Low-Carbon Concrete How Do We Get There?

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Opening Thoughts

- Low-Carbon Concrete
- What is it?
- And why should I care?

- Let's start by discussing the motivation… and the realities…

Opening Thoughts - Motivation

The times they are a changing

Bob Dylan, 1964

Far Out/Alamy

Others are not Waiting…

dezeen Next story Follow:

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

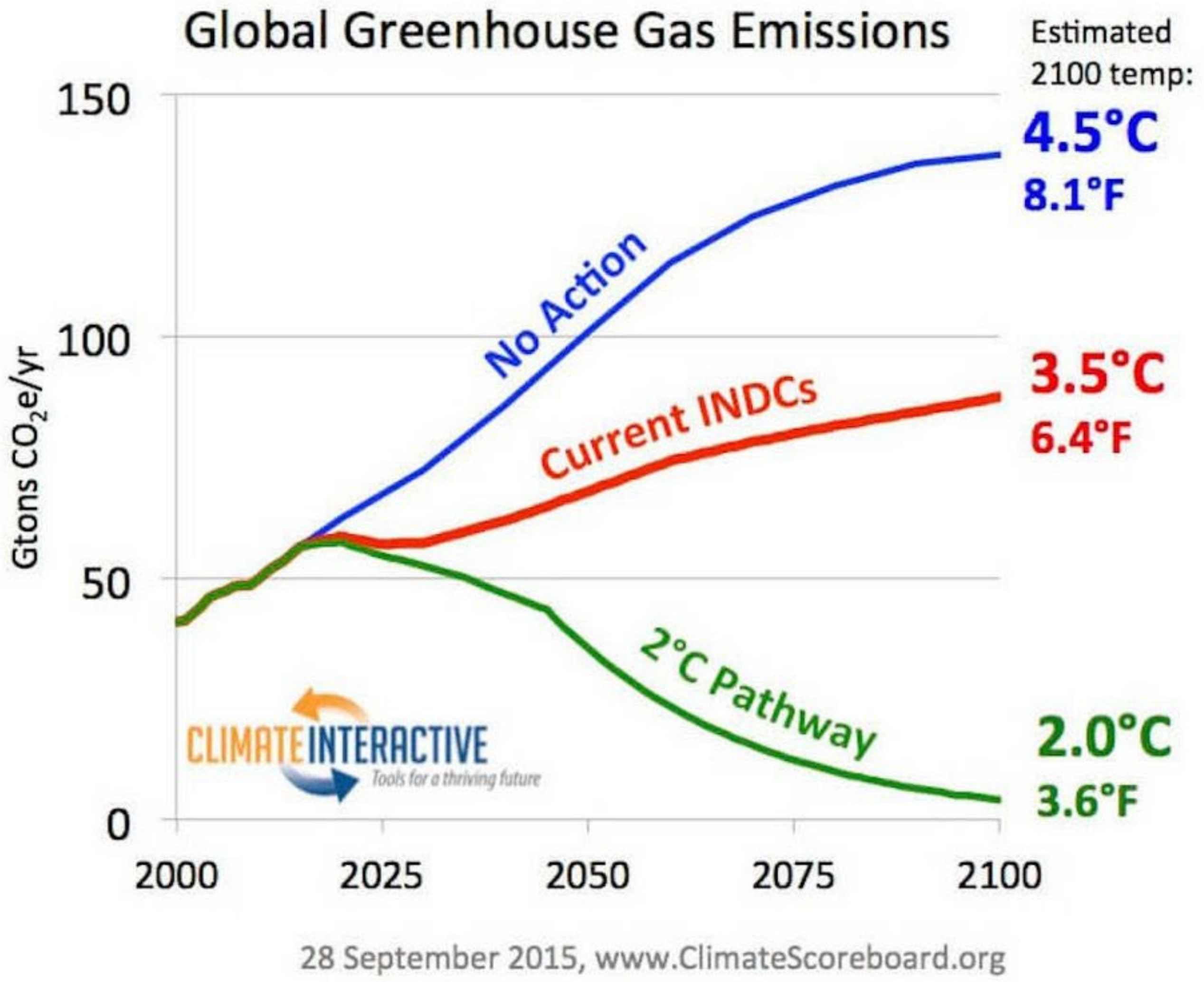


IMAGE: MIT AND CLIMATE INTERACTIVE

Goals have been set and we can argue if they are right or wrong…

However…

Opening Thoughts

The times they are a changing

Bob Dylan, 1964

Far Out/Alamy

Opening Thoughts

The times they are a changing

Bob Dylan, 1964

misunderstanding

There is more ~~stupidity~~ than hydrogen in the universe, and it has a longer shelf life.

Frank Zappa

Far Out/Alamy

Portland Cement is Not Going Away

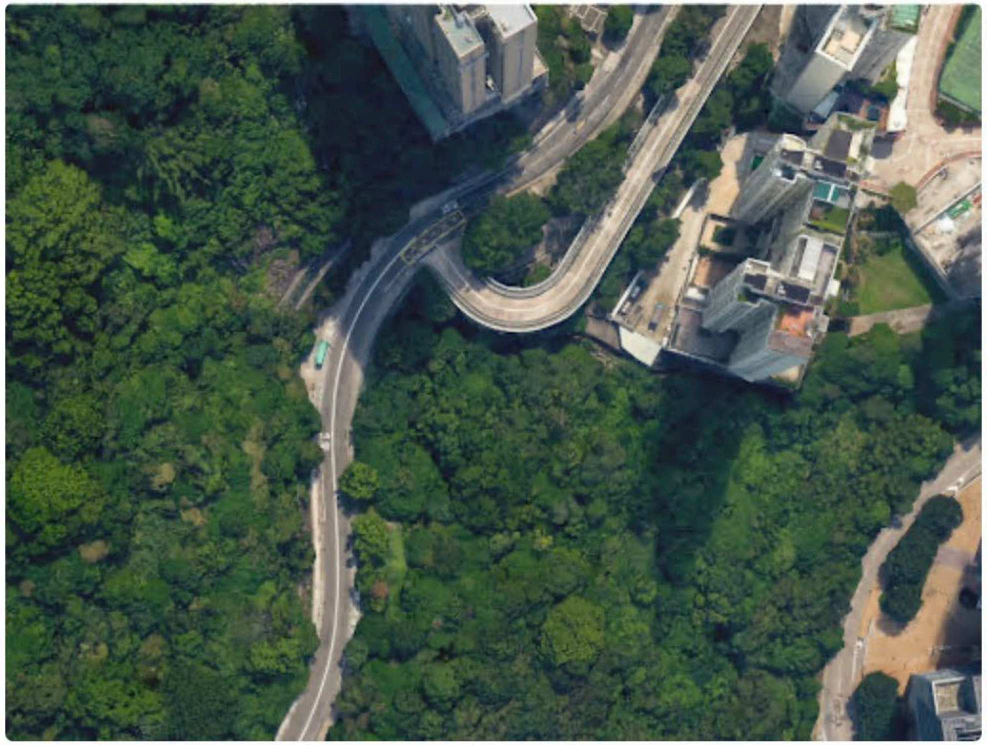
- *We* (society) need concrete and *we* need to accept a few facts.
  - Portland cement is not going away probably ever – we need to make it work
  - New materials will have a role but…
  - Our goals must be realistic – we need to use the materials we have better
  - We cannot completely disrupt an industry as pervasive as construction
  - If we want low-carbon concrete we need to make changes in cooperation with industry – it cannot be forced
  - And we (society) have few choices if we want to maintain our lifestyles

Where is the User Community Going?

- Before looking at paths forward – lets look at the demand side
- Is net-zero carbon concrete important to owners?

Where is the User Community Going?

Google



CIRCULAR ECONOMY COMMITMENTS

Our ambition is to maximize the reuse of finite resources across our operations, products, and supply chains and enable others to do the same.

A circular Google →

Supporting partners →

Empowering people →

sutter engineering llc

Michigan Tech

Where is the User Community Going?

Google

Google has completed its first mass timber office building in Sunnyvale CA

Google has begun construction of its first mass-timber building in Sunnyvale. The five-story project could pave the way for future buildings constructed using that method.

GOOGLE LLC

Where is the User Community Going?

Google

gb&d

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PROJECTS

Google: Can Post-Consumer Glass Be Used in Concrete to Reduce Carbon Footprints?

BY KATE GRIFFITH JULY 2, 2018

Where is the User Community Going?

CNET Your guide to a better future

News

Meta AI Finds New Concrete Recipes to Cut Meta's Carbon Footprint

Stephen Shankland
April 27, 2022 2:36 p.m. PT

3 min read

Facebook's parent company, Meta, is using AI to develop new concrete recipes that emit less carbon dioxide.
Meta

amazon Search Who We Are What We Do Our Workplace Our Impact Our Planet Follow Us Subscribe EN

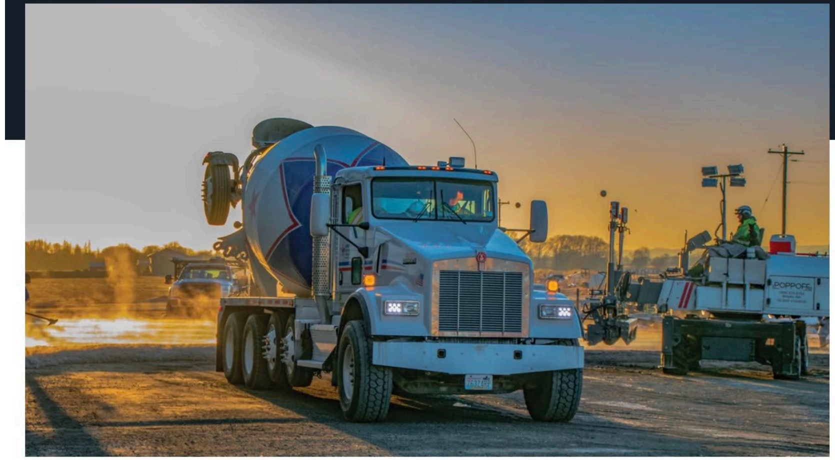
News / AWS

4 min

October 6, 2022

AWS is partnering with a concrete company to develop a more sustainable concrete mix for its data centers

Written by Amazon Staff



4 min

Reading:
AWS is partnering with a concrete company to develop a more sustainable concrete mix for its data centers

American Rock Products is collaborating with AWS to lower the carbon footprint of new data centers in Oregon.

Over the last year, a 40-year-old construction materials company located on the border of Washington and Oregon—American Rock Products (ARP), a CRH Company—has been working with Amazon Web Services (AWS) to develop a new, more sustainable concrete mix that will lower the carbon

GSA Lightens the Environmental Footprint of its Building Materials

March 30, 2022

Market insights from industry inform first standards for low-carbon concrete and environmentally preferable asphalt used at GSA job sites

WASHINGTON – With considerable marketplace feedback gathered from small businesses and other industry partners, the U.S. General Services Administration (GSA) has issued new standards for the concrete and asphalt used in nationwide GSA construction, modernization, and paving projects. These standards are the first in the U.S. to apply beyond a local jurisdiction. They will help strengthen American leadership in clean manufacturing, catalyze clean energy innovation, and combat climate change.

"GSA is excited to deploy these groundbreaking standards as part of this administration's all-hands-on-deck effort to catalyze clean energy innovation and strengthen American leadership on clean manufacturing," said **GSA Administrator Robin Carnahan**. "The feedback we received from industry is proof positive that combating climate change is also an opportunity to boost American innovation. We were impressed by the industry's overall 'can-do' response to our requests for information, and by the fact that over 44% of the manufacturers that responded were small businesses."

Where is the User Community Going?

GSA U.S. General Services Administration

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Where is the User Community Going?

4.8.5 LOW EMBODIED CARBON CONCRETE

All GSA projects that use at least ten (10) cubic yards of a concrete mix must:

1. Provide a product-specific cradle-to-gate Type III environmental product declaration (EPD) for each concrete mix design specified in the contract and used at the project, using NSF International's product category rule for concrete. Send EPD(s) with each concrete mix batch design (including type [e.g. standard or lightweight mix] and volume) to embodiedcarbon@gsa.gov, and upload the submittals into GSA's project management information system.
2. Provide low embodied carbon concrete that meets the global warming potential (GWP) limits of the table below, for concrete of the mix type and strength class.

Table 4.1 Low Embodied Carbon Concrete

	Maximum Global Warming Potential Limits for GSA Low Embodied Carbon Concrete (kilograms of carbon dioxide equivalent per cubic meter - CO2e kg/m3)		
Specified compressive strength (f'c in PSI)	Standard Mix	High Early Strength	Lightweight
up to 2499	242	314	462
2500-3499	306	398	462
3500-4499	346	450	501
4500-5499	385	500	540
5500-6499	404	526	N/A
6500 and up	414	524	N/A
These numbers reflect a 20% reduction from GWP (CO2e) limits in proposed code language: "Lifecycle GHG Impacts in Building Codes" by the New Buildings Institute, January 2022.			

Where is the User Community Going?

THE WHITE HOUSE

FEBRUARY 15, 2022

Fact Sheet: Biden-Harris Administration Advances Cleaner Industrial Sector to Reduce Emissions and Reinvigorate American Manufacturing

BRIEFING ROOM ▸ STATEMENTS AND RELEASES

New Pro-Climate, Pro-Worker Actions Create Jobs and Harness the Bipartisan Infrastructure Law, Federal Purchasing Power, and Trade Policy

Supported by $5 billion in funding from the Inflation Reduction Act

Where is the User Community Going?

THE WHITE HOUSE

Launching "Buy Clean" Procurement

The federal government is the largest purchaser in the world, with annual purchasing power of over $650 billion. To harness that power to support low-carbon, made in America materials, the Council on Environmental Quality and White House Office of Domestic Climate Policy are establishing the first-ever Buy Clean Task Force. As directed by the President's December 2021 executive order on federal sustainability, the Task Force will promote use of construction materials with lower embodied emissions and pollutants across their lifecycle—including each stage of the manufacturing process.

Where is the User Community Going?

THE WHITE HOUSE

- Identifying materials, such as steel and concrete, as well as pollutants to prioritize for consideration in Federal procurement and federally funded projects
- Increasing the transparency of embodied emissions through supplier reporting, including incentives and technical assistance to help domestic manufacturers better report and reduce embodied emissions
- Launching pilot programs to boost federal procurement of clean construction materials

Where is the User Community Going?

THE WHITE HOUSE

The Department of Transportation (DOT) is announcing new efforts to support **use of low-carbon materials in federal transportation projects**. A new pilot program will target key products and services to increase use of Environmental Product Declarations and incentivize acquisition of low-carbon materials. Additionally, DOT is standing up a Department-wide Embodied Carbon Working Group to assess and implement actions to reduce lifecycle emissions of construction materials used in transportation infrastructure.

Where is the User Community Going?

But wait… there's more

Where is the User Community Going?

- There is not just policy – there is legislation.
- New York State's Low Embodied Carbon Concrete Leadership Act (LECCLA)
  - Lower Carbon Concrete Specification
  - *Affected entities shall, to the maximum extent practicable, procure lower-carbon concrete … while meeting strength and other performance requirements as designed by the Design Professional in the Technical Specifications for the project*

Where is the User Community Going?

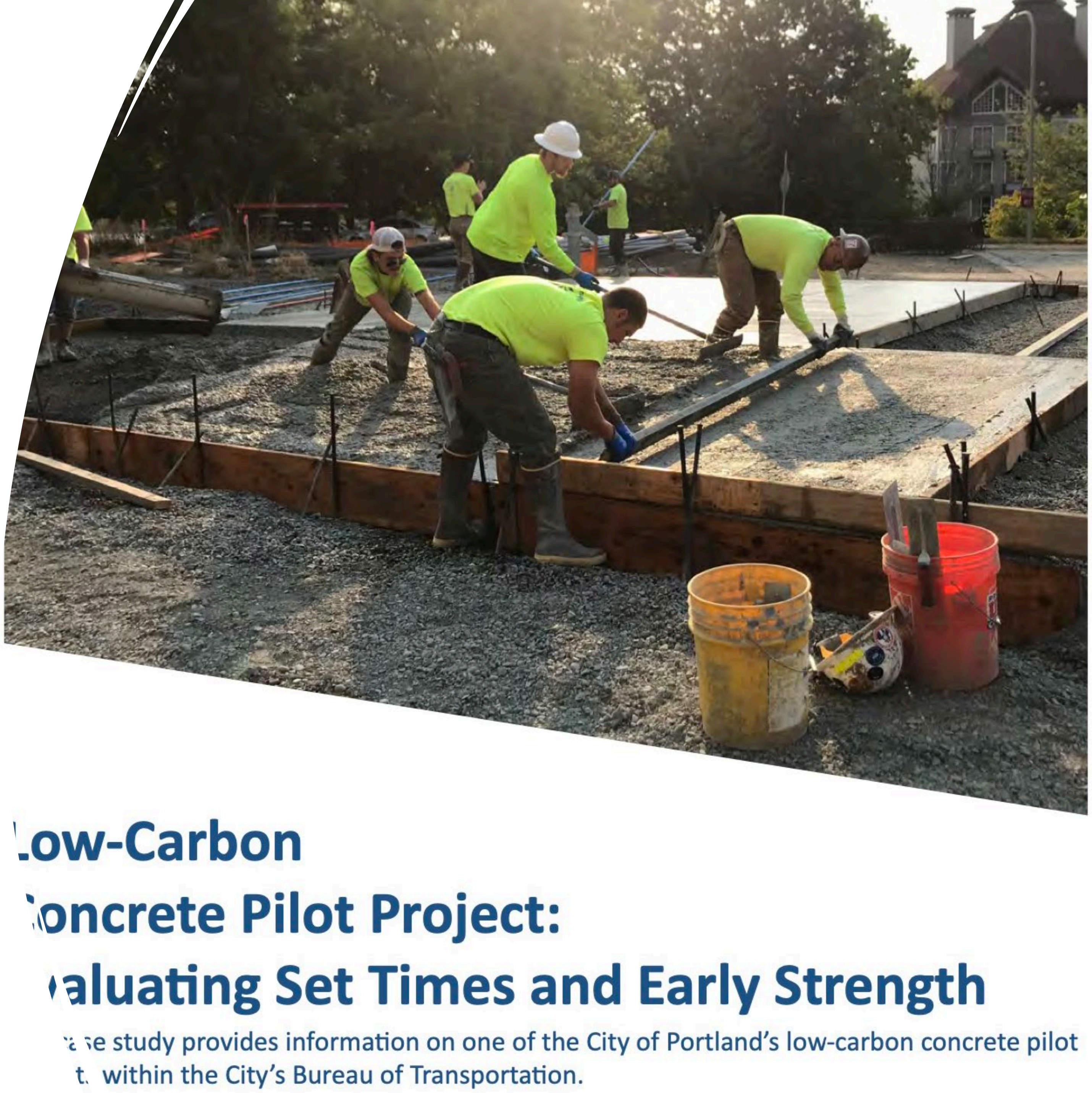
- Batch Plant Ready-mix concrete delivered to jobsite:
- **Provide an EPD where available – If not, industry averages are stipulated in the law**
- **Set Cement Content limits.**
  - Mix designs are limited to a maximum portland cement content of **400 pcy**.
    - This does not include sidewalks, slabs on grade, or any application that requires a final finish.
  - Mix designs are limited to a maximum portland cement content of **300 pcy** for mass concrete and all concrete applications below grade and against earth, or below grade and confined concrete such as concrete fill within steel pipe piles.

