Development and Testing of Aerogel Sorbents for CO_2 Capture

2014 CO_2 Capture Technology Meeting
Pittsburgh, Pennsylvania
July 29 – August 1, 2014

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Aspen Aerogels, Inc.

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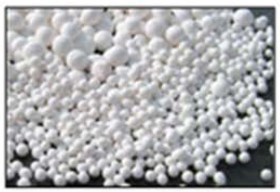
Aspen Aerogels, Inc.

- Founded in 2001
- 220 Employees
- Locations:
  - Northborough, MA
    - *(headquarters, R&D laboratories)*
  - East Providence, RI
    - *(manufacturing facility)*
- World’s leading manufacturer of flexible aerogel blanket insulation
- “Large Scale Nanomaterial Manufacturing”
- ISO 9001-2000 (BVQi certified)

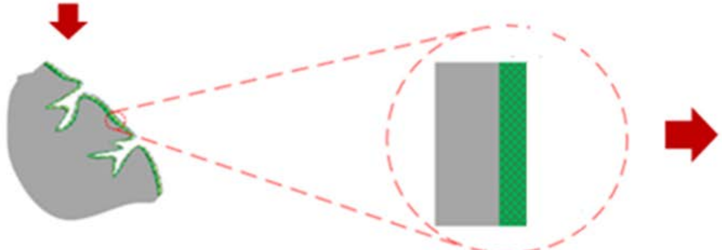
Project Overview

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

Amine Functionalized Aerogel Sorbent



Form Pellets with Binder



Develop Compatible SOx resistant barrier

Develop Aerogel Sorbent at Bench Scale for CO_2 Capture

- Improve Amine Functionalized Aerogels
- Develop Pellet Binder Formulations
- Develop Pellet forming process
- Develop SOx diffusion barrier
- Test & Evaluate Sorbent Technology at Bench Scale

Bench Scale Evaluation

Project Periods

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 Beads) Evaluation
BP3 (2015 – 2016)	Pellet (or beads) Production
	Fluidized Bed Evaluation
	Techno-Economic Evaluation
	Environmental Health and Safety Evaluation

Project Partners

Sorbent optimization – bench scale production

Sorbent testing – bench scale evaluation

Sorbent pelletizing – Sorbent flue gas poisoning optimization

- 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

Amine Functionalized Aerogel (AFA) Development

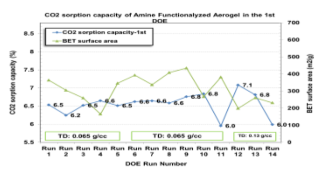
SBIR Phase I

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**
- **Good routes for manufacture at reasonable cost and at high volume**

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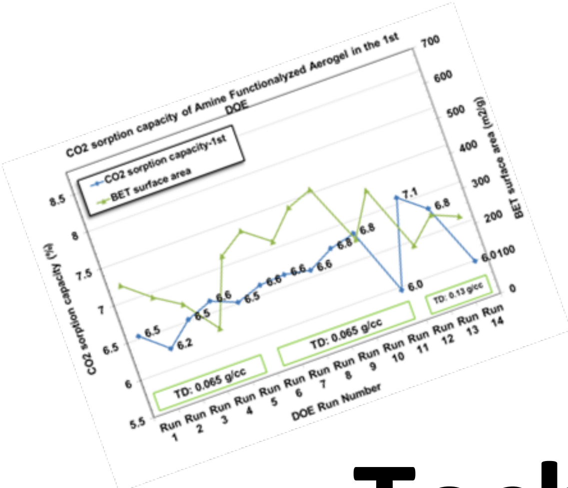
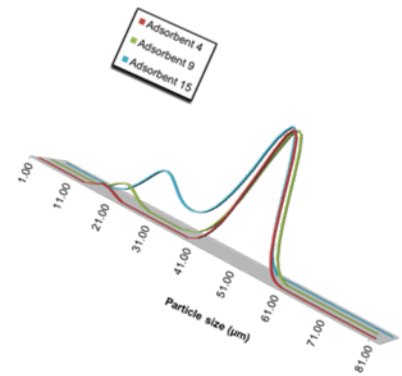
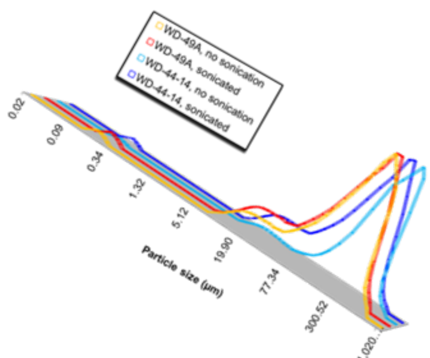
Project Objectives

