Guide for Reducing the Cradle-to-Gate Embodied Carbon Content of Paving Grade Concrete

ACPA and CP Tech Center's Tech Tuesday Webinar

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About the Presenters

Thomas J. Van Dam, Ph.D., P.E., F.ACI joined WJE in 2023 with over 35 years of civil engineering experience, specializing in concrete materials related to pavement and slab design, sustainability, and overall evaluation. His major areas of interest include performance assessment, durability, forensic investigations, and greenhouse gas emission reduction. Dr. Van Dam has worked successfully in academia and the private sector, directing pavement design, materials, and sustainability groups in conducting investigative and research projects for federal agencies, state departments of transportation, local agencies, private industry, and foundations.

In total, Dr. Van Dam has published over 100 technical papers, articles, and reports and is a frequent presenter on concrete materials and sustainability.

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About the Presenters

Robert P. Spragg, Ph.D. is a Concrete Materials Engineer in FHWA's Office of Infrastructure, where he leads the deployment and transfer of innovative technologies in concrete materials and concrete pavements. He has 15 years of experience in the concrete materials topic area, and has delivered a range of successful projects, including durability assessment using resistivity, durability assessment of Ultra-High Performance Concrete, assessment of opening to traffic. Dr. Spragg joins us today talking about Sustainability of Concrete, a topic he has been working on for the last three years.

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Today's Learning Objectives

- Gain a better understanding of why low embodied carbon concrete is of such interest among the concrete pavement stakeholders
- Learn strategies that can be used to reduce the embodied carbon in paving concrete, focused on reducing the use of portland cement
- Understand the use of environmental product declarations (EPDs) in benchmarking and measuring improvement

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Agenda

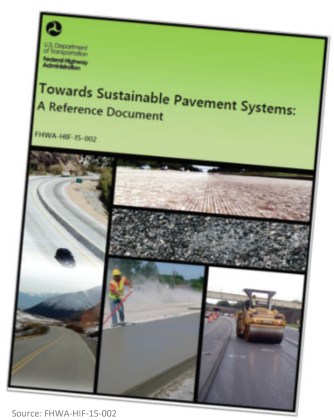
1. Carbon Reduction in the Context of Sustainability
2. Motivation for the *Guide*
3. Background and Scope
4. Strategies for Reducing Cradle-to-Gate Embodied Carbon
5. Quantification
6. Closing Thoughts

"Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

- Our Common Future: Report of the World Commission on Environment and Development (1987)

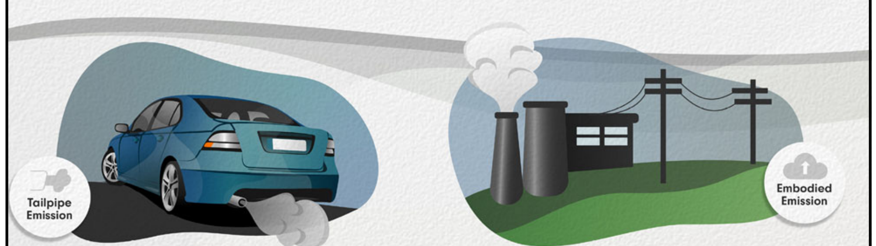
Sustainability and Pavements

- Sustainable pavements achieve the engineering goals for which they were constructed.
- Sustainability is an aspirational goal.
- Sustainability is context sensitive.
- Sustainability pertains to all areas related to pavement and materials.
- Sustainability assessment is an evolving field.



Source: FHWA-HIF-15-002

EMISSIONS FROM HIGHWAY TRANSPORTATION SYSTEMS



What are tailpipe emissions?
Tailpipe emissions are pollutants from exhaust gases discharged from vehicles equipped with an internal combustion engine. Tailpipe emissions incurred during the use stage of the pavement life cycle are considered operational emissions.

What are embodied emissions?
Embodied emissions include emissions from manufacturing, material transport, construction, maintenance, and disposal of transportation infrastructure building materials. Embodied emissions of greenhouse gases (GHG) are also known as embodied carbon.

Source: Emissions from Highway Transportation Systems. (dot.gov)

E.O. 14057 - Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability (Dec. 8, 2021)- link

Sec. 303. Buy Clean.

- Establishes Buy Clean Task Force to:
  - **Identify and prioritize pollutants and materials to be covered under a Buy Clean policy**, considering relevant and available data, including those from Environmental Product Declarations, and consistency with existing requirements.
  - Make recommendations to increase transparency, procedures for auditing **environmental product declarations** and verifying accuracy of reported emissions data.
  - Make recommendations for financial and technical assistance to support domestic manufacturers in enhancing capabilities to **report and reduce embodied emissions**.
  - Make recommendations of pilot programs that **incentivize Federal procurement of construction materials with lower embodied emissions**.

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DOT Initiative - September 15, 2022

"So today, as we work to implement President Biden's historic Bipartisan Infrastructure Law, which will modernize our infrastructure and create good paying jobs across the nation, the U.S. Department of Transportation will launch a Buy Clean Initiative that will assess and address the **embodied carbon emissions** that come from the engineering, design, construction, procurement, maintenance, and disposal of transportation projects."

-- USDOT Secretary Pete Buttigieg

https://www.transportation.gov/priorities/climate-and-sustainability/policy-statement-buy-clean-initiative

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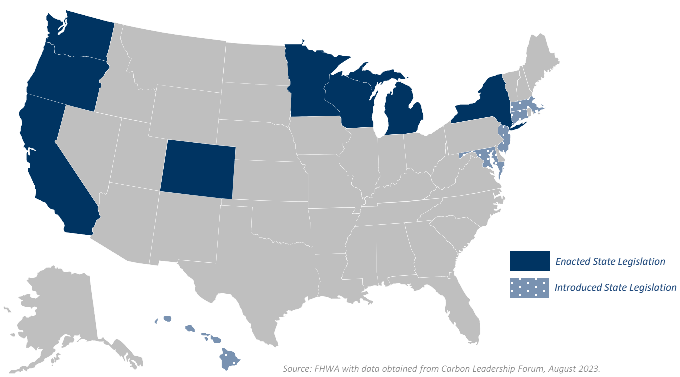
State Initiatives



Source: FHWA with data obtained from Carbon Leadership Forum, August 2023.

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IRA Section 60506 (23 U.S.C. 179)

- Low Carbon Transportation Materials and Products
- Amount: $2 billion to remain available until September 30, 2026.
- Agency: Federal Highway Administration.
- Purpose: To reimburse or provide incentives for the use, in projects, of construction materials and products that have substantially lower levels of embodied greenhouse gas emissions associated with all relevant states of production, use, and disposal as compared to estimated industry averages of similar materials or products, as determined by EPA.

LOW CARBON TRANSPORTATION MATERIALS

https://www.fhwa.dot.gov/lowcarbon/

Why a *Guide*?

Practitioner focused resources.

Context sensitive nature.

Curated list of strategies.

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Curated Strategies:

- **Quantifiable**: Demonstrate with EPD (using PCR that is ISO 14025/21930 conformant).
- **Practical**: An agency needs to be able to use it and incorporate it into their programs.
- **Implementation-Ready**: Needs a defined framework (i.e., more than a laboratory or foundational concept).

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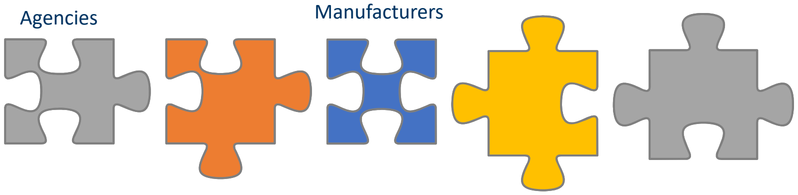
Partnership Approach to Sustainability



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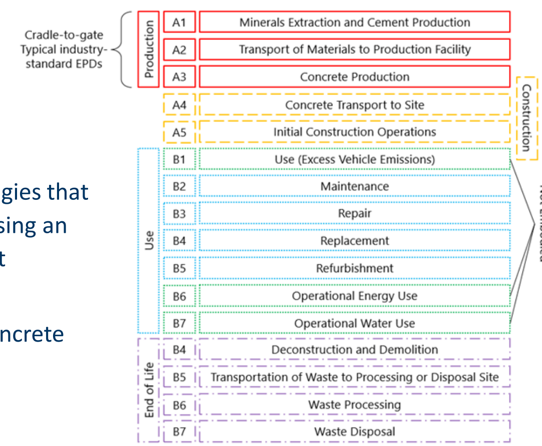
Cradle-to-Gate Embodied Emissions

- Scope limited to strategies that would be quantified using an Environmental Product Declaration (A1-A3).
- Raw Material up to Concrete leaving mixing plant.



