Harvested Fly Ash

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Background

- We expect one key property from concrete: Longevity
- Service demands have increased
  - Use of aggressive deicing chemicals
- We have increased our expectations for reduced environmental impact and lower initial and lifecycle costs
- SCMs assist us in meeting these goals
- **Coal Fly Ash is our go-to SCM**

Effects of SCMs on Properly Cured Hardened Concrete

Reduced *No/Little Effect* *Increase* *Varies*

	Fly ash	Slag	Silica fume	Natural Pozzolan
Strength Gain	↕	↕	↑	↕
Abrasion Resistance	→	→	→	→
Freeze-Thaw and Deicer-Scaling Resistance	↑	↑	↑	↑
Drying Shrinkage and Creep	→	→	→	→
Permeability	↓	↓	↓	↓
Alkali-Silica Reactivity	↓	↓	↓	↓
Chemical Resistance	↑	↑	↑	↑
Carbonation	→	→	→	→
Concrete Color	↕	↕	↕	↕

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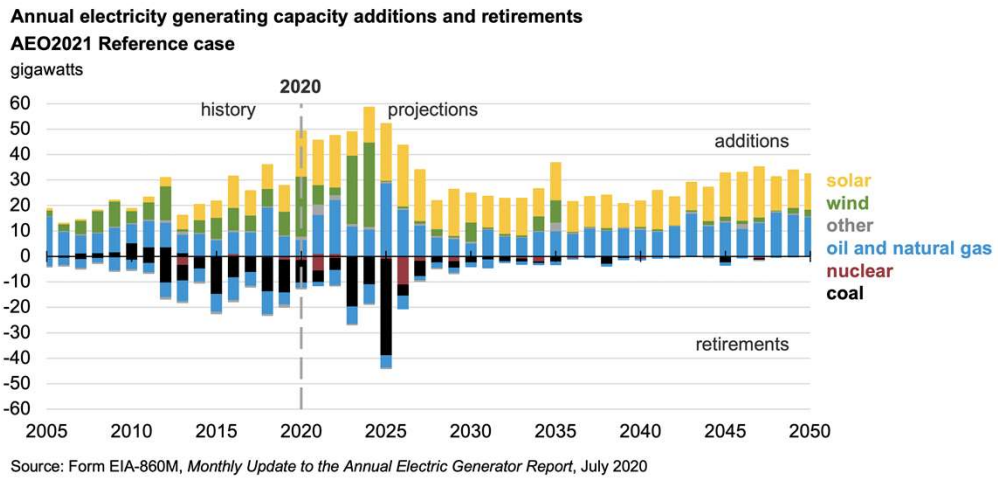
So what's the problem?

The Problem

- Fly ash supplies are challenged by coal-fired power plant closures and conversions to natural gas
- Fly ash spot shortages have been reported in many U.S. markets
- Concerns center on the fact that no other material is available with the reserves that fly ash historically has provided

Coal-fired Power Plants are Being Retired



Source: Form EIA-860M, *Monthly Update to the Annual Electric Generator Report*, July 2020

Navajo Generating Station

- 2250 megawatt net coal-fired powerplant
- Largest coal fired electrical generating station west of the Mississippi
- Produces approximately 500,000 tons a year of Class F fly ash
- Closed 2020

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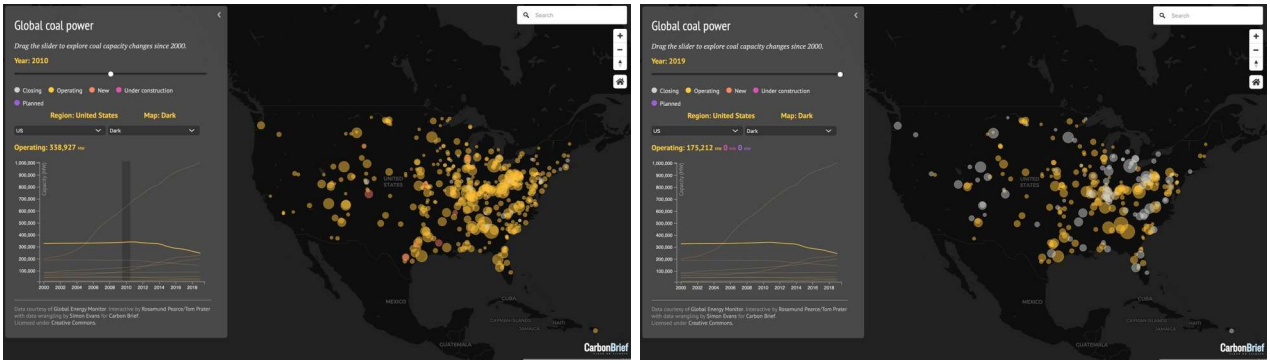

