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Since the publication of this MAP Brief, the interim *Guide for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete* discussed in this document has been finalized and published by AASHTO. The final guide can be found here.

"Moving Advancements into Practice"

MAP Brief Spring 2024

Best practices and promising technologies that can be used now to enhance concrete paving

What Can Be Done to Reduce the Embodied Impacts of Concrete?

(A summary of the Guide for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete)

Introduction

As part of their sustainability efforts, transportation agencies across the nation are striving to quantify and reduce the cradle-to-gate embodied carbon emissions of their paving concrete—or the emissions generated before the concrete leaves the plant.

To assist with these efforts, the Federal Highway Administration (FHWA) established the Low-Carbon Transportation Materials (LCTM) Program (https://www.fhwa.dot.gov/ lowcarbon/), which is making \$1.2 billion available to state departments of transportation (DOTs), as well as the District of Columbia and Puerto Rico, to fund activities and projects that advance the use of low-carbon materials and products. The application period for this funding opened on March 12, 2024, and closes on June 10, 2024. An award of at least \$22 million is anticipated for each agency that submits an application. For the purposes of this program, eligible materials categories include concrete (and cement), asphalt mixtures, steel, and glass.

Tools are available to help transportation agencies apply for this LCTM funding. FHWA can connect agencies with their local FHWA offices and provide technical assistance in the planning, design, construction, preservation, and improvement of public roads and in the stewardship of federal funds. For assistance, visit https://www.fhwa. dot.gov/bipartisan-infrastructure-law/ technical support.cfm. Additionally, the American Concrete Pavement Association (ACPA), National Concrete Pavement Technology Center (CP Tech Center), and other engineering professionals established the Reduced Carbon Concrete Consortium (RC3)

(<u>https://rc3.acpa.org/</u>) to disseminate information on carbon reduction and assist qualifying agencies with their LCTM applications. The RC3 will remain relevant after applications are submitted, providing technical assistance to agencies and facilitating contractor preparedness for critical next steps such as the development and use of environmental product declarations (EPDs).

In cooperation and coordination with the FHWA, the CP Tech Center recently published the *Guide for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete.* This guide has passed an AASHTO ballot and will become an AASHTO guide in the near future. The purpose of this MAP brief is to summarize the key information in the guide.

Scope of the Guide

The guide offers several practical and implementation-ready strategies for material selection and proportioning that transportation agencies, contractors, and concrete suppliers can use to reduce the cradle-to-gate embodied carbon emissions of paving concrete in readily quantifiable ways.

In the product life cycle defined by the International Organization for Standardization (ISO), illustrated in Figure 1, the cradle-to-gate production of a material corresponds to the Production stage and includes Modules A1 through A3 (hereafter referred to as A1–A3). While the Construction stage (Modules A4 through A5), Use stage (Modules B1 through B5), and End of Life stage (Modules C1 through C4) also present significant opportunities to reduce the embodied carbon emissions of a transportation system, these stages are not included in the scope of the guide.



Recreated from FHWA, adapted from ISO 21930 Figure 1. Life-cycle stages

Partnership Approach

Lowering the embodied carbon emissions of concrete requires a partnership effort, and for this effort to be successful it is important to engage relevant stakeholders early in the process. Since concrete paving mixtures are specified by owners and consulting engineers, provided by concrete producers, and placed by concrete paving contractors, providing this diverse stakeholder group sufficient opportunity to discuss, understand, and contribute to these goals is important, even before construction begins.

Portland Cement and Embodied Carbon Emissions of Concrete

Today's concrete technology is largely dependent upon portland cement clinker as the main binding material. For typical concrete mixtures, it is estimated that almost 90% of the embodied carbon emissions in a concrete mixture before it leaves the gate of the concrete plant are from the production of portland cement. The remaining 10% are from the mining, transportation, blending, and mixing of materials at the concrete plant. A breakdown of these percentages is illustrated in Figure 2.

