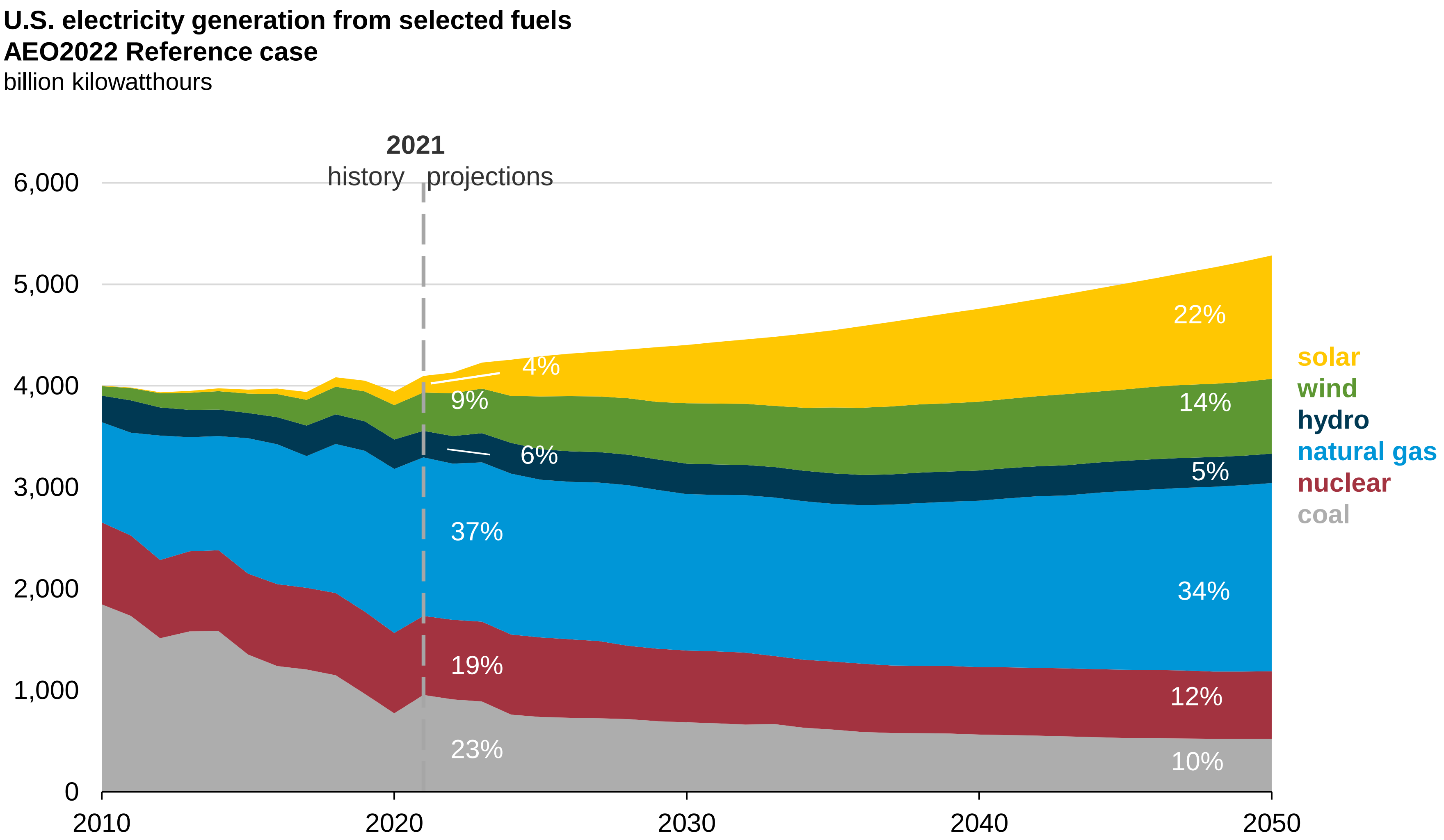
Use of Ground Bottom Ash in Concrete

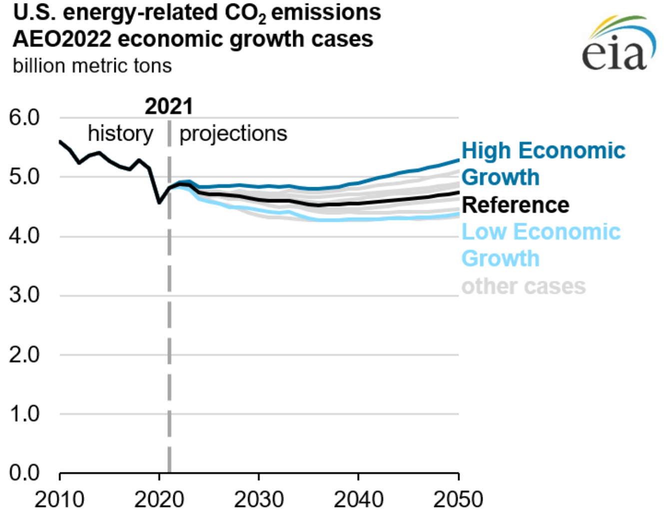
Origin of Bottom Ash and Use in Concrete

Benjamin Gallagher, PE
Program Leader

ACI Concrete Convention
March 27, 2022

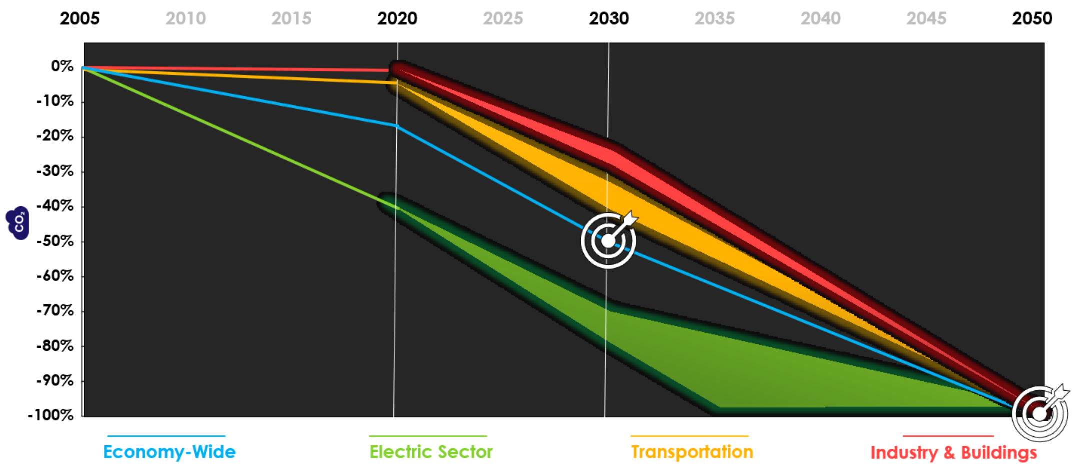
Future US Electricity – Business as Usual



