Sustainability and Carbon Reduction in Iowa Concrete Pavements

National Concrete Pavement Technology Center
Iowa's Lunch Hour Workshop
In cooperation with the Iowa DOT & the Iowa Concrete Paving Association

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center

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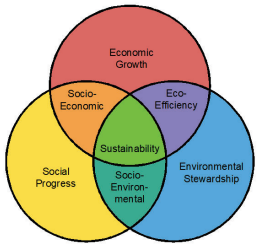
Road Map

- Sustainability and Concrete Pavements
- Reducing Concrete's Carbon Footprint
- Sustainable Practices in Iowa Today
- Future of Sustainable Concrete Pavements

Sustainability and Concrete Pavements

What is Sustainability?

- "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
- Categories
  - Economic
  - Environmental
  - Social



Why Concrete Sustainability?

- Not new – raises bar for good engineering
  - Fly ash, etc.
- Demand by Public, FHWA, DOT
- Concrete is most-used building material because of versatility, economy, local availability, and longevity
- Emphasize technologies that increase pavement life and reduce energy intensive or environmentally damaging materials

TechBrief

APRIL 2016 FHWA-HIF-16-013

STRATEGIES FOR IMPROVING SUSTAINABILITY OF CONCRETE PAVEMENTS

ABSTRACT

This Tech Brief summarizes guidance to the pavement community on sustainability considerations for concrete pavement systems, as presented in greater detail in the recently published *Towards Sustainable Pavement Systems: A Reference Document* (FHWA 2015). Sustainability considerations throughout the entire pavement life cycle are examined (from material extraction and processing through the design, construction, use, maintenance/rehabilitation, and end-of-life phases) and the importance of recognizing context sensitivity and assessing trade-offs in developing sustainable solutions is emphasized.

This Tech Brief focuses exclusively on sustainability considerations associated with concrete-surfaced pavement structures and the materials used in their construction. For the purposes of this document, all permanent surfaces constructed with hydraulic cement concrete are generically referred to as "concrete" pavements.

The primary audience for this document is practitioners doing work within and for government transportation agencies, and it is intended for designers, maintenance, material and construction engineers, inspectors, and planners who are responsible for the design, construction and preservation of the nation's highway network.

INTRODUCTION

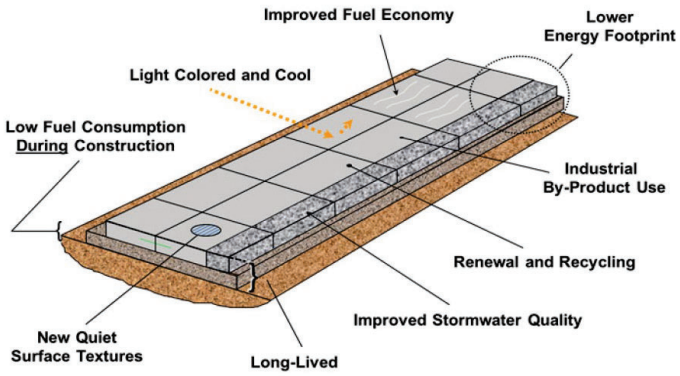
An increasing number of agencies, companies, organizations, institutes, and governing bodies are embracing principles of sustainability in managing their assets and conducting their business. Sustainability considerations are the overarching goal of considering four environmental, social, and economic factors in the decision-making process. Sustainability considerations are not new and, in fact, have often been considered indirectly or informally. In recent years, significant efforts have been made to quantify sustainability effects and to incorporate more sustainable practices in a systematic and organized manner.

A companion Tech Brief (FHWA 2016) presents a summary of the application of sustainability concepts to pavements. It provides an introduction to these concepts and how they are applied as best practices in the industry, focusing on current and emerging technologies and trends.

A sustainable pavement is one that achieves its specific engineering goals, while, on a broader scale, (1) meets basic human needs, (2) uses resources effectively, and (3) preserves/restores surrounding ecosystems. Sustainability is context sensitive and thus, the approach taken is not universal, but rather depends on the specific circumstances and needs. The ultimate sustainability goal as defined here is not yet fully achievable. Today it is an aspirational goal to be worked towards, and ultimately achieved at some point in the future as sustainability best practices continue to evolve.

