_2 Capture Adsorption Side

CO_2% in feed is 12.6% (dry basis)



The clean flue gas CO_2% (dry basis) for a 90.9% capture case on 8/31/19

CO_2 Capture Regeneration Side

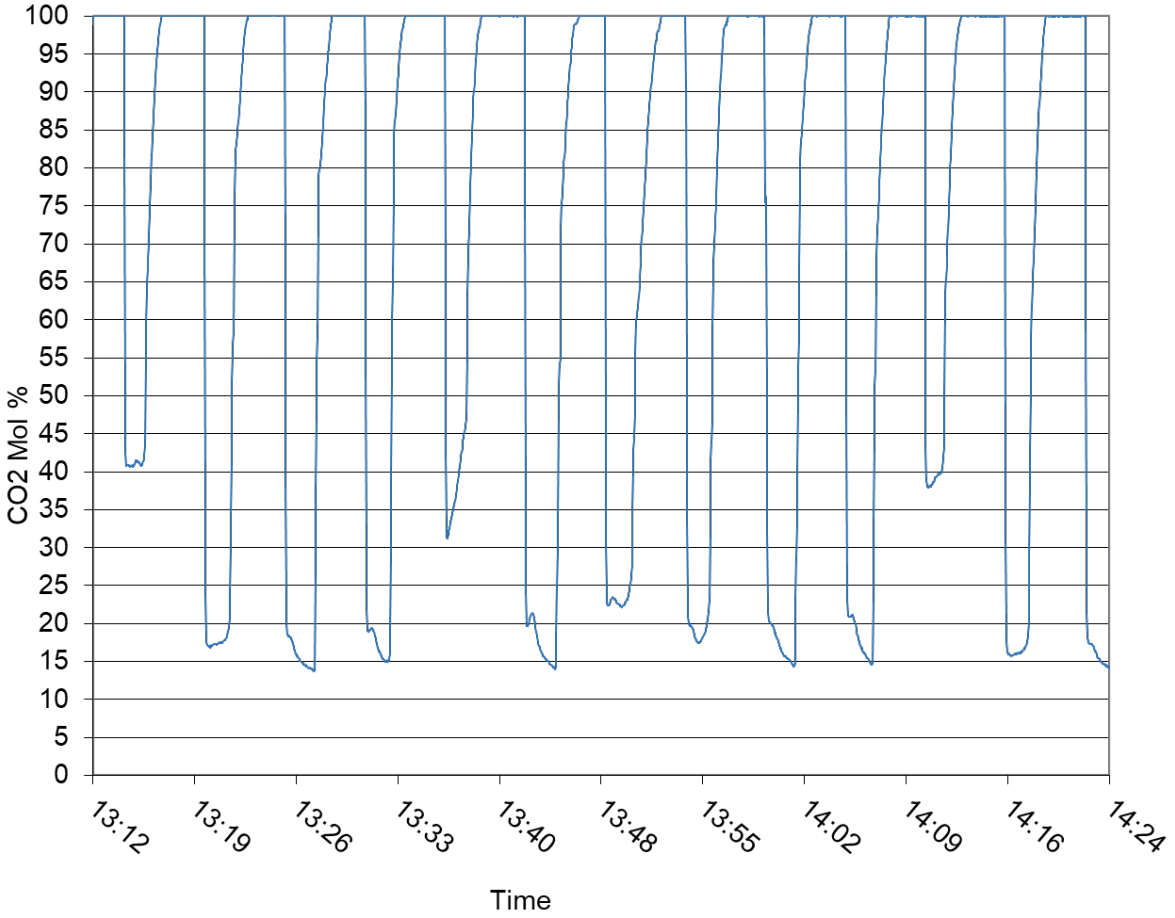


93.6% purity

The product gas composition for a 90.9% capture case on 8/31/19

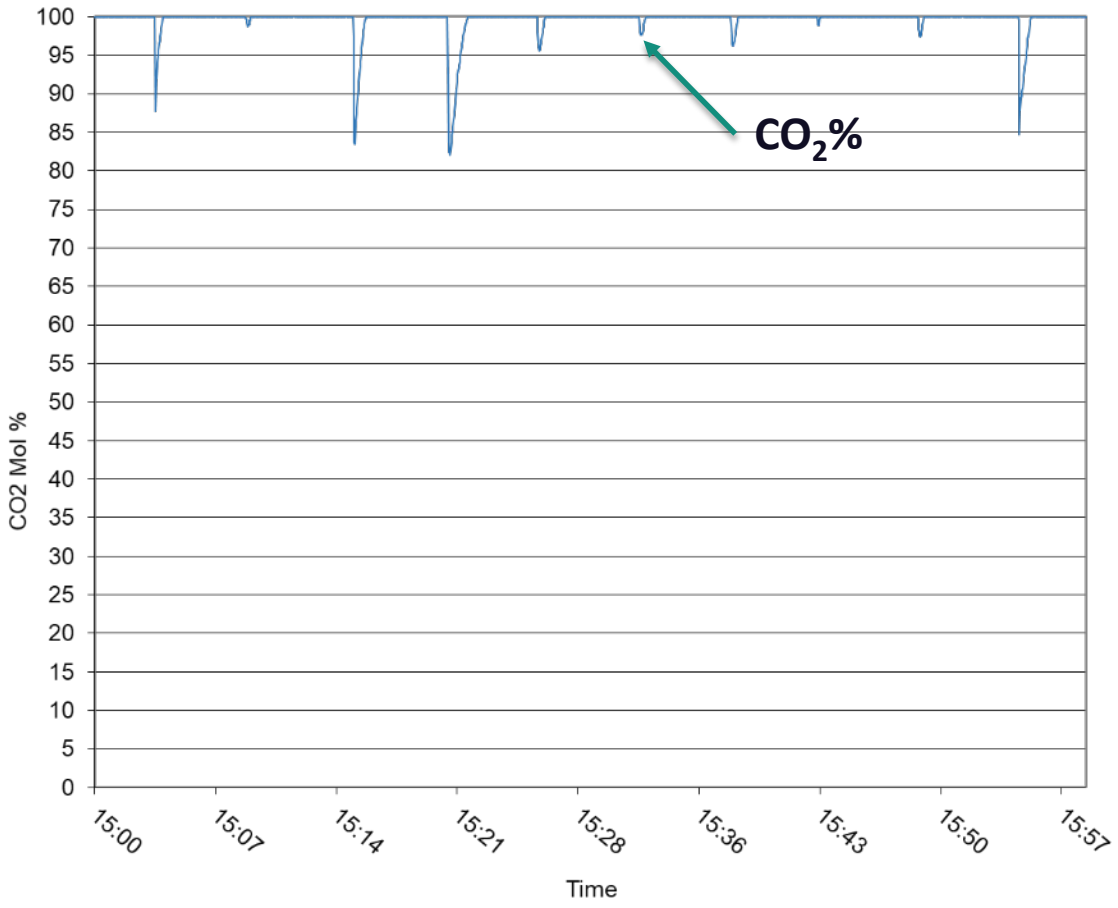
CO_2 Concentration in Regeneration

- At start of regeneration void space in sorbent bed contains N_2
- This void gas reduces product purity
- CO_2 does come off in high concentration after N_2



CO_2 Product Purity

- To achieve >95% CO_2 purity, the void gas is pushed out first and diverted from product
- Process demonstrated in pilot unit successfully maintains high purity CO_2
- Purity as high as 99% CO_2 can be achieved



