

# Setting Standards for Innovative Cementitious Materials

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## Change is happening ...

dezeen




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Tham & Videgird,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<sub>2</sub> intensive
  - Energy intensive
  - Exploits natural resources



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# What Do We Mean? Low-Carbon Concrete?

- Concrete has one of the lowest carbon footprints of any material... but...
- We used ~4.5 billion tons world-wide in 2020, projected to double by 2050
- ~1 cy/person/year
- ~140 million tons 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
- Actually we mean reduced-carbon concrete**

After Barcelo et al., 2014  
Data from Hammond and Jones (2011), Inventory of Carbon & Energy V2

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# What is CO<sub>2</sub> eq - CO<sub>2</sub> equivalent?

The relative global warming potentials of the main greenhouse gases

(Data: GWPs given for 100 year time horizon, IPCC 2021)

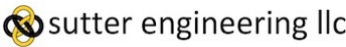
Source: ClimatePartner

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Example of GWP Expressed in as a CO<sub>2</sub> eq

EPDs – Environmental Product Declaration

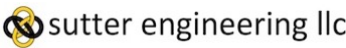
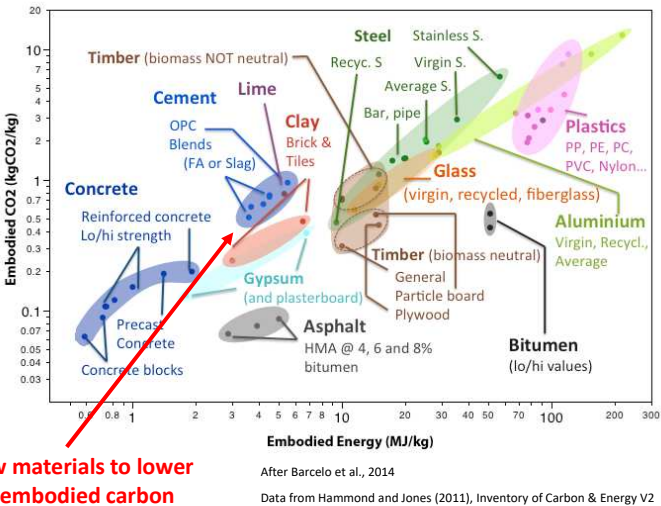
Material	GWP (kgCO <sub>2</sub> -eq/mt)	Source
Average Cement (U.S.)	922	EPD for the Portland Cement Association (PCA)(3/12/21)
Holcim Ste. Genevieve AASHTO M 85 Type I/II	748	EPD for Ste. Genevieve, MO Cement Plant (2/26/2021)
Holcim St. Genevieve AASHTO M 240 Type IL(8) <sup>1</sup>	724	EPD for Ste. Genevieve, MO Cement Plant (2/26/2021)
Class F fly ash	12.1	FHWA LCAPave Tool
Urban Mining Pozzotive <sup>®</sup> ground glass pozzolan	55.9	EPD for Urban Mining Pozzotive <sup>®</sup> ground glass pozzolan (5/11/20)



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The Path Forward To Reduce Carbon

- Concrete has one of the lowest carbon footprints of any material... but...
- **We used ~4.5 billion tons world-wide in 2020, projected to double by 2050**
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Use less cement per cubic yard of concrete

After Barcelo et al., 2014  
Data from Hammond and Jones (2011), Inventory of Carbon & Energy V2

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## Is it just us?

- CO<sub>2</sub> emissions in 2019
  - Coal – 15.2 GtCO<sub>2</sub>
  - Oil – 11.2 GtCO<sub>2</sub>
  - Gas – 33 GtCO<sub>2</sub>
  - Cement - 1.6 GtCO<sub>2</sub>**
  - Livestock - 7.1 GtCO<sub>2</sub> eq
    - Cattle - 2.9 GtCO<sub>2</sub> eq**
    - Dairy - 1.5 GtCO<sub>2</sub> eq**
    - Pork - 0.64 GtCO<sub>2</sub> eq**
- Become a vegan if you really want to make a difference...**

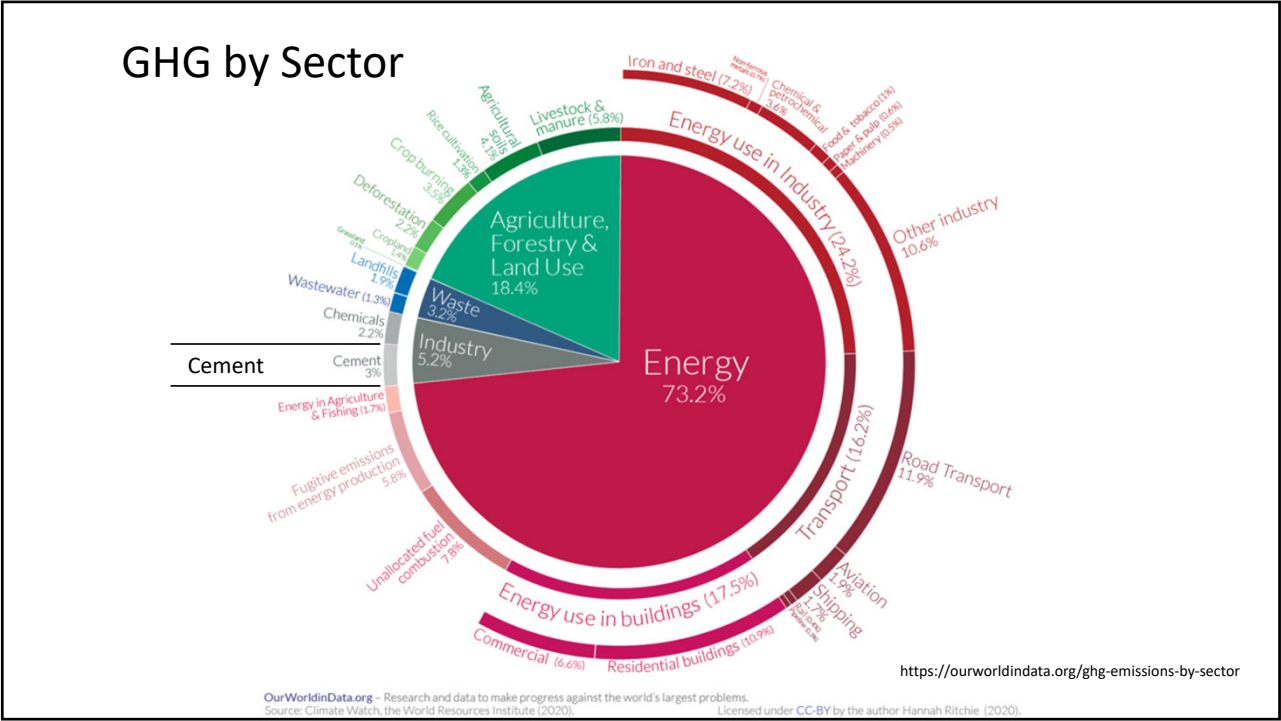
28 Methane

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# What's Driving the Change?