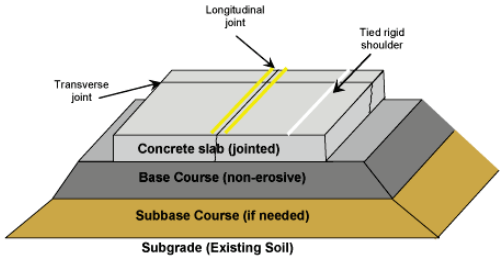
https://www.fhwa.dot.gov/pavement/sustainability/hif16013.pdf

Sustainable Concrete Pavement Features



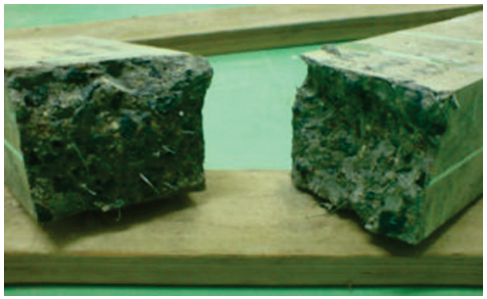
Sustainable Concrete Pavement Design

- More efficient designs
  - Avoid cut-and-paste
  - ME-Design procedure
  - Avoid replacing it
    - Longer lasting
    - Use existing equity of older pavements



Sustainable Concrete Pavement Materials

- Use of local materials
- Beneficial reuse of industrial materials
  - Fly ash & slag
- Enhanced durability



Durability and Concrete Pavement Sustainability

- Environmental savings of long-life pavements
  - Less frequent reconstruction
  - Less consumption of raw materials
  - Less energy in the use phase

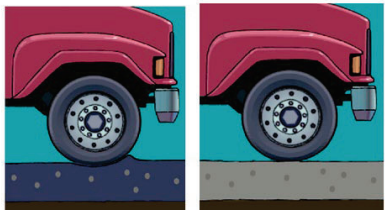
I-80 Adair Co. Built 1979 – Diamond Grind 2020

Concrete Pavement Sustainability in the Use Phase

- Traffic using the pavement has the biggest impact on the environment
  - The "use phase"
- Pavement type has a significant effect on environmental impact over the life cycle

Concrete Pavements and Fuel Consumption

- Rigid surface = lower deflection
- In-depth study by NRC Canada[1]
  - Reduction in fuel consumption for trucks of 0.8% to 6.9%
- Modeling by MIT found similar results[2]
- Further study on I-95 in Florida[3]
  - Fuel consumption reduced 3.2% to 4.5%

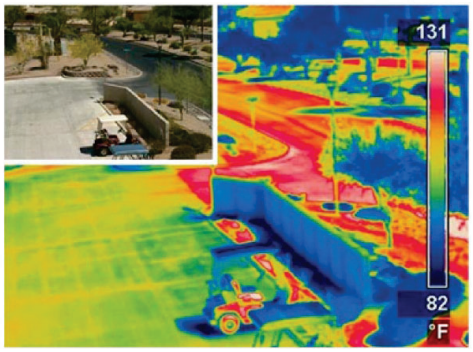


[1]https://hvttforum.org/wp-content/uploads/2019/11/Effects-of-Pavement-Structure-on-Vehicle-Fuel-Efficiency-Taylor.pdf

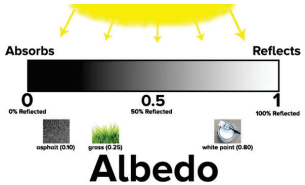
[2]https://news.mit.edu/2020/stiffer-roadways-improve-truck-efficiency-emissions-0611

[3]https://cshub.mit.edu/sites/default/files/documents/Comparison%20of%20Fuel%20Consumption%20on%20Rigid%20versus%20Flexible%20Pavements%20072713....pdf

