MnROAD Field Demonstration of Alternative Materials for Concrete

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Where is the industry going?

- Sustainability – Carbon neutral by 2050
- Because…

There's something happening here

What it is ain't exactly clear

Stephen Stills, Buffalo Springfield, 1966

You may have "highly informed" explanations or just disagree…

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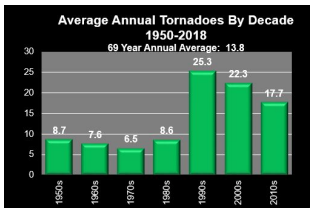
Scott Olson, Getty Images

"Tornadoes are not more common; they're over-hyped. They just send out news crews like lice on a dog!"



National Weather Service

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Scott Olson, Getty Images

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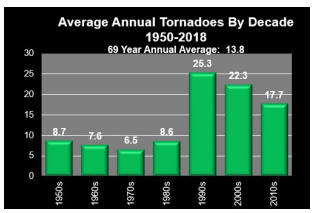

National Weather Service

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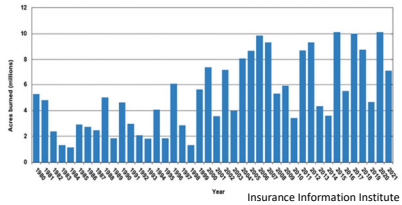
Noah Berger, AP Photo

LA Times

Annual Number of Acres Burned in Wildland Fires, 1980-2021



Insurance Information Institute

John Locher/AP

"It's those tree huggers that won't let us cut any trees!"

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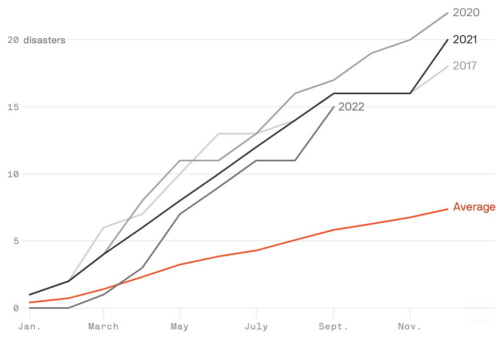
Ramon Espinosa, AP Photo

"Crazy fools that build right on the coast. What do they expect?"

U.S. cumulative billion-dollar climate and weather disasters, by year

As of Oct. 11, 2022; By month the climate event ended



Data: Climate Central, NOAA National Centers for Environmental Information. (Damages of at least $1 billion, adjusted for 2022 dollars. Average = 1980-2022.) Chart: Axios Visuals

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Stephen Stills, Buffalo Springfield, 1966

All theories are good theories – but if you are in the concrete business…

choose wisely…

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Your local Holiday Inn…

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Your local road…

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"Low Carbon" is and will be demand driven

- Many private companies see climate change as a threat to their long-term viability (2035 target – not 2050)
- Major companies are investing in strategies to reduce their carbon footprint now and into the future
  - Companies that have large infrastructure construction programs for warehousing, campuses, and data centers: Meta, Target, Amazon, etc.
- Looking for strategies to reduce the carbon footprint of concrete as part of an overall program

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National/State Level Policy Initiatives

- The federal government and many state and local agencies are requesting reduced carbon concrete – lower GHG emissions
- In some cases, carbon limits are being set for classes of concrete
  - Tracking carbon footprint of construction materials using environment product declarations (EPDs) has begun
- Several NGO's are working with elected officials to implement changes in policy to benchmark and reduce GHG emissions
  - Breakthrough Energy, Carbon Leadership Forum, Climateworks, National Resource Defense Council, Great Plains Institute, Rocky Mountain Institute, National Building Institute, AIA, ASCE, ACEEE

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- The [prime contractor] shall 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**.

Low Embodied Carbon Concrete Standards for all GSA Projects

	Maximum Global Warming Potential Limits for GSA Low Embodied Carbon Concrete (kilograms of carbon dioxide equivalent per cubic meter - CO_2e kg/m^3)		
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 (CO_2e) limits in proposed code language: "Lifecycle GHG Impacts in Building Codes" by the New Buildings Institute, January 2022.			

- These requirements apply to all GSA projects that use at least ten (10) cubic yards of a concrete mix.

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Current Sustainable Procurement Initiatives

Information

On this page

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Sustainable Procurement Reports and Case Studies

Low-Carbon Concrete Initiative

The City of Portland's 2016 Sustainable Supply Chain Analysis identified construction services as the top spend category contributing to the City's supply chain greenhouse gas (GHG) emissions. Within construction services, concrete is one of the most GHG-intensive materials typically used on City construction projects. As a result, in 2019, after gathering both internal and external stakeholder input, the City established its Low-Carbon Concrete Initiative to reduce the overall carbon intensity of the concrete mixes used on City projects. From 2019 to early 2022, the Initiative involved: 1) establishing a product-specific Environmental Product Declaration (EPD)

Low-Carbon Concrete Initiative

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For questions related to the Low-Carbon Concrete Initiative, contact Josh Huber, Materials Quality Compliance Specialist, Portland Bureau of Transportation, joshua.huber@portlandoregon.gov

Lower-Embodied Carbon Concrete Pilot Projects

In order to understand how lower-carbon concrete mixes perform compared to traditional 100% cement mixes, the City has been conducting pilot tests of different lower-carbon concrete mixes. The following case studies provide summaries of the pilot tests conducted to date.

