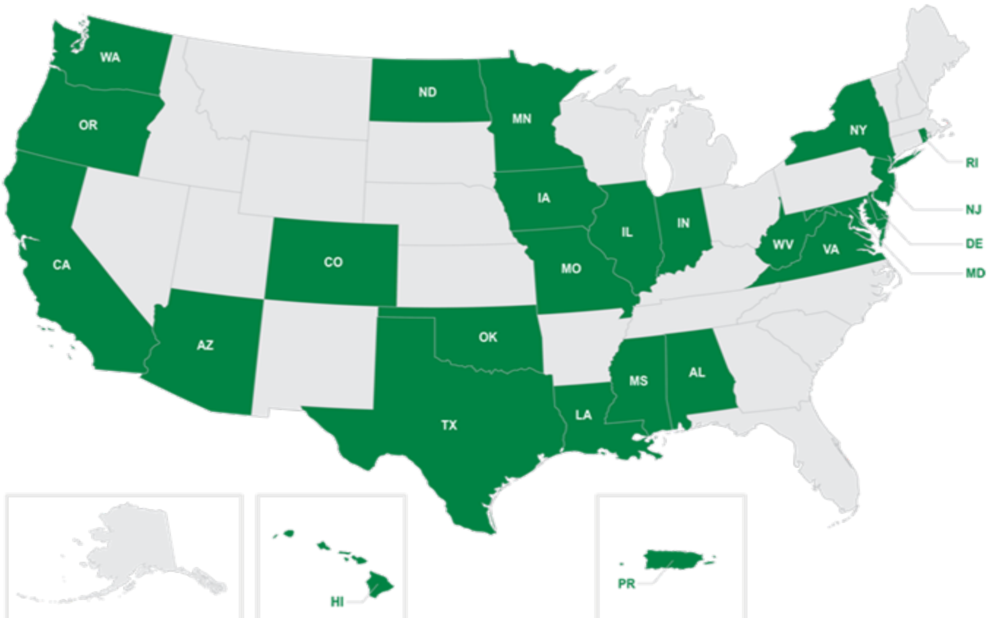
A Roadmap for Missouri: Assessing Needs an Implementation Framework for Incorporating Environmental Product Declarations



February 2025
Final Report

Project number TR202324
MoDOT Research Report number cmr 25-002

PREPARED BY:

John T. Kevern, Ph.D., P.E.

William Buttlar, Ph.D., P.E.

Punyaslok Rath, Ph.D.

Nandita Gettu

Iain Blair

University of Missouri-Kansas City and University of Missouri-Columbia

PREPARED FOR:

Missouri Department of Transportation

Construction and Materials Division, Research Section

Technical Report Documentation Page

1. Report No. cmr 25-002	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Roadmap for Missouri: Assessing Needs an Implementation Framework for Incorporating Environmental Product Declarations		5. Report Date December 2024 Published: February 2025 6. Performing Organization Code
7. Author(s) John T. Kevern[1], Ph.D., P.E., https://orcid.org/0000-0003-0038-4107, William Buttlar[2], Ph.D., P.E. https://orcid.org/0000-0002-1545-0165, Punyaslok Rath[2], Ph.D. https://orcid.org/0000-0002-6546-5429, Nandita Gettu[2], https://orcid.org/0009-0007-2950-3233, Iain Blair[1]		8. Performing Organization Report No.
9. Performing Organization Name and Address [1]University of Missouri - Kansas City 5110 Rockhill Road Kansas City, MO 64110 [2]Univerity of Missouri - Columbia 416 S Sixth St., Columbia, MO 65211		10. Work Unit No. (TRAIS) 11. Contract or Grant No. MoDOT project # TR202324
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR-B) Construction and Materials Division P.O. Box 270 Jefferson City, MO 65102		13. Type of Report and Period Covered Final Report (March 2023-December 2024) 14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at https://www.modot.org/research-publications.