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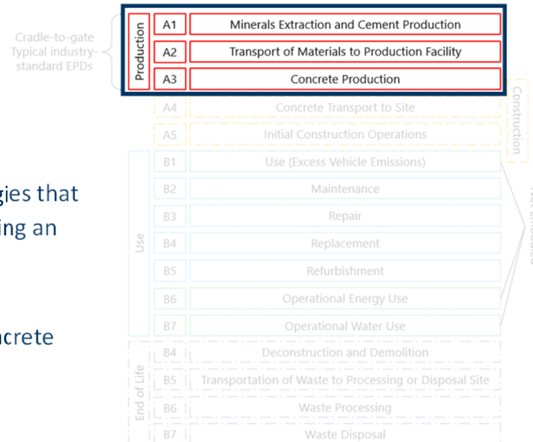

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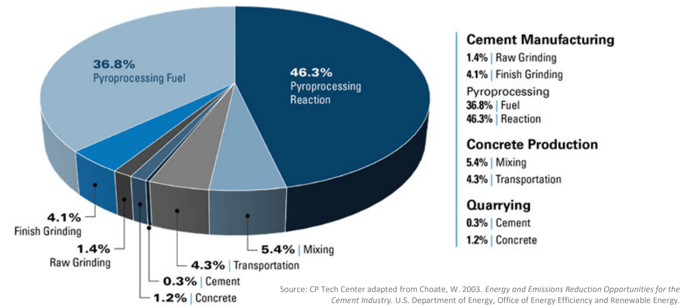
Typical Transportation Concrete



Source: CP Tech Center adapted from Choate, W. 2003. *Energy and Emissions Reduction Opportunities for the Cement Industry.* U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

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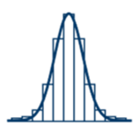
Implementation Considerations

Early Age Properties

Rate of Property Development



Quality Control and Variability

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Achieve Engineering Goals

Low maintenance, low roughness, and maintained stiffness throughout the desired service-life.

Highlights the importance of performance specifications.

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Use of the *Guide*

- 5 pathways that each include a series of strategies.
- Not all strategies work in every situation (context sensitive).
- Each strategy is accompanied by an *Implementation Table.*
- Quantification or Estimation of the Carbon Reduction.

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Agenda

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Part 2:Strategies

- There are 5 strategies presented in the order of their effectiveness in reducing ECC of paving concrete
  - Strategy 1 – Strategies Targeting the Cementitious Binder
  - Strategy 2 – Strategies Targeting Concrete Mixture to Optimize Binder Content
  - Strategy 3 – Reduce the ECC of aggregates
  - Strategy 4 – Strategies Targeting Mixture Performance Requirements
  - Strategy 5 – Other Factors to Consider
- This guide is not established to replace existing methods
  - Will supplement existing practice while reducing ECC

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Strategy 1 – Targeting Cementitious Binder

- Already discussed that portland cement clinker is responsible for almost 90% of the ECC is typical concrete
- Heart of this strategy is replacing portland cement clinker with supplementary cementitious materials (SCMs)
  - All SCMs currently in use have a lower ECC than portland cement
  - Alternative SCMs (ASCMs) that are emerging also have a lower ECC, and some may even have a net negative ECC
- Alternative cementitious materials (ACMs) are also considered.

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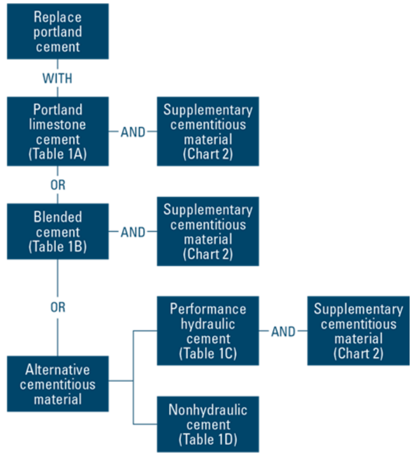
Pathways to Select a Lower ECC Binder

- Multiple pathways identified
  - Primary pathway is to replace portland cement with PLC, other blended cement, or ACM
  - Secondary pathway is to reduce portland cement through additional use of SCMs



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Support for Each Pathway

- Narrative supports use of pathways
- References are provided to available resources to assist users in implementing strategies
- Tables have been prepared for each pathway providing a description, recommendations, implementation steps, and potential barriers

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Table 1A. Summary of Portland Limestone Cement

Technology **Portland Limestone Cement (PLC)**
What is it? Portland limestone cement (PLC) is a hydraulic cement meeting the requirements of AASHTO M 240 (ASTM C595) Type IL. It has less embodied carbon than equivalent AASHTO M 85 (ASTM C150) portland cement as additional limestone is interground with the clinker during manufacturing. PLCs are engineered to replace AASHTO M 85 (ASTM C150) portland in nearly all concrete mixtures and can be used with nearly all types of supplementary cementitious materials (SCMs). PLCs have not demonstrated a statistically significant impact on later-age strength or durability performance compared to similar AASHTO M 85 (ASTM C150) portland cement,
Recommended Action/Dosage Replace AASHTO M 85 (ASTM C150) portland cement with AASHTO M 240 (ASTM C595) Type IL PLC. Changing cement type to PLC requires reverifying concrete mixture properties through trial batching.
Implementation Steps • Ensure AASHTO M 240 (ASTM C595) Type IL is allowed in your cement specifications. • Allow cement producers to submit AASHTO M 240 (ASTM C595) Type IL cements to your approved or qualified products list (APL or QPL). • Encourage contractors to submit trial batches using AASHTO M 240 (ASTM C595) Type IL cements.
Barriers to Implementation • Little to no local availability of AASHTO M 240 (ASTM C595) Type IL cements. • Contractors don't have approved concrete mix design using Type IL cements. • In some applications, construction crews are not familiar with Type IL cements and the reduced rate of bleed water associated with the finer grind.
Expected Impact on Cost AASHTO M 240 (ASTM C595) Type IL cement is reported to be similarly priced to conventional AASHTO M 85 (ASTM C150) portland cement.
References Practice-Ready Papers, FHWA PLC Technote (under development), GreenerCement.org.

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Table 1B. Summary of blended cements — Blended Cements

Table 1C. Summary of Performance Hydraulic Cement — Performance Hydrau

Table 1D. Summary of Non-Hydraulic Inorganic Cements

Technology **Non-Hydraulic Inorganic Cements**
What is it? Non-hydraulic inorganic cements are those that set and hardened due to alkali-activation causing the dissolution of alumino-silica precursors and the initiation of chemical reactions resulting in non-hydrated reaction products. These materials are at times referred to as geopolymers or inorganic polymer cements. The most common alumino-silica precursors include calcined kaolinite clays, low calcium fly ash, and slag cement. Common alkali-activators include sodium hydroxide and sodium silicate solutions of high molarity. These cements often have a low GWP and are highly resistant to many durability problems that can affect portland cement-based systems, such as sulfate attack. As novel materials, they are not readily available in the market and may be difficult to work with.
How does it work? Unlike portland cement-based systems and alkali-activated hydraulic cement, non-hydraulic inorganic cements rely on the formation of three-dimensional polymeric alumino-silicate chain and ring structures. The formation of these structures is rapid and occurs when the precursor materials first undergo dissolution in the highly alkali solution created by the alkali-activators, followed by polymerization. The water in the system is there to facilitate workability and is not part of the reaction products, instead being expelled during curing and subsequent drying. The polymerization reaction is sensitive to ambient temperatures. Conceptually simple, the reactions driving inorganic polymerization are complex and not fully understood. Further, the cements are largely proprietary and only have seen limited use in paving applications.
How would you quantify GWP reduction? Non-hydraulic inorganic cements are likely to have a lower GWP than AASHTO M 85 (ASTM C150) portland cement, depending on the alumino-silica precursor, as would be shown in an EPD. The amount of reduction will depend on the type of precursor materials and alkali-activator. For some applications, the use of non-hydraulic inorganic cement could result in a significant reduction of the GWP for concrete.
Recommended Action/Dosage Although there are some non-hydraulic inorganic cement available in the U.S., for the most part their use has been restricted to specialty applications and there is no known use in the U.S. for a cast-in-place pavement. Further, non-hydraulic inorganic cements are more difficult to work with than portland cement-based systems due to the alkali-activator, the sensitivity to temperature, and the general sensitivity of the system to subtle changes in materials or conditions. Current recommendation are to thoroughly test these materials in the laboratory for performance and robustness prior to construction of demonstration projects as a step to implementation.
Implementation Steps • Currently non-hydraulic inorganic cement suitable for large-scale pavement applications are in the early stages of development and are not ready for implementation. • Conduct robust laboratory testing and construct demonstration products to ensure viability.
Barriers to Implementation • New technology with unknown risks related to constructability and long-term performance. • High alkali activators must be carefully handled during concrete production.
Expected Impact on Cost Low GWP non-hydraulic inorganic cements would be expected to have higher costs than portland cement-based systems. Cost at market introduction would likely be very high with a reduction in cost occurring as market acceptance increases but will remain relatively high.
References Practice-Ready Papers, ACI ITG-10R-18 and ITG-10.1R-18, FHWA-HIF-10-014 (TechBrief: Geopolymer Concrete (dot.gov)).

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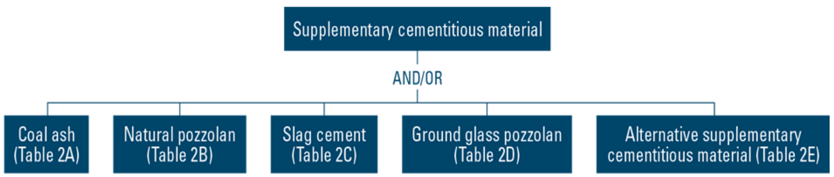
Secondary Pathways Further Defined



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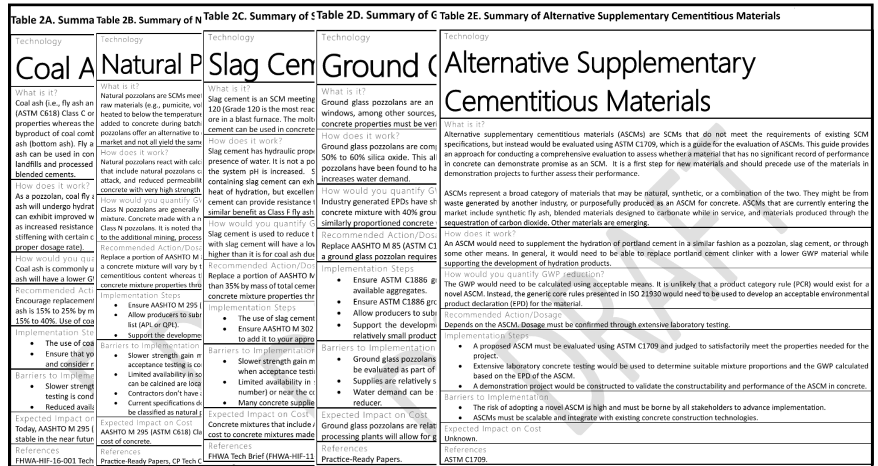


Table 2E. Summary of Alternative Supplementary Cementitious Materials

Technology

Alternative Supplementary Cementitious Materials

What is it?

