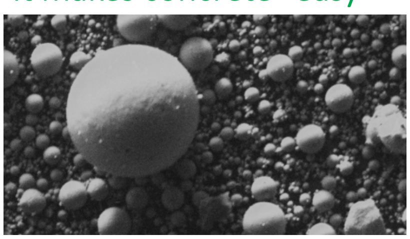
Why do we use fly ash in concrete?

It makes concrete "easy"



THE BALL BEARING EFFECT

The reduced water content contributes to denser and less permeable concrete which results in greater strength development and durability.

Physical Benefits: flowability, particle packing, workability, pumpability and reduced bleeding

2

Why do we use fly ash in concrete?

It makes concrete more durable

Chemical Benefits: The pozzolanic reaction consumes excess calcium hydroxide/alkalis improving durability and contributing to additional strength gain.

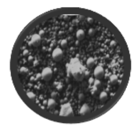
EXCESS LIME IS THE WEAK LINK IN THE DURABILITY OF PORTLAND CEMENT CONCRETE

Cement Hydration: $2Ca_3SiO_5 + 7H_2O \rightarrow 3(CaO)\cdot 2(SiO_2)\cdot 4(H_2O) + 3Ca(OH)_2$

C-S-H gel

more C-S-H gel

Excess lime reacts with fly ash



Calcium-Silicate-Hydrate (C-S-H) gel is the most abundant reaction product of portland cement binder and it occupies about 50% of the paste volume.

3

Why Do We Use Fly Ash in Concrete?

We also have Cost Reduction + Sustainability

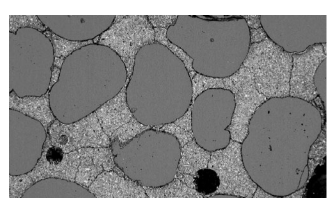
ASR

PERMEABILITY

RHEOLOGY

STRENGTH

TEMPERATURE RISE



SULFATE RESISTANCE

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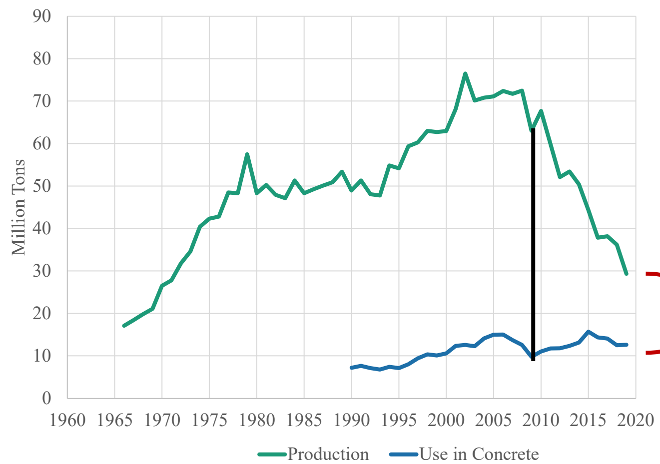
FLY ASH | the recent years



Since 2009:

Production dropped by more than 50%
while Use in Concrete increased by 30%

The tightening spread between fly ash supply from operating power plants and demand by the concrete industry has already caused shortages in many markets.

The ash industry has been adjusting, but more initiatives are needed to assure fly ash and other SCM's are available for concrete durability and sustainability.

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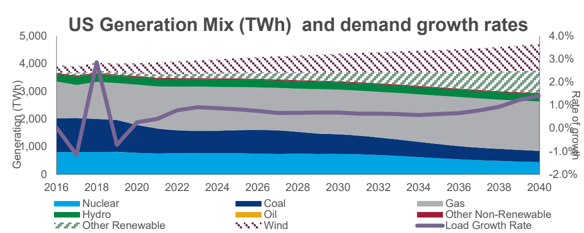
REALITY | coal outlook is bleak

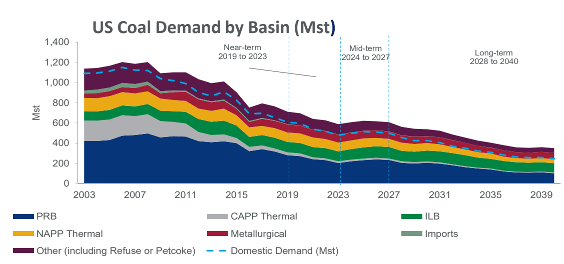
Natural gas and renewables have been covering electric demand growth as well as displace coal.

