More Sustainable Concrete Pavements

Peter Taylor

Iowa State University
Institute for Transportation

National Concrete Pavement Technology Center
Tech Center

Setting the Stage

What do humans need:

- Sustenance
- Shelter
- Help
- Hope

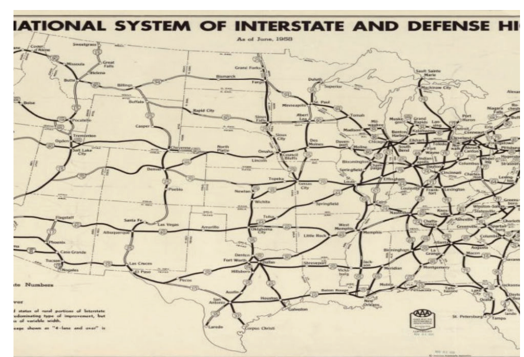
Setting the Stage

Imagine a world without infrastructure:

- Transportation
- Energy
- Expertise

Setting the Stage

- Transportation effects are non-trivial



 Python Maps

Library of Congress

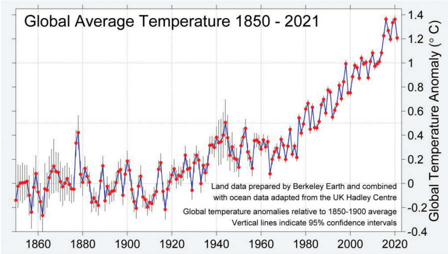
Setting the Stage

- Imagine a world without concrete
  - Buildings
  - Services
  - Transportation

Setting the Stage

So lets keep building!

- But…



Berkeley Earth

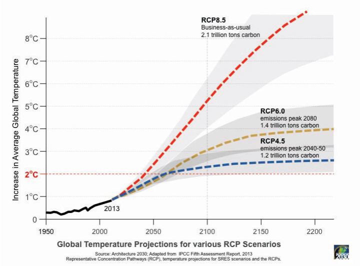
Setting the Stage

We use a lot of concrete

- Concrete impacts the environment
- Changes in environment affects infrastructure needs

Setting the Stage

The conundrum then is: how do we deliver/maintain the infrastructure without hurting the planet?

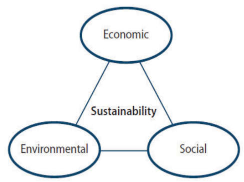


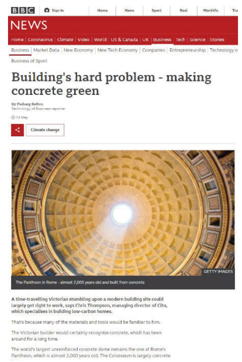
https://architecture2030.org/ipcc_analysis/

Setting the Stage

A Balancing Act

- Economics still rule
- It's more than carbon, but…

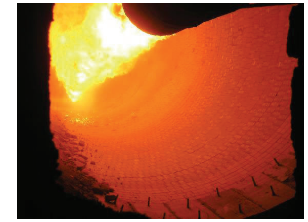




BBC

Where Does the Carbon Come From

- Heat! (about 40%)
  - Cement ingredients heated to ~1400ºC
  - Heat exchangers improve efficiency
  - Alternative fuels



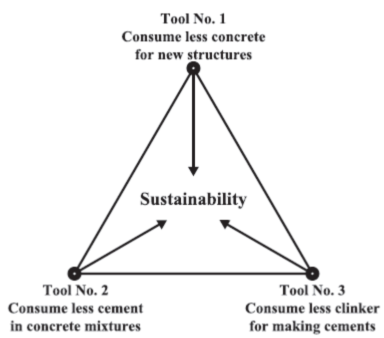
- Chemistry (the rest)
  - $CaCO_3 \rightarrow CaO + CO_2$
  - CaO + other stuff → portland cement
  - Can we use alternative calcium sources?
- Most of the CO_2 footprint is tied to the cementitious system

The Cement Institute

Materials

What can we do?

