FLY ASH AVAILABILITY FOR CONCRETE

NATIONAL CONCRETE CONSORTIUM

April 26, 2017
SLC, UT

HW HEADWATERS

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HEADWATERS RESOURCES INC

THE LEADING COAL COMBUSTION PRODUCTS MANAGEMENT COMPANY

Broad utility service capabilities at ~100 power plants in more than 35 states

Nationwide Infrastructure

- 50+ quality ash sources
- 30 fly ash terminals
- 250 trucks/1,000 railcars

Exclusive long-term supply agreements

SOUTHERN COMPANY

Luminant

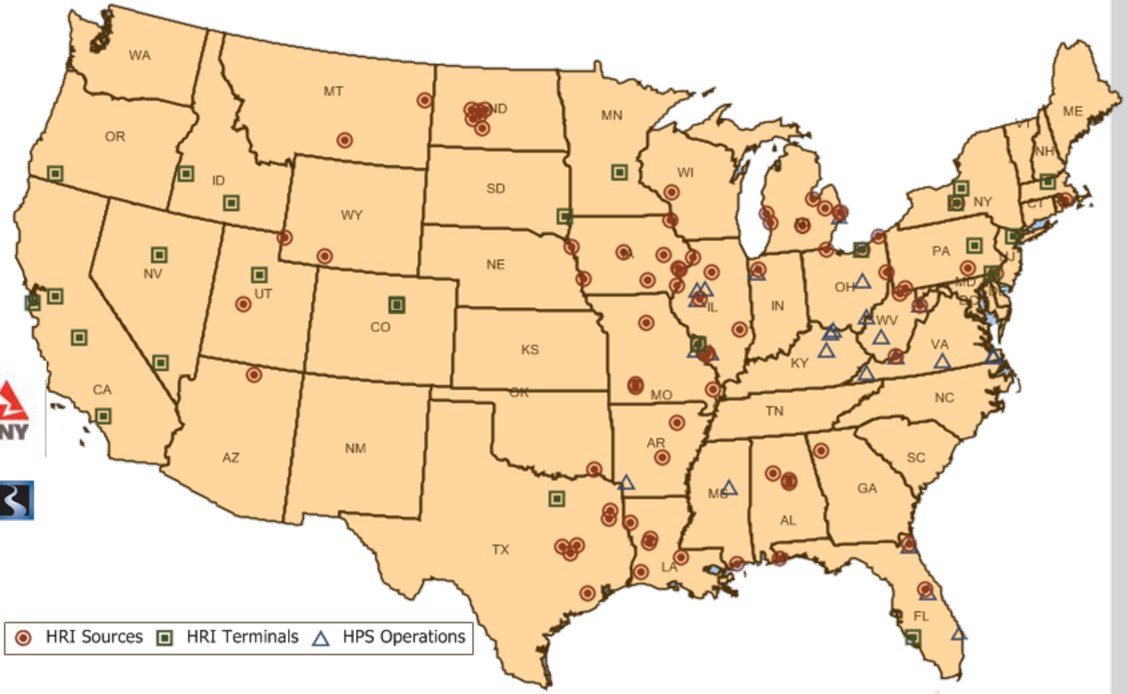
DTE Energy

GREAT RIVER ENERGY

MidAmerican ENERGY

Entergy

nrg



Some "legacy" contracts date back to the 1970's and 1980's

Affiliated Companies in leading building products market positions:

Eldorado Stone, Southwest Concrete Products, TAPCO group & Entegra roofing

A Strategic Building Material

- 2011 American Road and Transportation Builders Association study quantified the value of fly ash used in federally funded transportation projects
- Estimated savings of **$104.6 billion over 20 years**
  - $2.50 billion/year from lower price of materials
  - $2.73 billion/year in reduced repair work due to increased durability
  - $5.23 billion/year
  - 13% of federal aid to states for highway/bridge work.
  - $2 billion/year more than current federal government investment in the national Airport Improvement Program.

Why do we use fly ash in concrete?

- Reduce concrete cost
- Improve workability
- Reduce heat of hydration
- Long term strength gain
- Sustainability
- Reduce chloride permeability
- ASR Mitigation
- Sulfate resistance

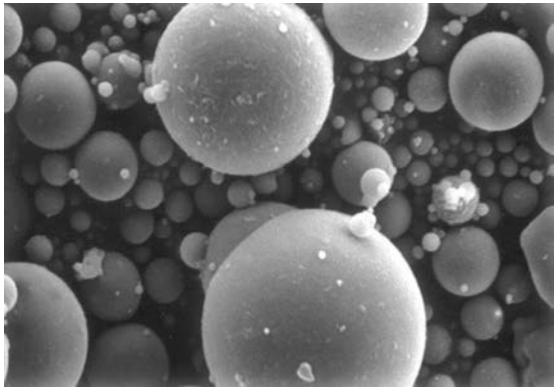
Where Does Fly Ash Come From?

Fly ash is produced when coal is burned to produce electricity

Coal's **major elements: carbon, sulfur, hydrogen and nitrogen combust to generate heat.**

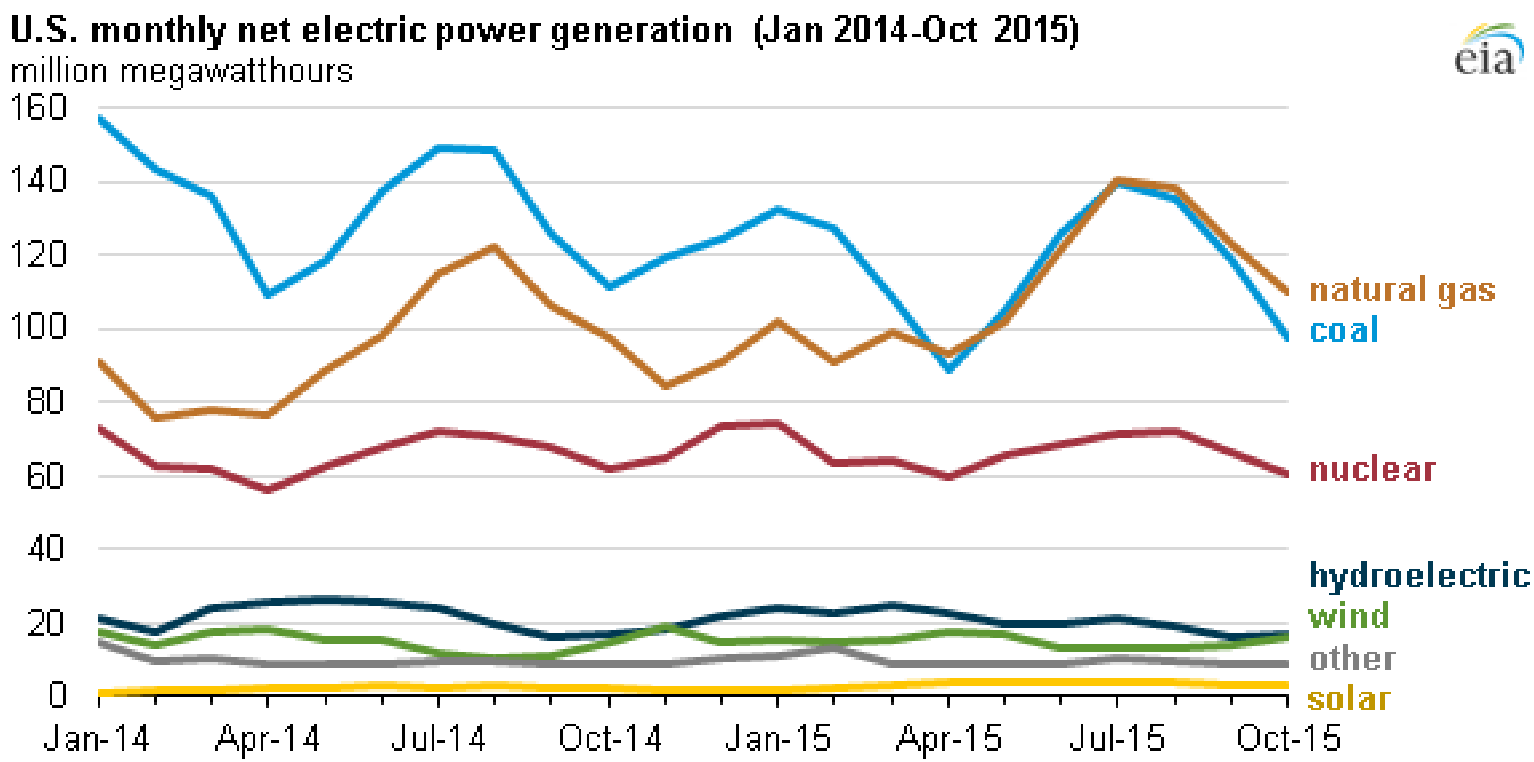
Coal's **minor elements: silicon, aluminum, iron, calcium, etc. "melt" and re-solidify to produce ash.**

The pozzolanic reactivity of ash comes from the rapid-quenching of the molten minerals in coal forming glassy amorphous particles.