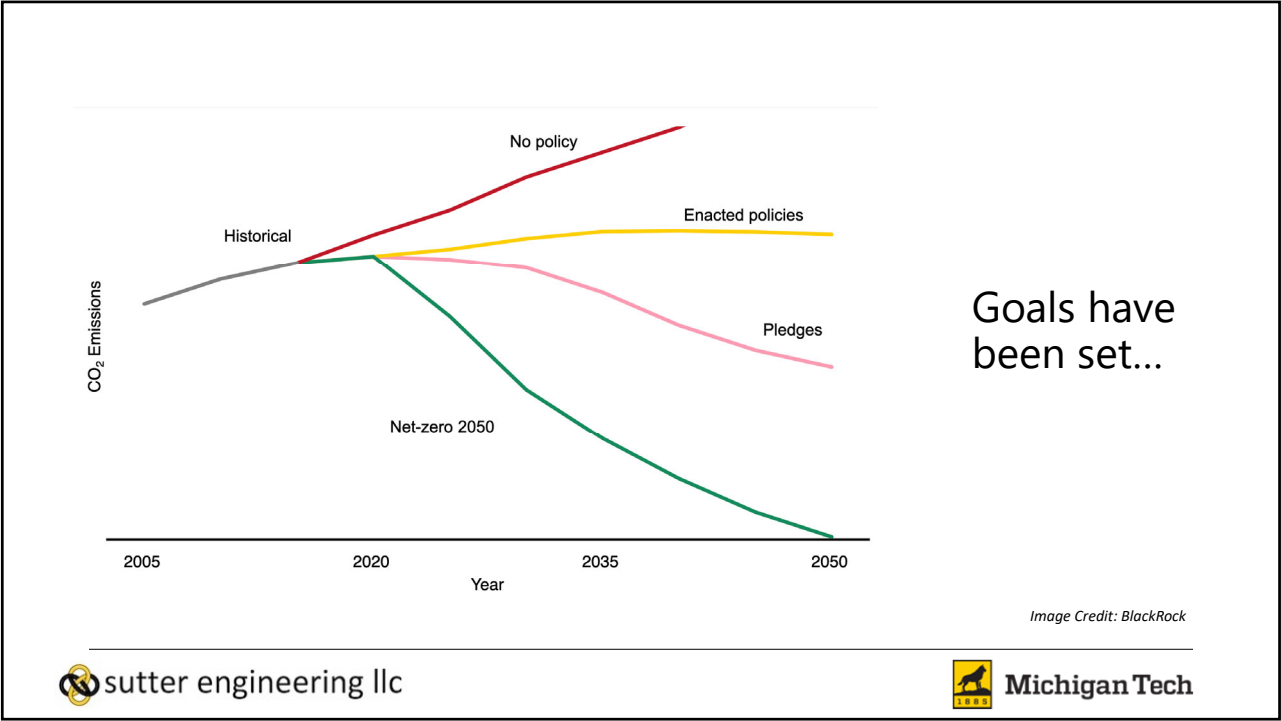
- Concrete has an image problem
  - "Dirty"
  - CO<sub>2</sub> intensive
  - Energy intensive
  - Exploits natural resources
- Don't whine. Don't complain. Don't make excuses. (John Wooden)**

"Can you be more specific?"

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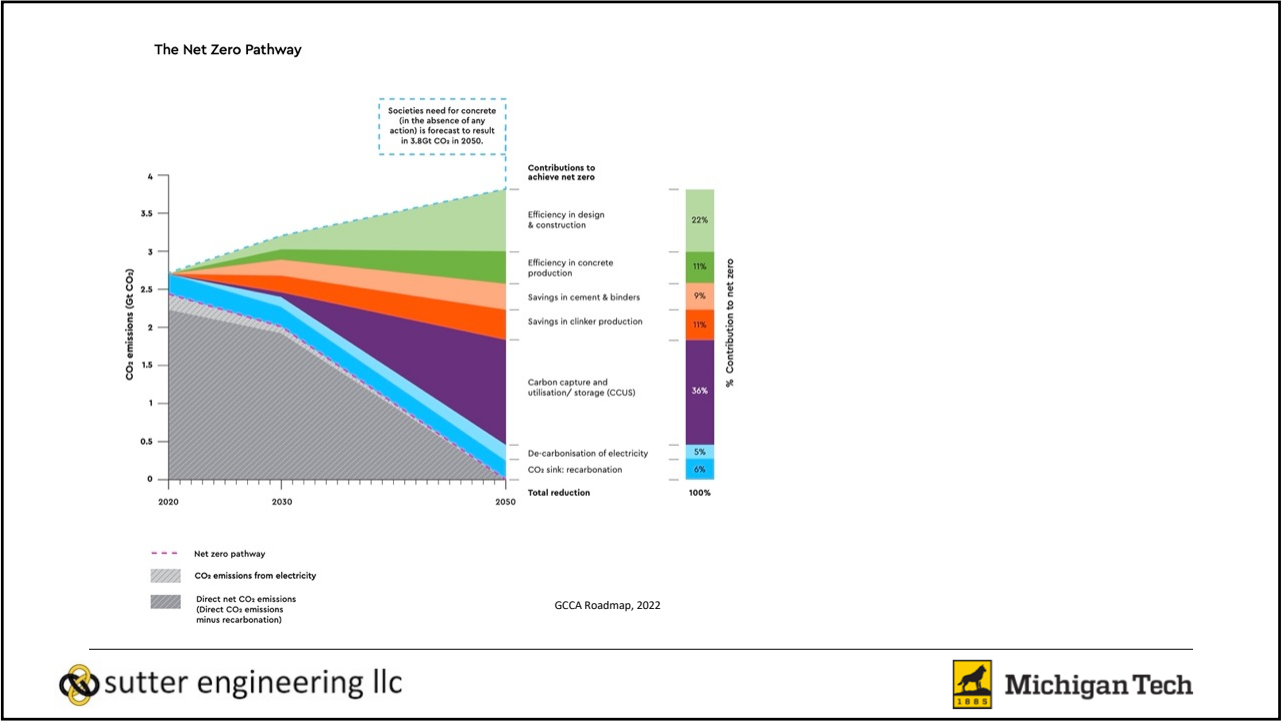
# Everyone has a Roadmap

- 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.

