Towards Innovative Cementitious Materials

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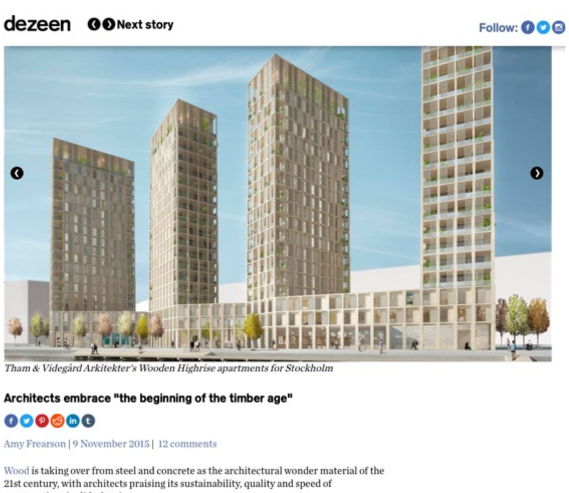
Change is happening …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Tham & Videgård Arkitekter's Wooden Highrise apartments for Stockholm

Architects embrace "the beginning of the timber age"

Amy Frearson | 9 November 2015 | 12 comments

Wood is taking over from steel and concrete as the architectural wonder material of the 21st century, with architects praising its sustainability, quality and speed of construction. (+ slideshow).

Your local Holiday Inn

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Your local road…

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What's Driving the Change?

- **Concrete has an image problem**
  - "Dirty"
  - CO_2 intensive
  - Energy intensive
  - Exploits natural resources

"Can you be more specific?"

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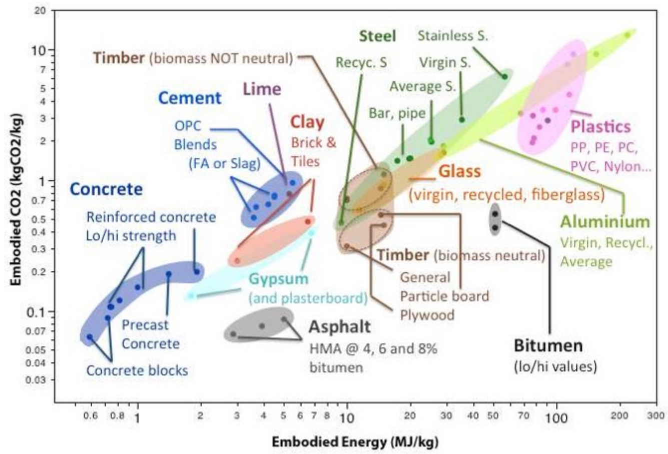
The Path Forward To Reduce Carbon

- Concrete has one of the lowest carbon footprints of any material… but…
- **Produced ~4.1 billion tons world-wide in 2023, projected CAGR ~1%** *
- **~1 cy/person/year**
- **~120 Mt of cement (U.S.) in 2023** **
- Concrete greenhouse gas (GHG) emissions at the gate
  - ~1.5% acquiring raw materials
  - ~9.5% concrete production
  - **~89% cement production**
    - **~37% from burning fuel**
    - **~46% from calcination**



After Barcelo et al., 2014

Data from Hammond and Jones (2011), Inventory of Carbon & Energy V2

* IEA/WBCSD Cement Roadmap, ** USGS, 2024

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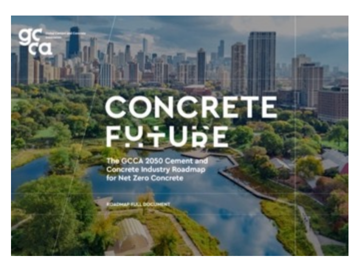
Everyone has a Roadmap

- The cement and concrete producers are committed to being net carbon neutral by 2050
- Common elements - address the carbon footprint across the entire concrete value chain
- Long-term (10-30 years out) - modification of cement production including carbon capture, utilization, and storage (CCUS)
- **Near term (next 5-10 years)** - significant progress must be achieved through enhancements in concrete production and use.



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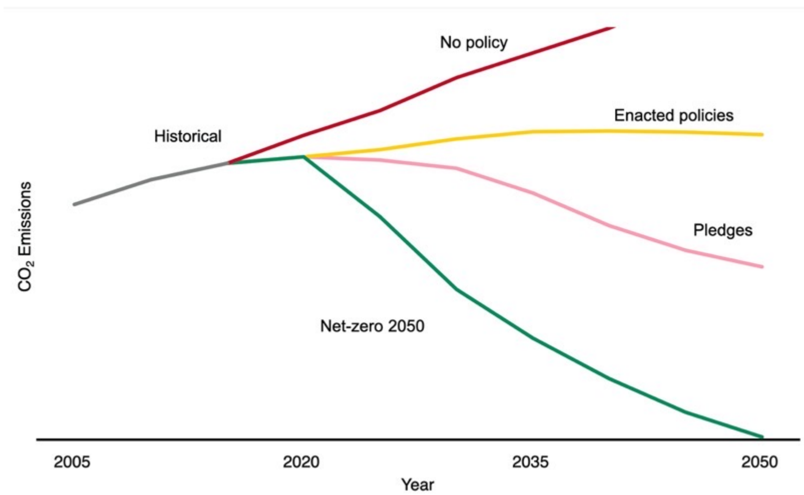

Goals have been set…

Image Credit: BlackRock

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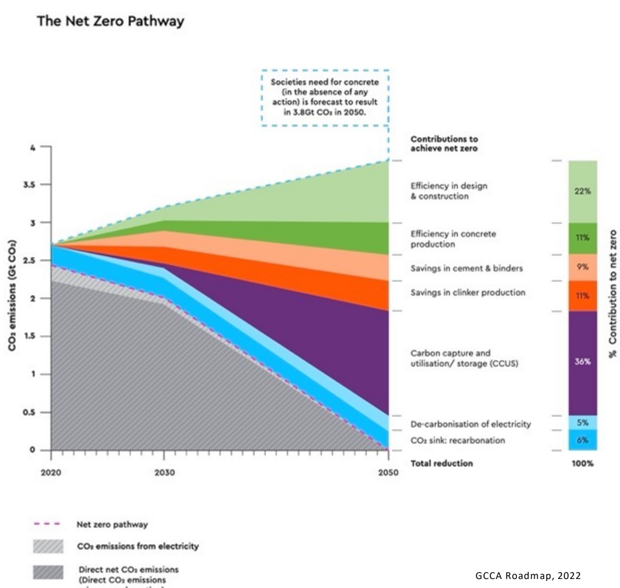

