Sorbent Based Post-Combustion CO_2 Slipstream Testing

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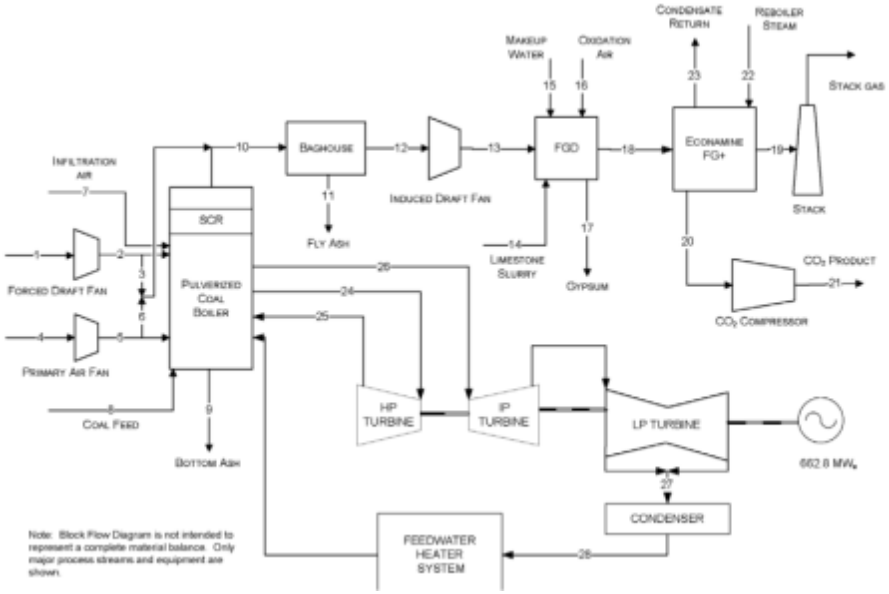
Project Objectives

- The objective is to develop solid sorbent capture technology that captures CO_2 at less than $40 per tonne without TS&M
- Demonstrate TDA's sorbent technology under realistic conditions at 0.5 MW_e (~10 tpd) scale to collect data necessary for scale up to 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



TDA CO_2 Capture on Supercritical 550 MW plant

TDA's Approach

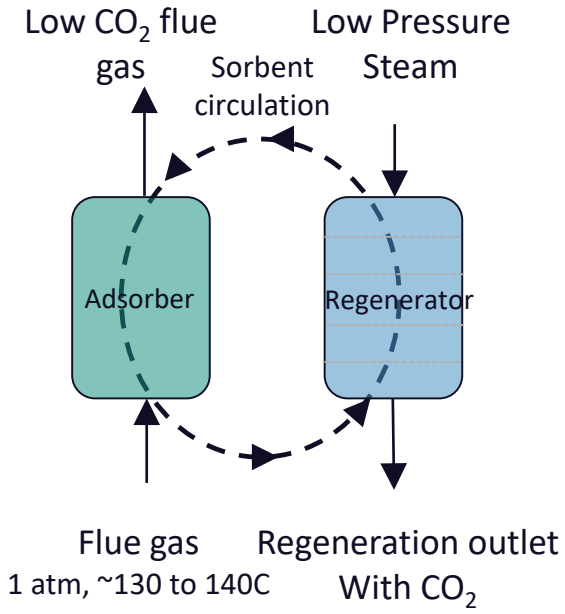
DoE Project # DE-FE0012870

TDA Research has developed:

- A low-cost, solid alkalized alumina adsorbent

- A CO_2 capture process designed specifically for this sorbent
- Multiple patents on the process

A unique CO_2 capture process using low cost sorbent to run adsorption and regeneration at near isothermal conditions



Advantages over moving bed

- Moving bed had expensive conveyors, although the beds would be smaller
- Selected multiple fixed bed design
  - ✓ Basic duct work
  - ✓ Low cost construction
  - ✓ Simple bed design
  - ✓ Eliminates power lost when moving the sorbent
- Lower overall cost than moving beds

Project Scope

DoE Project DE-FE0012870
Funding - Total Project $6,480,377

- **Budget Period 1: Optimization & Design**
  - April 2014 to February 2016
- **Budget Period 2: Construction & Installation**
  - March 2016 to October 2017
- **Budget Period 3: Operation**
  - November 2017 to January 2019