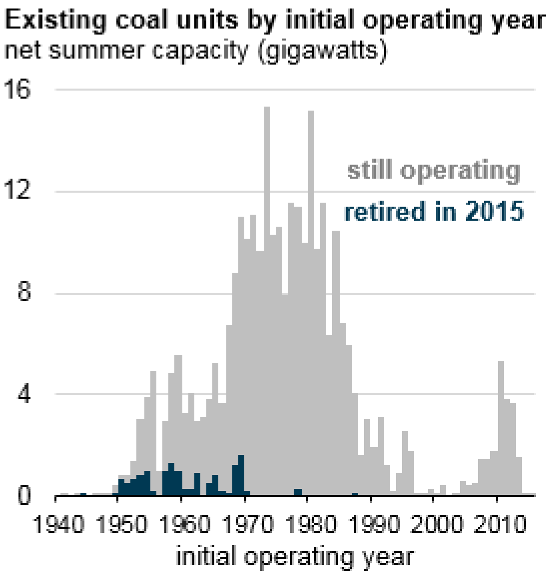
Coal’s Down – But Not Out

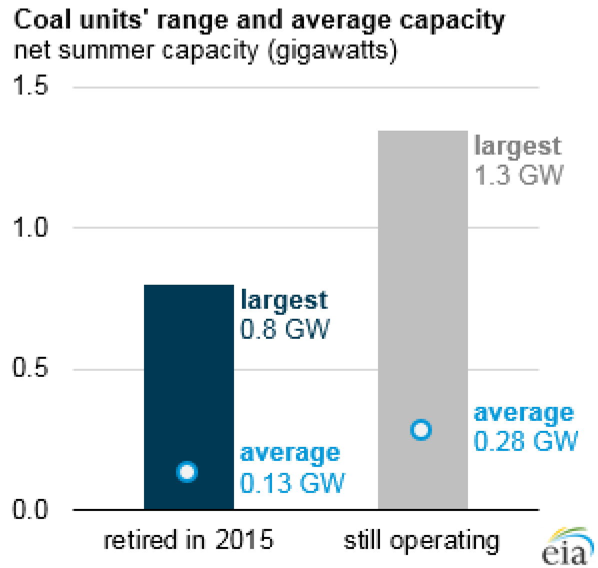
- U.S. coal fired generation has suffered recent setbacks
- Final 2015 share: coal 33.2 percent, natural gas 32.7 percent
- 2016 EIA forecast: natural gas 33 percent, coal 32 percent

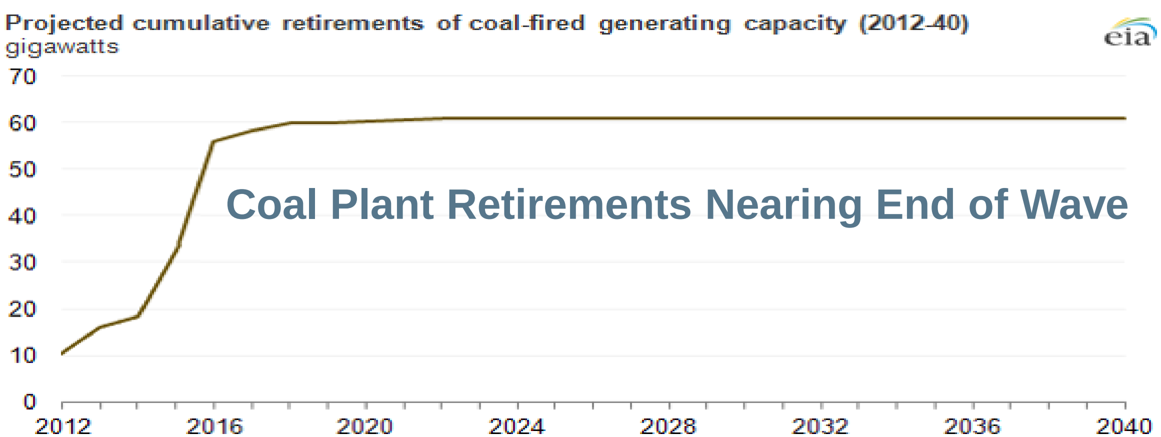


SOURCE: EIA Electric Power Monthly, January 2016

What’s Being Retired: Older and Smaller







Coal Plant Retirements Nearing End of Wave

Plant closures

(~ 60 of 310 GW current capacity) already baked in from latest regulations (MATS, etc.)

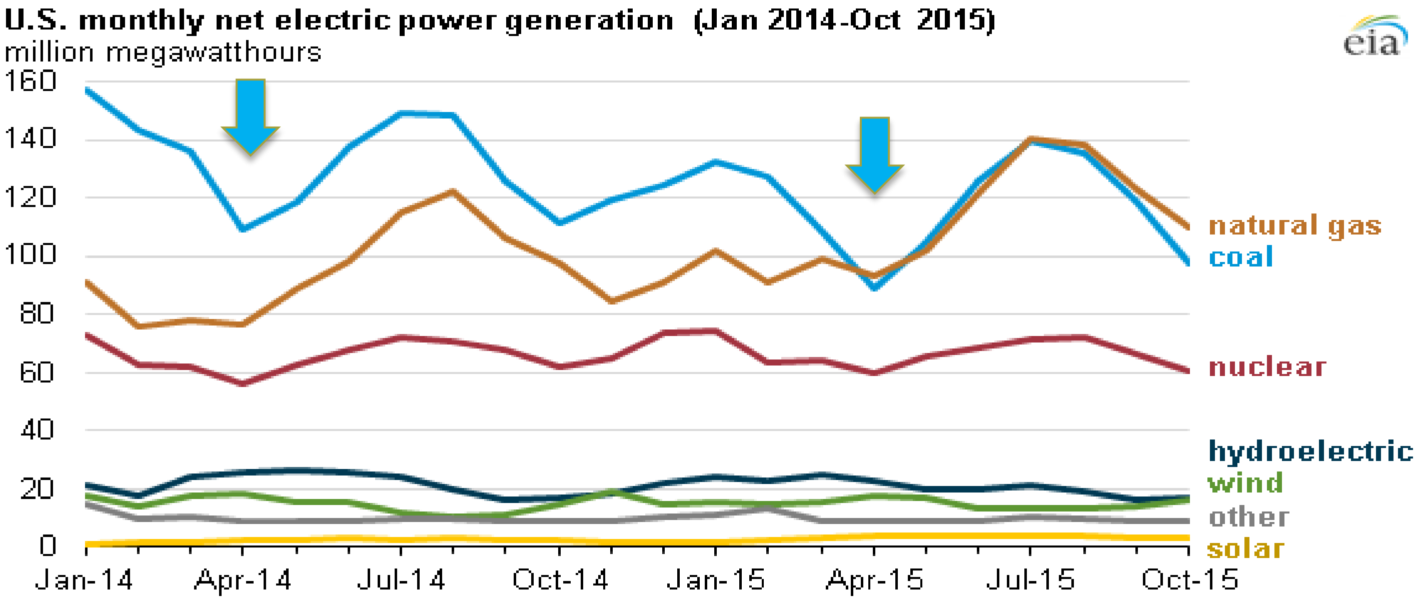
These are “capacity” closures. Generation reductions will depend on NG prices:

Source: EIA Annual Energy Outlook 2014 Reference Case and Annual Electric Generator Report

Current Fly Ash Supply Picture

2015-2016 construction seasons have experienced "perfect storm":

- Persistent low natural gas prices in competition with coal
- Implemented regulations (MATS, etc.) affected some ash quality
- Mild weather in key parts of country reducing electricity demand
- "Just in time" spring production fell short of peak construction demand.