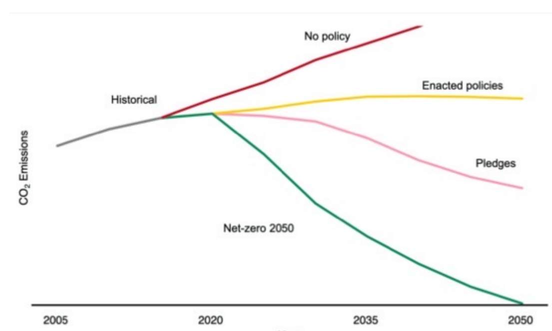

GCCA Roadmap, 2022

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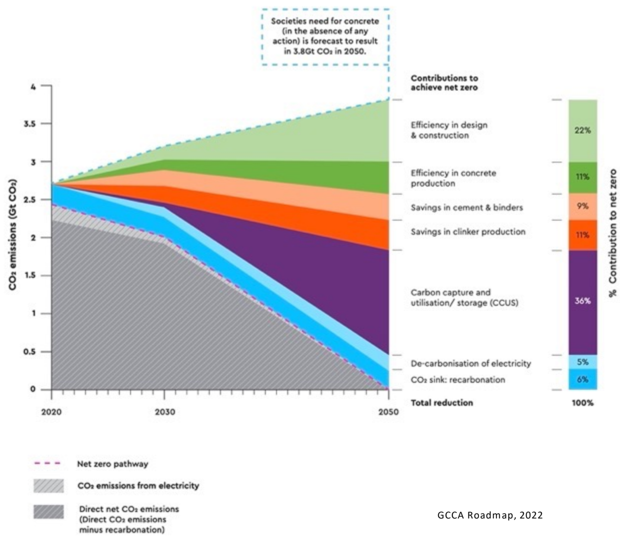
The Net Zero Pathway



GCCA Roadmap, 2022

This on concrete to make happen!

Efficiency in design & construction

Efficiency in concrete production

Savings in cement & binders

Approximately 42% of the total reduction…

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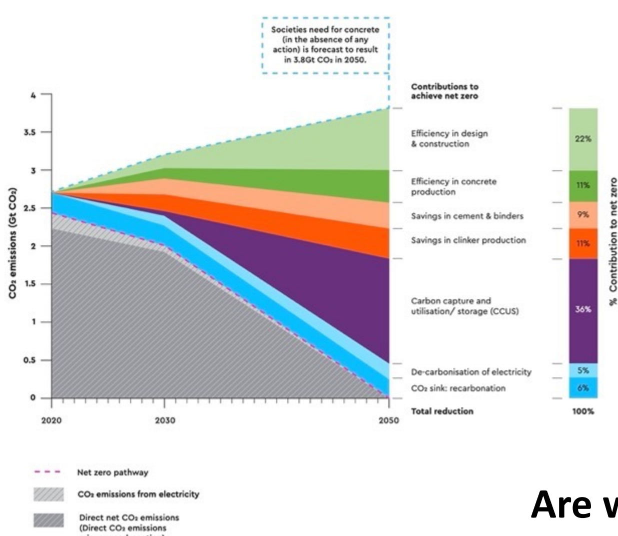
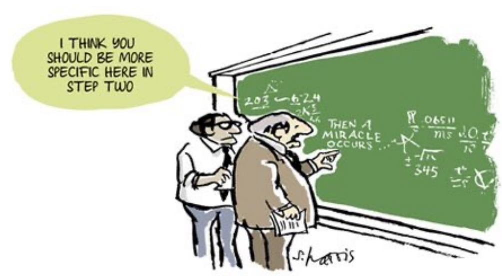
The Net Zero Pathway





Approximately 42% of the total reduction…

Are we relying on miracles?

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Portland Cement is Not Going Away

- Society needs concrete – but a different concrete
  - New materials will have a role
  - Our goals must be realistic
  - We cannot completely "disrupt" an industry as pervasive as construction
  - If we want low-carbon concrete, we need to make changes in cooperation with all industry stakeholders – it cannot be forced
    - We need to use the materials we have better
  - Society has few choices if we want to maintain our lifestyles… because…

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  - If we want low-carbon concrete, we need to make changes in cooperation with all industry stakeholders – it cannot be forced
    - We need to use the materials we have better
  - **Portland cement is here forever – we need to make it work**

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New Materials are Coming

- Alternative cements and SCMs are here – more coming
- Initially they will fill niche markets, could expand into broader use if enabled by specifications and testing (i.e., standards) and codes
- **We cannot "just say no"**
- The question is **"How do we get to yes?** (*from:* Anne Ellis)

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The Path Forward for Concrete

Less clinker in cement, less cement in concrete, less concrete in construction

- Replace clinker content in cement
  - Use blended cement (ASTM C595) or replace clinker with supplementary cementitious materials (SCMs) at concrete plant
- Use less cementitious materials
  - Optimized aggregate grading
  - Lower cementitious content
- Optimize designs & new mixtures
- Use alternative SCMs and/or alternative cementitious materials

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Less Concrete - New Designs for Materials and Structures

Roadmap Goal: Efficiency in design & construction - 22%

- **Optimize designs & implement new designs**
  - Use new materials and designs to achieve reductions in cement content
  - Example : Ultra High-Performance Concrete (UHPC)
  - Known since early 90's
  - 2x the cement; 0.25x concrete, net 50% reduction

Courtesy S. Foster

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Less Cement in Concrete

Roadmap Goal: Efficiency in concrete production - 11%

- In concept, replace cement with aggregate
- In practice, requires changing the way we think about concrete mixture proportioning
- Traditional approaches to proportioning include the absolute volume method (i.e., ACI 211)
- We need to use "mixture optimization"