Where is the User Community Going?

- **Achieve Additional Cement use reduction with inclusion of pozzolans.**
  - 30% minimum total SCM (including fly ash, slag, silica fume, GGP in alignment with ASTM C1866, and/or metakaolin) by total weight of all cementitious materials, unless otherwise shown on the Contract Drawings.
- **Cement use reduction through reduction in percentage of paste.**
  - Use of blended aggregates when available.
  - Other restrictions on gradation and content

City of Portland

Low-carbon concrete specification


.ow-Carbon
'oncrete Pilot Project:
'aluating Set Times and Early Strength
se study provides information on one of the City of Portland's low-carbon concrete pilot
t. within the City's Bureau of Transportation.

Jodie Inman
Chief Engineer, Portland Water Bureau

Steve Townsen
Chief Engineer, Portland Bureau of Transportation

Paul Suto
Chief Engineer, Bureau of Environmental Services

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May 23, 2022

NOTICE OF NEW REQUIREMENTS FOR CONCRETE

The City of Portland is adding Concrete Embodied Carbon Threshold requirements, as further specified below, to the approval process for the supply of Portland Cement Concrete (PCC), including: Commercial Grade Concrete (CGC), Plain Concrete Pavement (PCP), and High-Performance Concrete/Structural Concrete (HPC) for City construction projects. These Concrete Embodied Carbon Thresholds and related implementation procedures are based on the recommendations developed by a multistakeholder committee specifically convened for the task, referred to as the City of Portland Low-Embodied Carbon Concrete Threshold Committee. More information about the Committee and the Concrete Embodied Carbon Threshold development process can be found at: https://www.portland.gov/omf/brfs/procurement/sustainable-procurement-program/sp-initiatives#toc-low-carbon-concrete-initiative.

1.1 Concrete Embodied Carbon Thresholds – Per Mix

The embodied carbon of a concrete mix, based on an approved EPD, shall not exceed the value given in Table 1 (per yd3) or Table 2 (per m3).

Table 1: Concrete Embodied Carbon Thresholds (per yd3)

	Maximum GWP (kg CO2e)/yd3					
Concrete Strength (psi) (1)	Portland Cement Concrete (PCC) including: Commercial Grade Concrete (CGC), Concrete Pavement, High-Performance Concrete (HPC)/Structural Concrete	Lightweight Concrete	Controlled Low-Strength Material (CLSM)	Shotcrete	Drilled-Shaft	Grout
2500	180		180	n/a	n/a	n/a
3000	200	396				
4000	242	440				
5000	295	483				
6000	312					
8000	373					

(1) For concrete strengths between the stated values, use linear interpolation to determine cement and/or embodied carbon limits, rounded to the nearest whole number.
Example: for a 3300psi CGC mix:
(242-200)/(4000-3000) = 0.042
(0.042*(3300-3000)) + 200 = 212.6
213 is the Maximum GWP/yd3 for a 3300psi mix.

1.2 Concrete Embodied Carbon Thresholds – Project Average

Total embodied carbon (EC_{proj}) of all concrete mix designs within the same project shall not exceed the project limit ($EC_{allowed}$) determined using Table 1 or Table 2 (as applicable based on units) and Equation EC1.

Equation EC1

$EC_{proj} < EC_{allowed}$

where

$EC_{proj} = \Sigma EC_n v_n$ *and* $EC_{allowed} = \Sigma EC_{th} v_n$

and

n = the total number of concrete mixtures for the project

EC_n = the embodied carbon for mixture n per approved EPD, GWP/yd3

EC_{th} = the embodied carbon threshold for mixture n per Table 1, GWP/yd3

v_n = the volume of mixture n concrete to be placed, yd3

Where is the User Community Going?

- *NYC - New York City's Clean Construction Executive Order 23* – Agencies are ordered to establish low-carbon specifications, collect data on carbon intensity of concrete and steel, and perform whole-building life cycle assessment.
- *NJ – Senate Bill 287* - provides tax credits for low-carbon concrete and the cost of developing EPDs
- *California SB 596* – Greenhouse Gas (GHG) reduction to 40% below baseline by 2035, net-zero by 2045 for the "cement sector"
- *Marin County Green Building Code*

19.07.050 – Compliance

Compliance with the requirements of this chapter shall be demonstrated through any of the compliance options in Sections 19.07.050.2 through 19.07.050.5.

Table 19.07.050 Cement and Embodied Carbon Limit Pathways

	Cement limits for use with any compliance method 19.07.050.2 through 19.07.050.5	**Embodied Carbon limits** for use with any compliance method 19.07.050.2 through 19.07.050.5
Minimum specified compressive strength f'_c, psi (1)	Maximum ordinary Portland cement content, lbs/yd^3 (2)	Maximum embodied carbon kg CO_2e/m^3, per EPD
up to 2500	362	260
3000	410	289
4000	456	313
5000	503	338
6000	531	356
7000	594	394
7001 and higher	657	433
up to 3000 light weight	512	578
4000 light weight	571	626
5000 light weight	629	675

Notes

(1) For concrete strengths between the stated values, use linear interpolation to determine cement and/or embodied carbon limits.

(2) Portland cement of any type per ASTM C150.

Other Considerations - Who is Driving the Change?

Owners such as Google, Meta, Amazon, Target, etc. are obvious but it is non-governmental organizations (NGOs) and other non-profits that are shaping policy and legislation

Other Considerations - Who is Driving the Change?

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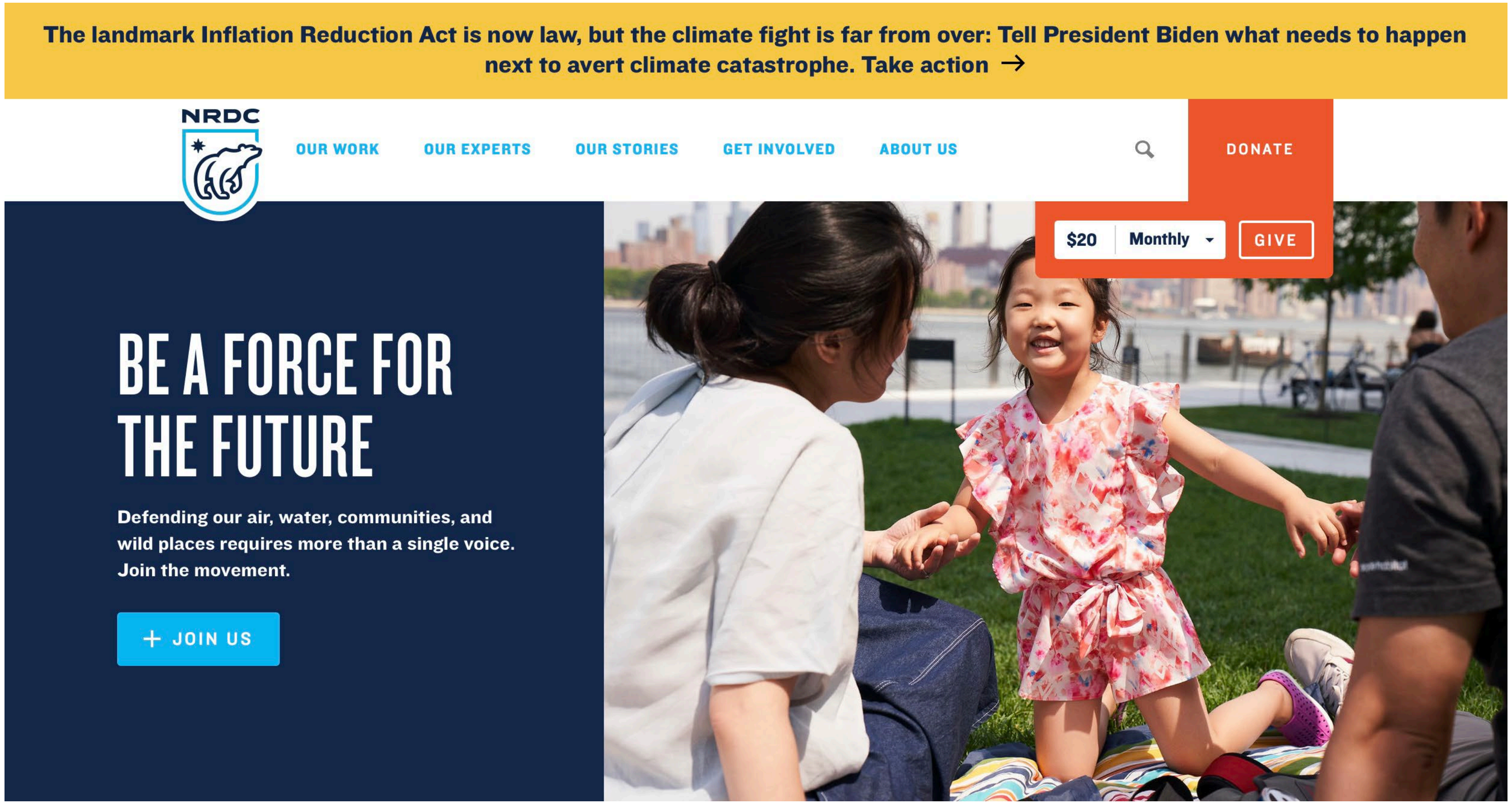

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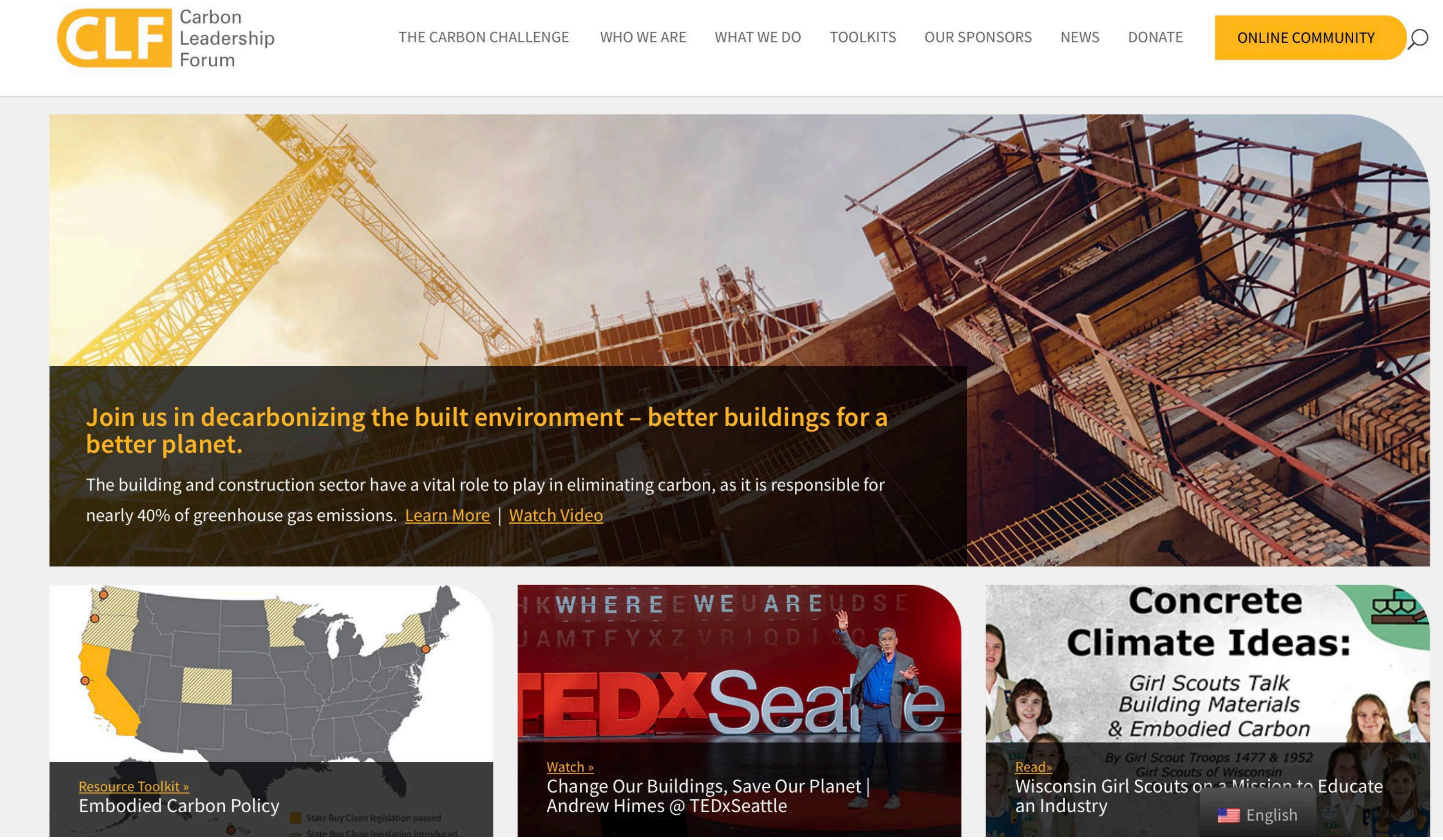

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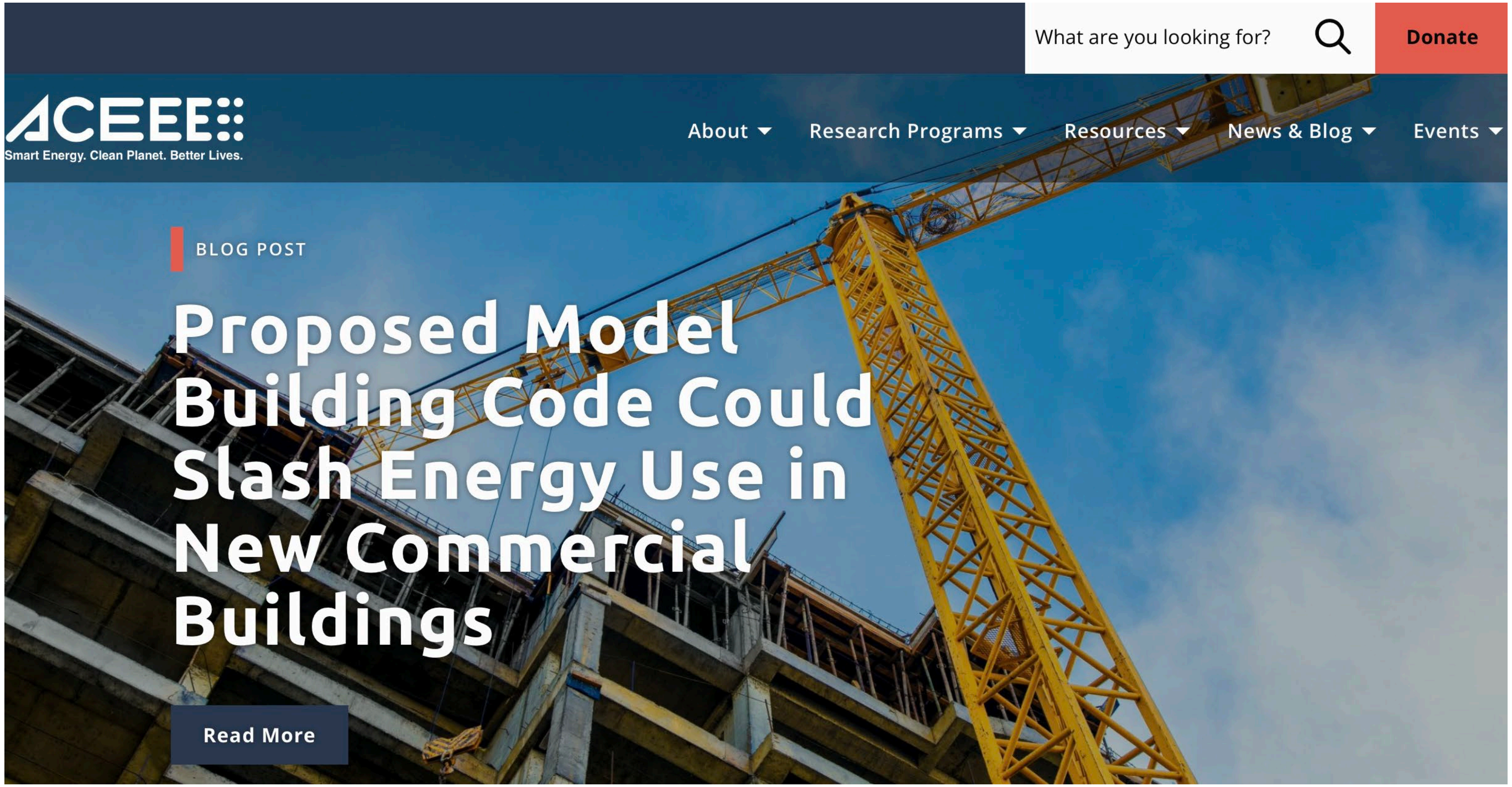
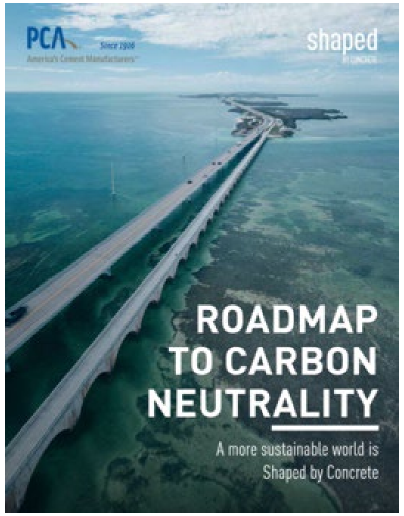