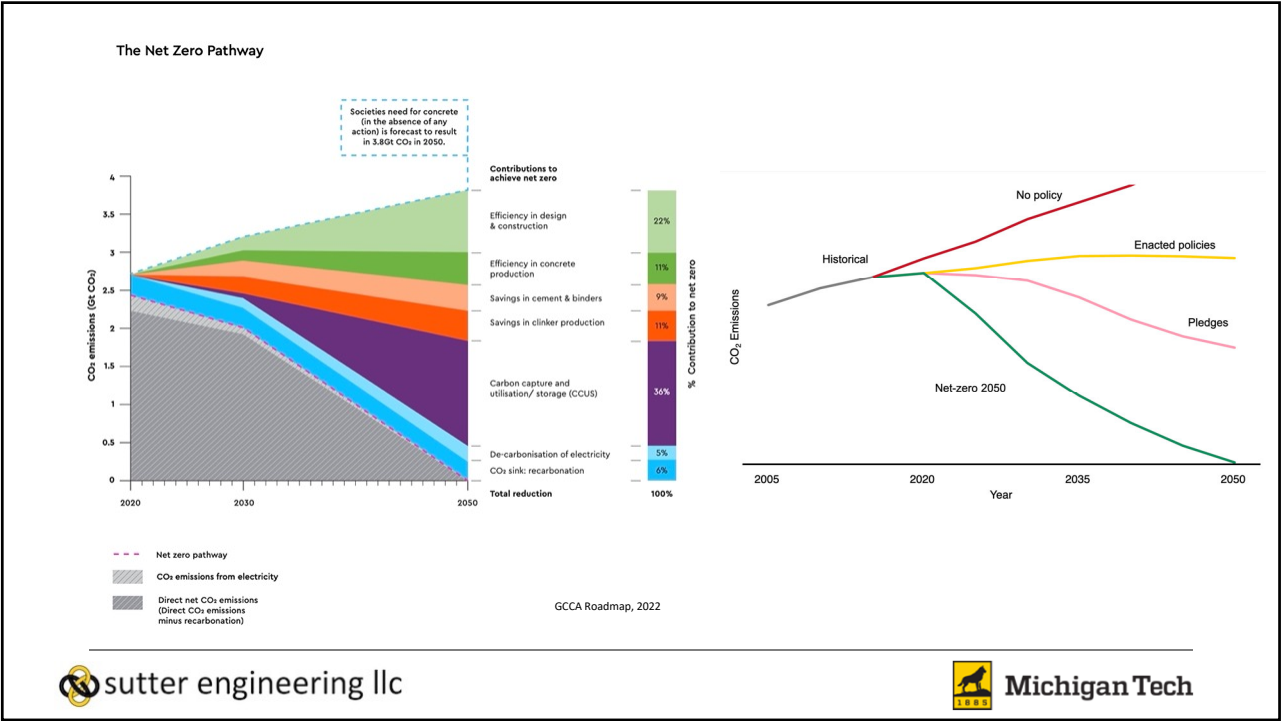
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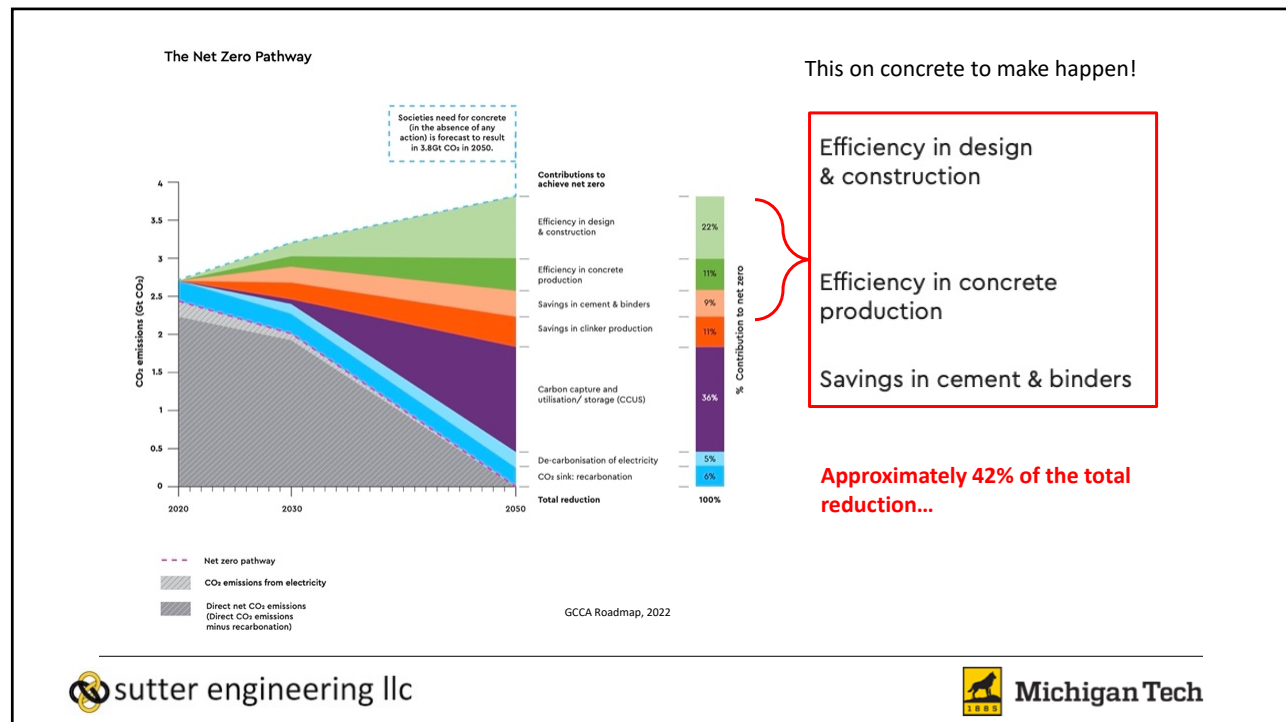


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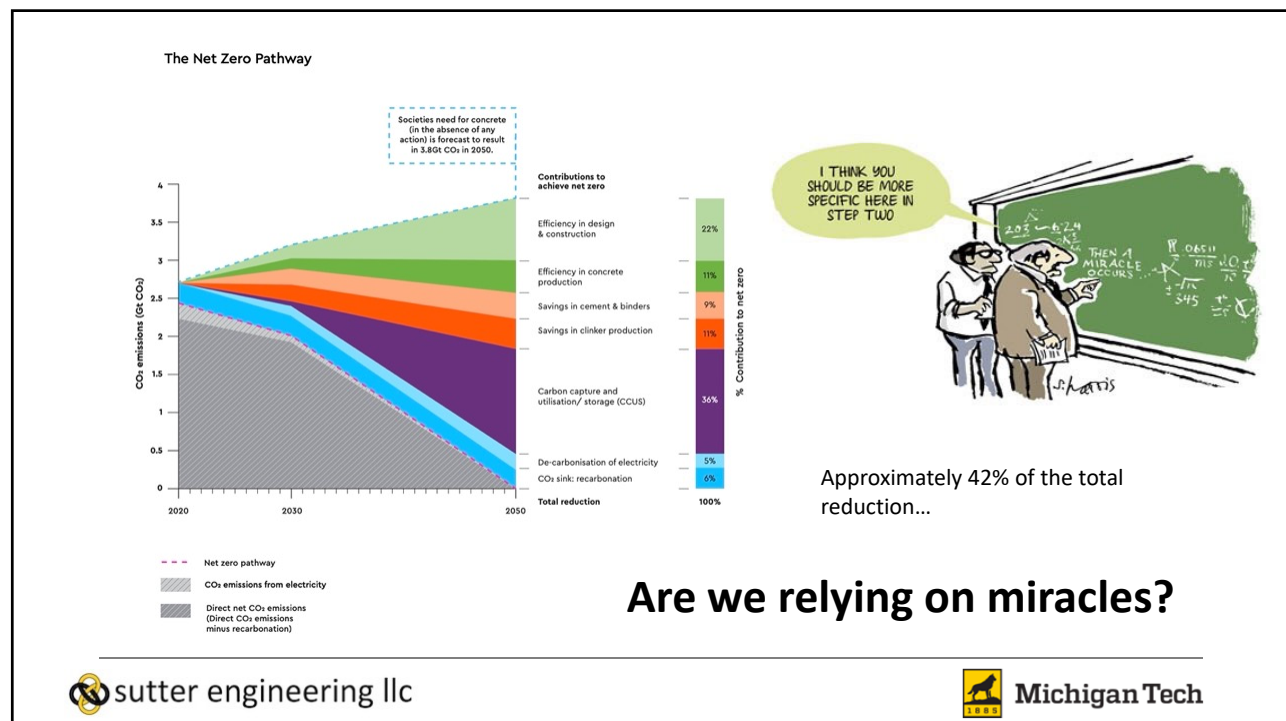


