GUIDE FOR

Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete









AASHTO

American Association of State Highway and Transportation Officials

First Edition

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AASHTO | American Association of State Highway and Transportation Officials

American Association of State Highway and Transportation Officials
555 12th Street, NW, Suite 1000
Washington, DC 20004
(202) 624-5800
transportation.org

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TABLE OF CONTENTS

ACKNOWLEDGMENTS XIV

PART 1: GENERAL 1-1

1.1. Introduction and Scope 1-1
1.2. Partnership Approach 1-3
1.3. Portland Cement and Emobided Carbon Emissions (ECEs) of Concrete 1-4
1.4. Implementation Considerations 1-5
1.5. Inadvertent Barriers Within Agency Specifications 1-5
1.6. Achieving Engineering Goals 1-6
1.7. Use of This Guide 1-6

PART 2: STRATEGIES 2-1

2.1. Strategy 1: Target the Cementitious Binder 2-1
2.1.1. Reduce Amount of Portland Cement Clinker 2-3
2.1.2. Increase Use of Supplementary Cementitious Materials 2-4
2.2. Strategy 2: Target the Concrete Mixture to Optimize Binder Content 2-5
2.3. Strategy 3: Reduce the Cradle-to-Gate ECEs of Aggregates 2-7
2.3.1. Reduce ECEs in the Production and Transportation of Aggregates 2-9
2.3.2. Use Recycled, Waste, and Byproduct Materials as Aggregate 2-10
2.3.3. Use Manufactured Aggregates with Reduced ECEs 2-10
2.4. Strategy 4: Target Mixture Performance Requirements 2-11
2.5. Strategy 5: Consider Other Factors 2-13
2.5.1. Reduce Fuel Consumption in the Production and Transportation of Concrete 2-13
2.5.2. Use Calcium Carbonate Mineralization in the Production of Concrete 2-14

PART 3: QUANTIFYING 3-1

3.1. Using an Environmental Product Declaration 3-1
3.2. Estimating the ECEs (Prior to Producing an Environmental Product Declaration) 3-2

GLOSSARY G-1

REFERENCES R-1

APPENDIX A. IMPLEMENTATION TABLES A-1

APPENDIX B. EXAMPLE METHOD FOR ESTIMATION OF ECEs A-21

APPENDIX C. REFERENCED DOCUMENTS A-25

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LIST OF FIGURES

Figure 1-1. Life-Cycle Stages 1-2

Figure 1-2. CO_2 Emissions for Quarrying, Cement Manufacturing, and Concrete Production . . 1-4

Figure 2-1. Effects of Supplementary Cementitious Materials on Hardened Concrete Properties 2-2

Figure 2-2. Chart 1: Pathways to Reduce Cradle-to-Gate Embodied Carbon Emissions Targeting the Cementitious Binder System. 2-3

Figure 2-3. Chart 2: Types of Supplementary Cementitious Materials. 2-5

Figure 2-4. Conceptual Illustration of Optimized Aggregate System 2-6

Figure 2-5. Tarantula Curve 2-7

Figure 2-6. Chart 3: Pathways to Reduce Embodied Carbon Emissions of Aggregates 2-9

Figure 2-7. Chart 4: Pathways for Reducing ECEs Related to Performance Specifications . . . 2-12

Figure 3-1. Sample Information from a Concrete Environmental Product Declaration. 3-1

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LIST OF TABLES

Table 2-1. Estimated National Average for Freight Movement Fuel Efficiency (Diesel) and Estimated Embodied Carbon Emissions per Ton per Mile Transported 2-9

Implementation Table AI-1A. Summary of Portland–Limestone Cement A-2

Implementation Table AI-1B. Summary of Blended Cements..... A-3

Implementation Table AI-1C. Summary of Performance Hydraulic Cements..... A-4

Implementation Table AI-1D. Summary of Non-Hydraulic Inorganic Cements A-5

Implementation Table AI-2A. Summary of Coal Ash A-6

Implementation Table AI-2B. Summary of Natural Pozzolans A-7

Implementation Table AI-2C. Summary of Slag Cement A-8

Implementation Table AI-2D. Summary of Ground Glass Pozzolan A-9

Implementation Table AI-2E. Summary of Alternative Supplementary Cementitious Materials..... A-10

