Development and Testing of Aerogel Sorbents for CO_2 Capture

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Project Overview

Develop and bench-scale test an advanced aerogel sorbent for post-combustion CO_2 capture from coal-fired power plants

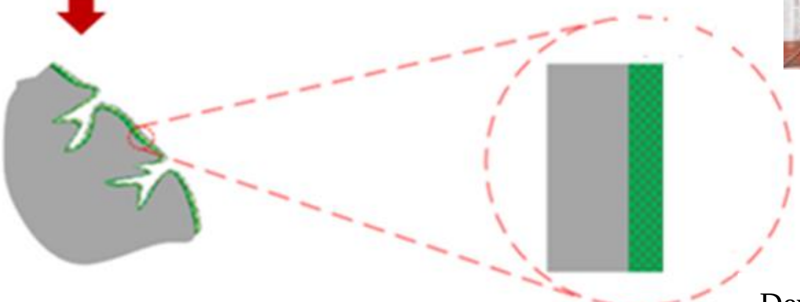
<u>Develop Aerogel Sorbent at Bench Scale for CO_2 Capture</u>

- Improve Amine Functionalized Aerogels (AFA)
- Convert optimized sorbent into bead form
- Develop pellet binder formulations, and pelletization process
- Develop SO_x diffusion barrier for AFA sorbents
- Test & evaluate sorbent technology at bench scale

"AFA"

Amine Functionalized Aerogel Sorbent Powder

AFA Pellets (powder + binder)



Develop Compatible SO_x Resistant Binder

Bench Scale Evaluation

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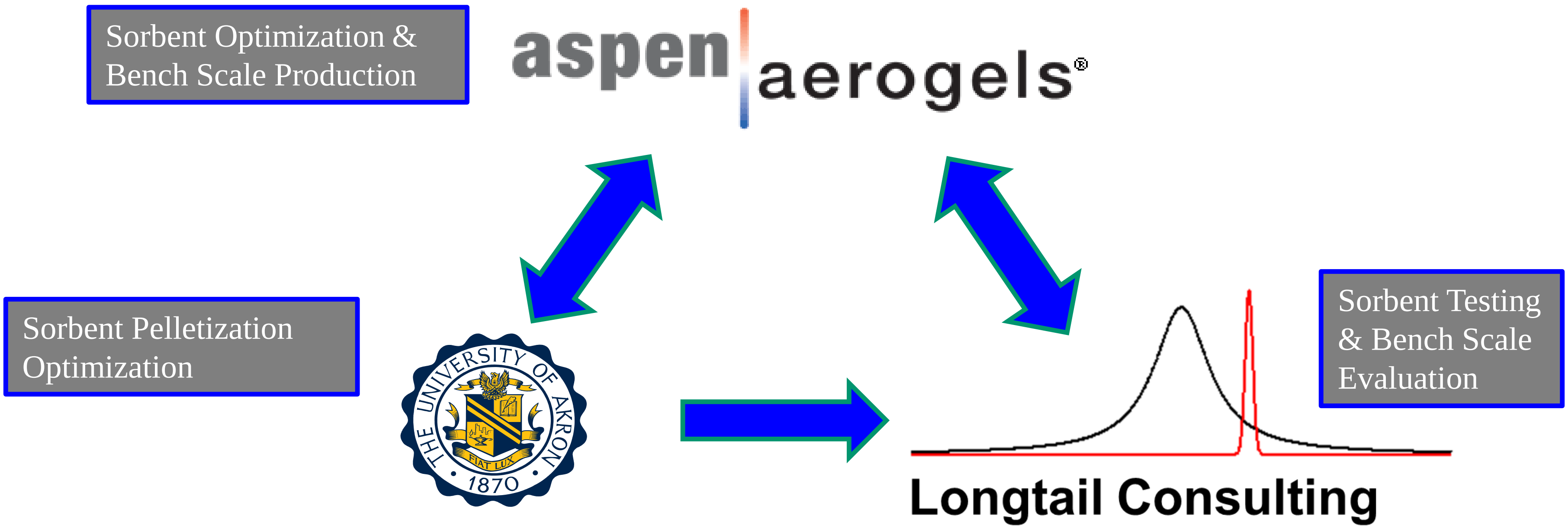
Project Objectives

1. Optimize sorbents for improved CO_2 capacity and SO_X poisoning resistance.
2. Convert optimized sorbent into durable pellet and bead form for analysis.
3. Produce the best candidate sorbent form (bead or pellet) in larger quantities for fluidized bed testing.
4. Assess the sorbent in fluidized bed bench-scale testing.
5. Conduct a technical and economic assessment of the sorbent technology and process.