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## Portland Cement is Not Going Away

- Society needs concrete
  - Portland cement is here probably forever – we need to make it work
  - New materials will have a role
  - Our goals must be realistic – we need to use the materials we have better
  - 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
  - And society has few if any choices if we want to maintain our lifestyles



# 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

- 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



The image shows two large, L-shaped concrete test specimens side-by-side in a warehouse. The specimen on the left is labeled 'Conventional' and is significantly thicker. The specimen on the right is labeled 'UHPC' and is much thinner, demonstrating a reduction in concrete volume while maintaining structural integrity.

Courtesy S. Foster

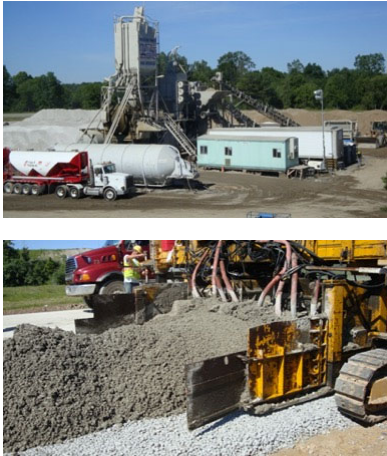
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### Less Cement in Concrete

- 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"



The image consists of two photographs. The top photo shows a concrete batching plant with a large mixer truck. The bottom photo shows a yellow excavator with a bucket full of concrete aggregate, illustrating the process of handling materials for concrete production.

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## Current Practice: Absolute Volume Method

- Slump tied to water content
- Water content is fixed
- Water-to-cementitious materials ratio ( $w/cm$ ) is varied by **increasing cementitious content**
- Coarse and intermediate aggregate content held constant
- Sand content decreased to compensate for added cement
- ACI 301 over-design is used assuming no prior data available; sets higher value for targeted compressive strength

Materials	337.5	412.5	487.5	562.5
ASTM C150 Type II-V Cement	112.5	137.5	162.5	187.5
ASTM C618 Class F	112.5	137.5	162.5	187.5
Total Cementitious	450	550	650	750
ASTM C33 I	510	510	510	510
	1190	1190	1190	1190
Sand	1639	1543	1448	1350
Water	271	271	271	271
W/C Ratio	0.60	0.49	0.42	0.36

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## Example of Using Absolute Volume Method

- The cementitious materials content is raised in 100 lbs increments to lower the  $w/cm$ 
  - Strength is increased and permeability decreased by lowering the  $w/cm$
- No consideration of the role of water-reducing admixtures in reducing water content
- Aggregate grading is not optimized to reduce the void space between aggregates
  - Numerous tools available to guide this process

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## Challenges When Reducing Cementitious Content

- Less cement means less heat generated
  - Can be helpful in hot weather or mass concrete placements
  - Can pose difficulties in cool weather or when early strength is required
- Less cementitious materials means moisture control is more critical as changes in water have a more profound impact on w/cm
- Less cementitious materials can mean difficulties when finishing
  - Partially compensated for when aggregate is optimized
- More cementitious materials required with some aggregates
  - Manufactured sands, some poor-quality aggregate



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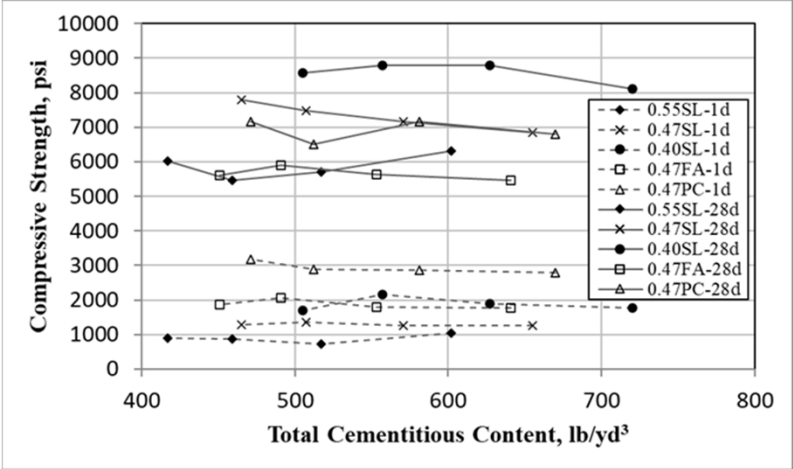
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## Increasing Cement Content Does Not Necessarily Increase Strength


Influence of cementitious content on compressive strength for mixtures at the same w/cm

SL=slag, FA=fly ash, PC=Portland cement, 0.55, 0.47, 0.40 = w/cm

Source: Obla, Hong, Lobo, and Kim. TRR No. 2629. 2017



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### Quick Summary of Void Ratio Method

- The Void Ratio Method proportions concrete mixtures assuming the amount of paste required in a mixture is dependent on the volume of voids
- All voids are filled, and a little extra paste provided to separate the aggregate particles
- Excessive extra paste is avoided to minimize issues with strength, permeability, shrinkage and sustainability
- Three basic components:
  - Select an aggregate system
  - Select a paste system
  - Select a paste quantity

**Tarantula**

Greater than 15% on the sum of #8, #16, and #30  
24%–34% of fine sand (#30–#200)

Sieve	Percent Retained, % vol
2"	0
1 1/2"	0
1"	10
3/4"	12
1/2"	14
3/8"	10
#4	14
#8	7
#16	7
#30	10
#50	15
#100	3
#200	0

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### Revisiting Mixture Proportioning

- Re-evaluate approach to mixture proportioning, considering the role of aggregate optimization and water-reducing admixtures
  - Seek life beyond “The Three-Point Curve”
- Several tools are available
  - Tarantula Curve - <http://www.tarantulacurve.com/>
  - Void Ratio Method - <https://cptechcenter.org/publications> under “Spreadsheets”

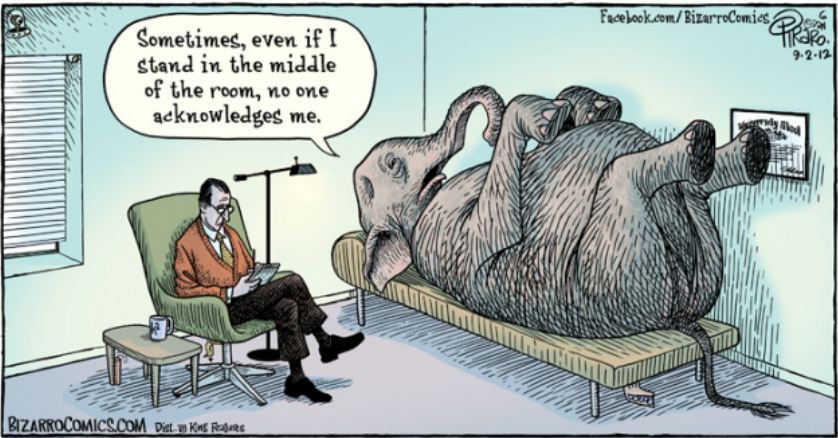
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## Less Cement in Concrete – Other Factors?