Pilot Project Case Study Reports

- Low-Carbon Concrete Sidewalk Pilot Project 2020 1.66 MB
- Low-Carbon Concrete Pole Footings Pilot Project 2021 2.07 MB
- Low-Carbon Concrete Type 1L Cement Pilot Project 2021 3.72 MB
- Low-Carbon Concrete Park Infrastructure Case Study 2022 636.02 KB
- Low-Carbon Concrete Set Time and Early Strength Case Study 2022 492.82 KB

Low-Carbon Concrete Pilot Project: Evaluating Set Times and Early Strength

This case study provides information on one of the City of Portland's low-carbon concrete pilot projects 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.

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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.

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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

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National/State Level Policy Initiatives

- The federal government and many state and local agencies are committed and acting to reducing GHG emissions
- In some cases, carbon limits are being set for classes of concrete
  - Tracking carbon footprint of construction materials using environment product declarations (EPDs) has been proposed by FHWA
- Several NGO's are working with elected officials to implement changes in policy to benchmark and reduce GHG emissions
  - Breakthrough Energy, Carbon Leadership Forum, Climateworks, National Resource Defense Council, Great Plains Institute, Rocky Mountain Institute, National Building Institute, ACEEE, AIA, ASCE

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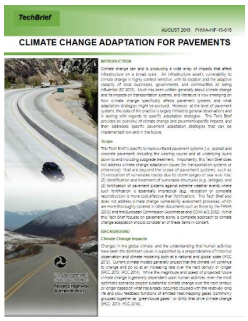
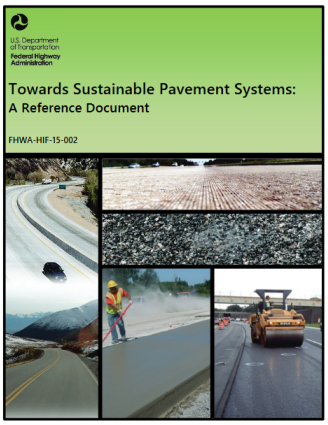
FHWA Sustainable Pavement Program: Work Products

- Sustainable Pavements Program Roadmap
- Toward Sustainable Pavement Systems: A Reference Document
- LCA framework document
- LCA Pave
- Tech briefs & Guides
- Case studies





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The Path Forward for Concrete Pavements

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 (UHPC)
- Use alternative SCMs and/or alternative cementitious materials
- Why alternative materials?

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Example: UHPC

photo credit: S. Foster

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Why Alternative Materials?

- Not the only solution
- Conventional materials in short supply
  - Fly ash (no more coal power)
  - Slag (no more blast furnaces)
- Performance
- Carbon reduction and sequestration

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The Path Forward for Concrete Pavements

The Three C's

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- Optimize designs & new mixtures (UHPC)
- Use alternative SCMs and/or alternative cementitious materials
- Why alternative materials?
- All require demonstration. But where? The **RISK** of trying something new…

RISK!

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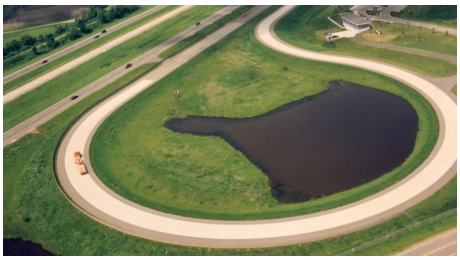
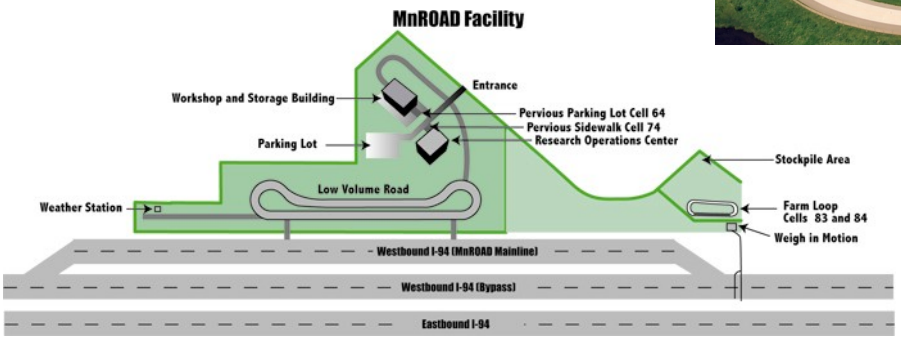
This Has Brought Us to MnROAD





Constructed 1990-93

A partnership between Minnesota Department of Transportation and the Minnesota Local Road Research Board

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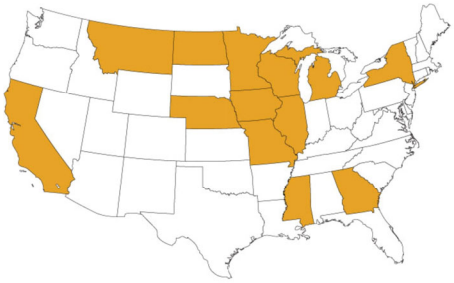
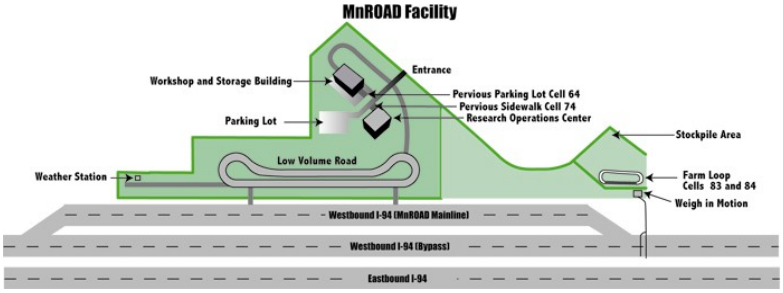
MnROAD - NRRA