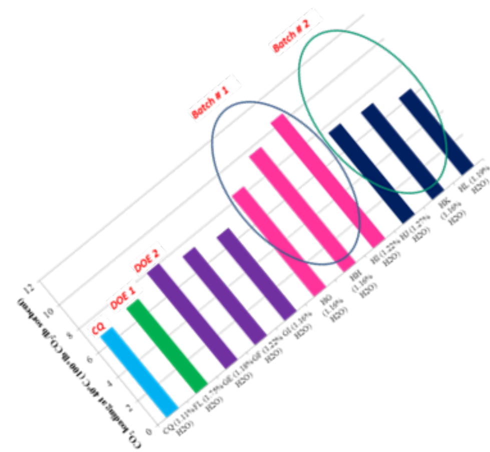
1. Optimize sorbents for improved CO_2 capacity and poisoning resistance.
2. Convert optimized sorbent into durable pellet and bead form.
3. Produce the best candidate sorbent form in larger quantities for fluidized bed testing.
4. Assess the sorbent in fluidized bed bench-scale testing.
5. Conduct a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





Technical Progress



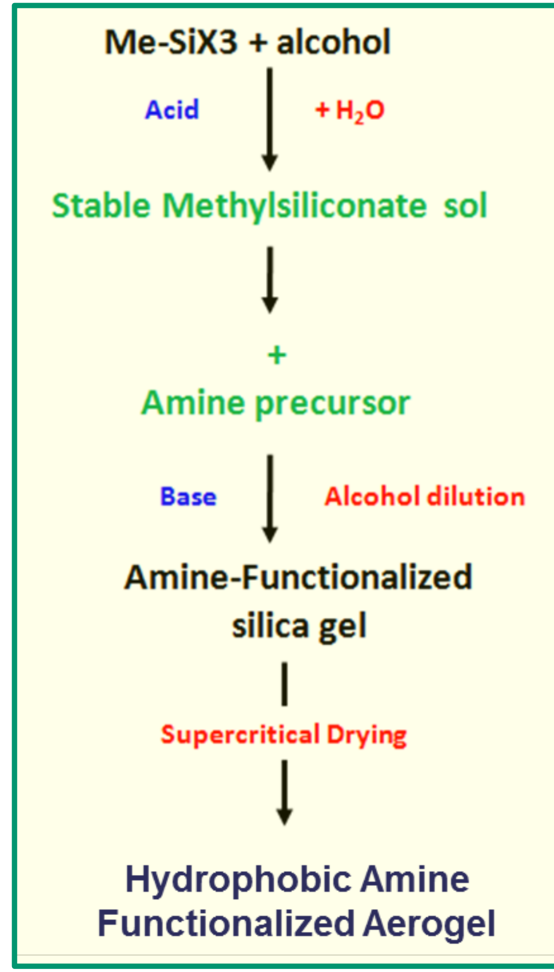


Amine Functionalized Aerogel Optimization

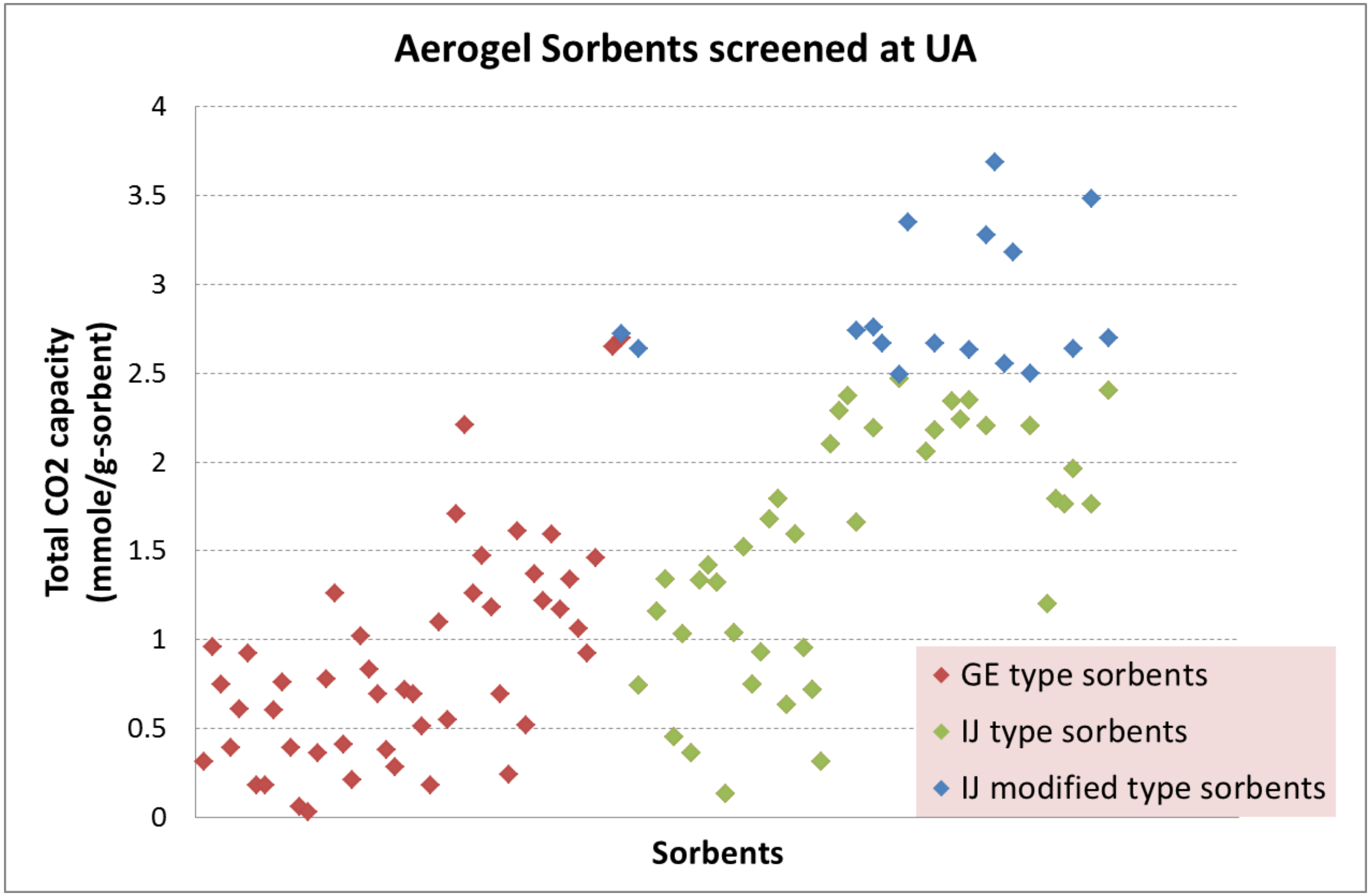