- 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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## The Path Forward for Concrete

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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

## 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)

## So what is ASTM C595?



- In 2007 Designation (HS) for high sulfate resistance was added
- 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 (AX)(BY) 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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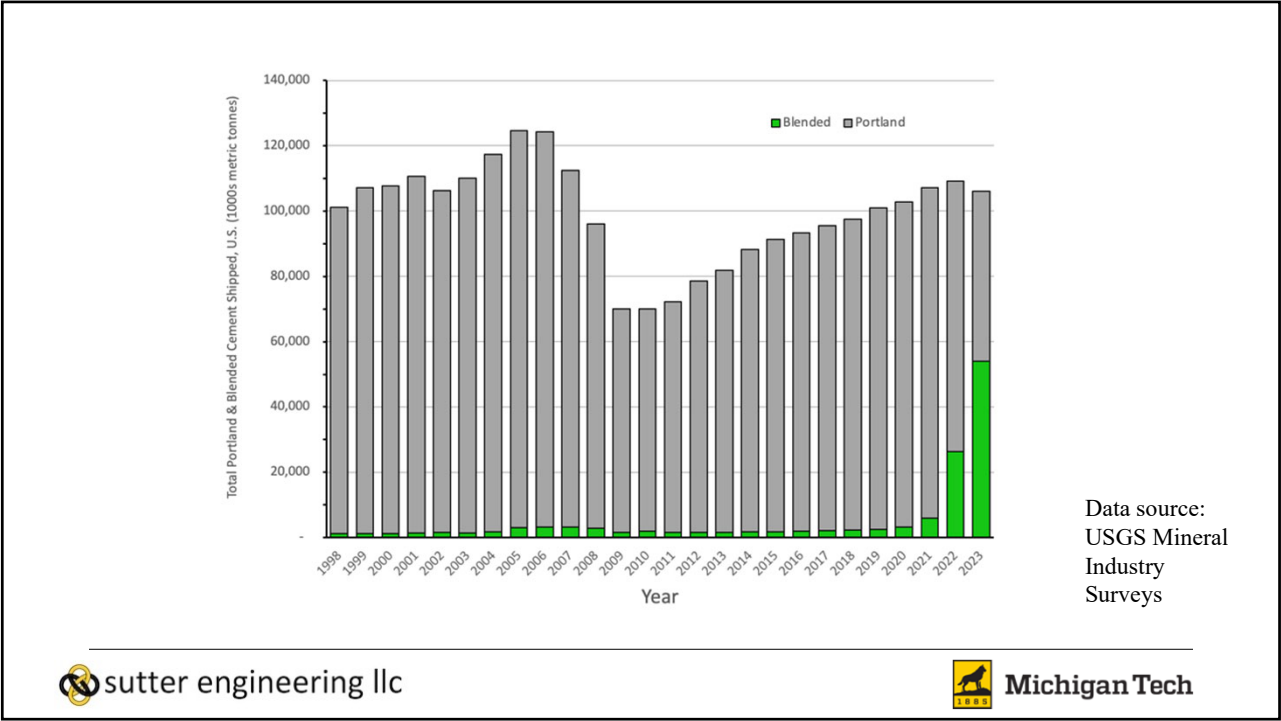
## So what is ASTM C595?

- In 2012 Type IL was added
  - 10 years before roll out
- 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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## 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](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
- Central to 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

Pozzolan + CH -> CSH

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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

Pozzolan + CH -> CSH

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CH from portland cement hydration is consumed

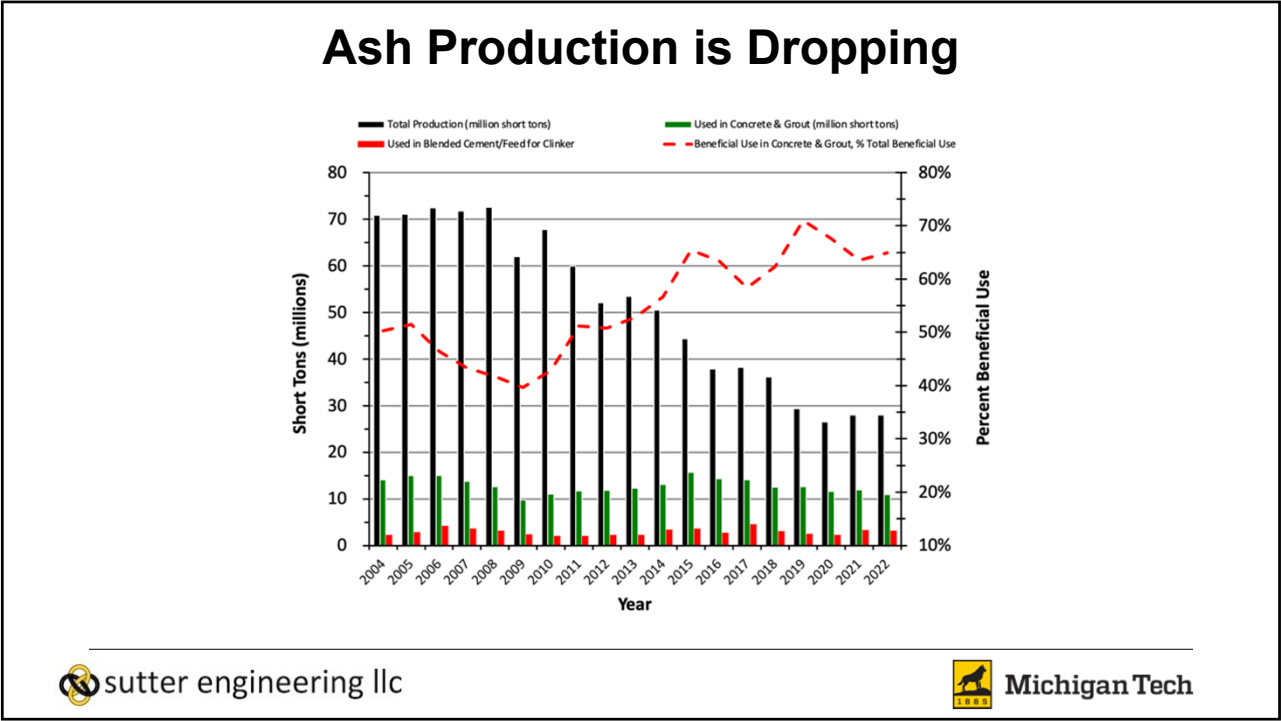
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## So what's the problem?