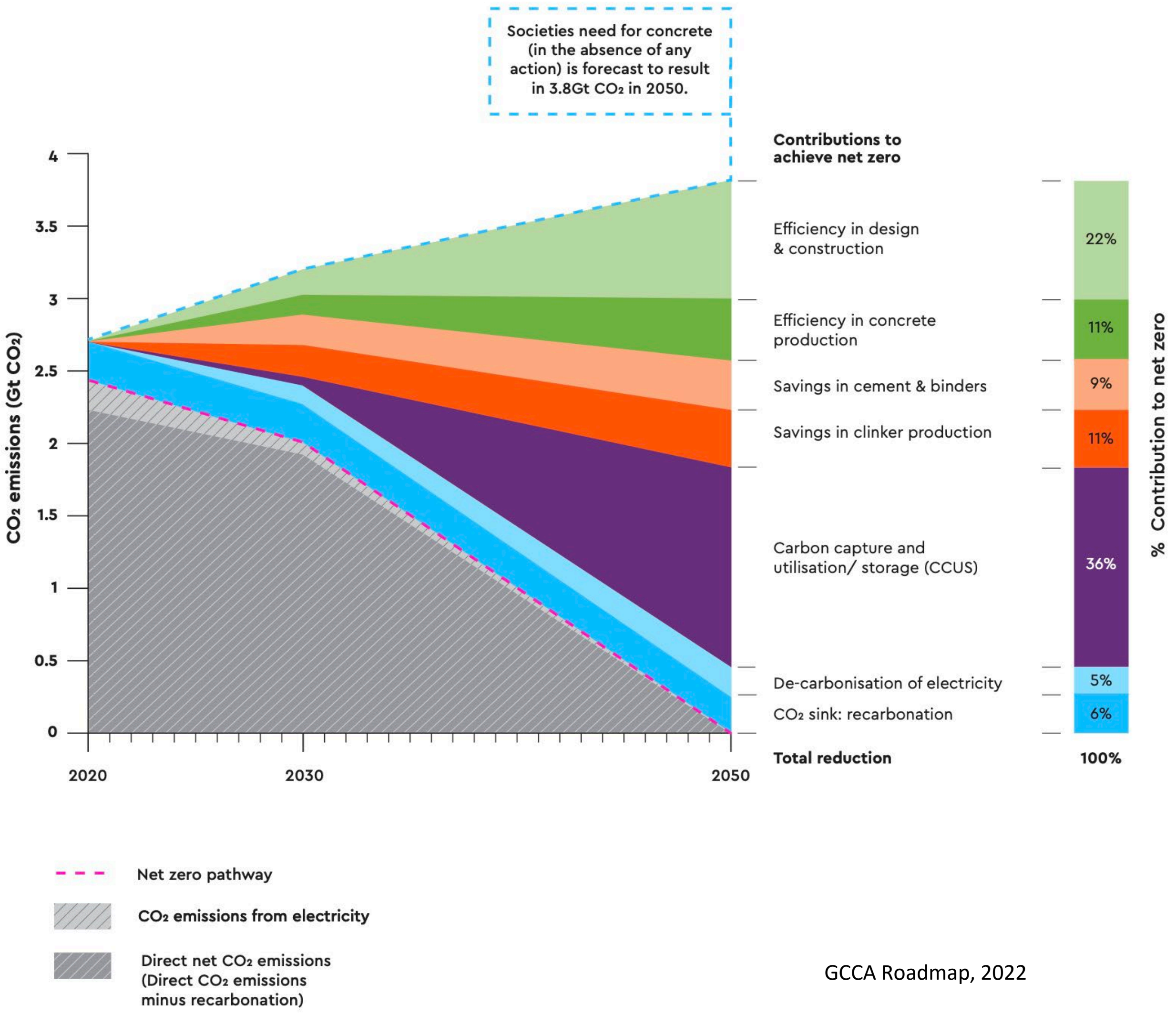
Has industry responded?

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.

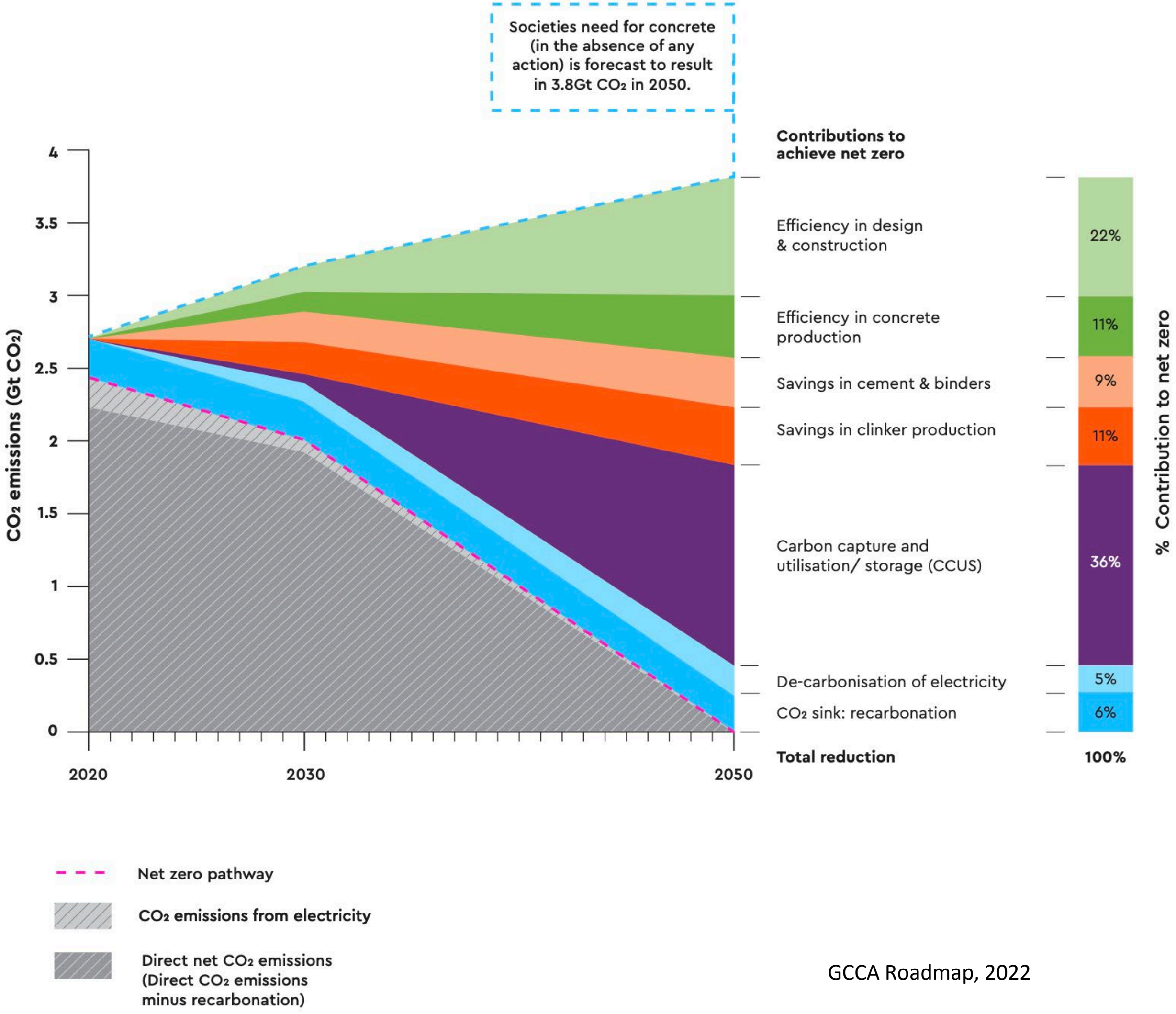


The Net Zero Pathway



GCCA Roadmap, 2022

The Net Zero Pathway



GCCA Roadmap, 2022

This is on concrete to make happen!

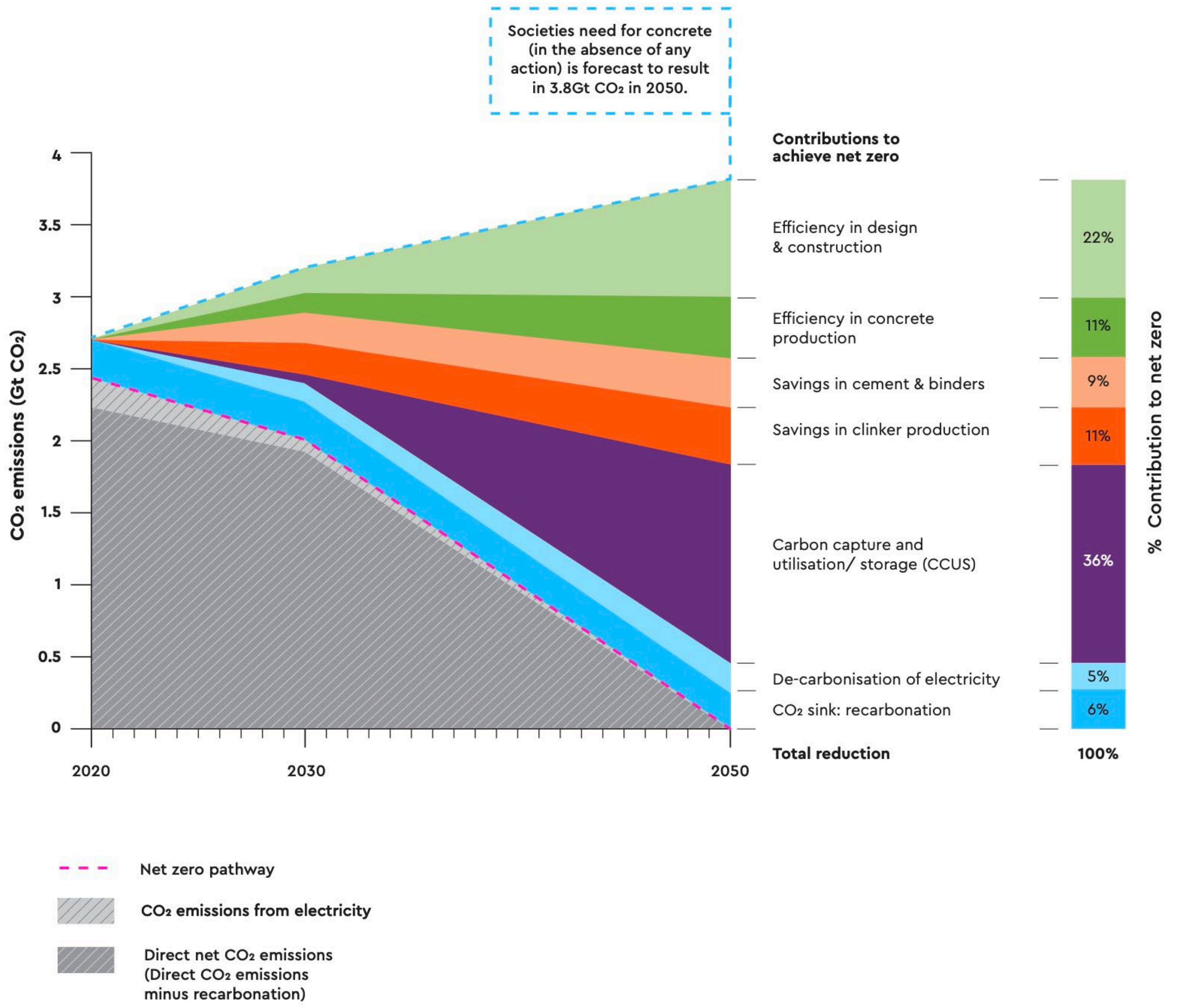
Efficiency in design & construction

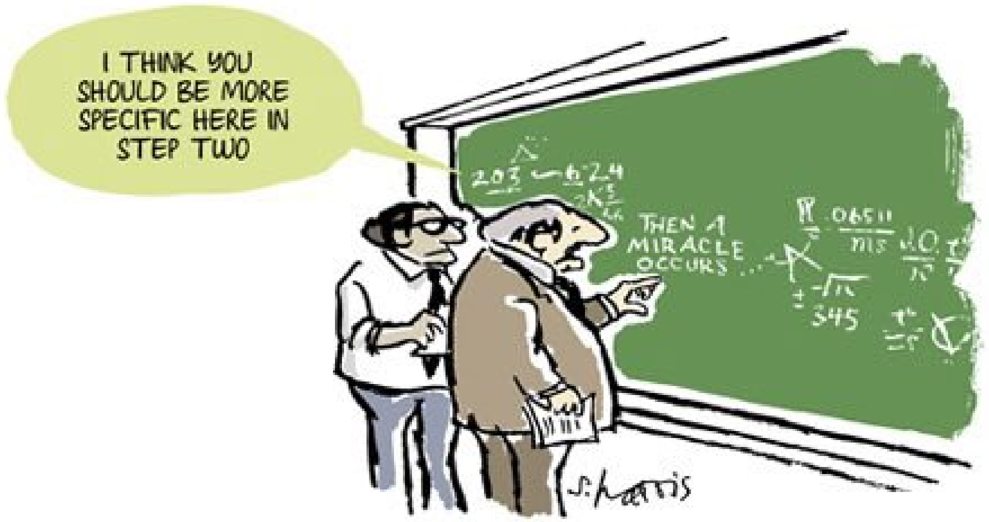
Efficiency in concrete production

Savings in cement & binders

Approximately 42% of the total reduction…

The Net Zero Pathway

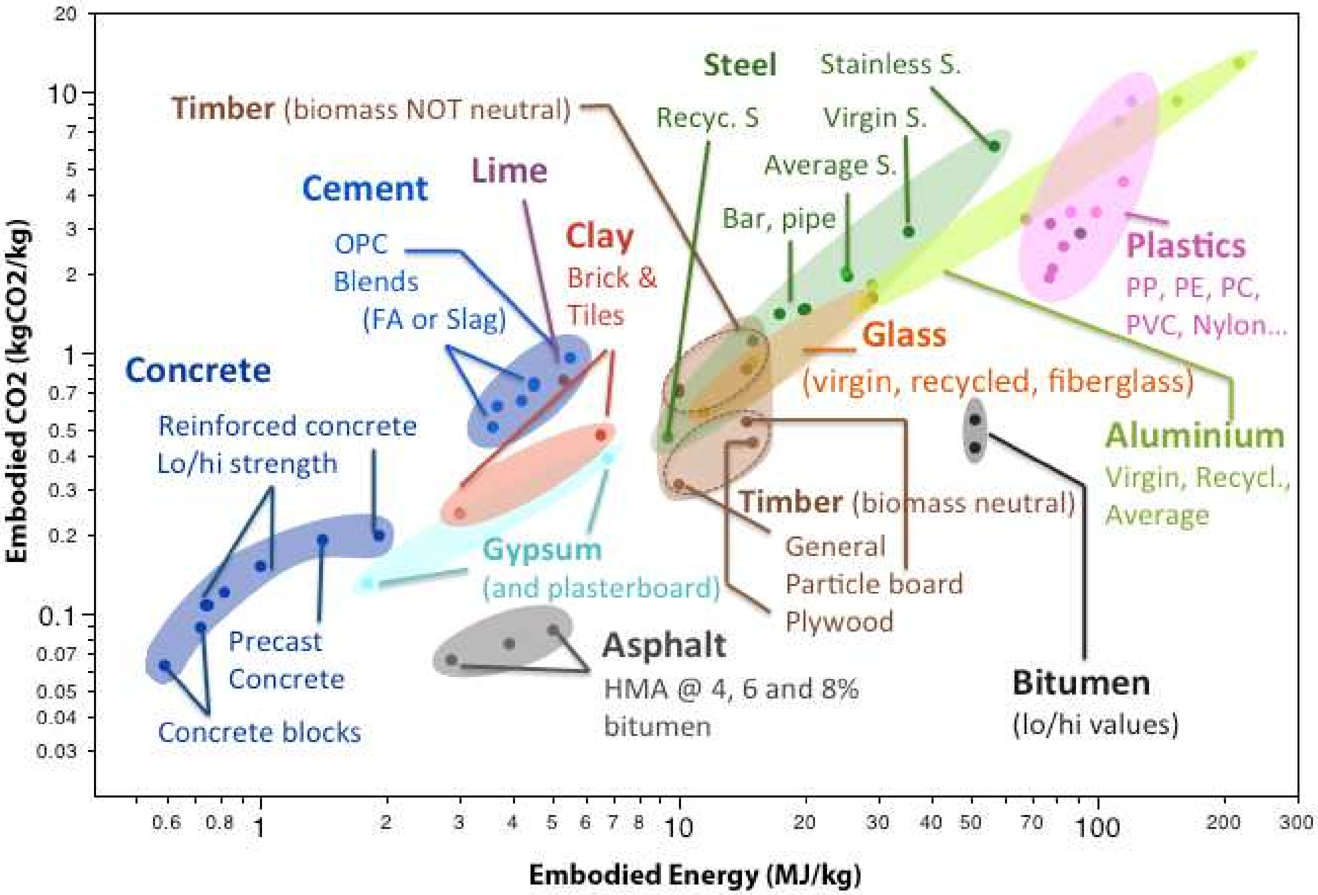




Approximately 42% of the total reduction…

What is 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
- ~2 cy/person/year
- ~120 million tons of cement (U.S.) in 2021
- Concrete Greenhouse Gas (GHG) Emissions at the Gate
  - 1.5% acquiring raw materials
  - 9.5% concrete production
  - 89% cement production