Implementation Table AI-3. Optimized Aggregate Grading..... A-11

Implementation Table AI-4. Aggregate Pathways to Reduce the ECEs of Concrete..... A-13

Implementation Table AI-5A. Use of Performance Specifications to Reduce the ECEs of the Concrete Mixture..... A-14

Implementation Table AI-5B. Removal of Slump Limits..... A-15

Implementation Table AI-5C. Removal of Prescriptive Water-to-Cementitious Materials Ratios..... A-16

Implementation Table AI-5D. Later-Age Strength Acceptance..... A-17

Implementation Table AI-5E. Maturity for Early Opening to Traffic A-18

Implementation Table AI-5F. Removal of Minimum Cement Content and Maximum Pozzolan Replacement Amounts A-19

Table B-1. Embodied Carbon Emissions Estimation Results A-22

Table B-2. Concrete Constituent Contents and Transportation Details..... A-23

Table B-3. Transportation Details..... A-23

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PREFACE

First published by AASHTO in 2025, the *Guide for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete* offers several strategies for material selection and proportioning that transportation agencies and contractors can use to reduce the cradle-to-gate embodied carbon emissions (ECEs) of paving concrete. The Guide is intended to support agencies' efforts to apply the principles of sustainability by quantifying the environmental impacts of their pavement materials. Although focused primarily on mixtures for paving, many of the strategies presented can be extended to concrete mixtures for other applications, including structural and ancillary uses.

The principles of sustainability are increasingly being applied to the design, construction, and maintenance of pavement and roadway infrastructure. A commonly accepted definition of sustainability is articulated in a 1987 report by the Brundtland Commission, which states, "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987; see References).

To address this issue, a growing number of transportation agencies across the nation are striving to quantify the embodied environmental impacts and emissions of their pavement materials. Reducing transportation materials' embodied greenhouse gas (GHG) emissions is one way that transportation agencies can reduce the environmental impacts of the transportation systems they construct, own, operate, and maintain. To do this successfully, agencies need clear guidance on strategies to reduce the cradle-to-gate ECEs of their transportation construction materials.

Nationally, the Inflation Reduction Act (IRA) established the Low-Carbon Transportation Materials (LCTM) Grants program, which provides funding for the use of construction materials that have substantially lower levels of GHGs. The purpose of the program is to reimburse or provide incentives to eligible recipients for the use, in projects, of construction materials and products that have substantially lower levels of embodied GHG emissions associated with all relevant stages of production, use, and disposal as compared to estimated industry averages of similar materials or products (U.S. EPA, 2024; see References).

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- Jamie Farny, Portland Cement Association
- Lindsey Geiger, Portland Cement Association
- Josh Gilman, Portland Cement Association
- Al Innis, Al Innis Consulting LLC
- Jim Mack, CEMEX
- Maria Masten, Minnesota Department of Transportation
- Dave Mensching, Federal Highway Administration
- Jim Pappas, Delaware Department of Transportation
- Mike Praul, Federal Highway Administration
- Kurt Smith, Applied Pavement Technology, Inc.
- Kerry Sutton, Slag Cement Association
- Paul Tennis, Portland Cement Association
- Michelle Wilson, Portland Cement Association

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PART 1. GENERAL

1.1. INTRODUCTION AND SCOPE

The principles of sustainability are increasingly being applied to the design, construction, and maintenance of pavement and roadway infrastructure. A commonly accepted definition of sustainability is articulated in a 1987 report by the Brundtland Commission, which states, "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987; see References). The report further describes sustainability as encompassing three aspects collectively referred to as the "triple bottom line" of sustainable development: environmental, social, and economic impacts. Sustainable solutions are those that recognize and attempt to balance all three aspects in the context of the goals, demands, characteristics, and constraints of a given project. The Federal Highway Administration's (FHWA's) *Towards Sustainable Pavement Systems: A Reference Document* (Van Dam et al., 2015; see References) identifies the features of a sustainable pavement as "system characteristics that encompass a pavement's ability to

1. achieve the engineering goals for which it was constructed,
2. preserve and (ideally) restore surrounding ecosystems,
3. use financial, human, and environmental resources economically, and
4. meet basic human needs such as health, safety, equity, employment, comfort, and happiness."