Inadvertent Barriers within Agency Specifications

While reducing the portland cement content of concrete can pose technical challenges, a significant barrier to immediate reduction often lies within current agency specifications. Agencies should consider the following:



Adapted from Choate 2003

Figure 2. $\ensuremath{\text{CO}_2}$ emissions for quarrying, cement manufacturing, and concrete production

- Agencies should not limit the type of cement that can be used in concrete. In addition to AASHTO M 85/ASTM C150 portland cement, AASHTO M 240/ASTM C595 blended cements should be allowed, and a recent national survey has shown that all states now allow AASHTO M 240/ASTM C595 Type IL (portland-limestone) cements. Agencies should also permit a wide range of supplementary cementitious materials (SCMs) with replacement rates higher than those traditionally used.
- Some agencies have eliminated minimum cementitious materials content requirements for paving concrete, while many agencies require relatively low minimums of around 500 lb/yd³ or lower. Requiring a minimum cementitious materials content above 500 lb/yd³ may create an unneeded barrier to reducing the embodied carbon emissions of the mixture.
- Agency specifications often require pavements to achieve design strength within the first 7 to 10 days, regardless of whether high early-age strength is needed. Over-specifying design strength or requiring that design strength be achieved at early ages can lead practitioners to use too much cement in the concrete mixture, which increases the embodied carbon emissions of the concrete. Shifting the age of acceptance testing from 28 days to 42 days or 56 days provides additional time for pozzolans to react and reflects the long-term strength of concrete made with a high amount of portland cement replacement.

Achieving Engineering Goals

When constructing a pavement system containing concrete with reduced embodied carbon emissions, care should be taken to define engineering goals that will help reduce maintenance, decrease roughness, and achieve the desired degree of safety and service life. Sacrificing these engineering goals can lead to an increase in the life-cycle embodied carbon emissions and adversely impact the total life-cycle emissions of the concrete, even if these do not show up in a material EPD that only considers A1–A3. The use of paving concrete with reduced embodied carbon emissions must not compromise service life and ideally would increase the lifetime of the pavement for additional reductions in life-cycle embodied carbon emissions.

Strategies

When proportioning paving concrete, each component of the system presents an opportunity to contribute to the goal of achieving an overall reduction in embodied carbon emissions. These system components include the cementitious binder used (cement and SCMs), the amount of cementitious binder in the concrete (reduced through optimization of aggregate grading), and the other constituents selected, including aggregates and admixtures. The embodied carbon emissions can also be reduced by reducing emissions associated with the transportation of materials from their sources to the concrete plant and improved efficiency during material handling, batching, and mixing at the concrete plant.

The guide focuses on several strategies to reduce the cradle-togate embodied carbon emissions of paving concrete that can readily be implemented by specifiers and mixture designers. While these strategies are listed separately, they must be considered holistically since the effects of some may offset the effects of others. For example, a high SCM substitution rate may not be possible if a switch is made from an AASHTO M 85/ASTM C150 portland cement to an AASHTO M 240/ ASTM C595 blended cement. In this case, it is important that the overall embodied carbon emissions of the paving concrete be reduced regardless of whether the embodied carbon emissions of the cementitious binder are reduced.

The following five strategies, used separately or in combination, can result in measurable reductions in the cradle-to-gate embodied carbon emissions of paving concrete:

- Strategy 1. Target the cementitious binder
- Strategy 2. Target the concrete mixture to optimize binder content
- Strategy 3. Reduce the cradle-to-gate embodied carbon emissions of aggregates
- Strategy 4. Target mixture performance requirements
- Strategy 5. Consider other factors

The strategies are presented in order of their effectiveness for reducing the cradle-to-gate embodied carbon emissions in typical applications, with Strategy 1 offering the greatest opportunity for improvement.

Each strategy is accompanied by an Implementation Table found in Appendix A of the guide. The tables provide background information about the strategy, a high-level overview of how the strategy can result in lower embodied carbon emissions, and actions and steps that can be taken to implement the strategy. This information is presented to help practitioners accelerate and facilitate implementation of these strategies based on past successes.

