Development and Testing of Aerogel Sorbents for CO_2 Capture

Award No. DE-FE0013127
Budget Period 1 Review
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Subcontractors: ADA-ES, Inc., University of Akron
BP1 Start Date: October 1, 2013
BP1 End Date: September 30, 2014

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Agenda

- Executive Summary
  - Project overview
  - BP1 performance targets/achievements
- Technical Results
  - Amine functionalized aerogel (AFA) sorbent optimization
  - Sorbent evaluation at UA
  - Sorbent Evaluation at ADA
  - Sorbent bead and SO_2 resistance coating studies initiated
  - Conclusions
- Risk Mitigation
- Budget
- Schedule/Milestones/Deliverables
- Variances

Program Objectives

Amine Functionalized Aerogel Sorbent

Form Pellets with Binder

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

Proprietary information has been deleted.

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

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BP1 Performance Targets

	Test Parameter	BP1 Performance Target
Amine Functionalized Aerogel (powder)	Total CO_2 adsorption capacity(1)	> 12 wt.% (2.72 mmolCO_2/g-sorb)
	Working CO_2 capacity(1)	> 6 wt.% (1.36 mmolCO_2/g-sorb)
	Adsorption/desorption kinetics(2)	Fast
	Water adsorption	< 1 % @ 40 °C
	Cycling stability (CO_2 adsorption/desorption)	Stable over 100 cycles.
Amine Functionalized Aerogel (pellets)	CO_2 adsorption capacity(3)	> 9 wt.% (2.04 mmolCO_2/g-sorb)
	Density (g/cc)	> 1.2 g/cc
	Size (micron)	300 - 350
	Attrition Index	3%(4)
SO_2 coating resistant Development	Initiate development of a SO_2 resistant coating for AFA sorbents. Evaluate preliminary results of poisoning resistance against SO_2	
Amine Functionalized Aerogel (Beads)	Initiate AFA bead synthesis and assess its CO_2 capture performance.	

(1): *Adsorption @ 40 °C, Desorption @ 100 - 120°C*
(2): *< 15 min. to reach 80% of total CO_2 capacity at 40 °C and 0.15 CO_2 bar*
(3): *After optimization of aerogel/binder ratio*
(4): *loss under fluidizing condition for 3 hours.*

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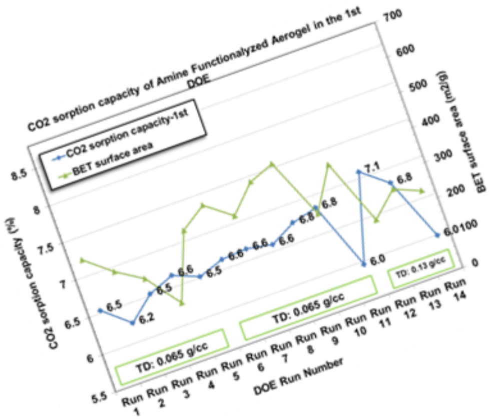
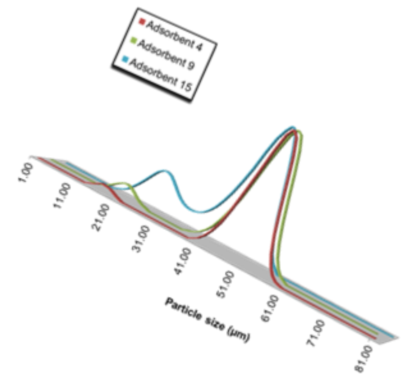
BP1 Achievement and Planned/Actual Completion Dates – *Through Month 9*

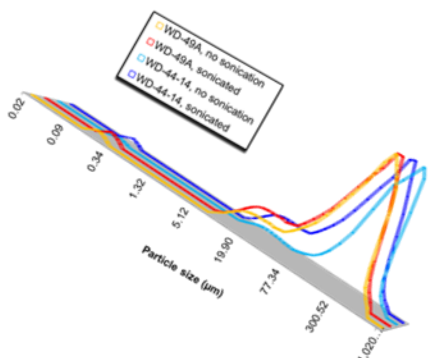
	Verification Method	BP1 Target	Planned Completion Date	Actual Completion Date
Optimize AFA Pellets	CO_2 adsorption capacity[(1)]	> 9% wt. (2.04 mmolCO_2/g-sorb)	06/30/2014	06/06/2014 **Exceeded Target** (17 wt.%)
	Density (g/cc)	> 1.2 g/cc	06/30/2014	06/06/2014 ~ **1.3 g/cc Achieved**
	Size (micron)	300 - 350	06/30/2014	06/06/2014 **Met Target** (300 -350 micron)
	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

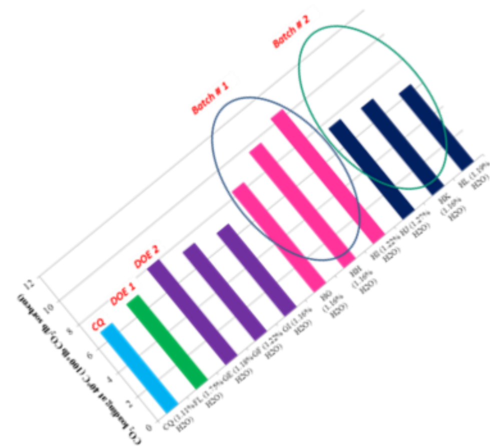
1): After optimization of aerogel/binder ratio.
2): loss under fluidizing condition for 3 hours.

Technical Progress









Amine Functionalized Aerogel (AFA) Formulations (Phase II)

➢ Optimize the 3 most promising AFA formulations developed in Phase II.

Sorbent	Total CO_2 loading (wt.%)	CO_2 delta loading (wt.%)	Kinetics	Stability
GE	8	6.4	**Fast**	**High**
IJ	~ 15	11	**Medium**	**Low**
IJ-modified	~ 22	12	**Slow**	**Low**

Adsorption: **40°C**, 0.15 PCO_2
Desorption: **130°C**, 0.8 PCO_2

GE sorbent: mono-amine functionalized hydrophobic aerogel

IJ sorbent: polyimine loaded hydrophobic aerogel (higher density of functional groups)

IJ-modified sorbent: polyimine grafted hydrophobic aerogel

Amine Functionalized Aerogel Optimization

Qualitative optimization of these aerogels has been dedicated to:

1) Maximizing the CO_2 capacity.
2) Decreasing the temperature of regeneration (< 130 °C).
3) Maintaining kinetics for realistic fluidized bed operation.
4) Maintaining high cyclic adsorption stability.

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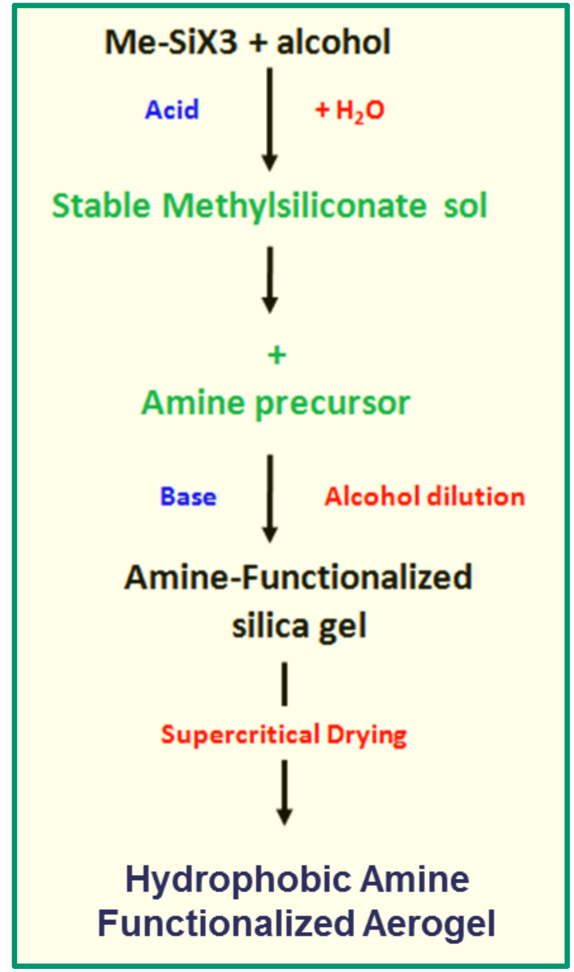
Amine Functionalized Aerogel Optimization

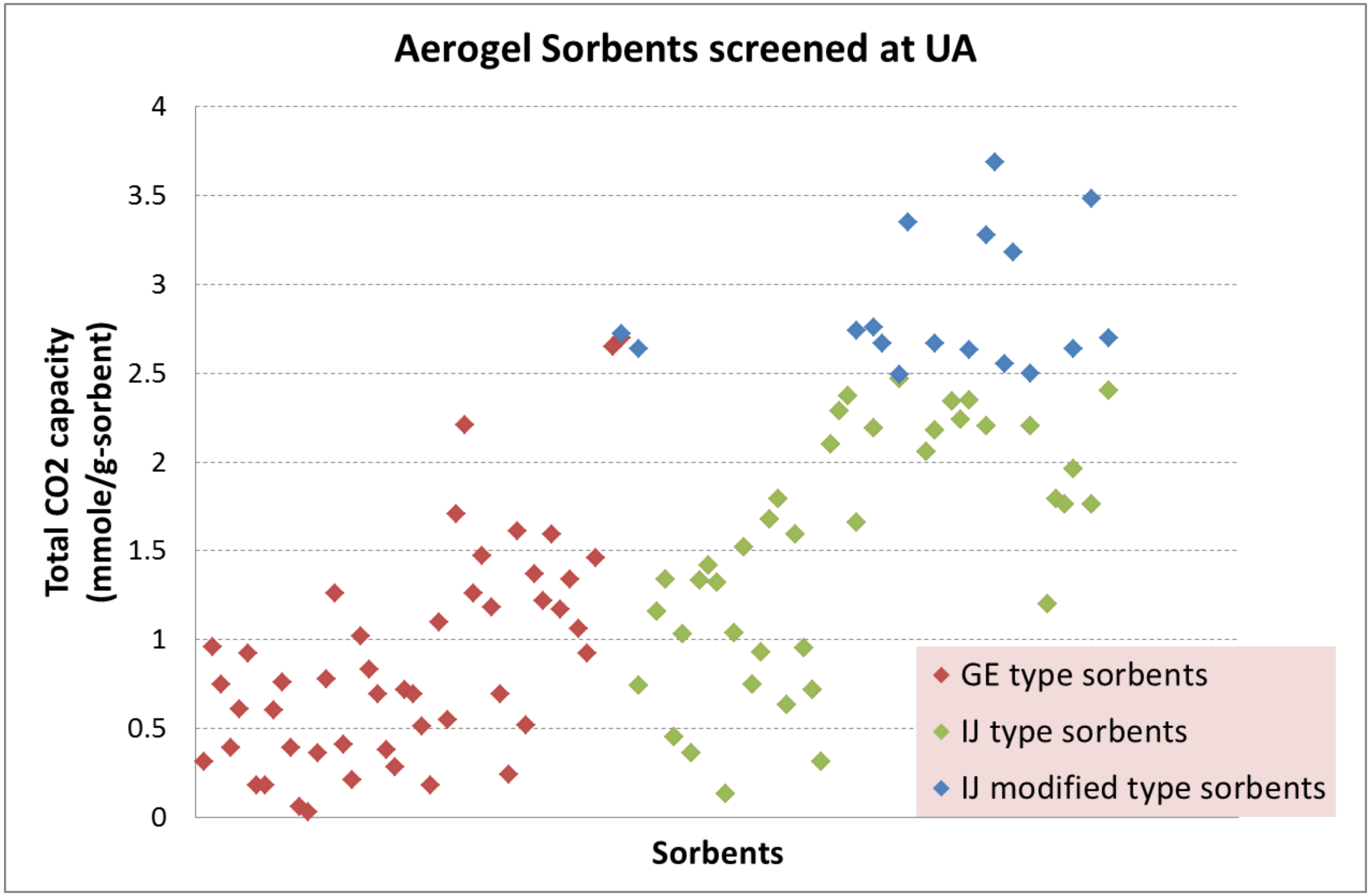
Aspen focused on improving the total CO_2 capacity of its sorbents while trying to maintain their lifetime/cycling stability, by:

- Adjusting % amine loading in the aerogel formulation.
- Increasing the density of the aerogels (> 0.25 g/cc).
- Optimizing amine grafted aerogel formulation.

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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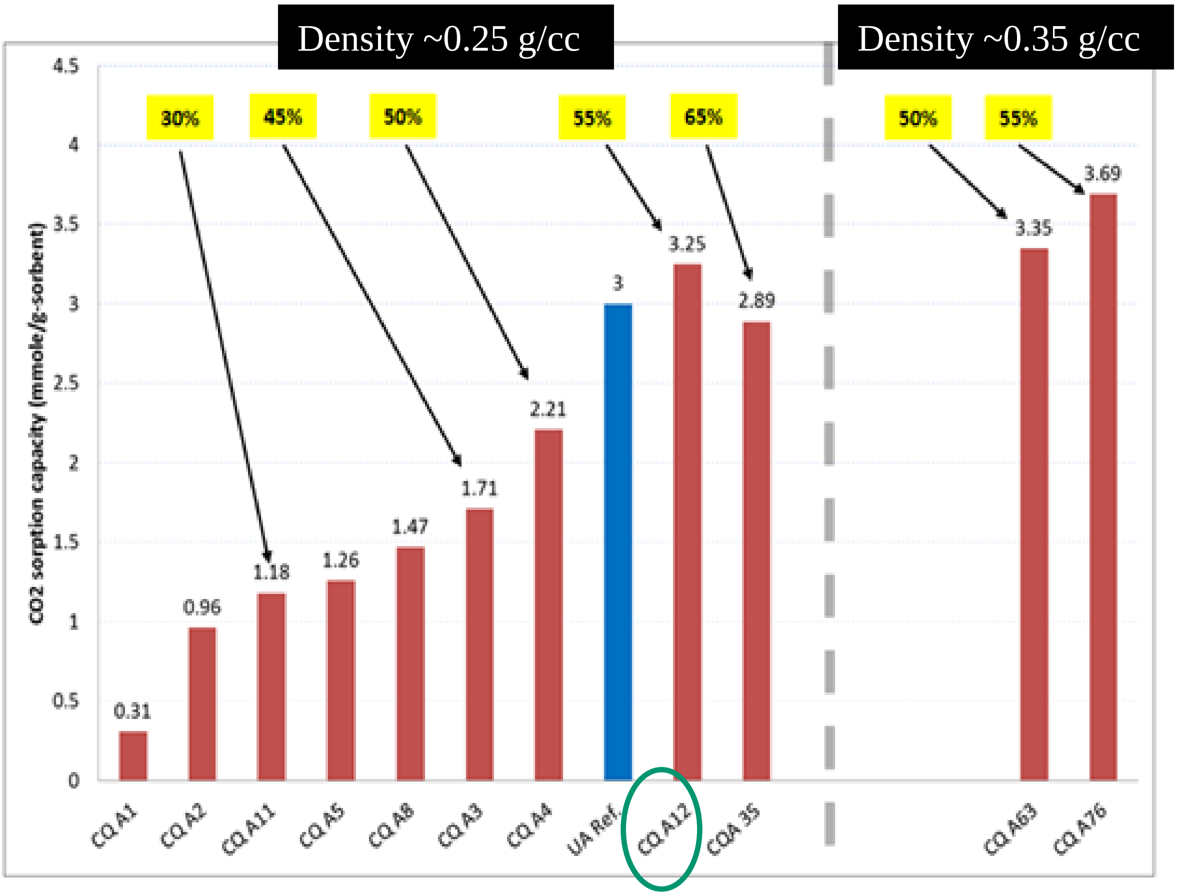
Amine Functionalized Aerogel Optimization – BP1 Results

	GE type sorbent[1]	IJ type sorbent[2]	IJ-modified[3]
Total CO_2 capacity (wt.%) ***[40°C, 0.15 PCO_2]***	9.4	13.75	19.87
Working CO_2 capacity (wt.%) ***[40°C, 0.15 PCO_2 → 100°C, 0.8 PCO_2]***	2.81	4.21	7.81
Kinetics	Fast	Fast	Medium-Fast
Cycling stability ***[40°C, 0.15 PCO_2 → 100°C, N2]***	Yes	No	Yes
vs. BP1 targets	Below	Below	Meet/Exceed

1. Mono-amine functionalized hydrophobic aerogel
2. Polyimine loaded hydrophobic aerogel
3. Polyimine grafted hydrophobic aerogel

- **IJ- Modified** - Polyimine grafted hydrophobic aerogel led to a sorbent with the highest CO_2 capture performance.
- The stability of the amine sites was greatly improved and the CO_2 capture performances measured were **above the targets**.

Effect of Polyimine Loading & Density on Total CO_2 Capacity



% Polyimine ↗ ⇨ CO_2 capacity ↗

Optimum loading ~ 55 wt.%

Gels are non-viable above 55%

Density ↗ ⇨ CO_2 capacity ↗

Kinetics slow

Densities > 0.25 g/cc exhibit slow kinetics

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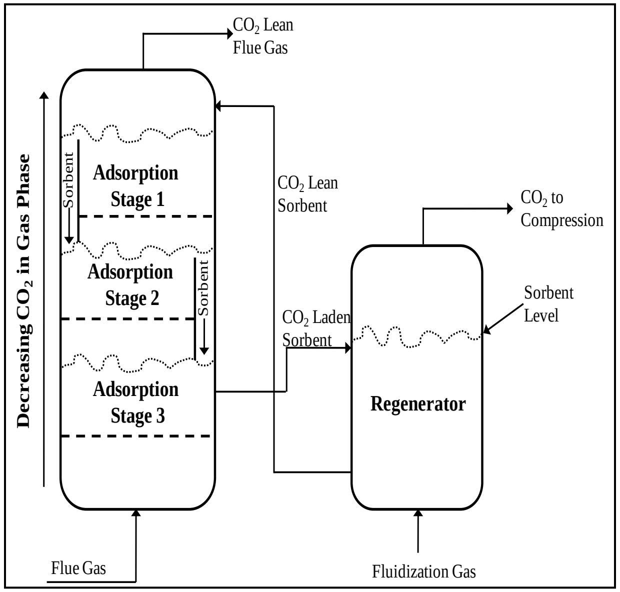
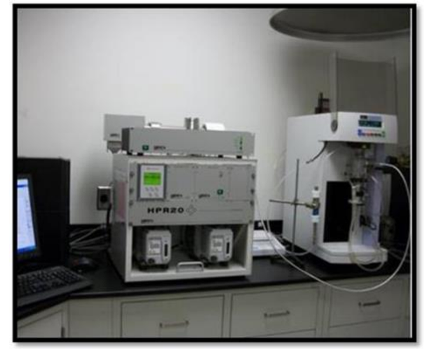
Aerogel Sorbent Evaluation at ADA



ADAsorb™ Process Overview



TGA and Mass Spec

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

CO_2 adsorption →	CO_2 desorption
40 °C	100 °C
P_{CO2} ~ 0.15 bar	P_{N2} ~ 1.0 bar

↓

Total CO_2 capacity

CO_2 adsorption →	CO_2 desorption
40 °C	100 °C
P_{CO2} ~ 0.15 bar	P_{CO2} ~ 0.80 bar