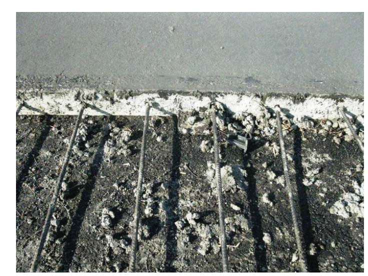
- Use less concrete
- Use less binder in the concrete
- Use less clinker in the binder



Mehta, CI Feb. 2009

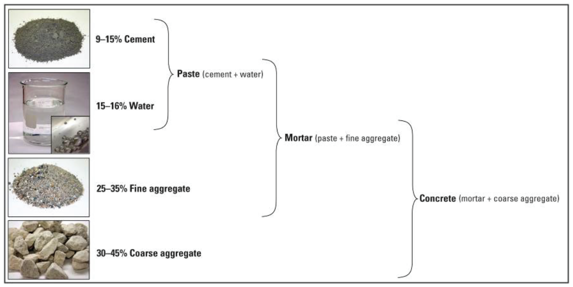
Use Less Concrete in the Structure

- More efficient designs
  - Beware of rules of thumb, and cut-and-paste
  - ME-Design procedure
- Avoid replacing it
  - Longer lasting
  - Use existing equity of older pavements (overlays)



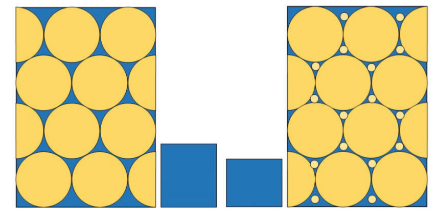
Use Less Binder in the Concrete

- Cementitious binder is about 9-15% by mass of concrete
- Many specifications call out a minimum
  - That may be more than needed



Use Less Binder in the Concrete

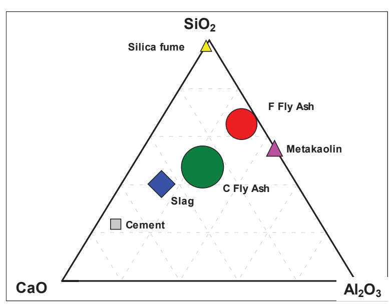
- Minimum required is defined by
  - Enough paste to fill the gaps between the aggregate, plus a bit
  - Aggregate gradation
  - Workability
- Excess can be deleterious
- Performance Engineered Mixtures
  - Some states are reporting cutting binder contents by 30%



Use Less Cement in the Binder

- Supplementary cementitious materials
  - Enhance performance
  - Increase longevity
  - Reduce disposal headaches
  - Ternary combinations

  - What about their carbon footprint?



Use Less Cement in the Binder

- Supplementary cementitious materials
  - Availability locally?
  - Harvested fly ash


TECH BRIEF

Advancing Concrete Pavement Technology Solutions

USE OF HARVESTED FLY ASH IN HIGHWAY INFRASTRUCTURE

Use Less Cement in the Binder

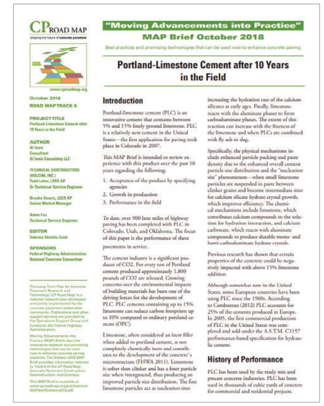
- Other SCMs
  - Recycled Ground Glass, ASTM C1866
  - Locally processed waste products

  - Cost of testing compared with value of product

Use Less Cement in the Binder

- Portland Limestone Cements
  - Up to 15% ground limestone
  - Similar performance

  - Becoming the norm



CP ROAD MAP
shaping the future of concrete pavement

www.cproadmap.org

October 2018
ROAD MAP TRACK 6

PROJECT TITLE
Portland-Limestone Cement after 10 Years in the Field

AUTHOR
Al Innis
Consultant
Al Innis Consulting LLC

TECHNICAL CONTRIBUTORS (HOLCIM, INC.)
Todd Laker, LEED AP
Sr Technical Service Engineer

Brooke Smartz, LEED AP
Senior Market Manager

Adam Fox
Technical Service Engineer

EDITOR
Sabrina Shields-Cook

SPONSORS
Federal Highway Administration
National Concrete Consortium

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by the Federal Highway Administration.

