Natural Pozzolans as Sustainable Supplementary Cementitious Materials

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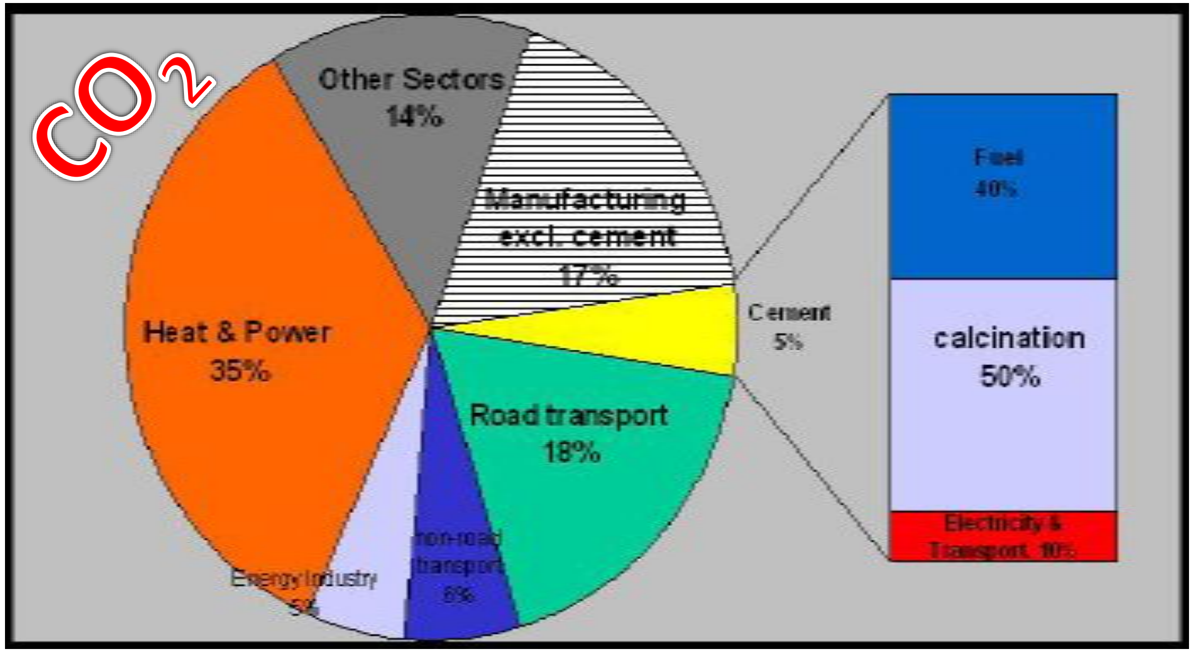
Why the need for SCMs?

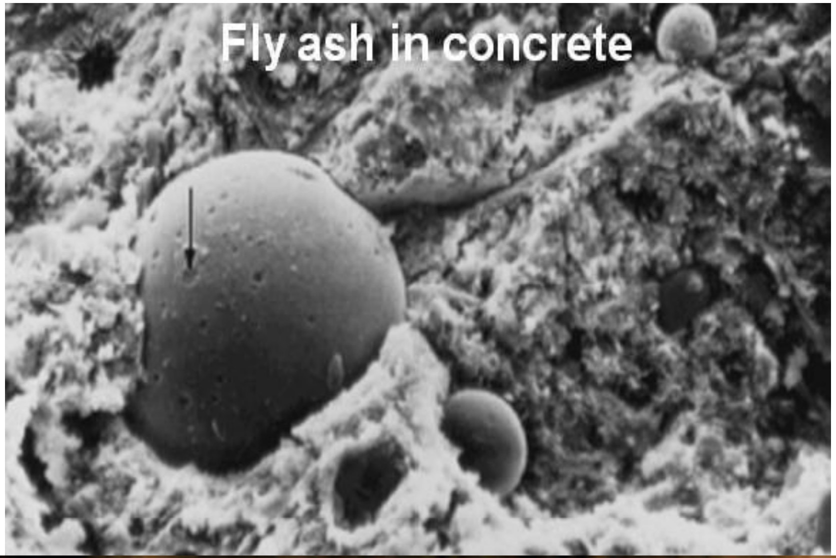
The concrete industry creates ~5% of worldwide man-made emissions of CO_2, of which 50% is from the chemical process and 40% from burning **fuel**.

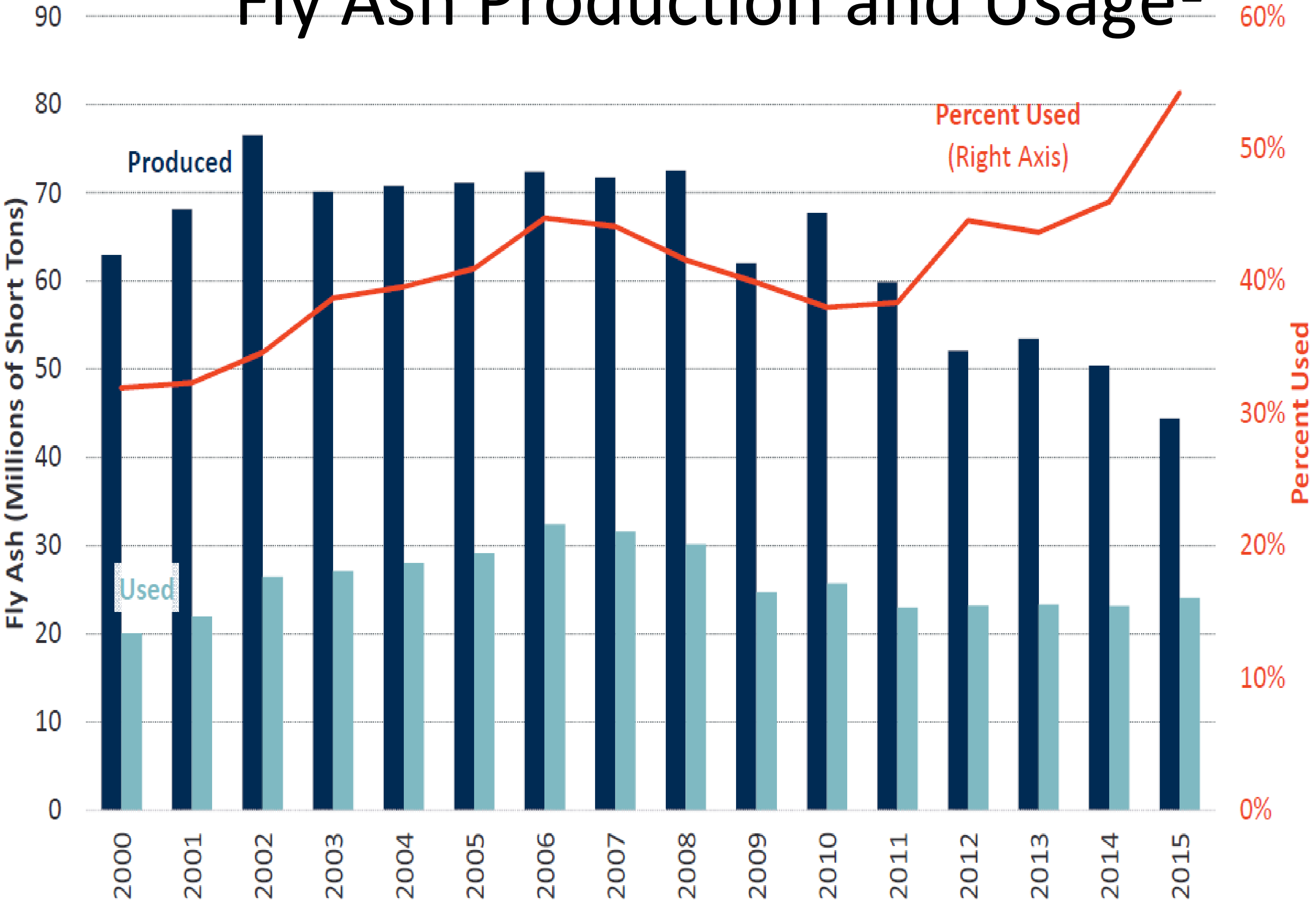


Why the need for SCMs?