Effect of Space Velocity on Performance

5+5 case

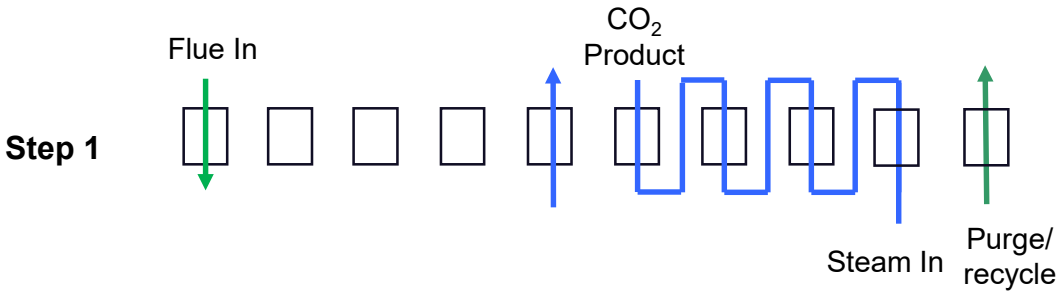
Date	Step time, s	Flue gas, scfm	Overall Capture rate, %
8/27	85	1035	81.6%
8/29	170	533	83.1%

Full flow pattern case

Date	Step time, s	SS, s	Flue gas, scfm	Overall Capture rate, %
8/28	70	20	1066	85.1%
8/30	100	30	811	86.7%
8/31	140	30	522	90.9%

Increasing flue gas flow rate only reduced the capture rate a little.

Evaluation of Individual Bed



- The performance of all the 10 beds was not the same because of variation in sorbent composition
- This 1+4 mode was used to evaluate them individually by running ¼ of the total SV for 4x as long. The flue gas SV for each bed was the same as the full flow (0.5 MW) case
- The most variation was observed among reprocessed sorbent
- The commercial sorbent showed decent performance and stability

Testing with Simulated NG

- The NG flue gas was simulated by diluting coal flue gas with air. The CO_2 mass flow in the flue gas was kept the same as the coal flue gas case. Thus, the actual flow rate was higher
- Our pilot unit has air blower to feed in dilution air
- 1+4 mode was run
- The flue gas inlet CO_2% ranged from 6.7% to 8.1% (wet basis), which corresponded to various purge gas recycle cases
- The CO_2 capture rate was achieved up to 89.2%.
- NG case has run for 230 hours

Additional Flow Pattern Optimization

- TDA's process uses internal recycles to maximize use of steam
- During operation we evaluated three ways to run this to increase efficiency and boost capture rate
- The capture rate increased from 81.4% to 86.0% under the ***same feed and regeneration conditions***

Date	Mode	CO_2% at inlet	Total flue gas, scfm	Bed 10 Capture, %
10/4	Standard SS	6.8%	349.3	81.4%
10/3	Variation 1	6.7%	348.2	84.3%
10/3	Variation 2	6.8%	349.7	86.0%

Increasing Capture

Current Status & Plans

- System was shut down from Oct. 4, 2019 to Jan. 24, 2020 (about 4 months). This impacted reprocessed sorbent
- Plans to replace some sorbent have not been implemented due to COVID delays
- Next testing will include:
  - Completing parametric testing
  - Test the optimized flow pattern for coal flue gas case
  - Run 2 months steady state testing
- Update TEA

Summary

- TDA's CO_2 capture system uses an alkalized alumina sorbent and a process designed specifically for this sorbent.
- Parametric tests were run on pilot unit at NCCC.
- High purity CO_2 product (> 95%) was achieved by tuning a process step that diverts a small fraction of the product stream when a bed first comes onto regeneration.
- Reducing the adsorption space velocity by half had little effect on the system performance.
- Natural gas flue gas cases were run by diluting the coal flue gas with air.
- A new steam saver flow pattern was optimized which improved the capture rate. With the same regeneration steam feed, the capture rate increased from 81.4% to 86.0%.
- Target capture rate demonstrated for coal flue gas and lower (diluted) flue gas concentrations.