## 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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### 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
  - Three large projects in Georgia coming on-line adding another 1 million tons over the next 12-15 months

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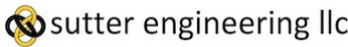
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## Harvested Ash – Production & Beneficiation

- 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<sup>ε1</sup> 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<sup>ε1</sup> 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 <sub>2</sub> Si <sub>2</sub> O <sub>8</sub> )	-	34.3	-	18.6
Quartz - (SiO <sub>2</sub> )	4.1	2.9	13.9	13.7
Diopside - (CaMgSi <sub>2</sub> O <sub>6</sub> )	-	8.1	-	-
Hematite - (Fe <sub>2</sub> O <sub>3</sub> )	1.2	0.9	0.4	0.3
Merwinite - [Ca <sub>3</sub> Mg(SiO <sub>4</sub> ) <sub>2</sub> ]	8.6	-	-	-
Lime - (CaO)	0.7	-	0.02	-
Periclase - (MgO)	2.4	-	0.03	0.2
Magnesite - (MgCO <sub>3</sub> )	0.3	-	-	-
Mullite - (Al <sub>6</sub> Si <sub>2</sub> O <sub>13</sub> )	-	-	11.4	2.0

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Unpublished data: L. Diaz

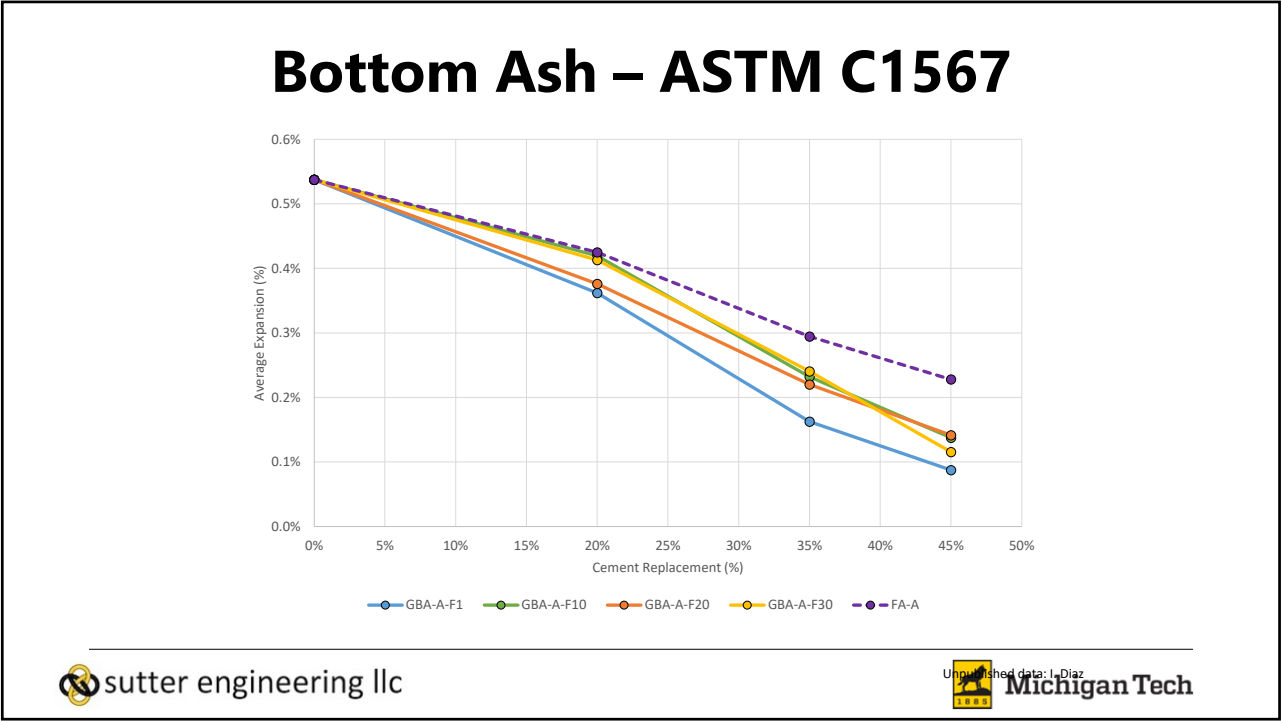
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Bottom Ash – Example Data

	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

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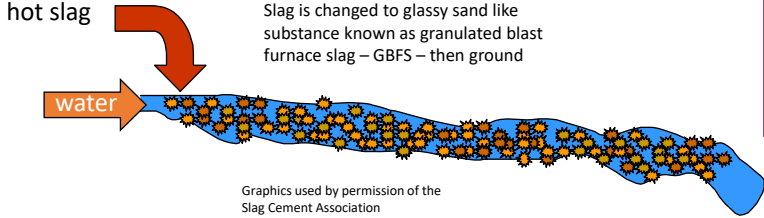
- Harvested Ash
- Concerns
    - Current federal and state regulations require near-term closure of disposal ponds, leaving insufficient time to recover and use all available ash
    - Power producers have little to no incentive to use ash beneficially, closure (cap-in-place) is the lowest cost option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



Slag is changed to glassy sand like substance known as granulated blast furnace slag – GBFS – then ground

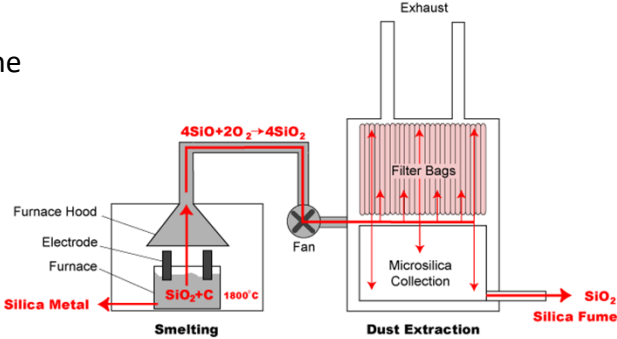
Graphics used by permission of the Slag Cement Association

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# Silica Fume


- Produced in arc furnaces during the production of silicon alloys


### Capture of Silica Fume



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

Image Source: [http://www.bulkmaterialsinternational.net/bmi\\_silica\\_fume.html](http://www.bulkmaterialsinternational.net/bmi_silica_fume.html)

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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)



### 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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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<sup>1</sup>

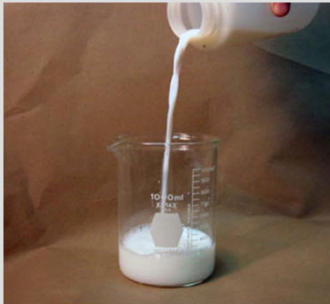
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## Colloidal Silica, Defined

*Liquid Dispersion of Nano Silica Particles*


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



Nano Silica Dispersion

Slide courtesy of J. Belkowitz

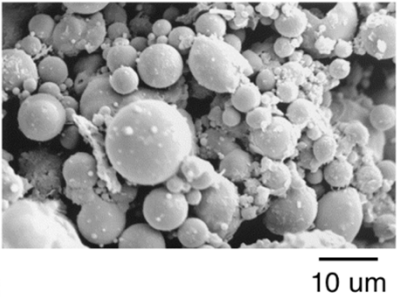
Green, B. ACI Materials Journal, SP-254-8, 121–132, 2008.