"Memo: Cost saving measure...replace all 'Yes Men' with bobbleheads."

Fly Ash Production and Usage[1]





ACAA, 2015 Coal Combustion Product (CCP) Production & Use Survey Report from https://www.acaa-usa.org/Portals/9/Files/PDFs/2015-Survey_Results_Charts.pdf

8 Comments

NV Energy pulls plug on coal-fired power plant near Las Vegas

JULIE JACOBSON

This May 14, 2012, file photo shows the Reid Gardner Generating Station near a farm on the Moapa Indian Reservation in Moapa.

By Ken Ritter, Associated Press
Thursday, March 16, 2017 | 12:01 p.m.

LAS VEGAS — Environmental advocates and members of an Indian tribe who live nearby hailed the closure today of an embattled coal-fired NV Energy power plant 40 miles north of Las Vegas.

Officials from the state's dominant electric utility marked the occasion by flipping a transformer switch to disconnect the fourth and final unit of the Reid Gardner Generating Station near Moapa from the regional power grid. The first three units shut down in late 2014.

The Moapa Band of Paiutes, which has long blamed the Reid-Gardner plant for environmental and health concerns, issued a statement applauding NV Energy "for standing by its commitment to retire this plant."

State lawmakers called for the closure in 2013.

RenewNV, a group of organizations advocating for use of renewable energy, called the shutdown a victory for clean air and healthy communities.

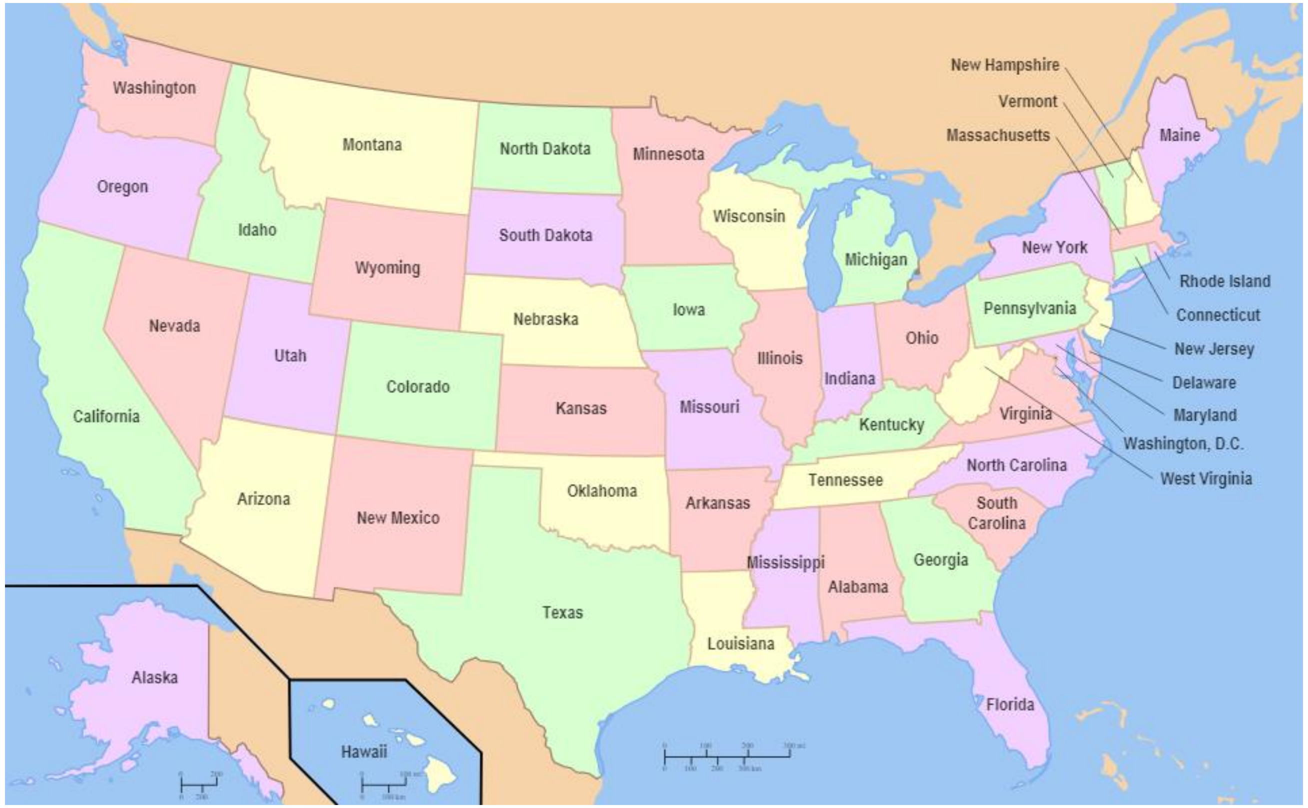
The closure leaves just one coal-fired generating station in the state — a plant that NV Energy co-ow near Valmy in northern Nevada. It is due to close by 2025.

NV Energy also plans by the end of 2019 to give up its 11.3 percent stake in the coal-fired Navajo Generating Station east of Page, Arizona. That plant is operated by Phoenix-based SRP.

NV Energy has shifted production since 2005 toward renewable sources, including 19 geothermal, 1 solar, six hydroelectric, one wind and several biomass and methane plants in Nevada, said Starla La company environmental services executive. She said carbon emissions have been cut 44 percent ove the same period.

Since 2010, nearly 40 percent of the capacity of the nation's fleet of coal-fired power plants has either been shut down or designated for closure

In 2015, 94 coal-fired power plants closed in US
→lost roughly the same total capacity of all of Kentucky's electric sector coal plants that year.



Statistics from [American Coalition for Clean Coal Electricity]

Coal-Fired Unit Closures Planned for 2017

COMPANY	PLANT	STATE	UNIT	NET SUMMER CAPACITY, MW	FIRST YEAR	ESTIMATED COAL USE, 2016, TONS
FEBRUARY						
Nevada Power	Reid Gardner [1]	NV	4	257	1983	**22,400**
MARCH						
Public Service of Colo.	Valmont [2]	CO	5	184	1964	**437,378**
APRIL						
Florida Power & Light	Indiantown [3]	FL	1	330	1995	**234,932**
Tennessee Valley Auth.	Paradise	KY	1	628	1963	**1,051,734**
	Paradise	KY	2	602	1963	**1,112,976**
Virginia Electric & Power	Yorktown	VA	1	159	1957	**15,332**
	Yorktown	VA	2	164	1958	**91,050**
JEMB Family; others	B.L. England [4]	NJ	2	150	1964	**40,642**
JUNE						
Great River Energy	Stanton	ND	1	188	1967	**612,216**
Brayton Point Energy	Brayton Point	MA	1	225	1963	**454,126**
	Brayton Point	MA	2	238	1964	**175,436**
	Brayton Point	MA	3	575	1969	**288,879**
PSEG	Mercer	NJ	1	316	1960	**0**
	Mercer	NJ	2	316	1961	**1,788**
PSEG	Hudson	NJ	2	620	1968	**4,746**
DECEMBER						
Appalachian Power	Kanawha River	WV	1	200	1953	**0**
	Kanawha River	WV	2	200	1953	**0**
Public Service of N.M.	San Juan	NM	2	340	1973	**1,058,979**
	San Juan	NM	3	497	1979	**1,418,054**
Tennessee Valley Auth.	Johnsonville	TN	1	107	1951	**361,965**
	Johnsonville	TN	2	107	1951	**367,866**
	Johnsonville	TN	3	107	1952	**335,621**
	Johnsonville	TN	4	107	1952	**333,329**
Xcel	Cherokee [5]	CO	4	352	1968	**934,543**
TOTALS:	**14 plants, 24 units**			**6,989**		**9,353,992**

[1] Closed February 28.

[2] Stopped burning coal March 3; will remain on "reserve shutdown" as a natural gas fired unit through October 1.

[3] FPL bought this plant in October, 2016, with the intention of shutting it down to save millions on an expensive power-purchase agreement, and said it would reduce the plant to 5 percent annual capacity factor immediately. The figure for coal used in 2016 reflects the amount that would not be used because of this reduction.