↓

Total working CO_2 capacity

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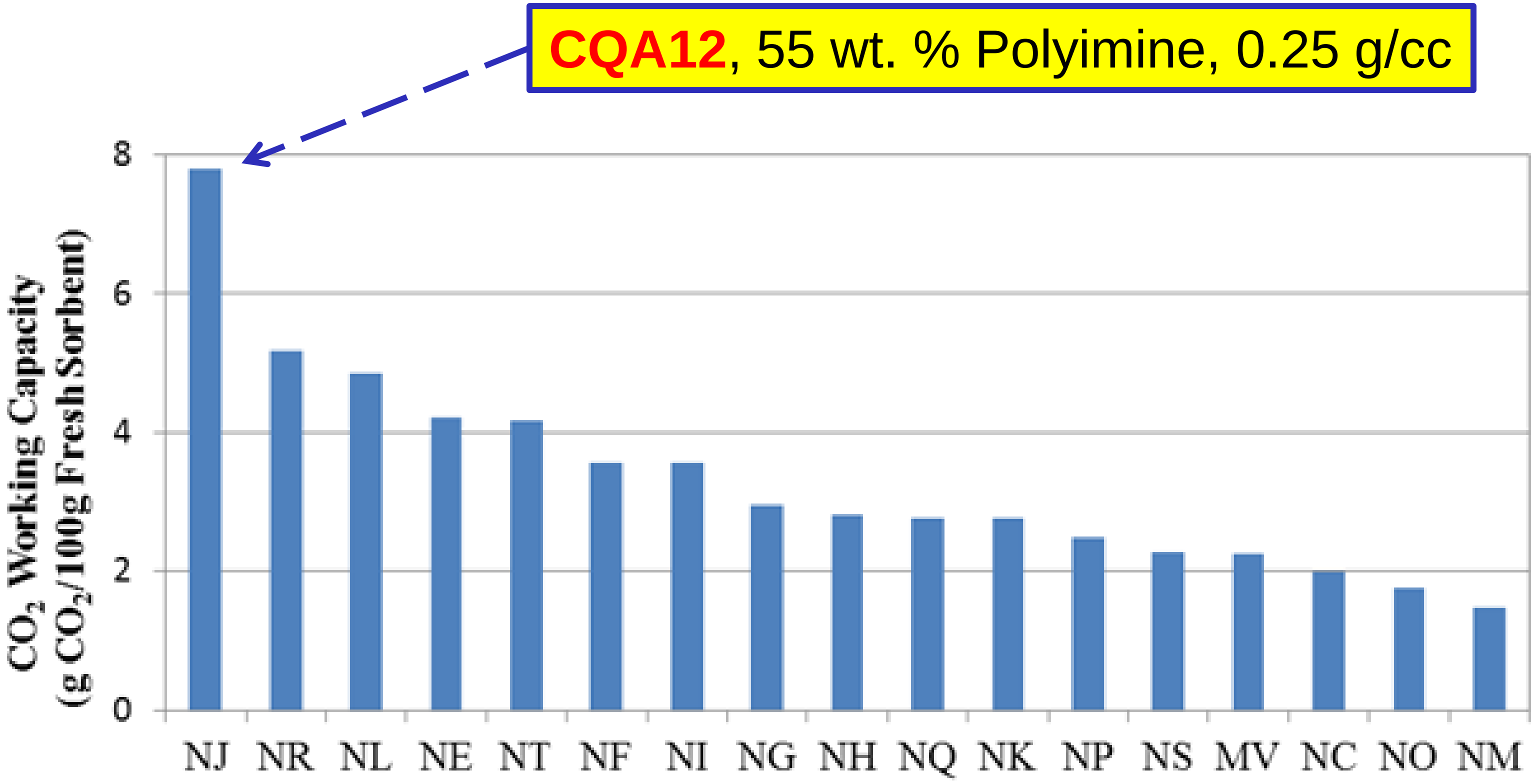
Aerogel Sorbent CO_2 Working Capacity - ADA



- Most sorbents evaluated with adsorption temperature of 40 °C showed fast kinetics, meaning that the time to reach 80% capacity equilibrium was less than 15 minutes.

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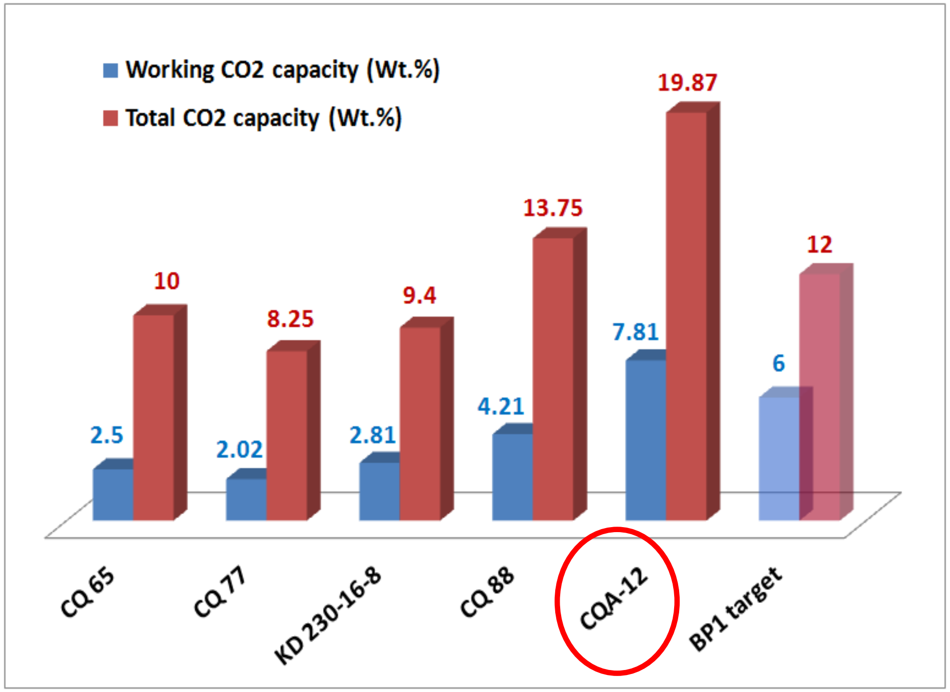
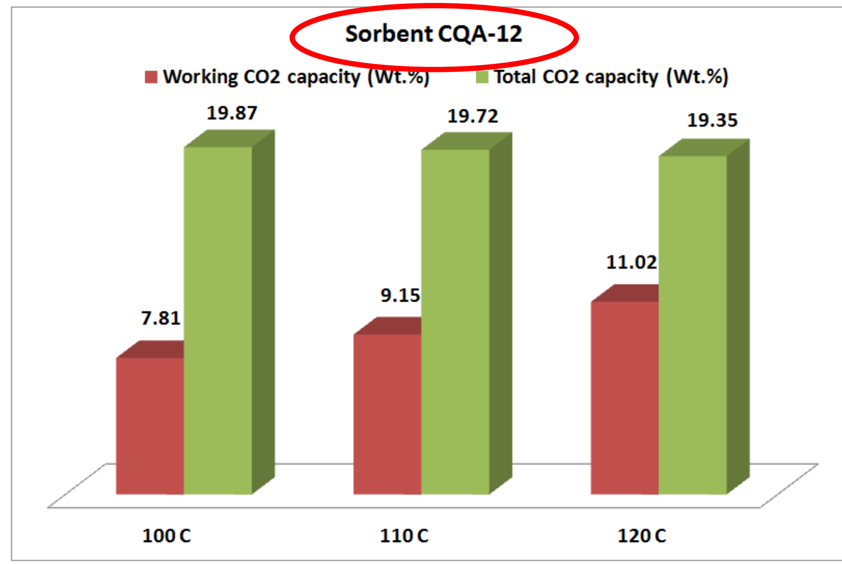
Total & Working CO_2 Capacity for CQA12 - ADA





- CQA12 has the highest CO_2 capture performance exceeding the BP1 target.

- Working CO_2 capture performance increases as the desorption temperature increases.

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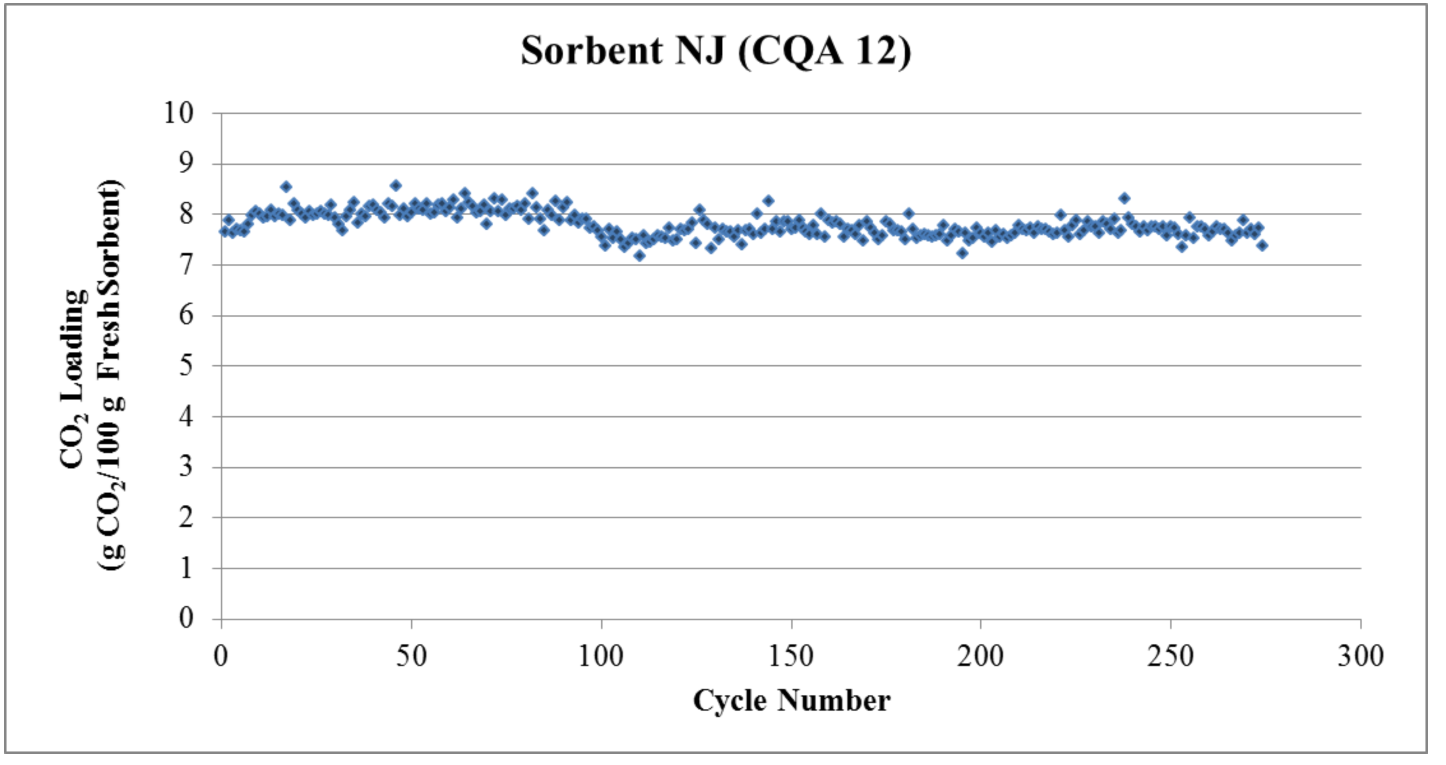
CQA12 Cyclic Stability (Automated Fixed Bed) - ADA