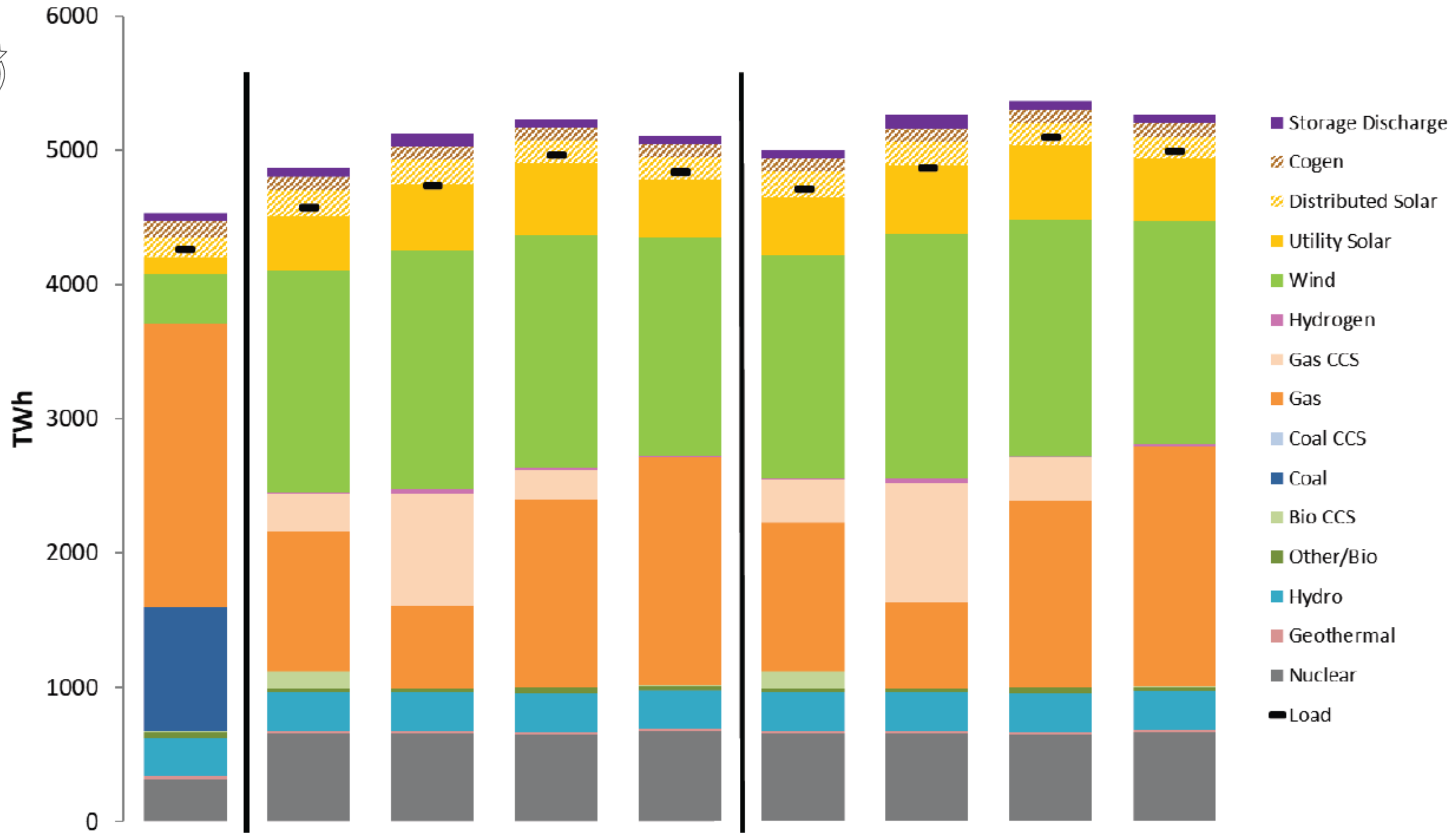


U.S. Energy Information Administration, Annual Energy Outlook 2022 (AEO2022) www.eia.gov/aeo

What About U.S. Carbon Reduction Goals?



U.S. Generation – 2035



EPRI 2021 Understanding Interactions Between Electric-sector and Economy-wide CO2 Policies (3002021397)

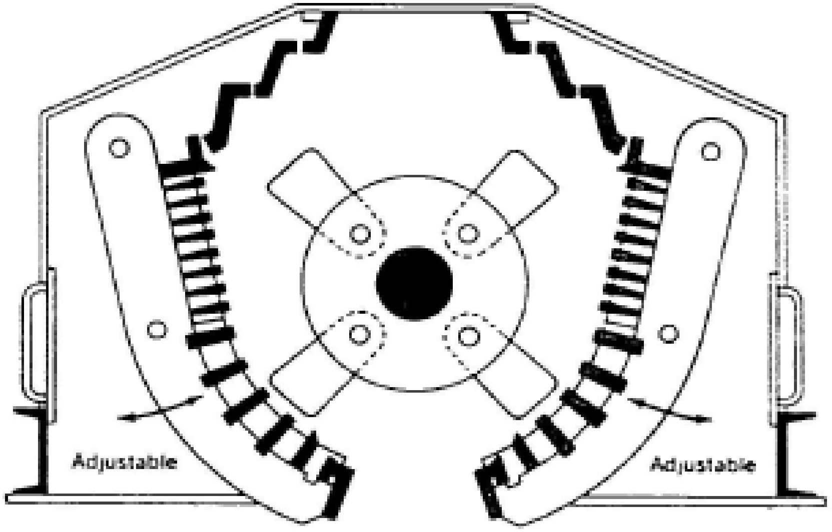
Options to Address Potential Shortfalls in SCM Availability