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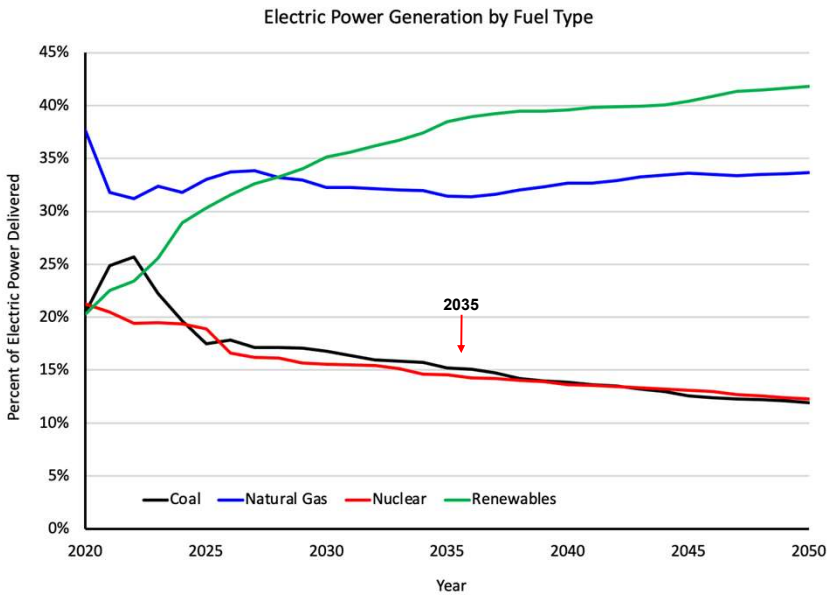

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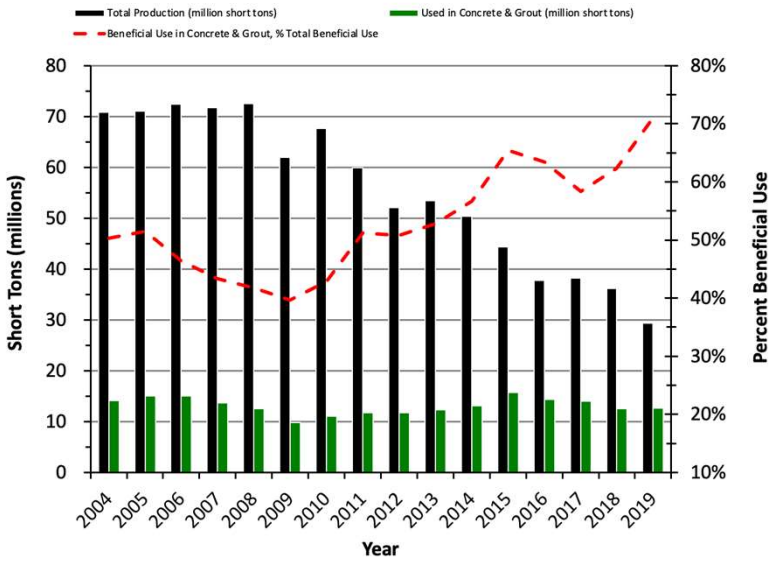
Source: U.S. Energy Information Administration, 2021

Ash Production is Dropping



So What's Up With Fly Ash?