Budget Period 2 Tasks

– Task 6. Sorbent Production Scale-up and Quality Assurance

- Scale-up production of the sorbent
- Two producers had competitive prices for sorbent production
- Sorbent is alkalized alumina
- Sorbent QA/QC testing at TDA in bench-scale unit
- Sorbent tested under proposed test conditions
- Evaluation of optimum steady state conditions

– Task 7. Procurement of Components and Fabrication of Units

- Construction of three skid-mounted units
- Fabricator constructing skid structure, manifolds and beds on two sorbent trailers, and service unit
- Instrument unit built at TDA
- Beds fabrication will be inspected prior shipment, control system shakedown on cold system, FAT testing

Budget Period 2 Tasks

– Task 8. Finalize Test Plan

- Operating conditions and key parameter parametric conditions selected
- Operator training

– Task 9. Pilot Plant Installation at NCCC

- Units transported to NCCC
- Skid Units installed

Manufacturer for the Sorbent

POROCEL

- ✓ Leading supplier of activated alumina products
- ✓ Over 35 years of experience in catalyst and sorbent manufacturing
- ✓ Over 15 years of toll processing experience
- ✓ Facilities in North America, Europe, and Asia
- ✓ Capabilities include extrusion, ball forming, drying, impregnation, calcination, and milling

We have evaluated multiple materials produced for us by Porocel

TDA

Properties of the First Round Sorbents

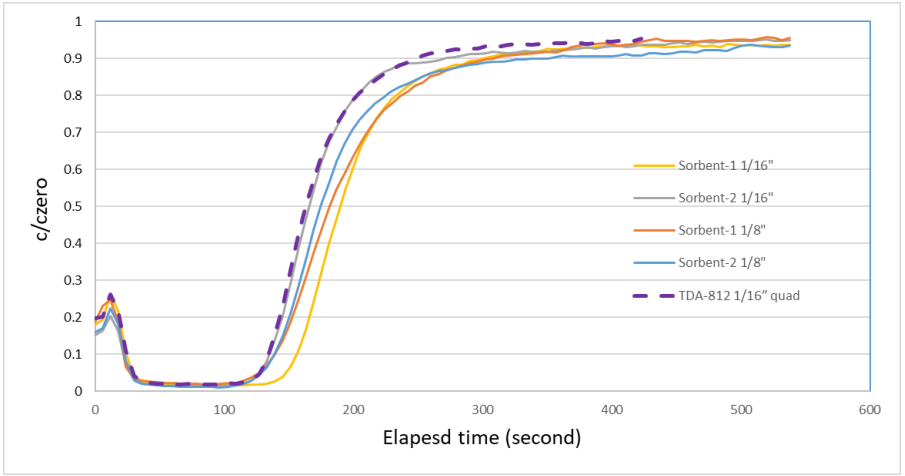
Sorbent	Bulk density (g/cc)	BET surface area (m^2/g)	BJH Adsorption Cumulative Pore Volume of pores (cm^3/g)	Adsorption Average Pore Diameter (nm)
Sorbent-1 1/16"	0.81	113.0	0.27	9.4
Sorbent-2 1/16"	0.81	65.4	0.27	17
Sorbent-1 1/8"	0.79	88.1	0.25	11.4
Sorbent-2 1/8"	0.78	76.5	0.26	13.5
TDA Sorbent	0.62 – 0.75	80 -145	0.36-0.53	9-11

Sorbents Screened in Single Fixed Bed

- ✓ Single reactor can take up to 300 mL sorbent
- ✓ Automation control
- ✓ All sorbents evaluated for 100+ cycles