Concrete Pavements and Albedo/Reflectance



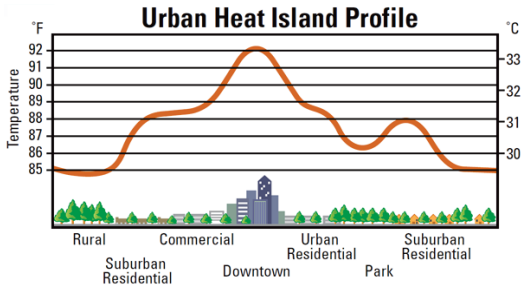
- Lighter, more reflective surface
  - Increased visibility
  - Reduced lighting demand
  - Mitigation of urban heat island effects[1]



[1]https://www.sciencefriday.com/educational-resources/the-albedo-effect-urban-heat-islands-and-cooling-down-your-playground/

Concrete Pavements and the Urban Heat Island

- MIT study of Boston and Phoenix published in 2021[1]
- Cool pavement strategies could offset greenhouse gas (GHG) emissions by
  - 1.0 to 3.0% in Boston
  - 0.7 to 6.0% in Phoenix
- Reduced demand for A/C and generation of electricity



[1]https://pubs.acs.org/doi/full/10.1021/acs.est.1c00664#

Reducing Concrete's Carbon Footprint

Reducing Concrete's Carbon Footprint

- The concrete and cement industries around the world are working to reduce their CO_2 emissions and carbon footprint

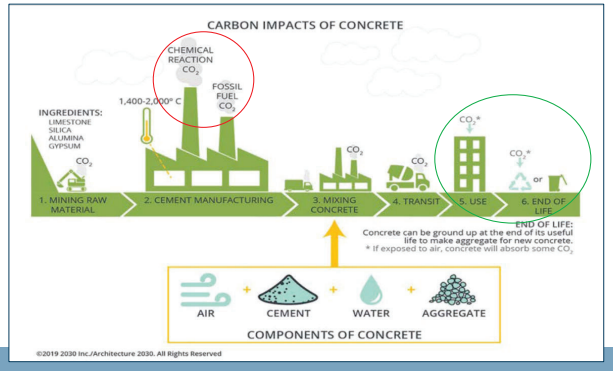


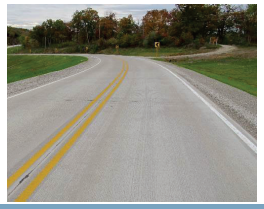
Image: Heidelberg Cement

Clinker – Portland Cement – Concrete

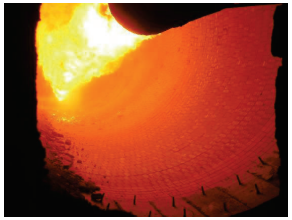
- Cement clinker produced from burning limestone, clay, etc

- Portland cement is ground clinker

- Concrete is mass of aggregates bound w Portland Cement



Where Does the Carbon Come From?



- Heat! (about 40%)
  - Cement ingredients heated to ~1400ºC
  - Dry processing reduces energy needed
  - 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

How to Reduce Concrete's Carbon Footprint

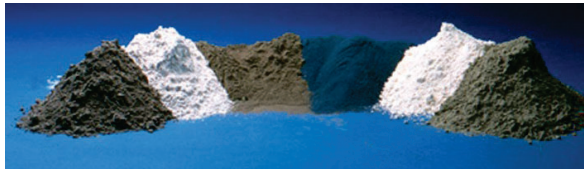
- Reduce or capture CO_2 emissions from clinker and Portland cement production
- Use blended cements to reduce the amount of clinker in cements
- Use SCMs to reduce the amount of Portland cement in the cementitious blend
- Optimize mix designs to reduce the total amount of cementitious material in the mix while still getting strength and durability
- Reduce emissions from concrete production and construction
- Big picture goal: carbon neutral concrete by **2050**

Cement Clinker

- Modern cement plants more efficient
- Efficiency at plant
  - Preheaters
  - Shorter kiln
- Alternative fuels
- Use of alternative materials

