Life Without Fly Ash: Concrete Dystopia or Hysteria

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Michigan Technological University

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Points to be Discussed Today

- Why are SCMs so important?
- What's the problem?
- What can we expect in the future?
- What can we do to keep producing quality concrete?

2

Disclosure

- I am not here representing one material or a single provider.

But…

3

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Sounded like a pop-punk band name…

5

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Available… but depreciated term

6

Available in MI as a plate, not as an SCM

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Disclosure

- Fly ash has been a main focus for me, particularly testing and specifications
- I promote all SCMs and want to see **optimal** SCM use in ALL concrete
- But – for you like me – fly ash has become part of all our lives…

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What is an SCM?

- **cementitious material, supplementary, (SCM)** - an inorganic material that *contributes to the properties* of a cementitious mixture through **hydraulic** or **pozzolanic** activity, or both
  - *DISCUSSION—Some examples of supplementary cementitious materials are fly ash, silica fume, slag cement, rice husk ash, and natural pozzolans. In practice, these materials are used in combination with portland cement.* (ASTM C125)

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Hydraulic Reaction (Hydration)

- Reaction of hydraulic cementitious materials with water results in production of calcium silicate hydrates (C-S-H) and calcium hydroxide (CH), also ettringite and other hydrated aluminate phases (C-A-H)
  - Examples: portland cement, slag cement, Class C fly ash
- **Hydraulic Reaction:**

  Hydraulic Cement + Water ⟶ C-S-H + C-A-H + CH

- **C-S-H** provides strength – desirable product
- **CH** provides little strength and is soluble, also is a reactant in many MRD mechanisms – undesirable product

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Pozzolanic Reaction

- Pozzolans consume calcium hydroxide (CH) through the pozzolanic reaction
  - Examples: fly ash, silica fume, natural pozzolans, ground glass
  - **Hydraulic Reaction:**

    Hydraulic Cement + Water ⟶ C-S-H + CH

  - **Pozzolanic Reaction:**

    Pozzolan + CH + Water ⟶ C-S-H

    - Increases strength
    - Increases paste density
    - Reduces alkali (ASR mitigation)
    - Reduces rate of heat evolution attributed to hydration reaction
    - Slows rate of strength development

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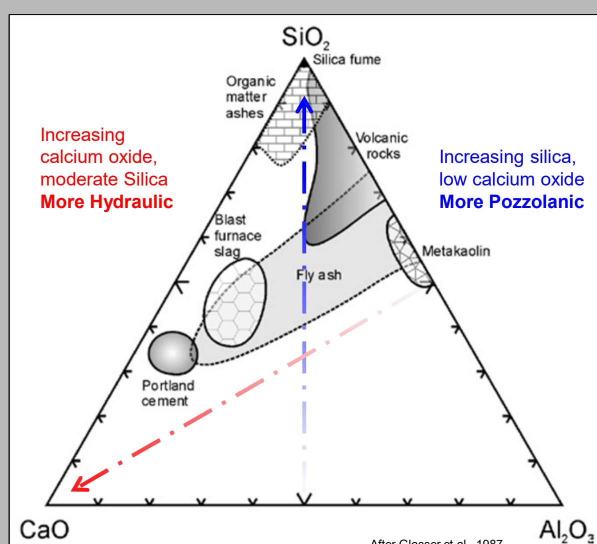
General Characteristics - Composition

- Coal Fly Ash
- Slag Cement
  - *Not a pozzolan*
  - *Consumes CH through its hydration reaction*
- Silica Fume



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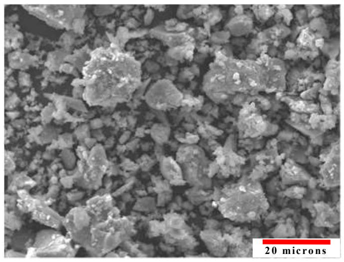
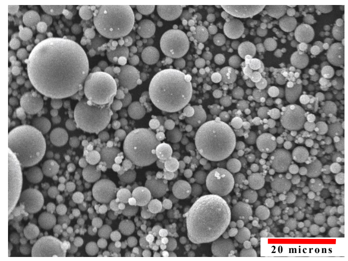
General Characteristics – Particle Size & Shape

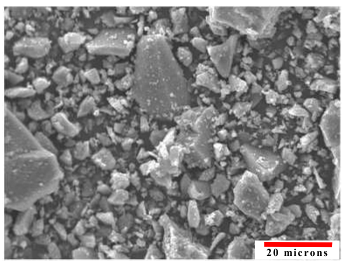
Portland Cement

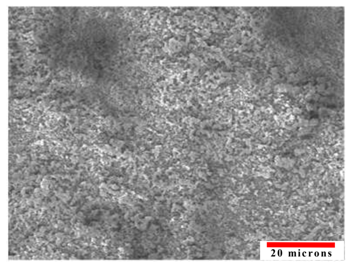




Fly Ash

Slag Cement





Silica Fume

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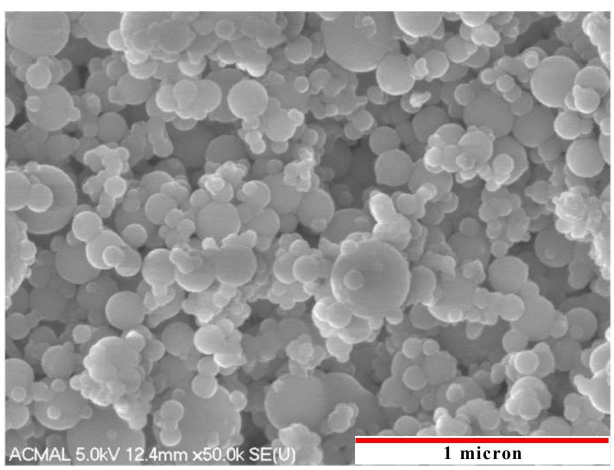
Silica Fume – Particle Size & Shape



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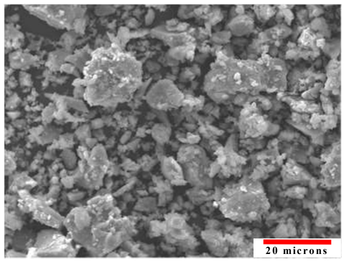
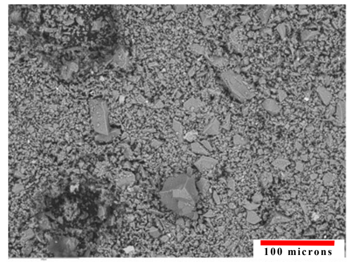
General Characteristics – Particle Size & Shape