[4] Was scheduled to close April 30, 2017, pending a coal-to-natural gas conversion. On April 17, however, the regional grid operator, PJM, announced the unit must stay available for longer for grid reliablility needs, though it is expected to be used very little if at all.

[5] Coal-to-natural-gas conversion.

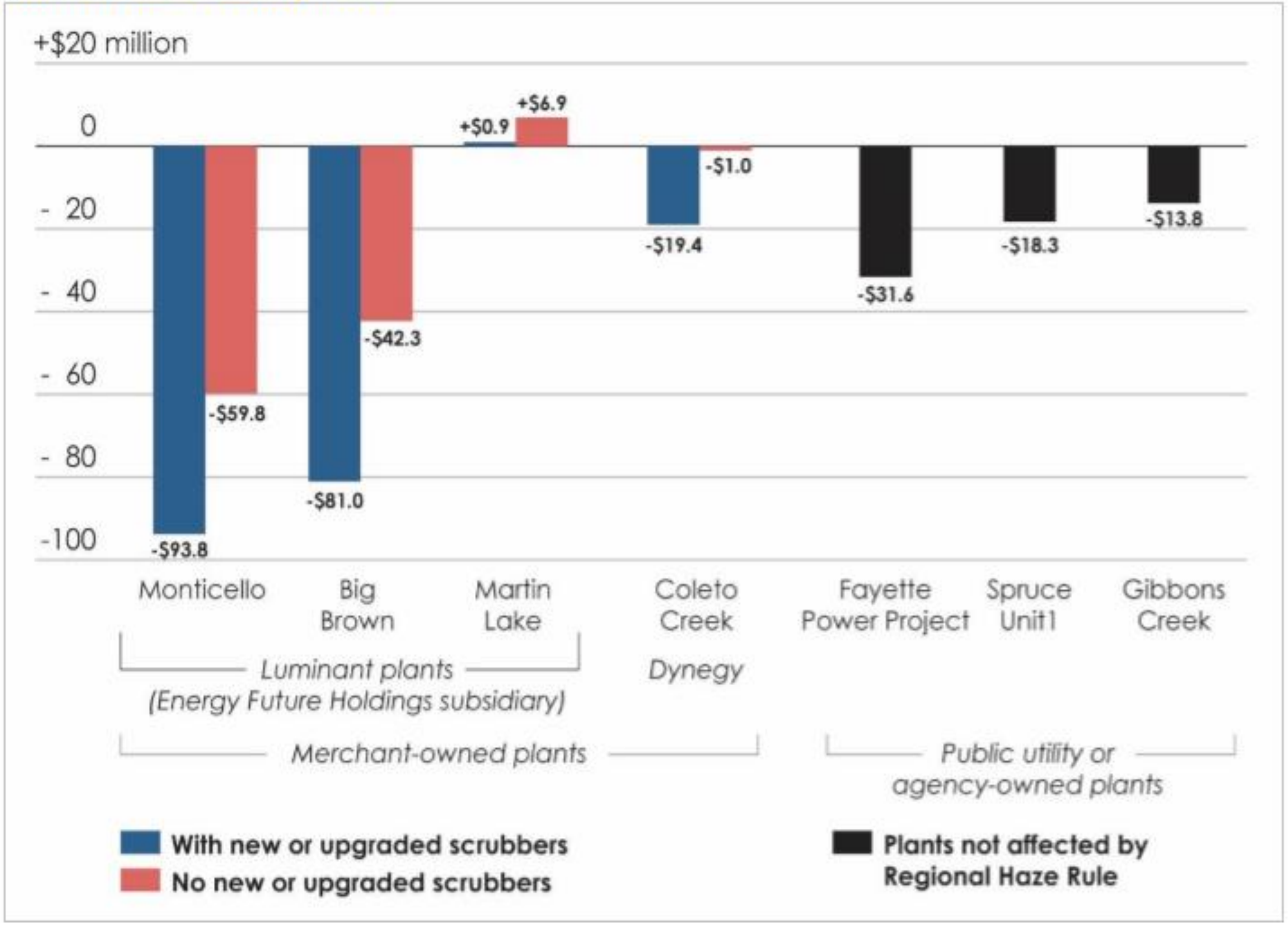
Coal-Fired Unit Closures Planned for 2018

COMPANY	PLANT	STATE	UNIT	NET SUMMER CAPACITY, MW	FIRST YEAR	ESTIMATED COAL USE, 2016, TONS
APRIL						
Duke Energy Florida	Crystal River	FL	1	370	1966	**268,261**
	Crystal River	FL	2	499	1969	**288,691**
JEA; Florida Power & Light	St. Johns River	FL	1	626	1987	**1,128,494**
	St. Johns River	FL	2	626	1988	**1,272,466**
JUNE						
Dayton Power & Light; Dynegy; AEP	J.M. Stuart	OH	1	577	1971	**1,121,413**
	J.M. Stuart	OH	2	577	1970	**1,149,981**
	J.M. Stuart	OH	3	577	1972	**1,035,753**
	J.M. Stuart	OH	4	577	1974	**1,189,575**
Dayton P. & L.; Dynegy	Killen	OH	2	600	1982	**1,553,113**
Tennessee Valley Auth.	T. H. Allen	TN	1	247	1959	**646,521**
	T. H. Allen	TN	2	247	1959	**757,089**
	T. H. Allen	TN	3	247	1959	**691,913**
Northern Indiana Public Service/NiSource	Bailly	IN	7	160	1962	**361,446**
	Bailly	IN	8	320	1968	**491,660**
DECEMBER						
City of San Antonio	J. T. Deely	TX	1	420	1977	**738,482**
	J. T. Deely	TX	2	420	1988	**823,488**
Midwest Generation/EME	Will County	IL	4	510	1963	**1,281,054**
Wisconsin P. & L.	Edgewater	WI	4	302	1969	**652,862**
ALLETE (Minnesota Power); WPPI Energy	Clay Boswell	MN	1	68	1958	**269,742**
	Clay Boswell	MN	2	68	1960	**264,356**
Oklahoma Gas & Electric	Muskogee [1]	OK	4	487	1977	**1,545,543**
	Muskogee [1]	OK	5	502	1978	**1,296,912**
TOTALS:	**11 plants, 22 units**			**9,027**		**18,828,816**

[1] Coal-to-natural gas conversion.

https://cleantechnica.com/2017/04/24/us-coal-plant-closures-likely-eliminate-30-million-tonnes-annual-coal-demand/

Figure ES-1: Profitability of Coal-Fired Generators with IEEFA Base Case Generation and Market Price Assumptions