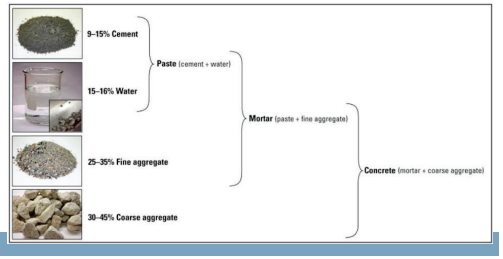
Portland Cement

- Clinker is ground with gypsum to produce Portland cement
- Blended cements (IS, IP & IL) increase cement supply per ton of clinker
  - IS = slag, IP = pozzolans (fly ash), IL = limestone
  - We have used Type IS & IP cements since 1995 in Iowa
  - Type IL is in the process of becoming the new standard cement today



Methods for Sustainable Concrete Pavement

- Portland Cement ~10-12% of Concrete Volume
- Reduce Cement Content in Pavement
  - Enough paste to fill the gaps between the aggregate, plus a bit for workability
  - PEM, well graded aggregate
- Reduce Portland Cement in Binder
  - Use of SCM's
  - Type IP & IS cement
  - Type IL Cement

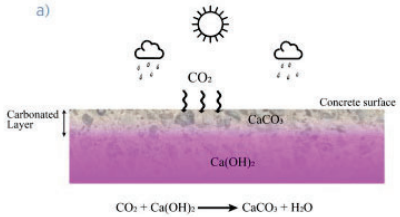


Carbonation and CO_2 Absorption

- CO_2 in the atmosphere reacts with $Ca(OH)_2$ in concrete to produce calcium carbonate ($CaCO_3$)
- In US, concrete pavements can absorb about 5.8 million tons of CO_2 over the next 30 years[1]
  - Helps offset CO_2 emitted during production of cement[2]
  - Could help even more if crushed and re-used at end of pavement life

[1]https://cshub.mit.edu/sites/default/files/images/0120%20Carbon%20Uptake%20Brief.pdf

[2]https://news.mit.edu/2021/unravelling-carbon-uptake-concrete-pavements-0126



Sustainable Practices in Iowa Today

Iowa's History of Sustainable Concrete Practices

- 1984 – Fly ash used to reduce Portland cement 15% by weight
- 1995 – Blended cements approved: Type IP and IS
- 1995 – Approved use of slag as Portland cement replacement
- 1999 – Introduction of well-graded mixes into QM-C spec (Shilstone Chart)
- 2013 – Approved use of Type IL Blended cements – Two Sources Approved
  - 2021 – Approved several more sources.
- 2018 – Performance Engineered Mix (PEM) design and testing
  - National pooled fund study headed by National CP Tech Center
- 2021 - CarbonCure – Two ready mix plants Iowa City and Des Moines
  - Inject CO2 into concrete mix
  - Reduce Portland cement by 3%

Sustainable Practices in Iowa Today

- Big picture goal: carbon neutral concrete by **2050**
- What new is happening in Iowa today?
  - Optimizing cement content
  - Ternary mixes
  - Type IL cement
  - CarbonCure
  - SCMs

Optimizing Cement Content

- Performance Engineered Mixtures (PEM): designing concrete to survive the environment
  - Concrete durability is the most important design goal
  - Use as much cement as you need for strength, but no more
  - Optimized gradation and cement content: QM-C and C-SUD mixes

West Des Moines (2015)

Optimizing Cement Content

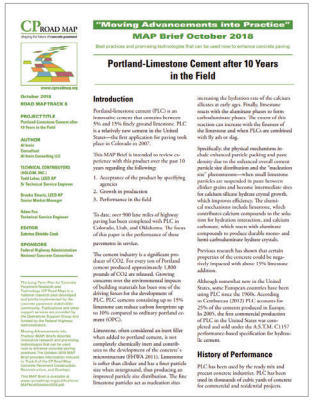
- PEM national pooled fund study led by Iowa
- Utilizing PEM test methods to validate mix design with reduced cement content
- Able to produce workable mix with better smoothness and reduced cement content to 499 lbs/cy
  - A reduction of 60 lbs compared to QM-C and C-SUD mixes