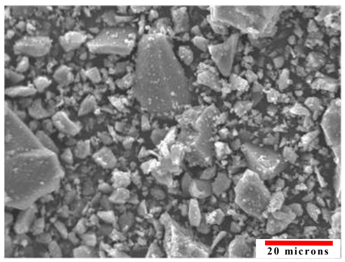
Portland Cement

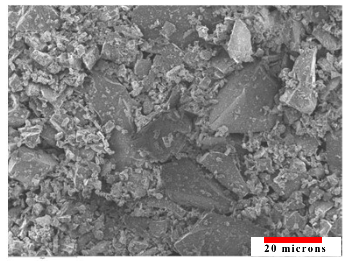




Natural Pozzolan

Slag Cement





Natural Pozzolan

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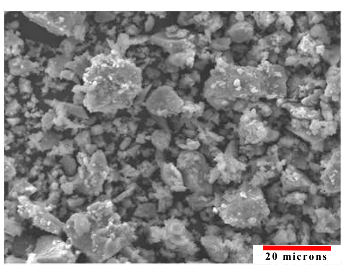
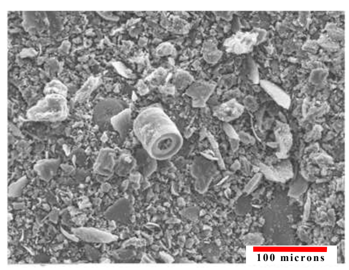
General Characteristics – Particle Size & Shape

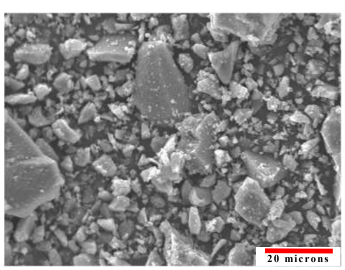
Portland Cement

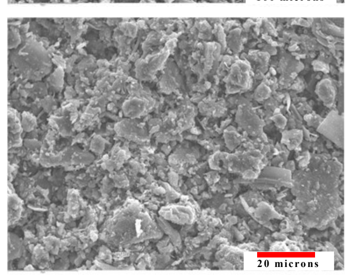




Natural Pozzolan

Slag Cement





Natural Pozzolan

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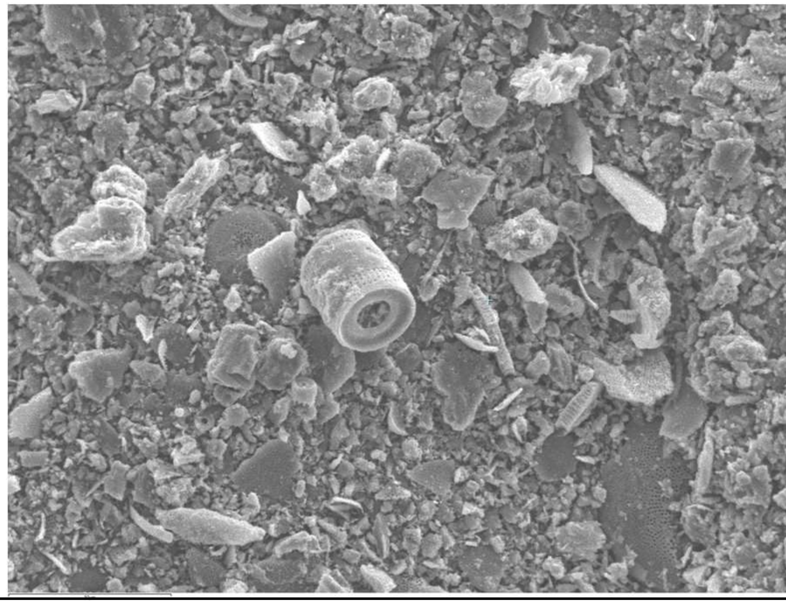
Natural Pozzolan – Particle Size & Shape



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SCMs – What's our options?

- Fly ash has been our "go-to" material
- Many materials can be used
  - fly ash, slag cement, natural pozzolans, ground glass, silica fume
- Each has strengths and weaknesses
- Market availability often dictates what alternatives we have to fly ash, if any

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Why do we use fly ash?

- Clearly the “go-to” SCM for many years

1. Fly ash improves the properties of concrete and offers other advantages
2. Reserves – there is nothing else available that provides the same performance and advantages, and is available in comparable quantities

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Why do we use fly ash?

- It works
  - Cement replacement
  - Improves concrete performance
  - Ancillary benefits

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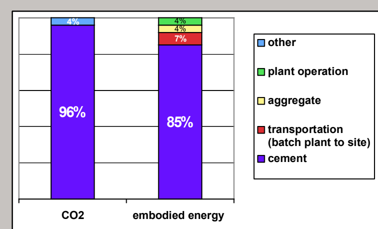
Cement Replacement

- Reduces cost – 3:5:6
  - If we cannot reduce cost with an SCM, straight cement is an option **<u>IF</u>** we meet performance criteria (e.g., ASR mitigation, protection from sulfate attack) … except…
- Sustainability goals
  - Reduces GHG
  - Reduces embodied energy



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Performance – Key Reason for Use

- Since its first use in the 1940's fly ash has been recognized as improving concrete properties

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Performance – Key Reason for Use

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JOURNAL
of the
AMERICAN CONCRETE
INSTITUTE

7400 SECOND BOULEVARD, DETROIT, MICHIGAN . . . . . . MAY-JUNE 1937

Properties of Cements and Concretes Containing Fly Ash*

BY RAYMOND E. DAVIS[1], ROY W. CARLSON[2], J. W. KELLY[3], AND HARMER E. DAVIS[4]
MEMBERS AMERICAN CONCRETE INSTITUTE

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1937 – Davis et al. identified:

Concretes containing properly constituted fly-ash cements when compared with concretes containing portland cements exhibit:

(1) About the same water requirement to produce a given consistency

(2) Somewhat lower compressive strength at early ages but substantially higher compressive strength at later ages under normal conditions of moist curing

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1937 – Davis et al. identified:

Concretes containing properly constituted fly-ash cements when compared with concretes containing portland cements exhibit:

(3) Compressive strengths which are substantially higher at early ages when cured at higher temperatures