After Barcelo et al., 2014

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

- **Actually we mean reduced-carbon concrete**

Environmental Product Declarations (EPDs)

- Developed under ISO 14040 (LCA) and 14025 standards
- Quickly becoming required by many private and public owners

Summary of
Environmental Product Declaration

Central Concrete

Mix 340PG9Q1

San Jose Service Area

EF V2 Gen Use P4000 3" Line 50% SCM

Performance Metrics

28-day compressive strength	4,000 psi
Slump	4.0 in

Environmental Impacts

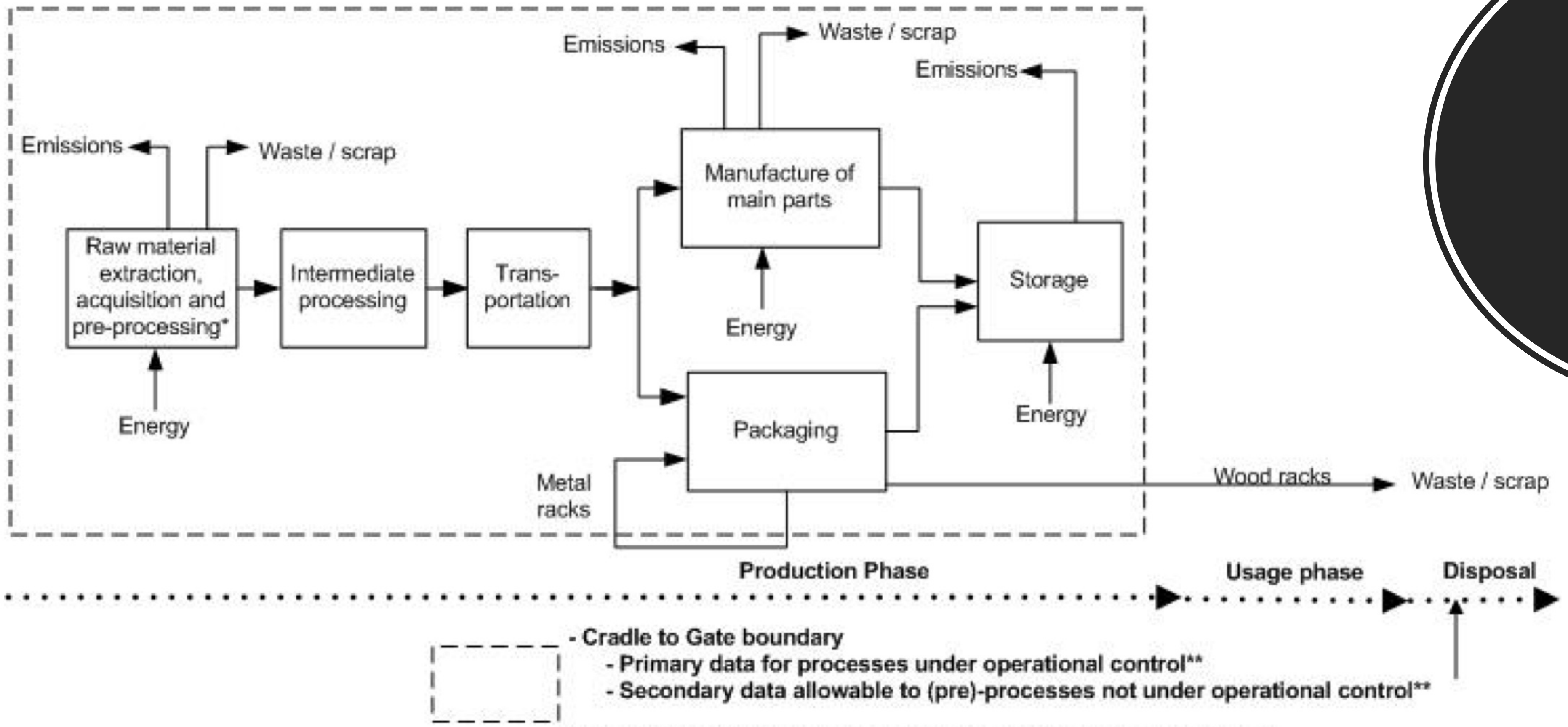
Impact name	Unit	Impact per m3	Impact per cyd
Total primary energy consumption	MJ	2,491	1,906
Concrete water use (batch)	m3	6.66E-2	5.10E-2
Concrete water use (wash)	m3	8.56E-3	6.55E-3
Global warming potential	kg CO2-eq	271	207
Ozone depletion	kg CFC-11-eq	5.40E-6	4.14E-6
Acidification	kg SO2-eq	2.26	1.73
Eutrophication	kg N-eq	1.31E-1	1.00E-1
Photochemical ozone creation	kg O3-eq	46.6	35.7

A sample EPD for a concrete mix design by Central Concrete Supply Co.

Credit: Central Concrete Supply

- Report Global Warming Potential (GWP) in kg $CO_{2\ eq}$ / kg product
- $CO_{2\ eq}$ is a composite number
- All GHG converted to the equal effect of an amount of CO_2

Life-Cycle System Boundary



* Possible inclusion of post-consumer cullet from other operations.

**Operational control will differ from organization to organization. Please see Section 7.1 Types and sources of data for additional information.

Figure 1: System Boundaries, example flow

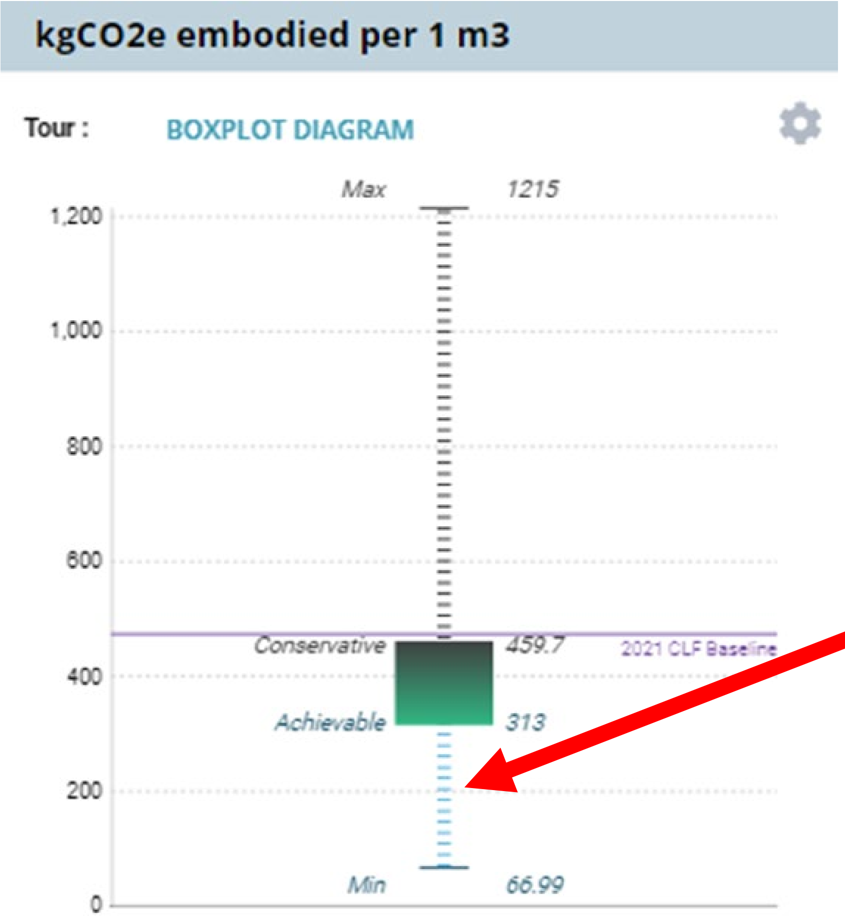
Life-Cycle System Boundary

Building Life Cycle Information Modules																
Product stage			Construction Process stage		Use stage							End-of-life stage				
Raw Material supply	Transport	Manufacturing	Transport	Construction/Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste processing	Disposal
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4

Figure 1. Life cycle stage schematic – alpha-numeric designations as per NSF PCR (adapted from CEN 15978:2011)

NRMCA Industry Wide LCA Project Report – V3.2

Environmental Product Declarations (EPDs)



From EC3 Tool

ENVIRONMENTAL IMPACTS

Declared Product:
Mix 3A21-RGSC • MAPLE GROVE READY-MIX Plant
Description: 3900,3A21-RGSC,20AEBM,ZC30,G7
Compressive strength: 3900 PSI at 28 days

Declared Unit: 1 m^3 of concrete (1 cyd)

Global Warming Potential (kg CO_2-eq)	220 (169)
Ozone Depletion Potential (kg CFC-11-eq)	7.07E-6 ([illegible])
Acidification Potential (kg SO_2-eq)	0.65 (0.50)
Eutrophication Potential (kg N-eq)	0.29 (0.22)
Photochemical Ozone Creation Potential (kg O_3-eq)	15.6 (11.9)
Abiotic Depletion, non-fossil (kg Sb-eq)	4.37E-5 (3.34E-5)
Abiotic Depletion, fossil (MJ)	1,341 (1,025)
Total Waste Disposed (kg)	0.51 (0.39)
Consumption of Freshwater (m^3)	3.08 (2.35)

Product Components: natural aggregate (ASTM C33), type 1L cement (ASTM C595), batch water (ASTM C1602), fly ash (ASTM C618), admixture (ASTM C494), admixture (ASTM C260)

Example of Embodied Carbon (GWP)

Material	GWP ($kgCO_2$-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)[1]	724	EPD for Ste. Genevieve, MO Cement Plant (2/26/2021)
Class F fly ash	12.1	FHWA LCAPave Tool
Urban Mining Pozzotive® ground glass pozzolan	55.9	EPD for Urban Mining Pozzotive® ground glass pozzolan (5/11/20)

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

Supplementary Cementitious Materials (SCMs)

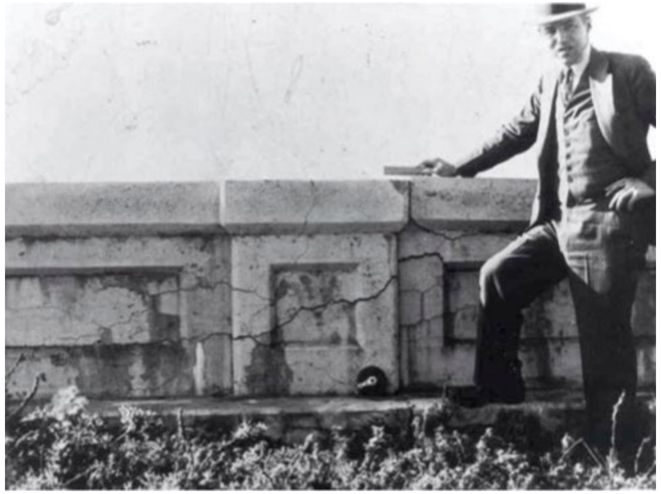
- The production and supply of SCMs is an important factor that will impact the drive to net carbon neutral concrete.
- Every concrete industry roadmap for carbon reduction relies on increasing the use of SCMs to reduce the clinker content of cement.

- The Portland Cement Association (PCA) *Roadmap to Carbon Neutrality* estimates the **current clinker factor** to be ~0.90, calling for a reduction to 0.85 by 2030, 0.80 by 2040, and 0.75 by 2050.
- Requires significant increase in SCM use.

Wilson, M. L. and P. D. Tennis. 2021. *Design and Control of Concrete Mixtures.* 17th Edition. Portland Cement Association, Skokie, IL.

Supplementary Cementitious Materials (SCMs)

- Benefits
- Cost reduction (historically)
- Durability
  - Alkali Silica Reaction
  - Sulfate Resistance
- Chemical resistance to deicers
- Reduced heat of hydration
- Improved performance (e.g., strength)



Alkali-Aggregate Reactivity (AAR) Facts Book. Thomas, M.D.A., Fournier, B., Folliard, K.J.

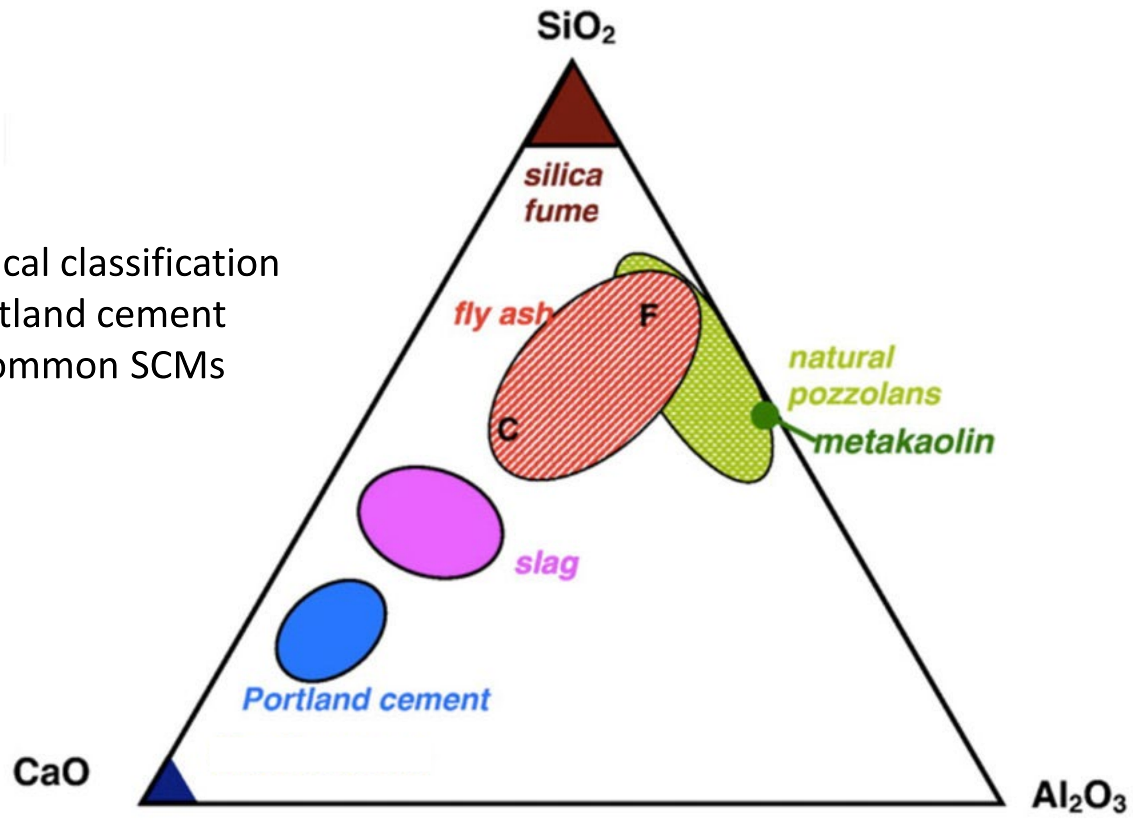
L. Sutter

Portland Cement Association

Supplementary Cementitious Materials (SCMs)

- Common Use Types
  - Coal Ash (fly ash and bottom ash)
  - Slag Cement
  - Silica Fume
- Emerging Use Types
  - Natural Pozzolans
  - Ground Glass
  - Calcined Clay
- Alternative SCMs
  - Manufactured