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The October 2018 MAP Brief provides information relevant to Track 6 of the CP Road Map: Concrete Pavement Construction, Reconstruction, and Overlays.

This MAP Brief is available at www.cproadmap.org/publications/MAPbriefOctober2018.pdf.

"Moving Advancements into Practice"
MAP Brief October 2018
Best practices and promising technologies that can be used now to enhance concrete paving

Portland-Limestone Cement after 10 Years in the Field

Introduction

Portland-limestone cement (PLC) is an innovative cement that contains between 5% and 15% finely ground limestone. PLC is a relatively new cement in the United States—the first application for paving took place in Colorado in 2007.

This MAP Brief is intended to review experience with this product over the past 10 years regarding the following:

1. Acceptance of the product by specifying agencies
2. Growth in production
3. Performance in the field

To date, over 900 lane miles of highway paving has been completed with PLC in Colorado, Utah, and Oklahoma. The focus of this paper is the performance of these pavements in service.

The cement industry is a significant producer of CO2. For every ton of Portland cement produced approximately 1,800 pounds of CO2 are released. Growing concerns over the environmental impacts of building materials has been one of the driving forces for the development of PLC. PLC cements containing up to 15% limestone can reduce carbon footprints up to 10% compared to ordinary portland cement (OPC).

Limestone, often considered an inert filler when added to portland cement, is not completely chemically inert and contributes to the development of the concrete's microstructure (FHWA 2011). Limestone is softer than clinker and has a finer particle size when interground, thus producing an improved particle size distribution. The fine limestone particles act as nucleation sites increasing the hydration rate of the calcium silicates at early ages. Finally, limestone reacts with the aluminate phases to form carboaluminate phases. The extent of this reaction can increase with the fineness of the limestone and when PLCs are combined with fly ash or slag.

Specifically, the physical mechanisms include enhanced particle packing and paste density due to the enhanced overall cement particle size distribution and the "nucleation site" phenomenon—when small limestone particles are suspended in paste between clinker grains and become intermediate sites for calcium silicate hydrate crystal growth, which improves efficiency. The chemical mechanisms include limestone, which contributes calcium compounds to the solution for hydration interaction, and calcium carbonate, which reacts with aluminate compounds to produce durable mono- and hemi-carboaluminate hydrate crystals.

Previous research has shown that certain properties of the concrete could be negatively impacted with above 15% limestone addition.

Although somewhat new in the United States, some European countries have been using PLC since the 1960s. According to Cembureau (2012) PLC accounts for 25% of the cements produced in Europe. In 2005, the first commercial production of PLC in the United States was completed and sold under the A.S.T.M. C1157 performance-based specification for hydraulic cement.

History of Performance

PLC has been used by the ready mix and precast concrete industries. PLC has been used in thousands of cubic yards of concrete for commercial and residential projects.

Reduce Carbon Footprint of Cement

- PCA has a plan…

PRODUCTION: AT THE CEMENT PLANT	
Replace raw materials with decarbonated materials	Using decarbonated materials eliminates CO_2 emissions from processing traditional raw materials, like limestone.
Use alternative fuels	Replacing traditional fossil fuels with biomass and waste-derived fuels lowers greenhouse gas (GHG) emissions and keeps materials out of landfills.
Continue efficiency improvements	Increasing energy efficiency reduces the amount of CO_2 emitted for each ton of product.
Implement carbon capture, utilization, and storage (CCUS) technology	CCUS directly avoids a significant portion of cement manufacturing emissions.
Promote new cement mixes	Creating new cements using existing and even alternative materials reduces emissions from mining for new materials, while optimizing the amount of clinker used ensures emissions correspond to necessary production.
Increase use of portland-limestone cement (PLC)	As an existing lower-carbon blend, universal acceptance of PLC will reduce clinker consumption and decrease emissions.
CONSTRUCTION: DESIGNING AND BUILDING	
Optimize concrete mixes	Considering the specific needs of the construction project and using only the materials necessary, avoiding excess emissions.
Use renewable fuels	Switching to solar, wind and other renewable sources of energy directly reduces emissions from other energy sources.
Increase the use of recycled materials	Diverting these materials from landfills.
Avoid overdesign and leverage construction technologies	Designing for the specific needs of the construction project reduces unnecessary overproduction and emissions; incorporating just-in-time deliveries.
Educate design and construction community	Improve design and specifications to be more performance oriented which will permit innovation in cement and concrete manufacturing. Encourage the use of advanced technologies to improve structural performance, energy efficiency, resiliency, and carbon sequestration.
EVERYDAY: CONCRETE INFRASTRUCTURE IN USE	
Incentivize energy efficient buildings	Increasing buildings' energy efficiency can cut energy use and resulting emissions from heating and cooling.
Reduce vehicle emissions by improving fuel efficiency	Because of its rigidity, concrete pavements enhance the fuel efficiency of vehicles driving over them, reducing vehicle emissions.
Decreased maintenance	Due to their durability, concrete structures (buildings, pavements, bridges, dams, etc.) last longer and require less frequent maintenance.
Recycling	Concrete in place can be 100% recycled, limiting the use of raw materials and production emissions.
Carbonation	Every exposed concrete surface absorbs CO_2 and over the course of its service life, a building can reabsorb 10% of cement and concrete production emissions.