(4) Shrinkage is likely to be no more and may be less

(5) Lower heat of hydration

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1937 – Davis et al. identified:

Concretes containing properly constituted fly-ash cements when compared with concretes containing portland cements exhibit:

(6) About the same or somewhat less resistance of freezing and thawing

(7) Greater resistance to sulfate action

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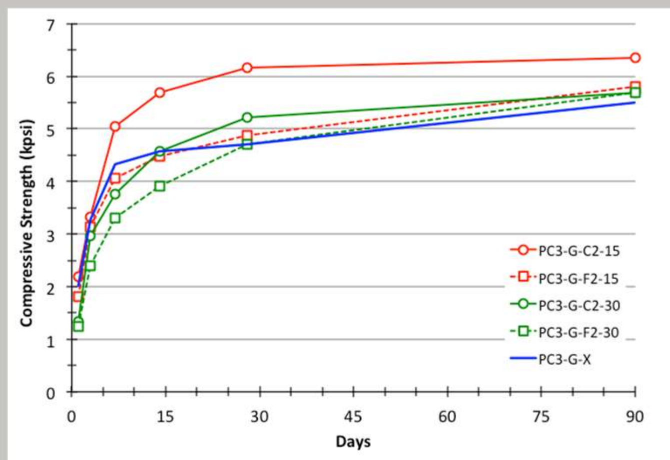
Strength – 2014 Research



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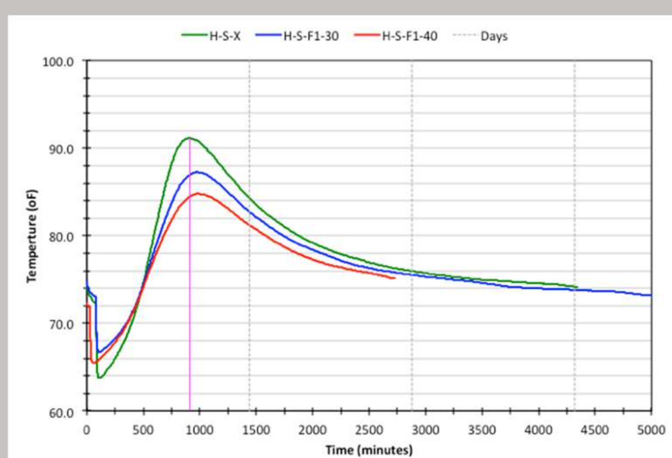
Calorimetry – 2014 Research



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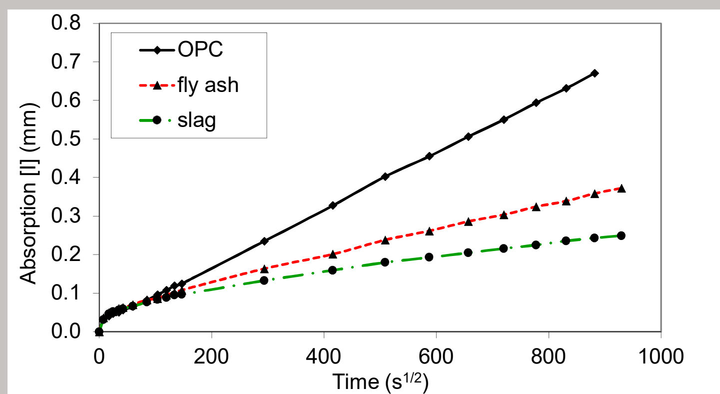
Sorptivity of 15% $MgCl_2$ into Different 0.45 *w/c* Concrete Mixtures



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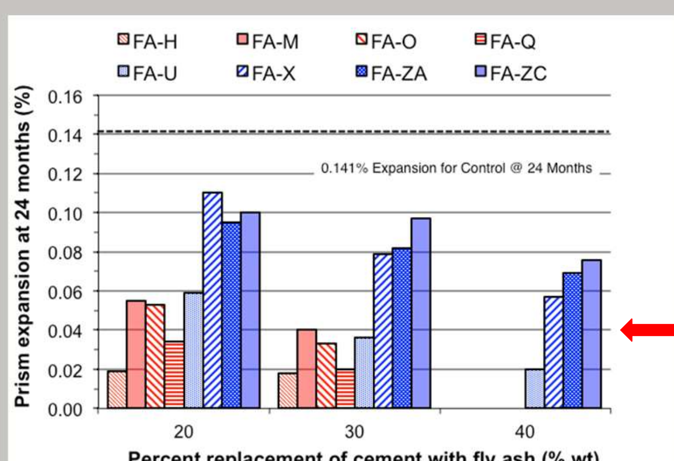
ASTM C1293



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So what's the problem?

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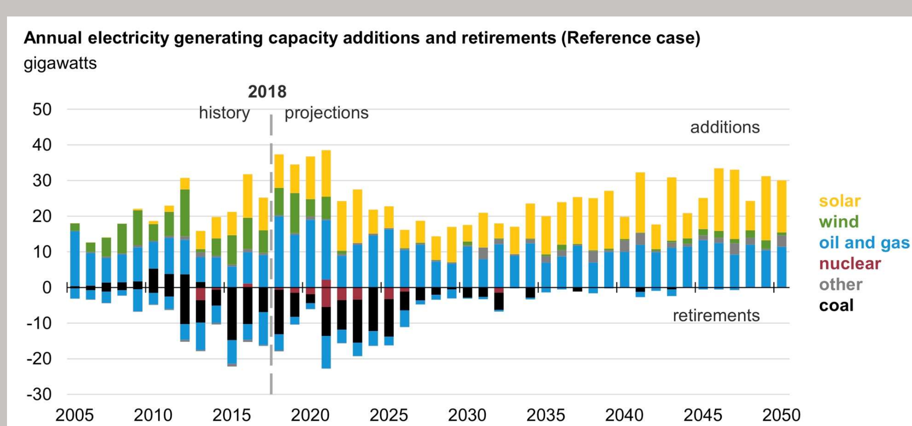
Coal-fired Power Plants are Being Retired