- 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.**

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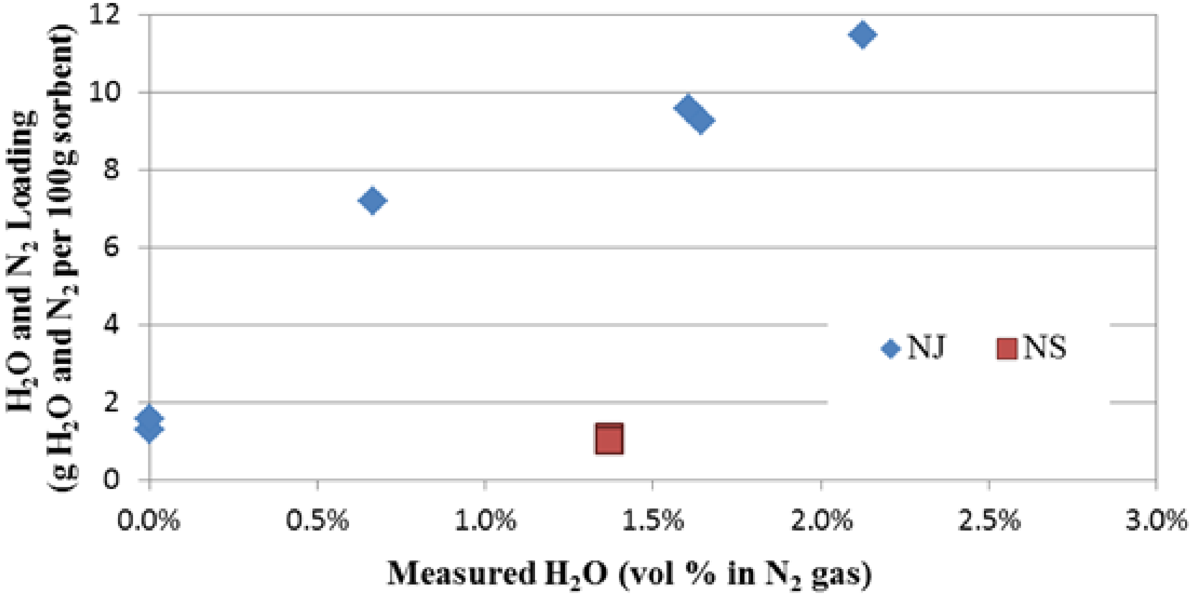
Moisture Uptake for CQA12 - ADA



NJ = **CQA12**

NS = **“HT” CQA12**

- NJ (CQA12) has a high affinity for water (~ 7.2 wt. %).
- 1 wt. % moisture uptake is ideal (for the ADAsorb™ process).
- “Hydrophobic treatment” (“HT”) of sorbent NJ (CQA12) is required to decrease the water uptake to (or below) 1 wt.% (NS).

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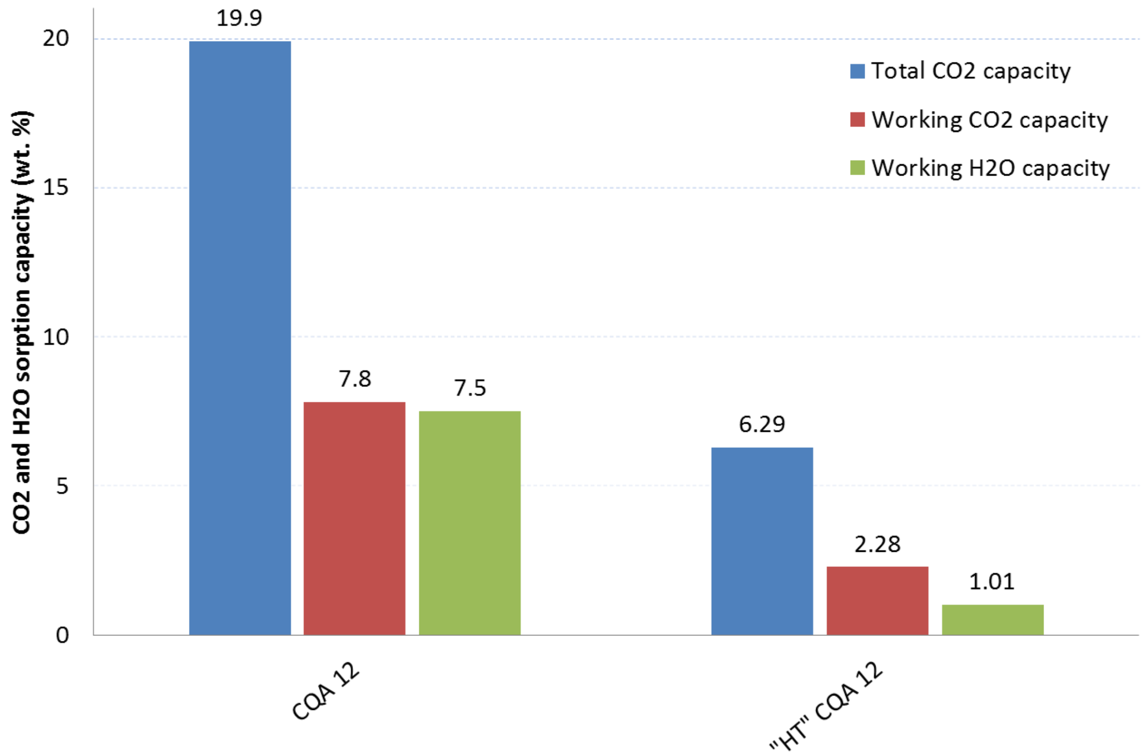
CQA12 and “HT” CQA12 Performance Comparison - ADA



- Hydrophobic treatment (“HT” CQA12) greatly reduces the water adsorption for CQA12; unfortunately, it negatively impacts its CO_2 capture performance.

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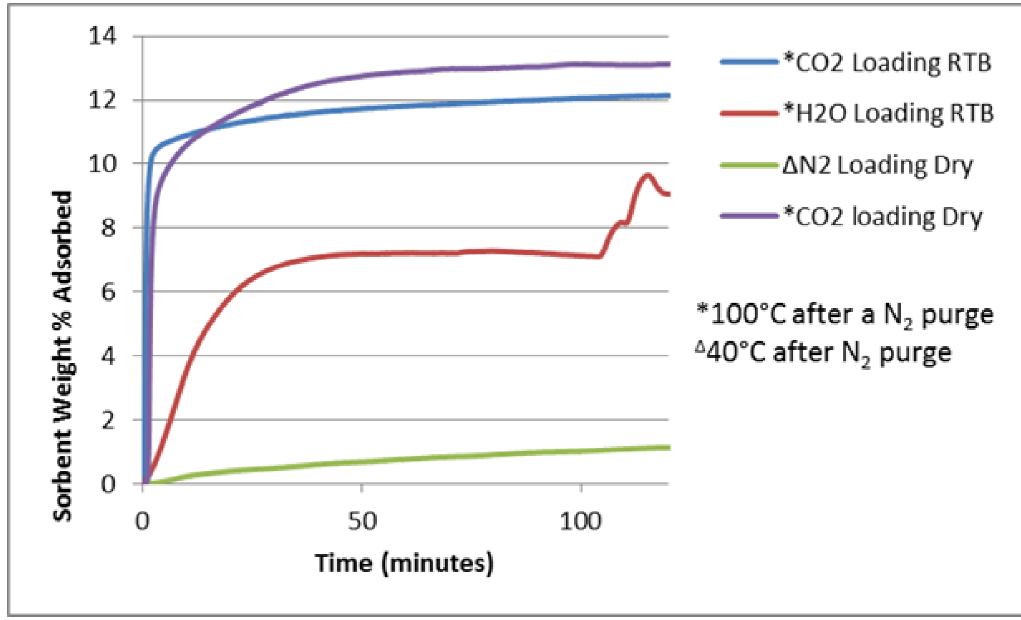
CO_2 and H_2O Adsorption Rate Comparison

- Water adsorption rate and the preferential adsorption of CO_2 vs. H_2O are very important.

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 acceptable CO_2 loading performance.

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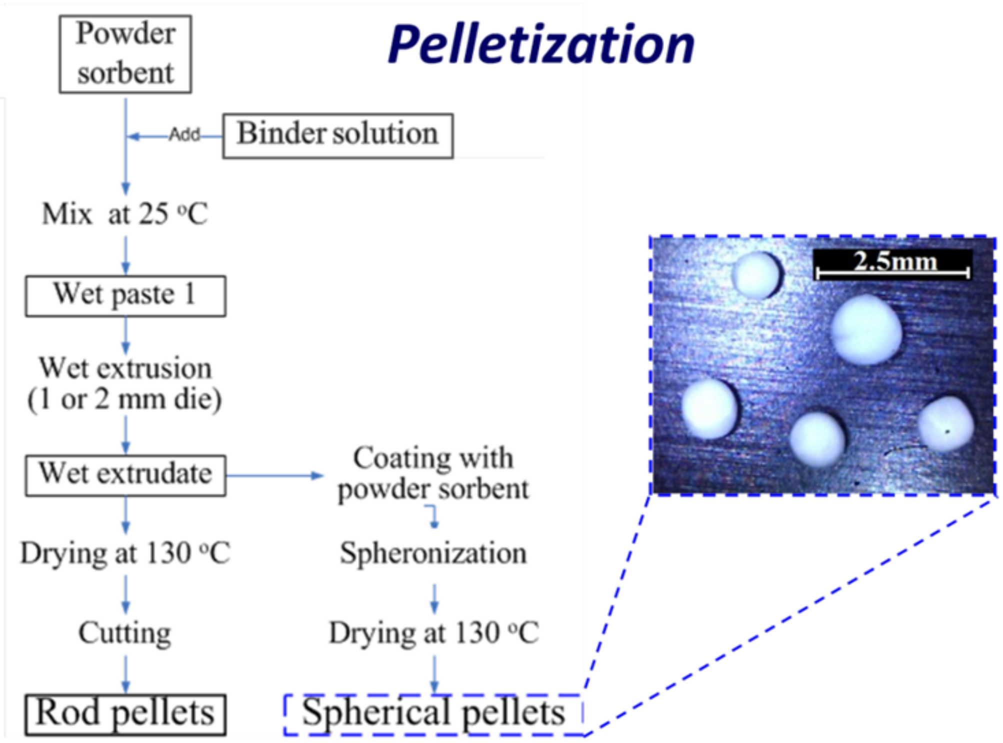
Pelletization Process Optimization - UA

- CQA12 sorbent (powder) was pelletized by mixing the sorbent with the UA Standard binder solution, and newly developed binder solutions E5, E10 and E10K.

- The ratio of binder/sorbent was adjusted to incorporate 2.5%, 5%, or 10% of solid binder in the final pellet.

- The density of the pellets was estimated ~ 1.3 g/cc.