Project Team



- Period of Performance:
  - 10-1-2013 through 09-30-2016
- Funding:
  - U.S.: Department of Energy: $2.99M
  - Cost share: $ 0.77 million
  - Total: $3.76 million

BP3 Project Tasks

BP#	Description
BP1 (2013 – 2014)	AFA Sorbent Development
	Pellet Development and Optimization
	Sorbent Evaluation
BP2 (2014 – 2015)	Aerogel Bead Fabrication
	Coating Development
	Coated Pellet and Bead Evaluation
BP3 (2015 – 2016)	AFA Pellet Production
	Fluidized Bed Evaluation
	Techno-Economic Evaluation
	Environmental Health and Safety Evaluation

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Amine Functionalized Aerogel (AFA) Development

SBIR Phase I

Bench Scale Development and Testing

Cooperative Agreement Project

2011 2012 2013 2014 2015 2016

SBIR Phase II

AFA benefits

- High surface/high porosity material
- Hydrophobic to enhance CO_2 adsorption selectivity and stability
- Low specific heat, thus low energy regeneration
- High temperature stability
- Methods identified for manufacture at reasonable cost and high volume

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Accomplishments to Date

AFA formulation optimization

AFA Sorbent CO_2 Capture Performance

- Direct amine grafting process
- "Double functionalization" process.

AFA Sorbent in Bead form

Pelletization of AFA sorbent

- Total and working CO_2 adsorption capacities (~ 15 wt.%, ~ 8 wt.%)*
- Fast CO_2 adsorption kinetics
- Stable for at least 500 cycles
- Low moisture uptake

	Beads	Pellets
Working CO_2 capacity	6.0	6.5
H_2O uptake	2.0 – 2.2	2.4 – 2.7
Cycling stability	Stable	Stable
Selectivity CO_2/H_2O	High	High
Attrition and Crush performance	Low/low	Low/high
Large scale Prep.	Very challenging	Achievable

Top AFA Sorbent (powder) Scale-Up

Completed

EH&S Evaluation

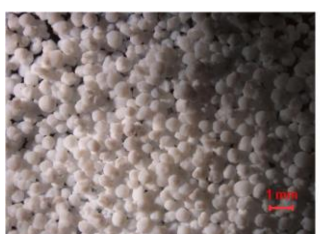
Completed

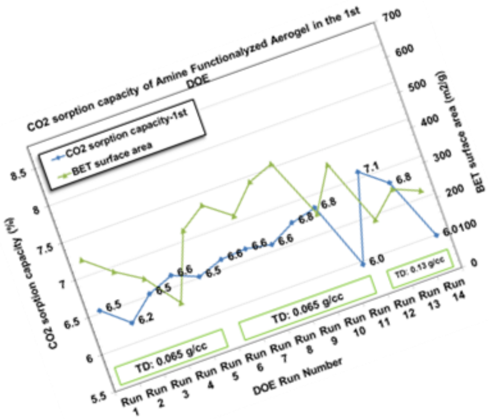
Pelletization Scale-Up

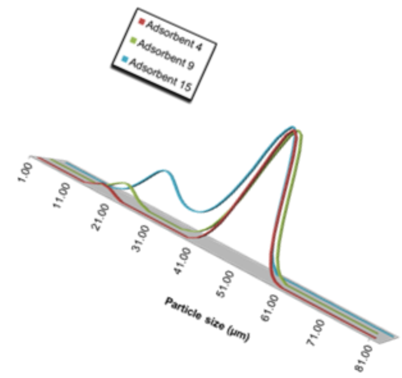
Completed

Bench Scale Cold-Flow Fluidized Bed and TEA

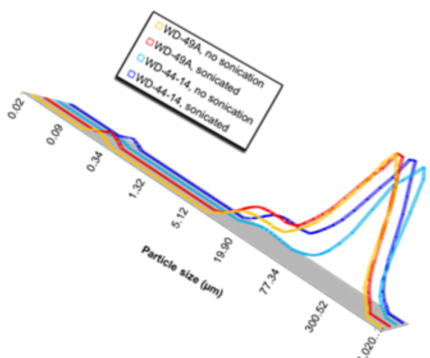
Scheduled

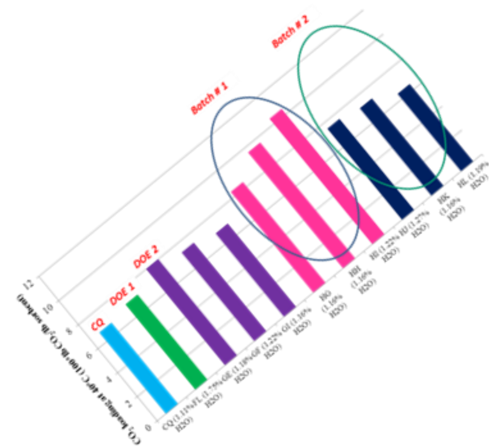






Technical Progress





AFA Pellet vs. Bead Performance

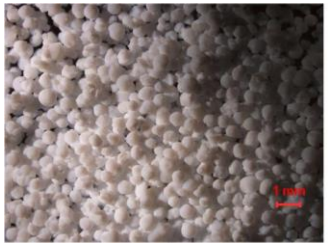
Tests performed on Aspen's AFA bead and pellet sorbents in order to down-select the AFA form to be pursued during BP3.