Alternative supplementary cementitious materials (ASCMs) are SCMs that do not meet the requirements of existing SCM specifications, but instead would be evaluated using ASTM C1709, which is a guide for the evaluation of ASCMs. This guide provides an approach for conducting a comprehensive evaluation to assess whether a material that has no significant record of performance in concrete can demonstrate promise as an SCM. It is a first step for new materials and should precede use of the materials in demonstration projects to further assess their performance.

ASCMs represent a broad category of materials that may be natural, synthetic, or a combination of the two. They might be from waste generated by another industry, or purposefully produced as an ASCM for concrete. ASCMs that are currently entering the market include synthetic fly ash, blended materials designed to carbonate while in service, and materials produced through the sequestration of carbon dioxide. Other materials are emerging.

How does it work?

An ASCM would need to supplement the hydration of portland cement in a similar fashion as a pozzolan, slag cement, or through some other means. In general, it would need to be able to replace portland cement clinker with a lower GWP material while supporting the development of hydration products.

How would you quantify GWP reduction?

The GWP would need to be calculated using acceptable means. It is unlikely that a product category rule (PCR) would exist for a novel ASCM. Instead, the generic core rules presented in ISO 21930 would need to be used to develop an acceptable environmental product declaration (EPD) for the material.

Recommended Action/Dosage

Depends on the ASCM. Dosage must be confirmed through extensive laboratory testing.

Implementation Steps

- A proposed ASCM must be evaluated using ASTM C1709 and judged to satisfactorily meet the properties needed for the project.
- Extensive laboratory concrete testing would be used to determine suitable mixture proportions and the GWP calculated based on the EPD of the ASCM.
- A demonstration project would be constructed to validate the constructability and performance of the ASCM in concrete.

Barriers to Implementation

- The risk of adopting a novel ASCM is high and must be borne by all stakeholders to advance implementation.
- ASCMs must be scalable and integrate with existing concrete construction technologies.

Expected Impact on Cost

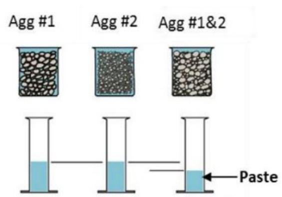
Unknown.

References

ASTM C1709.

Strategy 2 – Concrete Mixture to Optimize Binder Content

- This strategy reduces ECC by reducing total cementitious materials content
  - Accomplished by optimizing aggregate grading
- For the same binder and water-to-binder ratio, reducing total cementitious materials content reduces paste volume
  - Improves hardened concrete properties



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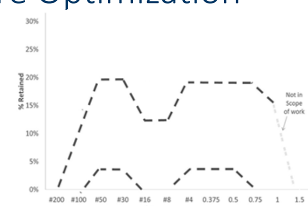
Strategy 2 – Concrete Mixture Optimization

- The key is to reduce paste volume by blending aggregates (often from three or more sources) to minimum void volume
  - Must maintain fresh concrete properties including workability and air content
  - Also achieve harden concrete properties including strength and durability
- Several tools are available including the "Tarantula Curve"



T. Ley and D. Cook 2014

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Table 3. Optimized Aggregate Grading

Technology

Optimized Aggregate Grading

What is it?

Optimized aggregate grading considers the combined aggregate particle size distribution in lieu of focusing solely on the gradation of source aggregates. When the aggregate grading is optimized, a minimum amount of paste is needed to fill the void space that exists between the aggregate particles, separating them slightly and allowing the paste to act as a lubricant to ensure mixture workability. In this way, the paste volume can be reduced while workability and performance are improved.

How does it work?

Using a tool, such as the Tarantula Curve, the percent retained on each standard sieve size for the combined aggregate particle size distribution is optimized to fall within the recommended limits (see Figure 6). There are additional recommendations on the combined percent of coarse sand (#8 through #30 sieve) and fine sand (#30 through #200) for slipformed paving and flowable concrete to ensure workability. The general mix design strategy is to optimize the combined grading of quality aggregates as discussed. Next the cementitious materials are selected to create a durable and low GWP paste that meets engineering needs. The final step is to select the paste volume needed to fill the voids in the aggregate system while providing workability. Spreadsheet tools are available in the references to facilitate this process.

How would you quantify GWP reduction?

GWP reduction is incurred by reducing the overall volume of cementitious materials. Cementitious materials containing portland cement will have a higher GWP than aggregates for a given volume. Therefore, replacing cementitious materials with aggregate will reduce the GWP of the concrete, all other components held equal. A mixture specific EPD will demonstrate this GWP reduction.

Recommended Action

Specifications for slipform paving and flowable concrete should be reviewed and modified, if needed, to consider the optimized aggregate grading. Application of the guidance provided in AASHTO R 101 with regards to development of a concrete mixture proportions should be followed.

Implementation Steps

- Ensure specifications allow the use of combined aggregate grading and optimization.
- Ensure specifications do not have minimum cementitious materials contents that are above what is appropriate for the application and climatic conditions. Some SHAs have set minimum cementitious materials contents for slipform paving concrete with optimized aggregate grading as low as 470 lbs/yd^3.
- In time incentivize, and then require, the use of optimize aggregate grading with reduced cementitious materials contents for paving and flowable concrete.

Barriers to Implementation

- Many SHAs have set minimum cementitious materials content limits that are unnecessarily high and create a barrier to GWP reduction.
- Optimized aggregate grading often requires three or more aggregate sources requiring some concrete producers to obtain additional bins. In urban areas with space limitations, stockpiling additional aggregates may not be feasible.
- Lack of familiarity in proportioning concrete with optimized aggregate grading will need to be overcome.

Expected Impact on Cost

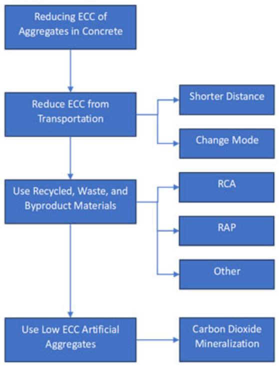
Initially there would likely be a small increase in cost as this strategy is introduced into locations where it is not current practice. In time, it will be cost neutral or even reduce cost of in-place concrete.

References

FHWA-HIF-15-019: https://www.fhwa.dot.gov/pavement/concrete/pubs/hif15019.pdf.
CP Tech Center: https://cptechcenter.org/mix-proportioning/.
Tarantula Curve: http://www.tarantulacurve.com/recommended-specification.html.

Strategy 3 – Reduce the ECC of Aggregates

- In addition to aggregate optimization:
  - Aggregate shape and texture affect water demand, especially for manufactured fine aggregates
  - Aggregates must be durable, being resistant to alkali-aggregate reaction in concrete and not susceptible to freeze-thaw damage
- Considerations to reduce ECC of concrete
  - Reduce emissions when transporting aggregates
  - Use recycled, co-product, and waste materials as aggregate if it makes sense
  - Use low ECC manufactured aggregates



Transportation of Aggregates Matters

Table 5. Estimated national average freight movement fuel efficiency (diesel) and estimated GWP per ton per mile transported of freight transportation modes[25]

Mode	Short Ton-Miles/Gallon Consumed	GWP per short ton per mile travelled (Kg CO_2)[A]
Truck[B]	150	0.0679
Rail	478	0.0213
Inland Barge	616	0.0165

[A] The GWP per ton per mile was calculated based on one gallon of diesel fuel consumed emitting 22.44 lbs (10.18 kg) of $CO_{2\,eq}$.
[B] Truck load assumed to be 25 tons on a 40-ton gross vehicle weight truck, loaded one-way.

Table 4. Aggregate Pathways to Reduce the ECC of Concrete

Technology

Aggregate Pathways to Reduce ECC

What is it?

Although aggregates have a relatively low ECC, because they are the largest component in concrete, they do impact the overall ECC of concrete. The main focus on reducing the ECC of aggregates is to reduce the GWP associated with transportation, using recycled, waste, and byproduct materials in lieu of natural aggregate where it makes sense, and using low ECC artificial aggregates as they become available.

How does it work?

Although the ECC of natural aggregates is relatively low, the shear mass of aggregates used in concrete production means their impact needs to be considered. The transportation of aggregates from source to the point of concrete production is often done by trucks, which is the least efficient and most carbon intensive means of moving materials. If possible, the distance between aggregate source and the concrete plant should be minimized and alternative, more efficient, modes of transportation such as rail and barges used to ship aggregates over longer distances. The use of recycled, waste, and byproduct materials as aggregate can reduce the ECC of concrete, although the impact needs to be assessed on a project level. And emerging low to negative ECC artificial aggregates are being produced through CCUS that may offer opportunities for further carbon reduction in the future.

How would you quantify GWP reduction?

GWP reduction is incurred by replacing aggregates with relatively high ECC with those with lower ECC. The assessment is done at the concrete plant reflecting the GWP incurred due to shipping. A mixture specific EPD will demonstrate this GWP reduction.