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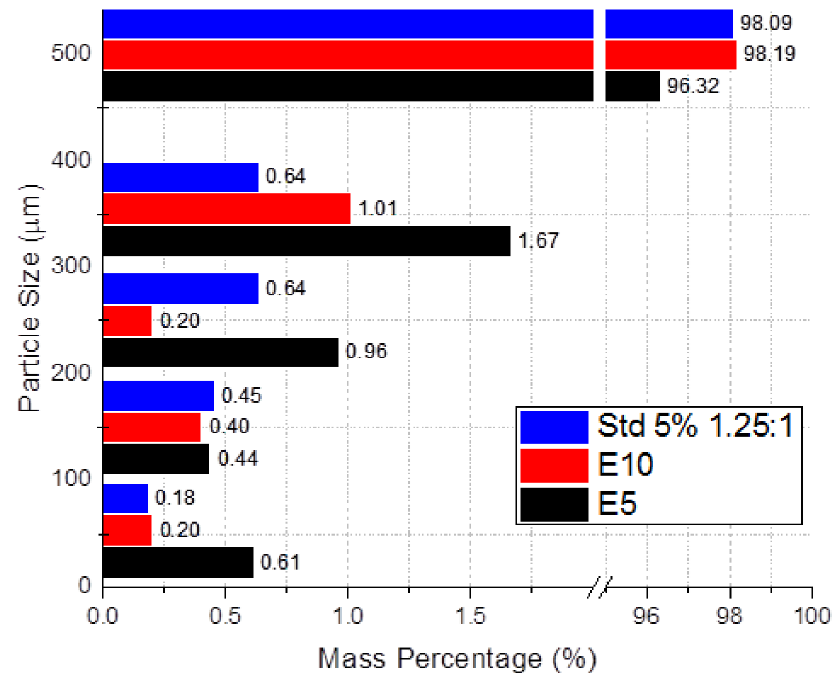
CO_2 Capture Capacity of Aerogel Pellets - UA

Sample	Sorbent/Binder Ratio (wt.)	Binder Solution	CO_2 Capture Capacity (mmol/g)	Std. dev.	Retained CO_2 Capture Capacity
CQA12	/	/	3.29	0.17	100.00%
CQA12p	1:1	5%	2.98	0.17	90.58%
CQA12p	1:1.25	5%	2.87	0.22	87.23%
CQA12p	1:1.5	5%	2.80	0.09	85.11%
CQA12p	1:1.75	5%	2.65	0.07	80.55%
CQA12p	1:2	5%	2.44	0.11	74.16%
CQA12p	1:1	10%	2.83	0.30	86.02%
CQA12p	1:1.25	10%	2.68	0.23	81.46%
CQA12p	1:1.5	10%	2.66	0.10	80.85%
CQA12p	1:1.75	10%	2.59	0.07	78.72%
CQA12p	1:2	10%	2.00	0.22	60.79%

- 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

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 sizes of the tested pellets ~ 500 µm.
- % mass attrited measured after 3 hours of attrition testing.
- UA's binder recipe E10 and standard binder (Std 5% 1.25:1) solution both resulted in pellets with **<2% attrition**.



- Modified E series binding solution recipe will be applied as an SO_2 resistance coating, too.
- The attrition test results should also be taken into account while tweaking the recipe by balancing the SO_2 resistance and the pellets' strength.

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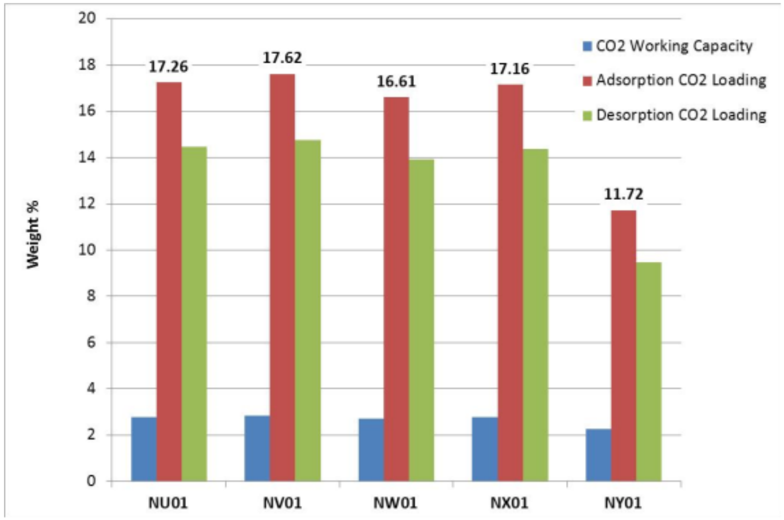
Pellet CO_2 Capture Performance Testing - ADA

Top five CQA12 pellets were sent to ADA for CO_2 capture performance evaluation.

Pellet No.	UA (#ID)	ADA (#ID)	Size (micron)	CO_2 Capture Capacity (mmol/g)*
1	Std 5% 1:1	NU	Not attrited	2.98
2	Std 5% 1.25:1	NV	Not attrited	2.87
3	Std 2.5% 1:1	NW	250 - 355	N/A
4	Std 10% 1.25:1	NX	250 - 355	2.68
5	E10	NY	250 - 355	1.49



- Pellets have a high total CO_2 capacity (~17 wt.%), exceeding the target (9 wt.%)
- None of the pellets have a CO_2 working capacity >3 wt. %.
- All pellets had 'fast' kinetics and were in the 10 – 14 minute range for time to 80% capacity at adsorption conditions.

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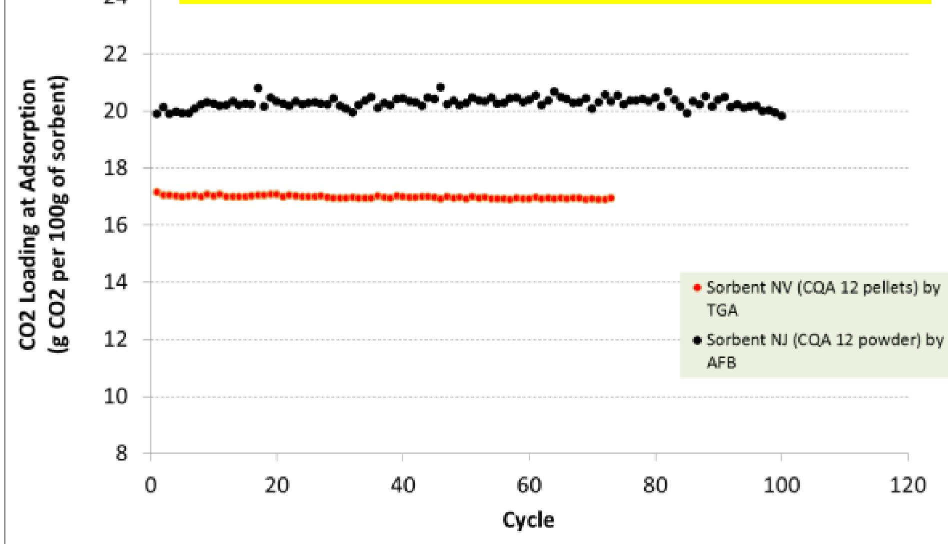
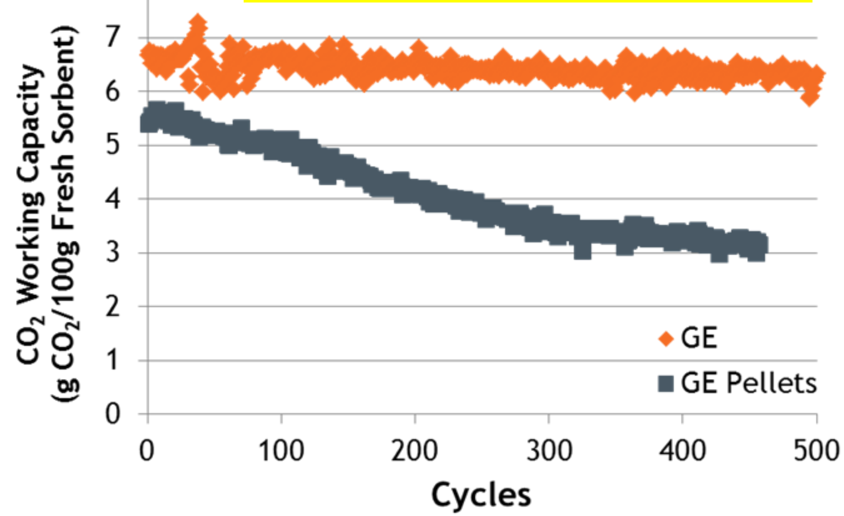
Cyclic Stability of CQA12 Pellets - ADA

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

CQA12 sorbent and pellets



GE sorbent and 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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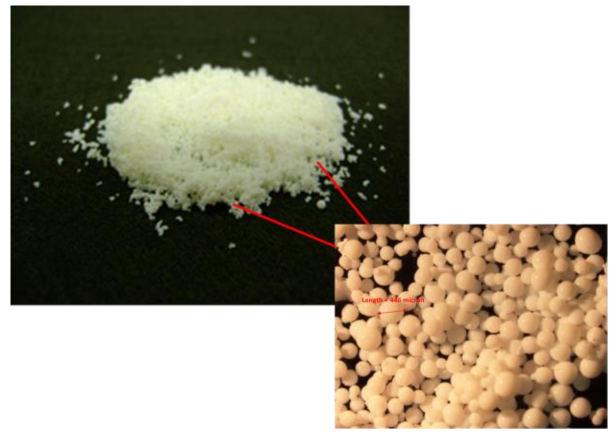
Aerogel Sorbent Beads - Study Initiation

- The objective of making sorbent beads is to skip the pelletization process; thus reducing the cost of production if the sorbent beads perform better (or "as good as") the pellets.