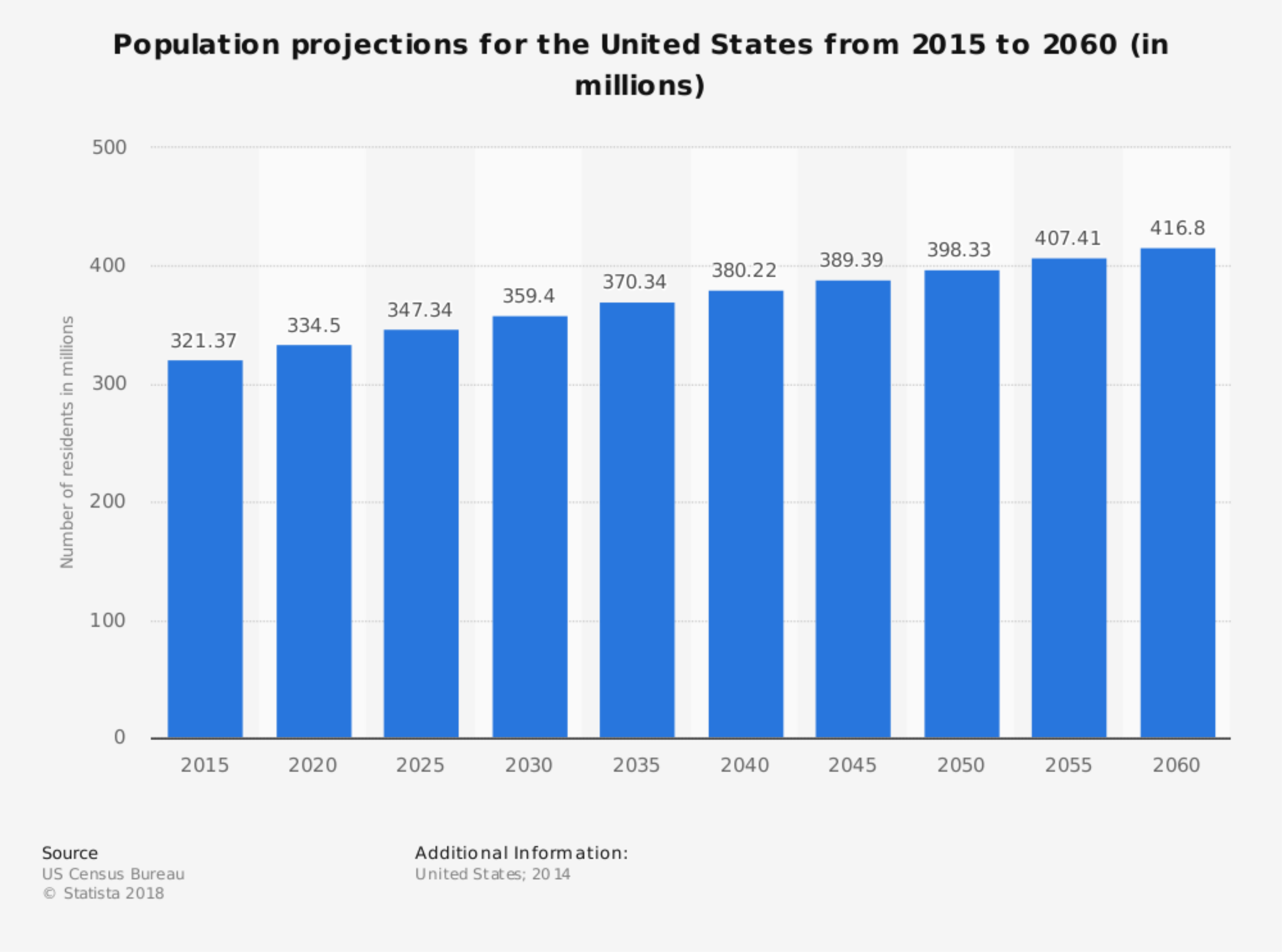


- EPA's regional haze rule
- Increase generation of natural gas-fired power plants & collapse of natural gas prices
  - Electricity generation from coal is 2nd to Natural Gas.
- Increased competition from new wind and solar resources due to steep declines in installation prices, improved operating efficiencies and transmission upgrades,
- Low energy market prices due to deregulated wholesale markets

Report from Institute for Energy Economics and Finiancial Analysis
http://ieefa.org/wp-content/uploads/2016/09/The-Beginning-of-the-End_September-2016.pdf

Supply and Demand Problems

- Population increasing
  - Current population is 7.3 million; UN projects worldwide pollution to reach 8.5 billion by 2030.
- Cement demand projected to increases
  - Currently global production is 3.6 billion tons of cement per year; this is expected to rise to 5.8 billion tons in 2050
- Majority of concrete contains SCMs
- Supply of fly ash will not keep place with demand



https://www.statista.com/statistics/267364/world-cement-production-by-country/

The importance of fly ash in concrete, coupled with reductions in fly ash supply in the US, has spurred a movement in the concrete sector to identify new sources of SCMs that can be fill this gap in the fly ash supply puzzle.

Supply Chain Puzzle: A Natural Fit

Pozzolan: reacts with $Ca(OH)_2$ from hydrated cement to form C-S-H

What makes a good pozzolan?

- High SiO_2 (and/or Al_2O_3) content
  - High amorphous content
- Fine powder

All at a Low Cost!

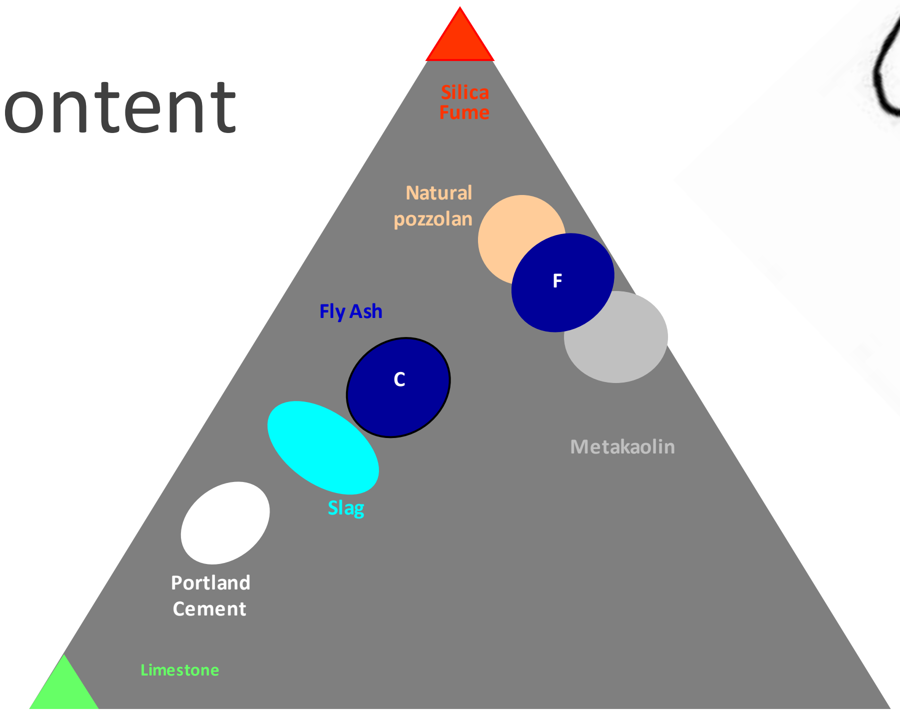


Figure: K. Scrivener

non-synthesized materials that are also pozzolanic; heated naturally

E.g., Volcanic ash; Tuffs; Zeolites; Pumice; Perlite; diatomaceous earth

Not a new material

- Many early-mid 20th century US concrete construction used All of these used natural pozzolans:
  - Golden Gate Bridge
  - Oakland Bay Bridge
  - Davis Dam
  - Flaming Gorge Dam
  - Friant Dam

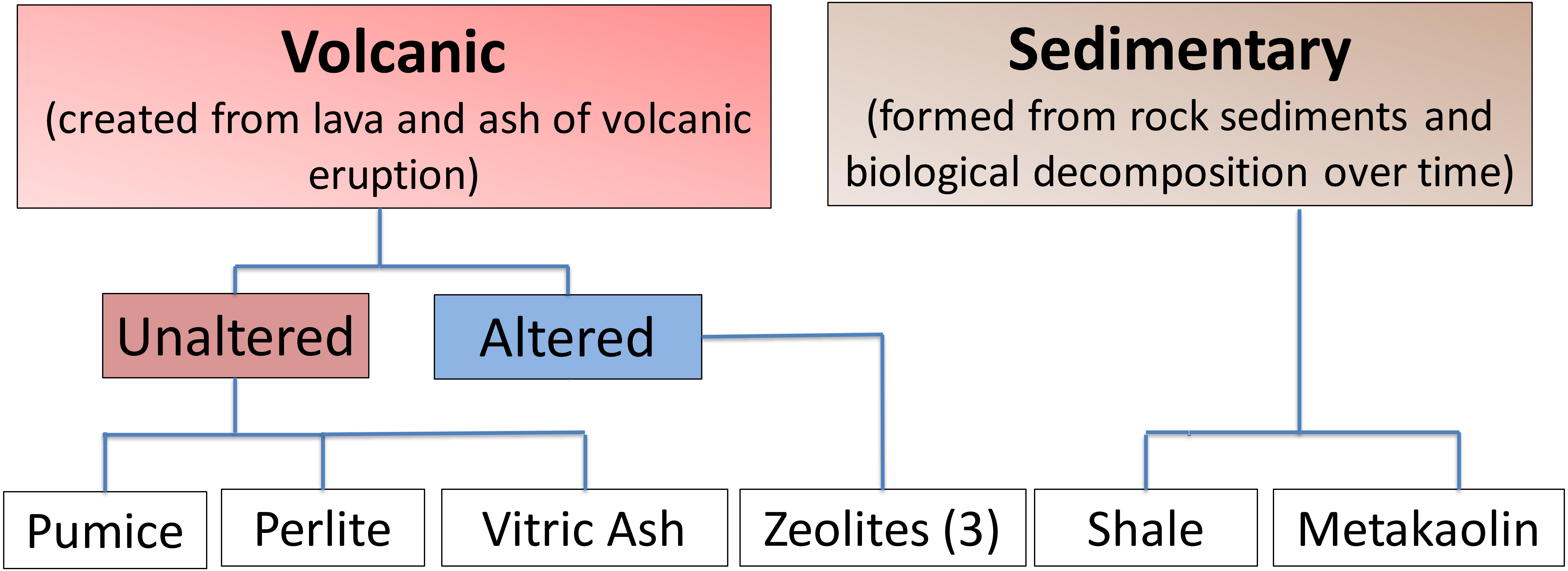
http://www.northsouth-h.com/wp-content/uploads/North-South-Holdings-Pozzolan-Project.pdf