Now there is a renewed interest in expanding nuclear power

Only high natural gas prices can slow this downward trend.



Source: Wood Mackenzie Coal Market Service



Source: Wood MacKensie

Natalie Biggs
US Coal Market Outlook
National Coal Transportation Association
September 10, 2019

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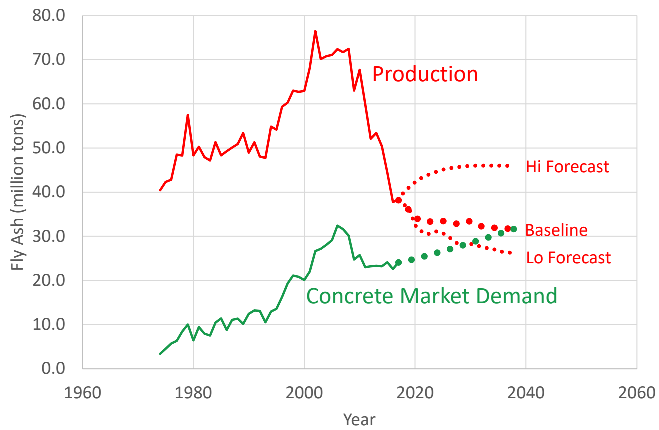
FORECAST | fly ash production and concrete market demand



The production forecasts do not account for:

- **material quality**
- **regional disparity**
- **seasonal disparity**
- **type disparity**

Source: ARTBA/ACAA 2020 Study

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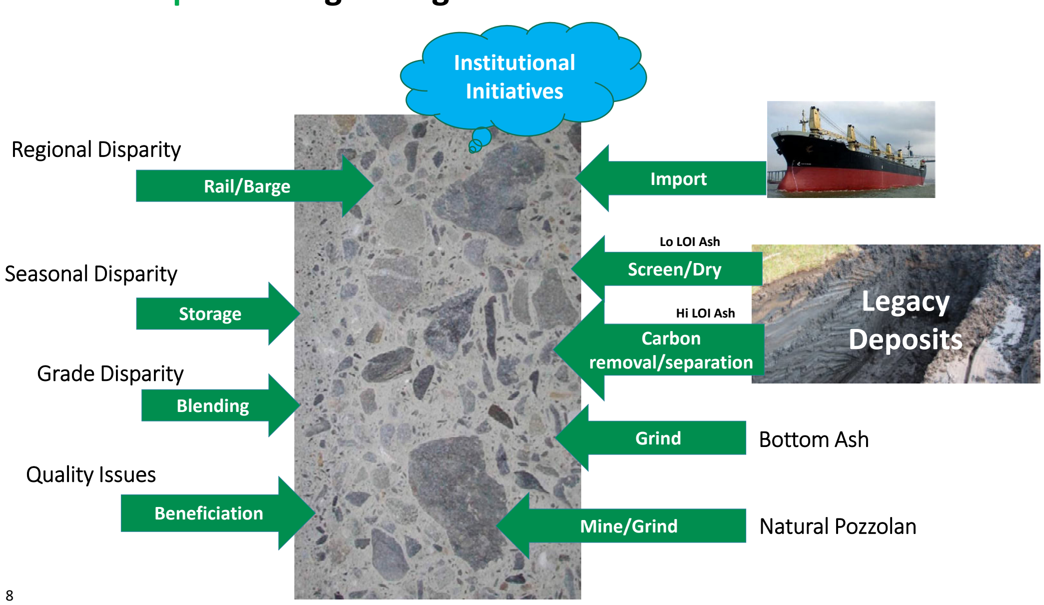
INITIATIVES | to meet growing demand for SCMs