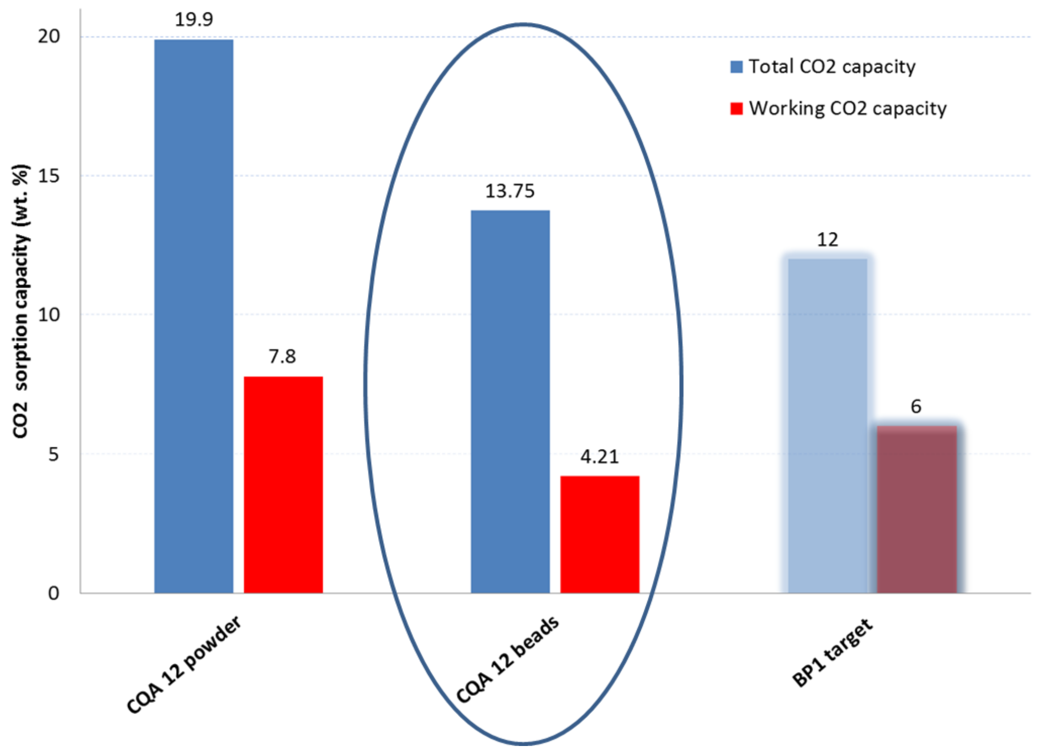


- The optimum aerogel formulation (CQA12) was used to make small quantities of beads with different sizes (<500 microns – 3 mm), using Aspen's patented bead fabrication process.

- The conditions of preparation will be optimized and well controlled during BP2.

CO_2 Adsorption Capacity of Aerogel Sorbent Beads

The first aerogel sorbent beads produced exhibit very promising CO_2 adsorption capacity, as measured at ADA.



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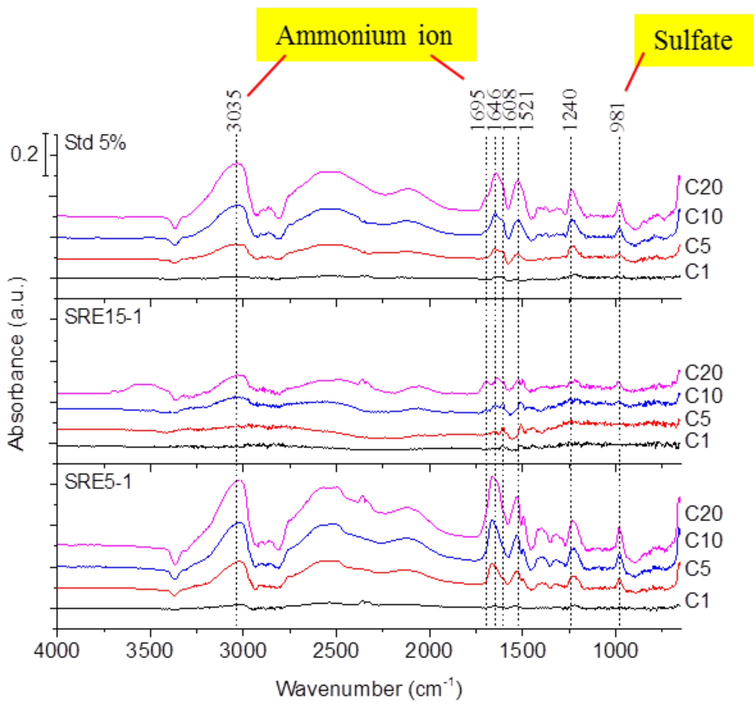
SO_2 Resistant Coating – Preliminary Study

- CO_2 adsorption/desorption processes for CQA12 coated with UA standard binding solution (Std 5%, as reference) and SRE5-1 coating, and SRE15-1 coating were monitored by in-situ FTIR, in the presence of **40 ppm of SO_2** in the gas flow.

- The significant peaks at 3035 cm^{-1}, 1695 cm^{-1}, 1646 cm^{-1} (ammonium ion), and 981 cm^{-1} (sulfate) indicate the accumulation of SO_2 on the sorbents.

SRE15-1 coating showed the highest SO_2 resistance among the tested samples.



IR spectra after TPD process in selected cycles

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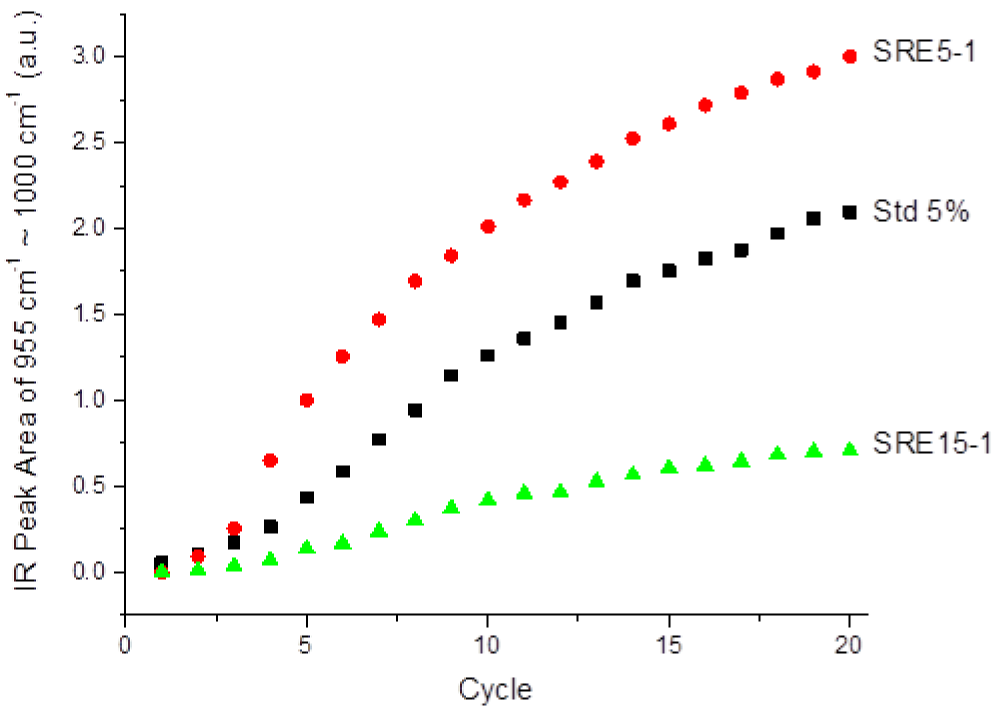
SO_2 Resistant Coating - Preliminary Study

- 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 to elevate the ability of SO_2 resistance will be performed during BP2.
- Studies on how these coatings retain the original CO_2 capture capacity and affect the long-term performance will also be conducted.



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

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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 (> 19.9 wt.%)*
  - ✓ *High CO_2 working capacity (> 7.8 wt.%)*
  - ✓ Stable for up to 250 adsorption/desorption cycles
- CQA12 sorbent showed a moisture uptake higher than the original target (1 wt.%).
  - ✓ The CO_2 adsorption rate is far greater than the rate of moisture uptake.
  - ✓ Sorbent cycling time can be reduced to control moisture loading.
    - ***Several process advantages*** (smaller quantities of sorbent, reduced size of the reactors, reduced capital costs, *etc.*).
- Optimized pellet fabrication – up to 90% CO_2 capture retention and low attrition index (< 2%).
- Aspen's team initiated two important studies that will continue during BP2:
  - ✓ SO_2 resistant coating development
  - ✓ Amine Functionalized Aerogel bead development

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BP1 Risk Mitigation

Description of Risk	Probability (L,M,H)	Impact (L,M,H)	Risk Management (Mitigation and Response Strategies)
Technical Risks:			
Sorbent exhibited low working capacity	Moderate	Moderate	- Increased amount of amine precursors. - Functionalized polyimine to improve grafting mechanism on the silica matrix and decrease the amount of amine leached out during the fabrication process
Sorbents exhibited low stability (durability)	Moderate	Moderate	- Lower temp. of regeneration to 100 °C (thus lower energy of Regeneration) - Functionalized the polyimine and improve grafting process (better thermal oxidation resistance)
Sorbents exhibited high water uptake	Moderate	High	- Hydrophobic treatment of the AFA sorbents solves the problem but affects the CO_2 performance. - Moisture adsorption rate is slower than the CO_2 adsorption rate. - Lowering the cycle time for adsorption will reduce the water uptake.

Project Status

BP 1

- Sorbent formula optimization completed
- Pellet development and optimization completed
- Detailed characterization of sorbent

BP 2

- Aerogel bead sorbent fabrication process development
- SO_x coating resistant development
- Coated sorbents (pellet/bead) evaluation

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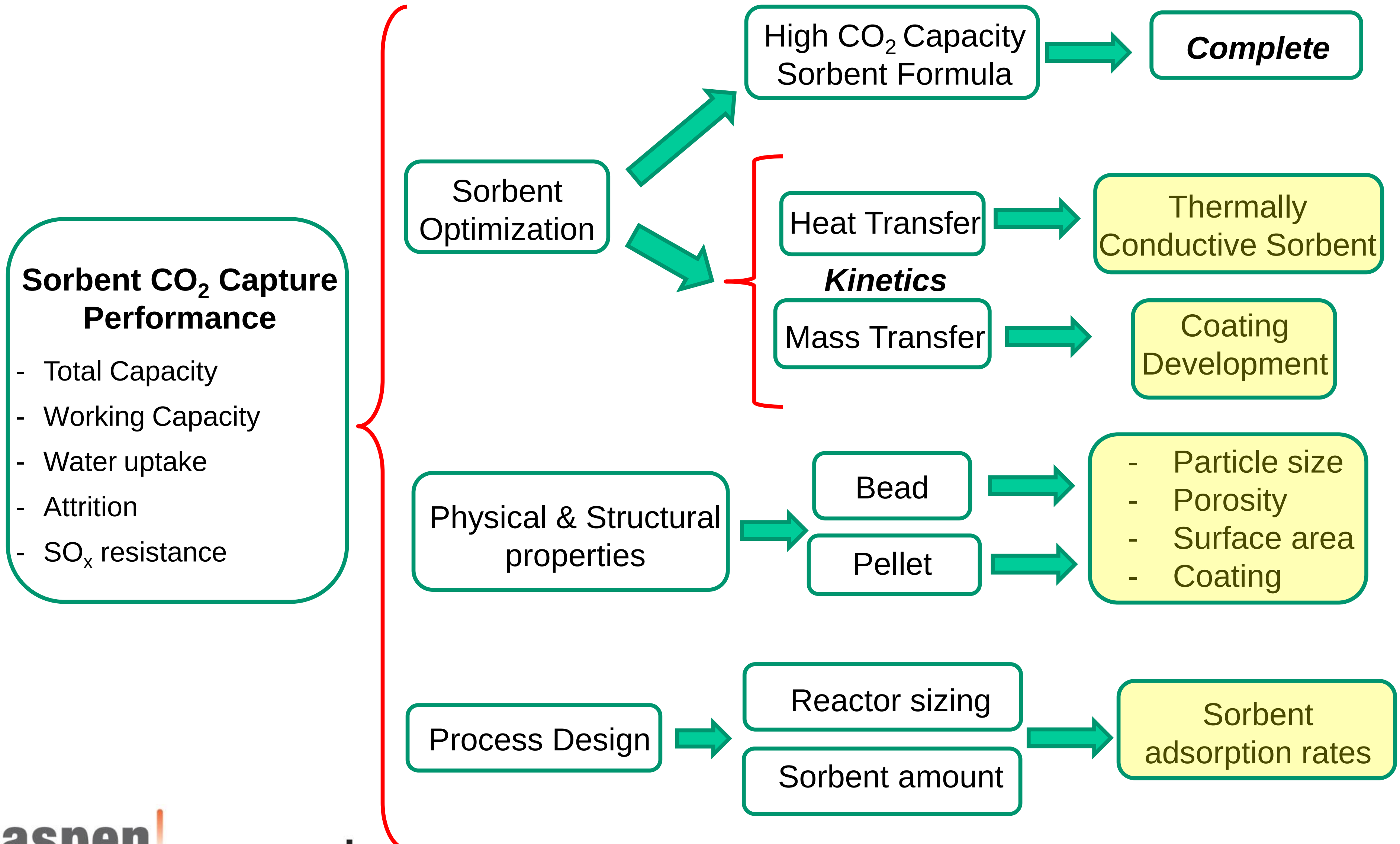
Budget Period 2