- Sorbent isotherms
- Sorbent selectivity (CO_2 vs. H_2O)
- Attrition and Crush tests
- Moisture uptake
- Cyclic stability

Pelletization at UA

Aerogel powder sorbent → **Mixed with SRE binder, extruded, dried** → **AFA Pellets**

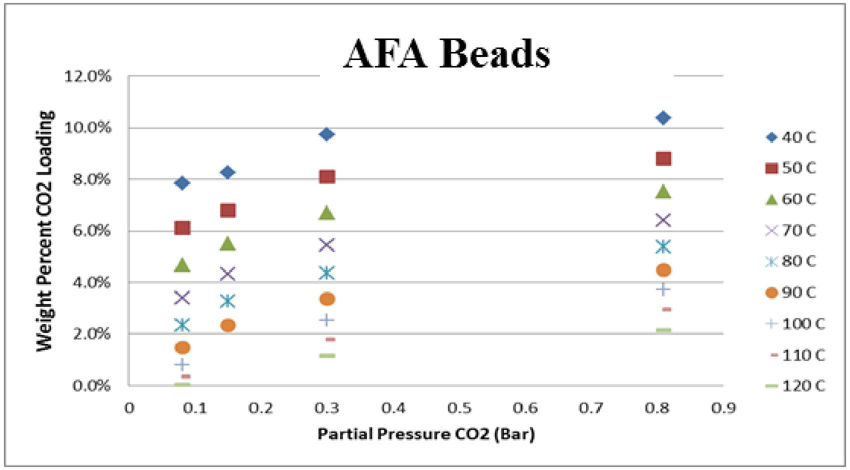
Aerogel bead sorbent → **Coated with SRE binder at UA** → **AFA Beads**



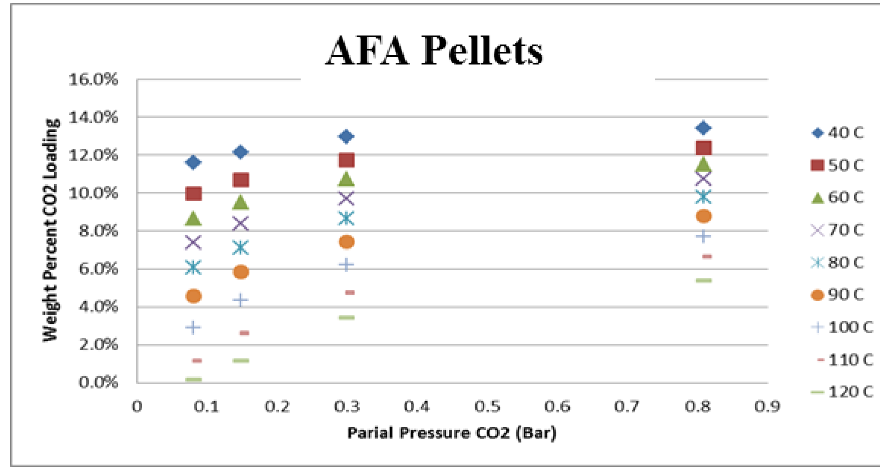
- ⇨ **SRE designed for pelletization and SO_2 poisoning resistance.**
- ⇨ **< 4% degradation after a 20-cycle exposure to 40 ppm SO_2 in the simulated flue gas.**

AFA Pellet vs. Bead Performance

Sorbent Isotherms



6 wt.% working capacity



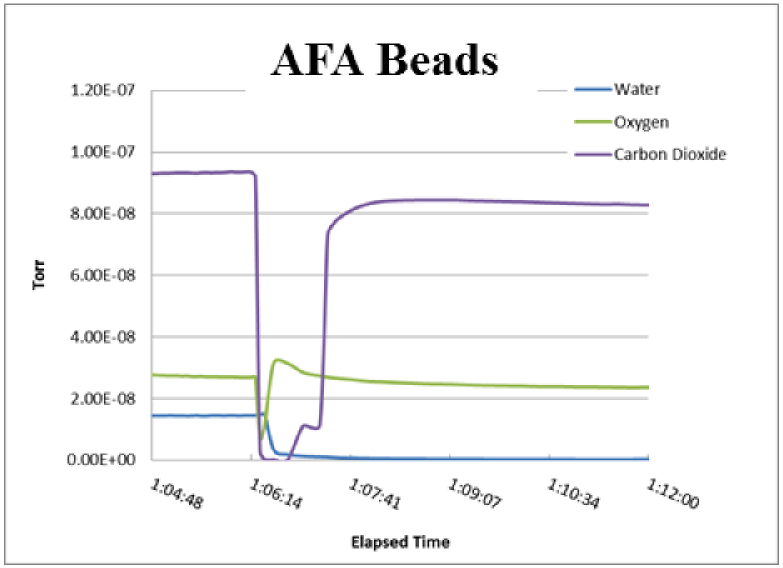
6.5 wt.% working capacity

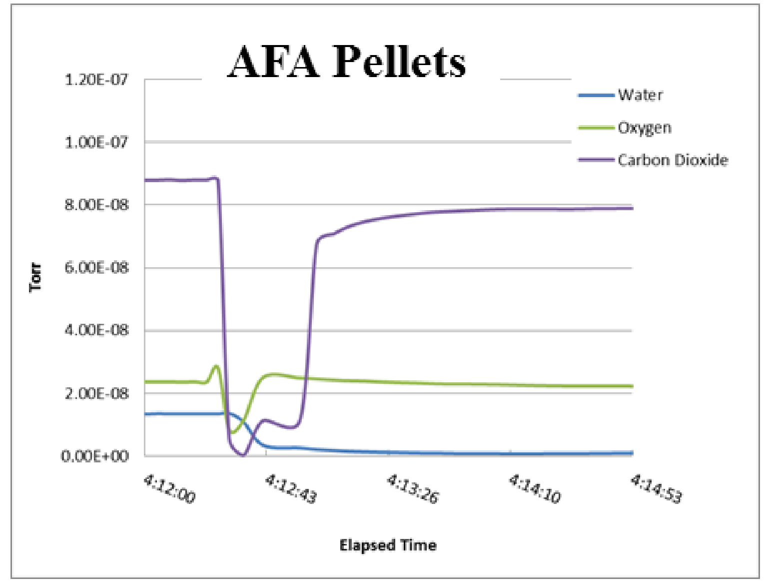
Working Capacity = Adsorp. @ 40 C, 0.15 atm CO_2 – Adsorp. @ 100 C, 0.8 atm CO_2