Recommended Action

Specifications for slipform paving and flowable concrete should be reviewed to ensure that barriers to the use of quality recycled, waste, and byproduct aggregate materials, as well as artificial aggregates are removed. Incentivizing the use of low ECC concrete, validated through an EPD, will facilitate reducing transportation emissions.

Implementation Steps

- Incentivize the use of low ECC concrete as validated through an EPD.
- Ensure specifications allow the use of quality recycled, waste, and byproduct materials, as well as artificial aggregates.
- Conduct demonstration projects with concrete made with quality recycled, waste, and byproduct aggregate materials, as well as artificial aggregates, as they become available.

Barriers to Implementation

- Little to no local availability of quality aggregates and limited ability to change mode of transportation in some markets.
- Lack of familiarity with concrete made with quality recycled, waste, and byproduct aggregate materials.
- Specification barriers may exist that need to be evaluated.
- Lack of supply and uncertain quality for artificial aggregates.

Expected Impact on Cost

Initially there would likely be a small increase in cost as this strategy is introduced into locations where it is not current practice. In time, it will be cost neutral or even reduce cost of in-place concrete.

References

CP Tech Center: https://intrans.iastate.edu/app/uploads/2018/09/RCA_practioner_guide_w_cvr.pdf.
FHWA-HIF-22-020: https://www.fhwa.dot.gov/pavement/concrete/pubs/hif22020.pdf.

Strategy 4 – Performance Specifications for Concrete Mixtures

- Requirements for concrete should include both ECC targets and performance of concrete over time
- Prescriptive requirements often create barriers to reducing ECC without assurance of long-term performance
  - Prescriptive requirements are rooted in past experiences
    - This is not bad, but does limit the ability to do something new
  - There are often restrictions on cementitious materials types and allowable replacement levels, minimum cementitious materials content requirements, and strength-based milestones to be achieved that are not linked to performance, yet may provide a barrier to reducing ECC
- Adoption of AASHTO R 101 - *Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures* can help

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Pathways Using Performance Specifications

- Narrative and tables to support pathways based on performance specifications
- This is an evolving area of interest and will be a major focus of continuing efforts

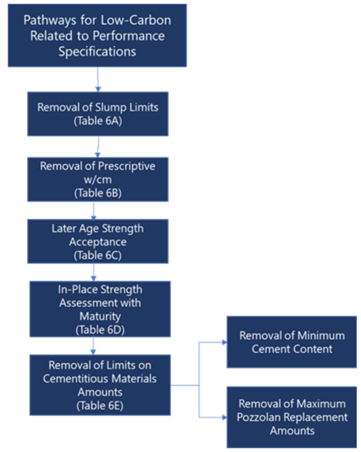

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Table 6. Use of Performance Specification to Reduce the ECC of the Concrete Mixture

Technology **Performance-Specifications**
What is it? Traditional concrete specifications are predominantly prescriptive, meaning the specifications explicitly identifies the materials to be used on the project (e.g., cement type, minimum cementitious materials content, minimum *w/cm*, etc.) as well acceptance criteria. Today's specifications often rely on a limited number of test methods (e.g., slump, total air content, strength., etc.) that often have very little direct correlation to future performance. These specifications have been adequate in the past but tend to limit innovation by making it difficult to introduce new material technologies. Performance specifications define the functional requirement for the project (e.g., structural capacity, durability) and use performance measures that are more directly linked to in-service performance, such as cracking tendency and permeability.
How does it work? AASHTO recently adopted the R 101 *Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures*. This standard practice can be used to guide agencies in adopting performance specification that consider properties of concrete directly linked to workability and long-term performance. Developed for pavement mixtures, elements of this standard practice can be adopted for use with other classes of concrete with little to no changes.
How would you quantify GWP reduction? Adoption of performance-related specifications opens the door to further carbon reduction by eliminating barriers to innovation that exist in prescriptive specifications. This allows consideration of innovative, lower carbon concrete materials that otherwise could not be considered. Quantification of benefit would rely on generating an EPD.
Recommended Action Agencies should review their specifications considering guidance presented in AASHTO R 101, as well as other performance-related specifications. Changes should be made to their specifications to support adoption of performance-related specifications and performance measures.
Implementation Steps • Review existing specifications and add performance-related specifications and associated performance measures. • Ensure specifications allow a broad range of cementitious binders, significantly reduce or eliminate minimum cement content requirements, and adopted optimized aggregate grading. • Move away from strength as sole acceptance requirement and instead look to performance measures linked to durability and long-term service. • Bring in ECC as a goal of mixture proportioning.
Barriers to Implementation • Agencies need to be educated on performance-related specification and performance measurements. • Suppliers may be resistant to change if they perceive that risk is being shifted onto them. • Testing laboratories will need to acquire equipment and qualifications needed to conduct testing that is not currently standard practice.
Expected Impact on Cost Initially there would likely be an increase in cost as local suppliers and testing firms acquire additional equipment and skills. In time, it will likely be cost neutral.
References AASHTO R 101: https://store.transportation.org/Item/PublicationDetail?ID=4993

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Strategy 5 – Other Considerations

- Reduced fuel consumption in production and transportation of concrete
  - Renewal energy grid, optimized plant operations, natural gas fueled trucks, etc.
- Calcium carbonate mineralization in production of concrete
- Other?

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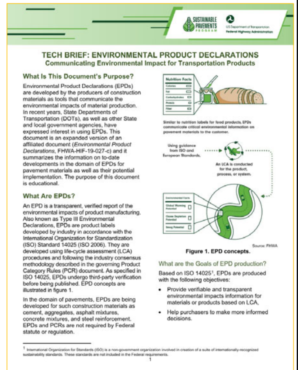
Part 3: Quantification

- Quantify greenhouse gas (GHG) emissions is an essential element in producing low ECC concrete
- The use of an environmental product declaration (EPD) produced in accordance with ISO 14025 is the preferred quanitification tool
- An GHG emission estimating tool is provided for use if an EPD is not yet available



SUSTAINABLE PAVEMENTS PROGRAM
U.S. Department of Transportation Federal Highway Administration

TECH BRIEF: ENVIRONMENTAL PRODUCT DECLARATIONS
Communicating Environmental Impact for Transportation Products

What Is This Document's Purpose?

Environmental Product Declarations (EPDs) are developed by the producers of construction materials as tools that communicate the environmental impacts of material production. In recent years, State Departments of Transportation (DOTs), as well as other State and local government agencies, have expressed interest in using EPDs. This document is an expanded version of an affiliated document (*Environmental Product Declarations*, FHWA-HIF-19-027-c) and it summarizes the information on to-date developments in the domain of EPDs for pavement materials as well as their potential implementation. The purpose of this document is educational.

What Are EPDs?

An EPD is a transparent, verified report of the environmental impacts of product manufacturing. Also known as Type III Environmental Declarations, EPDs are product labels developed by industry in accordance with the International Organization for Standardization (ISO) Standard 14025 (ISO 2006). They are developed using life-cycle assessment (LCA) procedures and following the industry consensus methodology described in the governing Product Category Rules (PCR) document. As specified in ISO 14025, EPDs undergo third-party verification before being published. EPD concepts are illustrated in figure 1.

In the domain of pavements, EPDs are being developed for such construction materials as cement, aggregates, asphalt mixtures, concrete mixtures, and steel reinforcement. EPDs and PCRs are not required by Federal statute or regulation.

Similar to nutrition labels for food products, EPDs communicate critical environmental information on pavement materials to the customer.

Using guidance from ISO and European Standards.

An LCA is conducted for the product, process, or system.

Source: FHWA

Figure 1. EPD concepts.

What are the Goals of EPD production?

Based on ISO 14025[1], EPDs are produced with the following objectives:

- Provide verifiable and transparent environmental impacts information for materials or products based on LCA.
- Help purchasers to make more informed decisions.

[1] International Organization for Standards (ISO) is a non-government organization involved in creation of a suite of internationally-recognized sustainability standards. These standards are not included in the Federal requirements.

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Using This Guide

1. Following Strategy 1, select a lower ECC cement
   - Use higher than normal replacement level of portland cement with SCMs at the concrete plant
   - Replace AASHTO M 85 (ASTM C150) with AASHTO M 240 (ASTM C 595) blended cement
   - Aim to achieve 50% or less total portland cement for the binder
2. Following Strategy 2, reduce total cementitious content through aggregate optimization
   - An example would be to use the "Tarantula Curve" to blend in intermediate aggregates reducing total cementitious materials content from 564 pcy to 500 pcy

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Using This Guide

3. Following Strategy 3, use lower ECC aggregate
   - Use recycled concrete aggregate processed near site instead of transporting virgin aggregate long distance
     - Note that carbon savings needs to be demonstrated through supporting calculations
   - Use a manufactured aggregate produced through carbon sequestration
4. Following Strategy 4, adopt performance specifications that eliminate barriers inherent in prescriptive specifications
   - Move away from minimum cementitious contents and maximum SCM replacement levels
   - Adopt acceptance testing linked directly to performance
5. Following Strategy 5, investigate opportunities that emerge

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Using This Guide

- Quantification of ECC needs to become commonplace
  - Simply business as usual
- In time, this will be extended beyond Stages A1-A3
- In the short-term, it is essential that representative data is collected to create a meaningful benchmark to assess improvement

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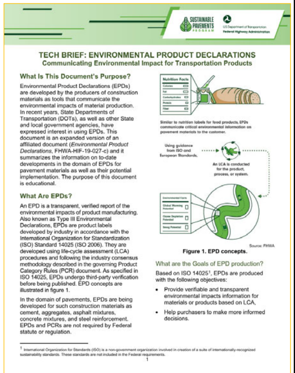
Part 3: Quantification

- Quantify greenhouse gas (GHG) emissions is an essential element in producing low ECC concrete
- The use of an environmental product declaration (EPD) produced in accordance with ISO 14025 is the preferred quanitification tool
- An GHG emission estimating tool is provided for use if an EPD is not yet available



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Part 3: Quantifying

Using EPDs

- Use this when:
  - EPDs are available
  - Making procurement decisions
  - Data will be distributed to a broader audience

Estimating the ECC

- Use this when:
  - Obtaining an initial estimate of a product GWP for internal purposes
  - Performing initial indications of potential GWP savings that may result from changing a mixture design
  - Deciding whether to produce an ISO-conformant EPD
  - As a training and educational tool

When Estimating the ECC:

Table B2. Concrete Constituents Contents and Transportation Details.