Objective

- Evaluate the performance of natural pozzolans in a modern day concrete mixture
  - ASTM C 618 requirements for Class N pozzolans
  - Heat of Hydration
  - Fresh State Properties
  - Compressive Strength
  - Durability
    - Alkali Silica Reaction
    - Sulfate Attack

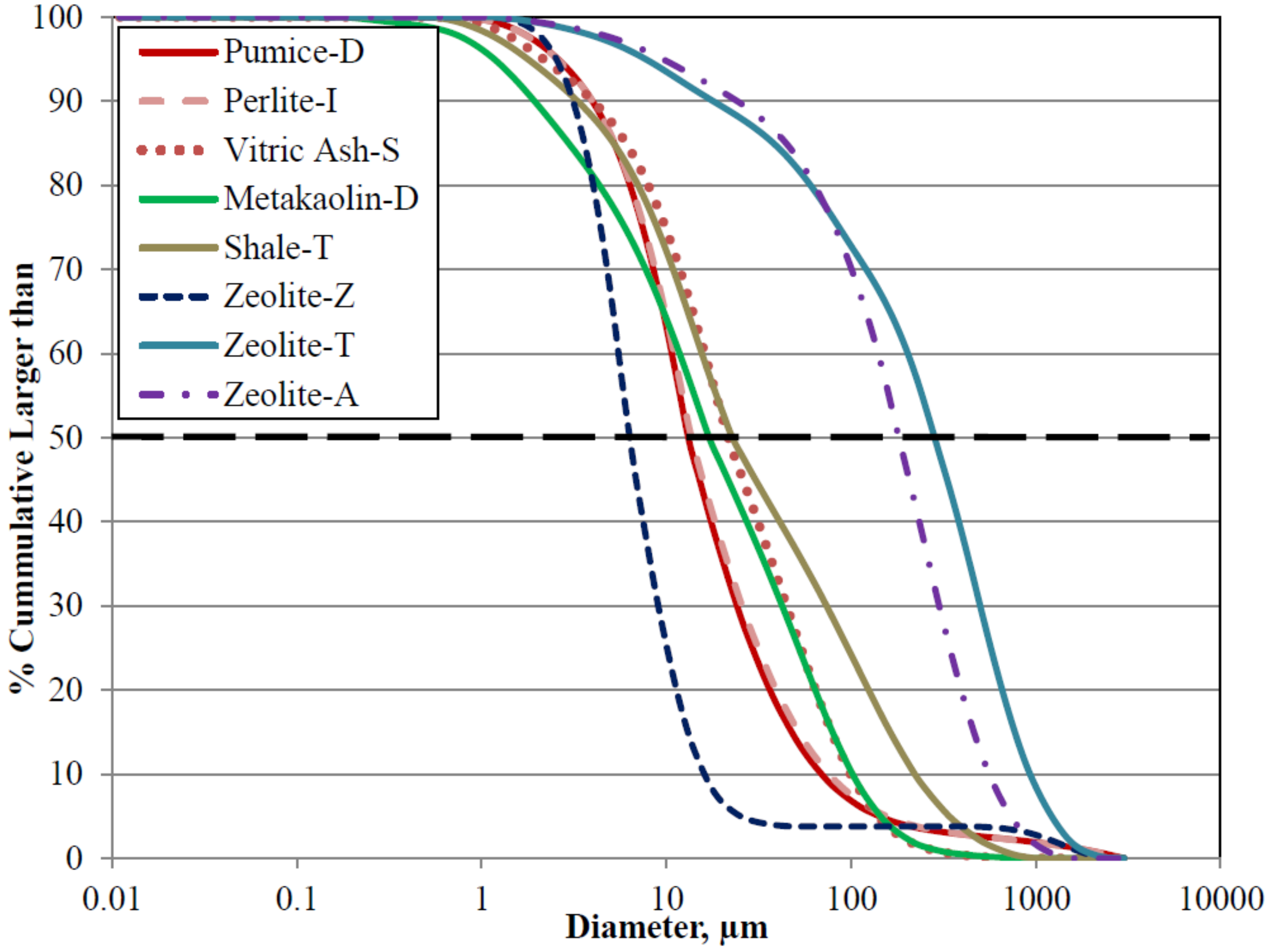
http://library.ctr.utexas.edu/ctr-publications/0-6717-1.pdf

Natural Pozzolan Classification: Origin



- All of these are fine powders with high SiO_2 and Al_2O_3
- Zeolites are crystalline, but dissolve anyway

Particle Size Distribution



Cost, Source, and Availability

Classification	Material	Approximate Cost ($/ton)	Availability ($tons/year)
Unaltered Volcanic	Pumice-D	$115	200,000
	Perlite-I	$125	N/A
	Vitric Ash-S	$130	300,000 - 1,000,000
Altered Volcanic	Zeolite-Z	$100	50,000
	Zeolite-T	$200*	10,000
	Zeolite-A	$150	500,000
Sedimentary	Metakaolin-D	$325*	30,000
	Shale-T	$50	4500

* Does not include shipping

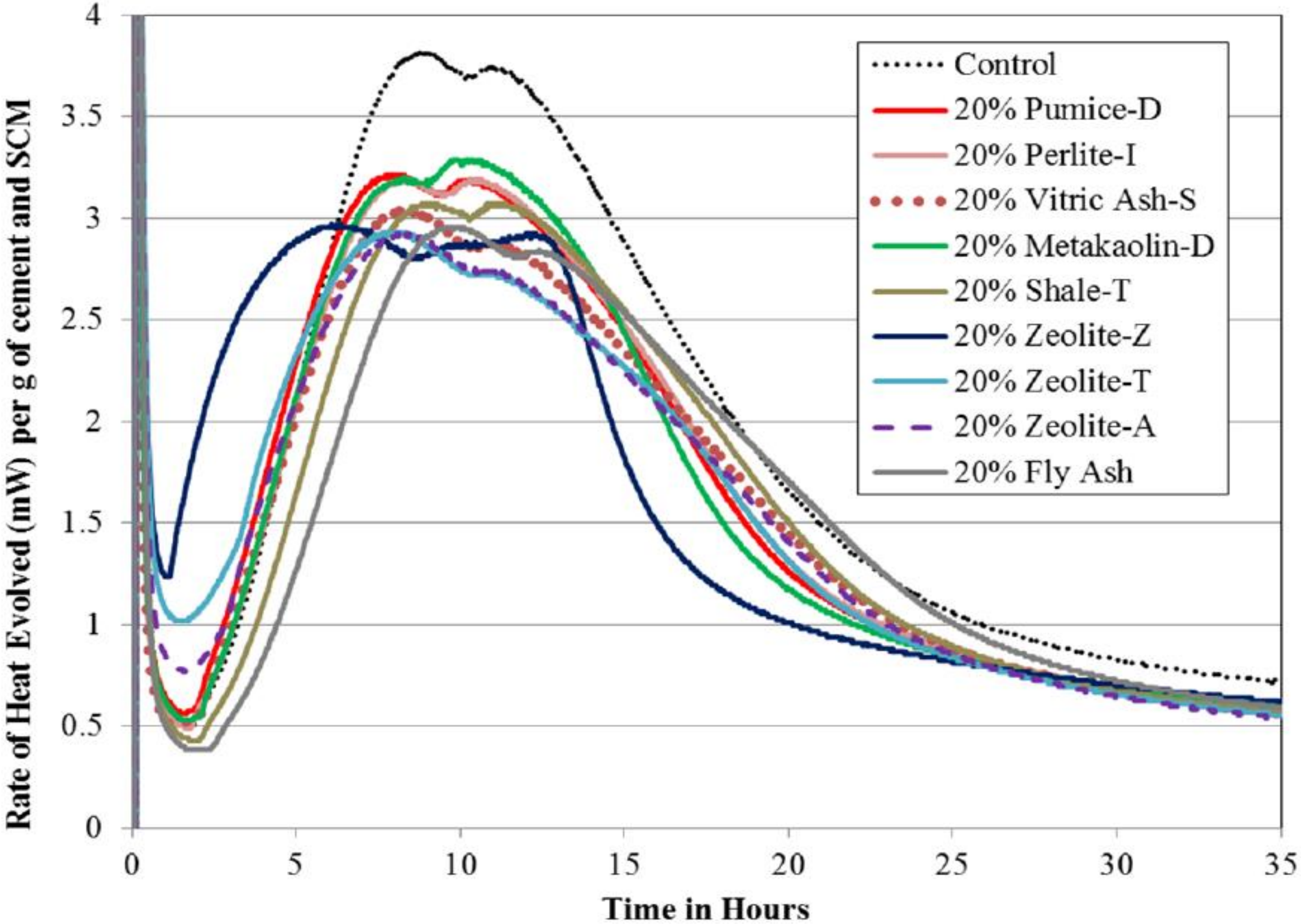
Cost of Cement: ~$110/ton
Cost of fly ash: ~$55/ton