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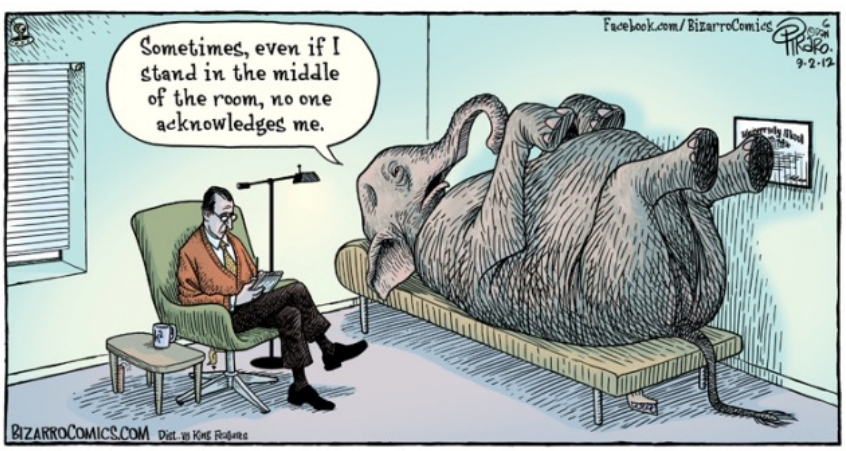
Less Cement in Concrete – Other Factors?

- Over cementing
- We need to address testing
- Separate conversation for another day
- Innovation will have a role – in situ testing, etc.



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Roadmap Goal: Savings in cement & binders - 9%

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So what is ASTM C595?

- Nothing new – first published in 1967
- Combined ASTM C 205-58T *Standard Specification for Portland Blast-Furnace Cement*, ASTM C 340-58T *Standard Specification for Portland Pozzolan Cement*, and ASTM C 358-58 *Standard Specification for Slag Cement*
- Revised in 2006 to take on existing naming convention

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So what is ASTM C595?

- Type IS – portland cement + slag
- Type IP – portland cement + pozzolan
- The Type is appended with (*X*) where *X* is the targeted percentage of slag or pozzolan in the blend (e.g., Type IP(25) has 25% pozzolan)
- Additional designations were (A) for air entraining, (MS) for moderate sulfate resistance, (MH) for moderate heat of hydration, and a new designation was added for low heat of hydration (LH)

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So what is ASTM C595?

- In **2009 Type IT** for ternary blends was added, these being combinations of portland cement and two different blending constituents
- The naming practice was expanded for ternary blends to use the form Type IT (A*X*)(B*Y*) where A is either "S" or "P" for the predominate blending constituent (i.e., slag or pozzolan) and *X* is the targeted percentage of that constituent, B is the minor blending constituent and *Y* is the targeted percentage of that constituent.

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So what is ASTM C595?

- In 2012 Type IL was added
  - 10 years before roll out in 2022
- Limestone content is 5 to 15%, can be used in a ternary blend but still limited to 5 to 15%
- In 2024 manufactured calcium carbonate was allowed for use as limestone (Note: previously limestone was only required to be 70% calcium carbonate)

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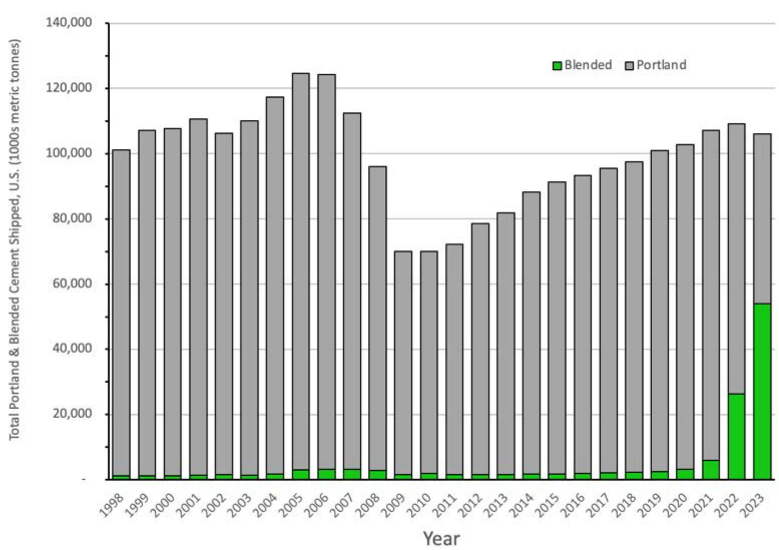

Data source: USGS Mineral Industry Surveys

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Ternary blends are not new

- Extensive research by FHWA in early 2010's
  - (http://publications.iowa.gov/17977/1/FHWA_IADOT_NCPTC_TPF_5_117_Taylor_Use_Ternary_Mixtures_in_Concrete_2014.pdf)
- Durability improves with use of pozzolans and slag
- Used by a number of DOTs with good field performance
- Advantage – sulfate balance
- Key to producing blended cements - **SCMs**

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Supplementary Cementitious Materials (SCMs)

cementitious material, supplementary, (SCM), n—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, **natural pozzolans**, and **ground-glass pozzolans**. In practice, these materials are used in combination with portland cement.

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Pozzolan vs. Cement

CSH = calcium silicate hydrate (good); CH = calcium hydroxide (bad)

- **Portland Cement Reaction**

Cement + Water -> **CSH** + **CH**

- **Pozzolanic Reaction**

CH from portland cement hydration is consumed

Pozzolan + **CH** -> **CSH**

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So what's the problem?