Aspen focused on improving the total CO_2 capacity of its sorbents while trying to maintain their lifetime/cycling stability, by:

- Adjust % amine loading
- Increase the density of the aerogel sorbent (> 0.25 g/cc).
- Optimize chemically grafted amine functional aerogel formula.

Sol-Gel/Aerogel process



Total CO_2 Capacity - The University of Akron (UA)



T adsorp. = 40 °C (100% dry CO_2), 10 min. adsorption
T desorp. = 100 °C (ambient), 10 min. desorption

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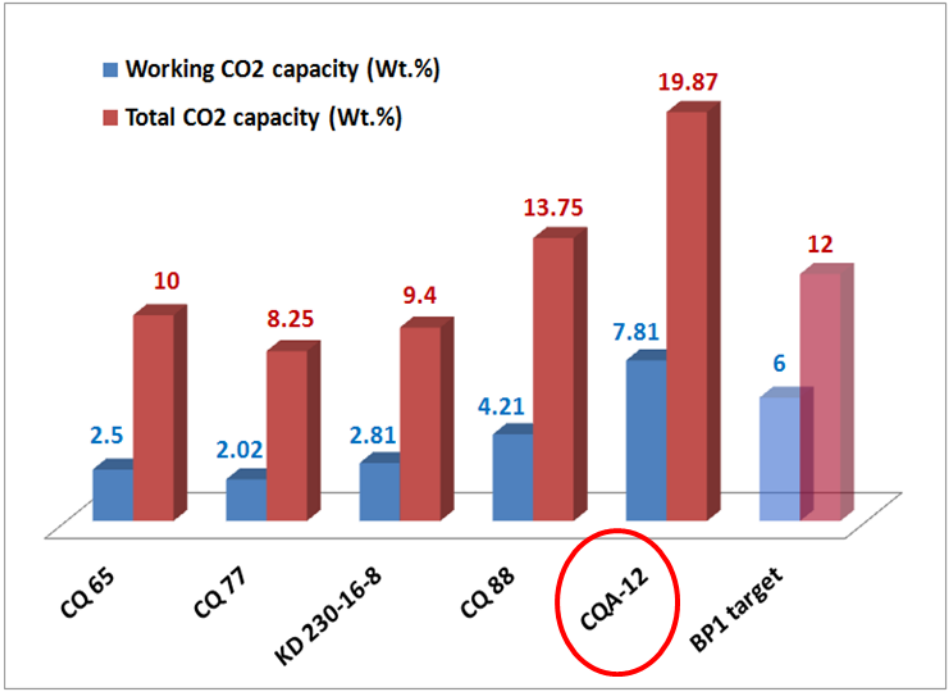
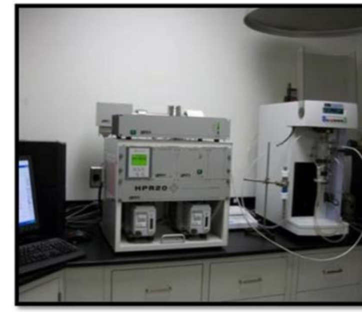
IJ-modified class chosen for further work