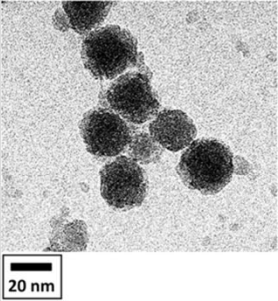
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## Enhancing with Newer Technology

*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.



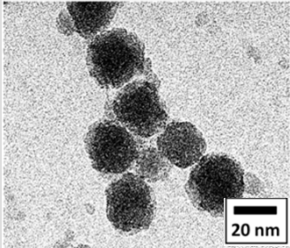
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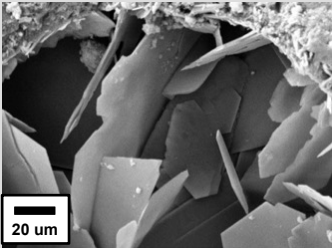
## Pozzolanic Reaction

*And more...*

Colloidal Silica (CS)                      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


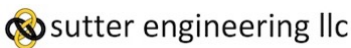


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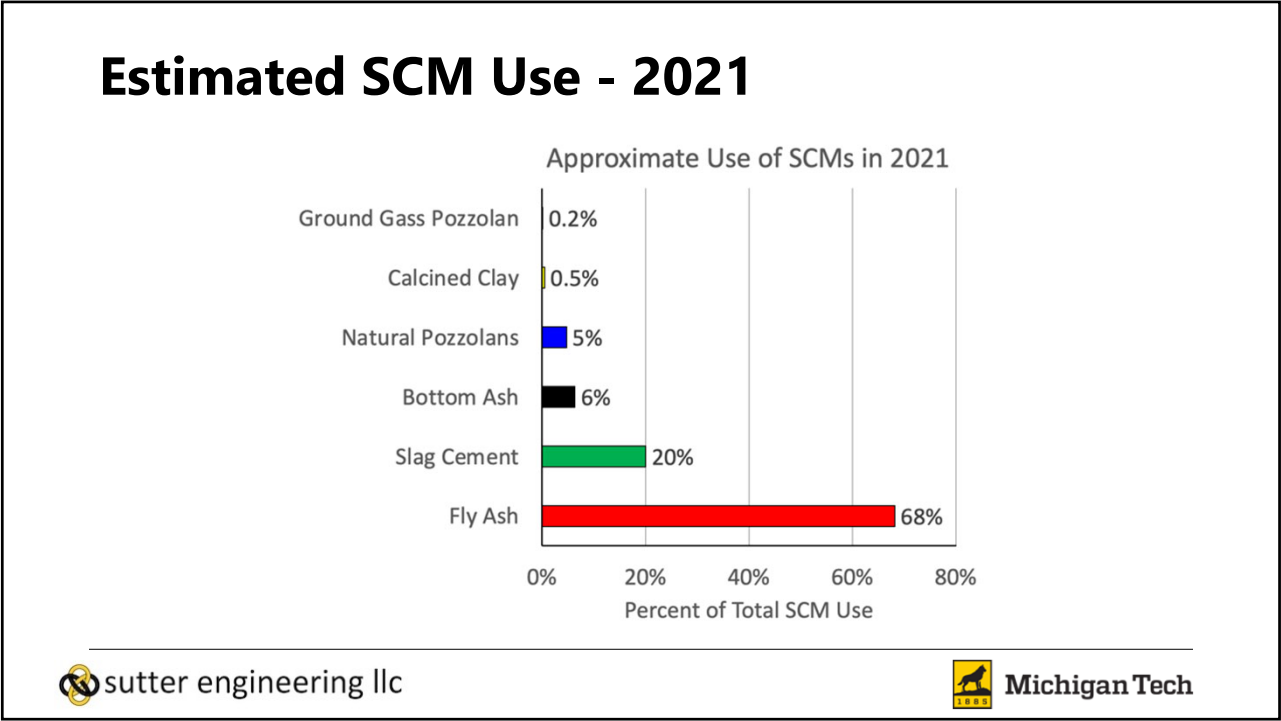
## Specification Changes

- 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 vary widely between formulations, dosages, and mixing methods – strength, strength development, ASR mitigation, permeability
- There will be a learning curve for the user

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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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### 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

T

E

R

R

A

CO2


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

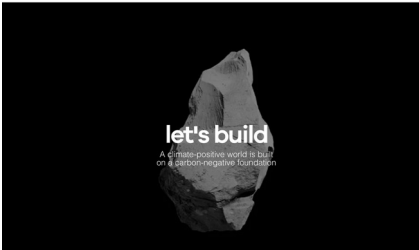

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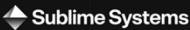
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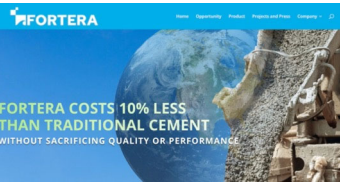
## Alternative Cementitious Materials (ACMs)

- Clinker-Free











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

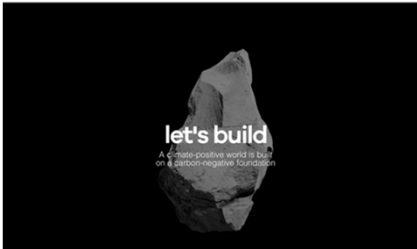

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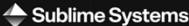
72

## Alternative Cementitious Materials (ACMs)


- Clinker-Free










Low-carbon cement, so we can keep building.





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



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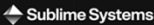
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## Alternative Cementitious Materials (ACMs)


- Clinker-Free
- Alkali-Activated (includes geopolymers)










Low-carbon cement, so we can keep building.











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<sub>2</sub> to produce calcium carbonate CaCO<sub>3</sub>





SOLIDIA®



CarbonBuilt™




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### Alternative Cementitious Materials (ACMs)


- **Cements that Require Carbonation**
- Based on calcium silicate (wollastonite) carbonation, or
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# Cements that Require Carbonation Curing




Designation: C1905/C1905M – 23


Standard Specification for  
Cements that Require Carbonation Curing<sup>1</sup>



Designation: C1910/C1910M – 23


Standard Test Methods for  
Cements that Require Carbonation Curing<sup>1</sup>


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# Don’t forget blended cements

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### New binder systems – Most not meeting ASTM C596

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

Limestone  
Calcined  
Clay  
Cement

LC<sup>3</sup>

Mass proportion (%)

Binder Type	Clinker (%)	Limestone (%)	Calcined clay (%)	Gypsum (%)
PC	~85	0	0	~15
PPC30	~65	~25	0	~10
LC3-50	~45	~35	~5	~15
LC3-65	~60	~25	~5	~10

Designation: C1157/C1157M – 20a

Standard Performance Specification for Hydraulic Cement<sup>1</sup>

High-Filler Low-Water (HFLW)

Aggregates  
Paste

water  
cement  
dispersant  
medium filler  
fine filler

Source: T. Prokeš et al., Cem. Conc. Res. 53 (2013) 38–46

Who we are

Moving from Clinker Factor to Clinker Efficiency – with next generation low-carbon cement technology

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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...