Good working CO_2 capacity for both sorbent forms

AFA Pellet vs. Bead Performance

Sorbent Selectivity



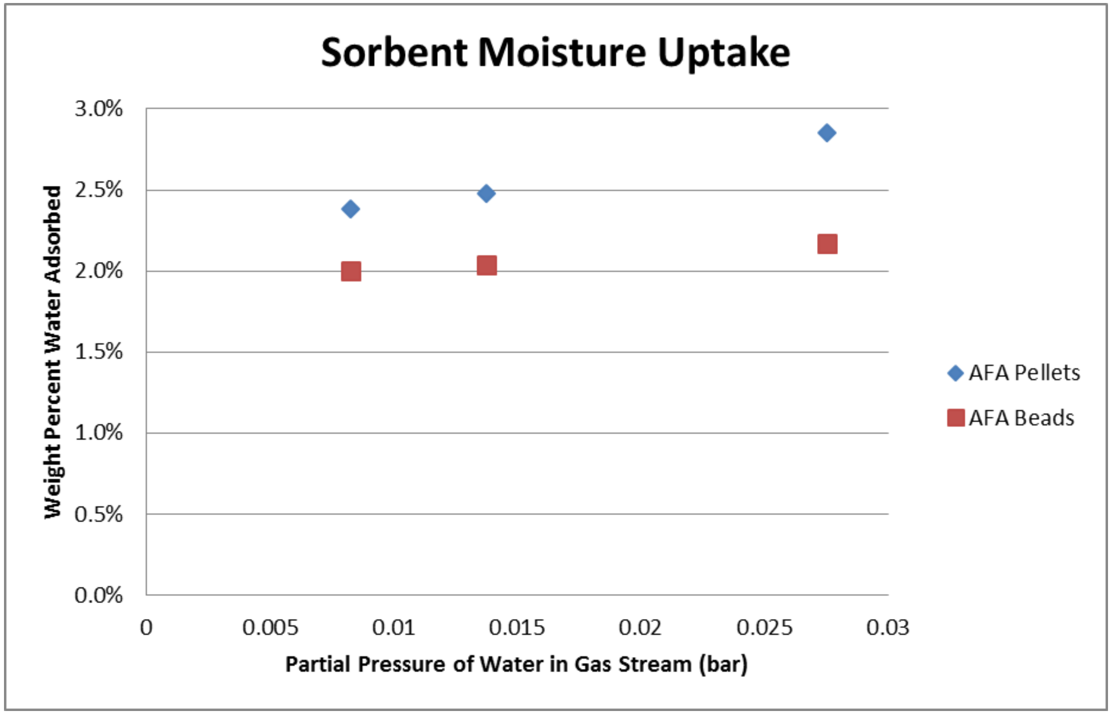


16 X more selective towards CO_2 than H_2O

13 X more selective towards CO_2 than H_2O

AFA Pellet vs. Bead Performance

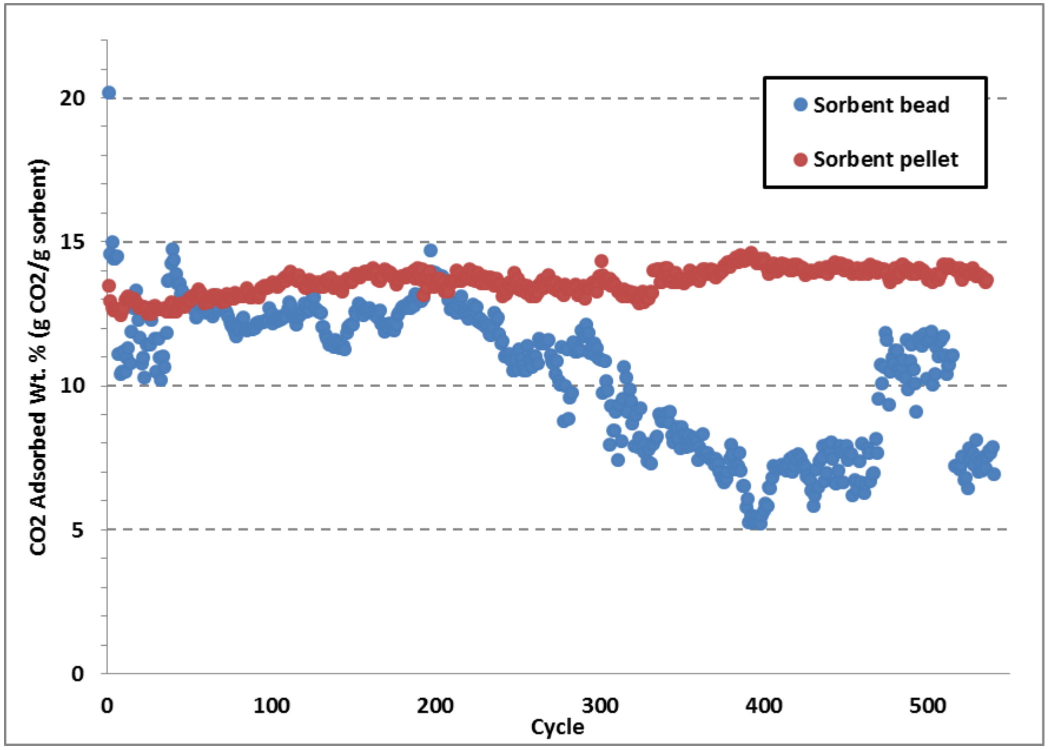
Water Uptake



- The two sorbent forms indicated very similar behavior.
- The bead form has slightly less water uptake than the pellets.

AFA Pellet vs. Bead Performance

Cycling stability:



AFA pellets show clear superiority to the beads in terms of reliable and consistent stability throughout long term CO_2 capture viability

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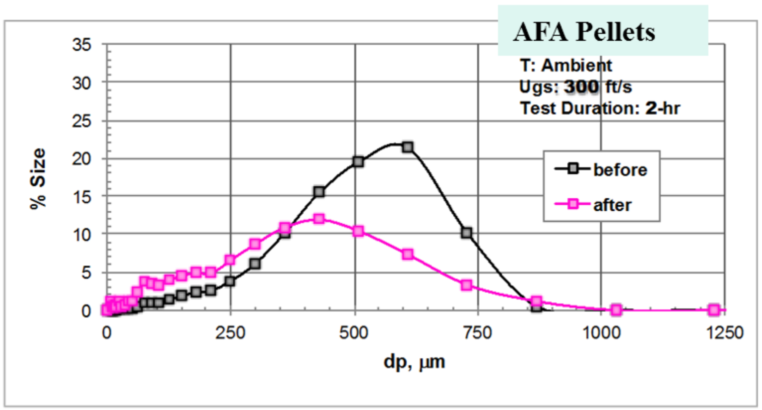
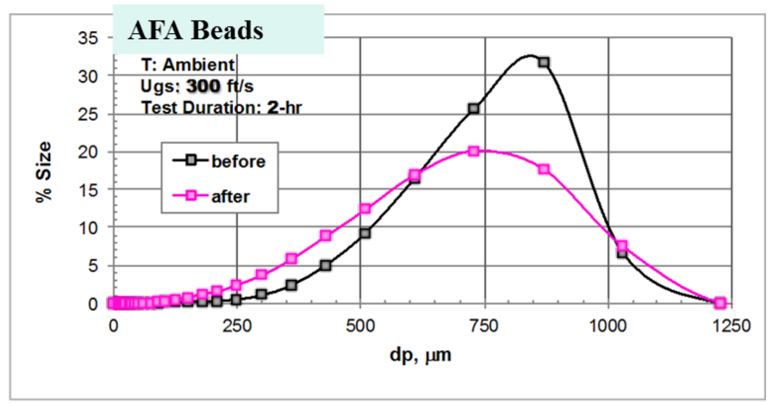
AFA Pellet Vs. AFA Bead (Performance)