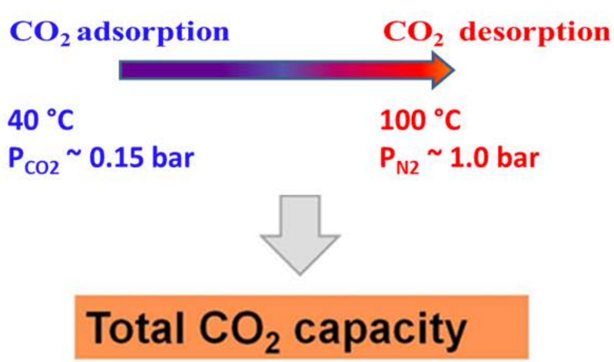
Aerogel Sorbent Evaluation at ADA

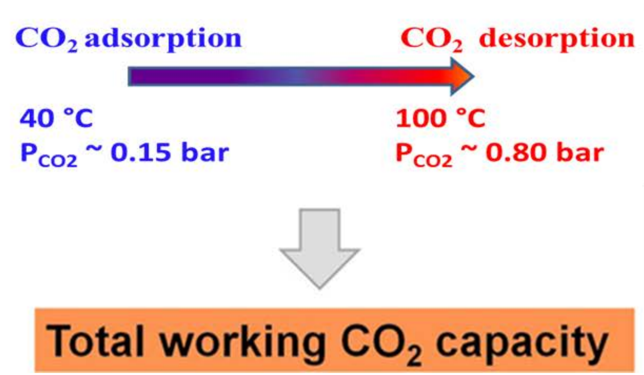




TGA and Mass Spec

- Thermogravimetric analysis (TGA)
  - 100% CO_2 for regeneration
- ~ 1 vol.% moisture
- Various pressures of CO_2 (P_{CO2})





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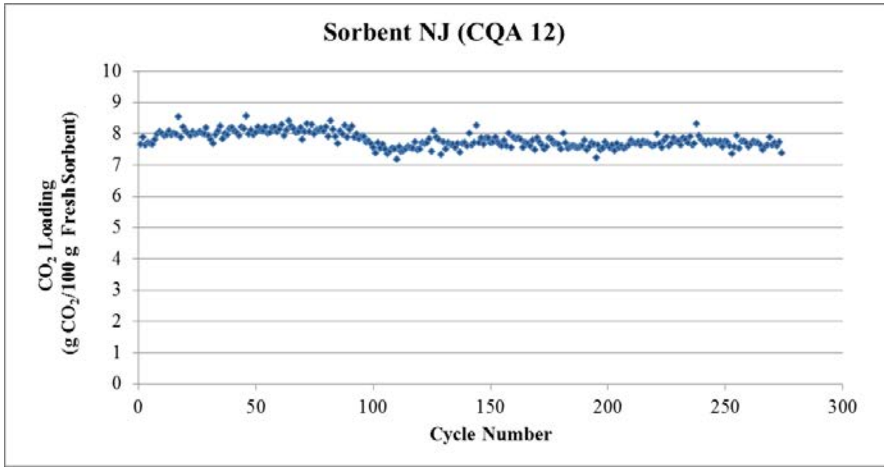
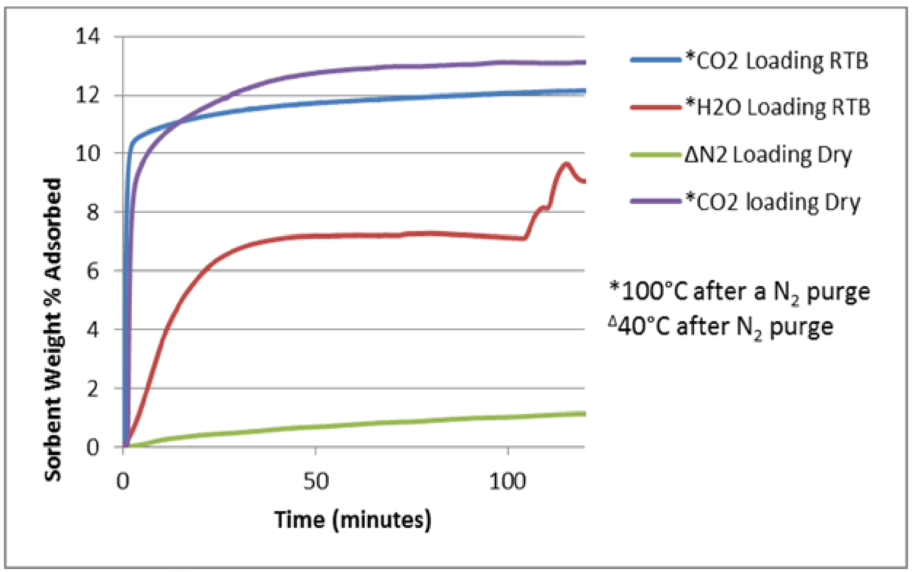
Sorbent Cyclic Stability & CO_2 / H_2O Adsorption Rate Comparison