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The Problem

- Fly ash is our primary SCM
- Fly ash supplies are challenged by coal-fired power 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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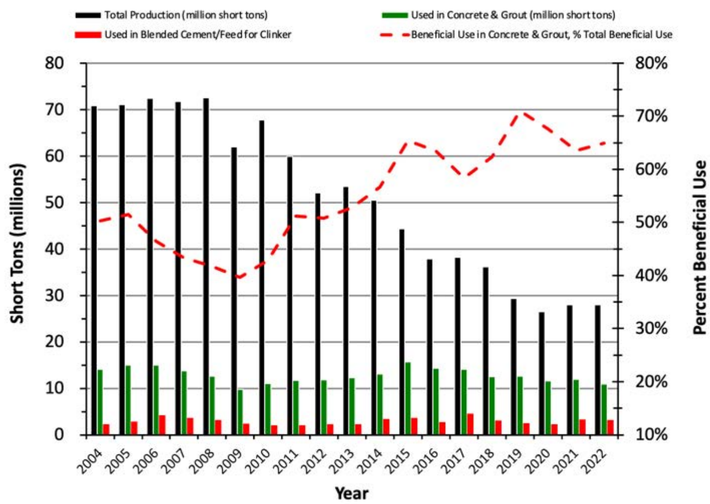
Ash Production is Dropping



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So What's Up With Fly Ash?

- Domestic fly ash production (new production) will continue slowly decreasing over the next 20 years and beyond
- Harvested ash from landfills/ponds is becoming a significant fraction of the total reserves
  - ~ 1.8 million tons of harvested in concrete in 2022; projecting ~3 million for 2023
  - Multiple large projects coming on-line adding another 1 million tons over the next 12-15 months; further increases beyond

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Harvested Ash – Production & Beneficiation

- With very few exceptions, harvested ash will be processed for use in concrete
  - Drying
    - Needed to meet moisture limits
  - Screening or air classification, or both
    - Primarily to address comingled bottom ash
  - Grinding (last resort)
    - Bottom ash, cemented particles
  - Post-treatment
    - Carbon removal or mitigation

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Harvested Ash – Production & Beneficiation

- In the near term, harvested ash will be sourced from mono-fills where only fly ash was deposited
- Long term, fly ash co-mingled with other materials will be harvested, requiring more extensive processing
- **Mixtures of fly ash and bottom ash will be produced**
- Testing – primarily reactivity testing – will become more important to ensure uniformity
- Logistics is still a challenge

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Specification Changes

- ASTM C618-22$^{\varepsilon 1}$ has numerous changes to address harvested ash
- *Standard Specification for* ***Coal Ash*** *and Raw or Calcined Natural Pozzolan for Use in Concrete*
  - Now called coal ash which includes fly ash, bottom ash, and combinations of the two
  - Bottom ash is explicitly allowed
  - Processing is now acknowledged as part of "ash production"
- ASTM C618-22$^{\varepsilon 1}$ and AASHTO M 295-24 are harmonized

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Bottom Ash – Example Data

Phase (%)	FA-A	GBA-A	FA-B	GBA-B
Amorphous	83	53.9	72.7	64.0
Anorthite - ($CaAl_2Si_2O_8$)	-	34.3	-	18.6
Quartz - (SiO_2)	4.1	2.9	13.9	13.7
Diopside - ($CaMgSi_2O_6$)	-	8.1	-	-
Hematite - (Fe_2O_3)	1.2	0.9	0.4	0.3
Merwinite - [$Ca_3Mg(SiO_4)_2$]	8.6	-	-	-
Lime - (CaO)	0.7	-	0.02	-
Periclase - (MgO)	2.4	-	0.03	0.2
Magnesite - ($MgCO_3$)	0.3	-	-	-
Mullite - ($Al_6Si_2O_{13}$)	-	-	11.4	2.0

Unpublished data: I. Diaz

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Bottom Ash – Example Data

	C618 Limits	Fly Ash A	Ground Bottom Ash A				Fly Ash B	Ground Bottom Ash B			
			F1	*F10*	*F20*	*F30*		*F1*	*F10*	*F20*	*F30*
Fineness	*34 max*	12.9	1.4	10.4	19.6	27.7	31.4	1.2	12.6	18.3	29.3
7-Day SAI, %	*75 min*	97	84	79	79	72	85	83	80	80	82
28-Day SAI, %	*75 min*	102	94	90	83	77	88	86	87	81	79
Water Req., %	*105 max*	94	97	97	97	100	100	102	100	100	100

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Unpublished data: I. Diaz

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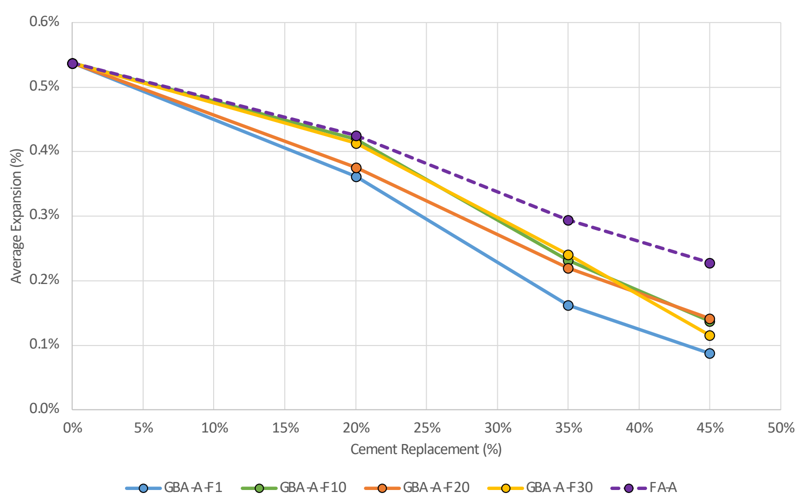
Bottom Ash – ASTM C1567



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Unpublished data: I. Diaz

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Harvested Ash

- Concerns
  - Current federal and state regulations require near-term closure of disposal ponds, leaving insufficient time to recover and use all available ash
  - Power producers have little to no incentive to use ash beneficially, closure (cap-in-place) is the lowest cost option and cost is recoverable in the rate
- Benefits of landfilled ash
  - 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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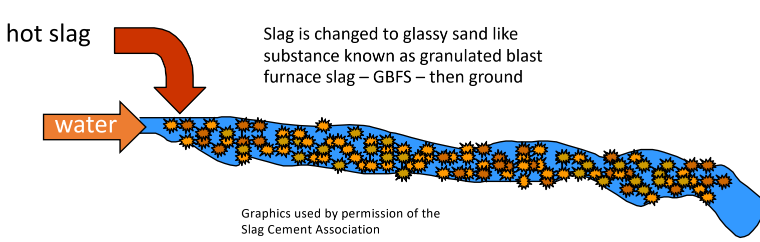
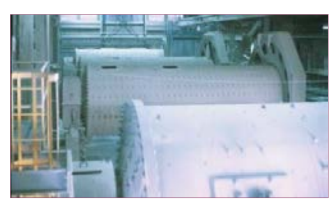
Slag Cement