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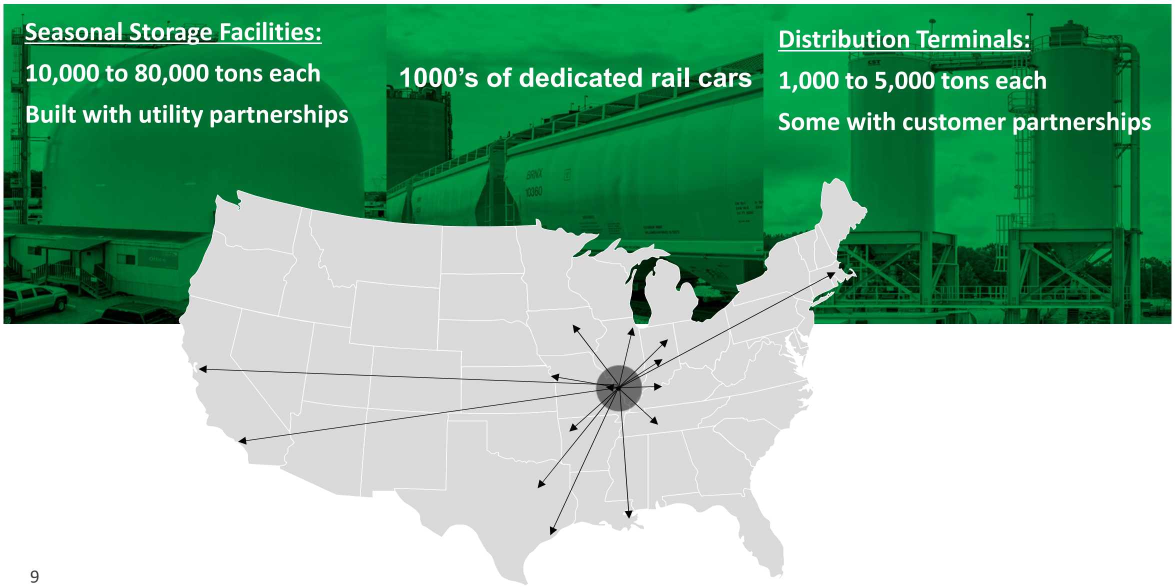
LOGISTICS | to mitigate regional and seasonal disparities



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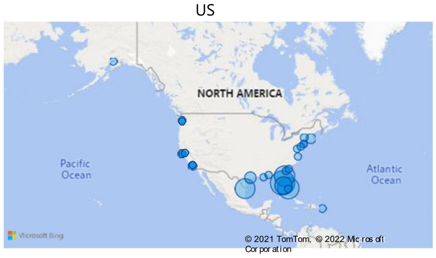
FLY ASH | U.S. imports



Descartes Datamyne™
Fly Ash US Imports Maritime Bill of Lading
2017 - 2021

Country of Origin	Mtons	Share
TURKEY	1,566,661	54.55%
SPAIN	592,707	20.64%
ITALY	202,585	7.05%
NETHERLANDS	151,245	5.27%
SINGAPORE	83,400	2.90%
PORTUGAL	78,935	2.75%
INDIA	75,248	2.62%
CHINA	60,921	2.12%
PAKISTAN	41,860	1.46%
GERMANY	10,582	0.37%
POLAND	2,591	0.09%
JAPAN	1,494	0.05%
RUSSIA	767	0.03%
HONG KONG	741	0.03%
Total	**2,871,717**	**100.00%**

11.5 million tons of slag were imported in the same 5-year period, mainly from Japan and China.

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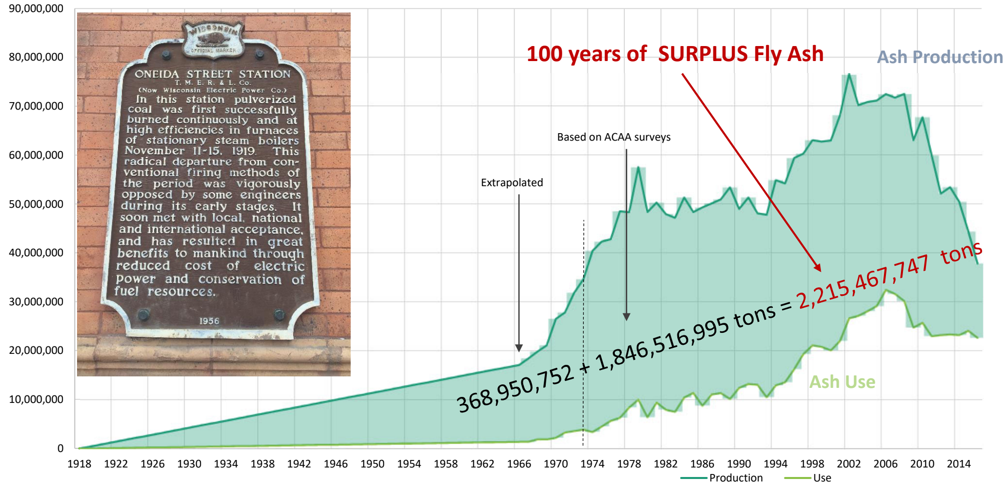
SURPLUS ASH | 100⁺ years of pulverized coal power generation