- 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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Project Ramp-Up

- MnDOT contracted with NCE and Sutter Engineering LLC to help structure and execute the experiment
  - Identify materials providers
  - Establish mixture requirements
  - Manage trial batching
  - Coordinate logistics (i.e., herd cats)
  - Structure the testing program to support the desired research

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NRRA Research Projects

- Use of Carbon Dioxide for Sustainable and Resilient Concrete Pavements – *Iowa State University*
- Use of Alternative Pozzolanic Materials Towards Reducing Cement Content in Concrete Pavements – *APTech*
- Use of Alternative Cementitious Materials in Concrete Pavements – *NCE*

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Possible Technologies - Alternative SCMs

- Harvested coal ash
  - From landfills and ponds
  - Mix of fly ash and bottom ash
  - Requires processing
- Ground glass pozzolan
  - ASTM C1866
- Manufactured SCMs
  - ASTM is working on standards for alternative SCMs

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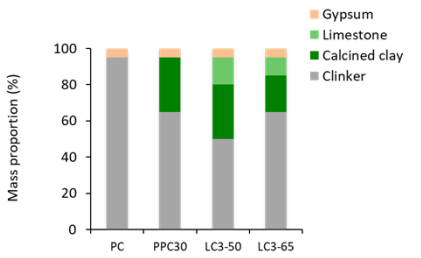
Possible Technologies - Alternative Cements

- Non-traditional blended hydraulic cements
  - LC3 – portland cement, ground limestone, calcined clay,
  - High-limestone replacement blended cements
- Alkali-activated hydraulic cements
  - Alkali activator – liquid or powder; hydration occurs
  - Precursor containing calcium and alumino-silica minerals
    - e.g., Class C fly ash, slag cement
- Alkali-activated non-hydraulic cements (geopolymers)
  - Alkali-activated non-hydraulic reaction based on low calcium alumino-silica minerals
  - Dissolution and polymerization process



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

K. Scrivener, 2020

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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 plant and paved using conventional slip-form paving equipment

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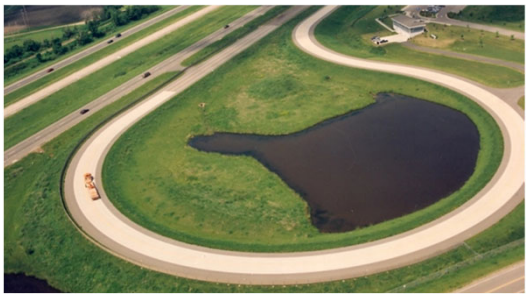
Final Test Site Construction

- 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
  - 7 alternative SCM cells *(nominal)*
  - 3 alternative cements *(nominal)*
- Construction completed August 2022



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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

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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

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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

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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

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Project Specific Mixtures - ACMs

- **Ash Grove – IP(30)**
  - Thought we were getting LC3 using 50% clinker, 30% calcined clay, 15% limestone
  - Mixture Design – 570 pcy total cementitious using calcined clay as the pozzolan
- **Continental Cement – High Limestone [Type IL(20)]**
  - Blended cement with 20% limestone
  - Mixture Design – 570 pcy total cementitious
- **UltraHigh Materials**
  - 0% portland cement clinker-based hydraulic cement (meets ASTM C1157)
  - Mixture Design – 650 pcy total cementitious

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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

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Case Studies Technical Data

Enhanced Fly Ash (EFA)

Property Enhancements

- 5 - 15% embedded CO_2 in material by mass
- 40% improvement in strength activity
- 60% improvement in ASR Mitigation
- 70% improvement in Sulfate Expansion
- Stabilizes sequestered CO_2 to 600°C
- Minimal particle size reduction

Recommended Applications

Class C2 and C4 Concrete Exposures: garage floors, porches, steps, pavements, sidewalks, cubs, and gutters.

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

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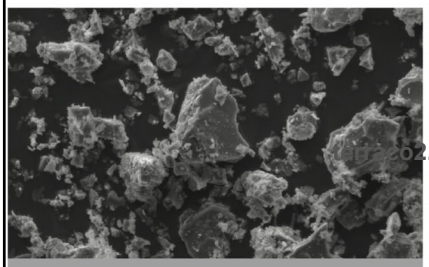
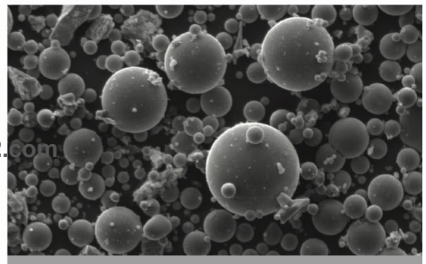
WHAT ARE THE BENEFITS OF HAVING A NEW LOW COST SCM LIKE OPUS SCM?

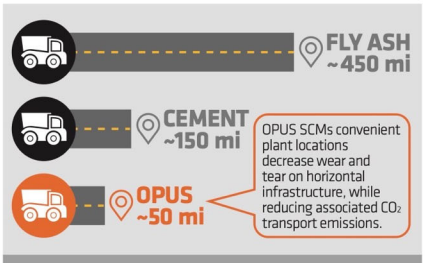
1. OPUS SCM is potentially cheaper than fly ash (depending on haul distance).
2. OPUS SCM manufacturing scales to meet increasing demand, unlike coal fly ash.
3. OPUS SCM does not use coal energy. Carbon-neutral production will be possible when industrial renewable energy sources become feasible.