Use Low-Carbon Cements

- Geopolymer cements / Activated fly ashes
- Calcium sulfo-alumina-cements
- Belite cements
- Other chemistries

- Balancing availability, cost, constructability and longevity…

Use Low-Carbon Cements

- Test sections being planned at MNRoad
  - Assess CO_2 savings
  - Measure performance under traffic
  - 16 sections
    - Control and optimized mixtures
    - Reclaimed fly ashes
    - Geopolymers
    - Carbon injection
    - Innovative SCMs

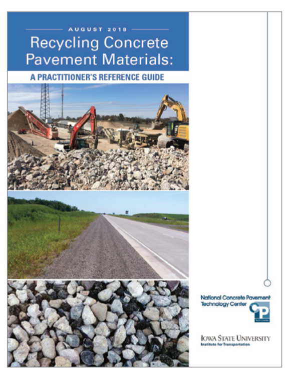
Other Actions

- Recycled Concrete
  - Reduces need for virgin materials
  - Eliminates disposal needs
  - Foundation or in the concrete?
    - Depends on quality needs
  - About 140 Million Tons recycled annually

Recycled Concrete Aggregate

Technical products developed:
- How to engineer RCA applications
- Use RCA in most advantageous way

Coming soon
- Construction by-products
- RCA in pavement mixtures
- Industrial by-products



Cavalline

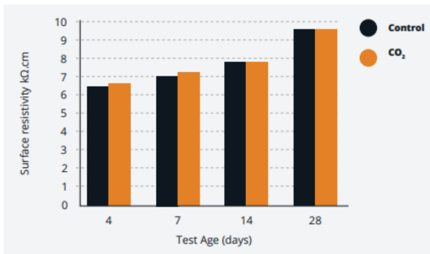
Put the Carbon Back!

Natural carbonation
- Slow
- Dependent on environment
- Can compromise steel protection

- Can be accelerated with grinding

Put the Carbon Back!

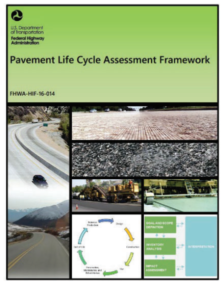
- Inject carbon dioxide into concrete in the mixer
- CO_2 is mineralized then converts to solid $CaCO_3$
- Reported to improve permeability

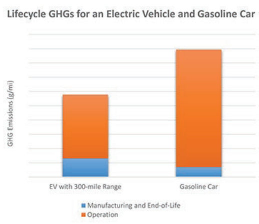


CarbonCure

Measurement

- Life-cycle assessment (LCA)

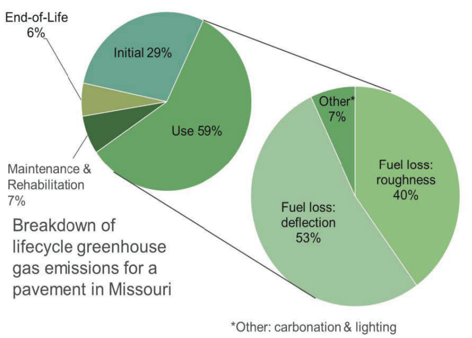




https://www.epa.gov/greenvehicles/electric-vehicle-myths#Myth5

Use Phase

- Fuel consumption
- Care and keeping



MIT CSHub

Measurement

- EPDs are coming

Table 8a. Summary Results (A1-A3): 3001-4000 psi (20.7-27.6 MPa) RMC product mix design, per cubic meter