Results: ASTM C618 Class N requirements

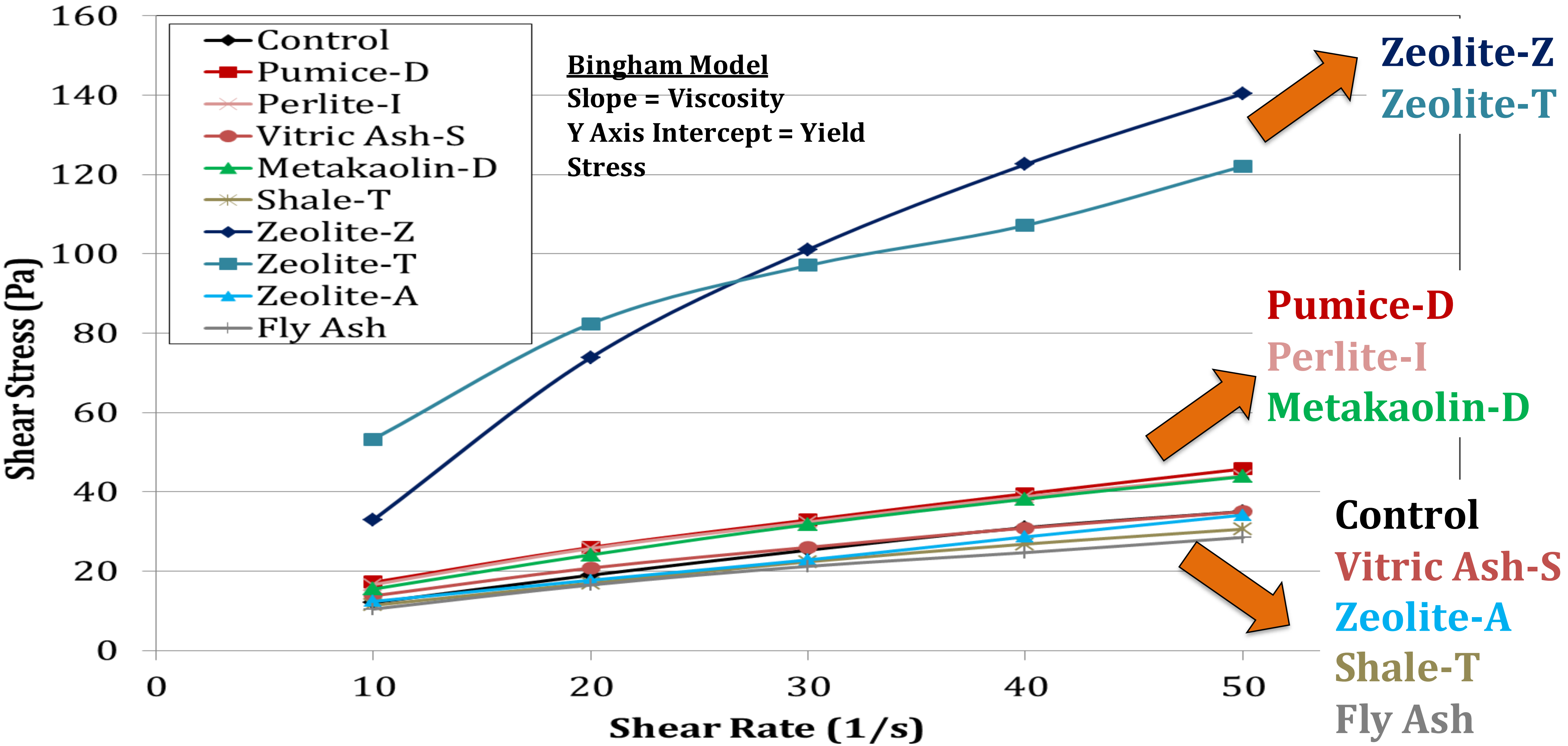
Classification	Material	SiO_2+ Al_2O_3+ Fe_2O_3	Moisture Content	LOI	Fineness	SAI, 7 day	SAI, 28 day	Water Requirement	Passes ASTM C618
Unaltered Volcanic	Pumice-D	82.9	1.5	4.4	2	82	93	104	Yes
	Perlite-I	84.3	0.6	3.4	2	86	94	100	Yes
	Vitric Ash-S	76.9	2.3	5.9	15	72	83	102	Yes
Altered Volcanic	Zeolite-Z	78.6	**5.1**	2.5	0	71	100	**116**	No
	Zeolite-T	75.2	**11.6**	4.6	**43**	**47**	**61**	**132**	No
	Zeolite-A	74.6	**4.8**	4.8	**61**	**60**	**64**	**118**	No
Sedimentary	Metakaolin-D	88.9	0.9	1.0	7	94	108	102	Yes
	Shale-T	85.7	0.3	0.4	30	72	81	103	Yes
ASTM C618 Criteria		70% min	3% max	10% max	34% max	75% min	75% min	115% max	