- Produced from blast-furnace slag (reduction of iron ore) in a blast furnace
- Slag cement is hydraulic and produces calcium silicate hydrate (CSH) as a hydration product
- Slag cement is not projected to increase in supply





Graphics used by permission of the Slag Cement Association

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Silica Fume

- Produced in arc furnaces during the production of silicon alloys

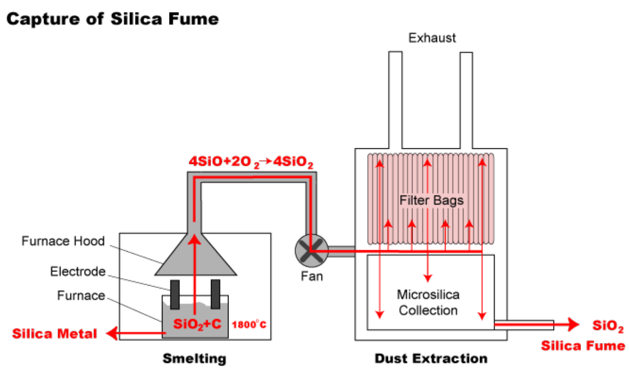

Image Source: http://www.bulkmaterialsinternational.net/bmi_silica_fume.html

- Extremely fine particle size (i.e., particle size averaging 0.1 to 0.2 micron in diameter)
- 100% Amorphous silica that is highly pozzolanic

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Specification Changes

- No major changes for either slag cement ASTM C989 (AASHTO M 302) or silica fume ASTM C1240 (AASHTO M 307) specifications
- ASTM Subcommittee C09.27 on Slag Cement has discussed approaches to specifying slag cement other than blast furnace slag but no specific language developed
- Steel slag is emerging in some specialized applications (e.g., CarbiCrete)

CarbiCrete

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Natural Pozzolan

- With decreased fly ash supplies, natural pozzolan reserves once overlooked are being considered – and they should be
- An early use - early 1900's – LA Aquaduct
- Similar to Class F ash (sum of the oxides > 70%), low calcium
- Examples: Calcined Clay or Shale, Diatomaceous Earth, Volcanic Materials such as Dacite, Rhyolite
- NEW SOURCES - VERIFY PERFORMANCE
- Transportation…

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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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Specification Changes

- Natural pozzolans are currently specified as Class N in ASTM C618 (AASHTO M 295)
- Being split into separate specifications
- Once the new specification (ASTM C1945) is adopted, Class N will be removed from ASTM C618 (AASHTO M 295)

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Ground Glass Pozzolan

- In 2018, the most recent data available from the EPA, 11.2 million metric tons (12.3 million short tons) of container glass were produced.
- Of this production, approximately 2.8 million metric tons (3.1 million short tons) were recycled.
- Very little of the recycled glass made its way into concrete given the lack of material recovery facilities (MRFs) processing glass.
- Estimated annual production is on the order of 35,000 metric tons (40,000 short tons).

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Ground Glass Pozzolan

Designation: C1866/C1866M – 20

Standard Specification for
Ground-Glass Pozzolan for Use in Concrete[1]

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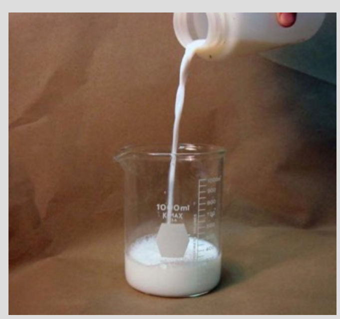
Colloidal Silica, Defined

Liquid Dispersion of Nano Silica Particles

- **Liquid Dispersion**
- **Clear to Milky Appearance**
- **Surface Area – 80 to 500+ m^2/g**
- **Solids Content – 5 to 50%**



Nano Silica Dispersion

CSCA

Slide courtesy of J. Belkowitz

Green, B. ACI Materials Journal, SP-254-8, 121–132, 2008.

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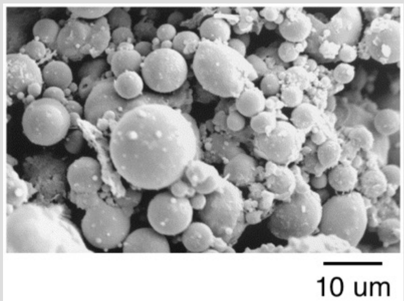
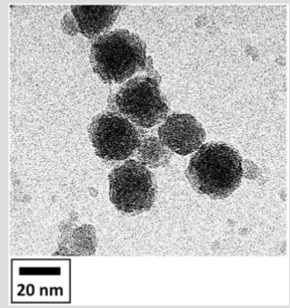
Enhancing with Newer Technology

Not Replacing Current Technologies – Enhancing



- **Class F Fly Ash**



- **Nano Silica**

FOR REFERENCE:
A strand of hair is approximately 100,000 nm in diameter.