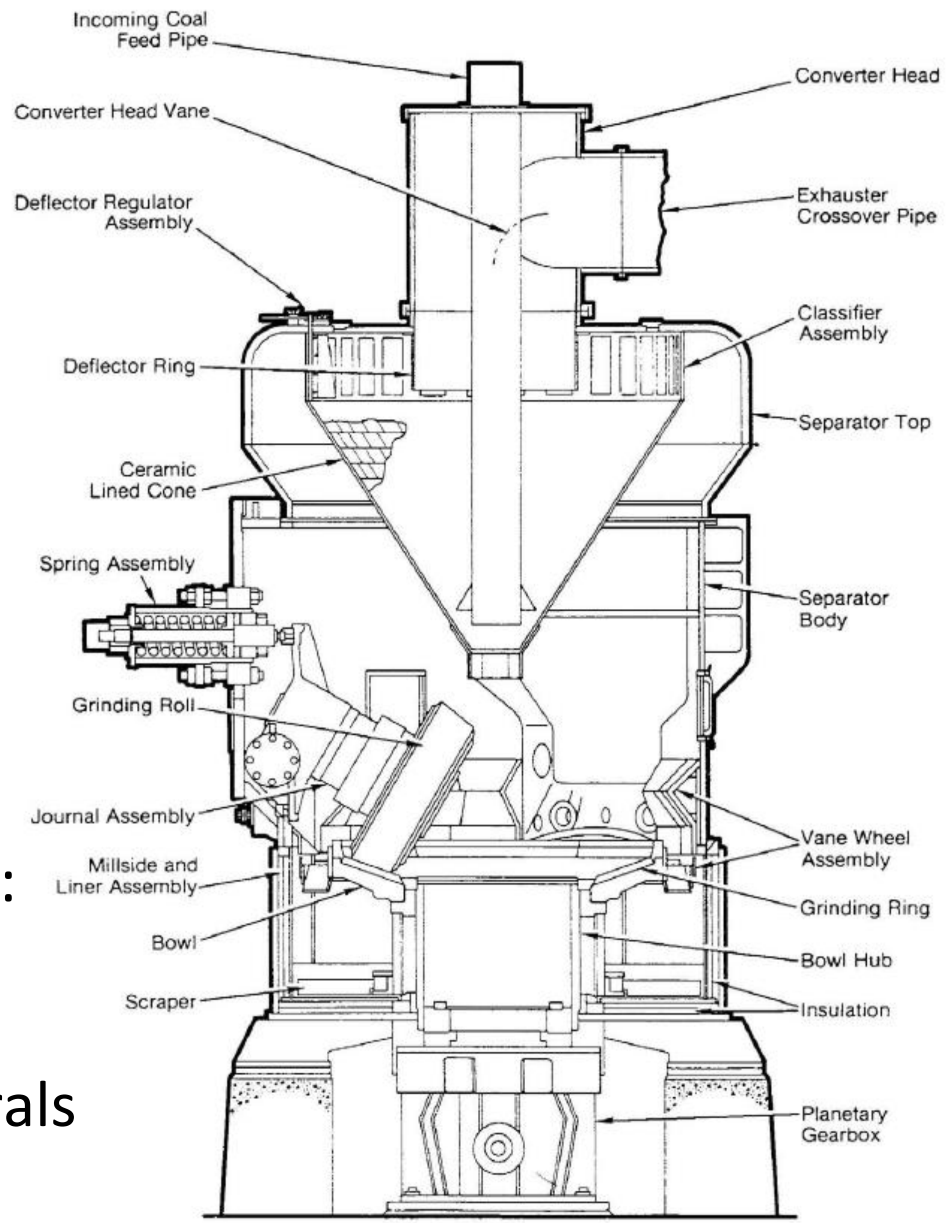
- Expand Use of "Off-Specification" Products
  - *Bottom ash is rarely used as an SCM*
  - Spray-dryer absorber materials often contain appreciable fly ash, provide functional benefits to concrete, and are currently underutilized
- Develop Harvesting from Existing Impoundments and Landfills
  - Some estimate 2 Billion tons of CCPs in storage in USA
  - 560 Ash Ponds Closing or Will Close
    - *Fly ash and bottom ash are often comingled*

US Coal Bottom Ash Sources

- Pulverized Coal Combustion
  - High combustion temp.
  - Small coal particle size
  - 10-20% of total ash is bottom ash
  - Boiler Bottom Design: Dry or Wet
  - Most widely used in US
- Cyclone Boiler Combustion
  - High combustion temp.
  - Large coal particle size
  - 80-90% of total ash is bottom ash
  - Boiler Bottom Design: Wet
  - Often used with low rank coal
- Fluidized Bed Combustion
  - Low combustion temp.
  - Moderate coal size
  - Bed ash sometime referred to as bottom ash
  - Often used with coal mining waste

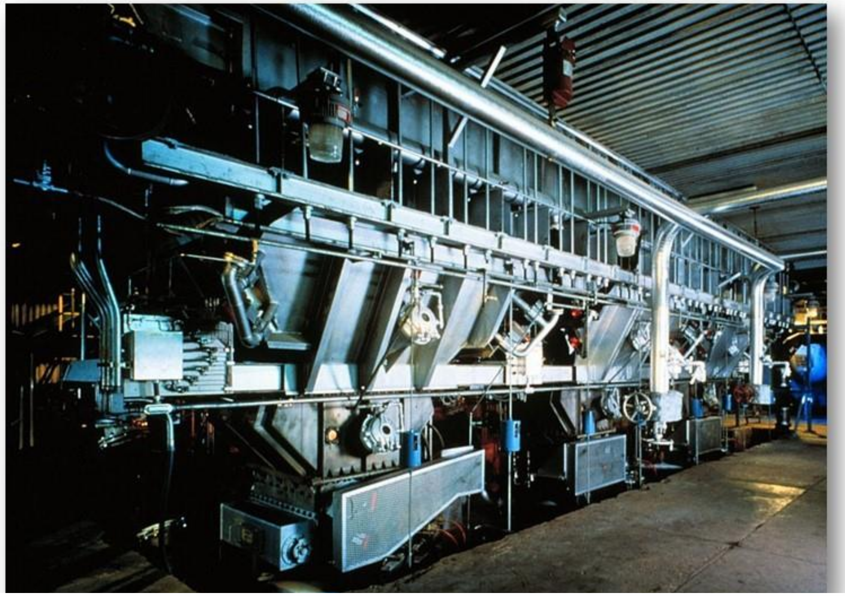
Pulverized Coal Combustion (PCC)