** Values in red do not meet the ASTM C 618 requirements

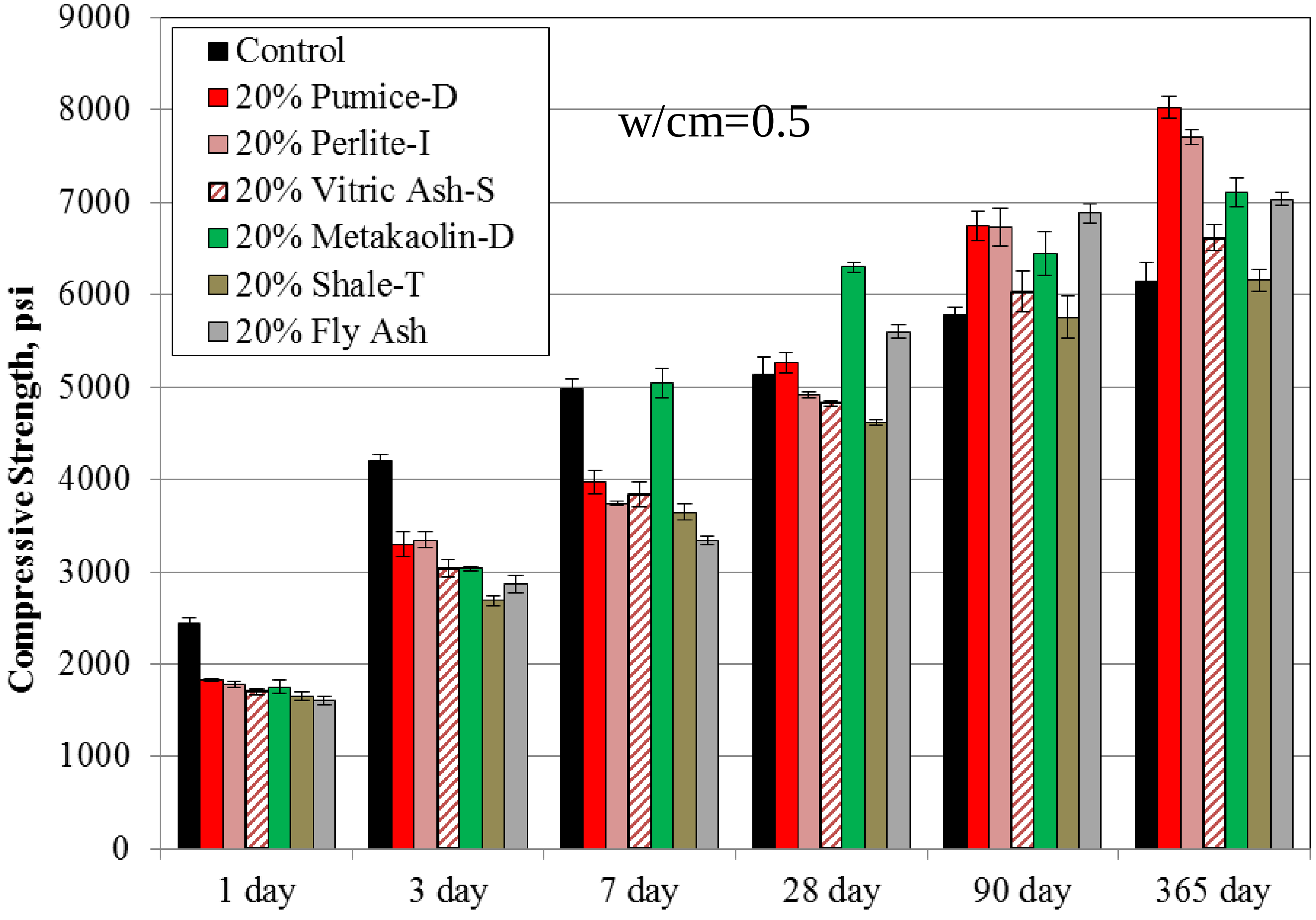
Heat of Hydration



Fresh State Properties



Compressive Strength of Mortars



55.2 MPa

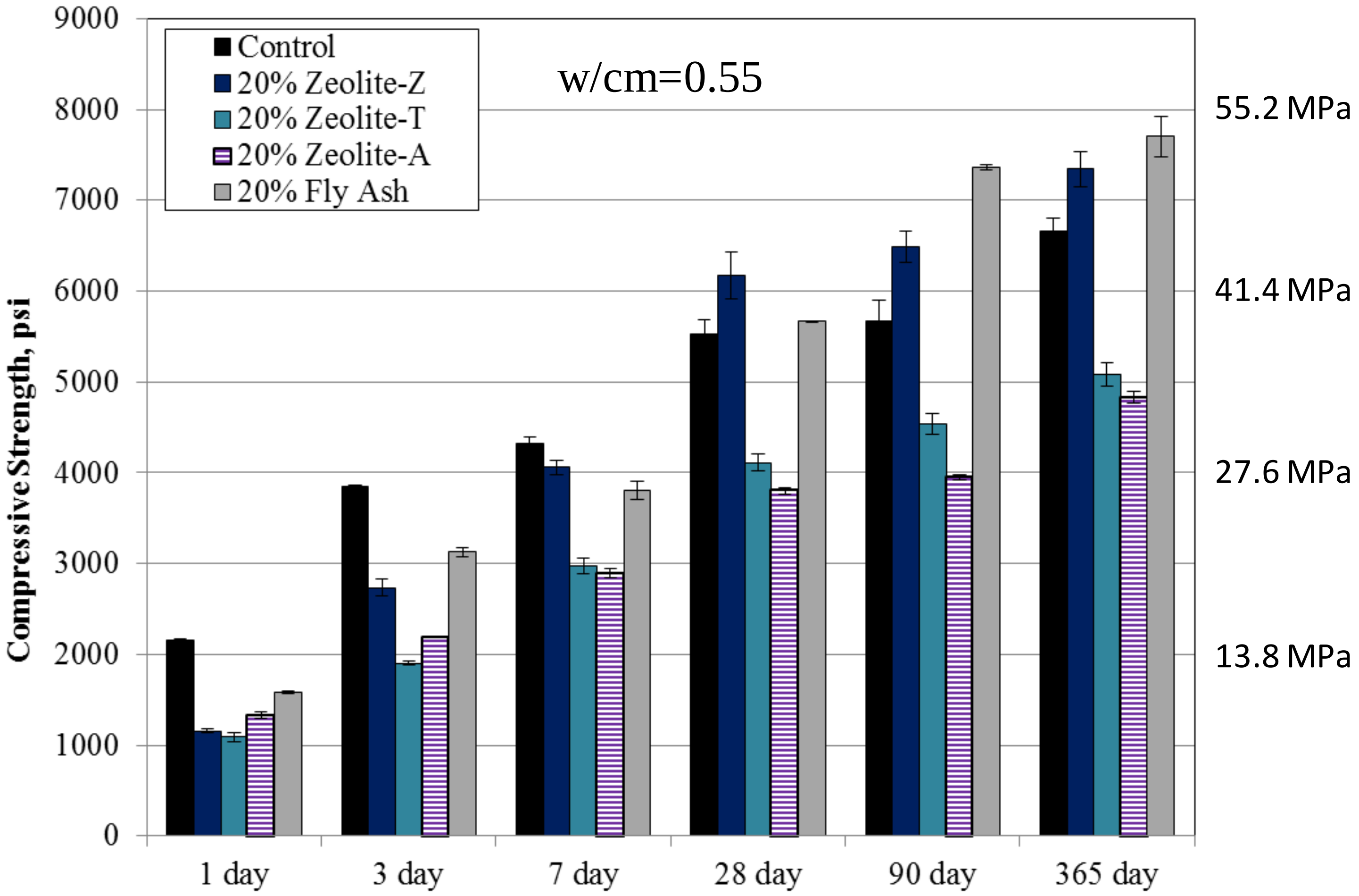
41.4 MPa

27.6 MPa

13.8 MPa

Many are pozzolanic and increase strength;
Best natural pozzolans for increasing strength are Pumice-D, Perlite-I, and Metakaolin