Slide courtesy of J. Belkowitz

• 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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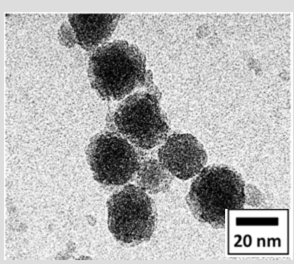
Pozzolanic Reaction

And more…

Colloidal Silica (CS)



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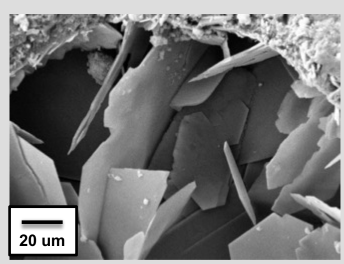
Calcium Hydroxide (CH)



1. CS promotes pozzolanic reaction and the development of C-S-H at the expense of CH
2. Particle-to-Particle Packing / Void Filling
3. Creates an environment not conducive to Chemical and Physical Attack

Slide courtesy of J. Belkowitz

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Specification Changes

- ASTM is developing a standard specification for colloidal silica
- Process is challenged by the wide range of colloidal silica formulations
- "*Not all colloidal silicas are created equal*"
- Performance attributes – strength development, ASR mitigation, permeability - vary widely between formulations, dosages, and mixing methods
- There will be a learning curve for the user

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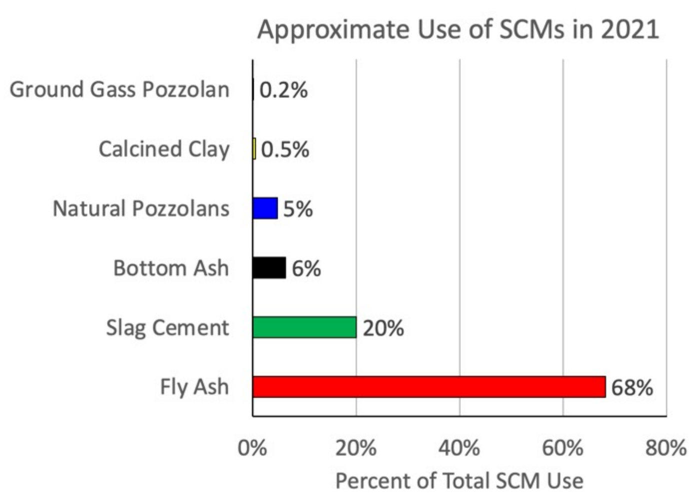
Estimated SCM Use - 2021



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Alternative Supplementary Cementitious Materials

- Given the questions around coal fly ash supply, alternative supplementary cementitious materials (ASCMs) are emerging.
- Various properties offered
  - Performance "similar to" fly ash
  - Lower transportation costs (some cases)
  - Performance as a filler material
  - Uniformity?
  - Carbon sequestration
  - Partial replacement of portland cement – less risk

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Alternative Supplementary Cementitious Materials (ASCMs)

- Different feedstocks
- Different processes
- Some are manufactured new materials
- Some are modified old materials

TERRA CO2

CARBON LIMIT

PROMETHEUS MATERIALS

BRIMSTONE

FORTERA

carbon upcycling

THINK pozzotive

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Alternative Cementitious Materials

- Full replacements of portland cement
- Varying feedstocks - proprietary processes – some leading to familiar material (e.g., clinker) and some creating new materials
- Three general classes
  - Clinker-free
  - Alkali activated
  - Carbonation hardening

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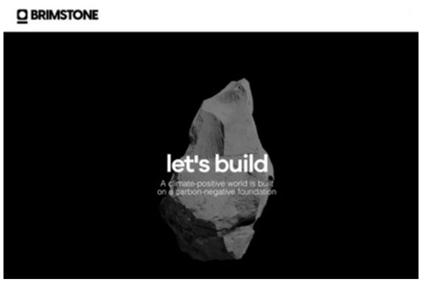
Alternative Cementitious Materials (ACMs)

- Clinker-Free

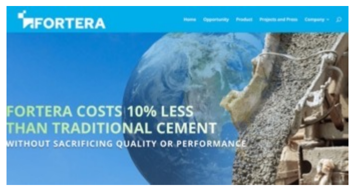


PROMETHEUS MATERIALS

Sublime Systems

Low-carbon cement, so we can keep building.

chement



- Chemically derived
- Bio-cements
- Different feedstocks
- Different processes

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Alternative Cementitious Materials (ACMs)

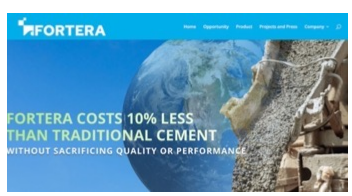
- Clinker-Free

PROMETHEUS MATERIALS

Sublime Systems

Low-carbon cement, so we can keep building.

chement



- In pilot plant production (Fortera, 15,000 tpy) or approaching that scale (Sublime 30,000 tpy in 2026)

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Alternative Cementitious Materials (ACMs)

- Alkali-Activated

- Clinker-Free

Sublime Systems
Low-carbon cement, so we can keep building.

chement

OTB OUTSIDE THE BOX MATERIALS

GEOPOLYMER INTERNATIONAL

C-Crete TECHNOLOGIES

PROMETHEUS MATERIALS

WAGNERS

EFC CONTAINS NO CEMENT

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Alternative Cementitious Materials (ACMs)

- **Cements that Require Carbonation**
- Based on calcium silicate (wollastonite) carbonation, or
- Based on calcium hydroxide/lime carbonation
- React with CO_2 to produce calcium carbonate $CaCO_3$

SOLIDIA®

CarbonBuilt™

CarbiCrete

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Cements that Require Carbonation Curing

ASTM INTERNATIONAL Designation: C1905/C1905M – 23

Standard Specification for
Cements that Require Carbonation Curing[1]

ASTM INTERNATIONAL Designation: C1910/C1910M – 23

Standard Test Methods for
Cements that Require Carbonation Curing[1]

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Don’t forget blended cements

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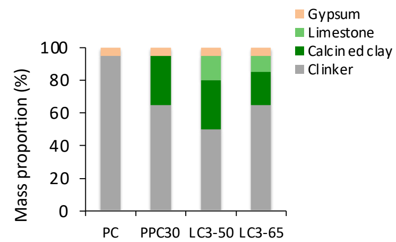
New binder systems – Most not meeting ASTM C596

- Old materials used in new ways
- Significant clinker reductions
- New blends under ASTM C1157 ?

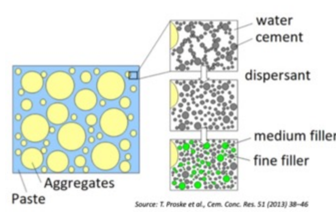
Limestone Calcined Clay Cement LC3



Designation: C1157/C1157M – 20a

Standard Performance Specification for Hydraulic Cement[1]

High-Filler Low-Water (HFLW)



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As you can see…

It’s getting complicated on the playground…

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It’s getting complicated on the playground

What it was…

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It’s getting complicated on the playground

What it was…

What it is quickly becoming…

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And without some adult supervision…

There will be growing pains…

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How will this affect specifications?