Ternary Mixes

- Ternary Mixes - blended cement + fly ash or Portland cement + fly ash + slag
- Pavements in Iowa: Type IS, IP, & IL
  - Up to 40% replacement of Portland Cement (~224 lbs)
  - >15,000,000 yd2 (>1,000 2 lane miles)
- HPC Structures
  - Up to 50% replacement of Portland Cement (~312 lbs)

Type IL (Portland Limestone Cement)

- Typical Type I/II already has ~5% limestone addition
- Portland Limestone Cements
  - Up to 15% ground limestone
  - Similar performance
  - Will become the normal cement in 2022
- Type IS cements will become Type IT (S20)(L10)
- Reduces carbon footprint of concrete



CP ROAD MAP

"Moving Advancements into Practice"

MAP Brief October 2018

Portland-Limestone Cement after 10 Years in the Field

Introduction

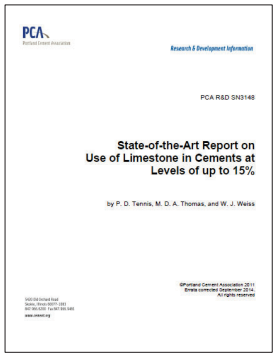
History of Performance

https://intrans.iastate.edu/app/uploads/2019/10/MAPbrief October2018.pdf

Type IL (Portland Limestone Cement)

When limestone is over 15%

- decreased strength & setting time
- increased heat of hydration
- increased permeability
- higher absorption and chloride diffusion
- greater carbonation
- no significant difference in salt scaling as long as similar/proper air void contents are maintained



PCA

Research & Development Information

PCA R&D SN3148

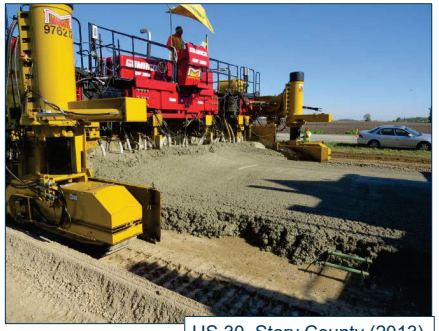
State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%

by P. D. Tennis, M. D. A. Thomas, and W. J. Weiss

Jamie Farny, PCA

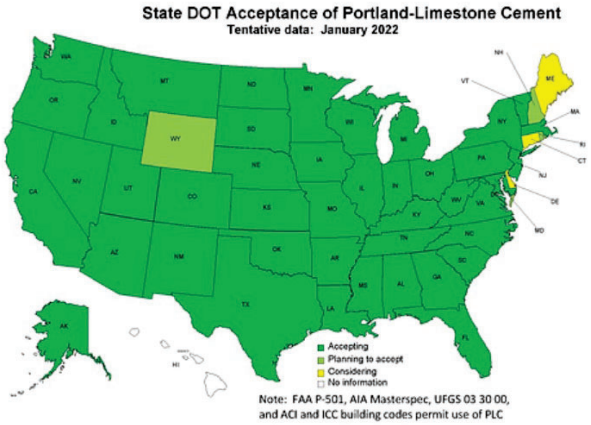
Type IL (Portland Limestone Cement)

- First trials in Iowa were done in 2013
  - Performance was roughly equivalent to standard Type I cement
  - Approved by Iowa DOT since that time
- In 2022, Type IL mixes should become the standard cement available in Iowa (and across most of the U.S.)