		Minimum	Maximum	3001-4000-00-FA/SL	3001-4000-20-FA	3001-4000-30-FA	3001-4000-40-FA	3001-4000-30-SL	3001-4000-40-SL	3001-4000-50-SL	6001-8000-50-FA/SL
Core Mandatory Impact Indicators											
GWP	kg CO_2e	261.19	426.75	426.75	365.48	332.37	297.41	327.67	294.65	261.62	261.19
ODP	kg CFC11e	7.84E-06	1.11E-05	1.11E-05	9.56E-06	8.73E-06	7.84E-06	1.01E-05	9.75E-06	9.41E-06	8.49E-06
AP	kg SO_2e	0.99	1.33	1.33	1.17	1.08	0.99	1.28	1.26	1.25	1.12
EP	kg Ne	0.37	0.55	0.55	0.48	0.44	0.40	0.45	0.41	0.38	0.37
POCP	kg O_3e	21.38	28.22	28.22	24.98	23.23	21.38	25.58	24.70	23.82	22.20
ADPf	MJ, NCV	1,522.19	2,229.70	2,229.70	1,921.20	1,754.51	1,578.49	1,850.63	1,724.28	1,597.92	1,522.19
ADPe	kg Sbe	2.44E-04	3.69E-04	3.69E-04	3.25E-04	3.02E-04	2.77E-04	2.94E-04	2.69E-04	2.44E-04	2.46E-04
FFD	MJ Surplus	143.16	180.58	180.58	162.85	153.28	143.16	172.58	169.91	167.24	154.43

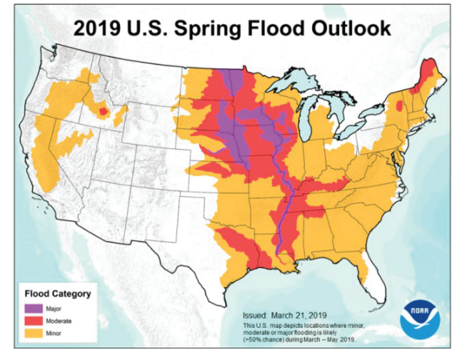
NRMCA

Construction

- Haul distance
- Delays
  - Traffic
  - Safety
- Disturbance
  - Noise
  - Dust
  - Access

Other Factors

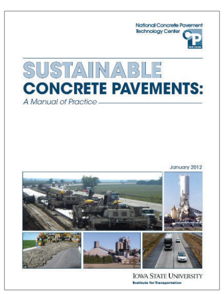
- Resilience
- Albedo (heat island)
- Lighting
- TiO2

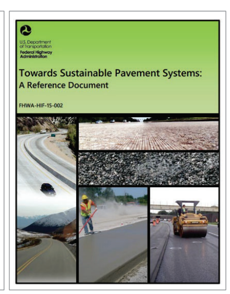


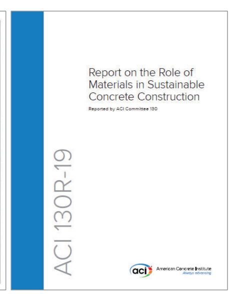
NOAA

So

- This is not new







So

- Change is inevitable
- Change has happened
- Incremental change will help - Is that enough?
- What next?

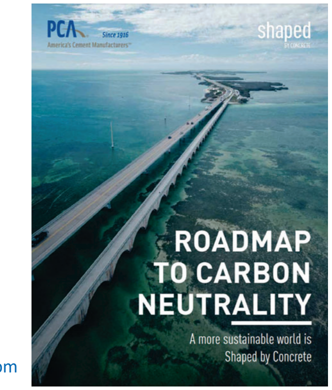

National Concrete Pavement
Technology Center
Tech Center
Iowa State
University
Institute for
Transportation

Increasing Concrete Pavement Sustainability while Improving Durability: Colorado's Experience