Stable for up to 250 adsorption/desorption cycles under flue gas conditions of 18.5% CO_2, 4% H_2O, and 77.5% N_2 - **exceeding the 100 cycle BP1 target.**



After 3.9 minutes, CQA12 adsorbs:

- 1 wt. % H_2O
- 10.54 wt. % CO_2

The sorbent cycling time may be reduced to control moisture loading and still maintain high CO_2 loading performance. → Smaller absorber system volume?

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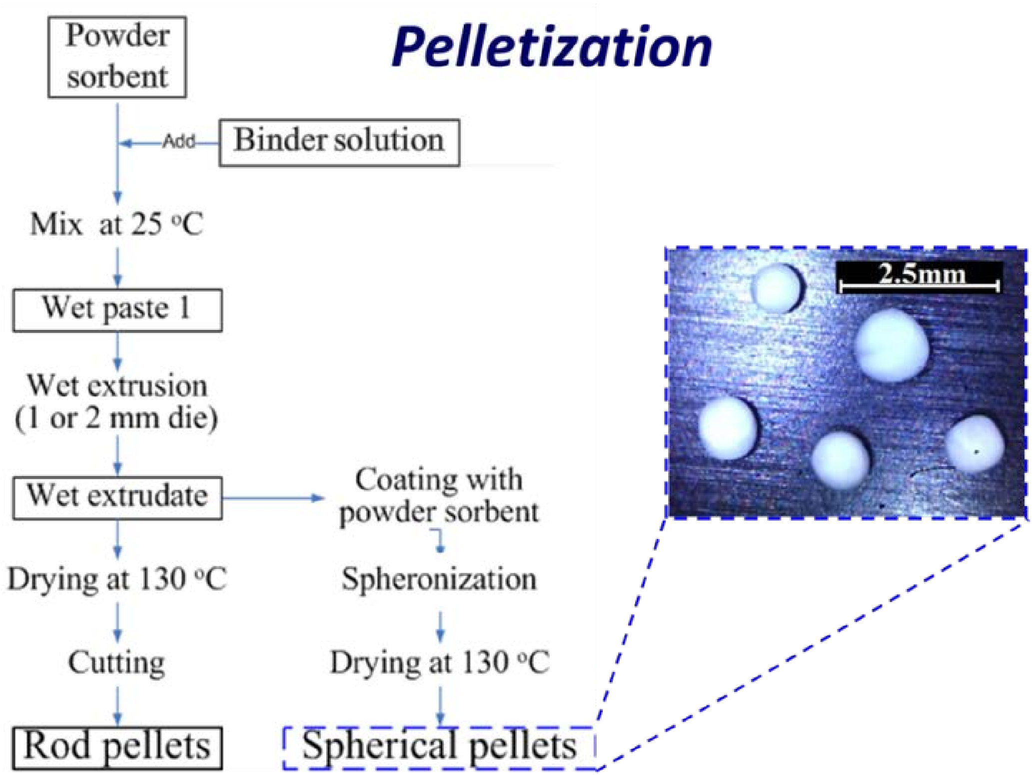
Pelletization Process Optimization - UA

- The CO_2 capture capacities of the pellets prepared with UA Standard binder solution can retain over **90%** of that of the powders.

- CO_2 capture retention for the pellets depends on binder/aerogel ratio and density of active amine sites.