16. Abstract
This report details the Missouri Department of Transportation's activities within the Federal Highway Administration's Climate Challenge program. The purpose of the program was three-fold, 1) to increase knowledge of environmental product declarations (EPDs) within the Missouri asphalt and concrete industry, 2) to assess the current state of Missouri EPDs and compare with appropriate regional and national benchmarks, and 3) to provide recommendations for lowering the global warming potential (GWP) of asphalt and concrete mixtures. Various government and private entities across the U.S. are at disparate positions regarding the requirement and application of EPDs. The ultimate goal of this process is to assess the state-of-the practice in Missouri, to support future informed decision-making. Per-phase GWP benchmarks for Missouri's asphalt EPDs were determined as per NAPA's benchmarking system for asphalt mixtures. However, limited data from asphalt plants in Missouri were available. The asphalt mixtures were also assessed to identify carbon-intensive mixture types and processes. Based on the findings, recommendations were made to lower the GWP of the asphalt mixtures to conform to the benchmarks. Very few concrete EPDs currently exist in Missouri, and none have been specifically created for MoDOT concrete mixtures. The existing EPDs are all consistent with NRMCA regional benchmarks. With relatively small allowable increases to the SCM content within the specifications or adoption of pavement Performance Engineered Mixtures (PEM), all concrete mixtures could achieve the US General Services Administration's GWP benchmarks with most exceeding the top 20% category. For MoDOT to set feasible benchmarks within the state, more mixture-specific EPDs need to be generated and collected.

17. Key Words Environmental product declarations; EPDs; Asphalt; Concrete; Low carbon transportation materials		18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 43	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

A Roadmap for Missouri: Assessing Needs an Implementation Framework for Incorporating Environmental Product Declarations

By

John T. Kevern, PhD, PE, F.ASCE, FACI, LEED AP
University of Missouri-Kansas City

William G. Buttlar, PhD, PE
University of Missouri-Columbia

Punyaslok Rath, PhD
University of Missouri-Columbia

Nandita Gettu
University of Missouri-Columbia

Iain Blair
University of Missouri-Kansas City

Prepared for
Missouri Department of Transportation

January 2025

Final Report

MoDOT MCTI Project #TR202324

Disclaimer

Data for this report was prepared under the research project TR202324, sponsored by the Missouri Department of Transportation (MoDOT). The content of this report reflects the views of the authors, who are responsible for the accuracy, analysis, and any inferences drawn from the information or material presented. This report does not endorse or approve any commercial product, even though trade names may be cited, does not reflect official views or policies of the Department or, and does not constitute a standard specification or regulation of the Department.

Acknowledgments

The research team would like to thank the Missouri Department of Transportation (MoDOT) for their generous support of this research. We would especially like to thank Jen Harper, Jenni Hosey, and Brett Trautman for their contributions in completion of this project.

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AASHTO........................American Association of State Highway and Transportation Officials

ACI...............................American Concrete Association

ACPA............................America Concrete Paving Association

BIL ....Bipartisan Infrastructure Law

DOT .... Department of Transportation

EC3...............................Embodied Carbon in Construction Calculator

EDC..............................Every Day Counts

EPA..............................U.S. Environmental Protection Agency

EPD..............................Environmental Product Declaration

FHWA .... Federal Highway Administration

GHG.............................Greenhouse Gas

GSA..............................U.S. General Services Administration

GWP.............................Global Warming Potential

ISO...............................International Organization for Standardization

LCA..............................Life Cycle Assessment

LCCA............................Life Cycle Cost Assessment

LCI...............................Life Cycle Inventory

LCTM...........................Low Carbon Transportation Materials

LF.................................Lime filler

MSCR...........................Multiple Stress Creep Recovery

NAPA...........................National Asphalt Pavement Association

NMAS..........................Nominal Maximum Aggregate Size

NRMCA........................National Ready Mixed Concrete Association

NTL .... National Transportation Library

PCCP............................Portland Cement Concrete Pavement

PCR..............................Product Category Rules

pcy...............................pounds per cubic yard

PG................................Performance Grading

PPA...............................Polyphosphoric Acid

RAP..............................Reclaimed Asphalt Pavement

RAS..............................Recycled Asphalt Shingles

ROSA P .... Repository & Open Science Access Portal

RV................................Reference Value

SBS...............................Styrene-Butadiene-Styrene

SCM.............................Supplemental Cementitious Material

23 CFR 420 .... Code of Federal Regulations, Title 23, Part 420

Executive Summary

Missouri Department of Transportation's (MoDOT) Climate Challenge project focused on two construction materials – asphalt and concrete. The primary goal of this project was to identify the key gaps in the implementation of Environmental Product Declarations (EPDs) across the construction industry and, to the extent possible, bring the industry up to speed with the latest developments. To that end, the researchers conducted a thorough review of the existing literature and conducted benchmarking studies for asphalt and concrete mixtures in Missouri. In addition, the researchers sought to bridge the information gap at the federal and local level by attending nationally organized meetings discussing sustainability efforts and disseminating that information within the state of Missouri through invited presentations at key conferences. The following sections detail the benchmarking efforts undertaken with this grant and provides key recommendations.