Angela Folkestad, P.E.
CO/WY Chapter – American Concrete Pavement Association

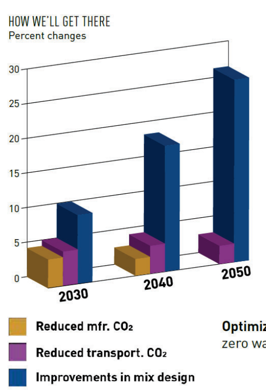
Stages of Opportunities for Reducing GHG Emissions & Increasing Sustainability

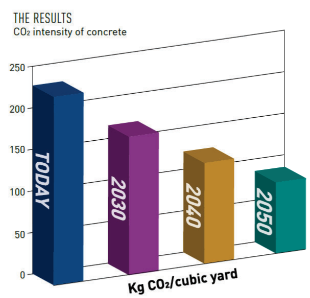
- Before Construction
- During Construction
- After Construction



ShapedByConcrete.com

Optimizing Concrete: Pushing Performance





Optimized concrete: Efficient manufacturing and transportation, zero waste, optimized mixtures engineered for peak performance

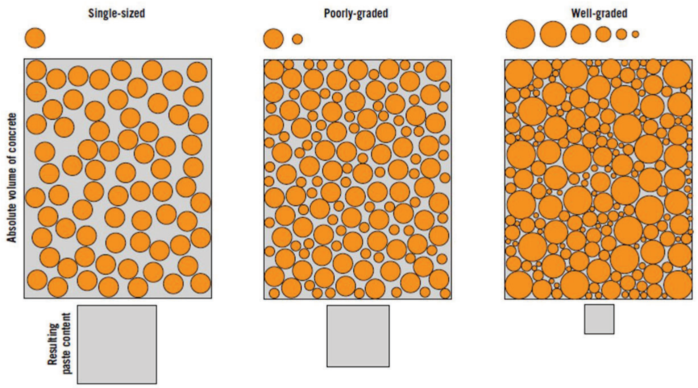
Source: PCA's Roadmap to Carbon Neutrality

Reducing Emissions Before & During Construction

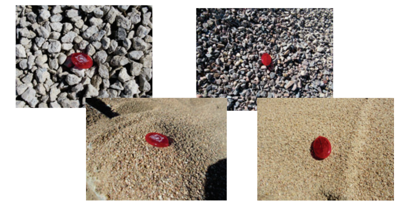
- Pavement Design
- Materials Selection and Mixture Design Specifications
  - Aggregates
    - Multiple gradations
    - Recycled concrete
  - Cementitious Materials
    - Portland Limestone Cement (PLC), or Type IL
    - Supplementary cementitious materials

Most common target of discussion based on cement's reputation as a large producer of greenhouse gas emissions

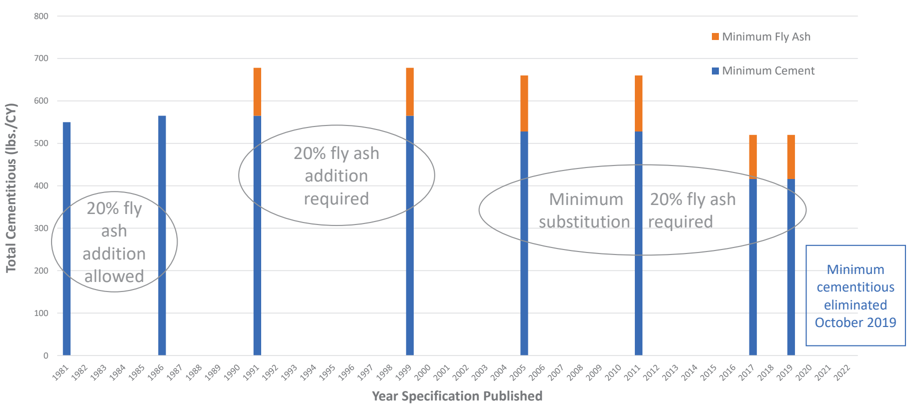
Optimized Gradations



Additional Aggregate Bins



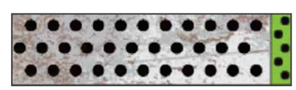
CDOT Concrete Pavement Minimum Cementitious Contents



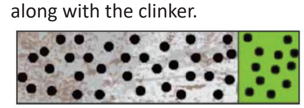
Portland Limestone Cement (PLC) – AKA Type IL

Blended cement with higher limestone content & average reduction in carbon footprint of 10%
www.greenercement.com

Portland cement can contain up to 5% limestone along with the clinker



Portland-limestone cement can contain from 5% to 15% limestone along with the clinker.