- Domestic fly ash production (new production) will continue decreasing over the next 20 years and beyond
  - Domestic use of coal for electrical power generation is predicted to continue decreasing
  - Fewer plants, running at a higher percentage of capacity
  - Suppliers believe that although total reserves will decrease, the volume of quality ash as a percentage of total production will increase due to dry handling – no more ponding
- Harvested ash from landfills/ponds will become a significant fraction of the total reserves

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lower ~40% capacity factor

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Harvested Ash

- With diminishing production, ash marketers are turning to land fills & ash ponds to recover fly ash
  - Most harvested sources are Class F ash
  - Limited research to date on performance of harvested ash
- All harvested sources will require processing
  - Drying
  - Sizing
  - Blending
- Could lead to more uniformity - or less - depending upon source and degree of processing

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Coal Fly Ash

- Benefits
  - Improved workability
  - Decreased heat of hydration
  - Reduced cost
  - Potential increased sulfate resistance and alkali-silica reaction (ASR) mitigation
  - Increased late strength, and decreased shrinkage and permeability
- Concerns
  - Air-entraining admixture adsorption by residual carbon in the fly ash
  - Slow initial strength gain (Class F)
  - Fly ash variability
  - **How reactive is it?**

Harvested Coal Fly Ash

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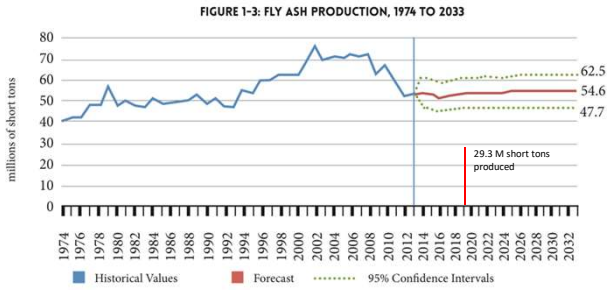
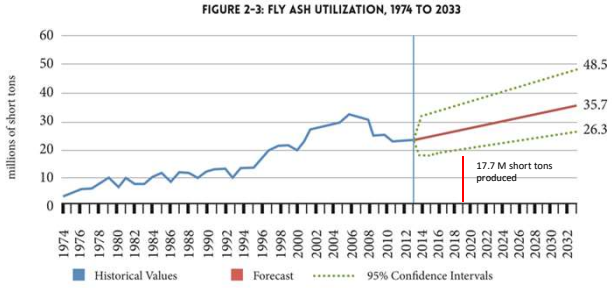
  - ✓ **How reactive is it?**

Harvested Ash

- Significant volumes of high-quality fly ash have been disposed
  - Approximately 2000 million short tons produced 1974 - 2013
  - Approximately 650 million short tons used 1974 – 2013
  - ~33% utilization – 1350 million short tons disposed
- Not all is recoverable, but a large fraction is

Production and Use of Coal Combustion Products in the U.S. ARTBA 2015





Harvested Ash – Production & Beneficiation

- Harvesting operations vary depending on the source characteristics
  - Standards are being developed to guide harvesting operations
    - ASTM E3183 *Standard Guide for Harvesting Coal Combustion Products Stored in Active and Inactive Storage Areas for Beneficial Use*
  - Provides a framework for characterization of the site, planning and scoping of a harvesting project, the site design and approval process (as applicable), and the implementation of harvesting
  - Does not address processing the material to meet ASTM C618 or AASHTO M 295

Harvested Ash – Production & Beneficiation

- With very few exceptions, harvested ash will be processed for use in concrete
  - Drying
    - Needed to meet moisture limits
  - Screening or air classification, or both
    - Primarily to address comingled bottom ash
  - Grinding (last resort)
    - Bottom ash, cemented particles
  - Post-treatment
    - Carbon removal or mitigation

Harvested Ash – Production & Beneficiation

- More on carbon removal
  - Many ashes were landfilled originally due to excessive carbon content
  - Beneficiation Methods
    - Triboelectrostatic separation
    - Carbon Burnout
    - Passivation

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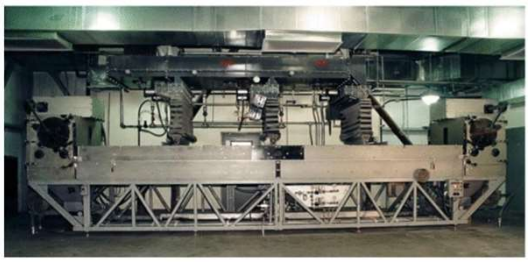
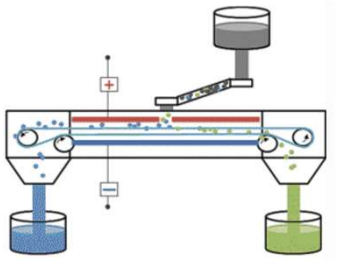
  - **Triboelectrostatic separation**