SOURCE: EIA Electric Power Monthly, April 2016

ACAA Survey Reports

American Coal Ash Association Phone: 720-870-7897
38800 Country Club Drive Fax: 720-870-7889
Farmington Hills, MI 48331 Internet: www.ACAA-USA.org
Email: info@acaa-usa.org

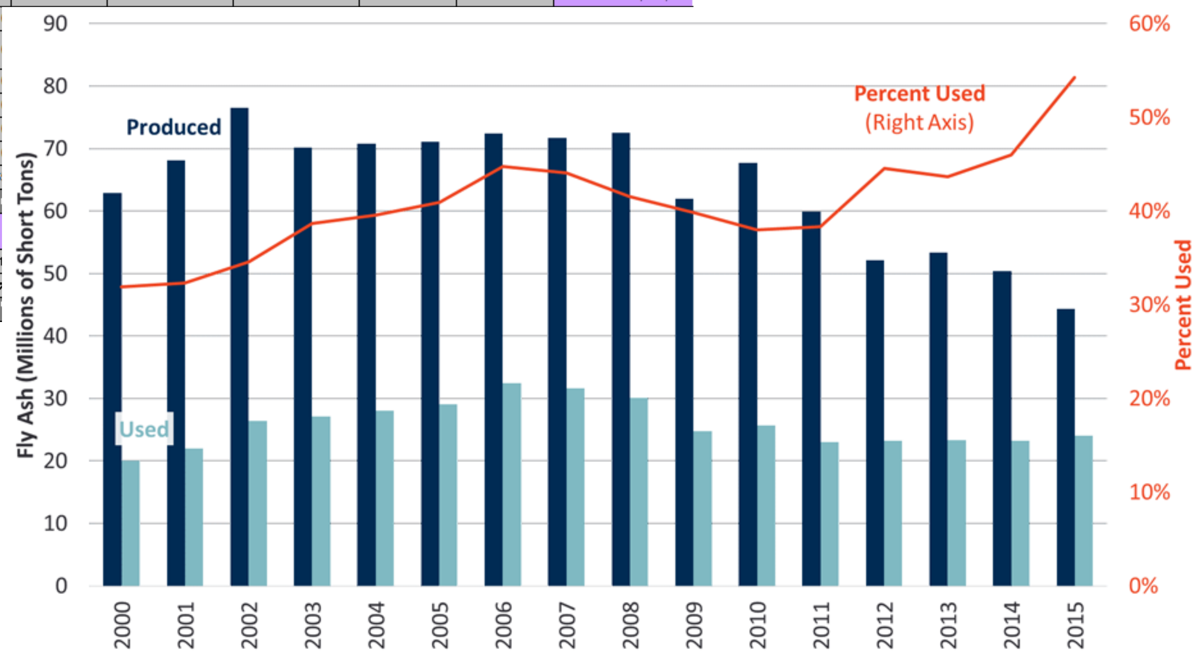
2015 Coal Combustion Product (CCP) Production & Use Survey Report

Beneficial Utilization versus Production Totals (Short Tons)

2015 CCP Categories	Fly Ash	Bottom Ash	Boiler Slag	FGD Gypsum	FGD Material Wet Scrubbers	FGD Material Dry Scrubbers	FGD Other	FBC Ash	CCP Production / Utilization Totals
Total CCPs Produced by Category	**44,365,587**	**12,010,425**	**2,228,205**	**32,661,536**	**11,313,960**	**1,311,947**	**206,314**	**13,191,460**	**117,289,432**
Total CCPs Used by Category	**24,062,786**	**4,819,205**	**1,866,912**	**17,058,178**	**1,249,438**	**252,849**	**20,697**	**11,723,843**	**61,053,908**
1. Concrete/Concrete Products /Grout	15,737,238	570,092	33,290	409,134	0	0	0	0	16,749,754
2. Blended Cement/ Feed for Clinker	3,629,151	1,130,802	0	1,649,934	0	0	0	0	6,409,887
3. Flowable Fill	107,263	9,106	0	0	0	0	0	0	116,369
4. Structural Fills/Embankments	1,277,356	1,561,531	305,770	1,221,865	100,940	0	0	0	4,467,462
5. Road Base/Sub-base	178,281	311,779	21	0	0	0	0	0	490,081
6. Soil Modification/Stabilization	216,483	66,253	0	8,053	0	0	0	0	290,789
7. Mineral Filler in Asphalt	52,784	0	14,176	0	0	0	11,479	0	78,440
8. Snow and Ice Control	0	527,695	77,935	0	0	0	0	0	605,630
9. Blasting Grit/Roofing Granules	0	184,712	1,400,455	173	0	0	0	0	1,585,340
10. Mining Applications	1,128,682	73,416							
11. Gypsum Panel Products (formerly Wallboard)	0	28,378							
12. Waste Stabilization/Solidification	1,138,078	242							
13. Agriculture	2,409	1,788							
14. Aggregate	0	173,472							
15. Oil/Gas Field Services	181,907	0							
16. Miscellaneous/Other	413,152	179,940	35,26						

Summa

CCP Categories	Fly Ash	Bottom Ash	Boiler Slag
Totals by CCP Type/Application	24,062,786	4,819,205	1,866,91
Category Use to Production Rate (%)	**54.24%**	**40.13%**	**83.79**
2015 Cenospheres Sold (Pounds)	948,787	Data in this survey represents 182 Monthly.	



2015 (million tons)

Fly Ash Production: 44.4

Beneficial Use: 24.1 (55%)

In Concrete: 15.7 (36%)

Cement: 3.6 (8%)

Source: ACAA

Ash use tracks R/M concrete production

Ash Use in Concrete:

2008 - 12.6 million tons

2009 - 9.8 million tons

2010 - 11.0 million tons

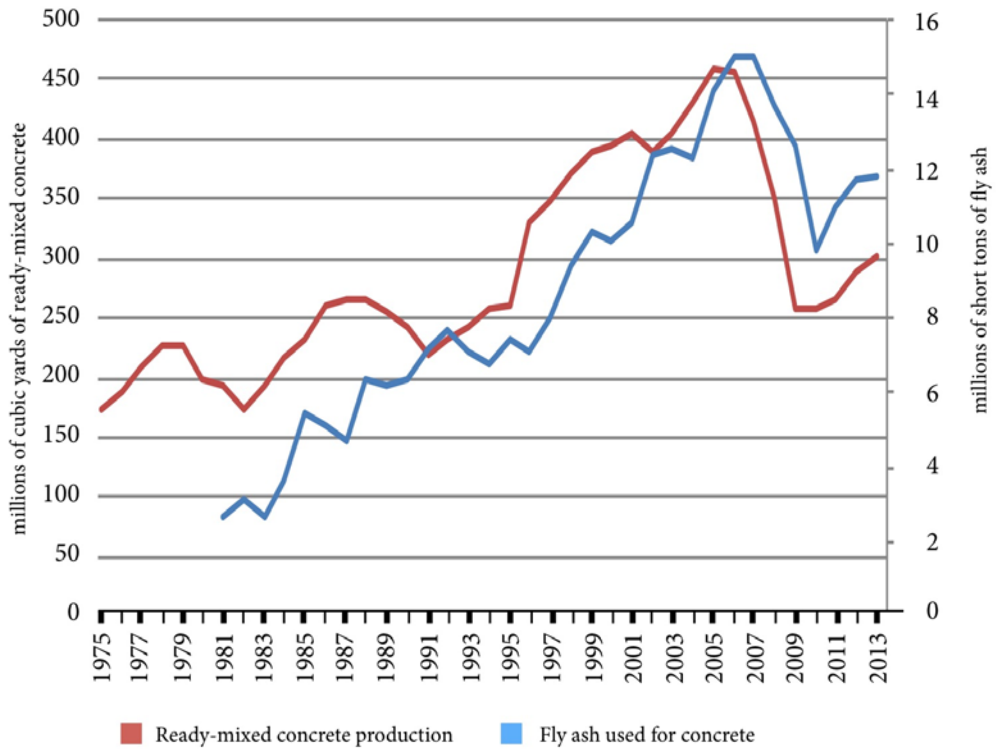
2011 - 11.8 million tons

2012 - 11.8 million tons

2013 - 12.3 million tons

2014 - 13.1 million tons

2015 – 15.7 million tons



The American Road & Transportation Builders Association (ARTBA) prepared a *Historical Market Analysis* and a *Market Forecast Through 2033* for the ACAA. (May 2015)