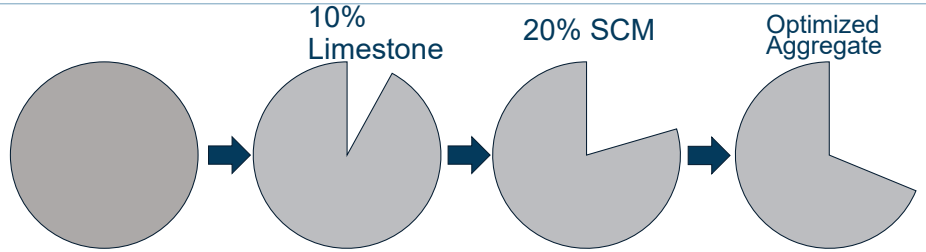


US 30, Story County (2013)

Type IL (Portland Limestone Cement)



Carbon Reduction by Reducing Cement



571 pcy Portland Cement

514 pcy Portland Cement

411 pcy Portland Cement

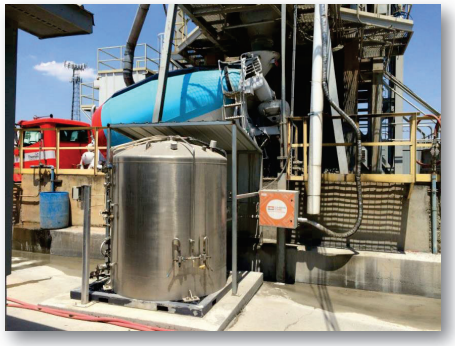
371 pcy Portland Cement

C3WR Mix

35% reduction of Portland cement

Carbon Sequestration and Reduced Cement Content

- CarbonCure system has been implemented in several ready mix plants in Iowa
- Waste CO_2 (12-24 oz per cy) is injected directly into the mix, which immediately mineralizes into solid calcium carbonate ($CaCO_3$)
- Improves concrete strength
  - Allows for 3% reduction in cement content (about 15 lbs/cy)



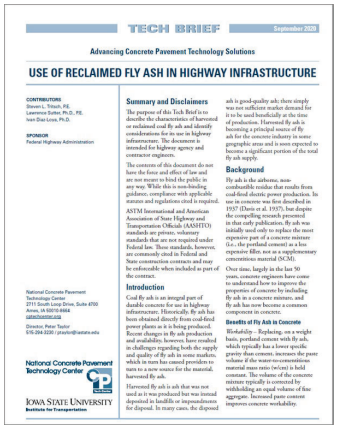
Supplementary Cementitious Materials

- SCMs like fly ash are a time-tested way to…
  - Improve concrete durability
  - Find a use for industrial byproducts
  - Reduce the carbon footprint of concrete
- Retirement of coal fired power plants and conversion to natural gas is poised to reduce fly ash supply

Supplementary Cementitious Materials

- Future – harvested fly ash from landfilled sources

https://intrans.iastate.edu/app/uploads/2020/09/use_of_harvested_fly_ash_TB.pdf



TECH BRIEF September 2020

Advancing Concrete Pavement Technology Solutions

USE OF RECLAIMED FLY ASH IN HIGHWAY INFRASTRUCTURE

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SPONSOR
Federal Highway Administration

Summary and Disclaimers

The purpose of this Tech Brief is to describe the characteristics of harvested or reclaimed coal fly ash and identify considerations for its use in highway infrastructure. The document is intended for highway agency and contractor engineers.

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. While this is non-binding guidance, compliance with applicable statutes and regulations cited is required.

ASTM International and American Association of State Highway and Transportation Officials (AASHTO) standards are private, voluntary standards that are not required under Federal law. These standards, however, are commonly cited in Federal and State construction contracts and may be enforceable when included as part of the contract.

Introduction

Coal fly ash is an integral part of durable concrete for use in highway infrastructure. Historically, fly ash has been obtained directly from coal-fired power plants as it is being produced. Recent changes to fly ash production and availability, however, have resulted in challenges regarding both the supply and quality of fly ash in some markets, which in turn has caused providers to turn to a new source for the material, harvested fly ash.

Harvested fly ash is ash that was not used as it was produced but was instead deposited in landfills or impoundments for disposal. In many cases, the disposed ash is good-quality ash; there simply was not sufficient market demand for it to be used beneficially at the time of production. Harvested fly ash is becoming a principal source of fly ash for the concrete industry in some geographic areas and is soon expected to become a significant portion of the total fly ash supply.