To partially address the second goal, a growing number of transportation agencies across the nation are striving to quantify the embodied environmental impacts and emissions of their pavement materials. Reducing the embodied greenhouse gas (GHG) emissions (referred to as embodied carbon emissions [ECEs] in this *Guide*) of transportation materials is one way that transportation agencies can reduce the environmental impacts of the transportation systems they construct, own, operate, and maintain. To do this successfully, agencies need clear guidance on strategies to reduce the cradle-to-gate ECEs of their transportation construction materials.

This *Guide* offers several strategies for material selection and proportioning that transportation agencies and contractors can use to reduce the cradle-to-gate ECEs of paving concrete. In the product life cycle defined by the International Organization for Standardization (ISO), illustrated in Figure 1-1, 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 ECEs of a transportation system, these stages are not included in the scope of this *Guide*. Despite not being included, these stages of a pavement life cycle also present significant opportunities to reduce the life-cycle ECEs of concrete pavement. As life-cycle assessment (LCA) use-phase modeling becomes more robust, these factors are likely to be included to provide a more complete assessment of the carbon emissions associated with a given concrete pavement.

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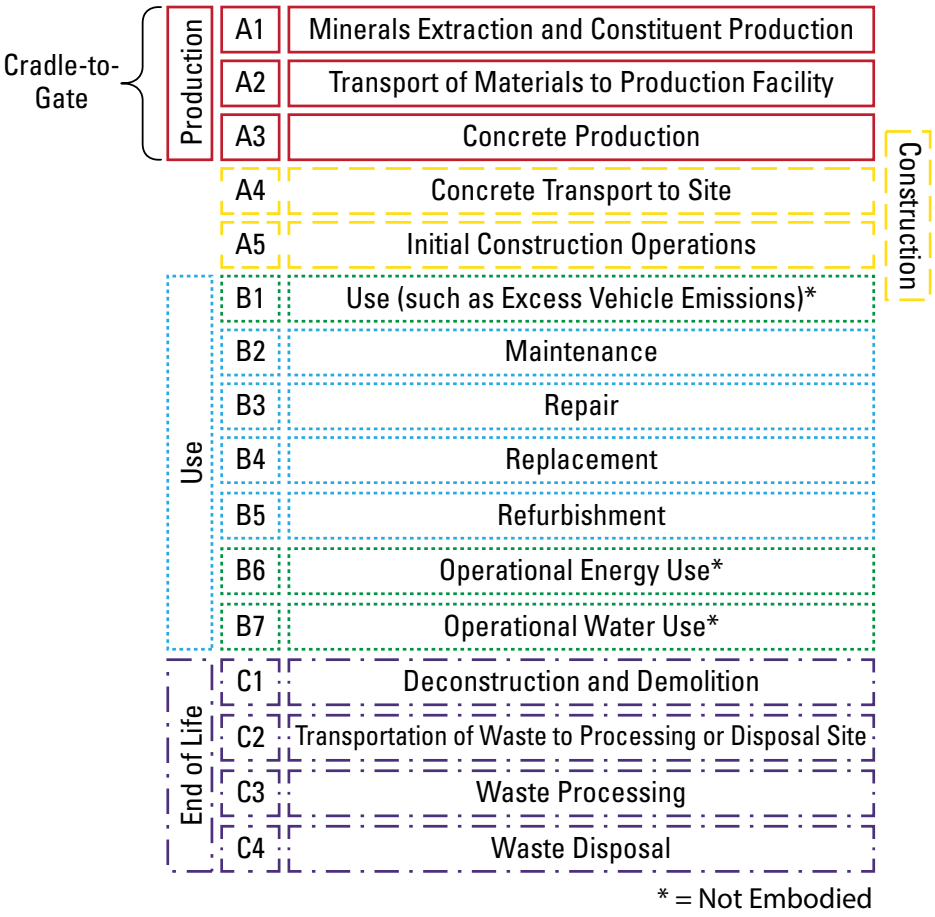