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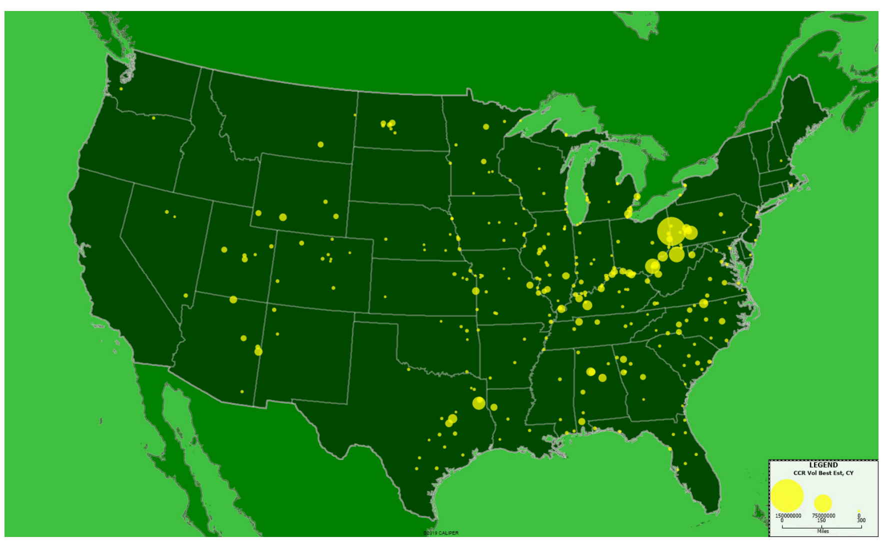
CCR DOT DENSITY MAP | potential synthetic pozzolan deposits



All CCR's including fly ash, bottom ash, boiler slag, FGD material, SDA, etc)

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HARVESTING | anatomy of a project

Key considerations in evaluating harvesting opportunities include:

- Ash quality and variability
- Technology – feasibility of beneficiation processes
- Market supply/demand – current and future
- Existing infrastructure – storage/loading/utilities/landfill
- Time frame – closure/utility constraints, etc.
- Permitting – active, closed, closing timeline
- Capital – who funds required investment?
- Risk and return metrics

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TECHNOLOGIES | to beneficiate fly ash

Legacy technologies used for run-of-plant fly ash:

- Blending: P2® - Performance Pozzolan (Class F & C blend)
- Chemical Treatment: RestoreAir®(passivation of carbon in ash)
- Thermal Treatment: CBO (Carbon Burn Out) & STAR
- Carbon Separation: STET
- Classification: C618 fineness improvement or to make Ultrafine Fly Ash (such as Micron3®)

Technologies needed to beneficiate harvested fly ash:

- ALL THE ABOVE plus…….
- Screening
- Drying
- Grinding and fine milling
- Blending with new pozzolans
- Carbon flotation
- Others…

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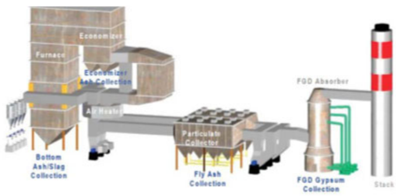
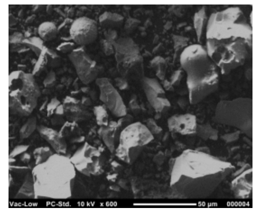
GROUND BOTTOM ASH | A Supply Expansion Option

Increase synthetic pozzolan output from a powerplant by 15% to 30%.

- same coal source as fly ash
- similar chemistry
- some mineralogy difference





EXAMPLE	Sum of main oxides	SO_3 [%]	LOI [%]	Fineness [% retained on 325 mesh]	SAI 7D [% cement control]	SAI 28D [% cement control]	Water req. [% cement control]
Fly ash	87.58	0.43	0.66	17.67	87	91	95
GBA	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

GBA performance can be catered to meet or exceed the same source fly ash

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NATURAL POZZOLANS | they have been around for a long time

Pozzolans, or "powdery ash" from *Puteoli*, now modern Pozzuoli, Italy.