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Change is needed…

- Yes change… but we need to keep change focused on the right things…

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Change – What do we focus on?

- Need to move to testing fundamental material properties and learning how to use those properties to understand mixture performance (i.e., materials engineering, like every other industry)
- Current material specifications, in general, do not measure fundamental properties
  - Tests need to focus on properties that affect how the material performs in a concrete mixture
  - Use appropriate tests to measure key properties; example, reactivity vs. strength activity index (SAI)

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Change

- Performance-Based Specifications
  - We can no longer prescribe specification limits for individual materials
    - There are too many materials, and they are too diverse
  - We need to measure and report fundamental properties (e.g., reactivity, particle size) that determines its performance in concrete, and learn how to use that information to design mixtures
- Developing a performance-based specification will likely be less of a challenge than is transitioning to using it

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Implementation

- The user community – primarily civil engineers – have relied on prescription for materials because they could (false security)
- Example: Fly ashes of the same type were considered similar enough, normally
  - Often this was not true – but they lived with it
- Experience with new measurements will come with time
- Design tools and guide documents will be needed

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Current initiatives for ASTM specifications

- Performance specification for SCMs
- Performance specification for alkali activated cements
- Changes to the blended cement specification to accommodate new binder systems

Designation: C595/C595M – 24

Standard Specification for Blended Hydraulic Cements

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SCM Specification

- At ASTM we are currently developing a performance-based specification for SCMs
- A new pathway to specify emerging materials and off-spec conventional materials
- Uses the recently developed standard tests for reactivity and for foam index

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New Tests

R3 Tests

Designation: C1897 – 20

Standard Test Methods for Measuring the Reactivity of Supplementary Cementitious Materials by Isothermal Calorimetry and Bound Water Measurements[1]

Foam Index

Designation: C1827 – 20

Standard Test Method for Determination of the Air-Entraining Admixture Demand of a Cementitious Mixture[1]

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Table 1 Physical Requirements

Fineness	
Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %	report only
Amount retained on 150-µm (No. 100) sieve, max, % [A]	10
Density [B]	report only
Strength activity index [C]	
Option 1	
At 7 days, percent of control, min, %	80
and	
At 28 days, percent of control, min, %	80
Option 2	
At 56 days, percent of control, min, %	80
Water requirement	
Water requirement, percent of control	report only
Reactivity [D]	
Procedure A:	
Cumulative heat release, 7 days, min, J/g of SCM	90
Procedure B:	
Bound water content, min, g/100 g dry paste	3.5
Time of initial setting [E]	
Setting time, minutes	report only
Uniformity	
The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than:	
Density, max variation from average, %	5
Percent retained on 45-µm (No. 325), max variation, percentage points from average	5

TABLE 2 Optional Physical Requirements

Foam index [A]	
Relative absolute volume of AEA, %	report only
Effectiveness in controlling alkali-silica reaction [B]	
Expansion of reference mixture at 14 days, %	report only
Expansion of test mixture, at 14 days, %	report only
Uniformity requirements	
The quantity of air-entraining admixture required to produce an air content of 18.0 vol % of mortar shall not vary from the average established by the ten preceding tests or by all preceding tests if less than ten, by more than, %	20

[A] Determine the foam index in accordance with Test Method C1827. The purchaser shall identify the air-entraining admixture (AEA) to be used. Report the type and brand of AEA used in the test and report the type, brand, and source of portland or portland limestone cement used in the test.

[B] Prepare a reference mixture in accordance with Test Method C1260 and a test mixture in accordance with Test Method ASTM C1567. Use a reactive aggregate source with a 14-day expansion greater than or equal to 0.20 % and less than or equal to 0.45 % when tested in accordance with Test Method ASTM C1260. Use 25 % by mass replacement of the SCM in the test mortar mixture and no SCM replacement in the reference mortar mixture. Report the expansion results for the test mixture and the reference mixture.

10.2.1 If the SCM meets the scope of one of the specifications referenced in 10.2, the supplier shall i) perform all required testing to establish compliance with the applicable specification identified in 10.2, ii) report all test results required by the applicable specification identified in 10.2, and iii) specifically identify which requirements or limits of the applicable specification identified in 10.2 the SCM does not comply with.

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Challenges

- Perceived risk of not requiring a chemical composition
  - Concerns of consistency, false comfort of “controlling” what you get by knowing the chemical composition
- Specifier needs more knowledge about materials in general
  - The need to understand reactivity, sulfate content, LOI, foam index
- More reliance on trial batching
  - Increased cost of testing? More skilled testing?
- For the producer – more responsibility to provide a consistent product

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Performance specification for alkali activated cements

- Based largely on ASTM C1157
- Incorporates the newly developed ASTM C1928 test method for compressive strength of AAC cubes

Designation: C1928/C1928M – 23

Standard Test Method for
Compressive Strength of Alkali Activated Cementitious Material Mortars (Using 2-in. [50 mm] Cube Specimens)

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Performance specification for alkali activated cements

- Defines two (2) types of alkali activated cementitious materials
  - Those tested with curing at standard laboratory temperatures (i.e., 20 ºC), “Type AACM RTC”
  - Those tested with curing at elevated temperatures (i.e., 60 ºC, “Type AACM ETC”
  - Each Type can be designated GU, HE, MS, HS, MH, LH
  - Physical requirements similar to ASTM C1157

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Changes to ASTM C595

- For the blended hydraulic cement specification, a new **Type IC** has been proposed
- Minimum 30% clinker or portland cement
- Can blend in any quantities or combinations: limestone, pozzolan (e.g., coal ash, natural pozzolan, silica fume) or slag cement
- Must meet all applicable requirements of the specification
- Will directly support development of LC3 or HFLW blends as part of an existing specification
  - ASTM C595 is harmonized with AASHTO M 240

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Challenges - Alternative Cementitious Materials

- Risk
  - Replacing portland cement completely is a major change
    - New cements with limited recorded field experience.
  - Critical design information is required
  - Increased use of ACMs will require significant investment in demonstration projects where the risk is underwritten by a third party and performance is demonstrated.
  - ASCMs represent less risk – partial replacement

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Challenges - Alternative Cementitious Materials

- Specification Environment
  - In the United States and Canada, all cement is specified using ASTM, AASHTO, or CSA standards.
  - Currently these standards are prescriptive and only cover hydraulic cement.
  - Only ASTM has a performance-based specification, but it is scope limited to cover only hydraulic cements.
  - Without a national specification, non-hydraulic ACMs will not be included in model building codes and will likely not be adopted by any state DOT.