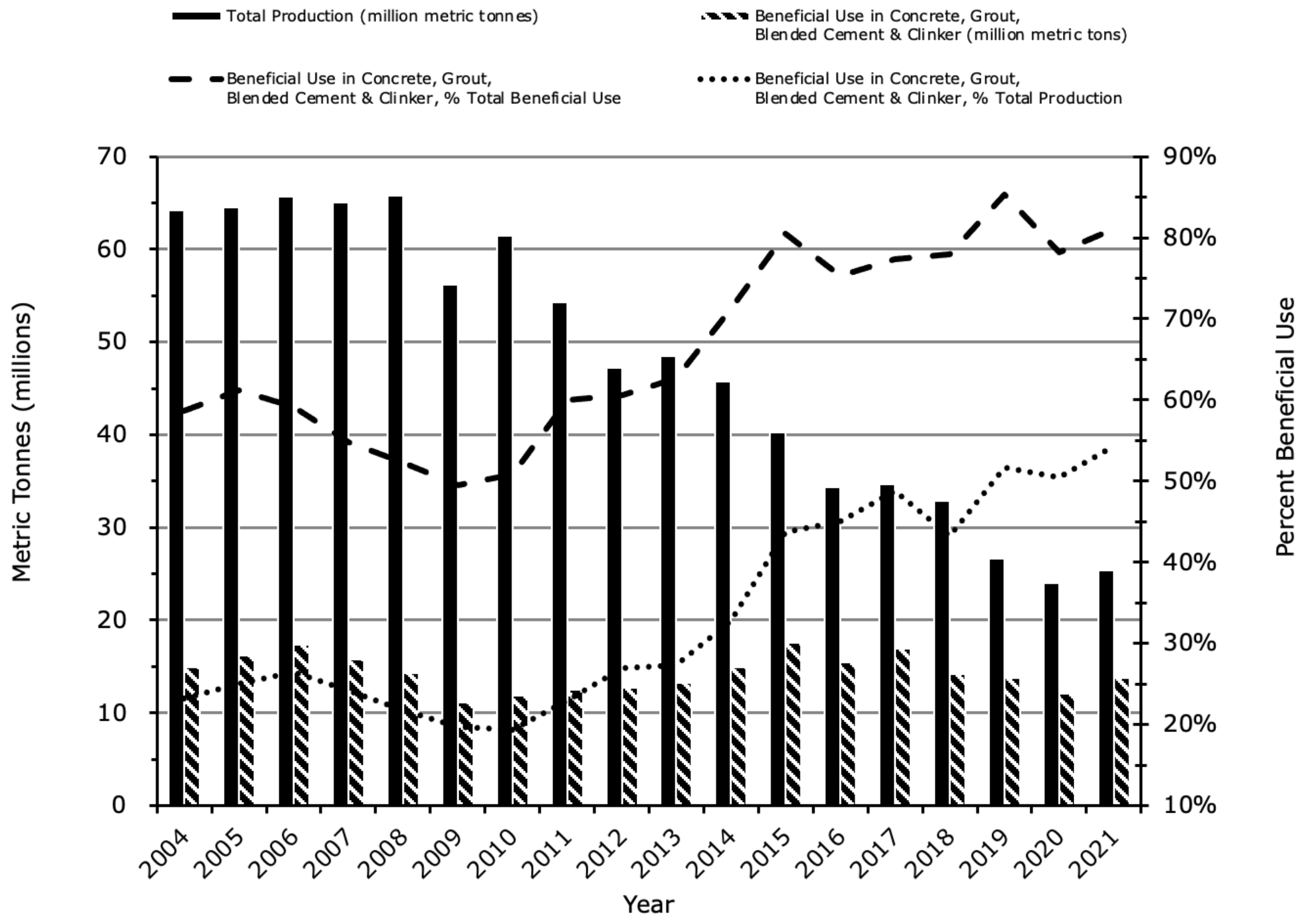
Chemical classification of portland cement and common SCMs



Rajabipour, Farshad & Zahedi, Mona & Kaladharan, Gopakumar. (2020). Evaluating the Performance and Feasibility of Using Recovered Fly Ash and Fluidized Bed Combustion (FBC) Fly Ash as Concrete Pozzolan.

Coal Fly Ash Supply & Use

- Carbon reduction road maps call for increased use of SCMs
- Coal fly ash is the most common SCM
- Supplies are challenged by power plant closures
- Harvesting offers the opportunity for increased supplies near-term



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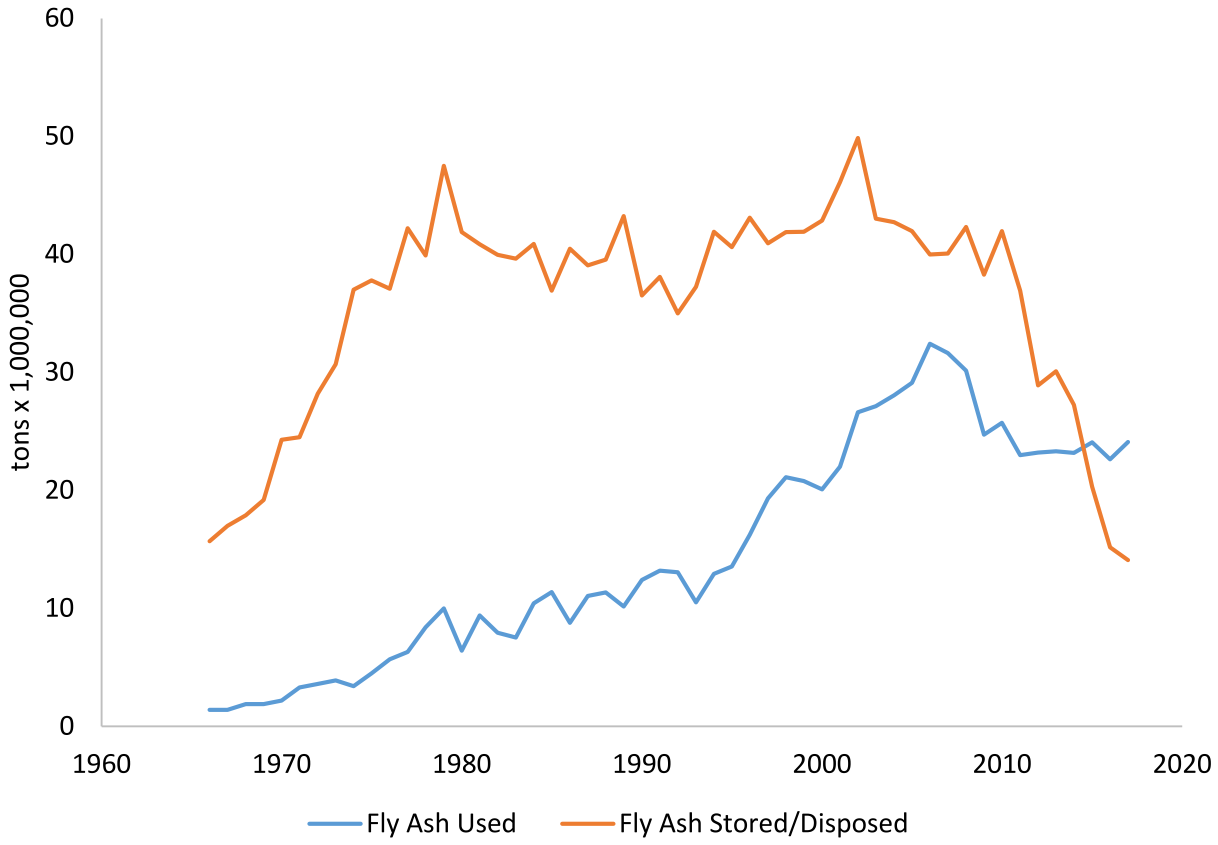

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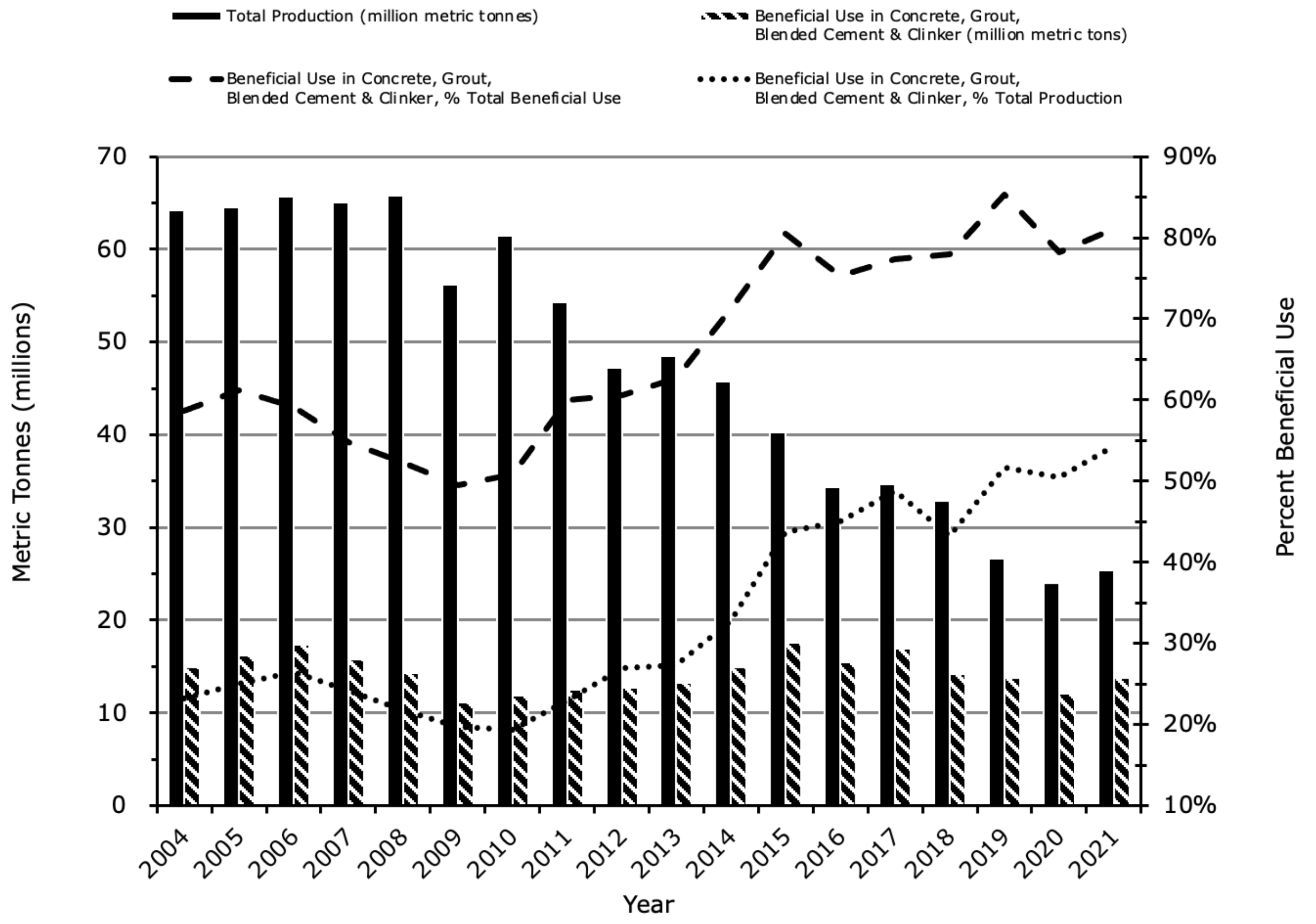
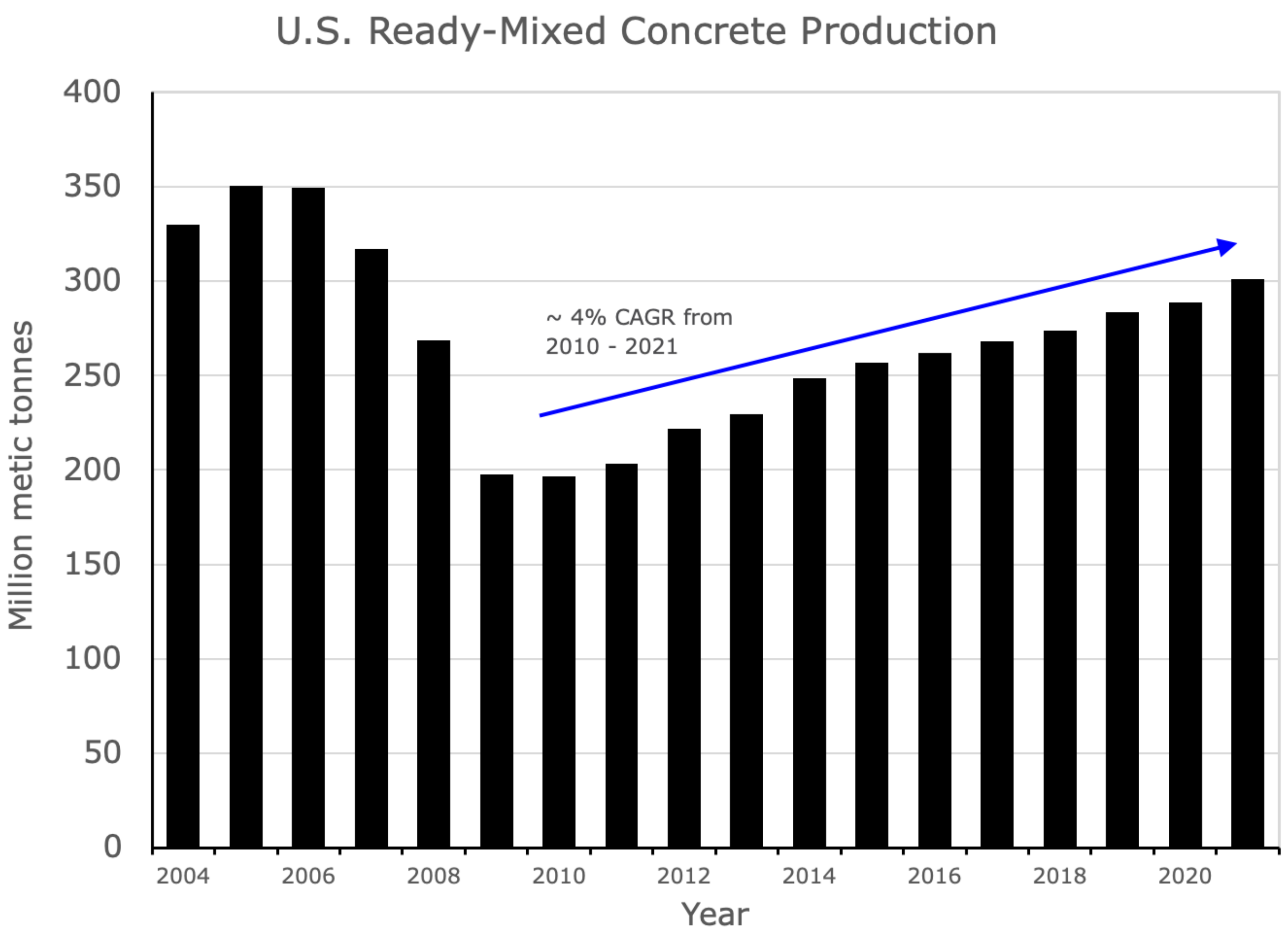


Coal Fly Ash Supply & Use

- Actual use normalized to concrete production
- Concrete use growing at a CAGR or ~4%
- Fly ash use (tons per year) remains relatively constant
- Use per cy concrete relatively constant or decreasing