Pozzolans are inorganic minerals, naturally occurring ash, that consist of amorphous silicates and aluminates, which when combined with calcined lime and water react to form stable binding hydrates.

The reaction was first described in 27-31 B.C by Vitruvius, an engineer and architect for Julius Caesar.

Colosseum 72-80 A.D.

Pantheon 120 A.D.

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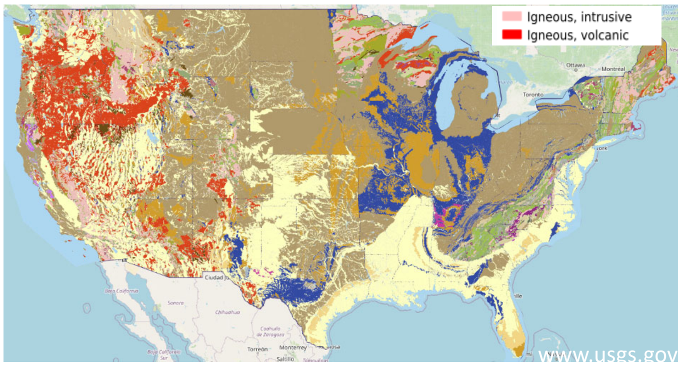
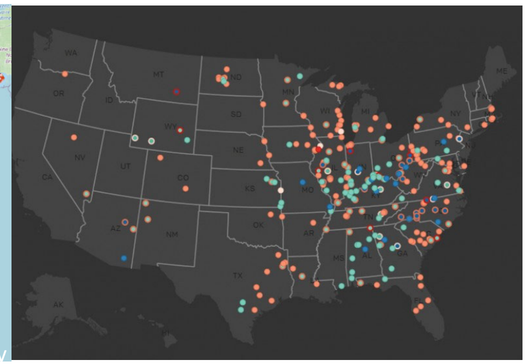
COMPLEMENTARY | natural and synthetic pozzolan deposits

Location of Potential Raw Natural Pozzolan Deposits



Location of Potential Fly Ash Deposits



According to the Natural Pozzolan Association, the current NP production capacity is 1.5 million tons per year

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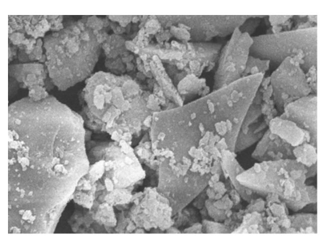
NATURAL POZZOLANS | Performance Characteristics

	NP
SiO_2	73.63
Al_2O_3	13.68
Fe_2O_3	1.49
Sum	88.80
SO_3	0.05
CaO	1.73
Na_2O	2.99
MgO	0.94
K_2O	4.34

	Sum of Oxides	SO3 %	LOI %	Density	Fineness % Retained	SAI 7d, % of control	SAI 28d, % of control	H_2O Req. (% of control)	Compared to C 618
Natural Pozzolan	88.80	0.05	3.67	2.39	0*	95	97	107	Pass
ASTM C618 Requirement	70% min	5% max	10% max	-	34% max	75% min	75% min	115% max	

Typically ground finer than fly ash

- High LOI's due to hydrates
- SAI – A function of minerology and fineness
- Higher water demand than fly ash
- ✓ It must provide durability such as ASR Mitigation or Sulfate Resistance



The angularity of the ground powder and porosity of the mineral will have an impact on the rheology of the concrete slurry

INSTITUTIONAL INITIATIVES | new standards development

- ✓ New ASTM Environmental guidance for harvesting CCPs (2018)
- ✓ ACAA/ARTBA 2020 Study
- ACI Tech Notes on Harvested Fly Ash
- ACAA Technical Committee and ASTM Initiatives
  - Harmonizing ASTM C618/AASHTO M295 (WIP)
  - Performance based specifications (WIP)
  - Specifications for ground bottom ash in C618 (WIP)
  - Specifications for harvested ash in C618 (WIP)
  - Product Category Rule (PCR's) for the development of Environmental product Declarations (EPD's)

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American Concrete Institute
Always advancing

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Rafic Minkara, Ph.D., P.E.,
770-330-0689

ECOMATERIAL TECHNOLOGIES