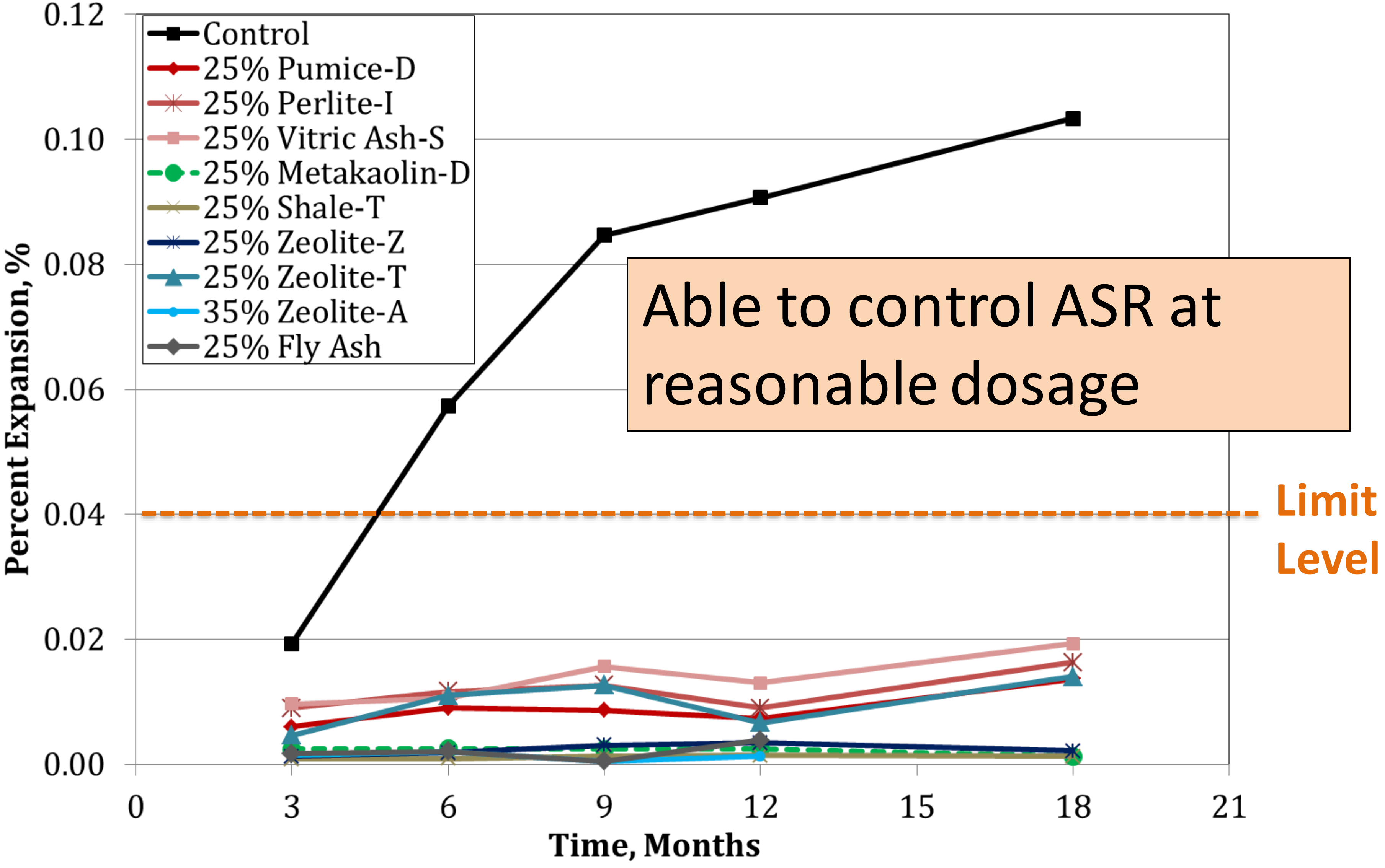
Compressive Strength of Mortars



Only Zeolite-Z performed well.

ASR in Concrete – ASTM C1293: Concrete Prisms

If average expansion is less than 0.04% at 2 years, then amount of SCM used is enough to prevent excessive expansion in field concrete from ASR

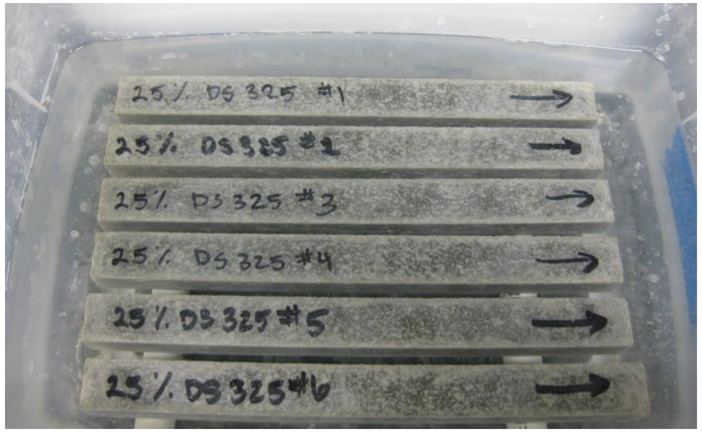


Resistance to Sulfate Attack

- ASTM C 1012 was used to test the ability of the pozzolans to mitigate expansions from sulfate attack.

- ASTM C 1012 measures the length change of mortar bars submerged in Na_2SO_4 solution.

- According to ACI 201, Guide to Durable Concrete, natural pozzolans can be qualified for sulfate resistance by demonstrating an expansion less than 0.10% in 1 year, using ASTM C 1012.



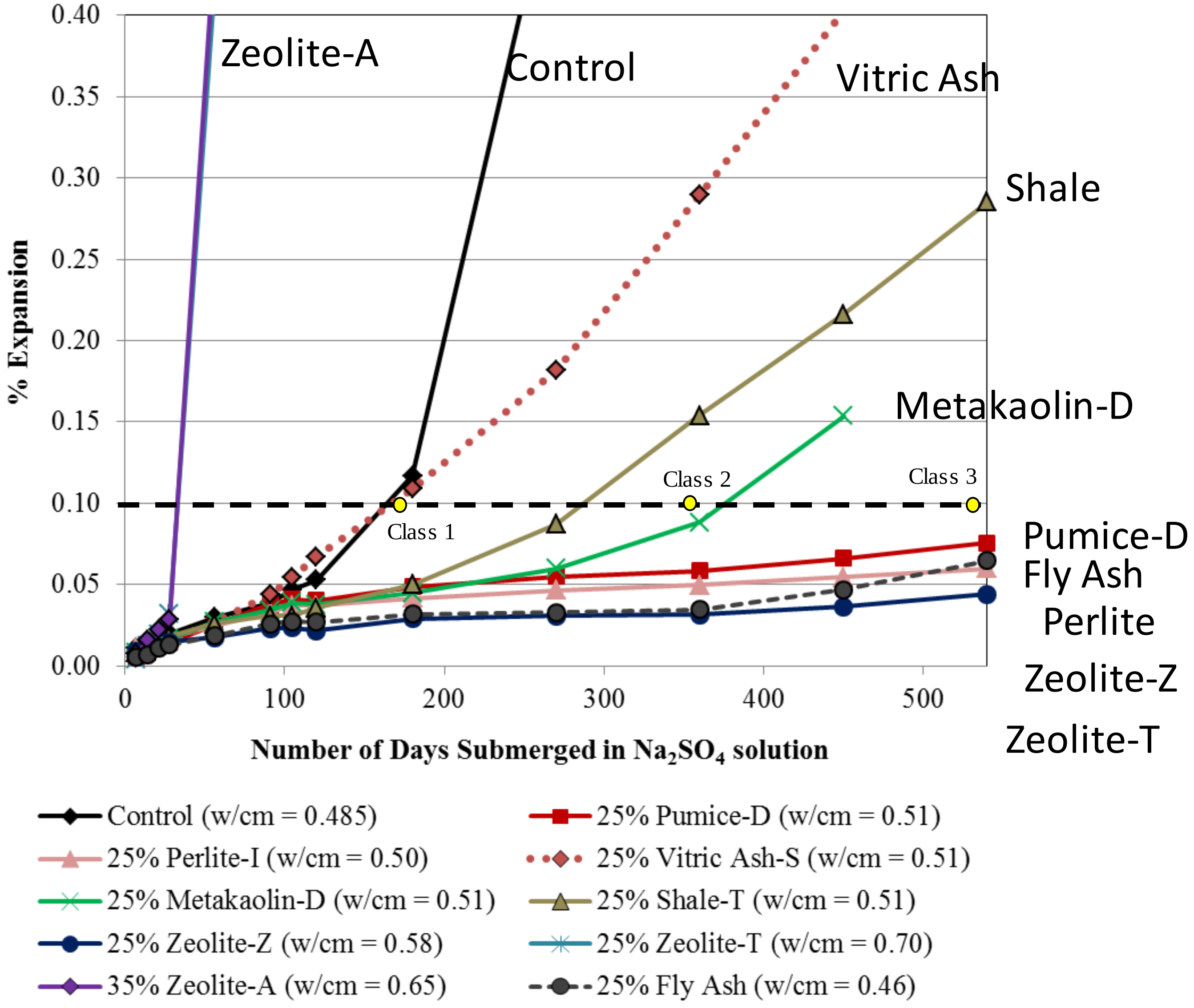
ASTM C1012 Sulfate Resistance

Pass Class 3:

- Pumice-D
- Perlite-I
- Zeolite-Z

Pass Class 2:

- Metakaolin-D



Conclusions

- Natural pozzolans can be used in concrete mixtures; depends on application:
  - Reduce heat of hydration.
  - Most perform well with respect to strength.
  - Help protect against ASR expansion, but not all protect against sulfate attack.