sutter engineering llc

Michigan Tech

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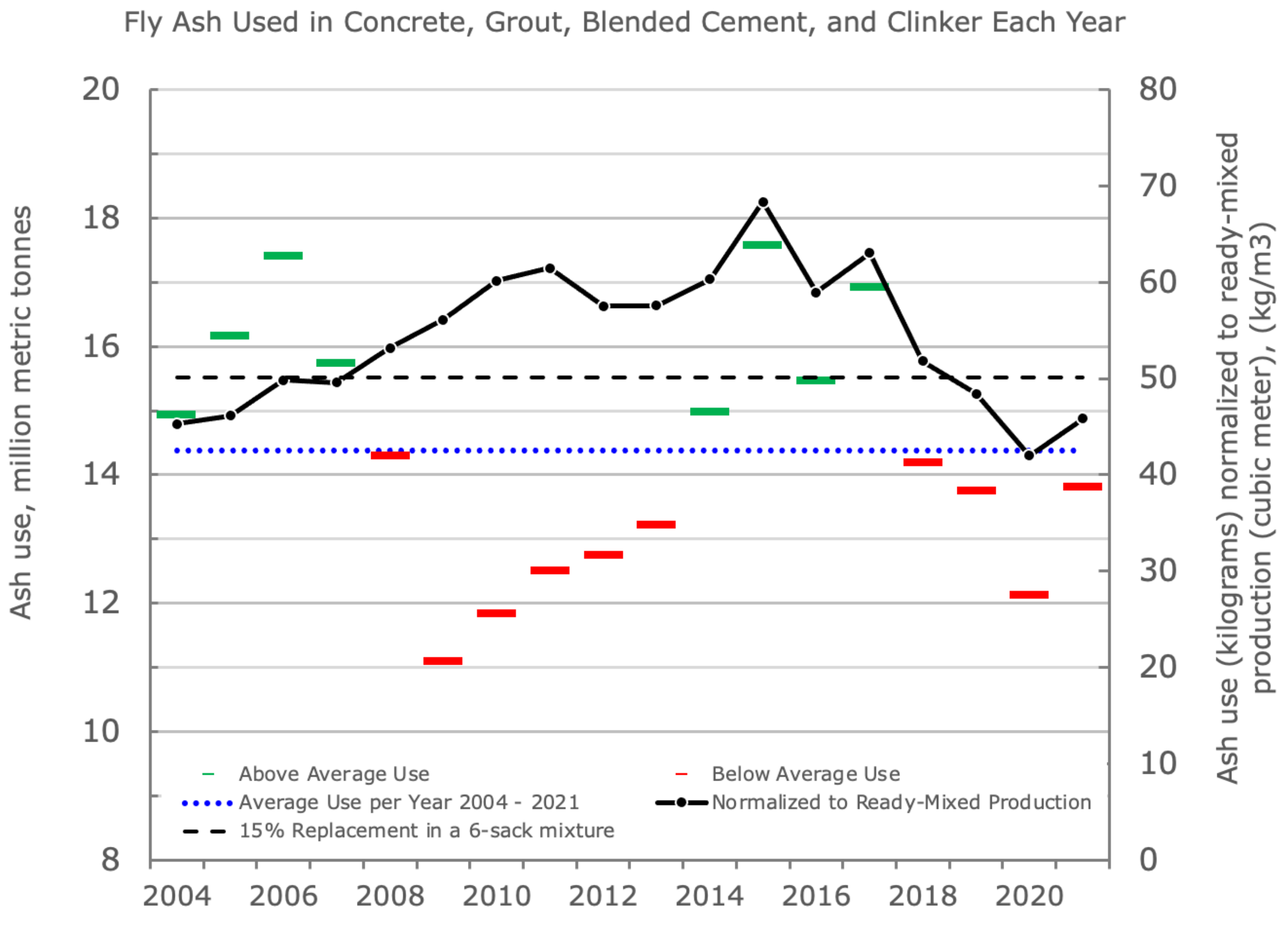
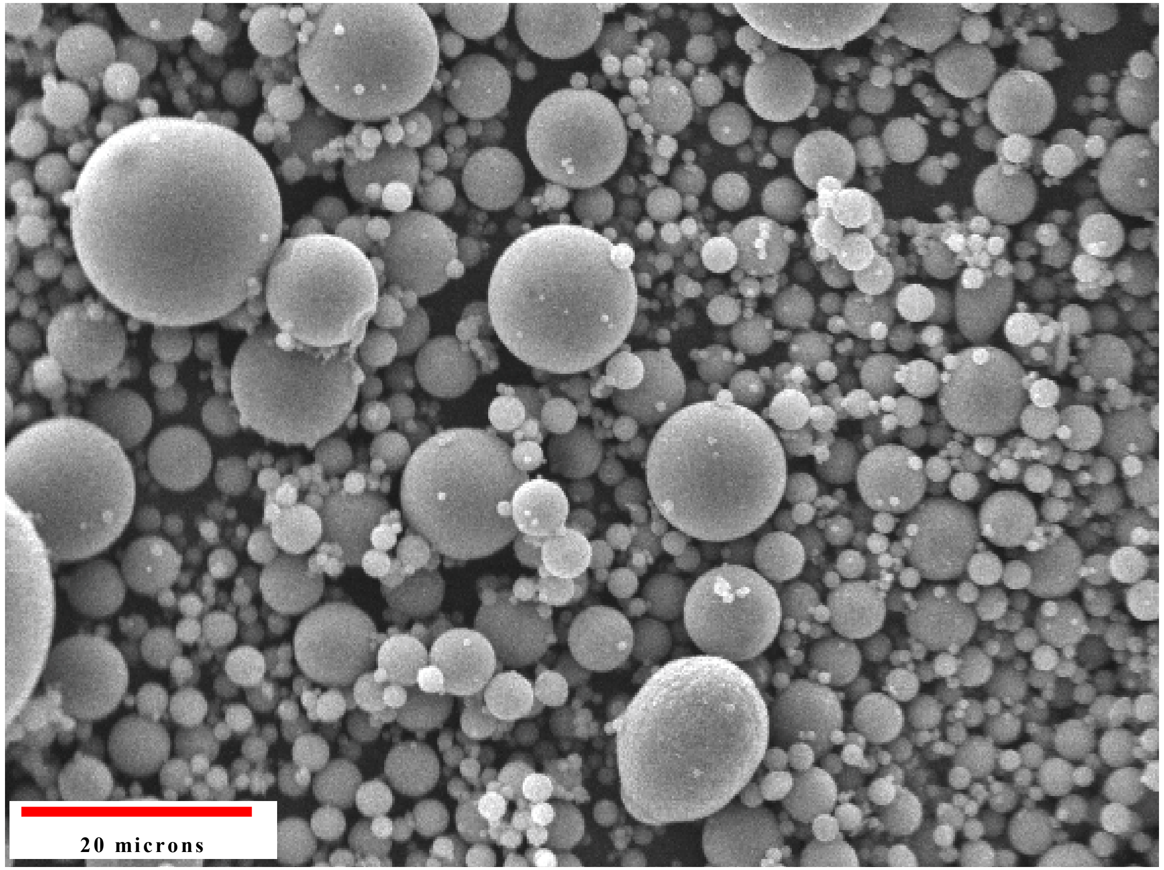


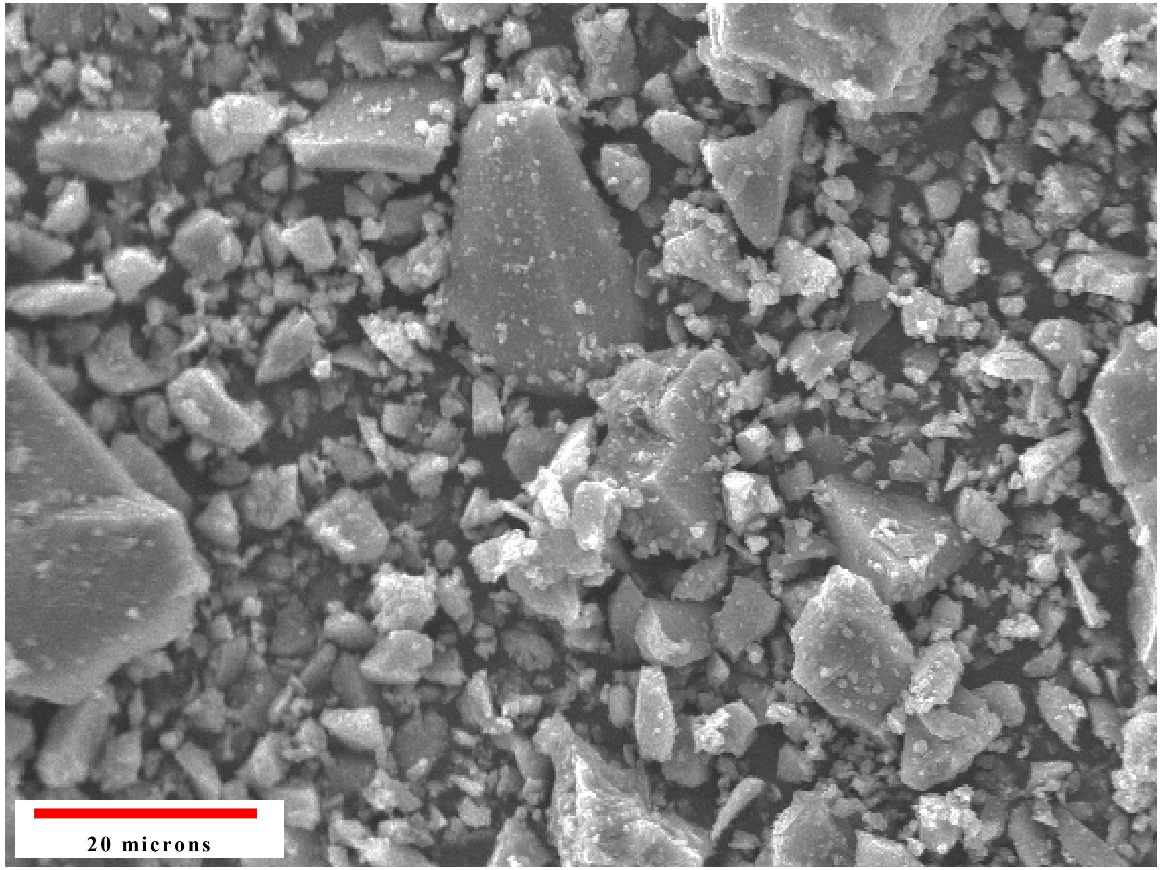
Coal Ash Supply & Use

- Approximately 14 million metric tons of fly ash used; 1.4 million metric tons of bottom ash.
- Used in concrete, blended cement, and cement production as a raw feed materials



Other SCM Supply & Use

- **Slag Cement**
- ~4 million metric tons (4.4 million short tons) used in 2021
- Availability tied to pig iron production by blast furnaces, which is expected to decrease over the next 10 years



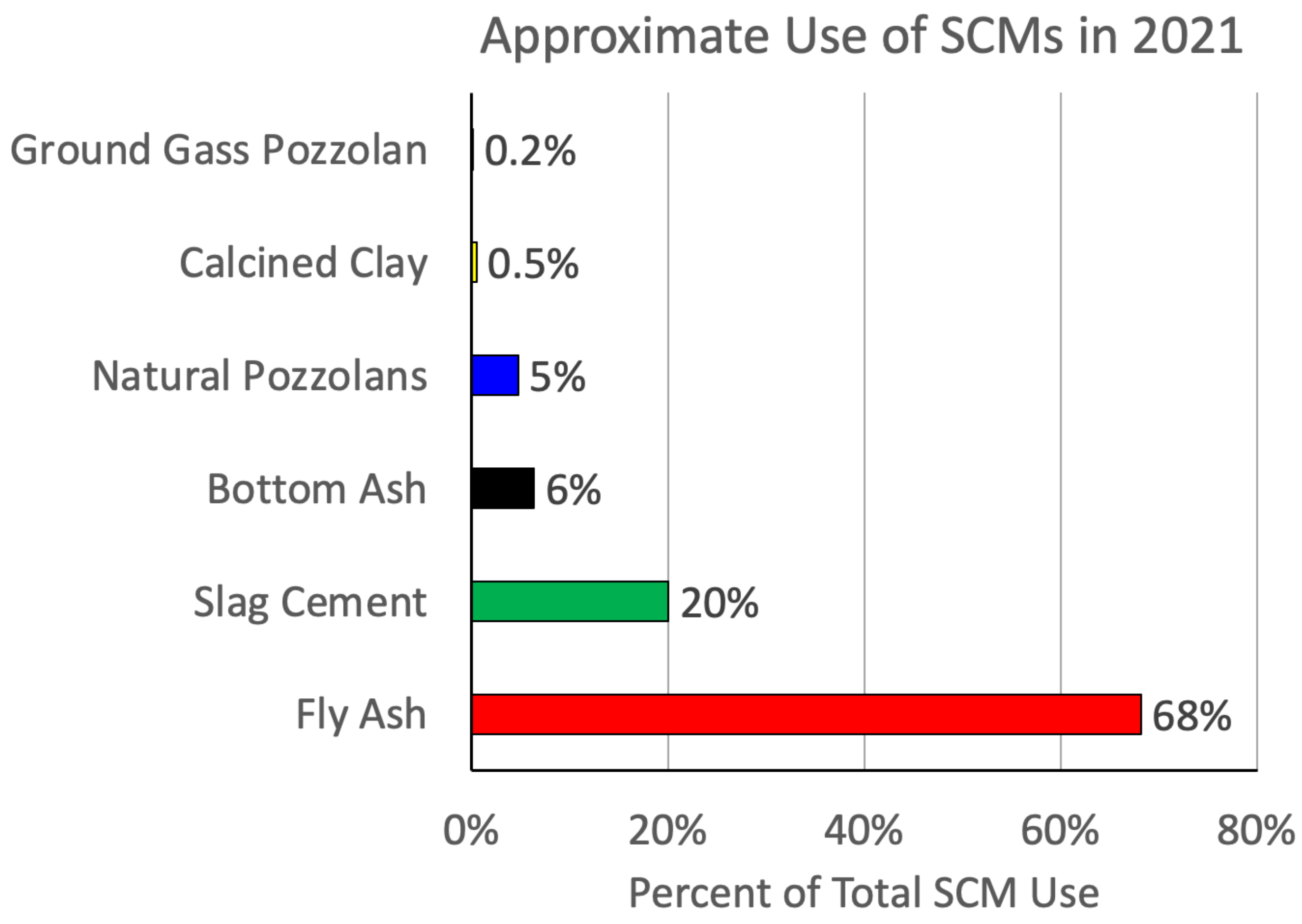
Other SCM Supply & Use

- **Natural Pozzolans**
- Use in 2021 was approximately 0.86 million metric tons (0.95 million short tons) and is expected to increase by approximately 25% in 2022
- Currently six commercial raw natural pozzolan plants and five calcined clay plants in U.S. production
- Current raw natural pozzolan capacity is estimated to be 1.35 million metric tons per year (1.5 million short tons per year) while calcined clay is estimated to be approximately 45,000 – 90,000 metric tons (50,000 – 100,00 short tons) in 2021.

Other SCM Supply & Use

- **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).

Estimated SCM Use - 2021



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

Less Cement in Concrete

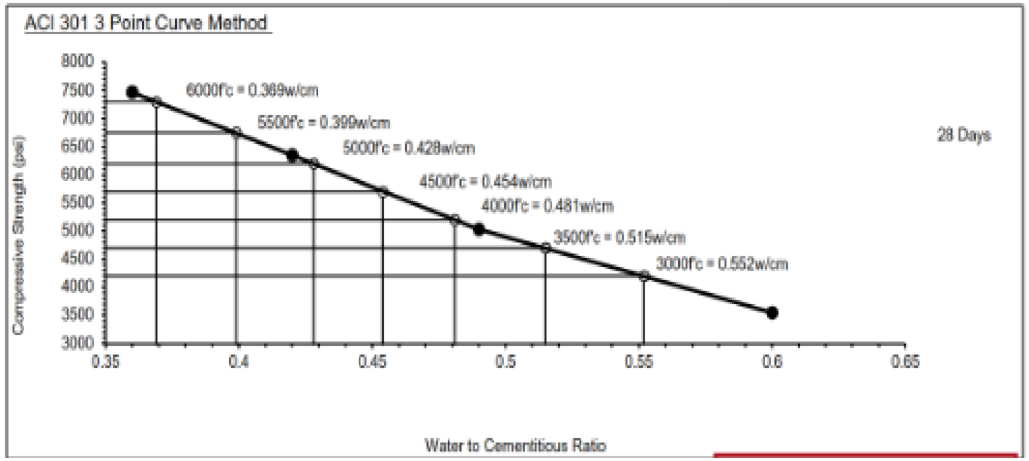
- In concept, replace cement with aggregate
- In practice, requires changing the way we think about concrete mixture proportioning
- Traditional approaches to proportioning include the absolute volume method (i.e., ACI 211, ACI 301, PCA Design & Control)
  - Some view this approach to mixture proportion as code or specified when it is only a tool
- We need to use "mixture optimization"

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 high value for targeted compressive strength

Technical Services Report Date: June 13, 2017
Trial Mixtures

Materials				
ASTM C150 Type II-V Cemen	337.5	412.5	487.5	562.5
ASTM C618 Class F	112.5	137.5	162.5	187.5
Total Cementitious	450	550	650	750
ASTM C33	510 1190	510 1190	510 1190	510 1190
Sand	1639	1543	1446	1350
Water	271	271	271	271
W/C Ratio	0.60	0.49	0.42	0.36



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

Challenges When Reducing Cementitious Content

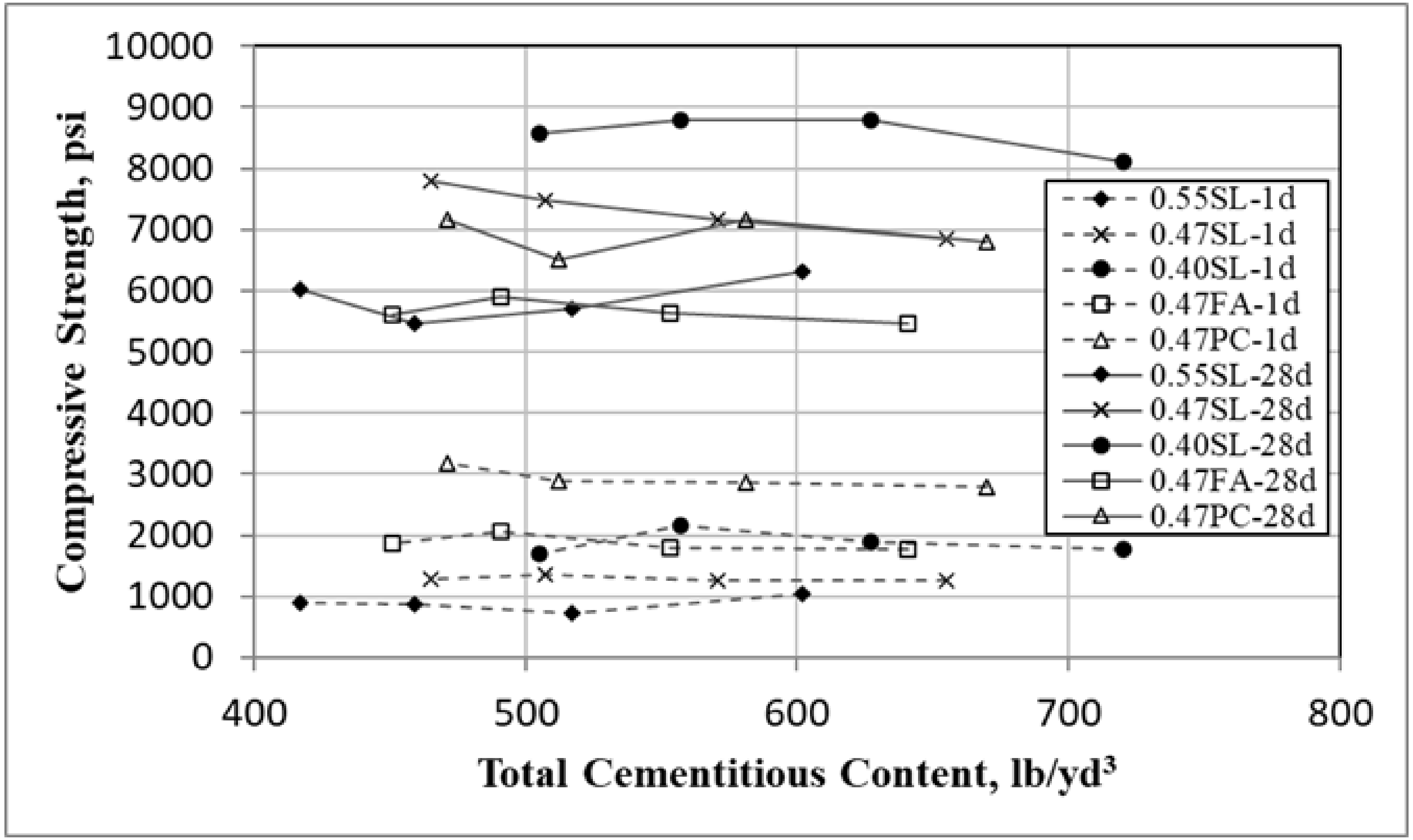
- Less cement means less heat generated
  - Can be helpful in hot weather or mass concrete placements
  - Can pose difficulties in cool weather or when early strength is required
- Less cementitious materials means moisture control is more critical as changes in water have a more profound impact on w/cm
- 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