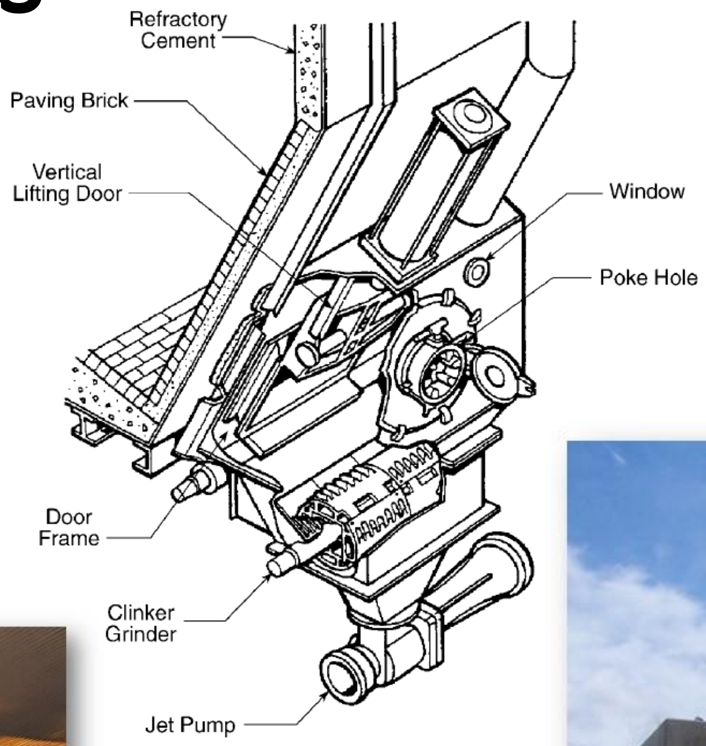




- Mined coal is crushed, pulverized, and classified before combustion
- Typical specification for pulverized coal feed to burners:
  - 99% finer than 300 microns
  - 70% finer than 75 microns
- Coal is 80-90% combustible material, 10-20% ash minerals

Bottom Ash Handling





Images Courtesy of UCC Environmental

PCC Bottom Ash Tested

Power Station Information

- Generating capacity: 2.9 GW
- Subbituminous fuel (Powder River Basin)
- 4 subcritical boilers each ~ 7 MW
  - Dry bottom design
- Dry bottom ash handling

Bottom Ash Composition (wt %)										
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	TiO_2	Na_2O	P_2O_5	SO_2	K_2O	LOI
42.42	20.69	19.78	8.17	3.41	1.43	1.26	0.64	0.62	0.59	0.57

Ground Bottom Ash in Concrete

- EPRI 2020 "**Performance-Based Mixture Proportioning of Concrete Incorporating Off-Spec Fly Ash: Mixture Proportioning Method Development and Validation**" 3002018795
- Included commercially ground bottom ash
  - D50 = 19 microns
- Research performed at Oregon State University
  - Lead by Dr. Isgor
  - Co-investigators Drs. Ideker, Trejo, and Weiss

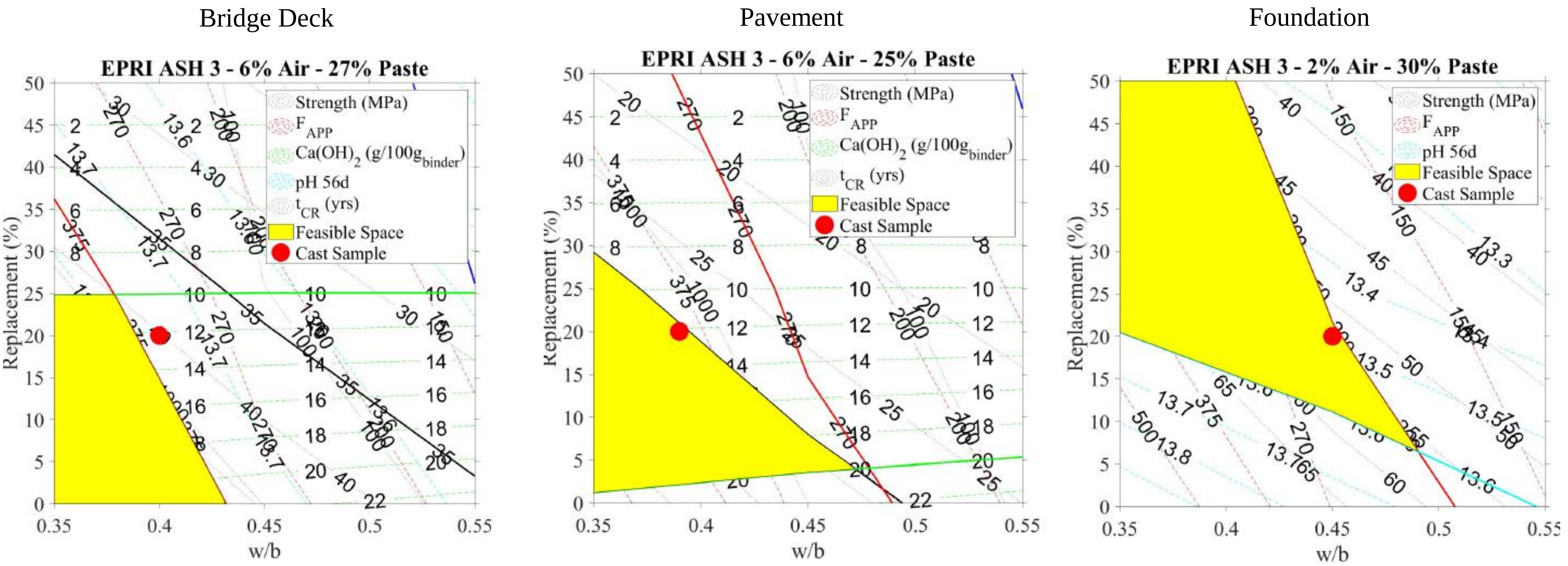
Concrete Mix Designs

Concrete Application	Bridge deck mixture	Midwest pavement mixture (no reinforcement)	Foundation mixture
Concrete Exposure	ACI 318: F3, S0, W0, C2 (Resistance to chloride ingress, corrosion, and freeze-thaw damage)	ACI 318: N/A (Resistance to CaOxy and freeze-thaw damage as specified by Indiana DOT [86])	ACI 318: F0, S1, W1, C0 (Moderate sulfate and ASR resistance)
Strength, f'_c (56 day, min)	5000 psi [34 MPa]	4225 psi [29 MPa]	4000 psi [27 MPa]
Slump (ACI 211 [1])	1–4 in (25–100 mm)	1–2 in (25–50 mm)	1–3 in (25–75 mm)
Formation Factor, F_{APP} (56 day, min)	375	270	200
Calcium Hydroxide **CH** (56 day)	10 g/100 g binder (min)	20 g/100 g binder (max)	N/A
pH (56 day)	12.8 (min)	N/A	13.6 (max)
Time to critical saturation, t_{CR}	30 years	30 years	N/A