Single Bed Testing Results for the First Round Sorbents

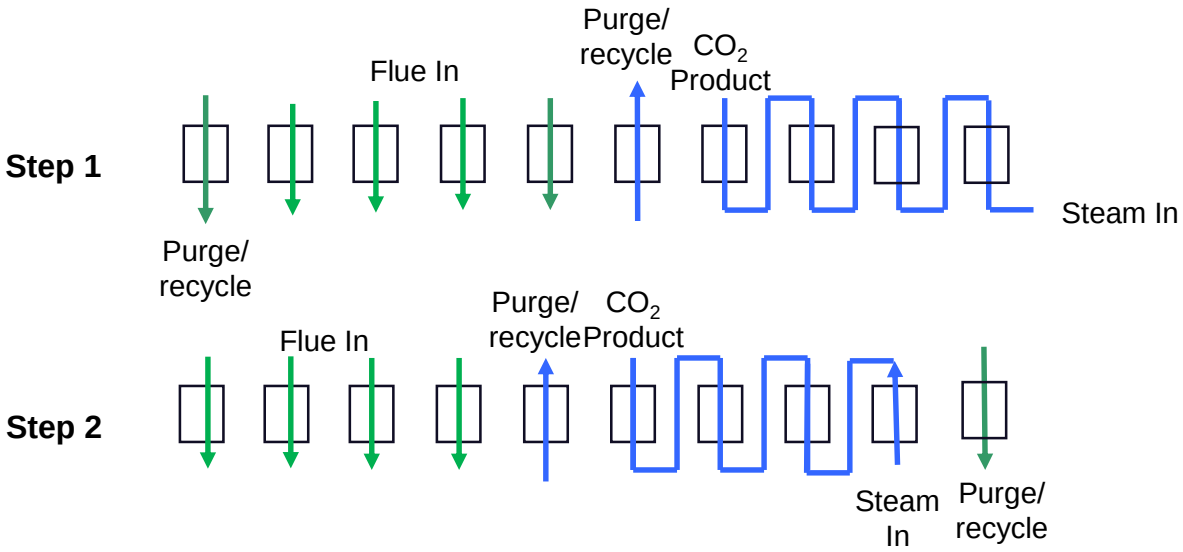
Date	Sorbent	Density (g/cc)	Ads Time	Reg Time	CO_2 loading (wt%)
2/21/17	Sorbent-1 1/16"	0.81	9.0	9.0	1.01
2/20/17	Sorbent-2 1/16"	0.81	9.0	9.0	0.92
2/28/17	Sorbent-1 1/8"	0.82	9.0	9.0	0.95
2/27/17	Sorbent-2 1/8"	0.78	9.0	9.0	0.93
3/2/27	TDA-812 1/16” quad	0.62	7.1	7.1	1.14



The CO_2 loadings of first round of sorbents are a little lower than TDA-812 sorbent but kinetic all looked comparable in single bed testing

TDA Bench-Scale Test Apparatus

- ✓ Ten 400 cc Fix Bed Reactors
- ✓ Continuous Adsorption and Regeneration
- ✓ Automation control



Bench-scale Testing Results for the First Round Sorbents

Date	Sorbent	Avg Bed Temps (°C)	CO_2 Loading, wt%	$\%CO_2$ Capture
8/10/16	TDA Sorbent	143.1	0.82	90.6%
4/10/17	Sorbent-1	144.7	0.38	79.1%
4/17/17	Sorbent-2	143.4	0.50	80.5%

The CO_2 capture rate for the first round of sorbents is lower under the same process conditions. We worked with Porocel to make second set of customized sorbents for further tests.

Properties of the Second Round Sorbents

Batch number	Bulk density (g/ml)	BET Surface Area (m^2/g)	BJH Adsorption Cumulative Pore Volume of pores (cm^3/g)	Adsorption Average Pore Diameter (nm)
Batch 1	0.728	84.3	0.214	10.15
Batch 2	0.709	79.2	0.333	16.76
Batch 3	0.727	82.4	0.356	17.3
TDA-Sorbent	0.6 – 0.75	80 -145	0.36-0.53	9-11

Single Bed Testing Results for the Second Round Sorbents

Date	Sorbent	Adsorption Time (min)	Regeneration Time (min)	CO_2 loading (wt%)	+/-
5/22/17	Batch 1	8.3	8.3	1.22	0.05
5/24/17	Batch 2	8.2	8.2	1.21	0.05
5/25/17	Batch 3	8.4	8.3	0.95	0.02
3/2/17	TDA-812	7.1	7.1	1.14	0.02
2/27/17	Sorbent -2	9.0	9.0	0.93	0.02