Increasing Cement Content Does Not Necessarily Increase Strength

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

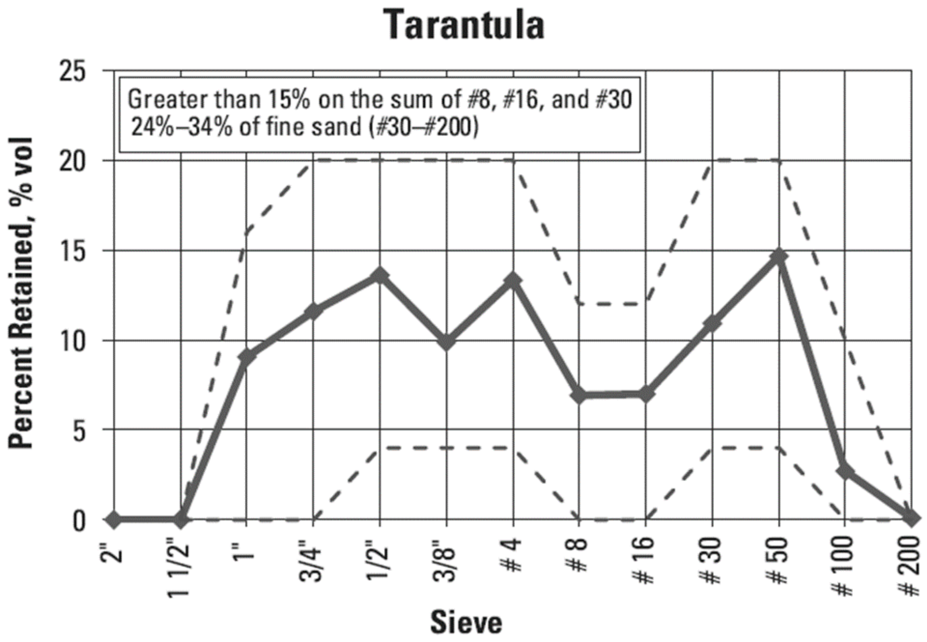
SL=slag, FA=fly ash, PC=Portland cement, 0.55, 0.47, 0.40 = *w/cm*

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



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



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"

CP Tech Center

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

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

New Designs for Materials and Structures

- Progressive owners are seeking solutions
- *Example*: Green DC Futures Team
- AWS, Meta, Microsoft and Google collaborating to advance low carbon concrete use in data center construction
- Open Letter published on the iMasons' website: https://climateaccord.org/news/greener-concrete-for-data-centers-an-open-letter/
- Seeking feedback on common challenges to implementing low carbon concrete

The Path Forward for Concrete

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Alternative Materials

- Not the only solution – not the first solution either… but…
- Conventional materials in short supply
  - Fly ash (decreasing coal power)
  - Slag (decreasing blast furnaces)
- Performance – can be better
- Carbon reduction and sequestration
- Increased uniformity possible

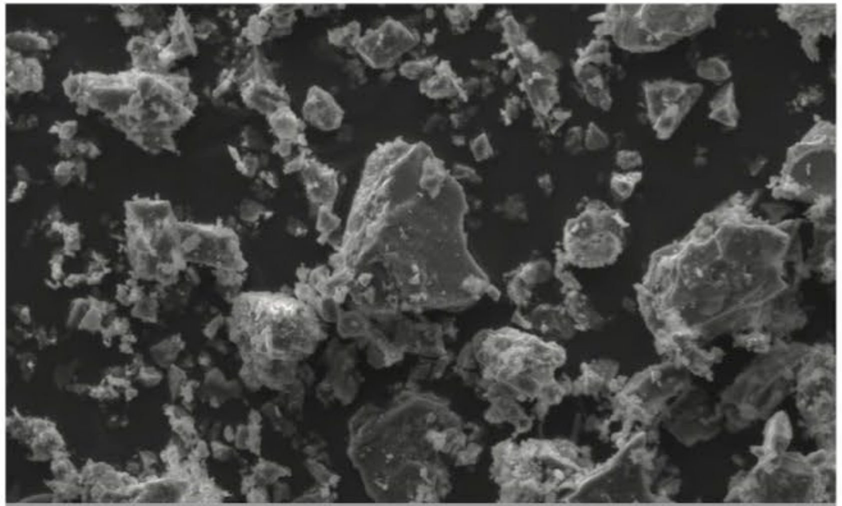
Alternative SCMs - Examples

- ***Carbon Upcycling***
- Patented technology (reactor)
- Ball milling of the material in a CO_2 environment
- Size reduction plus carbonation of components in the ash
- Claim the process works with fly ash, bottom ash, slag, ground glass, natural pozzolans and other natural minerals (e.g., talc)

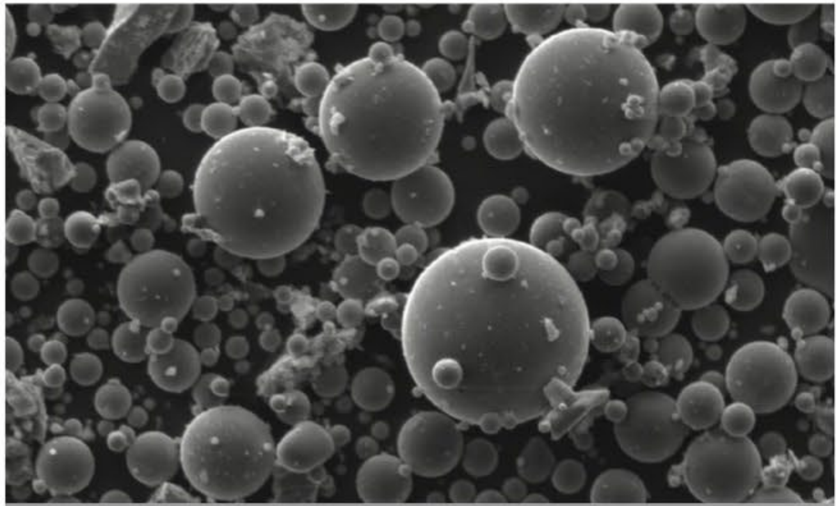
20 tonne reactor

Alternative SCMs - Examples

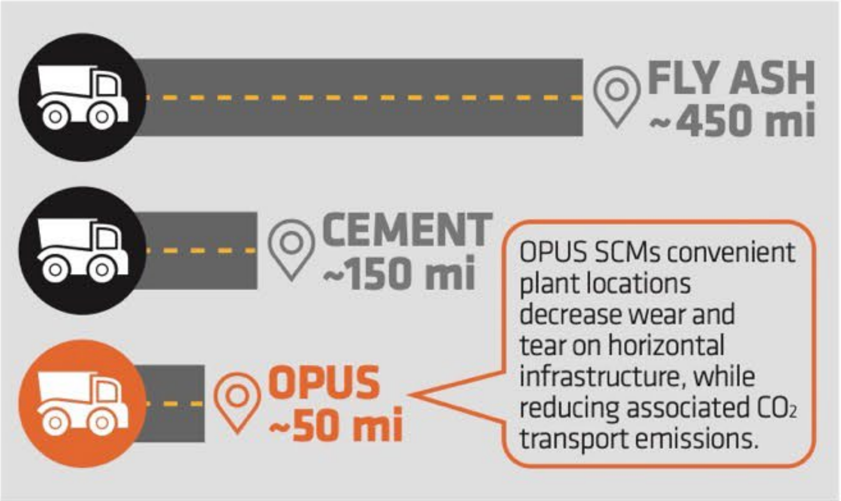
- ***Company: TerraCO2***
- Synthetic fly ash
- Taking rock with a composition similar to Class F ash, partially melting, cooling in an air stream to form spherical glass particles
- Composition, structure, morphology, particle size all mimic Class F ash



SEM image of raw feedstock at 1600x



SEM image of OPUS SCM at 1600x



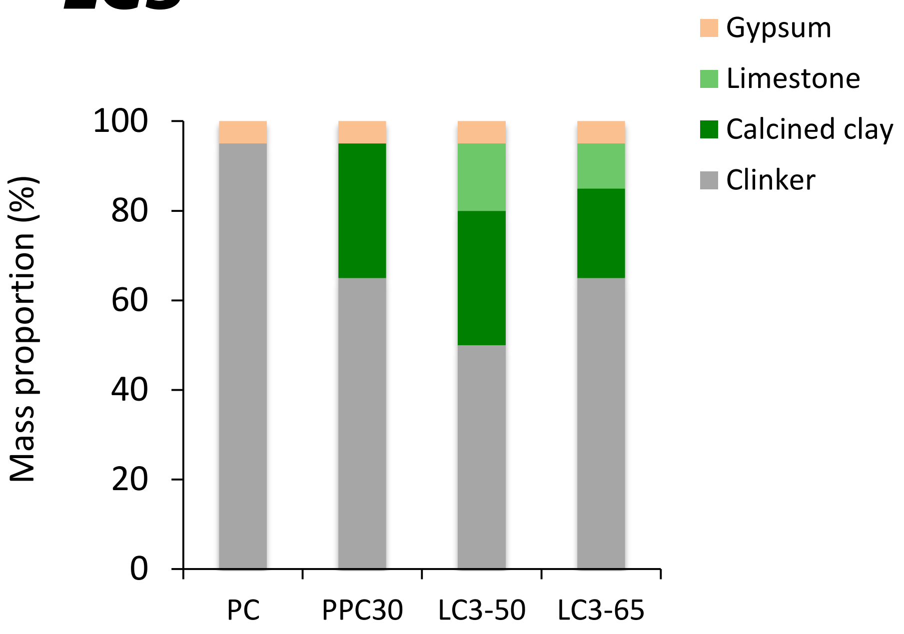
Transport emissions: State of Colorado example

Alternative SCMs - Examples

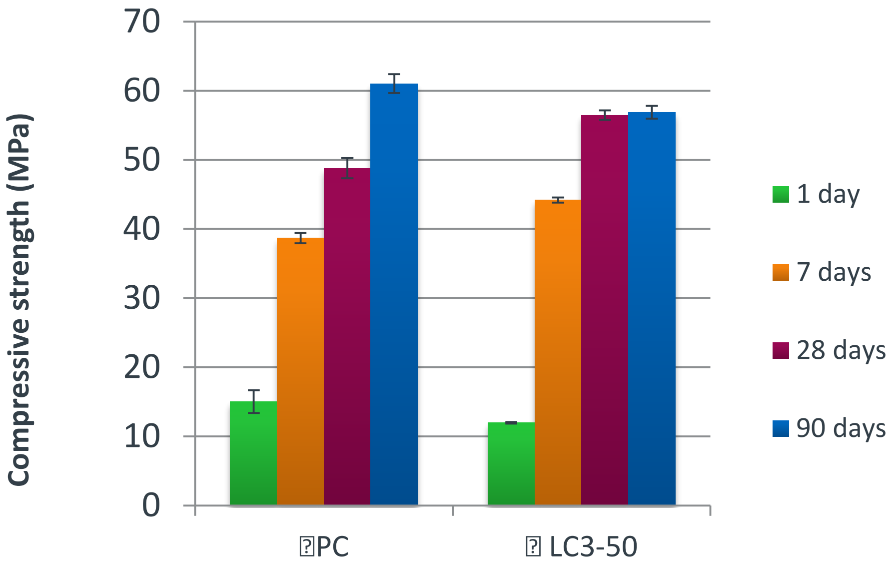
- ***Company: Carbon Limit***
- Non-calcined mineral admixture
- Replaces cement
- Adds a catalyst to increase CO_2 uptake
- Claims to adsorb more CO_2 in hardened state than portland cement concrete

Alternative Cements - Examples

- ***LC3***



LC[3] is a family of cements, the figure refers to the **clinker** content



- 50% less clinker
- 40% less CO_2
- Similar strength
- Better chloride resistance
- Resistant to alkali silica reaction

K. Scrivener, 2020

Blended Cements & Performance Specs

- ***Company: Continental Cement***
- Blended cement with 20% limestone replacement

4. Classification

4.1 This specification applies to the following types of blended cement that generally are intended for use as indicated.

4.1.1 Blended hydraulic cements for general concrete construction.

4.1.1.1 *Type IS*—Portland blast-furnace slag cement.

4.1.1.2 *Type IP*—Portland-pozzolan cement.

4.1.1.3 *Type IL*—Portland-limestone cement.

4.1.1.4 *Type IT*—Ternary blended cement.

INTERNATIONAL

Designation: C595/C595M – 21

Standard Specification for Blended Hydraulic Cements[1]

7.1.5 *Portland-limestone Cement*—Portland-limestone cement shall be a hydraulic cement in which the limestone content is more than 5 % but less than or equal to 15 % by mass of the blended cement.

Blended Cements & Performance Specs

Designation: C1157/C1157M – 20a

Standard Performance Specification for Hydraulic Cement[1]

This standard is issued under the fixed designation C1157/C1157M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This performance specification covers hydraulic cements for both general and special applications. There are no restrictions on the composition of the cement or its constituents (see Note 1).

NOTE 1—There are two related hydraulic cement standards, Specification C150/C150M for portland cement and Specifications C595/C595M for blended cements, both of which contain prescriptive and performance requirements

ization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube

The Path Forward for Concrete

The Three C's

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

RISK!!

- Replace clinker content in cement
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- Use less cementitious materials
  - Optimized aggregate grading
  - Lower cementitious content
- Optimize designs & new mixtures (UHPC)
- Use alternative SCMs and/or alternative cementitious materials

Broad Challenges That Must Be Overcome

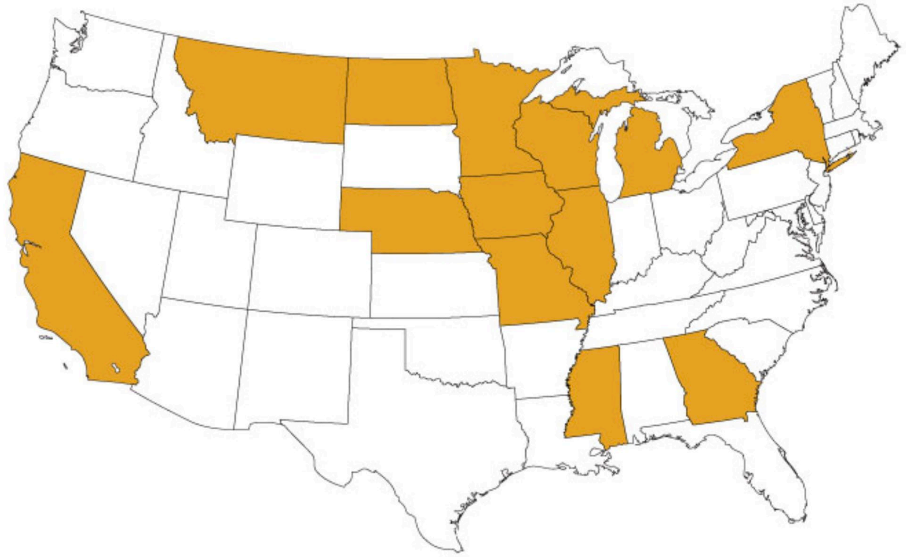
- Change is difficult and perceived to be risky
- The Licensed Design Professional (LDP) is responsible to meet the standard of care for their discipline
  - Life-safety cannot be compromised
  - Innovation is possible but not often pursued
- Risk often falls onto the General Contractor and/or concrete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

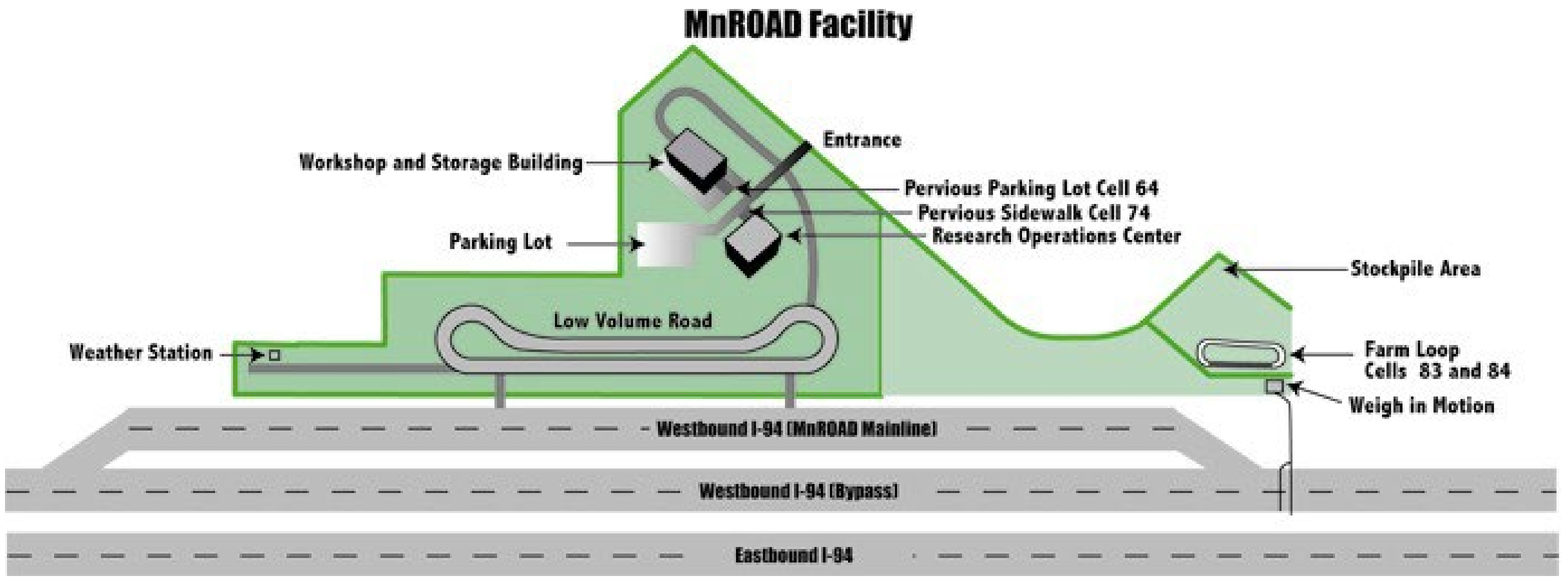
How to Mitigate the Risk?