Mirkowska, M., Kratzer, M., Teichert, C. *et al*. Principal Factors of Contact Charging of Minerals for a Successful Triboelectrostatic Separation Process – a Review. *Berg Huettenmaenn Monatsh* **161,** 359–382 (2016). https://doi.org/10.1007/s00501-016-0515-1

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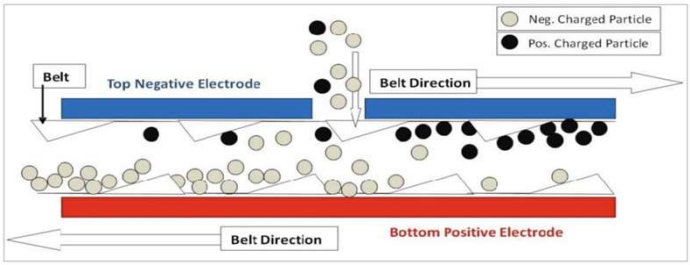

Source: http://www.indmin.com/events/download.ashx/document/speaker/8915/a0ID000000ZwxAGMAZ/Presentation

Harvested Ash – Production & Beneficiation

- More on carbon removal
  - Many ashes were landfilled originally due to excessive carbon content
  - **Carbon Burnout**
    - Reburn with coal feed
    - Fluidized bed combustion
    - STAR™ Staged Turbulent Air Flow (SEFA)

Harvested Ash – Production & Beneficiation

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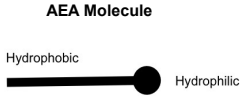
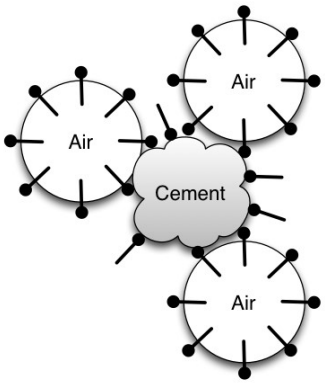
  - **Passivation**





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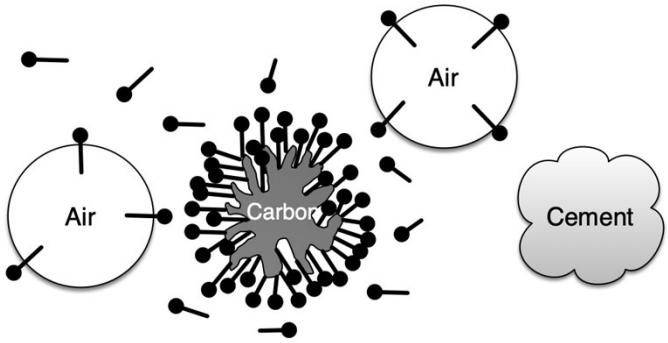

Harvested Ash – Production & Beneficiation

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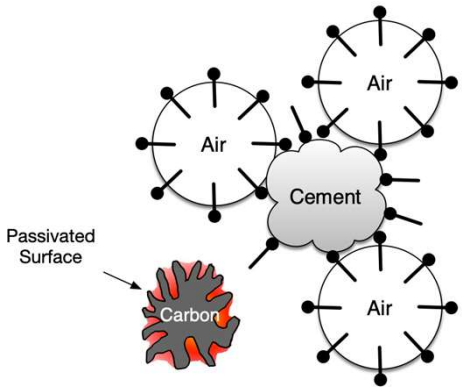
Passivation treatments render the surface of carbon non-adsorptive



Harvested Ash – Production & Beneficiation

- In the near term, harvested ash will be sourced from mono-fills where only fly ash was deposited
- Long term, fly ash co-mingled with other materials will be harvested, requiring more extensive processing
- Mixtures of fly ash and bottom ash will be produced
- Testing – primarily reactivity testing – will become more important to ensure uniformity

A Little More on Bottom Ash

- A common "concern" expressed – inclusion of bottom ash
- Bottom ash is chemically similar to fly ash from the same combustion process, and performs in a similar manner
- Grinding improves bottom ash performance and ground bottom ash has been shown to perform as well or in some cases better than fly ash from the same combustion process
- Coarse bottom ash can be separated by sieving; fine bottom ash cannot be separated from fly ash and will be a component of some harvested materials