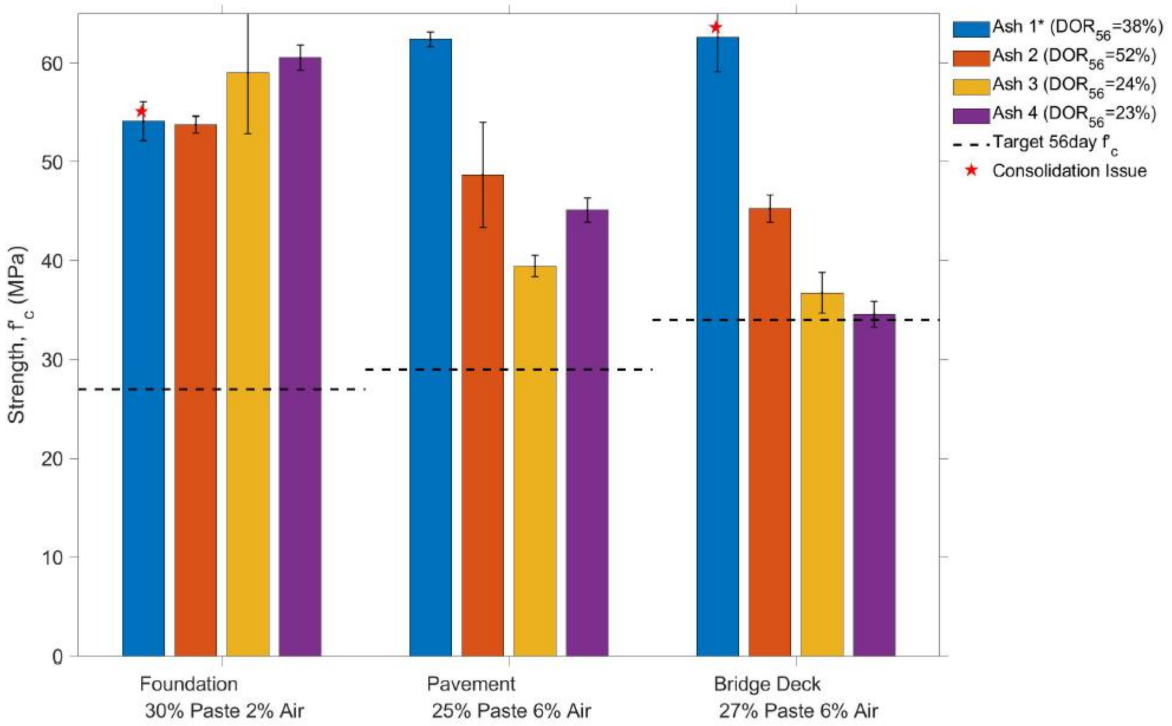
		Bridge Deck	Pavement	Foundation
EPRI Ash 3	Coarse aggregate	937	965	895
	Fine aggregate	822	842	816
	Cement	299	280	310
	Fly ash	75	70	78
	Water	119	110	116
	WRA	2160 (ml/$m^3_{concrete}$)	3024 (ml/$m^3_{concrete}$)	2450 (ml/$m^3_{concrete}$)
	AEA	648 (ml/$m^3_{concrete}$)	756 (ml/$m^3_{concrete}$)	-

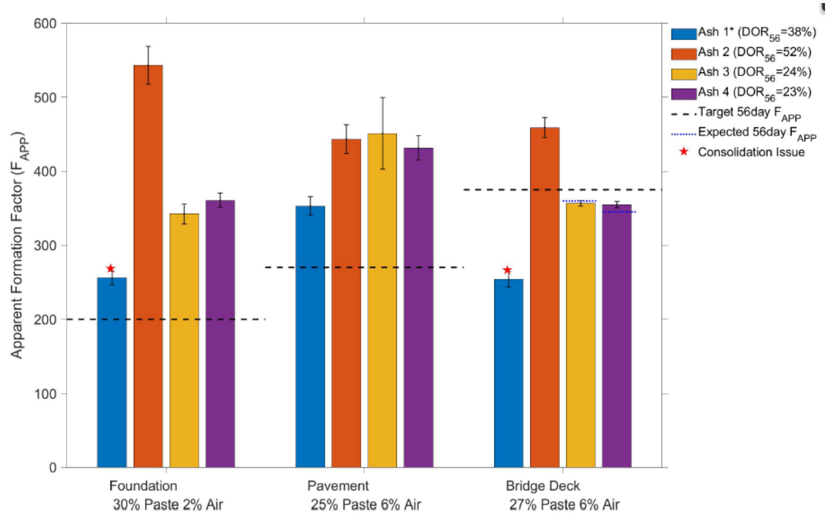
EPRI Ash 3	Slump (inches)	2.25	1.00	2.00
	Unit Weight (kg/m^3)	2195	2227	2371
	Fresh Air Content	7.0%	6.5%	1.6%
	Temperature	22.8°C	21.1°C	18.3°C