Background

Fly ash is the airborne, non-combustible residue that results from coal-fired electric power production. Its use in concrete was first described in 1937 (Davis et al. 1937), but despite the compelling research presented in that early publication, fly ash was initially used only to replace the most expensive part of a concrete mixture (i.e., the portland cement) as a less expensive filler, not as a supplementary cementitious material (SCM).

Over time, largely in the last 50 years, concrete engineers have come to understand how to improve the properties of concrete by including fly ash in a concrete mixture, and fly ash has now become a common component in concrete.

Benefits of Fly Ash in Concrete

Workability – Replacing, on a weight basis, portland cement with fly ash, which typically has a lower specific gravity than cement, increases the paste volume if the water-to-cementitious material mass ratio (w/cm) is held constant. The volume of the concrete mixture typically is corrected by withholding an equal volume of fine aggregate. Increased paste content improves concrete workability.

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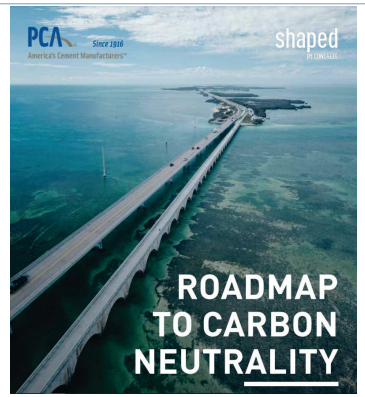
Institute for Transportation

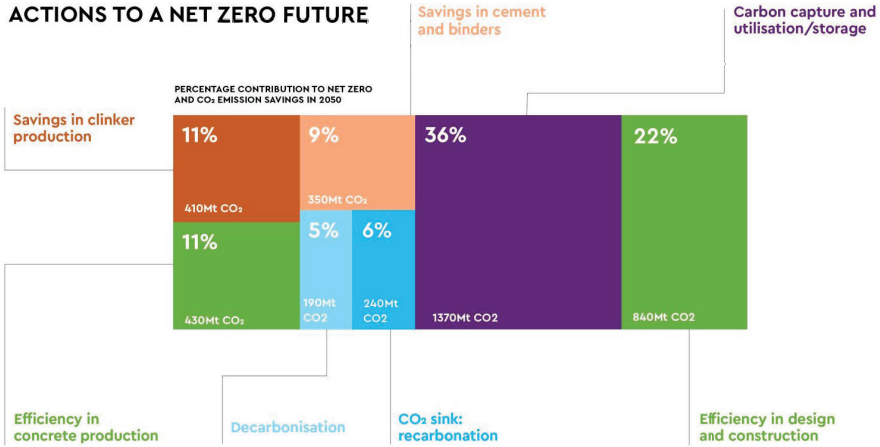
Future of Sustainable Concrete Pavements

Concrete Pavement Sustainability – Future

- Cement companies committed to carbon neutrality by 2050
  - Decarbonated materials
  - Alternate fuels
  - Carbon capture & storage (CCS)
  - Efficiencies
  - New cements



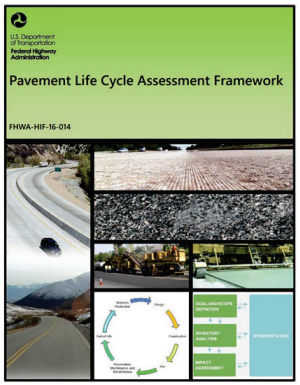
https://www.cement.org/sustainability/roadmap-to-carbon-neutrality