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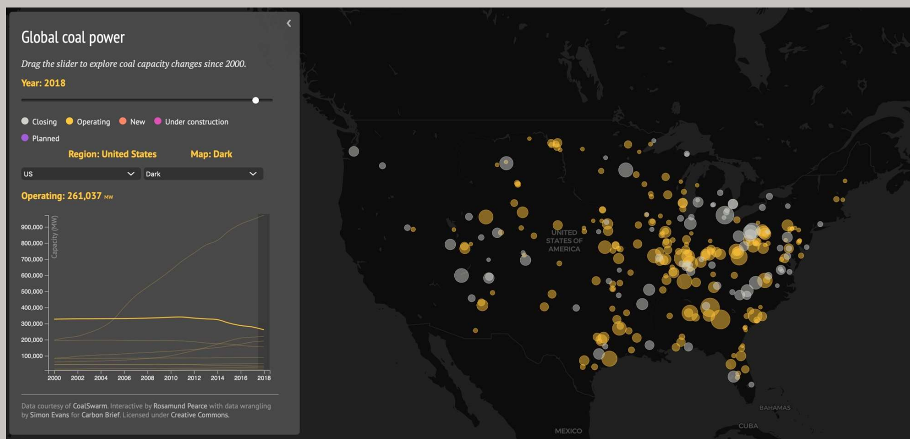

Source: CarbonBrief

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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
- Scheduled for closure at the end of 2019

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The Problem

- Fly ash supplies have been challenged by 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

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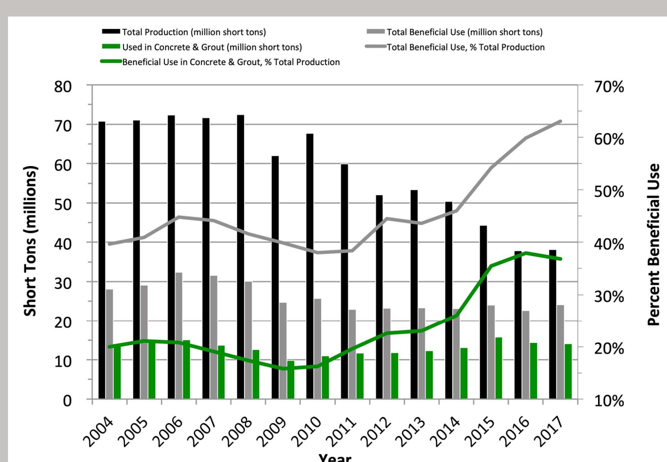
Ash Production is Dropping



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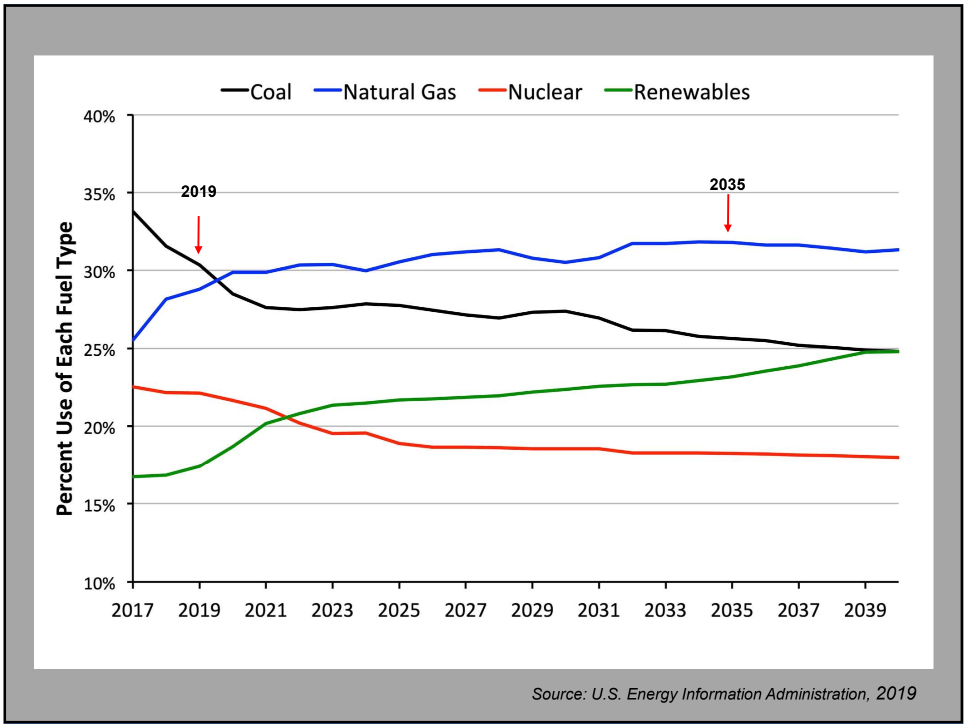
Coal
Natural Gas
Nuclear
Renewables
Percent Use of Each Fuel Type
40%
35%
30%
25%
20%
15%
10%
2019
2035
2017
2019
2021
2023
2025
2027
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2039
Source: U.S. Energy Information Administration, 2019

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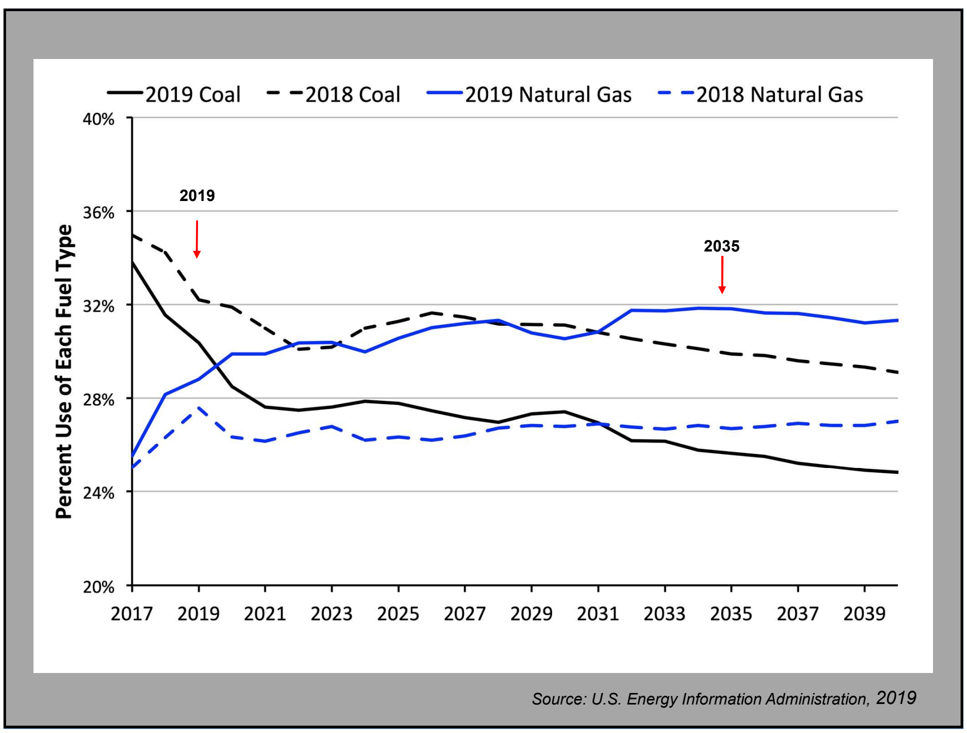
2019 Coal
2018 Coal
2019 Natural Gas
2018 Natural Gas
Percent Use of Each Fuel Type
40%
36%
32%
28%
24%
20%
2019
2035
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
Source: U.S. Energy Information Administration, 2019

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So What's Up With Fly Ash?