The performance of Batch 1 and 2 is good relative to the benchmark TDA-812 sorbent and better than first round sorbents

Bench-scale Testing Results for Second Round Sorbents

Simulation of Case 12 (13.5% CO_2)

Date	Batch	Step Time (s)	Avg Bed Temps (°C)	CO_2 loading (wt%)	% CO_2 Capture
5/27/17	1	85	141.1	0.76	89.8%
6/6/17	2	80	142.0	0.75	89.8%

10.5% NCCC Feed Composition where Pilot Unit expected to operate

Date	Batch	Step Time (s)	Avg Bed Temps (°C)	CO_2 loading (wt%)	% CO_2 Capture
6/15/17	1	115	144.7	0.69	89.9%
6/7/17	2	95	141.5	0.57	90.7%

90% CO_2 Capture demonstrated in continuous process in bench-scale unit

Bench-Scale Testing Results for the Second Round Sorbents

Batch 1 used to study the effect transition step time for controlling CO_2 purity

Transition step time (s)	N_2%	CO_2%
0	7.09	92.91
5	5.87	94.13
10	3.06	96.94
20	2.74	97.26
30	0.43	99.57

The N_2 and CO_2 level measured by GC.
95% CO_2 purity can be achieved.

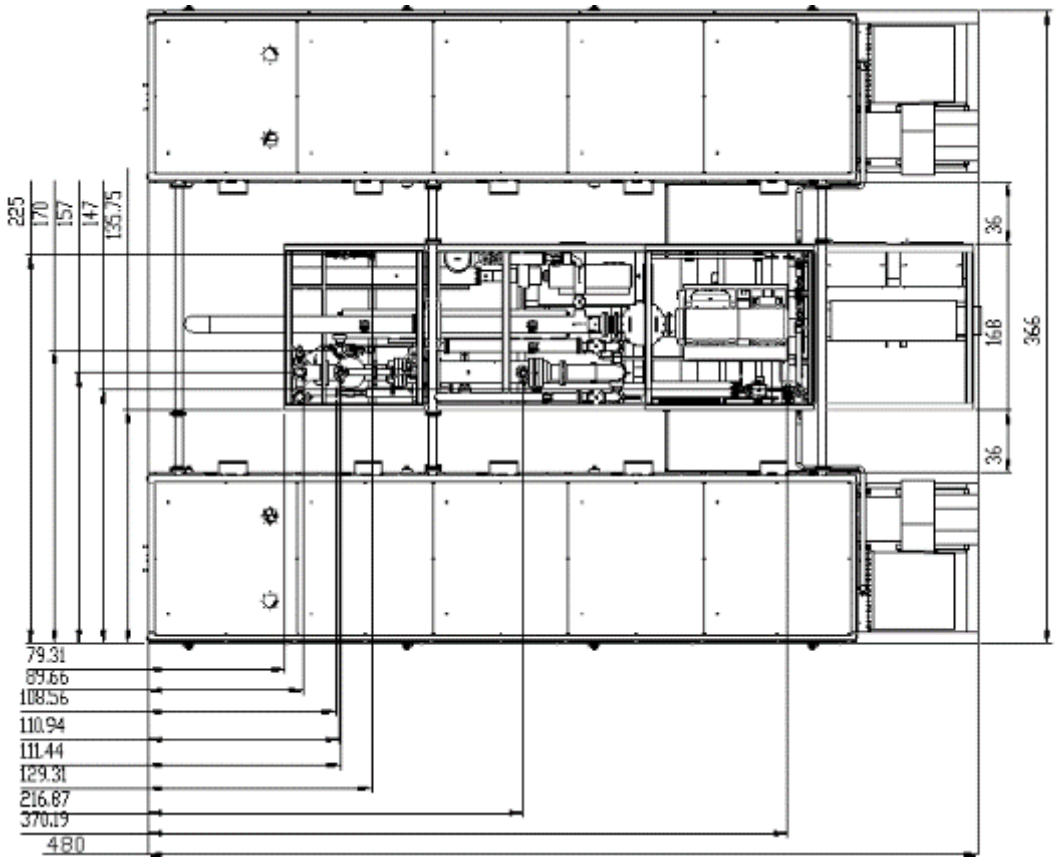
Pilot Unit System
0.5 MW Demonstration

2 Sorbent Bed Trailers

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

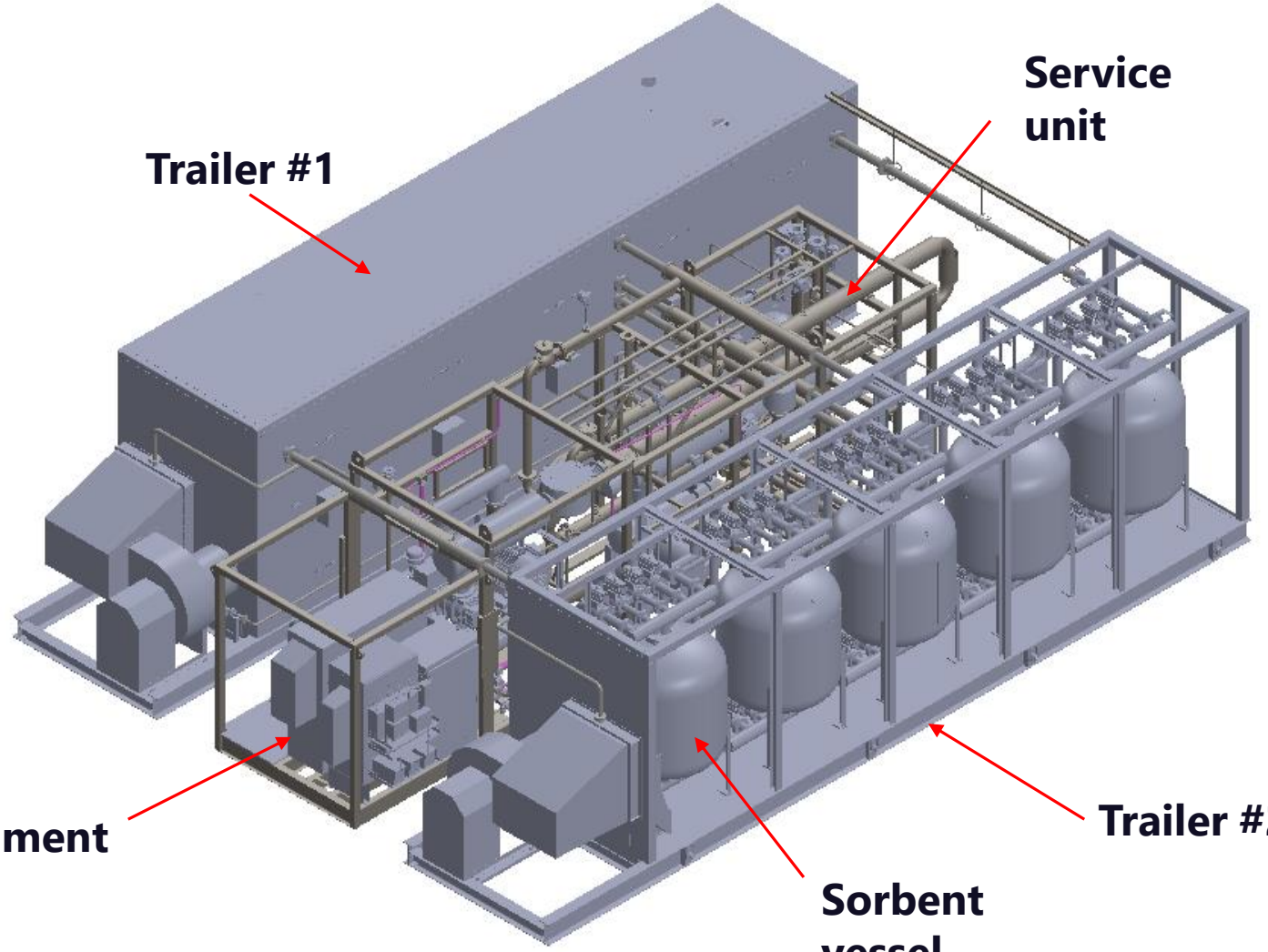
Service Unit/Instrument Trailer

- 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



System to be located at NCCC Pilot Bay #2 ~42’ x 35’

Pilot Unit Skids



Fabrication of Pilot Unit

- Sorbent Trailers and Gas conditioning units are being fabricated by Spring Fabrication, Inc. (200,000 sq ft facility, 220 employees) in Colorado Springs.