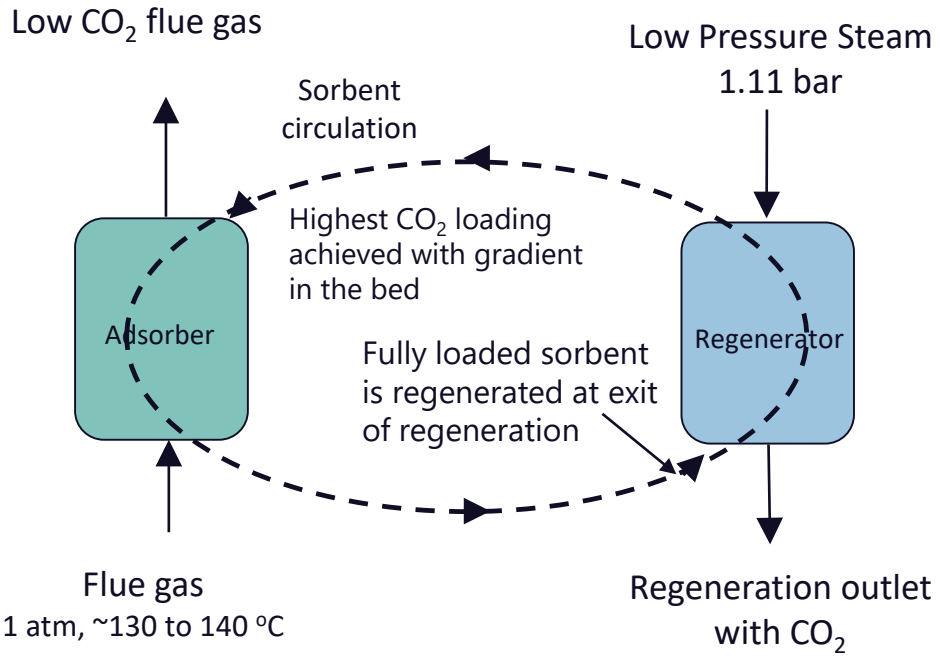
Acknowledgements

- Project funding provided under DoE Contract # DE-FE0012870
- DoE: Andy O'Palko and Lynn Brickett
- ExxonMobil
- NCCC team

Appendix

Adsorbents

- **Adsorbents loosely bind CO_2 to the surface**
  - Regeneration is fast and with low desorption energy requirement
  - High concentration of CO_2 during desorption
- **Adsorbents operate along a concentration gradient**