- https://gccassociation.org/concretefuture/

Assessing Pavement Sustainability

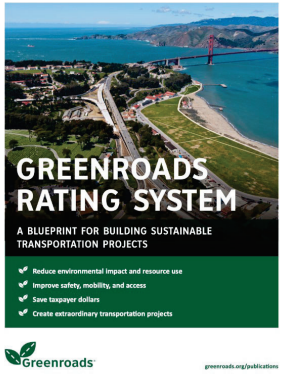
- Economic impacts are often assessed separately through life-cycle cost analysis (LCCA).
- Environmental impacts can be examined through a life-cycle assessment (LCA)



https://www.fhwa.dot.gov/pavement/sustainability/hif16014.pdf

Measuring Pavement Sustainability

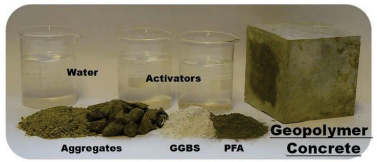
- Greenroads rating system
- Environmental Product Declarations (EPDs)
  - Communicates the environmental performance or impact of any product or material over its lifetime.



https://www.greenroads.org/

Low-Carbon Cements

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



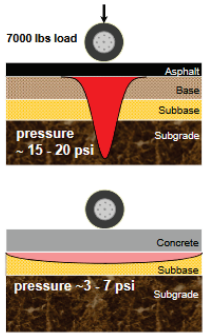
- Balancing cost, constructability and longevity…

Low-Carbon Cements

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

Resilience

- A resilient pavement system is sustainable
  - Reduced waste – if not damaged or destroyed, it does not need to be replaced or rehabilitated
- Flooding has major impacts on pavement foundations
  - Inundation of subgrade and subbase layers reduces strength
  - Concrete pavements are not as sensitive to underlying layer stiffness[1]



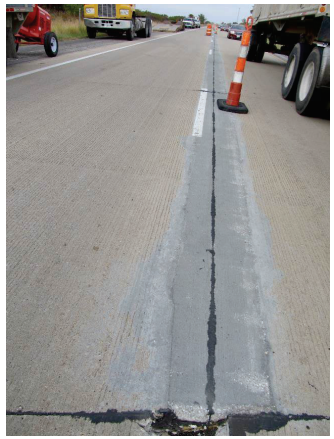
[1]https://intrans.iastate.edu/app/uploads/sites/7/2020/09/2Mack-Resilency_handout.pdf

Resilience

- I-680 Pottawattamie County
  - Missouri River flooding
- Concrete pavement with Flexamat shouldering increased resiliency
- Opened within two weeks after flooding again

Concrete Pavement Sustainability – Renewal

- Preventive maintenance techniques- patching, joint sealing, DBR, and diamond grinding
- Employ right fix at right time to maintain pavement in a good condition
- Cost effective and reduce life cycle environmental impact



Concrete Pavement - Renewability

- Concrete Pavement Restoration
- Diamond Grinding
  - Improve ride and fuel mileage

Concrete Pavement - Renewability

Concrete Overlays
- Use less raw material
- Uses existing structure
- Structural fibers
- Adds structure and improves ride
- Extend life of pavement with less disruption

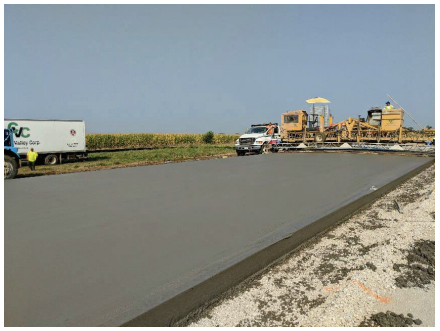
Concrete Pavement Sustainability – End of Life

- Ultimate goal of recycling is to achieve a zero waste stream
- Use all byproduct materials encountered in the rehabilitation or reconstruction of a concrete pavement.
- “Cradle to Cradle” instead of “Cradle to Grave”

Recycling Concrete Pavement Materials: A Practitioner’s Reference Guide (iastate.edu)

Conclusion

- Concrete pavement sustainability in Iowa has been accomplished utilizing fly ash and blended cements for several decades
- QM-C, C-SUD, and new PEM mix designs reduce cement content and improve long term durability
- Cement companies will continue to take measures to reduce CO_2 emissions and produce other blends to lower their carbon footprint



More Information

- https://cptechcenter.org/
- https://www.acpa.org/tag/sustainability/
- https://www.cement.org/sustainability
- https://cshub.mit.edu/

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