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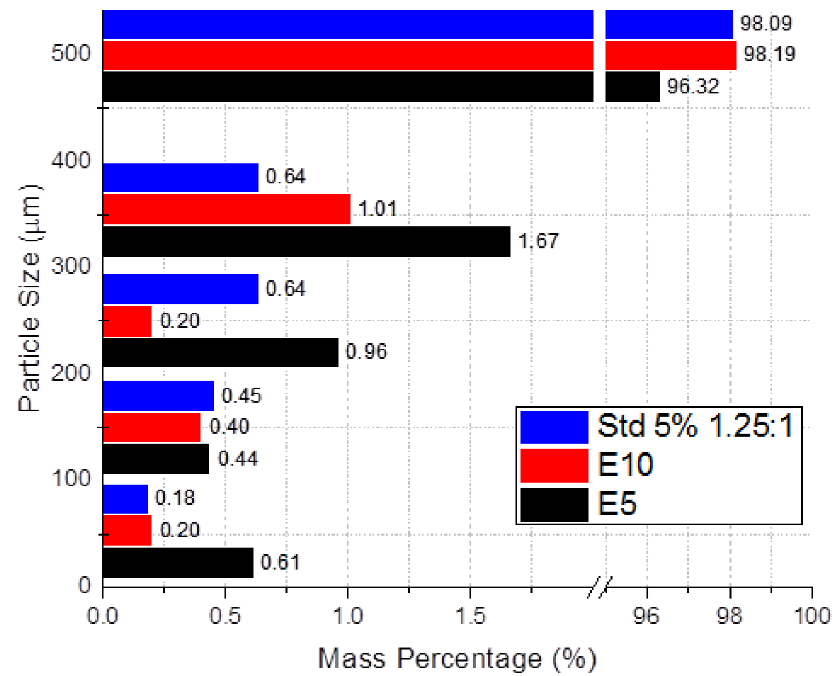
Attrition Index Measurement - UA

- CQA12 pellets were subjected to ASTM D5757 (*Standard Test Method for Determination of Attrition of FCC Catalysts by Air Jets*).
- Initial size ~ 500 μm.
- % mass attrited measured after 3 hours
- Two of UA's binder recipes gave **<2% attrition**.



- Modified E series binding solution recipe will be applied as an SO_2 resistance coating.

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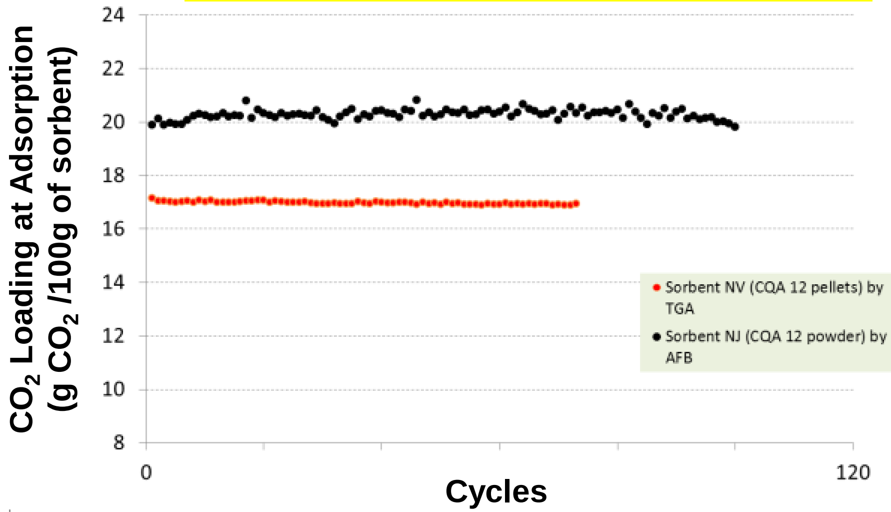
Cyclic Stability of CQA12 Pellets - ADA

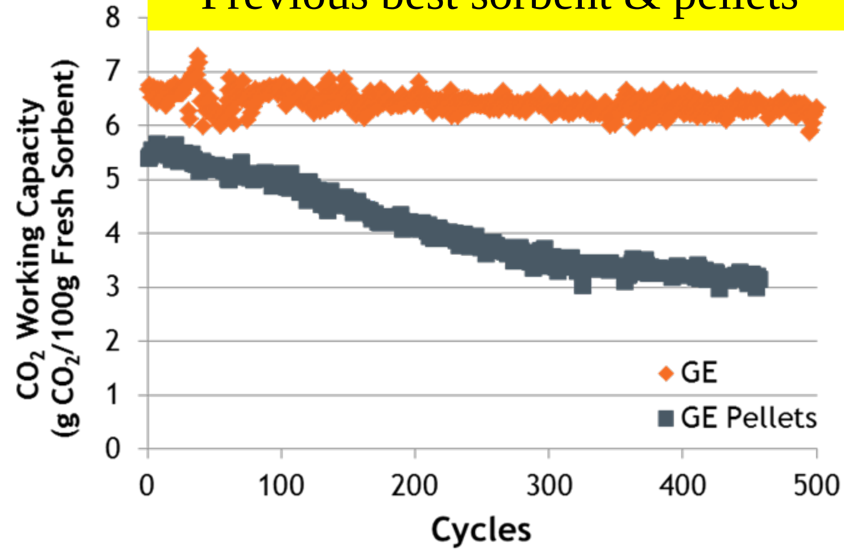
- CQA12 Pellet was tested for cyclic stability using TGA.
  - Retained > 88% of the total CO_2 capacity of CQA12 powder.
  - Kinetics were **fast** during CO_2 adsorption for the first 3 cycles as well as the last 3 cycles (cycles 71 – 73).