Jet Cup Attrition and Crush tests





AFA beads were more resistant to attrition than the pellets.

	Before drying	After drying
AFA Beads	-	8.4 lbf
AFA Pellets	40.2 lbf	14.0 lbf

ASTM D6175

AFA Pellets vs. Beads

Decision: Pellets or Beads ??

- Both product forms of AFA demonstrated comparable CO_2 capture performance.
- AFA **Pellet** form was selected for continuation into Budget Period 3.
- The selection was primarily made based on the scale-up production capabilities of the aerogel at Aspen, and the pelletization capabilities at Akron for future large scale production.

AFA Pellet Scale-Up

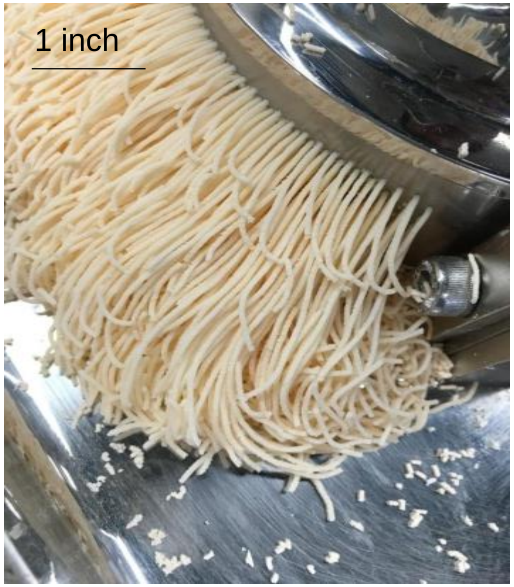
30 kg AFA sorbent was fabricated

Pulverizer (a miller, ~ 60 l/hr) used to convert sorbent into a fine powder (particle size ~ 70 micron)