- Education/Training
- Financial Incentives
- Changes in Contracting/Improvements in testing
- Performance Specifications (that include sustainability goals)
- Demonstration Projects

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





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

Final Test Site Construction

- Test cells were constructed at MnROAD to evaluate strategies to reduce GHG emission in concrete paving
- 16 test cells
  - 2 control cells
  - 1 optimized mixture (based on control)
  - 3 CarbonCure™ cells
  - 8 alternative SCM cells
  - 2 alternative cements
- Construction completed August 2022

Project Specific Mixtures

- **Control Mixtures** – Standard MnDOT paving mixture
  - 570 pcy total cementitious with 30% Class F fly ash (Coal Creek)
  - Water-to-cementitious materials ratio of 0.40
- Two control mixtures were needed to accommodate carbon mineralization study
  - One control mixture and the three CarbonCure™ cells will use one set of constituent materials
  - Other control mixture and remaining cells will use another set of constituent materials

Project Specific Mixtures

- **Optimized Mixture** – designed with conventional materials with reduced cementitious materials content
  - Mixture Design by Iowa State University (P. Taylor)
  - Mixture Design – 501 pcy total cementitious; 30% Coal Creek Class F

- **CarbonCure™**
  - One mixture designed by CarbonCure™ with CO_2 injection – 558 pcy total cementitious; 30% Coal Creek Class F
  - Same mixture as above without the CO_2 injection
  - Control mixture with CO_2 injection

Project Specific Mixtures - ASCMs

- **Carbon Upcycling**
  - Fly ash processed by grinding in a pressurized carbon-rich environment
  - Mixture Design – 500 pcy total cementitious; 30% treated ash
- **Urban Mining**
  - Ground-glass pozzolan meeting ASTM C1866
  - Mixture Design – 570 pcy total cementitious; 30% GGP
- **TerraCO2**
  - Manufactured SCM resembling fly ash
  - Mixture Design – 570 pcy total cementitious; 35% manufactured ASCM

Project Specific Mixtures - ASCMs

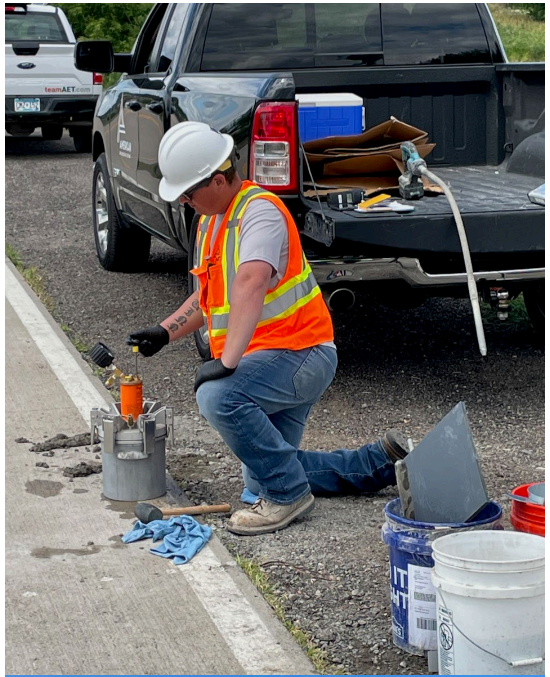
- **Carbon Limit**
  - Proprietary material, ground limestone, natural pozzolan
  - Mixture Design – 570 pcy total cementitious; 30% ASCM
- **Hess Pumice**
  - Pumice-based natural pozzolan meeting ASTM C618
  - Mixture Design – 570 pcy total cementitious; 30% pozzolan
- **3M**
  - Baghouse dust from shingle granules; natural pozzolan meeting ASTM C618
  - Mixture Design – 570 pcy total cementitious; 15% 3M pozz, 15% Portage Station Class F
- **Burgess Pigments**
  - Metakaolin natural pozzolan
  - Mixture Design – 570 pcy total cementitious; 12% metakaolin, 18% Coal Creek Class F

Project Specific Mixtures - ACMs

- **Ash Grove – IP(30)**
  - Type C595 IP(30) 30% calcined clay
  - Mixture Design – 570 pcy total cementitious using calcined clay as the pozzolan
- **Continental Cement – High Limestone [Type IL(20)]**
  - Blended cement with 20% limestone, 30% Class F ash
  - Mixture Design – 570 pcy total cementitious
- **UltraHigh Materials**
  - 0% portland cement clinker-based hydraulic cement (meets ASTM C1157)
  - Mixture Design – 650 pcy total cementitious

The Research

- Three research teams selected by NRRA
- Data from construction obtained by local testing firm and FHWA Mobile Trailer
- Post-construction testing will be performed by local firm and FHWA Turner-Fairbank
- Research teams will monitor pavement performance over 2 years
- Teams will report on performance including LCA
- **Construction report will be out in a few weeks**
- **MORE DEMONSTRATION PROJECTS ARE NEEDED FOR BOTH EMERGING AND CONVENTIONAL MATERIALS**



Closing Thoughts

The times they are a changing

Bob Dylan, 1964

Far Out/Alamy

The Next 5-10 Years Towards Net-Zero

- We need to deviate from what we have done historically, but not through disruption
- Owners need to create demand; the market will follow
- Implement new ways to measure our progress (EPDs)
- Make better use of existing materials
  - More SCMs
  - Optimized mixture designs
- Optimized structural designs to improve durability, constructability, and sustainability.
- New materials once proven through demonstration projects
- Sharing the risk through cooperation between the contracting parties

Questions?

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or

llsutter@mtu.edu

sutter engineering llc

periculosum est tempus indoctus

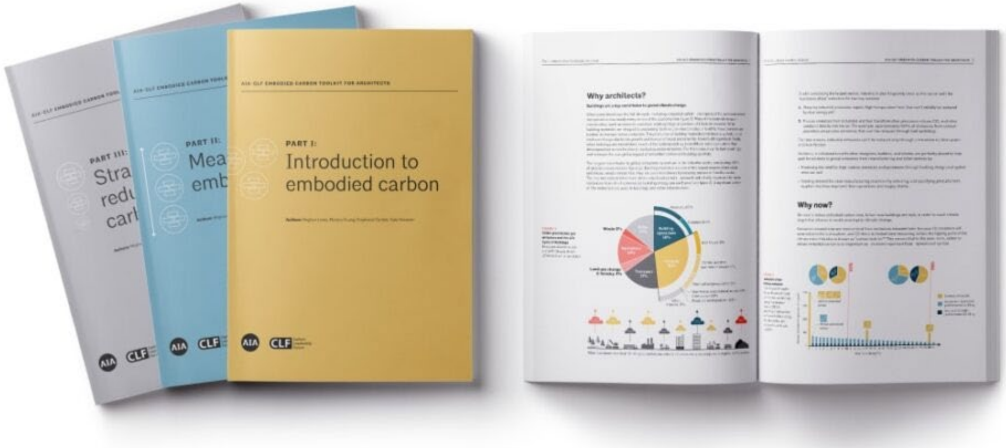
CLF Carbon Leadership Forum Wisconsin

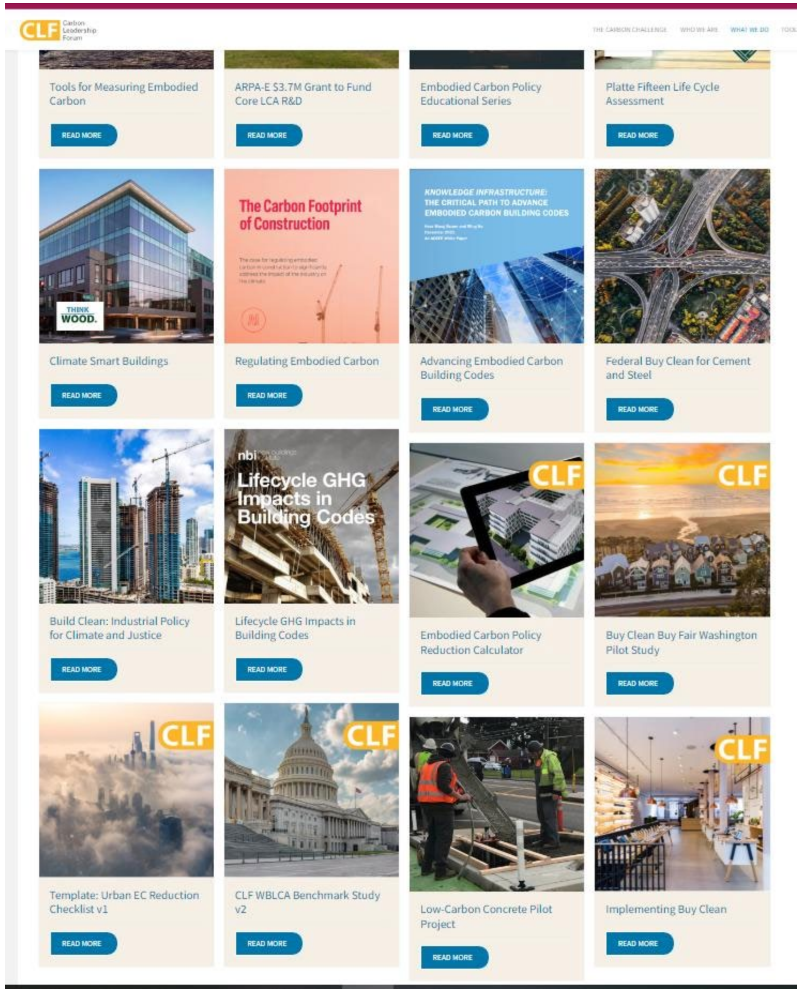
Julia Pooler
Co-Lead
Carbon Leadership Forum WI Hub

(Also Girl Scout Leader
for Troops 1477 & 1952)

What is the Carbon Leadership Forum?

- Research &Policy
- Toolkits
- Online Forum
- Resource Library
- Regional Hubs for Education/Engagement





ECHO PROJECT

Embodied Carbon Harmonization and Optimization

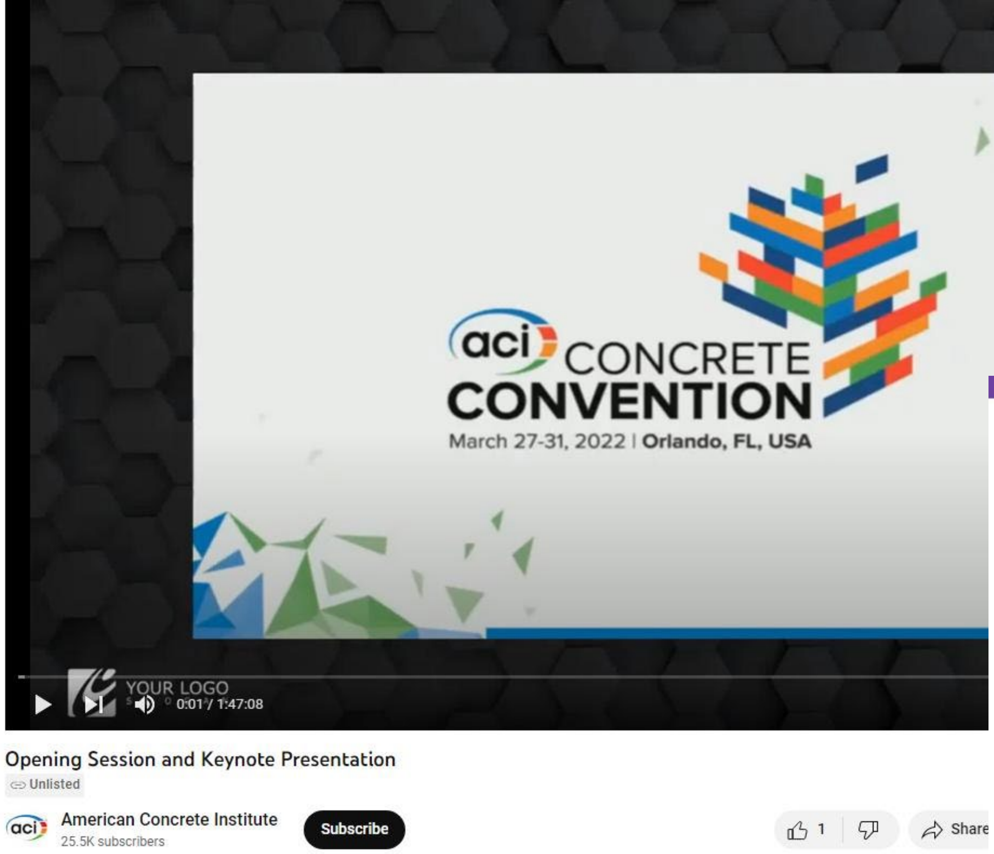
a collaboration between:

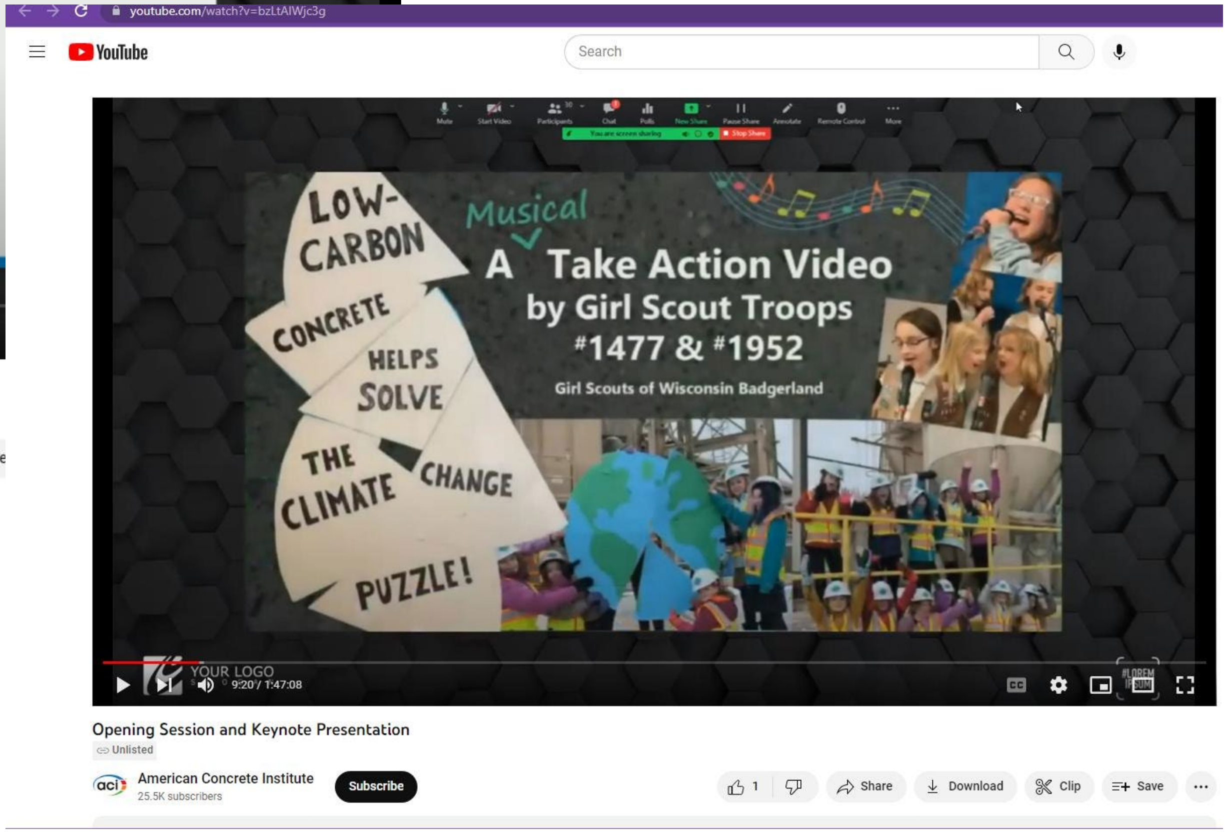
AIA
American Society of Landscape Architects
architecture 2030
ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS
SEI STRUCTURAL ENGINEERING INSTITUTE ASCE
SE2050 COMMITTING TO NET ZERO
Building Transparency
CLF
climatepositive design
CONTRACTOR'S COMMITMENT
Institute for Sustainable Infrastructure
U.S. GREEN BUILDING COUNCIL USGBC
INTERNATIONAL LIVING FUTURE INSTITUTE
MEP 2040 Committing to Zero
ULI Urban Land Institute

YOUR CLF Hub in Wisconsin

- Hub Co-Leads: Ben Austin, Kim Reddin, Julia Pooler, Chelsea Duckworth
  - This is your hub - everyone can help shape the direction!

- ***BEST WAY TO STAY IN TOUCH*** - Connect with the CLF Wisconsin Hub on **LinkedIn**





https://www.youtube.com/watch?v=tzL79SUBzgg

Thank you!

Questions?

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or

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