The strategies are supplemental to the proportioning methods and tools in use by concrete mixture designers. The strategies are therefore intended not to replace existing proportioning methods but to provide approaches that can reduce the embodied carbon emissions of paving concrete relative to current practice.

Strategy 1: Target the Cementitious Binder

Although efficiencies and optimizations need to be considered throughout the production stage, the key to an immediate and significant reduction in the embodied carbon emissions of paving concrete is clear: reduce the proportion of cementitious binder that is portland cement clinker. Replacing clinker with limestone at the cement plant (i.e., specifying AASHTO M 240/ASTM C595 Type IL portland-limestone cement) and with SCMs reduces the amount of portland cement clinker and therefore reduces embodied carbon emissions.

Increasing SCM use will lower embodied carbon emissions when SCMs are used as a direct replacement for portland cement on a mass basis. Further, SCMs often have a positive effect on the workability, durability, and long-term strength gain of paving concrete (Taylor et al. 2019). A potential downside of increased SCM use with a corresponding reduction in clinker content is that, in most cases, the hydration reaction slows, resulting in slower setting and a slower rate of strength development.

State and local transportation agencies should allow and encourage the use of cementitious binders in which the clinker is interground with limestone and that contain SCMs at the highest practical level, being cognizant of the impacts of slower set times and strength development. The ages when the pavement is opened to traffic and when acceptance testing is conducted may need to be shifted to accommodate slower strength gain, particularly for construction done during cooler weather. More information on the use of SCMs can be found in the second edition of *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual* (Taylor et al. 2019).



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Figure 3. Chart 1: Pathways to reduce cradle-to-gate embodied carbon emissions targeting the cementitious binder system

The approach taken in the guide to reduce the embodied carbon emissions of the cementitious binder system is depicted in Figure 3 (Chart 1). The Implementation Tables cited in this figure are presented in Appendix A of the guide. The use of this figure is described in the following sections.

Reduce Amount of Portland Cement Clinker (AASHTO M 85/ASTM C150)

The most effective strategy to reduce the cradle-to-gate embodied carbon emissions of paving concrete is to reduce the amount of portland cement clinker in the mixture. The first step to accomplish this reduction is to reduce the proportion of portland cement clinker in the cementitious binder by replacing portland cement (AASHTO M 85/ ASTM C150) with portland-limestone cement (AASHTO M 240/ASTM C595 Type IL) or a blended cement containing an SCM (AASHTO M 240/ASTM C595 Type IP, IS, or IT). The guide provides a description of the different blended cements in AASHTO M 240/ASTM C595 (portland-limestone cement [Type IL], portlandpozzolan cement [Type IP], portland-slag cement [Type IS], and ternary blended cement [Type IT]).

Increase Use of Supplementary Cementitious Materials

In addition to the options described above for lowering the portland cement clinker content of the cement, SCMs can be added at the concrete plant to further reduce the cradleto-gate embodied carbon emissions of cementitious binders, as shown in Figure 3 (Chart 1). The use of SCMs as a binder replacement is already common practice in many markets, but coupling increased SCM replacement rates at the plant with the use of cementitious binders designed to reduce embodied carbon emissions raises additional considerations with respect to the early-age behavior of the concrete.

Common SCMs are shown in Figure 4 (Chart 2) and are specified as follows:

- AASHTO M 295/ASTM C618, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- AASHTO M 302/ASTM C989, Standard Specification for Slag Cement for Use in Concrete and Mortars
- AASHTO M 307/ASTM C1240, Standard Specification for Silica Fume Used in Cementitious Mixtures
- ASTM C1866, Standard Specification for Ground Glass Pozzolan for use in Concrete

In addition to the SCMs noted in the listed specifications, several alternative SCMs are currently or will soon be on the market that do not fit under current standard specifications but may offer opportunities for reducing embodied carbon emissions.