Bottom Ash – Example Data

	Oxide Content (% wt.)			
	FA-A	GBA-A	FA-B	GBA-B
SiO_2	36.72	43.61	57.1	59.99
Al_2O_3	18.2	16.12	20.83	18.43
Fe_2O_3	5.69	9.57	4.75	6.45
SO_3	1.78	0.65	0.41	0.48
CaO	25.64	20.42	10.3	9.44
Na_2O	1.66	1.08	0.3	0.26
MgO	5.82	4.96	2.46	2.15
K_2O	0.43	0.39	1.03	0.91

Unpublished data: I. Diaz

Bottom Ash – Example Data

Phase (%)	FA-A	GBA-A	FA-B	GBA-B
Amorphous	83	53.9	72.7	64.0
Anorthite - ($CaAl_2Si_2O_8$)	-	34.3	-	18.6
Quartz - (SiO_2)	4.1	2.9	13.9	13.7
Diopside - ($CaMgSi_2O_6$)	-	8.1	-	-
Hematite - (Fe_2O_3)	1.2	0.9	0.4	0.3
Merwinite - [$Ca_3Mg(SiO_4)_2$]	8.6	-	-	-
Lime - (CaO)	0.7	-	0.02	-
Periclase - (MgO)	2.4	-	0.03	0.2
Magnesite - ($MgCO_3$)	0.3	-	-	-
Mullite - ($Al_6Si_2O_{13}$)	-	-	11.4	2.0

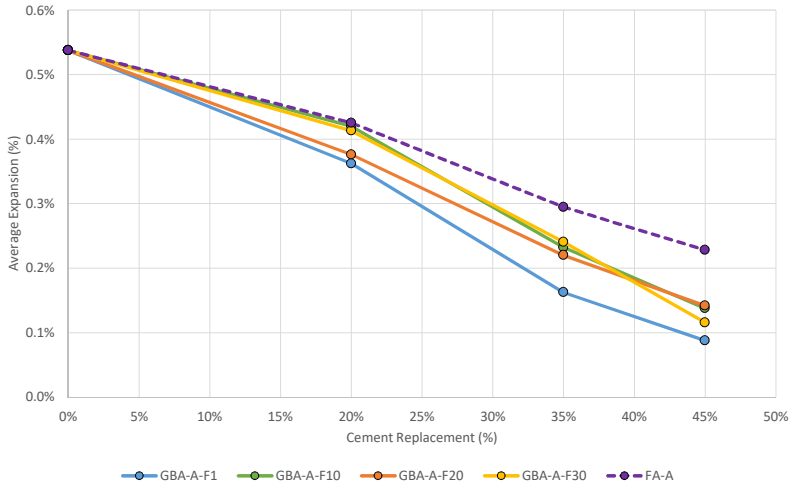
Unpublished data: I. Diaz

Bottom Ash – Example Data

	C618 Limits	Fly Ash A	Ground Bottom Ash A				Fly Ash B	Ground Bottom Ash B			
			F1	F10	F20	F30		F1	F10	F20	F30
Fineness	34 max	12.9	1.4	10.4	19.6	27.7	31.4	1.2	12.6	18.3	29.3
7-Day SAI, %	75 min	97	84	79	79	72	85	83	80	80	82
28-Day SAI, %	75 min	102	94	90	83	77	88	86	87	81	79
Water Req., %	105 max	94	97	97	97	100	100	102	100	100	100

Unpublished data: I. Diaz

Bottom Ash – ASTM C1567



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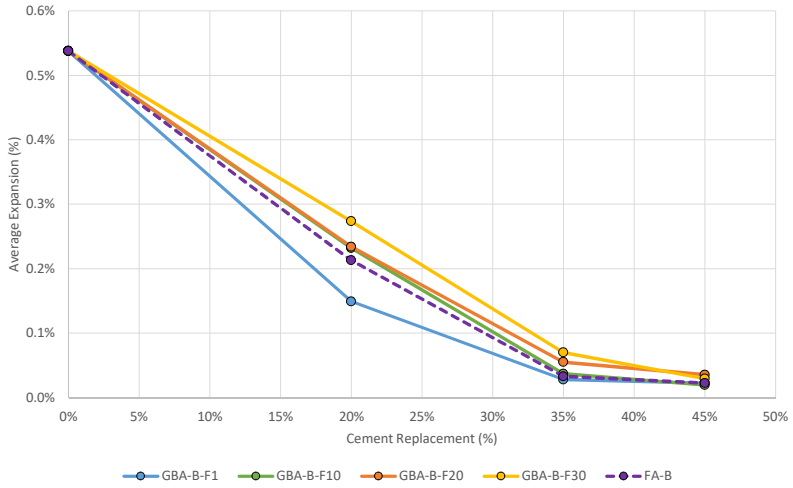