- Domestic fly ash production (new production) will be gradually decreasing over the next 20 years and beyond
  - Domestic production should stabilize (next 5 years) – reductions in coal–fired power will plateau
  - Fewer plants, running at a higher percentage of capacity
  - Suppliers believe that although total reserves may 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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So What Else is Up With Fly Ash?

- Challenges
  - Pollution control measures will affect "fresh" ash
    - Powdered Activated Carbon
    - Trona
  - Competing with other markets for the material
  - Lower supply – consider ash once rejected?
  - Harvested Ash – A New Frontier

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Options

- What will replace fly ash if needed?
  - Slag cement (*existing solution*)
  - Natural pozzolans (*existing solution*)
  - Harvested fly ash (*emerging solution*)
  - Ash Imports (*emerging solution*)
  - Lower quality fly ash (*last resort*)
  - New Materials (colloidal silica, ground glass)
  - Straight cement

Are existing tests and specifications adequate?

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Options

- Slag Cement
  - Currently used, excellent solution
  - Geographically limited
  - Good performance as a cement replacement and as an ASR mitigator
    - Higher replacement levels required compared to ash
  - Concerned about scaling? Make Curing Great Again!

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Slag Cement - Hydration

- Slag cement is hydraulic and produces calcium silicate hydrate (C-S-H) as a hydration product
- Slag cement reacts slower than portland cement
  - Hydration of portland cement produces C-S-H and CH
  - CH reacts with the slag cement, breaking down the glass phases and causing the material to react with water and form C-S-H
- Slag cement is not pozzolanic
  - It does consume CH by binding alkalis in its hydration products
  - Provides the benefits of a pozzolan

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Slag Cement

- Because slag cement is slower to react, strength development can be slower compared to OPC concrete
- Curing is always essential for achieving a quality product; it is more critical with slag-cement-based concrete given the prolonged set time
- The slower reaction rate, especially at lower temperatures, is often overlooked, and this can lead to durability issues such as scaling when not properly cured
- A slower reaction rate and associated lower heat evolution makes slag cement an ideal ingredient for mass concrete placement where control of internal temperatures is critical to achieving durability
- Up to 80% replacement of OPC with slag cement is used for mass concrete

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Slag Cement

- Slag cement is effective at mitigating ASR
  - Requires higher replacement rates than Class F ash (e.g., > 50%)
- ASR mitigation stems from a number of mechanisms
  - Slag cement binds alkalis in reaction products
  - Increased hardened cement paste density
    - Lower permeability
    - Improves resistance to ASR and external sulfate attack

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Options

- Natural Pozzolan
  - With decreased fly ash supplies, natural pozzolan reserves once overlooked are now being tapped
  - Similar to Class F ash in performance
  - Examples: Calcined clay or shale, volcanic materials such as dacite, rhyolite
  - Geographically limited – primarily in western U.S.
  - WITH NEW SOURCES - VERIFY PERFORMANCE

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Natural pozzolanic materials

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- Global distribution: natural pozzolans vs. volcanics

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Natural Pozzolans

- Examples of natural pozzolans include
  - Volcanic ashes
  - Opaline cherts and shale
  - Tuffs
  - Pumicite
  - Various calcined clays and shales
- Some natural pozzolans can be used as mined
- Most require processing such as drying, calcining, or grinding

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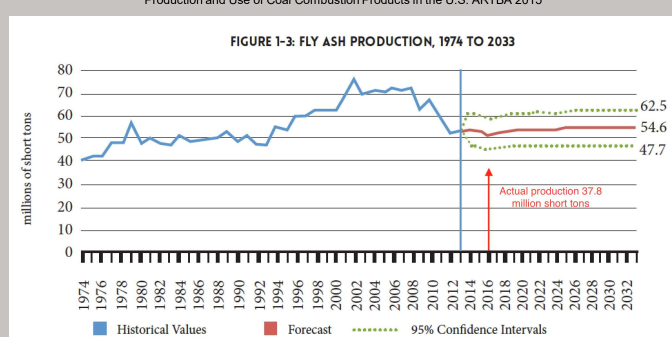
Recovered Ash

- Significant volumes of high quality fly ash have been disposed of
- Not all is recoverable, but a large fraction is

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



Approximately 2000 million short tons 1974 - 2013

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Recovered Ash

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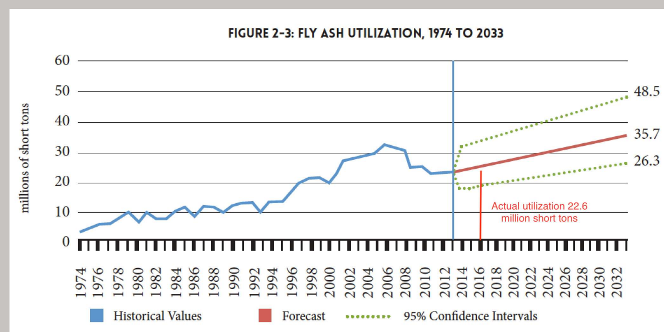
Production and Use of Coal Combustion Products in the U.S. ARTBA 2015



Approximately 650 million short tons 1974 – 2013
~33% utilization – 1350 million short tons disposed

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Harvested Ash

- With diminishing production, ash marketers are turning to land fills & ash ponds to recover fly ash
  - Most recovered sources are Class F ash – Class C possible
  - Limited research to date on performance of recovered ash – most is positive
- All recovered sources will require processing
  - Drying, sizing, and blending
  - Could lead to more uniformity if processed diligently

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Harvested Ash

- Concerns
  - Uniformity – ash in ponds will stratify based on density; strata in land fills/ponds will represent different coal sources and burning conditions
  - Weathering – Does storage alter the chemical or physical nature of the ash?
  - Adulteration – many land fills/ponds hold bottom ash, scrubber residue, and other wastes in addition to ash
  - Infiltration – clays and other materials may infiltrate and co-deposit
  - Testing – do current specifications provide tests & limits that will adequately screen recovered ash?