CO_2 Capture Performance Influences



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Task 1. Direct Aerogel Bead Fabrication

CQA12 formula will be used to fabricate aerogel sorbent beads with optimum performance.

Properties to consider:

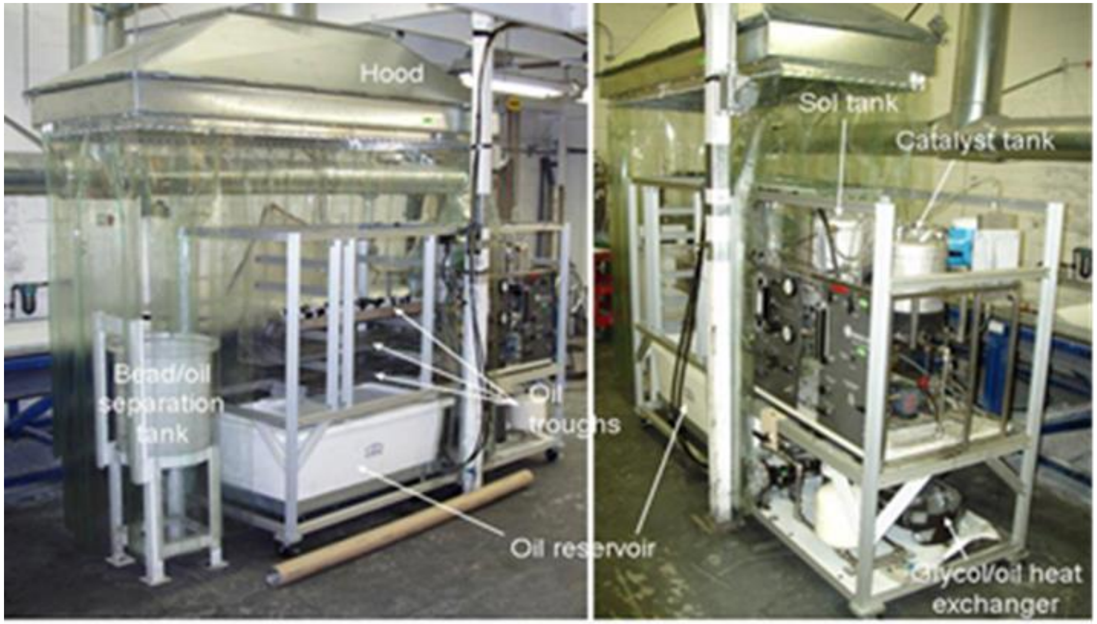
- Increase thermal conductivity of the sorbent to improve the heat transfer

  → Faster adsorption/desorption kinetics at lower temperatures

- Optimize aerogel/additives ratio and particle size for optimum sorbent bead (and powder) CO_2 capture performance

Task 1. Direct Aerogel Sorbent Bead Fabrication

1. Process control optimization for making sorbent beads.
2. Side-by-side comparison with the corresponding sorbent pellets.
3. Scale-up trials for making aerogel sorbent beads with optimum performance.



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Task 2. Sorbent Coating Development

- Perform CO_2 capture performance test screening on aerogel sorbents fabricated during Task 1.
- Develop an efficient low-cost coating technology that is compatible with the aerogel sorbent.
- Evaluate mass transfer (***CO_2 in & out***) and kinetics, based on:
  - Coating formula
  - Coating/aerogel ratio
  - Coating poisoning resistance
- Evaluate sorbent resistance in the presence of NO_x and SO_x.
  - Using simulated flue gas.
  - Determine CO_2, NO, NO_2 and SO_2 breakthrough curves during adsorption.
  - Calculate adsorption kinetics, and adsorption equilibrium loading.
- Sorbent structural properties and elemental composition will be determined.

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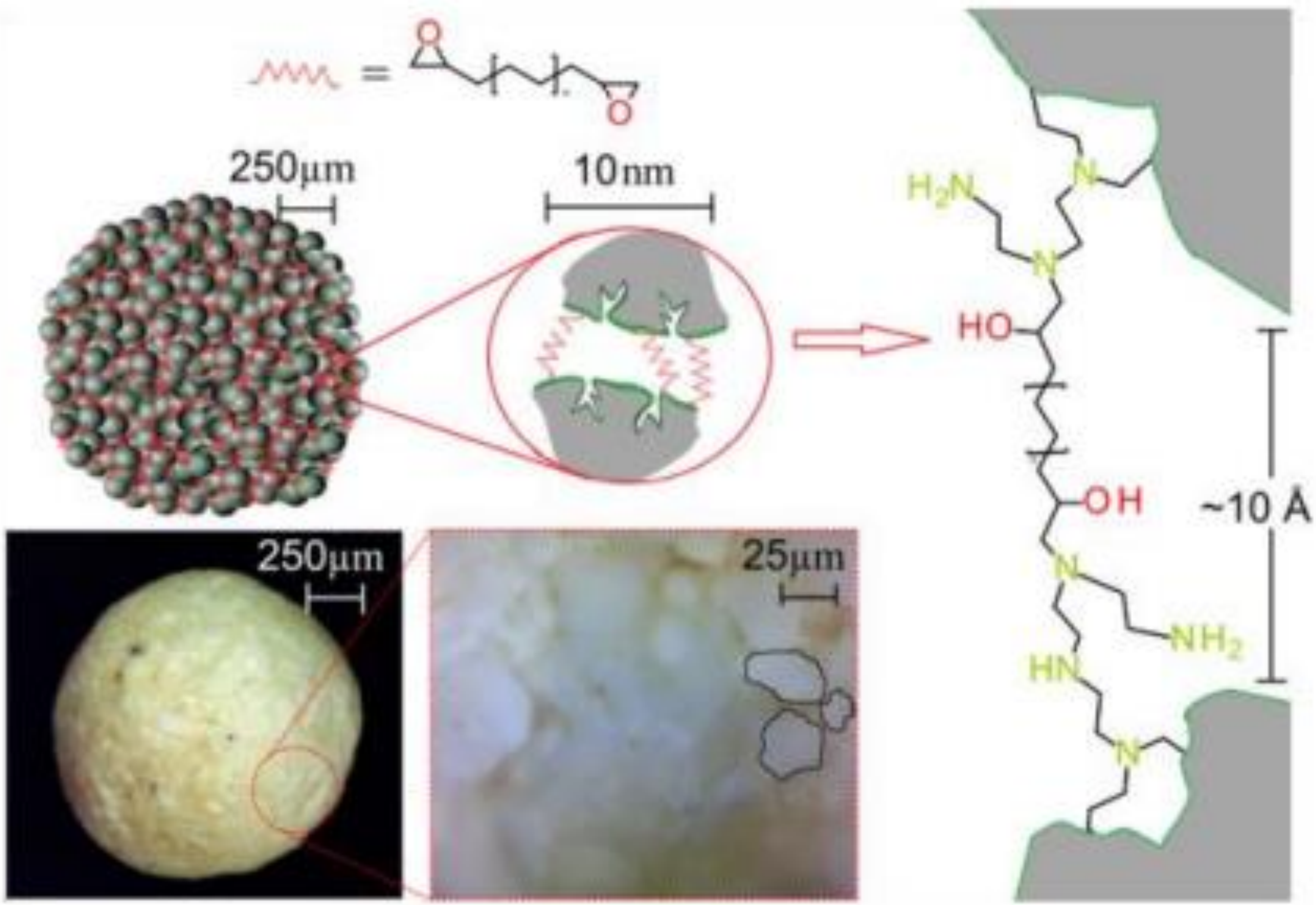
Task 2. Sorbent Coating Development



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Task 3. Aerogel Sorbent Bead/Pellet Evaluation

Aerogel bead (and pellet) sorbents will undergo a series of tests:

- Structural property characterization (surface area, porosity).
- Crush strength and attrition resistance.
- Assess the H_2O loading of the sorbent at select temperatures and H_2O partial pressures using a TGA.
- Develop the CO_2 loading isotherms over a range of temperatures and pressures.
- Assess the selectivity of the sorbent for CO_2 and any negative impacts from common flue gas constituents using a fixed-bed coupled with a mass spectrometer.
- Assess the longer-term stability of the sorbent when exposed to typical flue gas constituents using an automated fixed bed.

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ADA

Task 3. Aerogel Sorbent Bead/Pellet Evaluation

- Side by side performance comparison between sorbent beads and sorbent pellets.