Source: ACAA –ARTBA

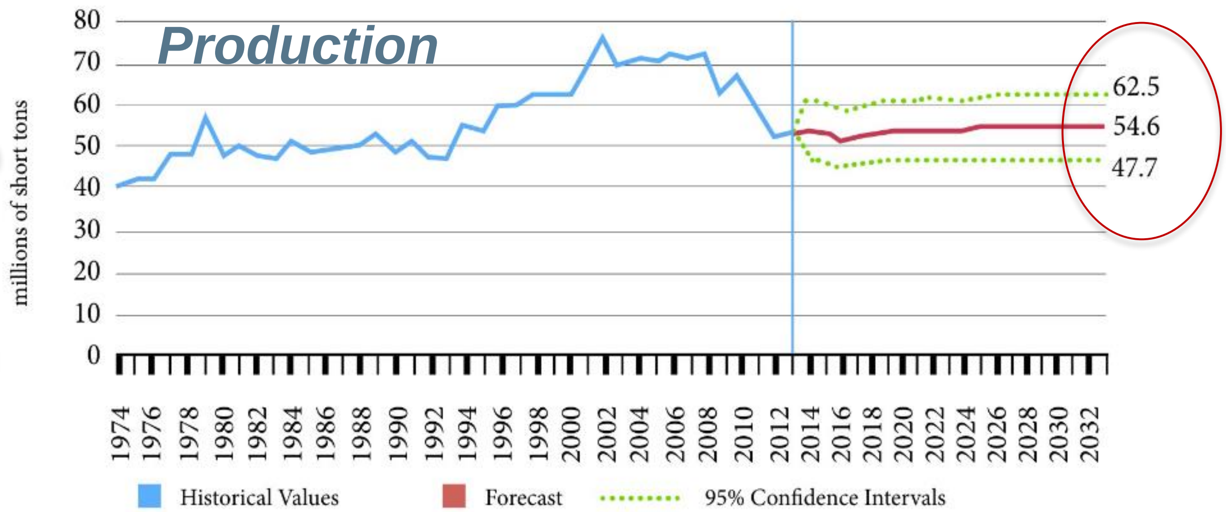
Tightening Supply/Demand Spread

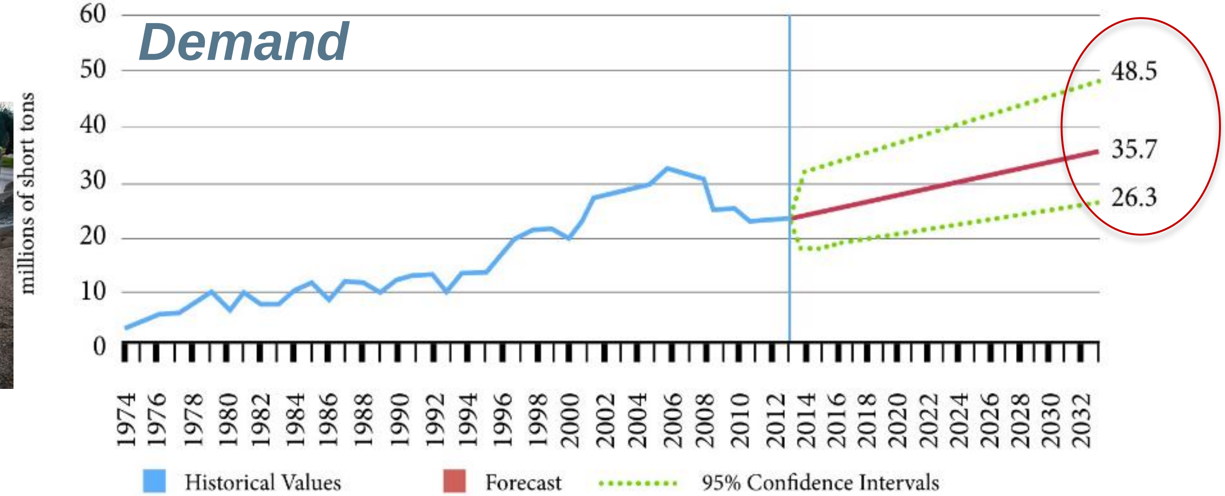
Seasonal Shortages

Regional Disparities

Logistical Challenges

Quality Issues





To Address Seasonal/Regional/Quality Concerns…

Storage/
Transportation

Beneficiation
Technologies

Plant Dry
Conversions

Fly Ash
Reclamation

Specifications

Other
Processed
CCPs

Extending Ash Reach with Logistics

Seasonal Storage facilities: 10 to 90 K tons, each

More dedicated rail cars in service
Hauls >1,000 miles

Rail to truck distribution terminals: 1 to 5 K tons, each

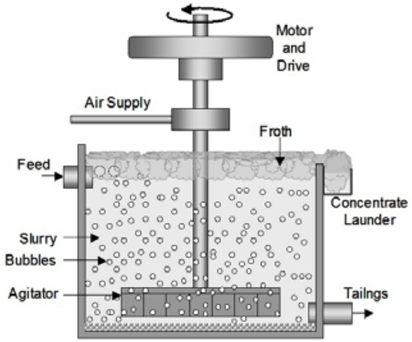
Company owned ash trucks
Hauls of 200~250 miles are common
Specialty application hauls 600~850 miles
Record truck haul = 1,875 miles

Beneficiation to Address Ash Quality

Carbon Passivation technologies such as RestoreAir are effective for remediating ash to mitigate the impact of carbon on air entrainment.

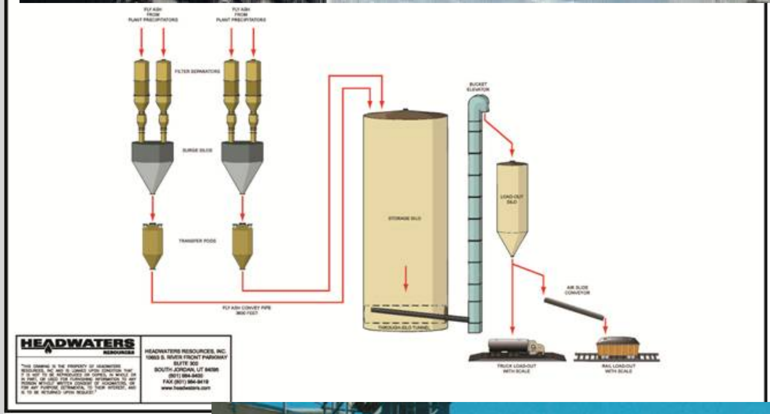
For high unburned carbon (LOI) in ash:

- Thermal processing to burn residual carbon is used.
- Electrostatic separation of carbon can also be used.
- Froth floatation of carbon from ash is effective in producing concrete grade pozzolan from ponded class F ash. This approach uses conventional mineral processing equipment.