	A	B	C	D	E
Mixture Design Parameter	Production Efficiency (kg of CO2-eq/metric ton)	Content (metric tons/m3 of concrete)	Material Production (kg of CO2-eq / m3 of concrete)	Transportation Method (Truck, Barge, or Rail)	Transportation Distance (km)
Cement	846[33]				
SCM (other than slag-cement)	50				
SCM (slag cement)	147[34]				
Water	0.22[35]				
Fine Aggregate	5.51[36]				
Coarse Aggregate	6.18[37]				
Air Entraining Admixture	439[38]				
Water Reducing Admixture / Superplasticizer	1340[39]				
Accelerating Admixture	1230[40]				
Retarding Admixture	1530[41]				

Table B3. Transportation Details.

	A	B	C	D
Transportation Mode	Transportation Efficiency (kg of CO2-eq/km/metric ton)	Transportation Distance (km)	Constituent Weight (metric tons)	Transportation Impacts (kg of CO2-eq/m3 of concrete)
Freight Truck	0.0465[42]			
Barge	0.0146[43]			
Rail	0.0113[44]			

Step 1: Determine if any EPDs are available for any of the constituents to be used in the concrete mixture. If so, input those GWP values indicated in those constituent EPDs to column A in Table B2. Including the production efficiency from a product-specific or facility-specific EPD for cement production will significantly increase the precision of this estimation. If an EPD is not available for one or more of the constituents, the values prepopulated in in Column A of Table B2 can be used for initial estimation purposes.

Step 2: Input the constituent contents into Column B of Table B2 for your specific concrete mixture design based on a total volume of 1 m^3 of concrete.

Step 3: Multiply the values in Columns A and B for each row within Table B2 and report the product in Column C of Table B2.

Step 4: Report the anticipated constituent transportation methods to the concrete production facility in Column D of Table B2. If multiple transportation methods are expected to be used, input both methods and separate the transportation distance traveled using each transportation method (e.g., Truck, Rail).

Step 5: Report the anticipated transportation distance of the constituent to the concrete production facility in Column E of Table B2. If multiple transportation methods are expected to be used, separate the transportation distances by transportation mode and input both travel distances (e.g., 20 miles (truck), 500 miles (rail)).

Step 6: Add all of the values in Column C of Table B2 and report the sum in Column A of Table B1.

Step 7: Add the transportation distances in Column E of Table B2 pertaining to each transportation method as identified in Column D of Table B2. Report the sum of transportation distance for each transportation method in Column B of Table B3.

Step 8: Add the constituent weights in Column B of Table B2 pertaining to each transportation method as identified in Column D of Table B2. Report the sum of constituent weights for each transportation method in Column C of Table B3.

Step 9: Multiply the values for each row in Columns A, B, and C of Table B3 and report the products for each row in Column D of Table B3.

Step 10: Add the values in Column D of Table B3 and report the sum in Column B of Table B1.

Step 11: Multiply the value in Column A of Table B1 by 0.02[32] and report the value in Column C of Table B1.

Step 12: Add the values in Columns A through C of Table B1 and report the value in Column D of Table B1. The value in Column D of Table B1 is the estimated GWP.

When Estimating the ECC:

Table B2. Concrete Constituents Contents and Transportation Details.

	A	B	C	D	E
Mixture Design Parameter	Production Efficiency (kg of CO2-eq/metric ton)	Content (metric tons/m3 of concrete)	Material Production (kg of CO2-eq / m3 of concrete)	Transportation Method (Truck, Barge, or Rail)	Transportation Distance (km)
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Table B3. Transportation Details.

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Transportation Mode	Transportation Efficiency (kg of CO2-eq/km/metric ton)	Transportation Distance (km)	Constituent Weight (metric tons)	Transportation Impacts (kg of CO2-eq/m3 of concrete)
Freight Truck	0.0465[42]			
Barge	0.0146[43]			
Rail	0.0113[44]			

Step 1: Determine if any EPDs are available for any of the constituents to be used in the concrete mixture. If so, input those GWP values indicated in those constituent EPDs to column A in Table B2. Including the production efficiency from a product-specific or facility-specific EPD for cement production will significantly increase the precision of this estimation. If an EPD is not available for one or more of the constituents, the values prepopulated in in Column A of Table B2 can be used for initial estimation purposes.

Step 2: Input the constituent contents into Column B of Table B2 for your specific concrete mixture design based on a total volume of 1 m^3 of concrete.

Step 3: Multiply the values in Columns A and B for each row within Table B2 and report the product in Column C of Table B2.

Step 4: Report the anticipated constituent transportation methods to the concrete production facility in Column D of Table B2. If multiple transportation methods are expected to be used, input both methods and separate the transportation distance traveled using each transportation method (e.g., Truck, Rail).

Step 5: Report the anticipated transportation distance of the constituent to the concrete production facility in Column E of Table B2. If multiple transportation methods are expected to be used, separate the transportation distances by transportation mode and input both travel distances (e.g., 20 miles (truck), 500 miles (rail)).

Step 6: Add all of the values in Column C of Table B2 and report the sum in Column A of Table B1.

Step 7: Add the transportation distances in Column E of Table B2 pertaining to each transportation method as identified in Column D of Table B2. Report the sum of transportation distance for each transportation method in Column B of Table B3.

Step 8: Add the constituent weights in Column B of Table B2 pertaining to each transportation method as identified in Column D of Table B2. Report the sum of constituent weights for each transportation method in Column C of Table B3.

Step 9: Multiply the values for each row in Columns A, B, and C of Table B3 and report the products for each row in Column D of Table B3.

Step 10: Add the values in Column D of Table B3 and report the sum in Column B of Table B1.

Step 11: Multiply the value in Column A of Table B1 by 0.02[32] and report the value in Column C of Table B1.

Step 12: Add the values in Columns A through C of Table B1 and report the value in Column D of Table B1. The value in Column D of Table B1 is the estimated GWP.

When Estimating the ECC:

Table B1. Concrete Constituents Contents and Transportation Details.

	A	B	C	D
	Life Cycle Stage			A1-A3 Total
	A1	A2	A3	
GWP Estimation (kg of CO_2-eq/m^3 of concrete)				

Step 1: Determine if any EPDs are available for any of the constituents to be used in the concrete mixture. If so, input those GWP values indicated in those constituent EPDs to column A in Table B2. Including the production efficiency from a product-specific or facility-specific EPD for cement production will significantly increase the precision of this estimation. If an EPD is not available for one or more of the constituents, the values prepopulated in in Column A of Table B2 can be used for initial estimation purposes.

Step 2: Input the constituent contents into Column B of Table B2 for your specific concrete mixture design based on a total volume of 1 m^3 of concrete.

Step 3: Multiply the values in Columns A and B for each row within Table B2 and report the product in Column C of Table B2.

Step 4: Report the anticipated constituent transportation methods to the concrete production facility in Column D of Table B2. If multiple transportation methods are expected to be used, input both methods and separate the transportation distance traveled using each transportation method (e.g., Truck, Rail).

Step 5: Report the anticipated transportation distance of the constituent to the concrete production facility in Column E of Table B2. If multiple transportation methods are expected to be used, separate the transportation distances by transportation mode and input both travel distances (e.g., 20 miles (truck), 500 miles (rail)).

Step 6: Add all of the values in Column C of Table B2 and report the sum in Column A of Table B1.

Step 7: Add the transportation distances in Column E of Table B2 pertaining to each transportation method as identified in Column D of Table B2. Report the sum of transportation distance for each transportation method in Column B of Table B3.

Step 8: Add the constituent weights in Column B of Table B2 pertaining to each transportation method as identified in Column D of Table B2. Report the sum of constituent weights for each transportation method in Column C of Table B3.

Step 9: Multiply the values for each row in Columns A, B, and C of Table B3 and report the products for each row in Column D of Table B3.

Step 10: Add the values in Column D of Table B3 and report the sum in Column B of Table B1.

Step 11: Multiply the value in Column A of Table B1 by 0.02[32] and report the value in Column C of Table B1.

Step 12: Add the values in Columns A through C of Table B1 and report the value in Column D of Table B1. The value in Column D of Table B1 is the estimated GWP.

For any Quantification process:

- Product-specific, facility-specific data (especially for cement production efficiency) is preferred
  - Will obtain a more precise GWP estimation
  - Cement production efficiency can vary GWP estimates by up to 60%
- Context for how the information will be used is important

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Next Steps

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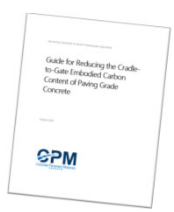

Anticipated Early 2024

Standards Organization Support (AASHTO)

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Concrete Pavement Materials PROGRAM

Tech Center

Advancing Concrete Pavement Technology Solutions
Cooperative Agreement

https://cptechcenter.org/research/in-progress/advancing-concrete-pavement-technology-solutions/

Acknowledgements

- Lower Carbon Technical Review Panel at CP Tech
- Concrete Pavement and Materials Technical Feedback Group (CPM-TFG)
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- Minnesota DOT and Michigan Technological University
- National Concrete Consortium
- FHWA Partners: Mobile Concrete Technology Center, Turner-Fairbank Highway Research Center, and the Sustainable Pavements Technical Working Group
- NCE and WJE
- Mark E. Felag, PE, LLC

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Slides continued on next page

WJE ENGINEERS ARCHITECTS MATERIALS SCIENTISTS
Wiss, Janney, Elstner Associates, Inc.