Pelletization Scale-Up

A scaled-up pelletization process has been developed by UA to prepare 30 kg of pellets for bench scale testing. The process includes four steps:

1. Mixing
2. Extrusion
3. Spheronization
4. Drying



commercial basket extruder and the extrudate

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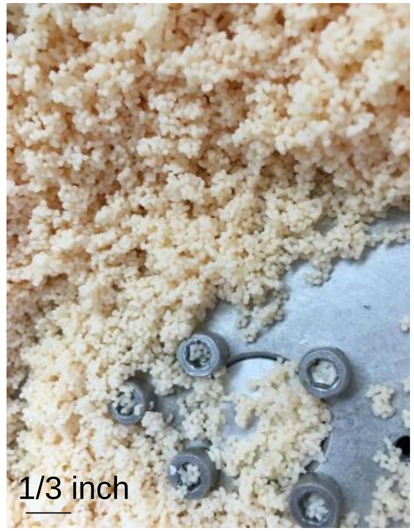
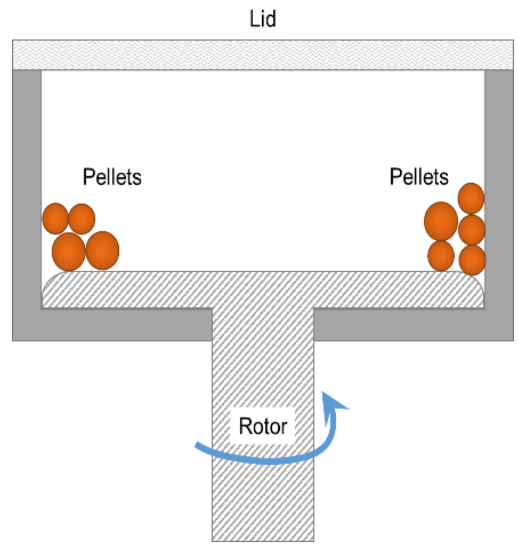
Pelletization Scale-Up - Spheronizer

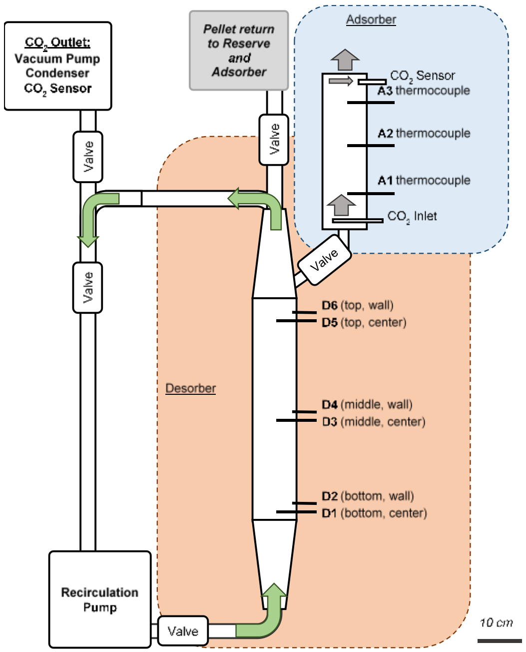


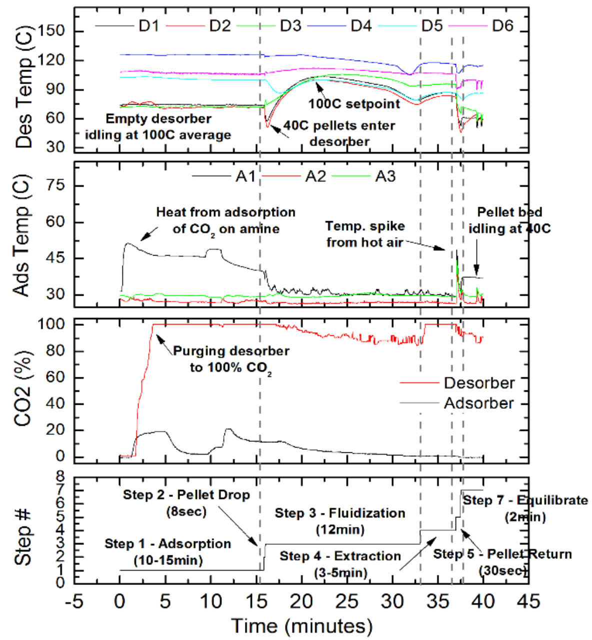


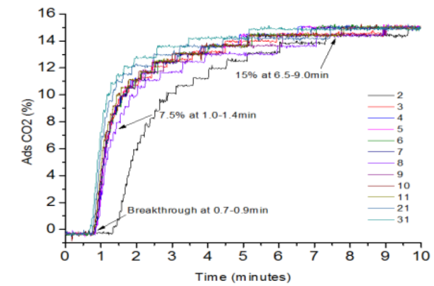
Spheronized pellets depend on the process parameters:

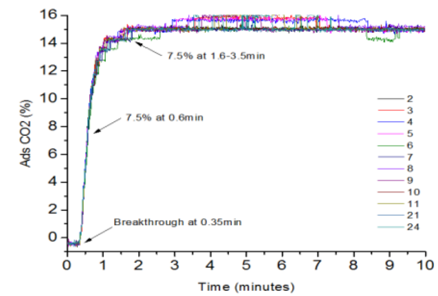
- The rotary speed of the extruder
- The rotary speed of the spheronizer
- The batch size of the extrudate fed into the spheronizer
- The drying conditions