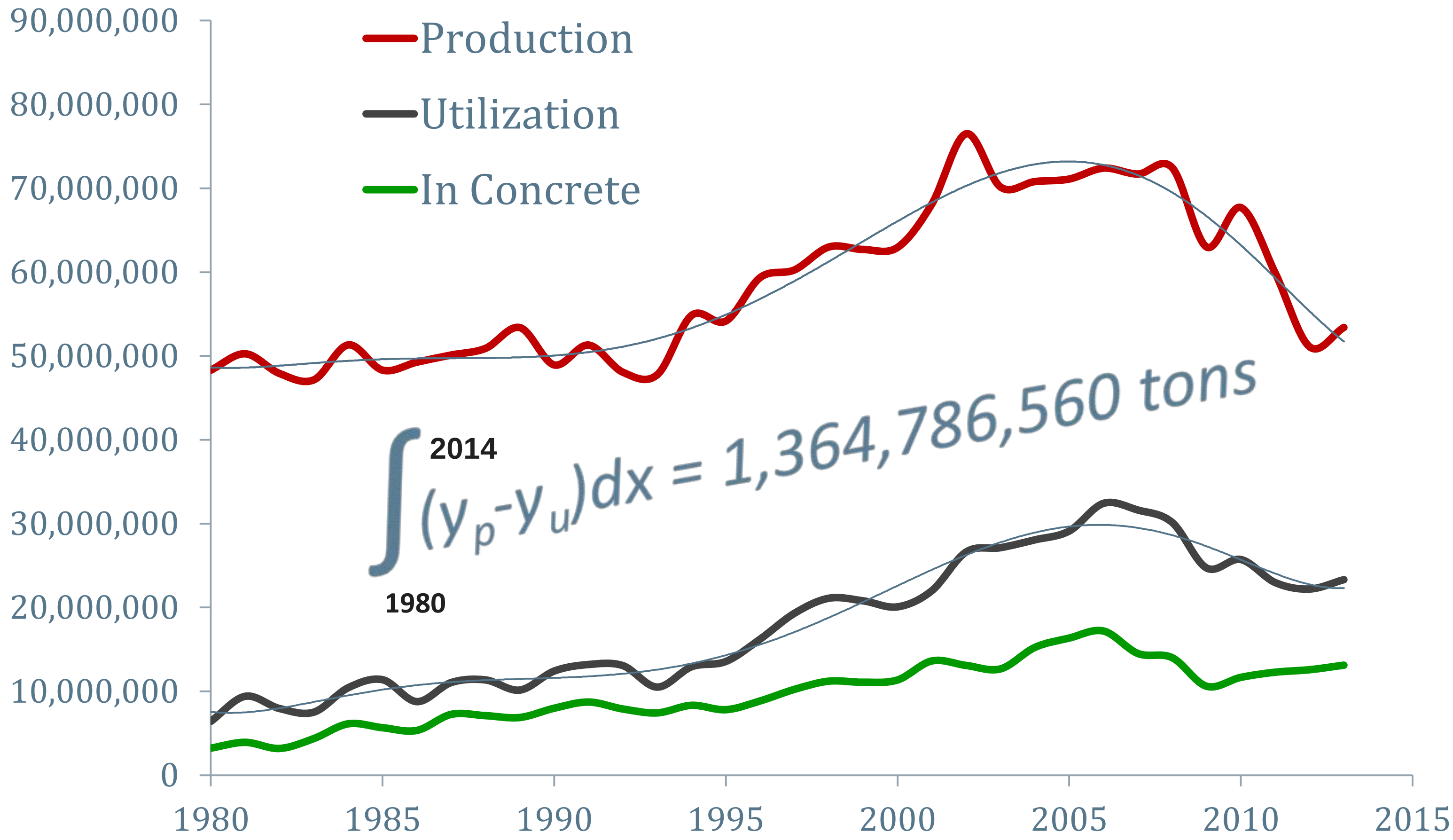


End of Wet Disposal as we know-it …….

559 wet impoundments at
239 coal fired utility sites

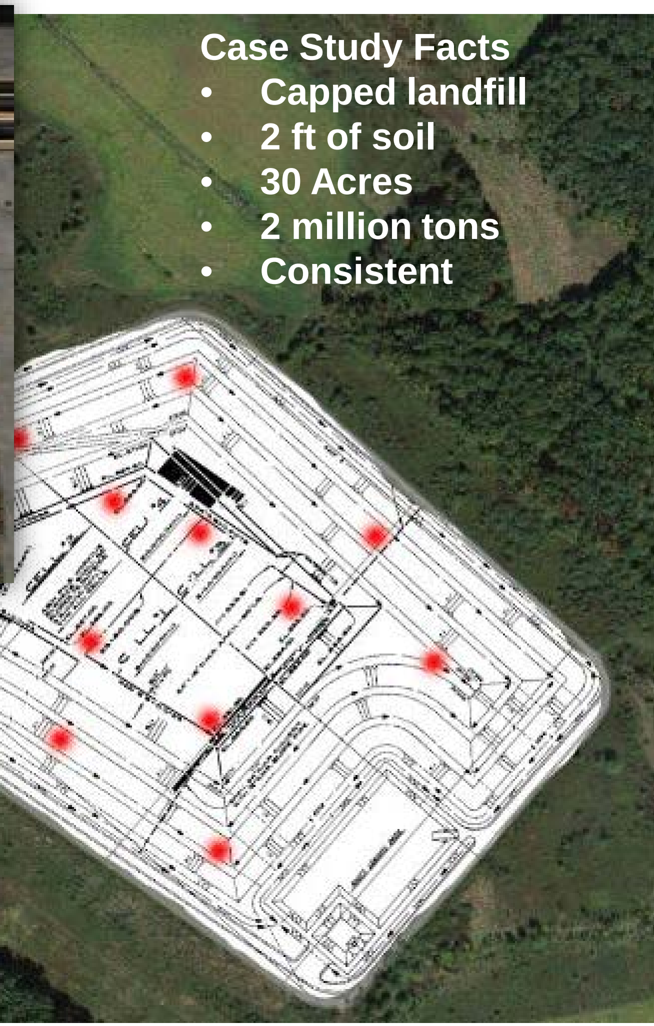


A Look at Fly Ash Through the Years…



National Synthetic Pozzolan Deposit

Landfill Reclamation for Pozzolan

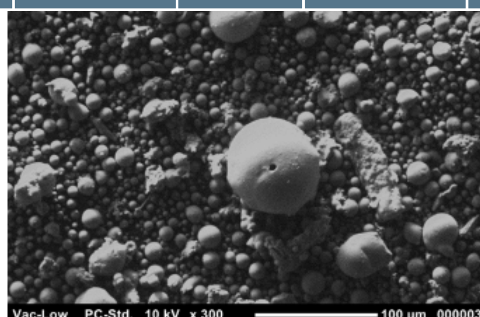


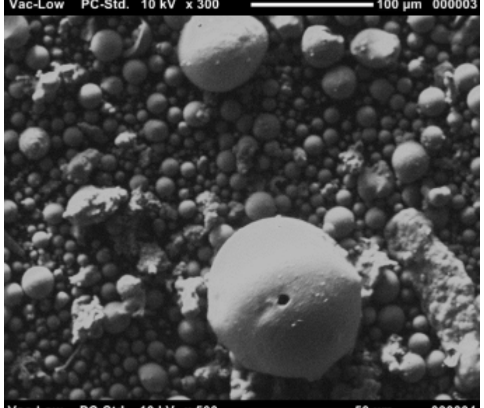
Case Study Facts

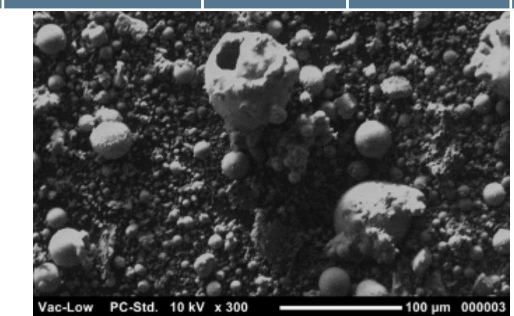
- **Capped landfill**
- **2 ft of soil**
- **30 Acres**
- **2 million tons**
- **Consistent**

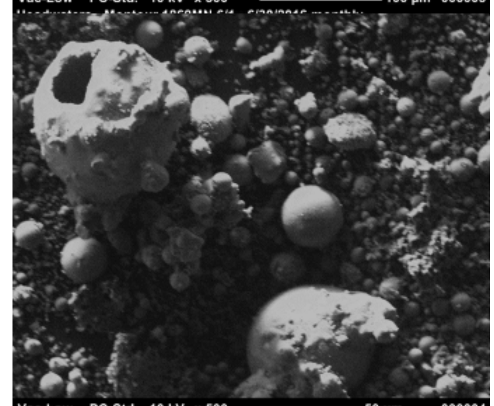
Which is which? Reclaimed vs Current Generation

	SiO_2+ Al_2O_3+ $Fe_2$03	SO_3	CaO	Moisture	LOI	Fineness	SAI 7 d	SAI 28 d	Water Req’
Current Generation	81.99	2.55	9.38	0.21	8.80	28.65	79	80	101
Reclaimed	90.84	0.19	2.21	0.16	3.05	11.90	79	83	100
ASTM C618 Class F	70% min	5% max	**	3% max	6% max	34% max	75% min	75% min	105% max