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Harvested Ash

- Concerns (continued)
  - Current federal and state regulations create pressure to close disposal ponds quickly, leaving insufficient time to recover and use the ash – also restrict opening closed impoundments
  - Power producers have little to no incentive to use ash beneficially under current regulations.
- Benefits
  - 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

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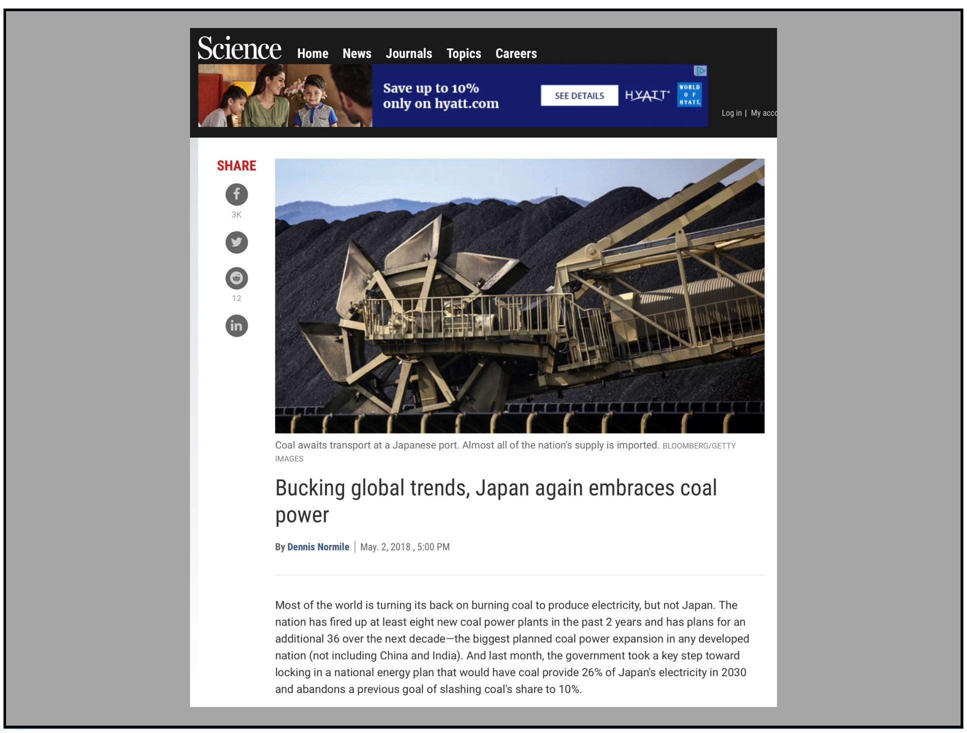

Coal awaits transport at a Japanese port. Almost all of the nation's supply is imported. BLOOMBERG/GETTY IMAGES

Bucking global trends, Japan again embraces coal power

By Dennis Normile | May. 2, 2018 , 5:00 PM

Most of the world is turning its back on burning coal to produce electricity, but not Japan. The nation has fired up at least eight new coal power plants in the past 2 years and has plans for an additional 36 over the next decade—the biggest planned coal power expansion in any developed nation (not including China and India). And last month, the government took a key step toward locking in a national energy plan that would have coal provide 26% of Japan's electricity in 2030 and abandons a previous goal of slashing coal's share to 10%.