CQA12 sorbent and pellets



- Improved stability achieved in BP1 at 3x improvement of capacity vs SBIR program best results

Previous best sorbent & pellets



- Cyclic stability (<u>**40°C – 130°C**</u>)
- <u>**Lost ~40%**</u> of initial delta CO_2 working capacity after 450 cycles.

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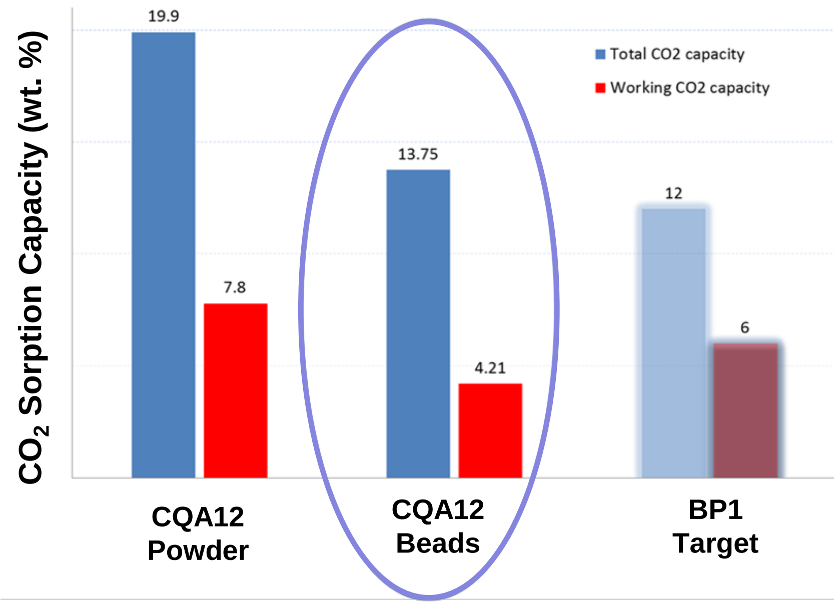
Aerogel Sorbent Beads - Study Initiation

- The optimum aerogel formulation (CQA12) was used to make small quantities of beads with different sizes (<500 microns – 3 mm)
- May offer alternative pathway to higher working capacity and faster kinetics without pelletization costs
- Further work on optimization in BP2.

Promising CO_2 adsorption capacity.



Beads will be optimized for better mass transport to increase working capacity

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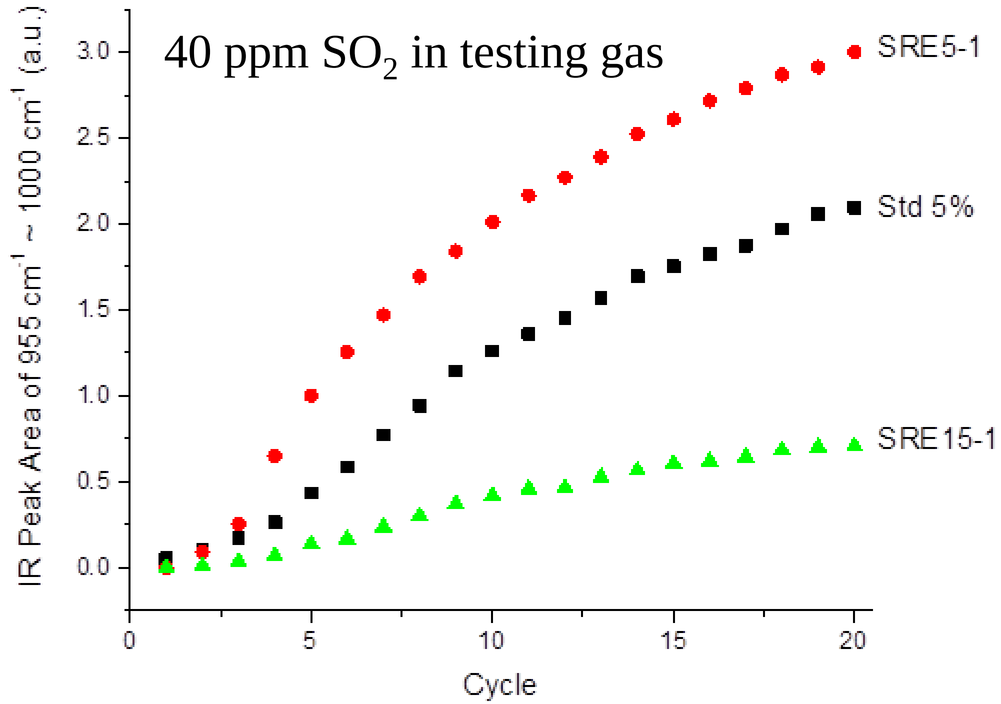
SO_2 Resistant Coating - Preliminary Study