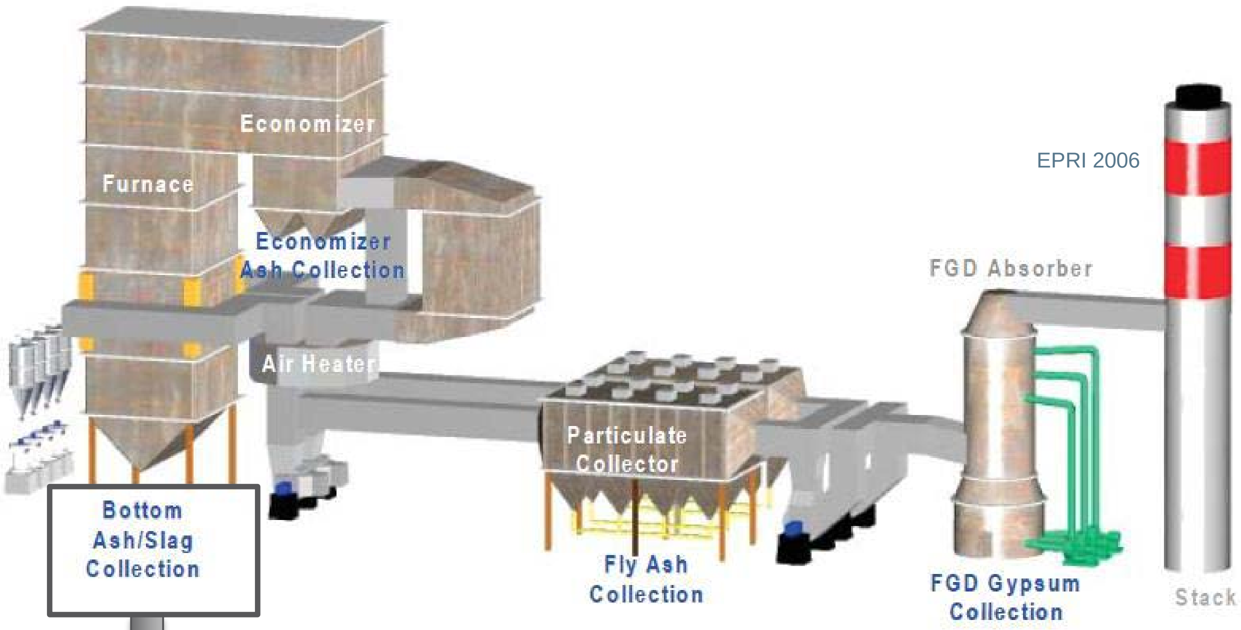
Ground Bottom Ash (GBA)

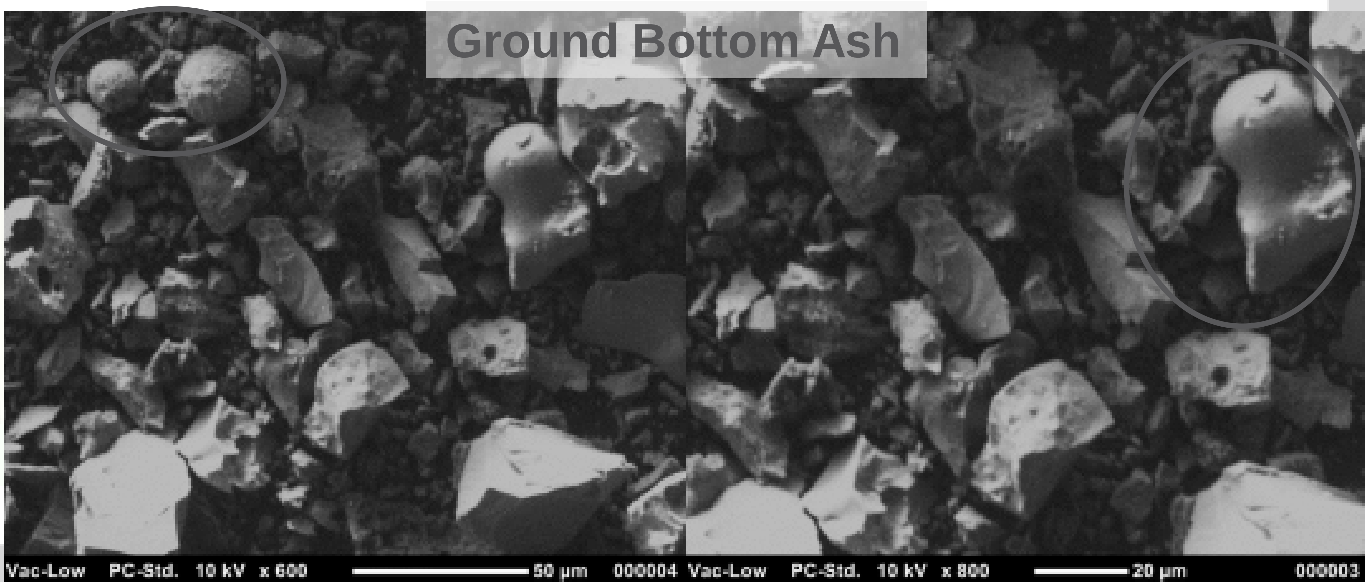
Commonalities

- Same source as fly ash
- Similar chemistry

Differences

- Slower cooling
- Lower amorphous content
- Angular vs spherical
- Requires milling





GBA has similar chemistry/C618 to its fly ash

Class F

	Sum of Main Oxides	SO_3 (%)	LOI (%)	Fineness (% retained on 325 mesh)	SAI 7D (% of cement control)	SAI 28D (% of cement control)	Water Req. (% of cement control)
Fly ash	87.58	0.43	0.66	17.67	87	91	95
Ground Bottom Ash	89.98	0.39	3.12	17.97	82	84	101
C 618 Criteria	70% min for F	3% Max.	6% Max.	34% Max.	75% Min.	75% Min.	105% Max.

Class C

	Sum of Main Oxides	SO_3 (%)	LOI (%)	Fineness (% retained on 325 mesh)	SAI 7D (% of cement control)	SAI 28D (% of cement control)	Water Req. (% of cement control)
Fly Ash	63.76	1.66	0.48	13.63	96	104	94
Ground Bottom Ash	72.08	0.32	2.2	3.03	83	87	101
C 618 Criteria	50% min for class C	3% Max.	6% Max.	34% Max.	75% Min.	75% Min.	105% Max.

Higher LOI

Lower SAI

Water Req. Closer to Control

Why do we use fly ash in concrete?

- Reduce concrete cost
- Improve workability
- Reduce heat of hydration
- Long term strength gain
- Sustainability
- Reduce chloride permeability
- ASR Mitigation
- Sulfate resistance

etc…..

Do we need all these attributes in all concrete projects?

Let's talk Specifications

Updating fly ash specifications

ASTM C 618

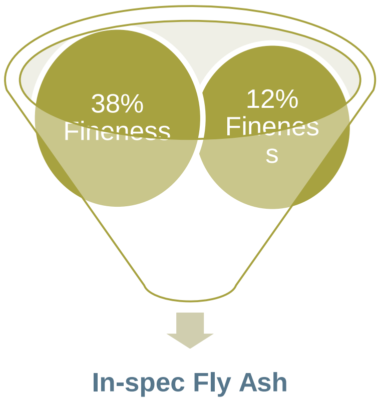
- Fineness, SAI, LOI and uniformity are the most common limits that result in rejecting potentially good fly ash for certain applications
- **Low-fineness/SAI fly ashes can be good for mitigating ASR, yet they are not considered concrete-grade.**
- Off-spec, high LOI fly ash can now be treated to neutralize the effect of unburned/activated carbon.

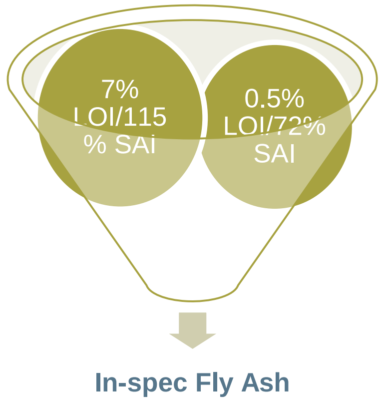
ASTM C 1697

6. Materials and Manufacture

6.1 All individual constituents used in the manufacture of the blended supplementary cementitious material shall conform to their applicable specification.

Requirements should be on the product, not on the raw ingredients.

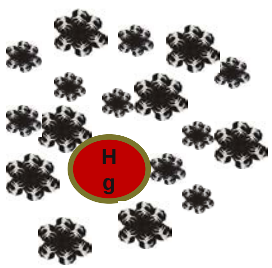




Blanket are keeping many fly ash sources off the market,
when in reality some materials that do not meet certain performance criteria can excel in others.