SEM image of raw feedstock at 1600x



SEM image of OPUS SCM at 1600x



Transport emissions: State of Colorado example

OPUS Supplementary Cementitious Material (OPUS SCM):

- is classified as a Class N pozzolan
- is an alternative to Class F fly ash
- reduces Portland cement emissions by 8-23% (at 10-30% substitution)

Cement is responsible for ~5 to 7% of global carbon emissions.

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

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Alternative Cements - Examples

- ***Company: UltraHigh Materials***
- Proprietary blend of materials
- Available as a hydraulic formulation or a geopolymer formulation
- Capable of very high strength concrete, ~25,000 psi compressive

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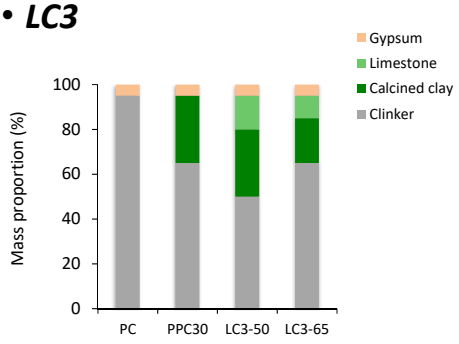
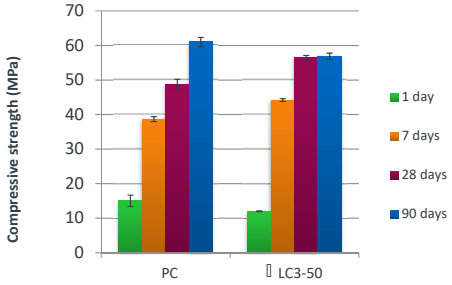
Alternative Cements - Examples

- ***LC3***



LC³ 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

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Alternative Cements - Examples

- ***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.

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.

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The Research

- Three research teams have been 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

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A Note on Environmental Impact

- Environmental Product Declarations (EPDs) are not currently available for many of the alternative materials
  - Would need to use ISO 21930 core PCR to develop EPD
- This will limit ability to assess environmental impact
  - Will gather data, draw boundaries, and do the best we can
- FHWA is working on the LCA Commons to provide the necessary LCI data for EPD development

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Some Inside Baseball…

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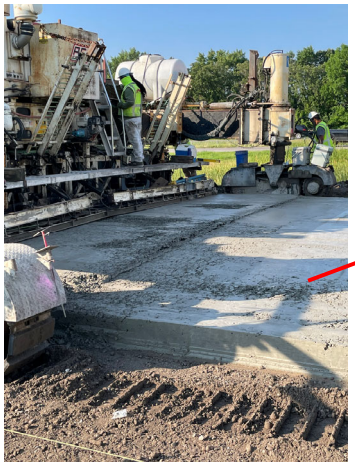
Some Inside Baseball…



- GGP
- Batch plant left out the admixture package

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Some Inside Baseball…

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Some Inside Baseball…

- Metakaolin
- Extremely high water demand.
- Should have been blended with the fly ash but was added separately into the truck

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Some Inside Baseball…

- Metakaolin
- Extremely high water demand.
- Should have been blended with the fly ash but was added separately into the truck

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Some Inside Baseball…

- Once dialed in it paved well

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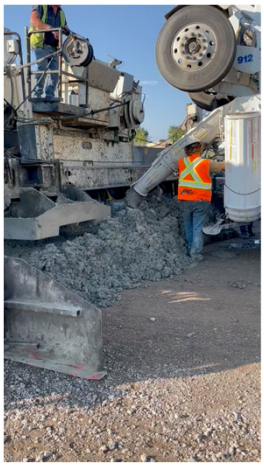
Some Inside Baseball…



- Carbon Limit
- Proprietary Material + Limestone + Natural Pozzolan

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Some Inside Baseball…

- Dialed in (25 gal water added)

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Some Inside Baseball…

- No Texture

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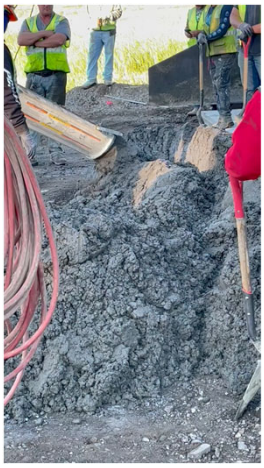
Some Inside Baseball…