About the Presenter

Thomas J. Van Dam, Ph.D., P.E., F.ACI joined WJE in 2023 with over 35 years of civil engineering experience, specializing in concrete materials related to pavement and slab design, sustainability, and overall evaluation. His major areas of interest include performance assessment, durability, forensic investigations, and greenhouse gas emission reduction. Dr. Van Dam has worked successfully in academia and the private sector, directing pavement design, materials, and sustainability groups in conducting investigative and research projects for federal agencies, state departments of transportation, local agencies, private industry, and foundations.

In total, Dr. Van Dam has published over 100 technical papers, articles, and reports and is a frequent presenter on concrete materials and sustainability.

Today's Learning Objectives

- Gain a better understanding of the why low carbon concrete is of interest and current funding opportunities to support it through IRA funding
- Learn strategies that can be used to reduce the embodied carbon in paving concrete, focused on reducing the use of portland cement
- Understand the use of environmental product declarations (EPDs) in benchmarking and measuring improvement

Part 2:Strategies

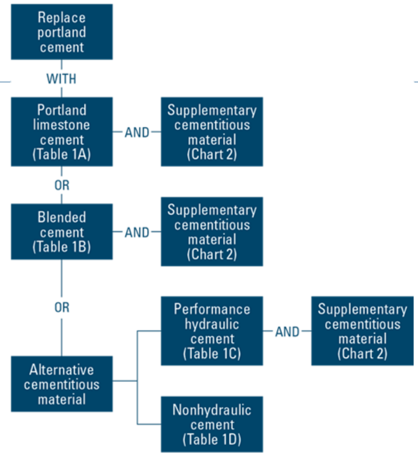
- There are 5 strategies presented in the order of their effectiveness in reducing ECC of paving concrete
  - Strategy 1 – Strategies Targeting the Cementitious Binder
  - Strategy 2 – Strategies Targeting Concrete Mixture to Optimize Binder Content
  - Strategy 3 – Reduce the ECC of aggregates
  - Strategy 4 – Strategies Targeting Mixture Performance Requirements
  - Strategy 5 – Other Factors to Consider
- This guide is not established to replace existing methods
  - Will supplement existing practice while reducing ECC

Strategy 1 – Targeting Cementitious Binder

- Already discussed that portland cement clinker is responsible for almost 90% of the ECC is typical concrete
- Heart of this strategy is replacing portland cement clinker with supplementary cementitious materials (SCMs)
  - All SCMs currently in use have a lower ECC than portland cement
  - Alternative SCMs (ASCMs) that are emerging also have a lower ECC, and some may even have a net negative ECC
- Alternative cementitious materials (ACMs) are also considered.

Pathways to Select a Lower ECC Binder

- Multiple pathways identified
  - Primary pathway is to replace portland cement with PLC, other blended cement, or ACM
  - Secondary pathway is to reduce portland cement through additional use of SCMs



Support for Each Pathway

- Narrative supports use of pathways
- References are provided to available resources to assist users in implementing strategies
- Tables have been prepared for each pathway providing a description, recommendations, implementation steps, and potential barriers

Table 1A. Summary of Portland Limestone Cement

Technology

Portland Limestone Cement (PLC)

What is it?

Portland limestone cement (PLC) is a hydraulic cement meeting the requirements of AASHTO M 240 (ASTM C595) Type IL. It has less embodied carbon than equivalent AASHTO M 85 (ASTM C150) portland cement as additional limestone is interground with the clinker during manufacturing. PLCs are engineered to replace AASHTO M 85 (ASTM C150) portland in nearly all concrete mixtures and can be used with nearly all types of supplementary cementitious materials (SCMs). PLCs have not demonstrated a statistically significant impact on later-age strength or durability performance compared to similar AASHTO M 85 (ASTM C150) portland cement,

Recommended Action/Dosage

Replace AASHTO M 85 (ASTM C150) portland cement with AASHTO M 240 (ASTM C595) Type IL PLC. Changing cement type to PLC requires reverifying concrete mixture properties through trial batching.

Implementation Steps

- Ensure AASHTO M 240 (ASTM C595) Type IL is allowed in your cement specifications.
- Allow cement producers to submit AASHTO M 240 (ASTM C595) Type IL cements to your approved or qualified products list (APL or QPL).
- Encourage contractors to submit trial batches using AASHTO M 240 (ASTM C595) Type IL cements.

Barriers to Implementation

- Little to no local availability of AASHTO M 240 (ASTM C595) Type IL cements.
- Contractors don't have approved concrete mix design using Type IL cements.
- In some applications, construction crews are not familiar with Type IL cements and the reduced rate of bleed water associated with the finer grind.

Expected Impact on Cost

AASHTO M 240 (ASTM C595) Type IL cement is reported to be similarly priced to conventional AASHTO M 85 (ASTM C150) portland cement.

References

Practice-Ready Papers, FHWA PLC Technote (under development), GreenerCement.org.

Table 1B. Summary of blended cements

Technology

Blended Cements

Table 1C. Summary of Performance Hydraulic Cement

Technology

Performance Hydrau

Table 1D. Summary of Non-Hydraulic Inorganic Cements

Technology

Non-Hydraulic Inorganic Cements

What is it?

Non-hydraulic inorganic cements are those that set and hardened due to alkali-activation causing the dissolution of alumino-silica precursors and the initiation of chemical reactions resulting in non-hydrated reaction products. These materials are at times referred to as geopolymers or inorganic polymer cements. The most common alumino-silica precursors include calcined kaolinite clays, low calcium fly ash, and slag cement. Common alkali-activators include sodium hydroxide and sodium silicate solutions of high molarity. These cements often have a low GWP and are highly resistant to many durability problems that can affect portland cement-based systems, such as sulfate attack. As novel materials, they are not readily available in the market and may be difficult to work with.

How does it work?

Unlike portland cement-based systems and alkali-activated hydraulic cement, non-hydraulic inorganic cements rely on the formation of three-dimensional polymeric alumino-silicate chain and ring structures. The formation of these structures is rapid and occurs when the precursor materials first undergo dissolution in the highly alkali solution created by the alkali-activators, followed by polymerization. The water in the system is there to facilitate workability and is not part of the reaction products, instead being expelled during curing and subsequent drying. The polymerization reaction is sensitive to ambient temperatures. Conceptually simple, the reactions driving inorganic polymerization are complex and not fully understood. Further, the cements are largely proprietary and only have seen limited use in paving applications.

How would you quantify GWP reduction?

Non-hydraulic inorganic cements are likely to have a lower GWP than AASHTO M 85 (ASTM C150) portland cement, depending on the alumino-silica precursor, as would be shown in an EPD. The amount of reduction will depend on the type of precursor materials and alkali-activator. For some applications, the use of non-hydraulic inorganic cement could result in a significant reduction of the GWP for concrete.

Recommended Action/Dosage

Although there are some non-hydraulic inorganic cement available in the U.S., for the most part their use has been restricted to specialty applications and there is no known use in the U.S. for a cast-in-place pavement. Further, non-hydraulic inorganic cements are more difficult to work with than portland cement-based systems due to the alkali-activator, the sensitivity to temperature, and the general sensitivity of the system to subtle changes in materials or conditions. Current recommendation are to thoroughly test these materials in the laboratory for performance and robustness prior to construction of demonstration projects as a step to implementation.

Implementation Steps

- Currently non-hydraulic inorganic cement suitable for large-scale pavement applications are in the early stages of development and are not ready for implementation.
- Conduct robust laboratory testing and construct demonstration products to ensure viability.

Barriers to Implementation

- New technology with unknown risks related to constructability and long-term performance.
- High alkali activators must be carefully handled during concrete production.

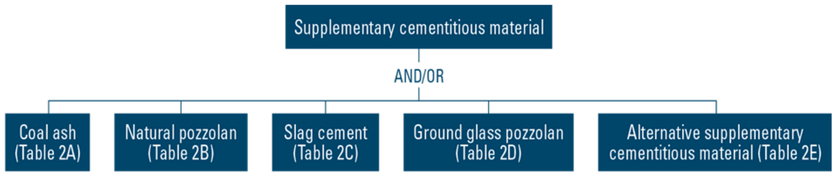
Expected Impact on Cost

Low GWP non-hydraulic inorganic cements would be expected to have higher costs than portland cement-based systems. Cost at market introduction would likely be very high with a reduction in cost occurring as market acceptance increases but will remain relatively high.

References

Practice-Ready Papers, ACI ITG-10R-18 and ITG-10.1R-18, FHWA-HIF-10-014 (TechBrief: Geopolymer Concrete (dot.gov)).