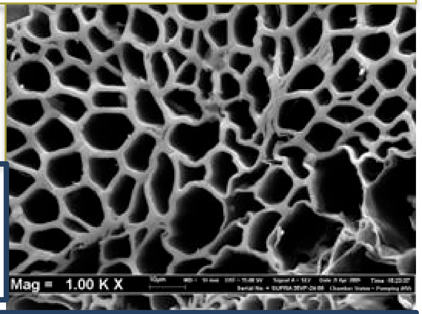
Concrete should be tested as a system; SCMs should be tested as a part of this system

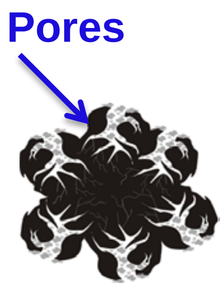
What's the problem with Activated Carbon?



Mercury in coal combustion flue gas is ~ 9 parts per billion. PAC is injected @ 1~3 lbs/million acf flue gas to capture Hg.

The mercury is sequestered in very small portions of the carbon structure.





These pores and surface areas of carbon also adsorb most organic compounds including:

Hydrophobic substances such as surfactants (AEA's).

AEA in fresh concrete mixtures would prefer adsorbing on carbon over entraining air

Fly ash can contain less than 1% LOI from Activated Carbon. However, its impact on AEA can exceed that of F-ash containing 6% LOI from unburned coal.

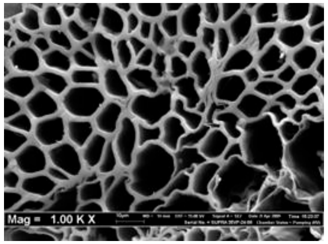
Activated Carbon in Ash

Impact on fly ash quality for concrete use:

- No impact on concrete set time or strength development
- No direct impact on concrete durability (unless it interferes with AEA's)

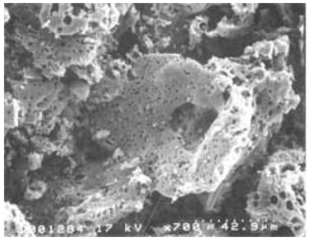
	Unburned Carbon %	Activated Carbon %	BET (m^2/g)
F-Ash	0.0	-	**0.35**
F-Ash	1.0	-	**0.75**
C-ash	0.9	-	**2.91**
F-Ash	6.8	-	**5.72**
C-Ash	0.5		**6.84**
C-Ash	2.4		**10.41**

Activated Carbon is more adsorptive than unburned coal.



Activated Carbon

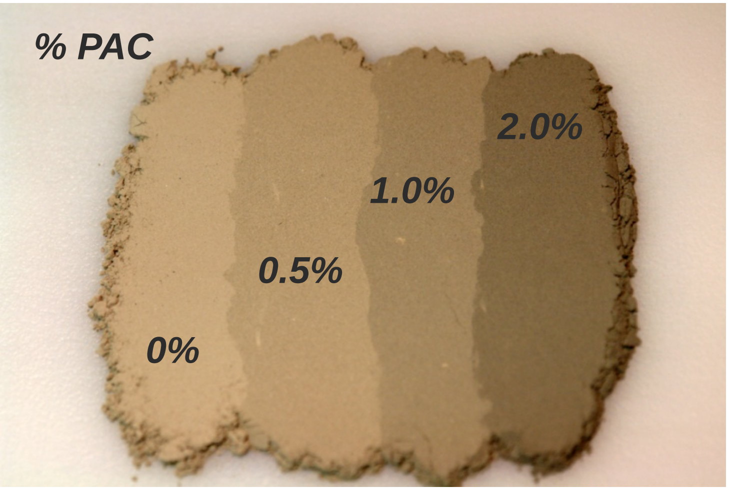
BET = 300 ~ 600 m^2/g



Unburned Carbon

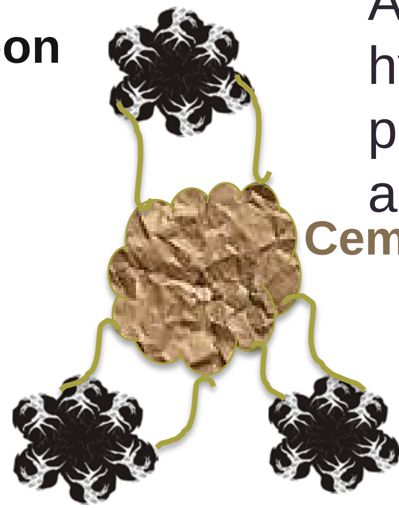
BET = 30 ~ 60 m^2/g (Bit)

BET = 100 ~ 200 m^2/g (Sub Bit)



Color sensitive applications?

Activated Carbon

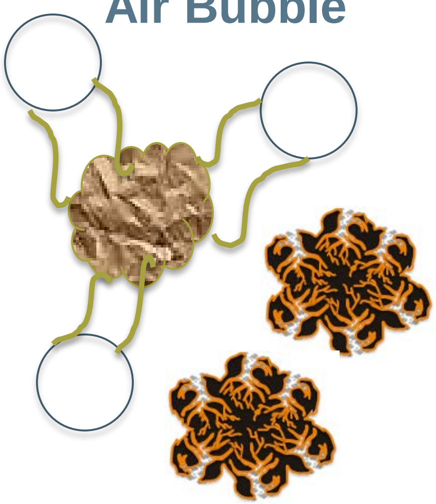


Activated carbon in concrete attracts the hydrophobic end of AEA's molecule and prevent it from collecting and entraining air.

Cement or fly ash

Air Entrainment Agents (AEA's) prefer activated carbon over air.

Air Bubble



RestoreAir® saturates the activated carbon surfaces with a sacrificial agent to prevent the carbon from attracting the AEA's.

RestoreAir®
2ND GENERATION CARBON TREATMENT

Based on the original carbon passivation technology developed 20 years ago

1. A reformulated reagent:
   - ✓ Improved dispersion and greater affinity to adsorb on activated carbon.
   - ✓ Tamed dose-response function to handle PAC variability.

2. An improved reagent injection system:
   - ✓ Provides accurate/uniform distribution of reagent in ash.
   - ✓ Can be fully automated.

3. A new ash adsorption test method/sensor: ***SorbSensor®***
   - ✓ Detects low PAC concentrations.
   - ✓ Can be used for QA or to determine treatment dosage.

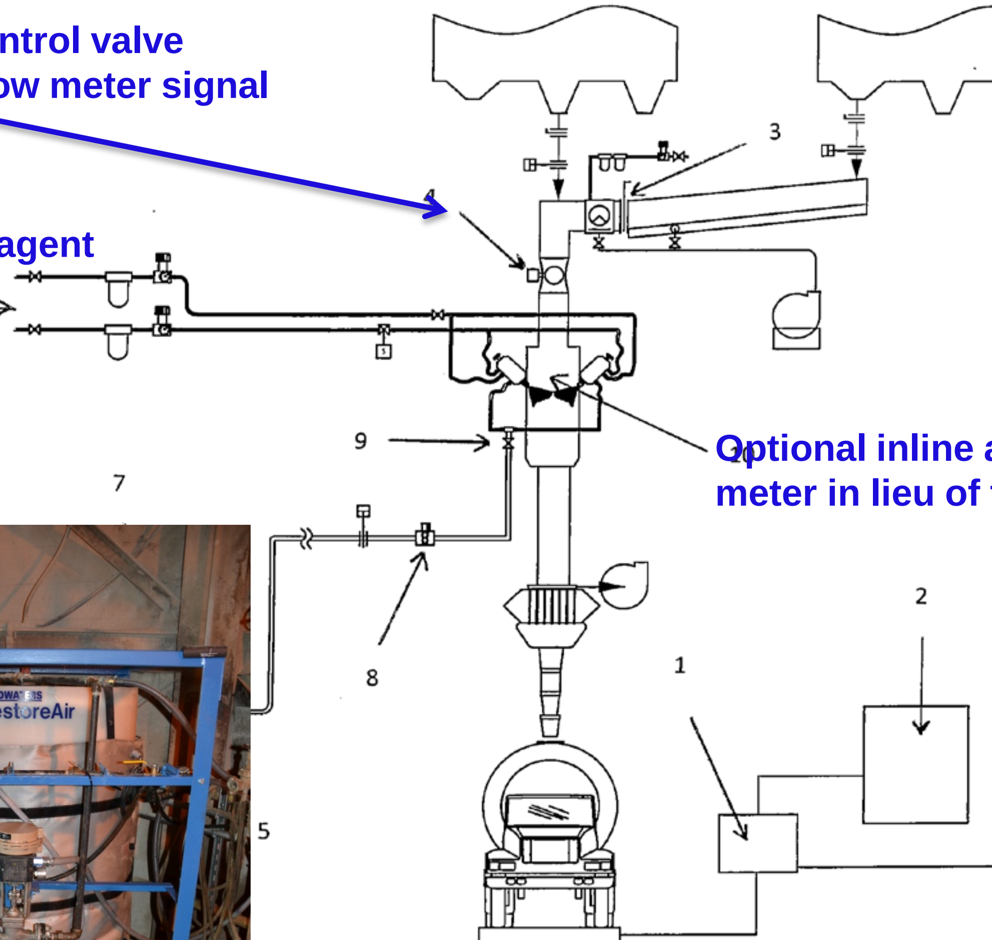
RestoreAir® Systems:

- ➢ *15 Installations with capacity to treat over 2 million tons of ash per year*
- ➢ *+ 6 Pending*

RestoreAir® ……………………………2. System

Automated flow control valve
uses truck scale/flow meter signal

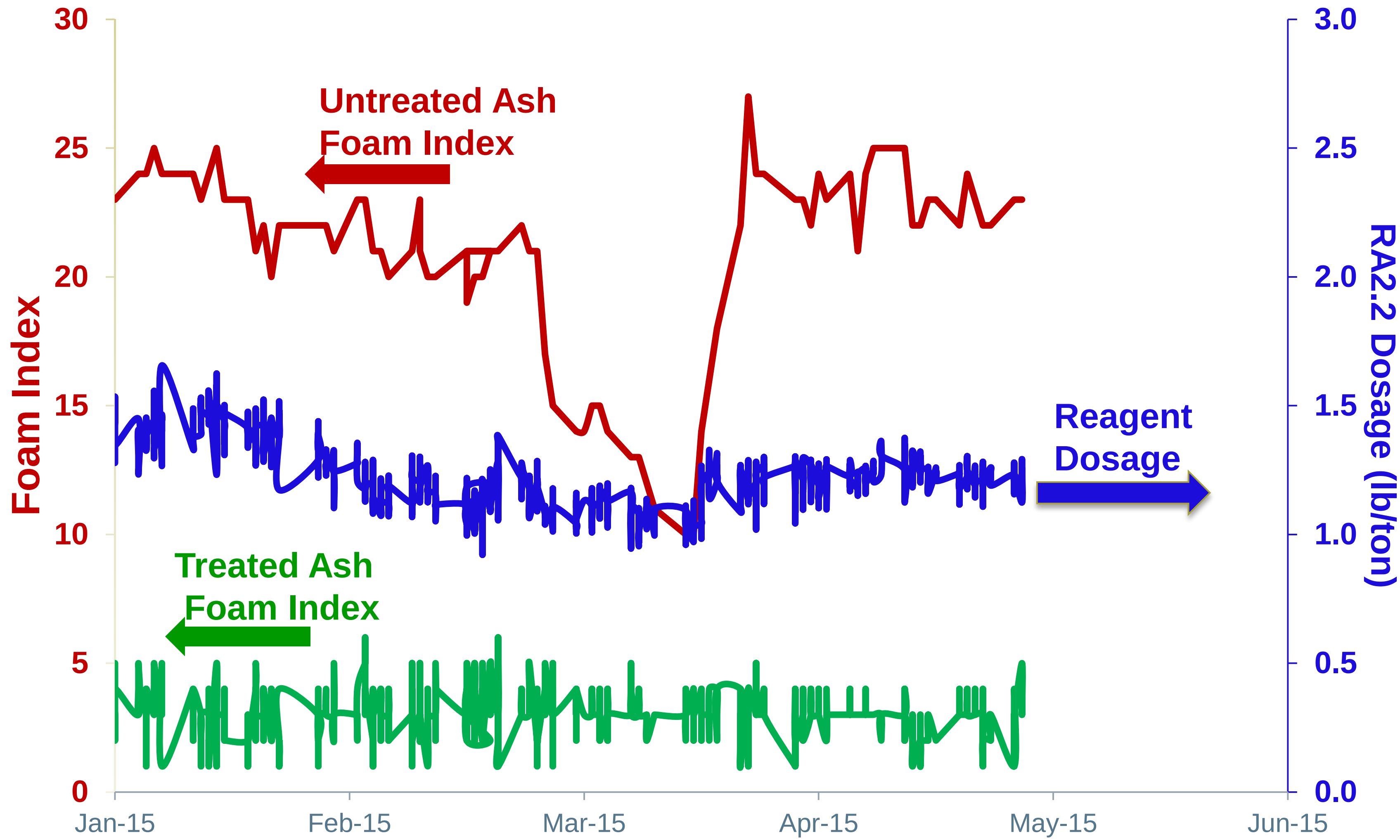
Compressed air for atomizing reagent
and spray control



Optional inline ash flow
meter in lieu of truck scale

Reagent System:
Day tank,
Metering pump,
Control valves
etc.

RestoreAir® System Performance Results



Concrete Testing Results……..No PAC, PAC & Treated

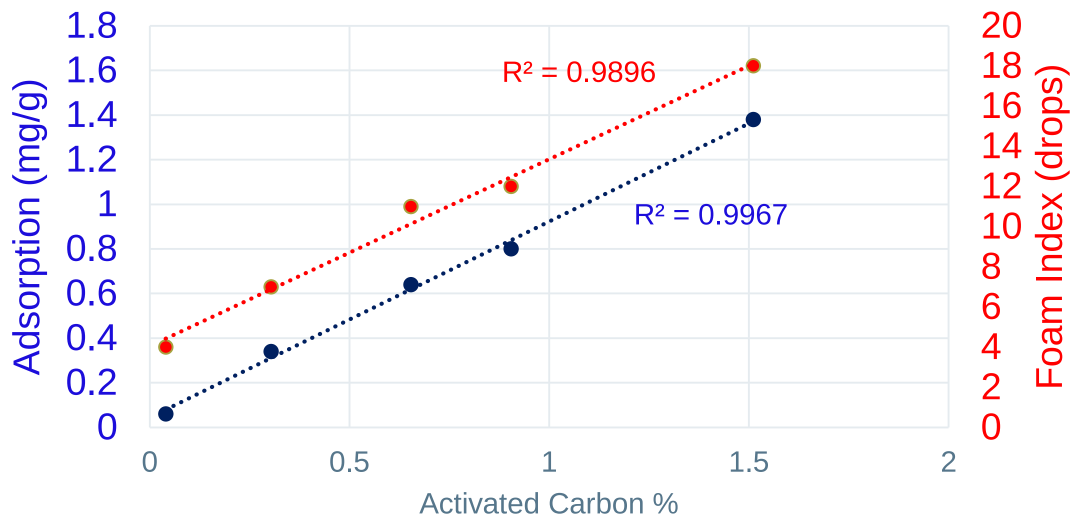
Concrete Testing Parameter	Control	Ash	Ash with PAC	
	Cement	No PAC	Untreated	**Treated RA 2.2**
Foam Index (MBVR)		***3***	***18***	***5***
AEA (MBVR) dosage (oz/cw)	*1.2*	***1.4***	***4.2***	***1.7***
Air Content (6%±1%)	7.0%	7.0%	6.3%	5.8%
Water/Cement Ratio	0.53	0.50	0.49	0.49
Slump, inches (6±1)	6.25	6.0	6.25	5.75
7 day, psi	3433	3689	3592	3918
28 day, psi	**4594**	**4802**	**4764**	**4908**

Treatment of ash restored the AEA dosage to same level expected with ash containing NO activated carbon.

Adsorption Capacity by Fluorescence using SorbSensor®

Computer operated in various modes:

- Single-point isotherm with set run time and reagent concentration
- Single-point isotherm until adsorption equilibrium is reached
- Breakthrough analysis where the ash is “titrated” with reagent



IN CLOSING…

- Coal based generation is expected to remain steady after recent closure of small and aging power plants.

- Recent shortages are being addressed:
  - Investment in storage and logistics
  - Remediation of quality issues
  - Reclamation of legacy ash deposits
  - Addressing specification obstacles

- Industry continues to develop and invest in new beneficiation and quality assurance technologies.