- Carbon Upcycling - Success

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Some Inside Baseball…

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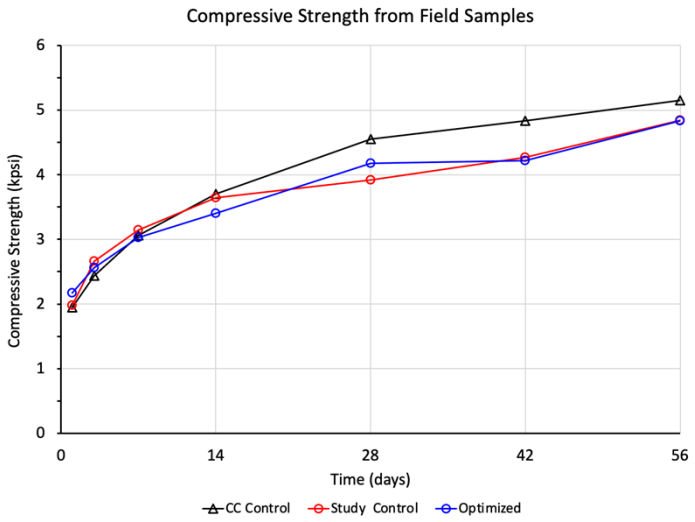
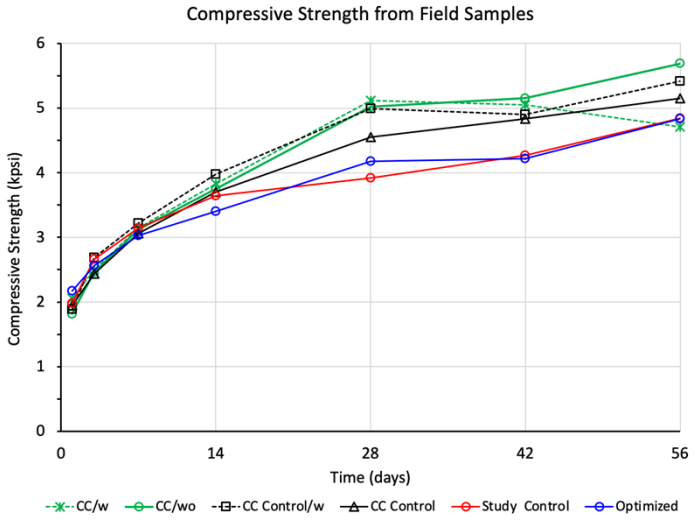
Preliminary Results – Compressive Strength

- Control Mixtures



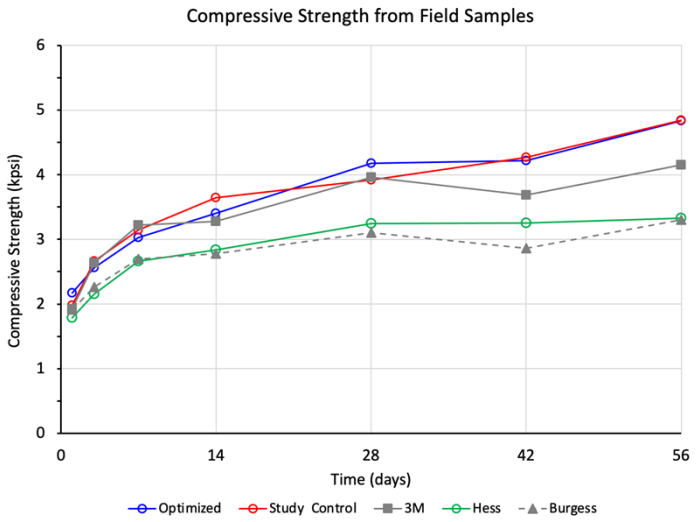
Preliminary Results – Compressive Strength

- CarbonCure™ Mixtures



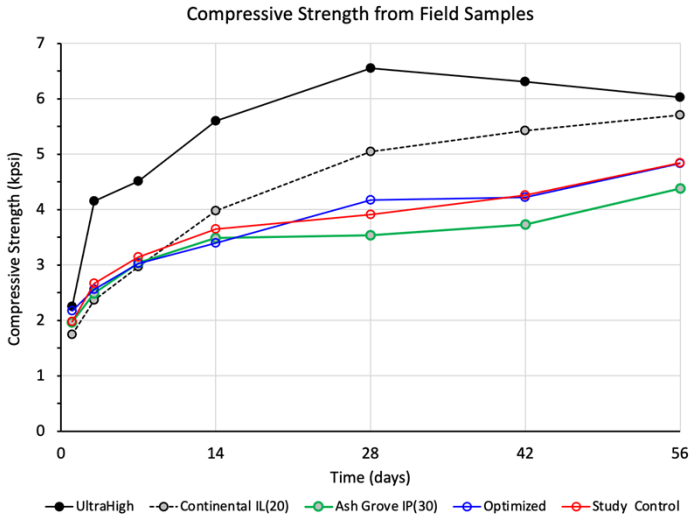
Preliminary Results – Compressive Strength

- Natural Pozzolan Mixtures



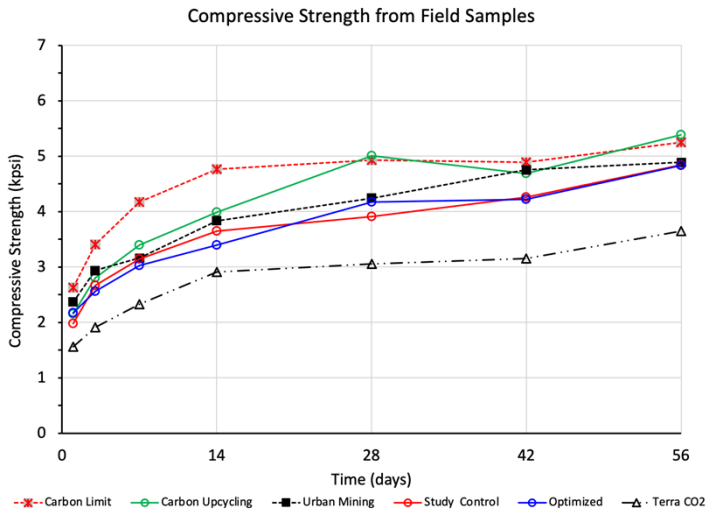
Preliminary Results – Compressive Strength