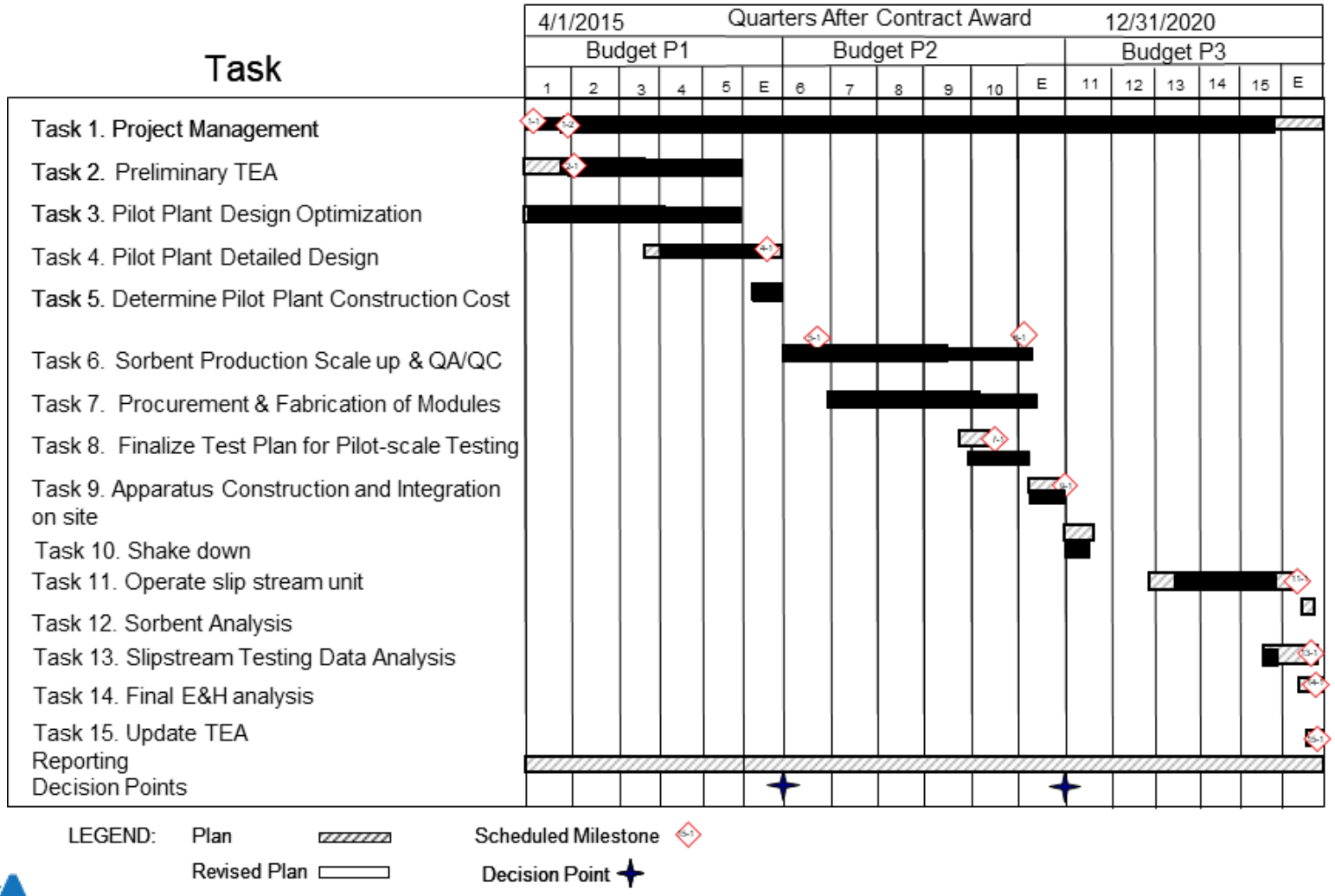
  - They absorb more CO_2 when the concentration is higher than when the concentration is lower
- **Optimum bed design is counter-flow**
  - Maximizes the loading on the adsorbent by having the adsorbent contact the gas stream with the highest CO_2 concentration at the end of its reactor residence time

Full Process Scheme Testing

- Optimized cycles has several features to benefit performance

Feature	Advantage	Benefit
10 beds (vs. 8 beds)	Additional regeneration stages	• Additional stripping for same steam usage • Beds needed for transition steps
Purge	Additional regeneration	• Higher capture rate • Less steam usage
Steam saver with controlled flow and timing	Steam recycled back to regeneration side to rehydrate bed can be optimized in controlled manner	• Steam usage decreased • Steam saver can be tuned for maximize benefit

Gantt Chart


Task
4/1/2015
Quarters After Contract Award
12/31/2020
Budget P1
Budget P2
Budget P3
1 2 3 4 5 E 6 7 8 9 10 E 11 12 13 14 15 E
Task 1. Project Management
Task 2. Preliminary TEA
Task 3. Pilot Plant Design Optimization
Task 4. Pilot Plant Detailed Design
Task 5. Determine Pilot Plant Construction Cost
Task 6. Sorbent Production Scale up & QA/QC
Task 7. Procurement & Fabrication of Modules
Task 8. Finalize Test Plan for Pilot-scale Testing
Task 9. Apparatus Construction and Integration on site
Task 10. Shake down
Task 11. Operate slip stream unit
Task 12. Sorbent Analysis
Task 13. Slipstream Testing Data Analysis
Task 14. Final E&H analysis
Task 15. Update TEA
Reporting
Decision Points
LEGEND:
Plan
Revised Plan
Scheduled Milestone
Decision Point

Future Plans

- Additional small scale demonstrations
- Demonstration of planned sorbent bed reactor design
- Next level scale up 25 MW