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Figure 4. Chart 2: Types of supplementary cementitious materials

Strategy 2: Target the Concrete Mixture to Optimize Binder Content

The next strategy involves reducing the cementitious binder content in the concrete. Reducing the binder content will not only reduce the embodied carbon emissions of the concrete but, assuming that the water-to-cementitious materials ratio (w/cm) remains constant, also reduce shrinkage and improve durability without impacting long-term strength (Obla et al. 2017). If the w/cm remains constant, a reduction in cementitious binder has a corresponding decrease in added water, and both factors together result in a lower cementitious paste volume (i.e., the percent volume of cementitious materials and water in a cubic yard of concrete). AASHTO R 101, Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures, recommends a maximum paste volume of 25% for paving mixtures. This limit represents a good target, but regional differences in materials may require the need for a slightly higher paste volume.

Reducing the total cementitious materials content must be accomplished while maintaining the required fresh concrete properties, including workability and air content, as well as the required hardened concrete properties, including strength and durability. The general approach to reducing the binder content is through optimized aggregate grading, in which the aggregate particle size distribution is selected to facilitate aggregate packing without compromising workability, as illustrated in Figure 5. Paving concrete featuring optimized aggregate grading is more cost-effective than concrete without optimized aggregate grading and often exhibits improved workability and enhanced durability.

Several resources are available that address optimized aggregate grading:

- <u>Integrated Materials and Construction Practices for Concrete</u> <u>Pavements: A State-of-the-Practice Manual, 2nd Edition</u> (Taylor et al. 2019)
- <u>Blended Aggregates for Concrete Mixture Optimization:</u> <u>Best Practices for Jointed Concrete Pavements</u> (Taylor and Fick 2015)



PCA, used with permission Figure 5. Conceptual illustration of optimized aggregate system

- <u>Improving Concrete through Optimizing Aggregate</u> <u>Gradation: Findings from the FHWA Mobile Concrete</u> <u>Trailer</u> (FHWA 2017)
- <u>Tarantula Curve</u> (Ley 2023)

The focus of aggregate grading should be on ensuring that the combined aggregate meets a given specification rather than on whether the individual aggregate sources meet specific sieve requirements (FHWA 2017). Additional paste beyond what is needed has little to no benefit and in fact may be detrimental to mixture economy and performance because it can result in increased shrinkage, permeability, and risk of cracking.

Most often, the use of a third or even a fourth aggregate (in addition to a coarse and fine aggregate) is needed to provide the intermediate-sized aggregate for optimized aggregate gradation. Multiple tools are available to assist the concrete mixture designer in combining multiple aggregate sources to select an optimized aggregate grading. These tools are reviewed in several documents, including Taylor et al. (2019) and Taylor and Fick (2015). The Tarantula Curve has been found to be a good approach to guiding the development of an optimized aggregate grading for slipform paving, as described in Ley and Cook (2014) and Ley 2023).

Strategy 3: Reduce the Cradle-to-Gate Embodied Carbon Emissions of Aggregates

In addition to the specific aggregate grading used in a mixture, as discussed under Strategy 2, the aggregates themselves also contribute to the embodied carbon emissions of the concrete, though to a lesser degree than the cementitious materials. Although aggregates have relatively low embodied carbon emissions per unit mass compared to other mixture constituents, they make up the largest share of mass in concrete and therefore have an impact on the overall embodied carbon emissions. Aggregates that meet AASHTO M 6 and AASHTO M 80 (ASTM C33) have proven to be satisfactory for use in concrete.

The primary considerations in choosing aggregate sources to support a reduction in the cradle-to-gate embodied carbon emissions of concrete are as follows:

- Aggregate shape and texture affect water demand, workability, and finishability.
- Aggregates must be durable. The primary durability concern is alkali-aggregate reactivity, which includes alkali-silica reactivity (ASR) and alkali-carbonate reactivity (ACR). AASHTO R 80/ASTM C1778 should be followed to identify potentially deleteriously reactive aggregates and to select appropriate preventive measures to minimize the risk of expansion when such aggregates are used in concrete. The guide discusses preventive measures for ASR-susceptible aggregates.
- Aggregates in some regions are also susceptible to damage (often referred to as D-cracking) when subjected to freezing and thawing. Agencies in regions that experience freezing and thawing cycles have developed mitigation strategies to address aggregate freeze-thaw damage largely based on AASHTO T 161/ASTM C666. (For example, see Chapter 4 in Harrington et al. [2018]).