- Other Cements Mixtures



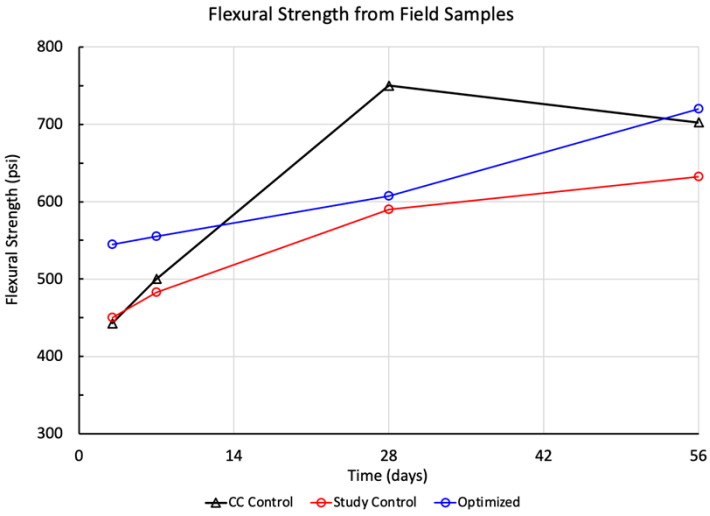
Preliminary Results – Compressive Strength