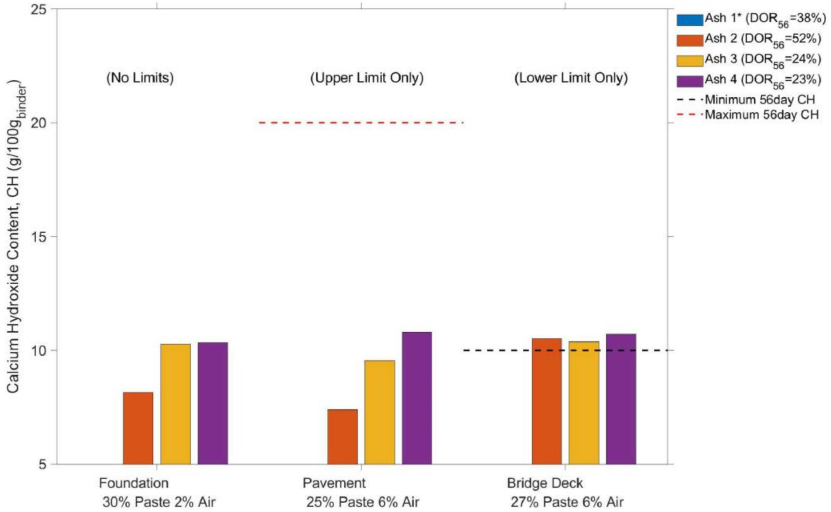
Concrete Modeling Results

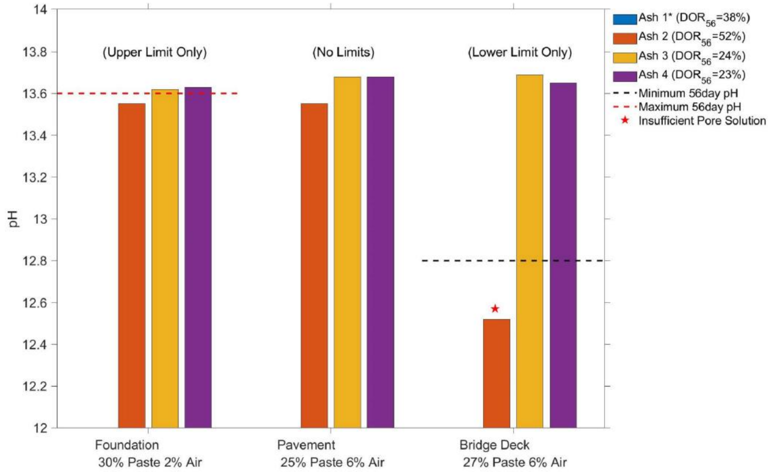


Concrete Physical Test Results







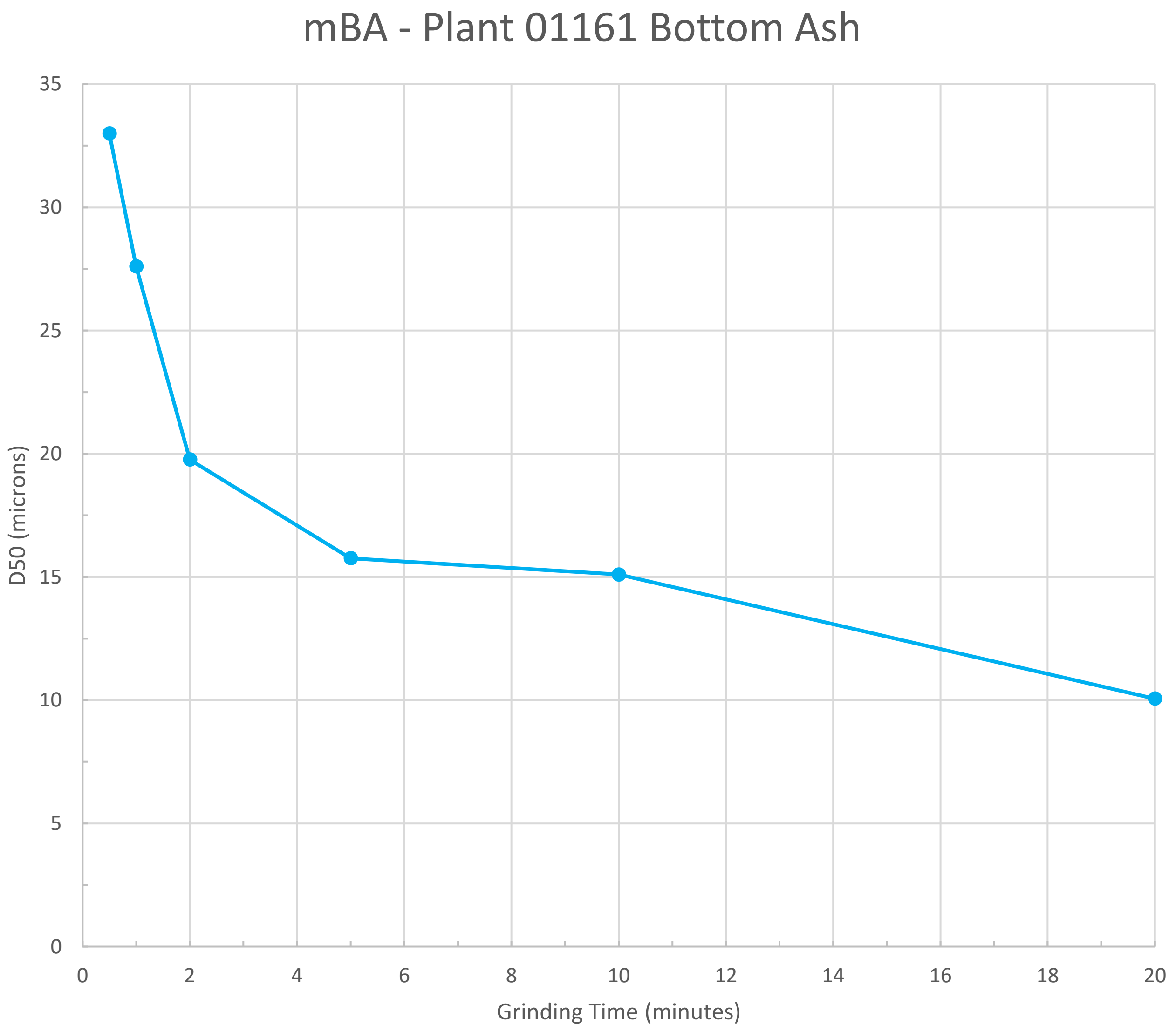


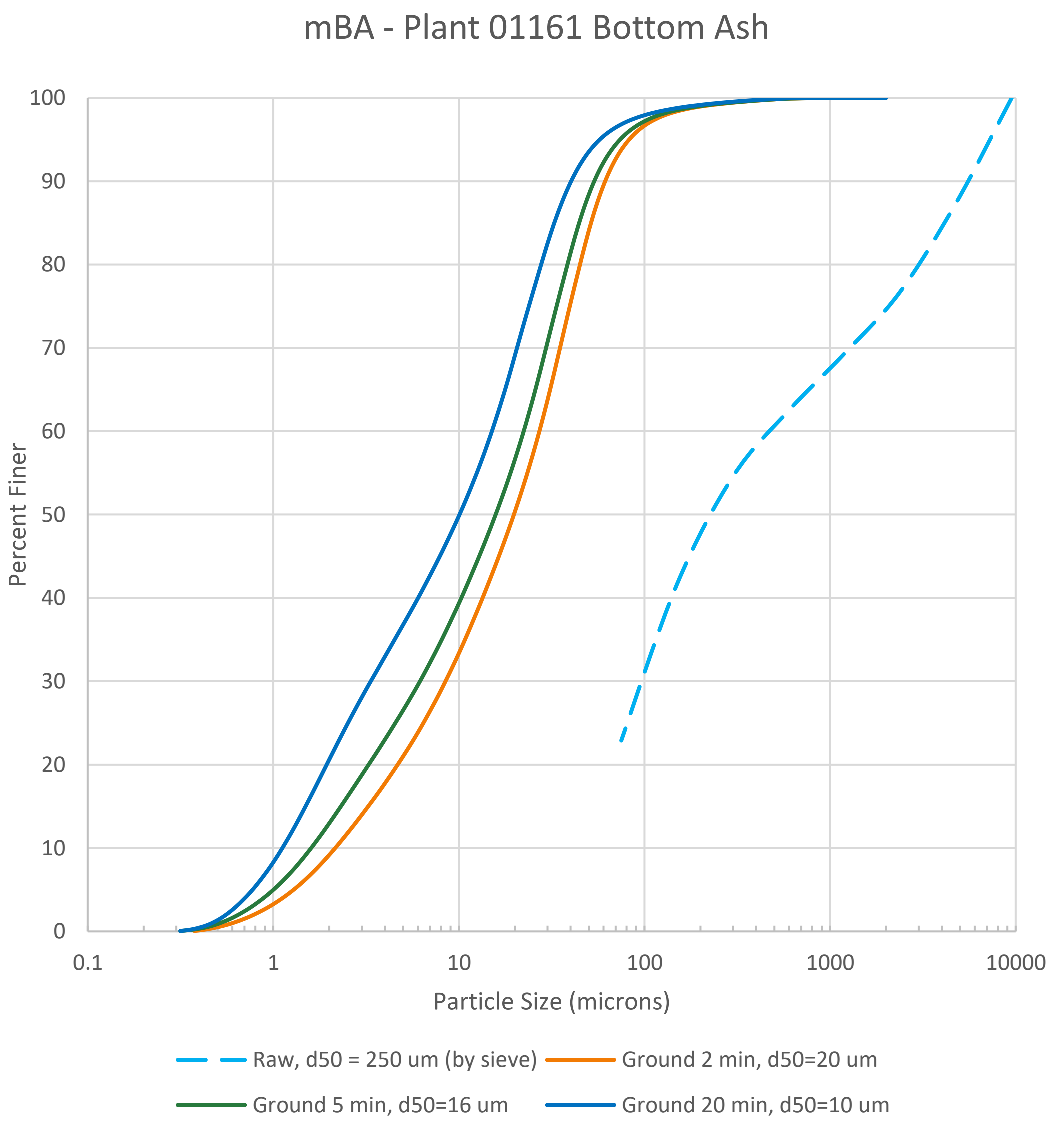
Grinding Time and Reactivity

- Dr. Bošnjak (Univ. Of Stuttgart) presented “Ground bottom ash as a supplementary cementing material” at EuroCoalAsh2021
- Included mortar strength results for bottom ash from Mann
  - Bituminous Fuel
  - Low Ca ash
  - Ground to 4 fineness (<10% retained on 45 micron, 10-20% retained, 25-30% retained and 40-45% retained)