AFA Pellet Performance on 1 kW Test System





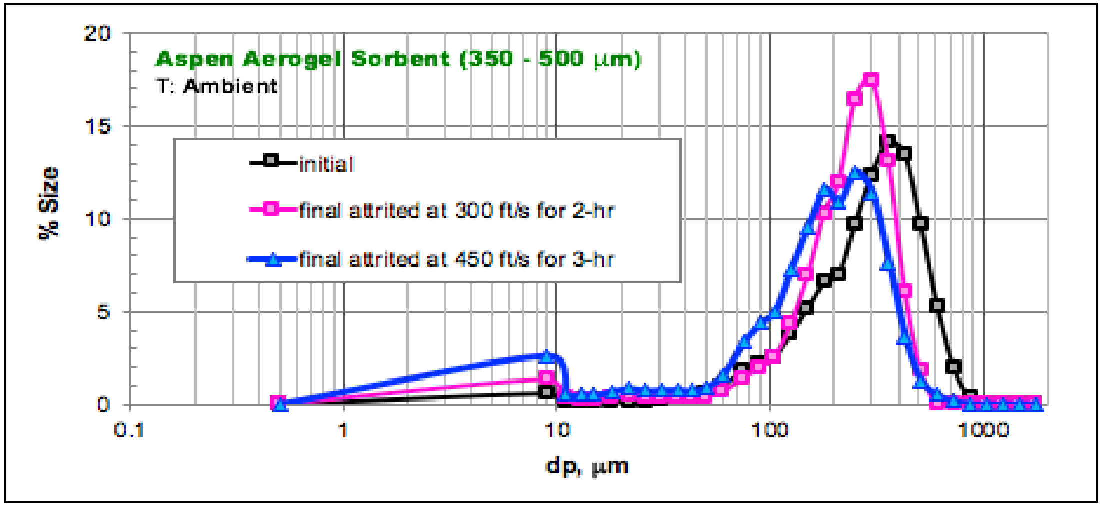




- 1.5 liter sorbent pellets tested
- Flue gas: 15% CO2 @ 5, 10, 20 LPM (liters per minute)
- CO_2 breakthrough occurs within 0.7 min. @ 5 LPM and 0.35 min. @ 20 LPM.

Pellet Sorbent Attrition Testing

AFA pellets were optimized for strength (less attrition) and re-tested.



Sample ID	Inventory g	Jet Velocity ft/s	Test Duration hr	AI (20)	AI (44)
Aspen Aerogel Sorbent (350 - 500 µm)	35 35	300 450	2 3	1.82 4.44	2.13 6.16
PSRI Std FCC Eq. (for Reference Purpose)	100 100	300 450	2 3	0.9 11.6	4.5 21.3

- The Attrition Index (AI) of AFA Pellets < Reference Fluidized Catalytic Cracker (FCC) catalyst sample
- AFA pellets should be able to survive many cycles in a multiple fluidized bed system without excessive degradation from mechanical attrition.

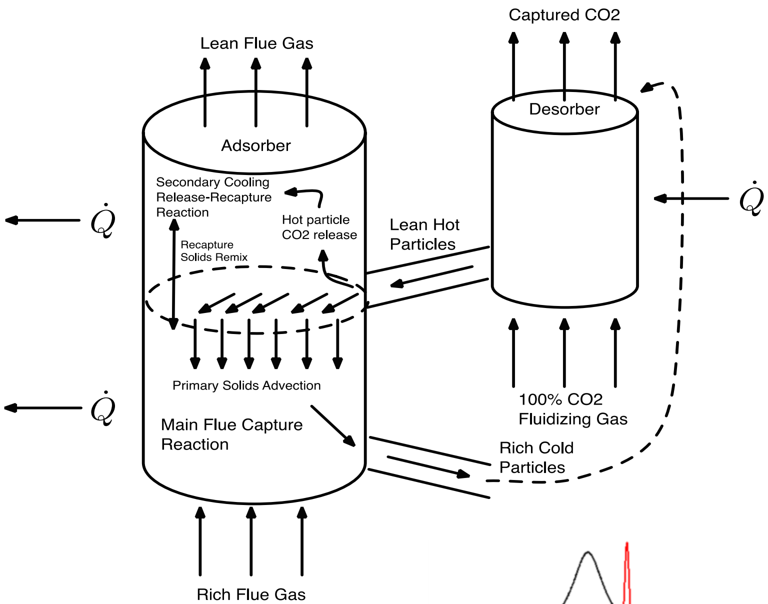
Fluidized Bed and Sorbent Evaluation

Longtail has worked on:

1. Detailed process engineering-based model of the fluidized bed capture system
2. The energy loads and flow inputs function derived from the capture system model
3. Analysis of Amine Functionalized Aerogel (AFA) sorbent kinetics:

$$k_d = \frac{15}{60} = 0.25 \ (sec^{-1}), \ k_a = K_{eq} k_d = \ 21.6709 \ (m^3 kg^{-1} sec^{-1}).$$