- ASCM Mixtures



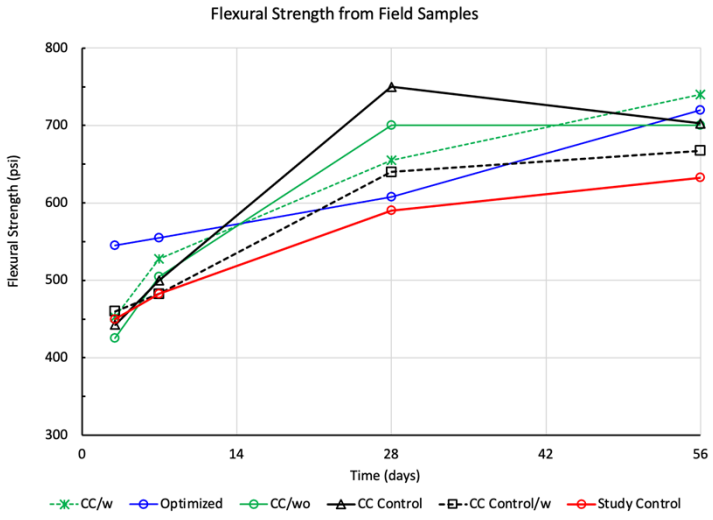
Preliminary Results – Flexural Strength

- Control Mixtures



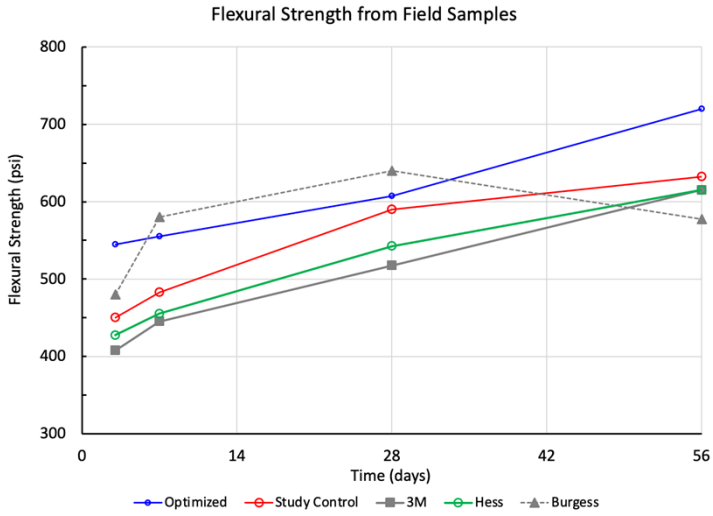
Preliminary Results – Flexural Strength

- CarbonCure™ Mixtures



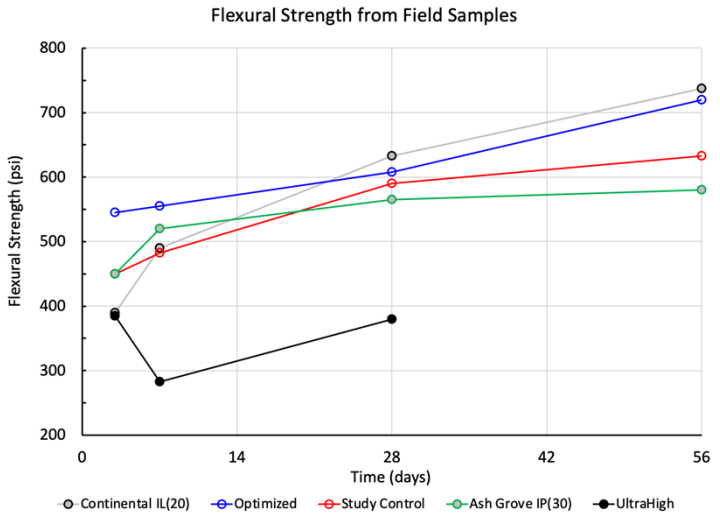
Preliminary Results – Flexural Strength

- Natural Pozzolan Mixtures



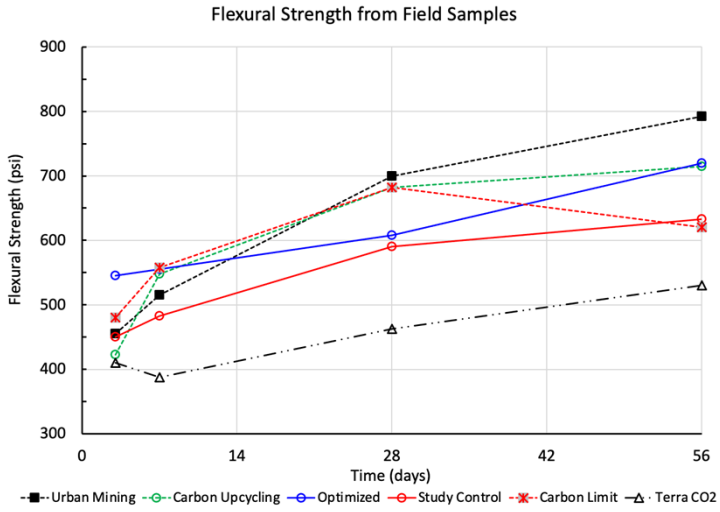
Preliminary Results – Flexural Strength

- Other Cements Mixtures



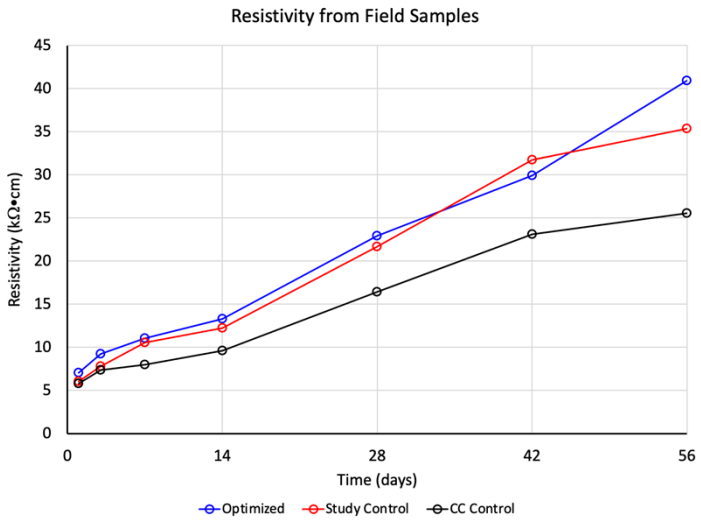
Preliminary Results – Flexural Strength

- ASCM Mixtures



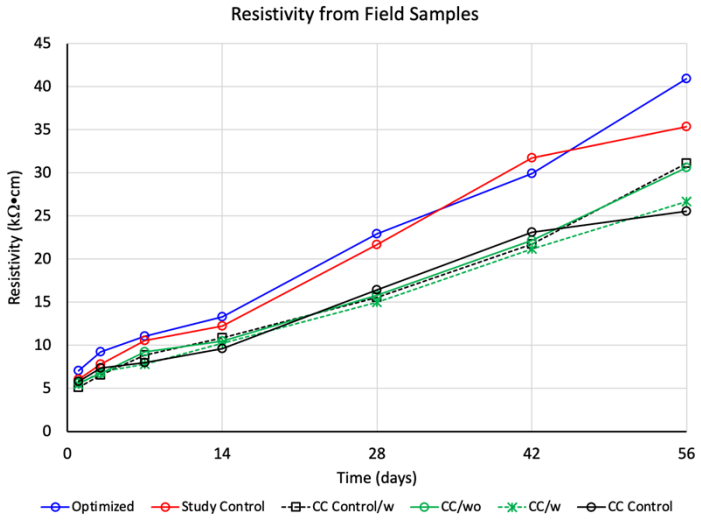
Preliminary Results – Resistivity

- Control Mixtures



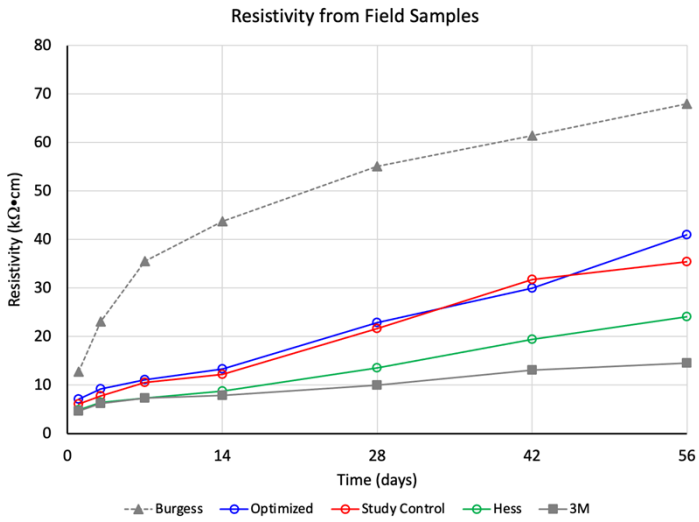
Preliminary Results – Resistivity

- CarbonCure™ Mixtures



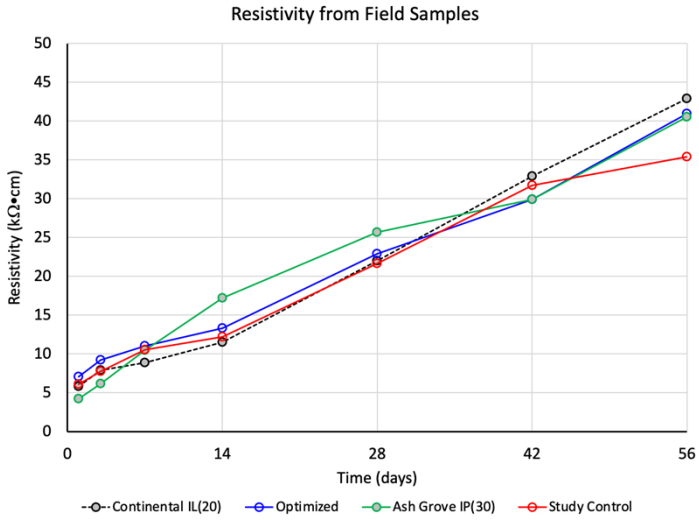
Preliminary Results – Resistivity

- Natural Pozzolan Mixtures



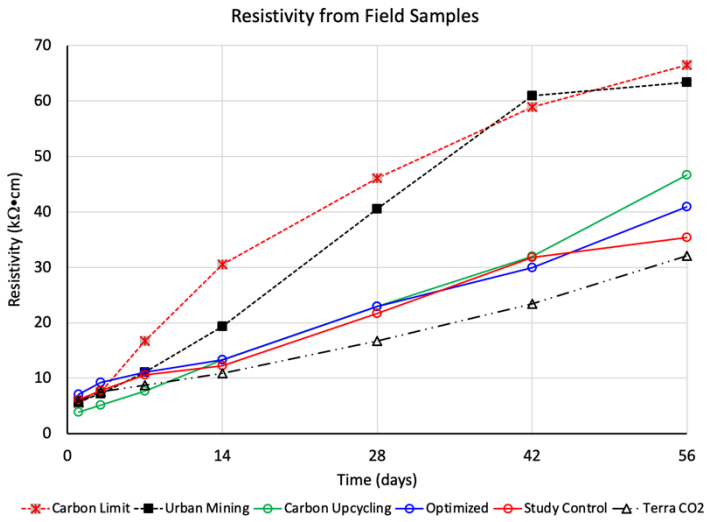
Preliminary Results – Resistivity