- Instrument control unit was fabricated at TDA.

Fabrication of Pilot Unit

12/9/2016

12/9/2016

12/9/2016

12/9/2016

Sorbent Trailers

Fabrication of Pilot Unit

2/28/2017

5/2/2017

5/8/2017

5/30/2017

Sorbent Trailers

Fabrication of Pilot Unit

5/30/2017

6/14/2017

6/22/2017

Sorbent Trailers

Fabrication of Pilot Unit

8/17/2017

8/17/2017

8/17/2017

8/17/2017

Service Unit

Fabrication of Pilot Unit

The instrument and control cabinets made by TDA

Power panel

Instrument Unit/ Electronics Cabinet

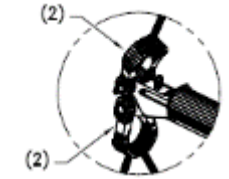
Collaboration with NCCC before the Delivery of Skids

TDA is committed to comply all the safety requirements from NCCC. We had continuous discussion with NCCC and provided the following items:

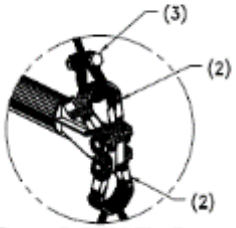
- The skid lifting and rigging plan issued by AL PE
- Structural review issued by AL PE
- Foundation drawing issued by Al PE
- The sorbent loading plan
- The type of pre-made electrical connectors which will be re-connected at NCCC

Additionally, TDA has sent NCCC the skid drawings, 3-D model, P&ID, electrical diagram, operating procedure, interlock table and AL PE documents.

Lift plan



A DETAIL A
SCALE: N.T.S.



B DETAIL B
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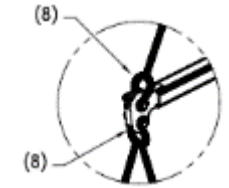

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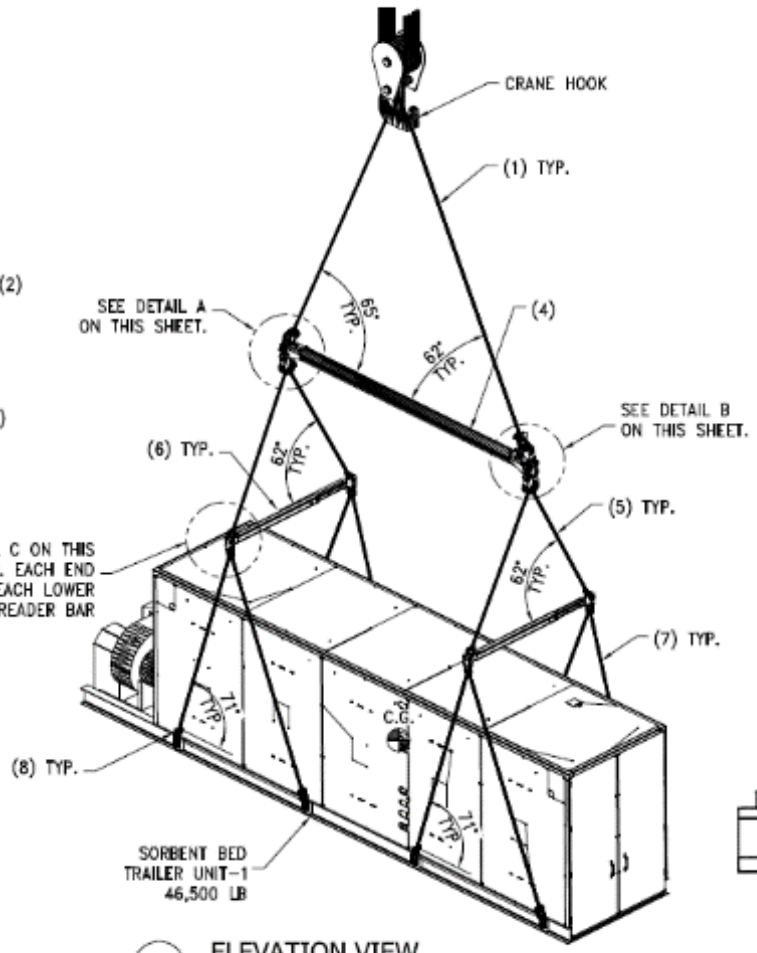
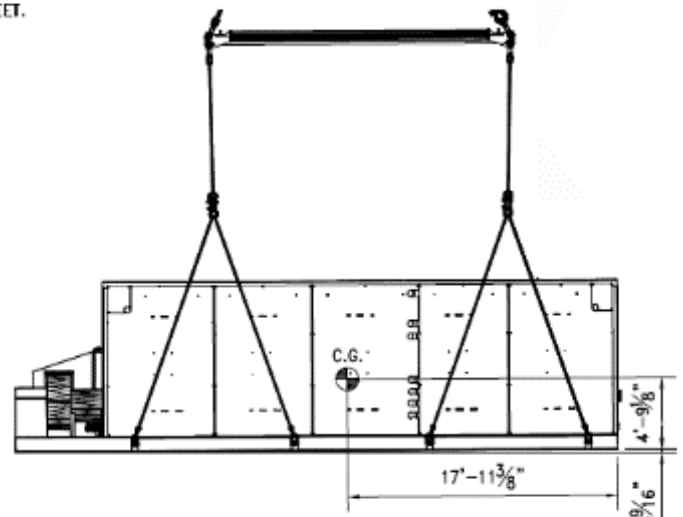