As the program operator for the asphalt industry, the National Asphalt Pavement Association (NAPA) has undertaken initiatives towards lowering greenhouse gas (GHG) emissions in asphalt mixture production. NAPA has established global warming potential (GWP) benchmarks for cradle-to-gate (A1-A3) life cycle stages of asphalt mixtures. To make asphalt life cycle assessment (LCA) and EPDs more effective, NAPA has recently made various updates to the product category rules (PCR) for asphalt mixtures. However, several key data gaps and limitations persist in the PCR and asphalt EPDs. These gaps and limitations were identified are as follows:

- The system boundary specified for asphalt LCA only accounts for the life cycle stages in the mixture production stage i.e., acquisition of materials (A1), transportation (A2) and asphalt plant operations (A3) of the asphalt mixtures of asphalt pavements. The environmental impacts associated with the construction of pavements (A4-A5), the use and maintenance (B1-B7), and the end-of-life stages (C1-C4) are not quantified or reported.
- Common mixture ingredients such as warm mix additives, anti-strip agents, cellulose and synthetic fibers, dry-process ground tire rubber and recycled waste plastic, amongst other materials, remain as data gaps.
- Environmental impacts related to A3 are a representation of the average annual impacts associated with the asphalt plant and therefore do not accurately depict the impacts respective to the production of a specific asphalt mixture.
- Inconsistencies with respect to asphalt mixture terminologies and lack of transparency in the EPDs were detected.

As a part of this research, a benchmarking study was conducted based on Missouri's asphalt EPDs published through NAPA's Emerald Eco-Label EPD tool, as GWP benchmarks specific to Missouri were not determined by NAPA. GWP data from a total of 86 EPDs were considered for this study. The benchmarks were determined as per NAPA's benchmarking method, where the top 20%, 40% and 50% best-performing limits and average GWP values were quantified. For the acquisition of materials stage (A1), the mixtures were categorized based on the type of mixture

or binder modifiers used in the mixture. Benchmarks were quantified for mixture categories that had sufficient data points, namely, virgin mixtures, mixtures with reclaimed asphalt pavement (RAP), and mixtures with RAP and polyphosphoric acid (PPA). Other mixture categories with fewer than five data points included mixtures exclusively with or with a combination of styrene-butadiene-styrene (SBS), PPA, recycled asphalt shingles (RAS), and lime filler. Assessing the average A1 GWP values of the mixture categories, it was found that the use of RAP in asphalt mixtures can reduce GWP emissions by 16% compared to virgin mixtures, while mixtures with RAP and PPA saw GWP reductions of 6%. Although benchmarks for Missouri are not available, NAPA more recently published state-wise A1 GWP reference values for Missouri's asphalt mixtures with a nominal maximum aggregate size (NMAS) of 12.5 mm and smaller. NAPA's reference values for Missouri were comparable to the reference values computed in this study.

NAPA stated that GWP values exhibited in the A2 (transportation) and A3 (asphalt plant operations) phases are influenced by regional and climatic factors and therefore, benchmarks were determined in accordance with the American Association of State Highway and Transportation Officials' (AASHTO) climate zones. The A2 GWP benchmarks quantified for Missouri were marginally higher than NAPA's reference values for the wet-freeze zone and the benchmarks for all states collectively, excluding Florida and Louisiana. While the A3 GWP benchmarks for Missouri were higher than NAPA's A3 benchmarks for the wet-freeze zone, limited asphalt plant data was available in the Missouri EPDs. Only seven data points were considered for the evaluation of the A3 benchmarks, resulting in an inaccurate representation of the GWP emissions of asphalt plants in the region.