- Other Cements Mixtures



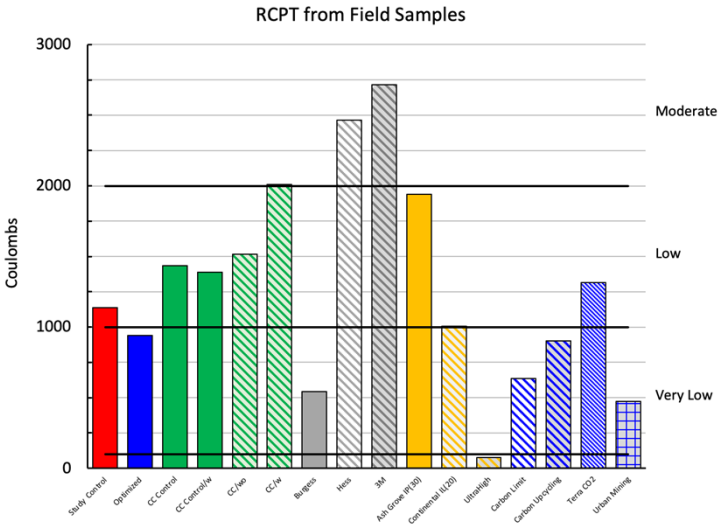
Preliminary Results – Resistivity

- ASCM Mixtures



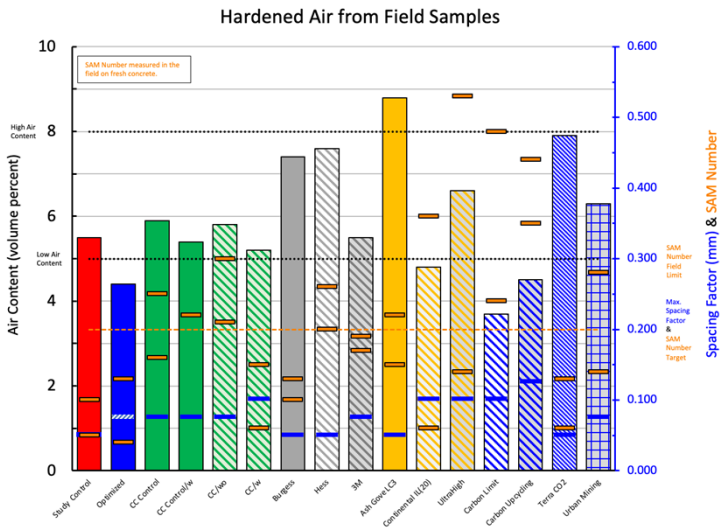
Preliminary Results – RCPT

- All Mixtures



Preliminary Results – Air–Void System

- All Mixtures



Closing Thoughts

- This MnROAD demonstration project is a critical step towards a transition to new materials for road and infrastructure construction
- Strong support from FHWA, MnDOT, and industry
- After construction is completed, performance will be monitored for three years under a separate contracts – Stay tuned!
- Preliminary results show good to excellent performance
- Notable: IL(20), Carbon Upcycling, Carbon Limit

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Questions?

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sutter.engineering@gmail.com

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periculosum est tempus indoctus