## 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)

## 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

## 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 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

## 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

## 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


# New Tests




Designation: C1897 – 20

Standard Test Methods for Measuring the Reactivity of Supplementary Cementitious Materials by Isothermal Calorimetry and Bound Water Measurements<sup>1</sup>

R3 Tests







Designation: C1827 – 20


Standard Test Method for Determination of the Air-Entraining Admixture Demand of a Cementitious Mixture<sup>1</sup>

Foam Index





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Table 1 Physical Requirements		
<i>Fineness</i>		
Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %		report only
Amount retained on 150-µm (No. 100) sieve, max, % <sup>A</sup>		10
<i>Density <sup>B</sup></i>		report only
<i>Strength activity index <sup>C</sup></i>		
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	
<i>Water requirement</i>		
Water requirement, percent of control		report only
<i>Reactivity <sup>D</sup></i>		
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	
<i>Time of initial setting <sup>E</sup></i>		
Setting time, minutes		report only
<i>Uniformity</i>		
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	
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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	

<sup>A</sup> 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.

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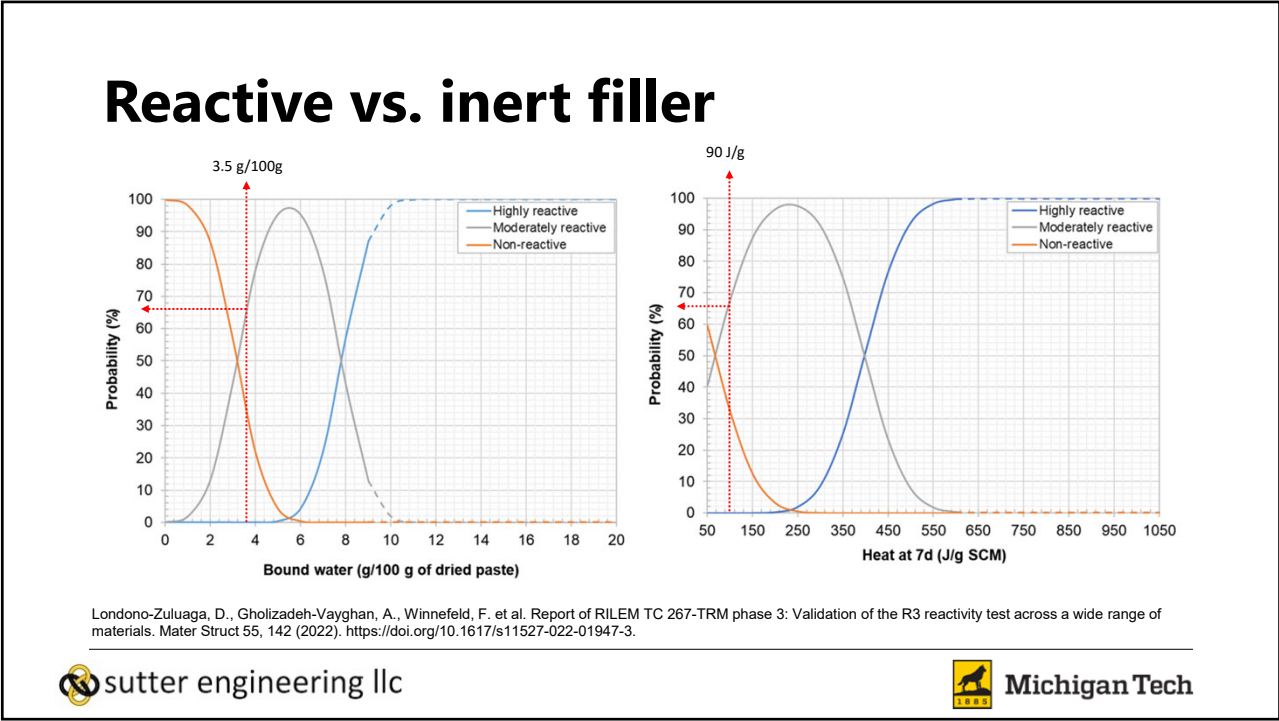
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<sup>A</sup> Determine the foam index in accordance with Test Method C1827. The purchaser shall identify the air-entraining admixture (AEA) to be used. Report the type and brand of AEA used in the test and report the type, brand, and source of portland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

<sup>B</sup> 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
  - Specifier needs more knowledge about materials in general
    - The need to understand things such as 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)

## 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 °C), “Type AACM RTC”
  - Those tested with curing at elevated temperatures (i.e., 60 °C, “Type AACM ETC”
  - Each Type can be designated GU, HE, MS, HS, MH, LH
  - Physical requirements similar to ASTM C1157

## 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

## 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

## 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.

## Durability

- Durability is a legitimate concern – and... durability testing 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



# Broad Challenges That Must Be Overcome

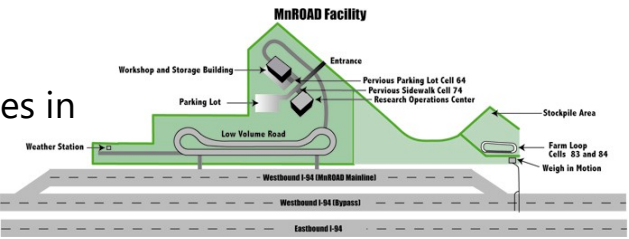

- Change is difficult and perceived to be risky
- The Licensed Design Professional (LDP) is responsible to meet the standard of care for their discipline
  - Life-safety cannot be compromised
  - Innovation is possible but not often pursued
- Risk often falls onto the General Contractor and/or concrete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


# 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!

## MnROAD - NRRA

- 3.5 mile of I-94 operated by **MnDOT**
- Partnership with the **National Road Research Alliance (NRRA)**
- 11 states, 50 industries, associations, and academia
- Designed to test new technologies in a real-world environment



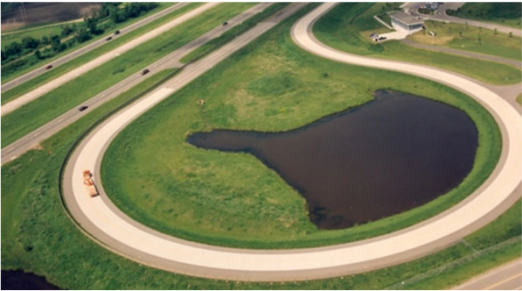
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## Test Site Construction

- 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*)
  - Batched and mixed at a central ready mixed plant and paved using conventional slip-form paving equipment

## 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


# Questions?

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*periculosum est tempus indoctus*



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