- Initiate process design study based on:
  - Sorbent CO_2 uptake performance
  - Sorbent stability
  - Sorbent CO_2/H_2O uptake rate (cycling time)
  - Sorbent size and form (bead or pellet)
  - Sorbent cost

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ADA

BP 2 Risks

Description of Risk	Probability (L,M,H)	Impact (L,M,H)	Risk Management (Mitigation and Response Strategies)
Technical Risks:			
Aerogel sorbent beads develop uneven particle size	Moderate	Moderate	- Sol injection nozzle, sol circulation rate and the geltime of the sol will be properly optimized for fixed particle bead size production.
The scale up production of aerogel sorbent (powder and bead) could be challenging.	Moderate	High	- Aspen is equipped with two large high pressure vessels. Therefore, the risk of scale up will be mitigated by using the two vessels (both, if necessary) to meet the amount of sorbent needed for large scale testing. - The bead machine will be mounted during the BP2.
Sorbent bead exhibited high water uptake	Moderate	Moderate	- Hydrophobic treatment will be apply on the beads. - Evaluate the moisture and CO_2 adsorption rates. Lower the cycle time for adsorption if moisture uptake rate is low versus CO_2 rate.
Beads and pellets coated with SOx resistant coating exhibit low CO_2 capacity	High	Moderate	- Optimize coating thickness/CO_2 performance. - Increase the porosity of the coating to ease the flue gas diffusion through the coating layers.

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BP2 Risks

Description of Risk	Probability (L,M,H)	Impact (L,M,H)	Risk Management (Mitigation and Response Strategies)
Resource Risks:			
Testing equipment unavailable (ADA, UA)	Moderate	High	- Provide ADA and UA a schedule. - Reschedule evaluation of aerogel sorbents
Management Risks:			
Subcontractor Delivery	Low	High	- Monthly team meeting. - Constantly in contact by phone or email
Cost	Low	High	Weekly monitoring
Schedule	Low	Moderate	Weekly monitor program progression
Safety	Low	High	Weekly monitor program progression

Risks – University of Akron

Description of Risk	Probability (L, M, H)	Impact (L, M, H)	Risk Management Mitigation and Response Strategies
Technical Risks:			
- Ability to optimize the sorbent composition/structure - Scale up the sorbent manufacture process.	Low	Moderate	Risk in sorbent optimization will be mitigated by carrying out high throughput sorbent preparation and testing. The key step in SO_2-resistant sorbent manufacture is coating the sulfur-resistant layer which requires control the concentration of the coating solution and mixing. The risks in reproducing and scaling up will be mitigated by measuring the viscosity of coating solution and infrared study of amine structure on the sorbents.
Resource Risks:			
Lab scale testing	Low	Moderate	Processing engineering and lab. scale testing risks will be mitigated by reproducibility studies.
Equipment failure	Low	Moderate	The risk of the equipment failure for the proposed R&D is mitigated by duplication of the key spare parts and the backup equipment. The core equipment for measurement of the adsorbed SO_2 and investigation of its adsorption mechanism is infrared spectrometer. Professor Chuang's laboratory has four infrared spectrometers which will allow uninterrupted study. The major operational issues of 3.25 kg-fluidized bed unit are leaking and heater failure. These risks will be mitigated by the proper inventory of spare parts.
Human resources	Low	Moderate	The operational risk associated with human resources will be mitigated by training of the back-up graduate students who were supported by the FirstEnergy fund.

Risks – ADA

Description of Risk	Probability (Low, Moderate, High)	Impact (Low, Moderate, High)	Risk Management Mitigation and Response Strategies
Technical Risks:			
Inability to obtain desired measurements from lab-scale testing	Low	Moderate	Testing will be conducted on proven equipment with established techniques. Discussion and initial planning has been conducted to accommodate required testing conditions. Moisture uptake and long term cyclic stability have been identified as two critical parameters for the CO2 capture process. In order to facilitate better investigation of these parameters, ADA is also examining optimization and improvement of previous methods to enhance the efficiency of cyclic stability testing and moisture uptake monitoring.
Inability to determine appropriate process engineering information such as heat capacity, heat of reaction, etc.	Moderate	Moderate	Process engineering information such as heat capacity of materials and heat of reaction between the sorbent and adsorbed species such as CO_2 and H_2O are critical for process design and economics. Measuring these parameters as well as determining how the characteristics of sorbents change under the pelletization process is difficult to perform at laboratory scale. Since these properties are important for the techno-economic analysis, ADA has identified and is working with several laboratories to perform the necessary baseline sorbent property investigations.
Resource Risks:			
Lab scale testing exceeds planned duration	Low	Moderate	ADA will be using existing test equipment in evaluating various sorbents on multiple programs. ADA will coordinate efforts to manage schedule.
Management Risks:			
Subcontractors do not adhere to project schedule	Low	Moderate	ADA will conduct internal project review meetings to review various project constraints: cost, scope, and schedule. ADA will keep Aspen Aerogels informed of any impact to schedule.

Budget

	BP1							
	Q1		**Q2**		**Q3**		**Q4**	
	10/1/13 - 12/31/13		**1/1/14 - 3/31/14**		**4/1/14 -6/30/14**		**7/1/14 - 9/30/14**	
Baseline Cost Plan	Q1	Cumulative	Q2	Cumulative	Q3	Cumulative	Q4	Cumulative
Federal Share	$263,524	$263,524	$263,524	$527,048	$263,524	$790,572	$263,524	$1,054,096
Non-Federal Share	$62,859	$62,859	$62,859	$125,718	$62,859	$188,577	$62,859	$251,436
Total Planned Cost	$326,383	$326,383	$326,383	$652,766	$326,383	$979,149	$326,383	$1,305,532
Actual Incurred Cost								
Federal Share	$203,547	$203,547	$194,152	$397,699	$169,964	$567,663		
Non-Federal Share	$7,833	$7,833	$41,743	$49,576	$36,541	$86,117		
Total Incurred Cost	$211,380	$211,380	$235,895	$447,275	$206,505	$653,780		
Variance								
Federal Share	$59,977	$59,977	$69,372	$129,349	$93,560	$222,909		
Non-Federal Share	$55,026	$55,026	$21,116	$76,142	$26,318	$102,460		
Total Variance	$115,003	$115,003	$90,488	$205,491	$119,878	$325,369		

Baseline Reporting Quarter	**Budget Period 2 (10/1/14-9/30/15)**							
	Q1		Q2		Q3		Q4	
	Q1	Project Total	Q2	Project Total	Q3	Project Total	Q4	Project Total
Baseline Cost Plan								
Federal Share	$237,505	$1,291,600	$237,505	$1,529,105	$237,505	$1,766,610	$237,505	$ 2,004,115
Non-Federal Share	$ 41,747	$ 293,181	$ 41,747	$ 334,928	$ 41,747	$ 376,675	$ 41,747	$ 418,422
Total Planned	$279,252	$1,584,781	$279,252	$1,864,033	$279,252	$2,143,285	$279,252	$ 2,422,537

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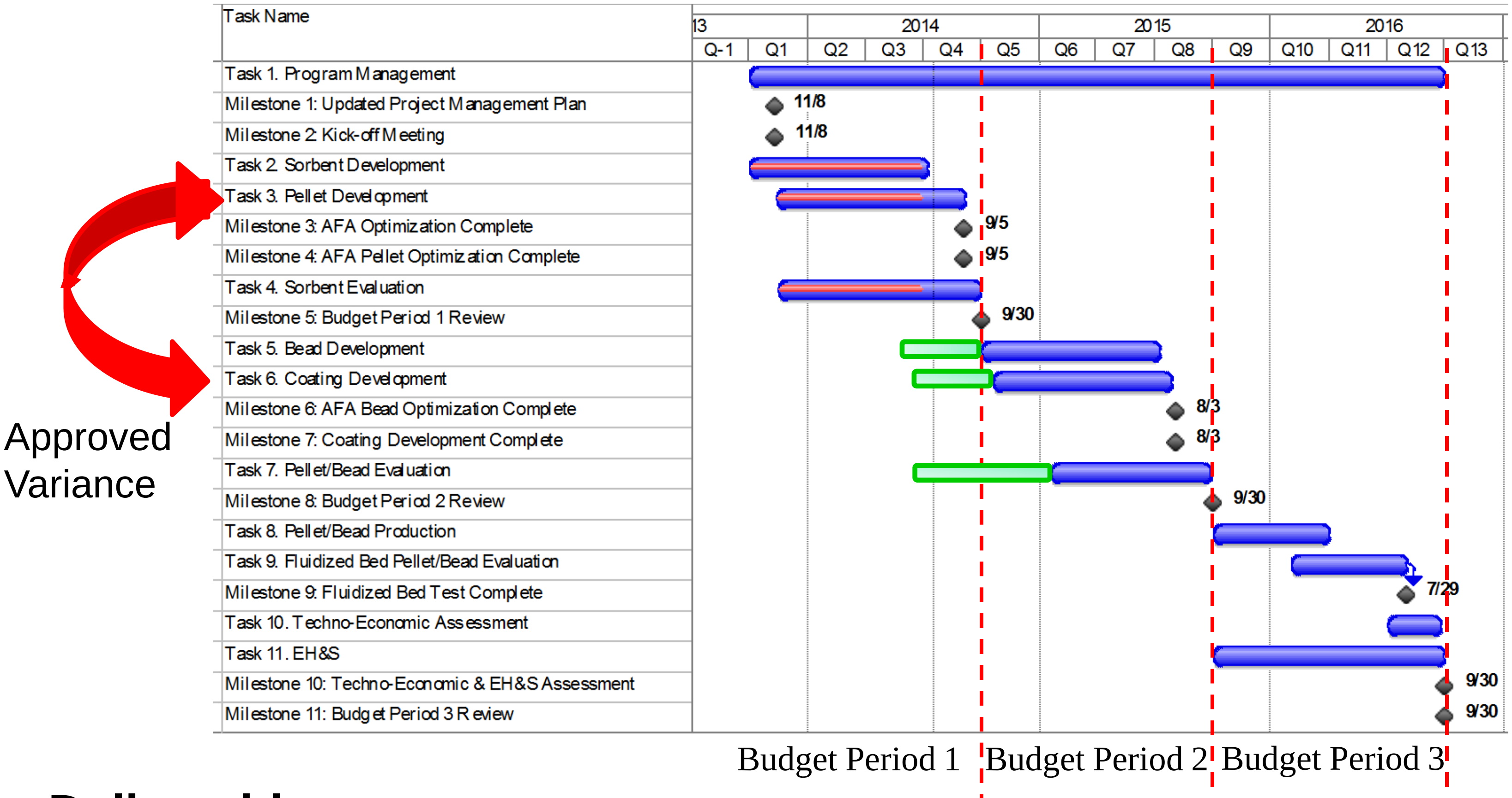
Schedule/Milestones/Variances



Deliverables:

- Quarterly Reports (next due 7/30/14)
- BP1 Topical Report (due 12/30/14)

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Thank You
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