If all cement used in the U.S. in 2019 had been converted to PLC (Type IL), it would have reduced CO_2 emissions by 8.1 million metric tons, which the U.S. EPA says is the equivalent of taking 1.75 million cars off the road for an entire year.

Why Portland Limestone Cement (PLC)?

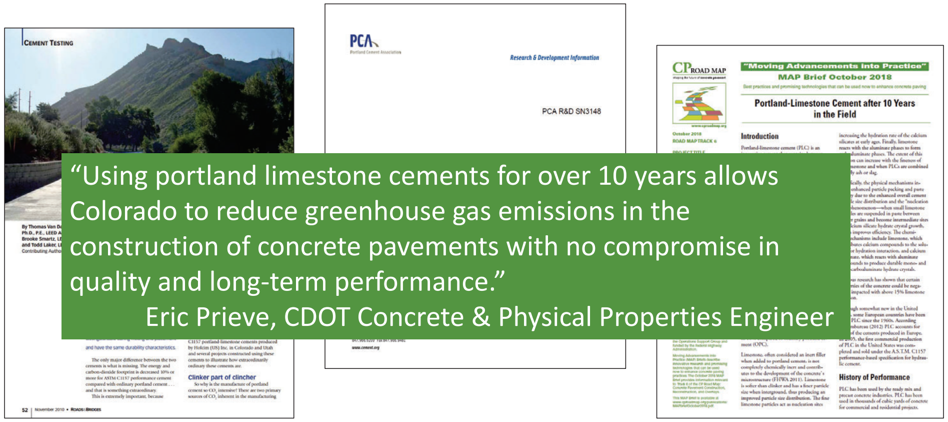
- Producing PLC reduces amount of cement clinker needed per ton
  - Reduces carbon footprint of cement/concrete
  - Every 10 tons of PLC produced reduces CO_2 emissions by approximately 1 ton compared to OPC
  - Reduces the amount of energy required per ton of cement
- Producing PLC increases cement plant capacity
  - Varies from plant to plant depending on clinker capacity vs. mill capacity
- Designed to perform the same as Ordinary Portland Cement (OPC)
  - Water demand may be slightly higher due to fineness
  - Early strengths may be higher
  - Set time should be equal
  - Color is slightly lighter

CDOT Specifications – PLC allowed since 2008

- ASTM C1157 GU used initially
- ASTM C595 Type IL introduced in fall 2014

1st CDOT Paving Project w/ PLC
US 287 (Ports to Plains route) in eastern CO

Documenting PLC Testing, Use & Performance



"Using portland limestone cements for over 10 years allows Colorado to reduce greenhouse gas emissions in the construction of concrete pavements with no compromise in quality and long-term performance."
Eric Prieve, CDOT Concrete & Physical Properties Engineer

1st CDOT PLC Project @ 11 years old (2019)

1,500 Lane-Miles of Concrete Pavement w/ PLC

US 36
Denver to Boulder

C-470 – SW Denver

Pena Blvd – Access to DEN

On-Site Aggregate Mining & Concrete Batching

Dramatically reduces truck trips & related emissions

Onsite Concrete Batch Plant & Recycled Concrete Aggregate (RCA)

Recycled Concrete Aggregate (RCA)

Recycled Aggregate Base

Concrete Mix Specifications: Use Performance Engineered Mixtures (PEM)

- Optimized gradations – reduces paste content (and cement)
- Recycled concrete
  - Aggregate in new concrete
  - Base material
- Allow for Portland Limestone Cement (PLC) – aka Type IL
- Require use of supplementary cementitious materials
  - Fly ash – byproduct of coal fired power production
  - Slag cement – byproduct of steel production
- Include permeability testing

Specification References

- Colorado DOT: https://www.codot.gov/business/designsupport/cdot-construction-specifications/2021-construction-specifications/2021-specs-book
  - Section 412 – Concrete Pavement
  - Section 601 – Structural Concrete (Class P is for Pavement)

- Municipal Government Pavement Engineers Council: http://www.mgpec.org/mgpec-specifications.html
  - Item 30 – Portland Cement Concrete Materials

Environmental Product Declarations (EPDs) Why are we talking about them in CO?