Figure 6 (Chart 3) shows the pathways for reducing the embodied carbon emissions of paving concrete through consideration of the aggregates used in the mixture. These pathways are divided into the following categories:

- Reduce embodied carbon emissions in the production and transportation of aggregates.
- Use recycled, waste, and byproduct materials as aggregate.
- Use manufactured aggregates with reduced embodied carbon emissions.

Reduce Embodied Carbon Emissions in the Production and Transportation of Aggregates

The transportation of materials consumes a considerable amount of fuel and is responsible for roughly 4% of the embodied carbon emissions associated with concrete production (Choate 2003). Aggregates can be moved from the source (i.e., quarry or pit) to the concrete plant using one or more modes of transportation (e.g., truck, rail, or barge). In general, shipping from the source by rail or barge produces fewer embodied carbon emissions per ton-mile of material transported than shipping by truck. Table 1 demonstrates that moving aggregate by rail is over three times more efficient and moving aggregate by inland barge is over four times more efficient than moving aggregate by truck.

Ideally, aggregates would be sourced locally, minimizing the distance to the concrete plant. Aggregates transported long distances should be shipped by rail or barge, if possible, to a nearby distribution point where trucks can then deliver them to the plant. The embodied carbon emissions attributed to the transportation of aggregate are included in concrete facility-specific EPDs, and reductions in embodied carbon emissions related to transportation would be quantified there as part of the overall cradle-to-gate embodied carbon emissions of the concrete.

The guide also discusses the option to blend aggregates to improve quality.



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Figure 6. Chart 3: Pathways to reduce embodied carbon emissions of aggregates

Table 1. Estimated national average for freight movement fuel efficiency (diesel) and estimated embodied carbon emissions per ton per mile transported

Mode	Short Ton-Miles/Gallon Consumed	Embodied Carbon Emissions per Short Ton per Mile Travelled (kg $\mathrm{CO_2})^{\mathrm{a}}$
Truck ^b	150	0.0679
Rail	478	0.0213
Inland Barge	616	0.0165

^a The embodied carbon emissions per ton per mile were calculated based on one gallon of diesel fuel consumed emitting 22.44 lb (10.18 kg) of CO₂-eq. ^b Truck load assumed to be 25 tons on a truck with a 40-ton gross vehicle weight, loaded one way.

Source: Kruse et al. 2012

Use Recycled, Waste, and Byproduct Materials as Aggregate

The use of recycled, waste, and byproduct materials as aggregate, such as recycled concrete aggregates (RCA) (Cavalline et al. 2022), air-cooled blast furnace slag (Smith 2012), foundry sand, and even reclaimed asphalt pavement (RAP), in lieu of freshly mined and processed natural aggregate should be considered. The overall impact of the use of these materials on the embodied carbon emissions of the concrete needs to be assessed on a project-by-project basis because the use of recycled, waste, and byproduct materials does not in itself ensure that the embodied carbon emissions will be reduced. For more information on the use of construction and industrial byproduct materials in concrete production, see Cavalline and Sutter (2024) and Cavalline et al. (2024).

Use Manufactured Aggregates with Reduced Embodied Carbon Emissions

An emerging technology that offers the potential for significant reductions in the embodied carbon emissions of aggregates can broadly be characterized as CO2 mineralization. This technology uses alkaline minerals, often industrial wastes, to permanently sequester CO2 as part of carbon capture, utilization, and storage (CCUS). The products from CO2 mineralization can be used as artificial aggregates in concrete production. Several commercial products based on this technology are already on the market. The degree of CO₂ uptake is highly dependent on the alkaline mineral used and the mineralization process, and therefore each product must be characterized individually to accurately assess the impact of this strategy on reducing the embodied carbon emissions of concrete. Further, the quality of these artificial aggregates needs to be characterized to ensure their suitability for long-term use in concrete (Cao et al. 2021).