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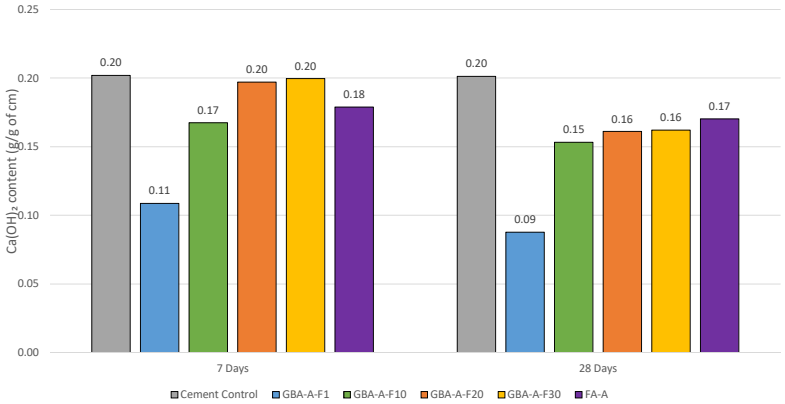

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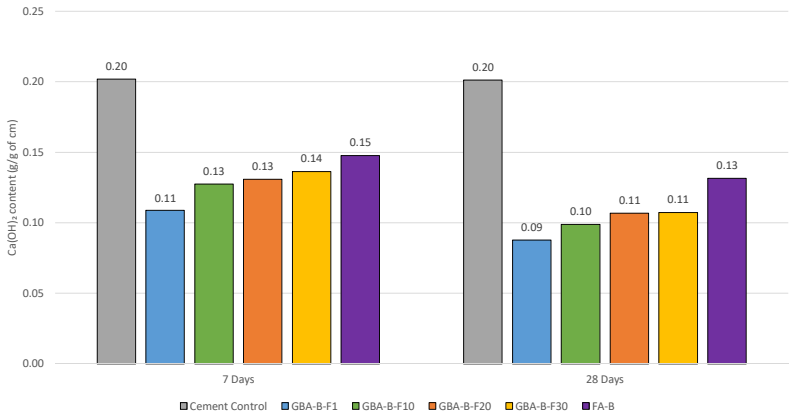

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Harvested Ash – Testing

- Testing **<u>for all coal combustion products</u>** needs to be improved – harvested ash is only instigating the change
  - Reactivity
    - R3 test, modified SAI
  - Particle Size Distribution
  - Adsorption Properties
    - Foam Index, Iodine Number, SorbSensor™
  - Uniformity
  - NCHRP 10-104 addressing many of these issues

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Harvested Ash

- Concerns
  - Current federal and state regulations require near-term closure of disposal ponds, leaving insufficient time to recover and use all available ash
  - Power producers have little to no incentive to use ash beneficially, closure (cap-in-place) is the lowest cost option.
- Benefits of landfilled ash
  - Well over a billion tons of ash in disposal
  - Proper processing *could* provide a more uniform product
  - Significant reserves could help limit cost increases although processing will add costs

A Word on "Off Spec" Ash

- So called "off-spec" ash is being considered for use
  - Note: Existing ash specifications do not address performance (i.e., meeting the specification does not guarantee performance)
- If performance of a material can be demonstrated – use it
- Common off-spec issues
  - LOI
  - Fineness
- Materials that are not coal fly ash are not off-spec; they are simply not fly ash – but they may work
- Verify reserves – Verify Uniformity

Summary

- Harvested ash is here to stay
- It will perform comparable to fly ash
- It will likely be more expensive due to processing costs
- It *could* be more uniform if processed properly
  - Specifications need to evolve to ensure this happens
- Bottom ash will be comingled with fly ash – it cannot be avoided
- It is necessary to test and ensure performance
- With luck, we will have ample reserves for the future

Questions?

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