Figure 1-1. Life Cycle Stages (Source: FHWA, modified from ISO 21930)

By focusing on reducing the cradle-to-gate ECEs of paving concrete during the Production stage, the strategies presented in this *Guide* can serve as an important early step in bringing attention to the need for broader carbon reduction while implementing quantifiable change. The ability to reduce the embodied carbon of concrete in a given location certainly depends a great deal on existing practice and the availability of concrete-making materials; a dramatic change in the types of cementitious materials used may be needed in some locations, while simple changes in mixture proportioning may be needed in others. In all cases, however, the strategies described in this *Guide* are within the scope of material suppliers and contractors as well as designers, material specifiers, and construction staff representing the interests of public/private agencies and owners of the assets. Most of the strategies presented can be implemented immediately to produce positive short-term improvements while broader, longer-term actions are planned. Early successes achieved during the Production stage can be built upon to further reduce ECEs in later stages of the concrete life cycle.

Strategies are presented for reducing the cradle-to-gate ECEs of concrete throughout all aspects of the Production stage, including raw material acquisition and processing (A1), transportation of materials to the concrete plant (A2), and in-plant concrete production (A3). Strategies to reduce the impacts of aggregates, whether mined or recycled, are discussed, while strategies to be utilized by cement producers (such as alternative fuels, renewable energy for cement plant operations, carbon capture) and supplementary cementitious materials (SCMs) suppliers (for example, waste recovery, processing

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options, CO_2 mineralization) are not discussed in detail because these processes are not under the direct control of concrete suppliers or agency representatives. However, reductions in ECEs will be evident in each concrete mixture's environmental product declaration (EPD), which incorporates the EPDs provided to the concrete supplier for the individual concrete constituents. The impacts of transporting constituent materials to the concrete plant (A2) are also accounted for in the EPD provided by the concrete supplier for each concrete mixture.

In describing the strategies for reducing the ECEs of concrete, the *Guide* emphasizes that concrete mixture proportioning should consider the economic and workability aspects of the mixture while ensuring that all performance requirements are met, including all engineering (such as strength, durability) and environmental requirements. This requires diligence in selecting desirable materials, the use of an appropriate approach to determine concrete mixture proportions, and adherence to best practices during concrete manufacture to ensure that the concrete is uniformly produced to facilitate proper placement, finishing, and curing.

1.2. PARTNERSHIP APPROACH

Lowering the ECEs of concrete requires a partnership effort, and, for this effort to be successful, it is important to engage relevant stakeholders early in the process. Among many criteria, public agencies desire innovations that are scalable, practical, and safe (Jamshidi, 2024; see References). 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.

A successful partnership involves early engagement of the affected parties in a planning or partnering meeting where the goals for reducing ECEs are communicated and discussed. Concrete producers and other material suppliers can play a key role in reducing ECEs because they have access to expertise and resources that owners and contractors do not, and they have significant expertise with locally available materials. Engaging concrete producers in the conversation allows them to contribute to the broader project goals by potentially selecting constituent materials that reduce the ECEs of the concrete. Concrete producers' expertise with locally available materials also gives them an in-depth understanding of how these materials can be combined and how interactions and compatibility can impact performance. Engaging this expertise facilitates compliance with the overarching goal to optimize concrete mixtures while achieving engineering goals and quantifiable carbon emission reduction. At the same time, owners/agencies and their representatives must recognize that current specifications may limit certain opportunities for reducing ECEs in concrete mixtures. Examples of such barriers are discussed in Sections 1.4, 1.5, 1.6, and Appendix A of this *Guide*. Mixture producers need to be aware that novel materials or new and innovative mixtures will act differently in a mixture. Possible impacts of specific strategies are outlined below, but it is ultimately up to the mixture producer to conduct additional quality control testing as needed, and make sure that changes to mixture designs don't negatively impact their ability to meet specifications. Owners should also be mindful of an increased need for quality assurance when using novel materials or new and innovative mixtures.

Given this reality, taking specific actions early in the process to make all parties aware of the project's goals for reducing ECEs makes it much more likely that these goals will be achieved. Communicating with partners early and often during project planning may avoid the need for changes and adjustments

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