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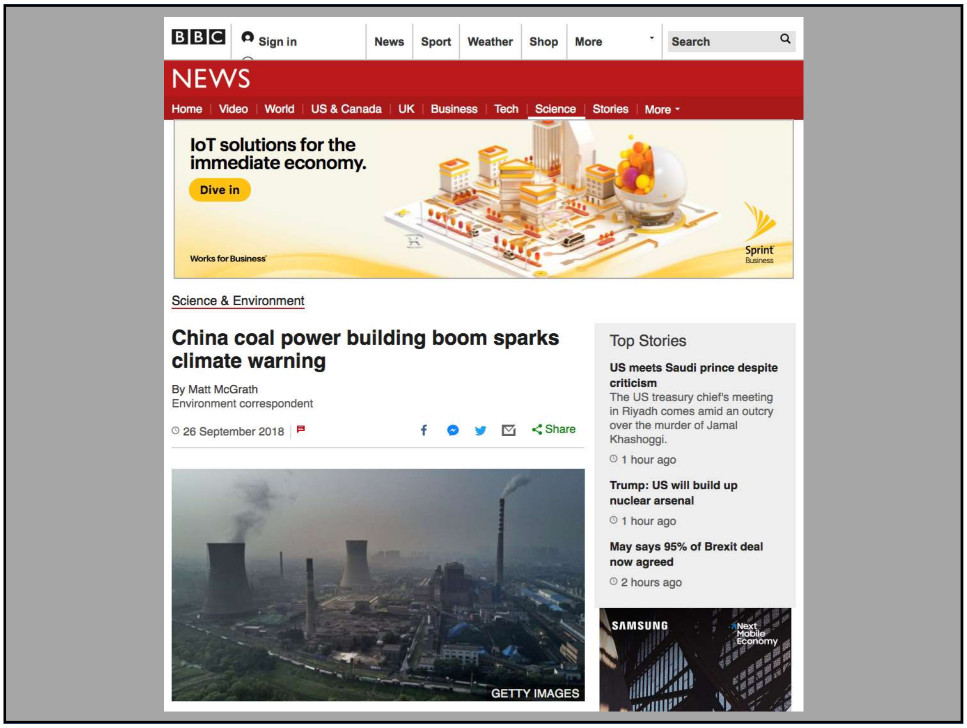
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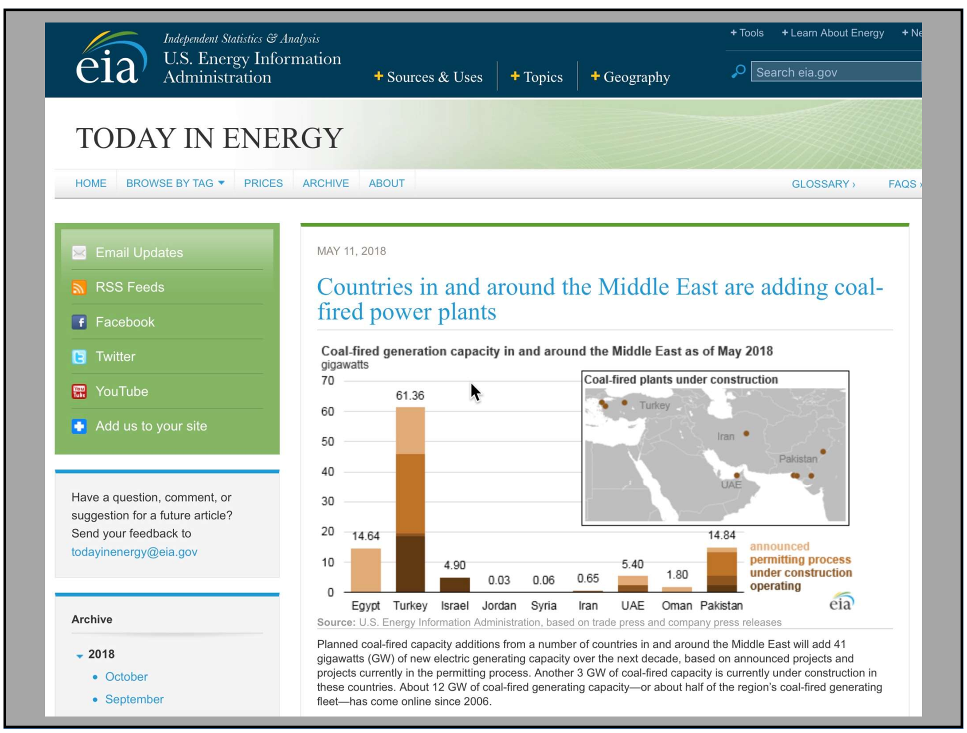
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Archive
2018
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September
MAY 11, 2018
Countries in and around the Middle East are adding coal-fired power plants
Coal-fired generation capacity in and around the Middle East as of May 2018
gigawatts
70
60
50
40
30
20
10
0
61.36
14.64
4.90
0.03
0.06
0.65
5.40
1.80
14.84
Egypt
Turkey
Israel
Jordan
Syria
Iran
UAE
Oman
Pakistan
Coal-fired plants under construction
Turkey
Iran
Pakistan
UAE
announced
permitting process
under construction
operating
eia
Source: U.S. Energy Information Administration, based on trade press and company press releases
Planned coal-fired capacity additions from a number of countries in and around the Middle East will add 41 gigawatts (GW) of new electric generating capacity over the next decade, based on announced projects and projects currently in the permitting process. Another 3 GW of coal-fired capacity is currently under construction in these countries. About 12 GW of coal-fired generating capacity—or about half of the region's coal-fired generating fleet—has come online since 2006.

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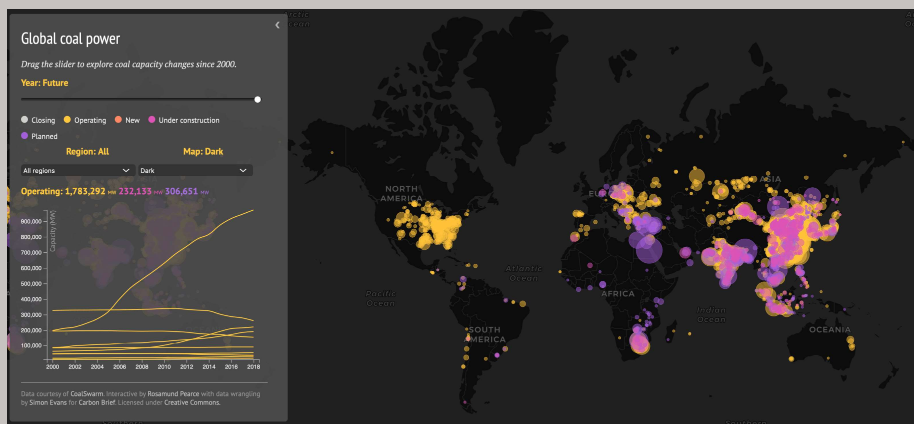
Coal-fired Power Plants are Being Retired



Source: CarbonBrief

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Imports

- Certainly in the near term, and potentially long term, imports will become a significant source
- Imports are already a significant contributor in some markets
- China is COMMITTED to keeping shipping costs low, making imports cost effective
- Issues of quality must be addressed

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Increased Need for Testing

- In general, inconsistent performance has caused ASTM & AASHTO to re-evaluate specifications
- Items under consideration
  - Revise classification
    - Use CaO instead of SUM (done); CaO more predictive of key properties
  - Move to ASTM C1567 for assessing ASR mitigation (done)
  - Pozzolanic and cementitious activity (major need)
    - Current SAI is inadequate in many cases
  - Particle size – need better test (major need)
  - Adsorption potential (tests have been developed)
    - Use adsorption based tests rather than LOI

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New Materials – Ground Glass

- Total Production (~ 11 million tons/year in U.S.)
  - Container Glass (~ 3 million tons/year in U.S.)
  - E-Glass (100,000 lbs/year in U.S.)
  - Recycling capacity exceeds generation (U.S. EPA)
- Primary Processing – Grinding
  - -325 mesh
  - Composition is uniform