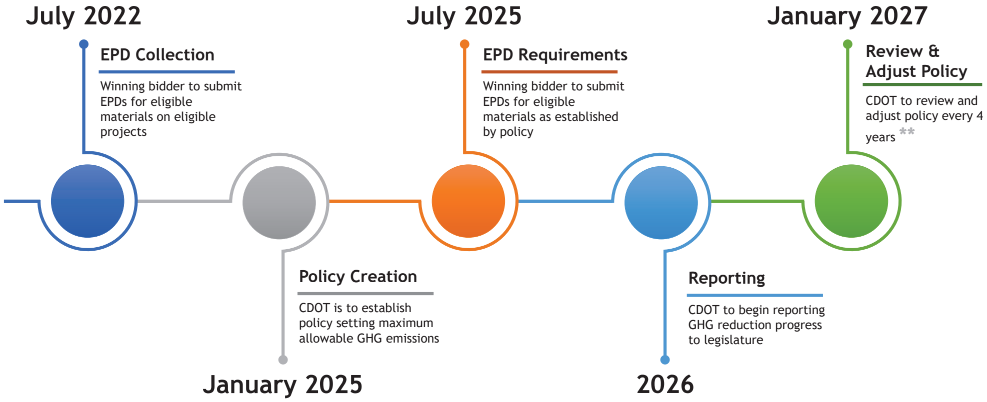
- HB 21-1303 signed & incorporated into C.R.S. 24-92 in July ’21
  - 24-92-117 – Office of the State Architect
  - 24-92-118 – Colorado Department of Transportation

- Requires CDOT to begin collecting EPDs per ISO 14025 on eligible projects for certain eligible materials

- CDOT must use collected EPDs to develop a policy establishing maximum Greenhouse Gas emissions for each eligible material

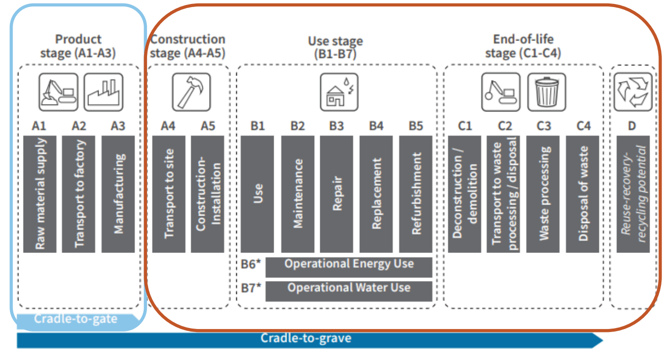
- CDOT working out details of exceptions to EPD submittal - will be outlined in the final “Buy Clean Colorado” Specification.

HB 21-1303 Timeline



Source: Colorado Department of Transportation

EPDs Measure Cradle to Gate Impacts



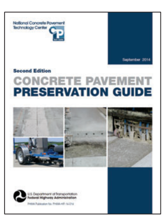
*Operational carbon stages that are typically excluded from life cycle assessments focused on embodied carbon.

Figure 1. Life cycle stages for building products, based on EN 15978:2011 and ISO 21930:2017.

Graphic Source: Carbon Leadership Forum (CLF)

Substantial portion of impacts are not captured through EPDs

Reducing Gate to Grave Impacts

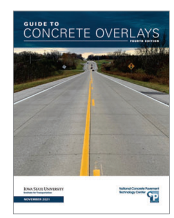


Pavement preservation/restoration

- Extend life of pavement
- Minimize disruption & maximize resource efficiency w/ negligible resource extraction
- Utilize numerous techniques including diamond grinding




Reducing Gate to Grave Impacts



Concrete overlays as preservation

- Resource efficient & eliminates disposal
- Cost effective & quick to construct
- Long life



Thank You!

Dr. Peter Taylor, P.E., FACI
Concrete Pavement Tech Center
ptaylor@iastate.edu

Angela Folkestad, P.E.
CO/WY Chapter – ACPA
afolkestad@pavement.com