Secondary Pathways Further Defined



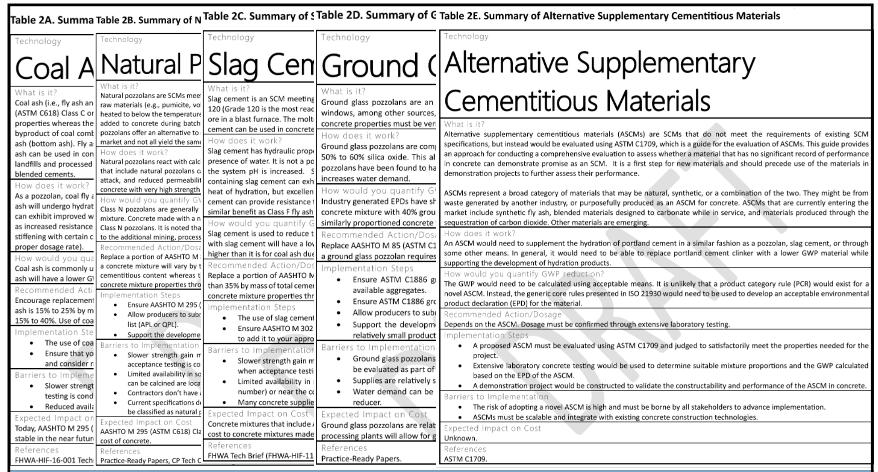


Table 2A. Summa | Table 2B. Summary of N | Table 2C. Summary of S | Table 2D. Summary of G

Coal A | Natural P | Slag Cem | Ground (

Table 2E. Summary of Alternative Supplementary Cementitious Materials

Technology

Alternative Supplementary Cementitious Materials

What is it?

Alternative supplementary cementitious materials (ASCMs) are SCMs that do not meet the requirements of existing SCM specifications, but instead would be evaluated using ASTM C1709, which is a guide for the evaluation of ASCMs. This guide provides an approach for conducting a comprehensive evaluation to assess whether a material that has no significant record of performance in concrete can demonstrate promise as an SCM. It is a first step for new materials and should precede use of the materials in demonstration projects to further assess their performance.

ASCMs represent a broad category of materials that may be natural, synthetic, or a combination of the two. They might be from waste generated by another industry, or purposefully produced as an ASCM for concrete. ASCMs that are currently entering the market include synthetic fly ash, blended materials designed to carbonate while in service, and materials produced through the sequestration of carbon dioxide. Other materials are emerging.

How does it work?

An ASCM would need to supplement the hydration of portland cement in a similar fashion as a pozzolan, slag cement, or through some other means. In general, it would need to be able to replace portland cement clinker with a lower GWP material while supporting the development of hydration products.

How would you quantify GWP reduction?

The GWP would need to be calculated using acceptable means. It is unlikely that a product category rule (PCR) would exist for a novel ASCM. Instead, the generic core rules presented in ISO 21930 would need to be used to develop an acceptable environmental product declaration (EPD) for the material.

Recommended Action/Dosage

Depends on the ASCM. Dosage must be confirmed through extensive laboratory testing.

Implementation Steps

- A proposed ASCM must be evaluated using ASTM C1709 and judged to satisfactorily meet the properties needed for the project.
- Extensive laboratory concrete testing would be used to determine suitable mixture proportions and the GWP calculated based on the EPD of the ASCM.
- A demonstration project would be constructed to validate the constructability and performance of the ASCM in concrete.

Barriers to Implementation

- The risk of adopting a novel ASCM is high and must be borne by all stakeholders to advance implementation.
- ASCMs must be scalable and integrate with existing concrete construction technologies.

Expected Impact on Cost

Unknown.

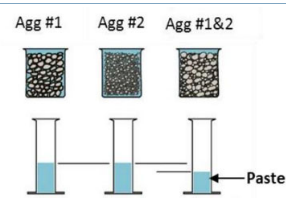
References

ASTM C1709.

DRAFT

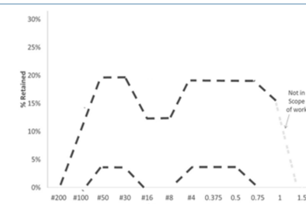
Strategy 2 – Concrete Mixture to Optimize Binder Content

- This strategy reduces ECC by reducing total cementitious materials content
  - Accomplished by optimizing aggregate grading
- For the same binder and water-to-binder ratio, reducing total cementitious materials content reduces paste volume
  - Improves hardened concrete properties



Strategy 2 – Concrete Mixture Optimization

- The key is to reduce paste volume by blending aggregates (often from three or more sources) to minimum void volume
  - Must maintain fresh concrete properties including workability and air content
  - Also achieve harden concrete properties including strength and durability
- Several tools are available including the "Tarantula Curve"



T. Ley and D. Cook 2014

Table 3. Optimized Aggregate Grading

Technology

Optimized Aggregate Grading

What is it?

Optimized aggregate grading considers the combined aggregate particle size distribution in lieu of focusing solely on the gradation of source aggregates. When the aggregate grading is optimized, a minimum amount of paste is needed to fill the void space that exists between the aggregate particles, separating them slightly and allowing the paste to act as a lubricant to ensure mixture workability. In this way, the paste volume can be reduced while workability and performance are improved.

How does it work?

Using a tool, such as the Tarantula Curve, the percent retained on each standard sieve size for the combined aggregate particle size distribution is optimized to fall within the recommended limits (see Figure 6). There are additional recommendations on the combined percent of coarse sand (#8 through #30 sieve) and fine sand (#30 through #200) for slipformed paving and flowable concrete to ensure workability. The general mix design strategy is to optimize the combined grading of quality aggregates as discussed. Next the cementitious materials are selected to create a durable and low GWP paste that meets engineering needs. The final step is to select the paste volume needed to fill the voids in the aggregate system while providing workability. Spreadsheet tools are available in the references to facilitate this process.

How would you quantify GWP reduction?

GWP reduction is incurred by reducing the overall volume of cementitious materials. Cementitious materials containing portland cement will have a higher GWP than aggregates for a given volume. Therefore, replacing cementitious materials with aggregate will reduce the GWP of the concrete, all other components held equal. A mixture specific EPD will demonstrate this GWP reduction.

Recommended Action

Specifications for slipform paving and flowable concrete should be reviewed and modified, if needed, to consider the optimized aggregate grading. Application of the guidance provided in AASHTO R 101 with regards to development of a concrete mixture proportions should be followed.

Implementation Steps

- Ensure specifications allow the use of combined aggregate grading and optimization.
- Ensure specifications do not have minimum cementitious materials contents that are above what is appropriate for the application and climatic conditions. Some SHAs have set minimum cementitious materials contents for slipform paving concrete with optimized aggregate grading as low as 470 lbs/yd^3.
- In time incentivize, and then require, the use of optimize aggregate grading with reduced cementitious materials contents for paving and flowable concrete.

Barriers to Implementation

- Many SHAs have set minimum cementitious materials content limits that are unnecessarily high and create a barrier to GWP reduction.
- Optimized aggregate grading often requires three or more aggregate sources requiring some concrete producers to obtain additional bins. In urban areas with space limitations, stockpiling additional aggregates may not be feasible.
- Lack of familiarity in proportioning concrete with optimized aggregate grading will need to be overcome.

Expected Impact on Cost

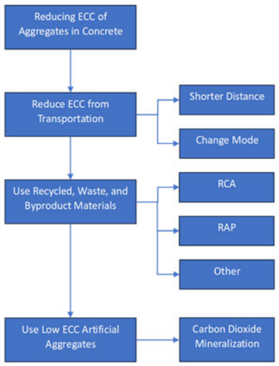
Initially there would likely be a small increase in cost as this strategy is introduced into locations where it is not current practice. In time, it will be cost neutral or even reduce cost of in-place concrete.

References

FHWA-HIF-15-019: https://www.fhwa.dot.gov/pavement/concrete/pubs/hif15019.pdf.
CP Tech Center: https://cptechcenter.org/mix-proportioning/.
Tarantula Curve: http://www.tarantulacurve.com/recommended-specification.html.

Strategy 3 – Reduce the ECC of Aggregates

- In addition to aggregate optimization:
  - Aggregate shape and texture affect water demand, especially for manufactured fine aggregates
  - Aggregates must be durable, being resistant to alkali-aggregate reaction in concrete and not susceptible to freeze-thaw damage
- Considerations to reduce ECC of concrete
  - Reduce emissions when transporting aggregates
  - Use recycled, co-product, and waste materials as aggregate if it makes sense
  - Use low ECC manufactured aggregates



Transportation of Aggregates Matters

Table 5. Estimated national average freight movement fuel efficiency (diesel) and estimated GWP per ton per mile transported of freight transportation modes[25]

Mode	Short Ton-Miles/Gallon Consumed	GWP per short ton per mile travelled (Kg CO_2)[A]
Truck[B]	150	0.0679
Rail	478	0.0213
Inland Barge	616	0.0165

[A] The GWP per ton per mile was calculated based on one gallon of diesel fuel consumed emitting 22.44 lbs (10.18 kg) of $CO_{2\,eq}$.
[B] Truck load assumed to be 25 tons on a 40-ton gross vehicle weight truck, loaded one-way.

Table 4. Aggregate Pathways to Reduce the ECC of Concrete

Technology

Aggregate Pathways to Reduce ECC

What is it?

Although aggregates have a relatively low ECC, because they are the largest component in concrete, they do impact the overall ECC of concrete. The main focus on reducing the ECC of aggregates is to reduce the GWP associated with transportation, using recycled, waste, and byproduct materials in lieu of natural aggregate where it makes sense, and using low ECC artificial aggregates as they become available.

How does it work?

Although the ECC of natural aggregates is relatively low, the shear mass of aggregates used in concrete production means their impact needs to be considered. The transportation of aggregates from source to the point of concrete production is often done by trucks, which is the least efficient and most carbon intensive means of moving materials. If possible, the distance between aggregate source and the concrete plant should be minimized and alternative, more efficient, modes of transportation such as rail and barges used to ship aggregates over longer distances. The use of recycled, waste, and byproduct materials as aggregate can reduce the ECC of concrete, although the impact needs to be assessed on a project level. And emerging low to negative ECC artificial aggregates are being produced through CCUS that may offer opportunities for further carbon reduction in the future.