  - 10, 20 and 30% cement replacement
- All mortars met strength requirements at 28 and 90 days
  - At 10 and 20% replacement, strengths were similar for all BA fineness
- At 30% replacement, 90-day mortar strength with ground BA at 40-45% retained was about 10% less than with ash ground to <10% retained

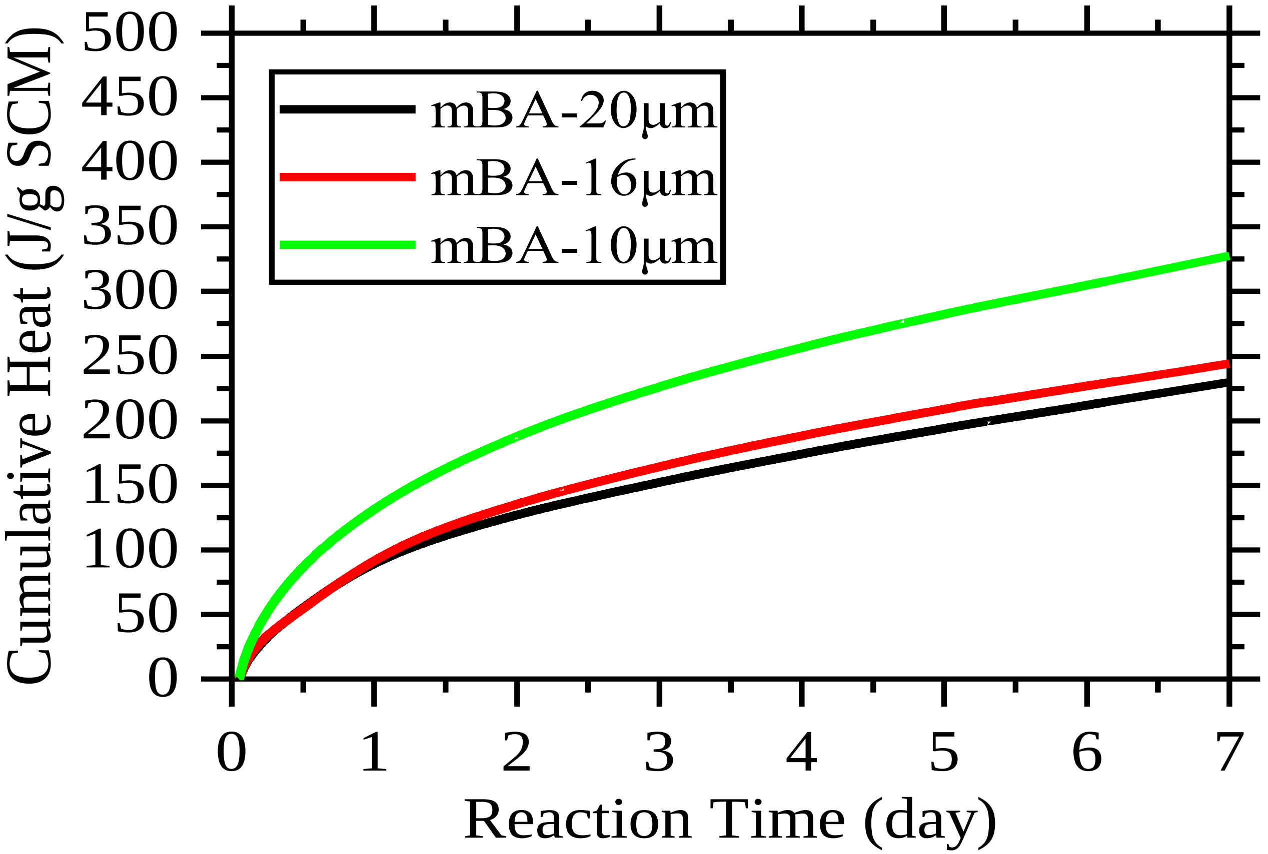
- How does BA reactivity in a pozzolanic reactivity test vary with grinding?
  - Ongoing Research lead by Dr. Ma at Missouri S&T university