Strategy 4: Target Mixture Performance Requirements

When proportioning concrete mixtures, the common objective is to determine the most economical and practical combination of readily available materials to produce concrete that will satisfy specification requirements, such as workability (e.g., slump), air content, durability, and strength. To achieve long-term reductions in embodied carbon emissions, however, the requirements for concrete should be broadened through the adoption of performance specifications to include not only the cradle-to-gate embodied carbon emissions at the time of production but also properties more directly linked to the long-term performance of the concrete. The adoption of performance specifications also tends to allow for innovation, which itself can lower the embodied carbon emissions of paving concrete.

Implementing performance specifications can help agencies remove prescriptive requirements from their standards, permitting the development of mixtures with lower embodied carbon emissions that meet or exceed design requirements. Adopting AASHTO R 101 provides agencies with test methods that will allow them to specify what is needed for the concrete mixture to perform well instead of placing restrictions on the mixture that may unnecessarily limit the ability of the mixture designer to reduce embodied carbon emissions.

The approach in AASHTO R 101 reduces reliance on strength alone (especially 28-day strength) as the measure of performance and focuses more broadly on workability, volume stability, and durability. While it is recognized that strength is important, it is also acknowledged that higher strength does not necessarily mean longer lasting, better performing pavements. Further, it is recognized that early-age strength requirements can compromise long-term strength gain and durability. AASHTO R 101 also eliminates prescriptive minimum requirements for cementitious materials content and does not limit SCM replacement levels. Workability tests other than slump are included that can support optimized aggregate grading and lower cementitious contents for paving concrete. Durability requirements, including susceptibility to shrinkage cracking, freeze-thaw durability, and transport properties, are also found in AASHTO R 101.

Figure 7 (Chart 4) presents specific pathways in which performance specifications can help reduce the embodied carbon emissions of paving concrete.



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Figure 7. Chart 4: Pathways for reducing embodied carbon emissions related to performance specifications

Specific changes to performance specification requirements that have the potential to result in concrete with reduced embodied carbon emissions are as follows:

- Removal of slump limits, because it is known that slump has minimal usefulness for assessing the workability of stiff slipform paving mixtures
- Removal of prescriptive w/cm ratios, because this concept becomes less meaningful as portland cement is replaced with SCMs at high levels
- Assessment of strength for acceptance at later ages (e.g., 56 or 90 days) to accommodate the slower strength gain of concrete made with high levels of SCMs
- Assessment of opening to traffic by use of maturity or inplace strength assessment rather than time-based opening criteria.
- Removal of minimum cement contents and maximum pozzolan replacement levels

Strategy 5: Consider Other Factors

Other considerations that expand upon the strategies that have already been discussed can impact the embodied carbon emissions of concrete. These considerations lie beyond the traditional scope of current EPDs, which are almost exclusively focused on the Production stage (A1–A3), and therefore fall outside the narrow scope of the guide; however, these considerations are worth noting as opportunities for reducing the embodied carbon emissions of concrete. These considerations may also involve emerging technologies that are potentially important but difficult to categorize. Two considerations discussed in the guide include reducing fuel consumption in the production and transportation of concrete and using calcium carbonate mineralization in the production of concrete.

Quantifying

An essential step that an agency can take to reduce the cradle-to-gate embodied carbon emissions of concrete is to select an approach to benchmark the agency's current classes or grades of paving concrete and then use the same approach to assess progress over time.

Using an Environmental Product Declaration

The preferred tool used by public agencies to assess and understand the embodied carbon emissions of a material is to request an ISO 14025 Type III EPD to obtain environmental impact data, as discussed in the FHWA tech brief entitled *Environmental Product Declarations: Communicating Environmental Impact for Transportation Products* (Rangelov et al. 2021). As stated in that tech brief, "an EPD is a transparent, verified report of the environmental impacts of product manufacturing," including the resources consumed, energy used, and emissions generated. Global warming potential (GWP), which encompasses embodied carbon emissions and is measured in units of kg CO₂-eq/m³ or kg CO₂-eq/yd³, is one of many environmental impacts reported in the EPD. The use of an EPD is required to quantify the potential improvements offered by the strategies presented in the guide.