- The SO_2 accumulation of adsorbed SO_2 is suppressed on SRE15-1 coated sorbent compared to the other two samples.
- The composition of the coating has a critical impact on the resistance to SO_2.
- Further studies on optimizing the composition of SO_2 resistant coatings in BP2.



Change of the IR peak area for the sulfate peak (peak center is 981 cm^{-1})

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BP1 Achievements and Planned/Actual Completion Dates – *Through Month 9*

	Verification Method	BP1 Target	Planned completion date	Actual completion date
Optimized AFA Powder	Total CO_2 adsorption capacity[(1)]	> 12 wt. % (2.72 mmolCO_2/g-sorb)	03/31/2014	2/17/2014 **Exceeded Target** (19.9 wt.%)
	Working CO_2 capacity[(1)]	> 6 wt.% (1.36 mmolCO_2/g-sorb)	03/31/2014	2/17/2014 **Exceeded Target** (7.8 wt.%)
	Adsorption/desorption kinetics	Fast [(2)]	03/31/2014	2/25/2014 **Medium-Fast at 40 - 100 °C[(3)] Fast at 40 - 110°C[(3)]**
	Water adsorption	< 1 wt. % @ 40 °C	05/31/2014	05/26/2014 **Met Target**[(4)]
	Cycling stability (CO_2 adsorption/desorption)	Stable over 100 cycles.	05/31/2014	3/21/2014 **Exceeded Target** (stable over 250 cycles)

1): Adsorption @ 40 °C, Desorption @ 100 °C
2): < 15 min. to reach 80% of total CO_2 capacity at adsorption temperature
3): Medium-fast (15.58 min.) , **Fast** (11.43 min.)
4): Water adsorption varies as a function of the hydrophobicity of the sorbent.

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BP1 Achievement and Planned/Actual Completion Dates
– Through Month 9

	Verification Method	BP1 Target	Planned Completion Date	Actual Completion Date
Optimize AFA Pellets	CO_2 adsorption capacity(1)	> 9% wt. (2.04 mmolCO_2/g-sorb)	06/30/2014	06/06/2014 **Exceeded Target** (17 wt.%)
	Density (g/cc)	> 1.2 g/cc	06/30/2014	06/06/2014 ~ **1.3 g/cc Achieved**
	Size (micron)	300 - 350	06/30/2014	06/06/2014 **Met Target** (300 -350 mm)
	Attrition Index	3% (2)	06/30/2014	06/18/2014 **Exceeded Target** (< 2%)
Develop SO_2 coating resistance	the preliminary results should demonstrate the poisoning resistance against SO_2		06/30/2014	Initiated on 06/15/2014
Initiate AFA bead development	Assess aerogel beads CO_2 capture performance.		06/30/2014	Initiated on 04/12/2014

1): After optimization of aerogel/binder ratio.
2): loss under fluidizing condition for 3 hours.

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BP1 Conclusions

- ➢ All milestones have been met and completed on schedule or ahead of schedule.
- ➢ Three methods of amine incorporation were investigated.
- ➢ Optimized AFA sorbents with a reduced delta T for adsorption/desorption (40 – 100 °C)
- ➢ Best performing sorbent (CQA 12) has demonstrated:
    - ✓ *High CO_2 total capacity (> 20 wt.%)*
    - ✓ *High CO_2 working capacity (8 wt.%)*
    - ✓ Stable for up to 250 adsorption/desorption cycles
- ✓ High sorbent selectivity → cycling time can be reduced to control moisture loading.
        - ✓ ***Several process advantages*** (smaller quantities of sorbent, reduced size of the absorber units, reduced capital costs, less parasitic loss *etc.*).
- ➢ Optimized pellet fabrication – up to 90% CO_2 capture retention and low attrition index (< 2%).
- ➢ Project team initiated two important studies that will continue during BP2:
    - ✓ SO_2 resistant coating development
    - ✓ Amine Functionalized Aerogel bead development

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Acknowledgements

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- University of Akron (**S. Chuang, E.S. Mojica, L. Zhang and U. Tumuluri**)

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