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Durability

- Durability is a legitimate concern – but - durability testing by itself cannot ensure durability for any concrete
- If we want to know about durability, we have to start using the materials and let the sands of time tell the story
- Back to we cannot just say no… We need to start saying yes…
  - Low-risk projects
  - Demo projects
  - Long-term test sites

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Broad Challenges That Must Be Overcome

- Change is difficult and perceived to be risky
- The Licensed Design Professional (LDP) is responsible to meet the standard of care for their discipline – limits first adopters
  - Life-safety cannot be compromised
  - Innovation is possible but not often pursued
- Risk often falls onto the General Contractor and/or concrete supplier
  - Impacts on constructability
  - Penalties if certain performance measures are not met
- **Advancement will be made through risk sharing, collaboration, and demonstrations**

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How to Mitigate the Risk?

- Education/Training
- Financial Incentives
- Changes in Contracting/Improvements in testing
- Performance Specifications (that include sustainability goals)
- Demonstration Projects – Get out of the lab!

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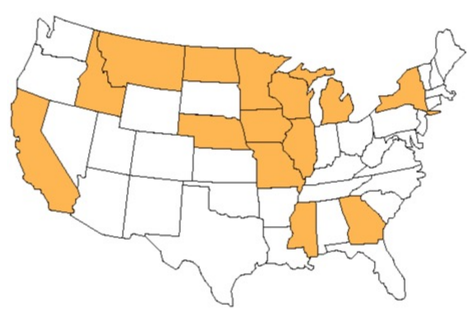
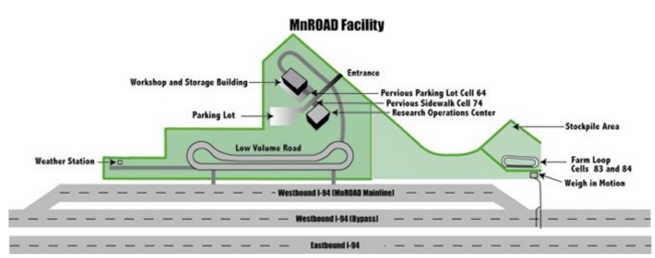
MnROAD - NRRA

- 3.5 mile of I-94 operated by **MnDOT**
- Partnership with the **National Road Research Alliance (NRRA) pooled fund**
- 14 states, FHWA, Minnesota LRRB, 80 industries, associations, and academia
- Designed to test new technologies in a real-world environment





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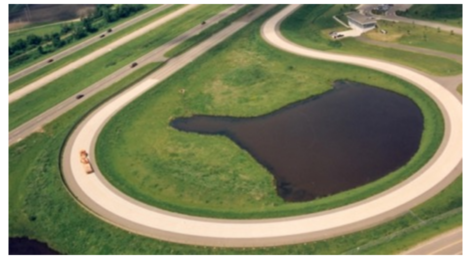
Test Site Construction

- Test cells were constructed at MnROAD to evaluate strategies to reduce GHG emission in paving
- 2022 - 14 test cells (plus controls) including
  - 1 optimized mixture (based on control)
  - 3 CarbonCure™, TerraCO2, Carbon Limit, Hess Natural Pozzolan, 3M Natural Pozzolan, Carbon Upcycling, Type (IL20), Type IP(30) with calcined clay, UltraHigh Materials, Metakaolin, Urban Mining GGP
- 2024 - 5 Test cells (plus controls)
  - C-Crete, LC3 (Ash Grove), Holcim IL plus, slag, fly ash, natural pozzolan, Ozinga CarbonSense, Holcim IT(P30)(S20)



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Project Requirements

- General Requirements
  - Portland cement mixtures will use an ASTM C595 Type IL(10) blended cement
  - Mixtures shall meet performance requirements based on AASHTO R 101 Developing Performance Engineered Concrete Pavement Mixtures *(required 500 psi flex @ 28 days, 5-8% air)*
  - Optimized aggregate gradation using concrete ready-mix plant aggregates meeting the requirements of MnDOT 2301.2C.3 of the 2020 Spec Book (Table 3).
  - Batched and mixed at a central ready mixed plant and paved using conventional slip-form paving equipment

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Wrap-Up

- Cement replacement (full or partial) is the short- and long-term goal
- Existing and new materials will be used
- New specifications are being developed to support the transition
- We will – slowly – turn to performance-based specifications and when we do… there will be more responsibility on the specifier.
- New tests and materials will be coming at us in an increasing rate
- Demo projects are a key step towards full implementation

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Questions?

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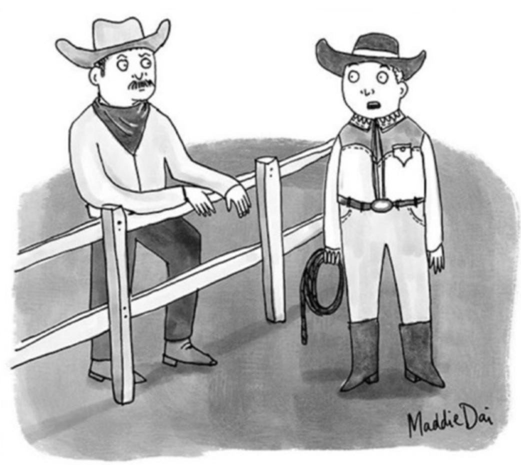
periculosum est tempus indoctus



"It's my second rodeo and everyone is acting like I should be some kind of expert."

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