How would you quantify GWP reduction?

GWP reduction is incurred by replacing aggregates with relatively high ECC with those with lower ECC. The assessment is done at the concrete plant reflecting the GWP incurred due to shipping. A mixture specific EPD will demonstrate this GWP reduction.

Recommended Action

Specifications for slipform paving and flowable concrete should be reviewed to ensure that barriers to the use of quality recycled, waste, and byproduct aggregate materials, as well as artificial aggregates are removed. Incentivizing the use of low ECC concrete, validated through an EPD, will facilitate reducing transportation emissions.

Implementation Steps

- Incentivize the use of low ECC concrete as validated through an EPD.
- Ensure specifications allow the use of quality recycled, waste, and byproduct materials, as well as artificial aggregates.
- Conduct demonstration projects with concrete made with quality recycled, waste, and byproduct aggregate materials, as well as artificial aggregates, as they become available.

Barriers to Implementation

- Little to no local availability of quality aggregates and limited ability to change mode of transportation in some markets.
- Lack of familiarity with concrete made with quality recycled, waste, and byproduct aggregate materials.
- Specification barriers may exist that need to be evaluated.
- Lack of supply and uncertain quality for artificial aggregates.

Expected Impact on Cost

Initially there would likely be a small increase in cost as this strategy is introduced into locations where it is not current practice. In time, it will be cost neutral or even reduce cost of in-place concrete.

References

CP Tech Center: https://intrans.iastate.edu/app/uploads/2018/09/RCA_practioner_guide_w_cvr.pdf.
FHWA-HIF-22-020: https://www.fhwa.dot.gov/pavement/concrete/pubs/hif22020.pdf.

Strategy 4 – Performance Specifications for Concrete Mixtures

- Requirements for concrete should include both ECC targets and performance of concrete over time
- Prescriptive requirements often create barriers to reducing ECC without assurance of long-term performance
  - Prescriptive requirements are rooted in past experiences
    - This is not bad, but does limit the ability to do something new
  - There are often restrictions on cementitious materials types and allowable replacement levels, minimum cementitious materials content requirements, and strength-based milestones to be achieved that are not linked to performance, yet may provide a barrier to reducing ECC
- Adoption of AASHTO R 101 - *Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures* can help

Pathways Using Performance Specifications

- Narrative and tables to support pathways based on performance specifications
- This is an evolving area of interest and will be a major focus of continuing efforts

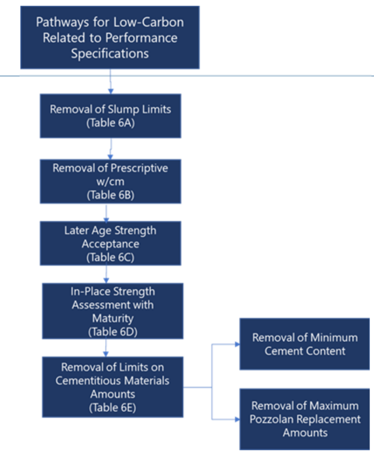


Table 6. Use of Performance Specification to Reduce the ECC of the Concrete Mixture

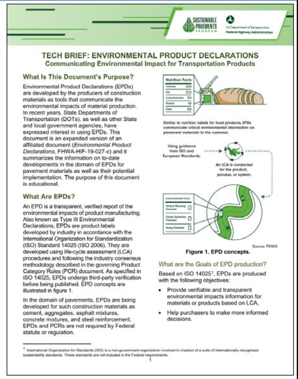
Technology **Performance-Specifications**
What is it? Traditional concrete specifications are predominantly prescriptive, meaning the specifications explicitly identifies the materials to be used on the project (e.g., cement type, minimum cementitious materials content, minimum *w/cm*, etc.) as well acceptance criteria. Today's specifications often rely on a limited number of test methods (e.g., slump, total air content, strength., etc.) that often have very little direct correlation to future performance. These specifications have been adequate in the past but tend to limit innovation by making it difficult to introduce new material technologies. Performance specifications define the functional requirement for the project (e.g., structural capacity, durability) and use performance measures that are more directly linked to in-service performance, such as cracking tendency and permeability.
How does it work? AASHTO recently adopted the R 101 *Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures.* This standard practice can be used to guide agencies in adopting performance specification that consider properties of concrete directly linked to workability and long-term performance. Developed for pavement mixtures, elements of this standard practice can be adopted for use with other classes of concrete with little to no changes.
How would you quantify GWP reduction? Adoption of performance-related specifications opens the door to further carbon reduction by eliminating barriers to innovation that exist in prescriptive specifications. This allows consideration of innovative, lower carbon concrete materials that otherwise could not be considered. Quantification of benefit would rely on generating an EPD.
Recommended Action Agencies should review their specifications considering guidance presented in AASHTO R 101, as well as other performance-related specifications. Changes should be made to their specifications to support adoption of performance-related specifications and performance measures.
Implementation Steps • Review existing specifications and add performance-related specifications and associated performance measures. • Ensure specifications allow a broad range of cementitious binders, significantly reduce or eliminate minimum cement content requirements, and adopted optimized aggregate grading. • Move away from strength as sole acceptance requirement and instead look to performance measures linked to durability and long-term service. • Bring in ECC as a goal of mixture proportioning.
Barriers to Implementation • Agencies need to be educated on performance-related specification and performance measurements. • Suppliers may be resistant to change if they perceive that risk is being shifted onto them. • Testing laboratories will need to acquire equipment and qualifications needed to conduct testing that is not currently standard practice.
Expected Impact on Cost Initially there would likely be an increase in cost as local suppliers and testing firms acquire additional equipment and skills. In time, it will likely be cost neutral.
References AASHTO R 101: https://store.transportation.org/Item/PublicationDetail?ID=4993

Strategy 5 – Other Considerations

- Reduced fuel consumption in production and transportation of concrete
  - Renewal energy grid, optimized plant operations, natural gas fueled trucks, etc.
- Calcium carbonate mineralization in production of concrete
- Other?

Part 3: Quantification

- Quantify greenhouse gas (GHG) emissions is an essential element in producing low ECC concrete
- The use of an environmental product declaration (EPD) produced in accordance with ISO 14025 is the preferred quanitification tool
- An GHG emission estimating tool is provided for use if an EPD is not yet available



SUSTAINABLE PAVEMENTS PROGRAM · U.S. Department of Transportation Federal Highway Administration

TECH BRIEF: ENVIRONMENTAL PRODUCT DECLARATIONS
Communicating Environmental Impact for Transportation Products

What Is This Document's Purpose?

Environmental Product Declarations (EPDs) are developed by the producers of construction materials as tools that communicate the environmental impacts of material production. In recent years, State Departments of Transportation (DOTs), as well as other State and local government agencies, have expressed interest in using EPDs. This document is an expanded version of an affiliated document (*Environmental Product Declarations*, FHWA-HIF-19-027-c) and it summarizes the information on to-date developments in the domain of EPDs for pavement materials as well as their potential implementation. The purpose of this document is educational.

What Are EPDs?

An EPD is a transparent, verified report of the environmental impacts of product manufacturing. Also known as Type III Environmental Declarations, EPDs are product labels developed by industry in accordance with the International Organization for Standardization (ISO) Standard 14025 (ISO 2006). They are developed using life-cycle assessment (LCA) procedures and following the industry consensus methodology described in the governing Product Category Rules (PCR) document. As specified in ISO 14025, EPDs undergo third-party verification before being published. EPD concepts are illustrated in figure 1.

In the domain of pavements, EPDs are being developed for such construction materials as cement, aggregates, asphalt mixtures, concrete mixtures, and steel reinforcement. EPDs and PCRs are not required by Federal statute or regulation.

Similar to nutrition labels for food products, EPDs communicate critical environmental information on pavement materials to the customer.

Using guidance from ISO and European Standards. An LCA is conducted for the product, process, or system.

Source: FHWA

Figure 1. EPD concepts.

What are the Goals of EPD production?

Based on ISO 14025[1], EPDs are produced with the following objectives:

- Provide verifiable and transparent environmental impacts information for materials or products based on LCA.
- Help purchasers to make more informed decisions.

[1] International Organization for Standards (ISO) is a non-government organization involved in creation of a suite of internationally-recognized sustainability standards. These standards are not included in the Federal requirements.

1

Using This Guide

1. Following Strategy 1, select a lower ECC cement
   - Use higher than normal replacement level of portland cement with SCMs at the concrete plant
   - Replace AASHTO M 85 (ASTM C150) with AASHTO M 240 (ASTM C 595) blended cement
   - Aim to achieve 50% or less total portland cement for the binder
2. Following Strategy 2, reduce total cementitious content through aggregate optimization
   - An example would be to use the "Tarantula Curve" to blend in intermediate aggregates reducing total cementitious materials content from 564 pcy to 500 pcy

Using This Guide

3. Following Strategy 3, use lower ECC aggregate
   - Use recycled concrete aggregate processed near site instead of transporting virgin aggregate long distance
     - Note that carbon savings needs to be demonstrated through supporting calculations
   - Use a manufactured aggregate produced through carbon sequestration
4. Following Strategy 4, adopt performance specifications that eliminate barriers inherent in prescriptive specifications
   - Move away from minimum cementitious contents and maximum SCM replacement levels
   - Adopt acceptance testing linked directly to performance
5. Following Strategy 5, investigate opportunities that emerge

Using This Guide

- Quantification of ECC needs to become commonplace
  - Simply business as usual
- In time, this will be extended beyond Stages A1-A3
- In the short-term, it is essential that representative data is collected to create a meaningful benchmark to assess improvement