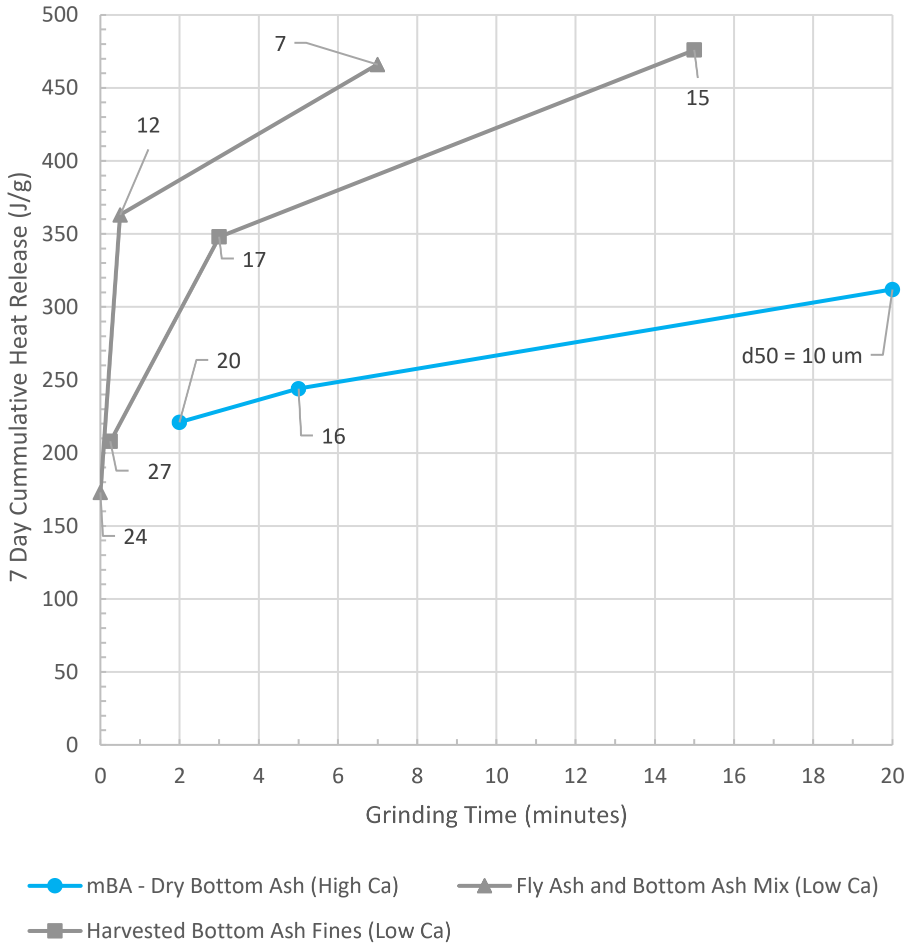
Bottom Ash Grinding Time and Particle Size Distribution





Preliminary Observations





Preliminary Observations

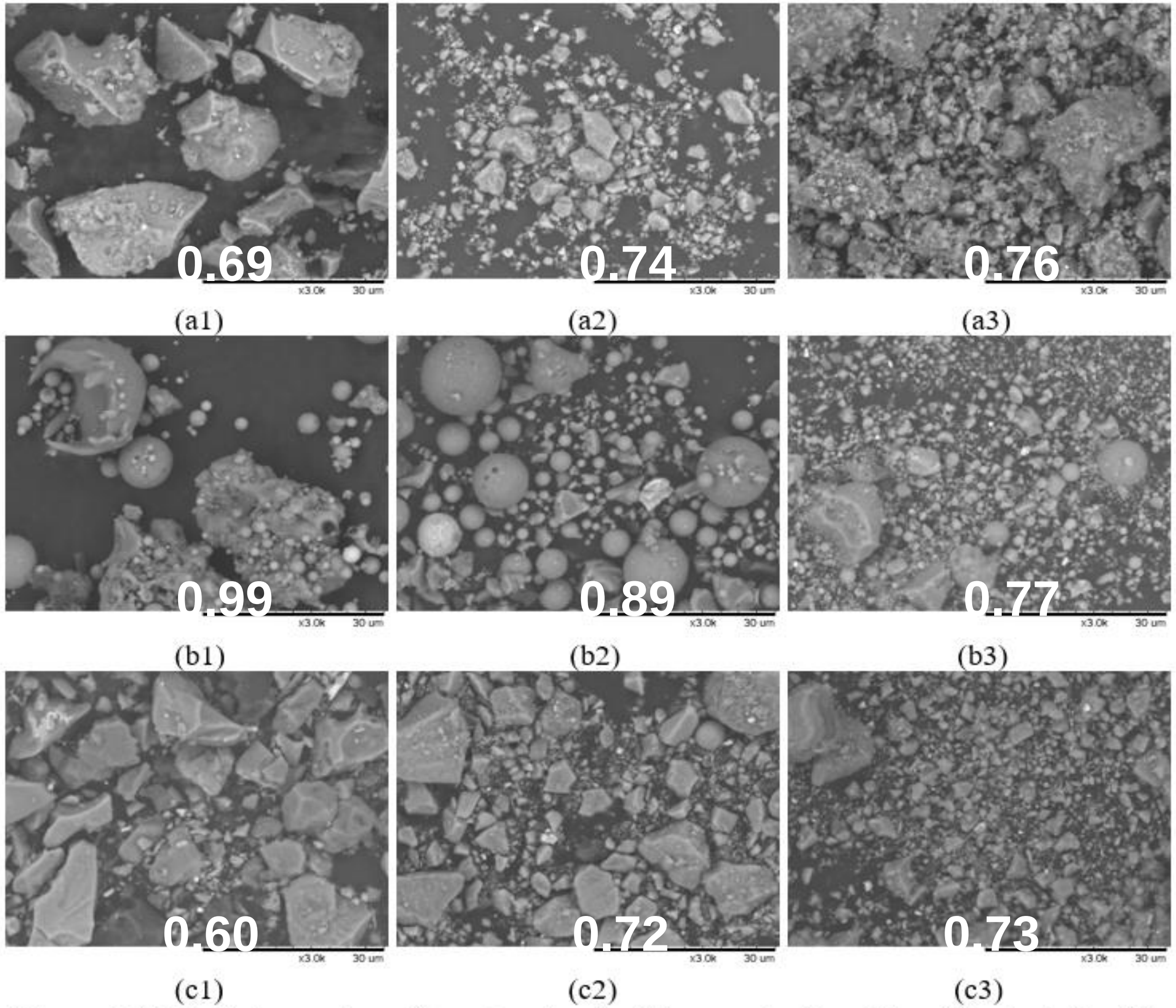


Figure 8 *SEM of ash samples with various levels of fineness (achieved by milling): (a1) mBA-20µm; (a2) mBA-16µm; (a3) mBA-10µm; (b1) pBA-24µm; (b2) pBA-12µm; (b3) pBA-7µm; (c1) rBA-27µm; (c2) rBA-17µm; and (c3) rBA-9µm.*

Together…Shaping the Future of Energy™