Figure 8 shows an example concrete EPD with typically included information. The reporting shown in this example is in accordance with requirements consistent with a product-specific Type III EPD as defined by the ISO.

ENVIRONMENTAL IMPACTS			
Declared Products:			
Description:Exterior 4000 PSI Compressive strength: 4000 PSI at 28 days			
Global Warming Potential (kg CO -eq)	318		
Ozone Depletion Potential (kg CFC-11-eq)	7.15E-6		
Acidification Potential (kg SO -eq)	0.95		
Eutrophication Potential (kg N-eq)	0.24		
Photochemical Ozone Creation Potential (kg O -eq)	20.7		
Abiotic Depletion, non-fossil (kg Sb-eq)	5.82E-5		
Abiotic Depletion, fossil (MJ)	658		
Total Waste Disposed (kg)	94.2		
Consumption of Freshwater (m ³)	2.40		
Product Components: natural aggregate (ASTM C33), Portland cement (ASTM C150), fly a C1602), admixture (ASTM C494), admixture (ASTM C260)	ash (ASTM C618), batch water (ASTM		

Rangelov et al. 2021

Figure 8. Sample information from a concrete EPD

It is important to use either product-specific or facilityspecific cement production data as appropriate when developing a concrete EPD. A product-specific EPD represents the environmental impacts of a specific product and manufacturer across multiple facilities (e.g., all AASHTO M 240/ASTM C595 Type IL cement produced by a cement manufacturer), whereas a facility-specific EPD is a product-specific EPD in which the environmental impacts are isolated to a single manufacturer and manufacturing facility (e.g., the AASHTO M 240/ASTM C595 Type IL cement produced at a given cement plant). In all cases, EPDs are developed to reflect a production environment (e.g., the conditions at a concrete plant) as opposed to a laboratory environment, where new mixtures might be evaluated.

Estimating the Embodied Carbon Emissions (Prior to Producing an Environmental Product Declaration)

Because the development of an EPD can require information that might not be available at the time an initial mixture design is developed, a supplier might initially want to use an embodied carbon emissions estimator (examples of which are listed below) to estimate the cradle-to-gate embodied carbon emissions of the concrete while awaiting development of a facility-specific concrete EPD. The use of data specific to the constituent materials will improve the precision of the estimation, especially product-specific and/or facility-specific cement production efficiency data obtained from an EPD.

Note that such estimates are not to be used in place of an EPD but should only be used as part of an initial approximation effort to determine potential reductions in embodied carbon emissions until an EPD can be produced. Specifiers should not use these estimation tools for the purposes of accepting a material or making informed decisions as part of the materials testing and evaluation process. As concrete mixture development continues, an EPD will need to be developed to support the decision-making process.

Tools for estimating the A1–A3 embodied carbon emissions of concrete are readily available online through a variety of entities. These include, but are not limited to, the following:

- National Ready Mixed Concrete Association (<u>https://nrmca.climateearth.com/</u>)
- Slag Cement Association (<u>https://www.slagcement.org/</u> <u>lca-calculator</u>)
- Circular Ecology (<u>https://circularecology.com/concrete-</u> embodied-carbon-footprint-calculator.html)
- WAP Sustainability Consulting (<u>https://thetaepd.com/</u> <u>signup/concrete</u>)

In addition to these tools, an example method is provided in Appendix B of the guide.

If these tools are utilized for the purposes of estimating the embodied carbon emissions of the production stage of a paving concrete, ensure that life-cycle stages beyond A1–A3 are not included in the estimation and that the sources of production efficiency data are appropriate.

Regardless of the approach taken, keep in mind that the estimate of the embodied carbon emissions of a newly formulated paving concrete is just that: an estimate. An estimate can help guide the early stages of mixture development, for example, but is insufficient to demonstrate that an actual reduction in embodied carbon emissions has been achieved. Doing so will require the development of an EPD.

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