Multiphase turbulent fluidized bed model



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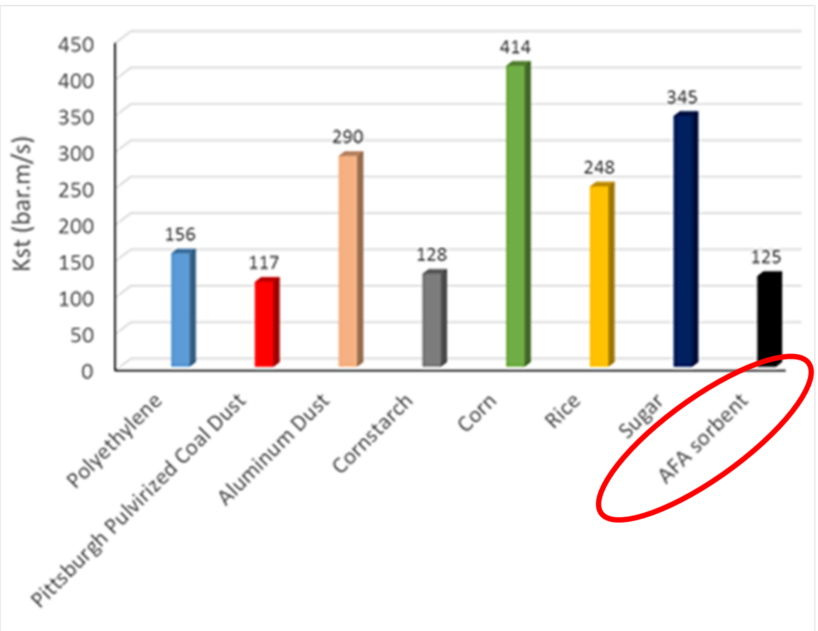
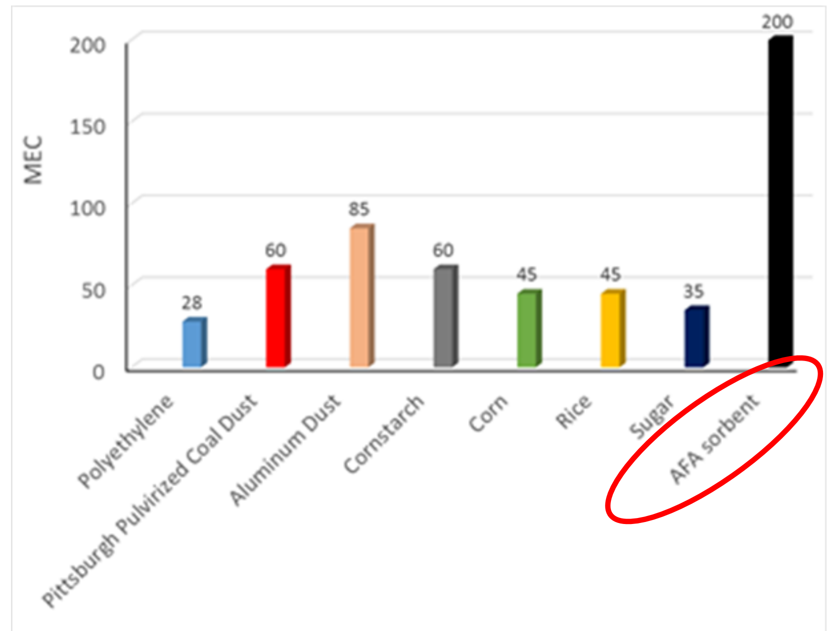
Environmental Health and Safety Evaluation

- AFA sorbent showed no corrosion on steel (ASTM C871, ASTM C1617)
- Airborne total dust, inhalable and respirable of AFA sorbent powder was monitored
  - showed an exposure concentration below the enforceable 8-hour OSHA PEL (Permissible Exposure Limit)
- AFA sorbent showed weak explosivity (ASTM E1226, ASTM E1515)
- Aspen has identified safer alternatives for AFA production to minimize the use of flammable substances.





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Future Plans

- Cold-flow fluidized bed testing (*Sept. 2016*)
- Conduct bench-scale sorbent evaluations for an optimally-sized sorbent in a fluidized bed configuration (*Oct. 16*)
- Techno-Economic Assessment (TEA) (*Nov. 2016*)

Beyond this project:

- Investigate the safer chemical alternatives identified for AFA production.
- Consider other AFA sorbent forms for large scale production.
- Partner with companies for large scale testing of AFA sorbent for CO_2 capture.

Summary

- Evaluated AFA bead performance versus pellets
  - Selected AFA pellet form for continuation into Budget Period 3.

Budget Period 3 Milestones

1. ***Bench-Scale Fluidized Bed Testing***
   - Scaled-up AFA production and pelletization (30 kg) (*completed*)
   - Fluidized bed sorbent modeling and sorbent kinetics evaluation (*completed*)
   - Cold flow fluidized bed testing (*scheduled*)

2. ***Techno-Economic Analysis***
   - *Scheduled*

3. ***EH&S Assessment***
   - ASTM tests (related to EH&S) (*completed*)
   - Safer alternatives for AFA fabrication identified

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- University of Akron **(S. Chuang, L. Zhang, H. Jin, S. Wang, E. Willett)**

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Thank You

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