1 ELEVATION VIEW
SCALE: N.T.S.

RIGGING WEIGHT TABULATION *Sorbent Bed Trailer Unit-1 to Crane*				
#	Item	Wt.	Qty.	Total Wt.
1	1½" Φ EIP IWRC, 20' Long, 60" Bridle, 36 Ton Bridle Capacity	125	2	250
2	75t Wide Body Shackle, Crosby G-2160 or Equivalent	100	4	400
3	35t Shackle, Crosby G-2130 or Equivalent	53	1	53
4	90 Ton Tandemloc 8" End Cap Spreader Bar, 20'-0" Eye to Eye	1,235	1	1,235
5	1¼" Φ EIP IWRC, 10' Long, 60" Bridle, 25 Ton Bridle Capacity	54	4	216
6	25 Ton G&R Plant Maint. 10'-16' Adj. Spreader Bar, 10' Eye to Eye	290	2	580
7	1" Φ EIP IWRC, 15' Long, 60" Bridle, 16 Ton Bridle Capacity	42	8	336
8	17t Shackle, Crosby G-2130 or Equivalent	19	16	304
	Rigging Weight Contingency	1,000	1	1,000
	Total Rigging Weight (LBS)			**4,374**
	Rigging Capacity - 36 Tons			

TOTAL LIFT WEIGHT = 46,500 LB + 4,374 LB = 50,874 LB



2 SIDE VIEW
SCALE: N.T.S.

3 END VIEW
SCALE: N.T.S.

Pilot Unit Testing Schedule

- October 2017: Skid Installation at NCCC
- November - December 2017: Integration/Shakedown
- March – July 2018: Pilot Unit Operation
  - Parametric testing
  - Steady state testing

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

Summary

- Pilot-Unit engineering completed. We have coordinated with NCCC on requirements for stamped engineering drawings and information required on the skid.
- Two round of sorbents samples were produced at Porocel. The second round of sorbents performed better in QA/QC testing at TDA. The test results for Batches 1 and 2 of the second round are very promising and close to the benchmark TDA sorbent.
- Sorbent production order for pilot unit was placed. Sorbent will be produced in Little Rock, Arkansas by Porocel.
- Pilot Unit construction is nearly complete. Construction of two sorbent trailers, instrument unit, and electrical control cabinet is finished. The fabrication of third service unit skid is partially complete.
- FAT testing will be conducted in late September/ early October. The skids to be delivered to NCCC in mid-October.

Acknowledgements

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