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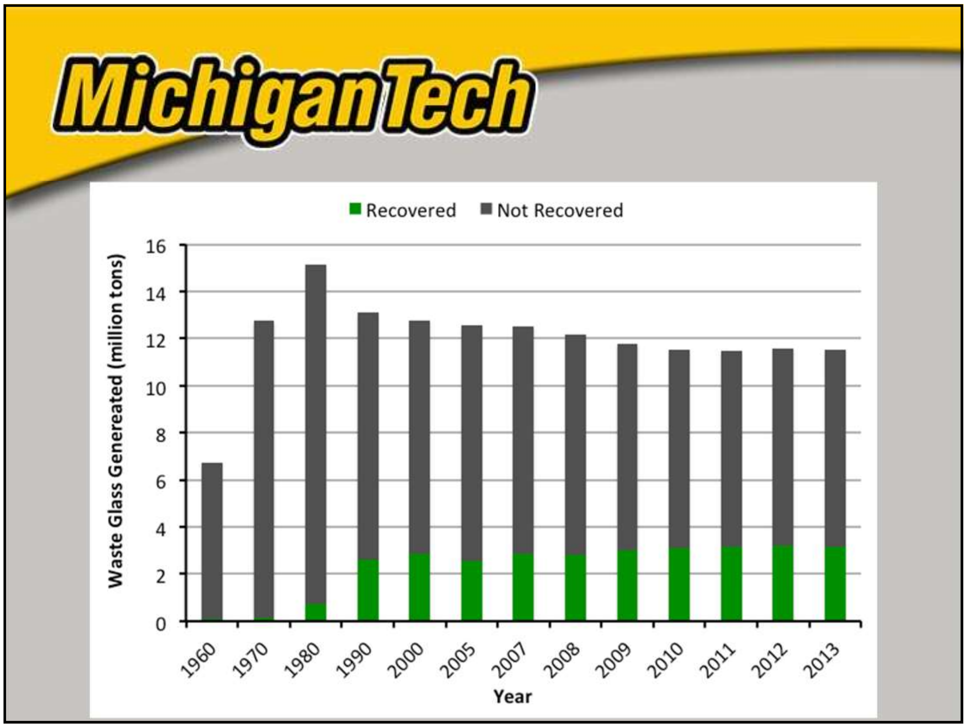

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Nominal Glass Composition

	Soda Lime Glass			E-Glass
	Bottle Glass	**Plate Glass**	**Display Glass**	
SiO_2	71	71	63	60
Al_2O_3	1.8	0.4	18	12.5
Fe_2O_3	0.6	0.4	0.0	0.4
B_2O_3	0.01	0.02	2.0	0.0
MgO	0.90	3.9	2.5	2.9
CaO	11	9.3	0.1	21
Na_2O	**13**	**13**	**13**	**0.75**
K_2O	0.5	0.05	0.0	0.06

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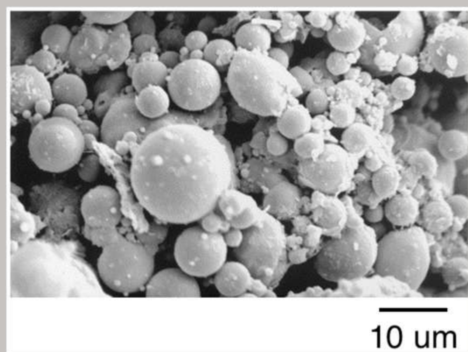
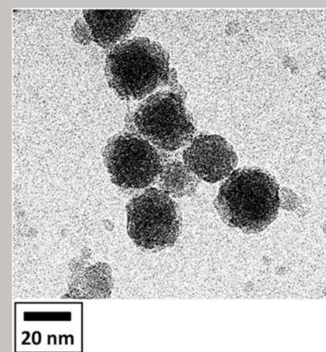
Colloidal Silica



- **Class F Fly Ash**



- **Colloidal Silica**

After J. Belkowitz, Intelligent Concrete LLC

•Green, B. ACI Materials Journal, SP-254-8, 121–132, 2008.
•Kudyba-Jansen, A., Hintzen, H., Metselaar, R. Materials Research Bulletin, 36, 1215 – 1230, 2001.

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Bottom Ash

- ASTM is discussing a "Class B" for bottom ash
- Mimics the properties of the fly ash from the same coal but attributes are subdued, relative to the fly ash
  - Contributes to concrete properties
  - Mitigates ASR
- Angular – increased water demand
- Commonly comingled with fly ash in recovered materials

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More cement?

- Once 3:5:6 doesn't apply (e.g., 6:6:6) the cement replacement advantage is diminished
- Sustainability goals are important <u>only</u> if incentivized (i.e., carbon tax)
- A higher cement content (particularly low alkali) is not out of reality **<u>IF</u>** the mixture meets performance
  - ASR mitigation
  - Sulfate attack prevention

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ASR Risk Mitigation - AASHTO

Standard Practice for

Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

AASHTO Designation: R 80-17[1]

Technical Section: 3c, Hardened Concrete

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ASR Risk Mitigation - ASTM

Designation: C1778 – 16

Standard Guide for
Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete[1]

- Standard guides for identifying reactive aggregates and recommending mitigation strategies
- USE THEM!

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ASR Risk Mitigation - ASTM

Designation: C1778 – 16

ASTM INTERNATIONAL

Standard Guide for
Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete[1]

- Performance Based Approach
- Prescriptive Approach
  - Limit alkali loading, or
  - Use SCMs

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Proper Testing

- Many specifiers use existing ASR tests incorrectly
  - The tests use are intended to evaluate a material performance, not a mixture performance
  - Expansion values based on the prescribed mass (volume) of aggregate
  - Results cannot be “mathematically combined”
  - Running ASTM C1260 (AASHTO T 303) and ASTM C1293 in any way other than how they were designed is a waste of time and money – and will lead to errors

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Proper Testing

- In a world where fly ash will cost as much – or more – than cement, the days of overdosing is over
- Even with recovered and import ash, it is difficult to envision a market – near term – where fly ash is not equal to or greater than cement in price
- Optimal use of SCMs will become critical to extend sources and minimize costs

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What about tests and specifications?

- Existing tests and specifications provide little information on performance
- As recovered materials and other sources become more common, new tests and specifications are required that relate to performance (i.e., pozzolanic activity, hydraulic activity, particle size, adsorption)
- Need to let go of historic limits established in a completely different concrete world that mean little now
- Need to get more materials in the market – without sacrificing performance and quality

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Wrap-up

- SCMs are needed to produce durable concrete, especially with lower quality aggregates
- Fly ash has been our main SCM
- Fly ash supplies are challenged but they are not gone – and they are not going away
- 3:5:6 – Logistics…

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Wrap-up

- Near term solutions to meet the needed volume
  - Harvested ash
  - Imports
- Other solutions
  - Other materials to replace fly ash (slag cement)
  - New materials to supplement fly ash
  - Challenge is meeting the needed volumes

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Quiz Time!

- What is the primary reason for using fly ash in concrete?

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Quiz Time!

- At what year was the first research on fly ash use in concrete published?

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Quiz Time!

- Approximately how much ash is estimated to be available for harvesting from landfills/ponds?

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I'm not a psychic but I will answer any questions I can?

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