Finally, GWP benchmarks for the overall production stage (A1-A3) of Missouri asphalt mixtures were quantified. The asphalt mixtures had an average GWP of 76.5 kilograms of CO2 equivalent, per ton of asphalt mixture. Average A1-A3 GWP values were evaluated for each mixture category to identify the high carbon-intensive mixture types and the carbon-efficient processes. The following GWP trends were observed:

- Mixtures with a combination of SBS and lime filler exhibited the highest average GWP values compared to all other mixture types, with an average GWP of 183 kg-CO2e/ton.
- All mixture categories containing lime filler had average GWP values higher than 90 kg-CO2e/ton.
- Mixtures exclusively with RAP exhibited the lowest GWP values, with an average of 65 kg-CO2e/ton.
- Mixtures with SBS and PPA-modified binders exhibited average GWP values in the range of 82-92 kg-CO2e/ton.

Based on the findings and conclusions of this study, the following recommendations are made to produce lower-embodied carbon asphalt mixtures:

- Utilizing recycled materials that reduce the consumption of virgin binder and aggregates in asphalt mixtures, such as RAP, is the most effective method to reduce GWP emissions.

- Use of aggregates and mineral fillers from local sources can assist in maintaining low GWP emissions in the transportation stage.
- Evaluation of environmental impacts associated with technologies that lower mixture production temperatures, namely warm mix asphalt and rejuvenators.

The National Ready Mix Concrete Association (NRMCA), as the program operator for concrete mixtures, has undertaken initiatives towards lowering GHG emissions in concrete mixture production by establishing GWP baselines for cradle-to-gate (A1-A3) life cycle stages of concrete. The baselines were assessed using the Building Transparency ED3 tool. This tool contains a repository of EPDs which are provided by various US program operators. The Missouri EPDs were compared with NRMCA regional baselines and the GSA benchmarks for cement and concrete. The top 20%, 40%, and 50% best-performing limits and average GWP values were quantified. A total of 17 Missouri-specific EPDs were considered for this study.

Since A1 cementitious materials contribute 85% of the total GWP of the mixture production, optimizing the amount and the composition of the cementitious materials produces the greatest GWP reduction to a concrete mixture. As such, the A1 GWP embodiment of the Missouri B, B-1, B-2, MB-2, and PCCP mixes from data provided by MoDOT, were assessed assuming a 2020 baseline. None met the criteria for the GSA top 20% classification of <284 kgCO2e. B and MB-2 met the top 40% classification of <326 kgCO2e, and all but B-2 met the top 50% classification of <352 kgCO2e. When the assessment is updated to the current practice of using ASTM C595 Type IL cement, B and MB-2 mixtures achieve the top 20% classification with B-1 and PCCP meeting the top 40% classification. Additional scenarios were evaluated to include various levels of supplemental cementitious materials (SCM) currently allowed and consideration of performance engineered mixtures (PEM) for concrete pavement. With current practice updates, most mixture classifications were able to achieve the GSA'S best 20% performance benchmark.

Based on the findings and conclusions of this study, the following recommendations are drawn for lower-embodied carbon asphalt mixtures:

- Sufficient, Missouri-specific EPDs do not exist for MoDOT mixtures. Before benchmarking can occur, significant data collection is required to address regional variability. MoDOT should begin requiring EPD submissions for concrete mixtures.
- The B-2 mixture had the highest GWP. Since MB-2 is already allowed, remove B-2 as a mixture option under normal circumstances.
- Increase the minimum SCM replacement rate to replace higher-carbon cement with lower carbon waste materials that yield more durable mixes.
- Implement performance engineered concrete mixtures for pavements which are accepted, industry-wide, as being more durable and used in 28 other state DOTs.
- Incentivize ternary mixtures (a combination of 3 SCMs) on all projects and require ternary mixtures for those applications with the highest exposure conditions, such as mainline pavement, as ternary mixtures are accepted, industry-wide, as being the most durable, resilient, and sustainable mixes.

Chapter 1. Introduction

1.1 Background and Motivation

The Infrastructure Investment Job Act (public law 117-58), also referred to as the Bipartisan Infrastructure Law (BIL), was put into effect in November 2021 by the Biden administration. This law provides financial means for the US Department of Transportation (DOT) to invest resources into the infrastructure and transportation sectors across the country. With trillions of dollars of authorized funding available, a sizable portion has been invested in new major projects, with the rest invested in rehabilitation programs. For example, investments include $148 billion into the National Highway Performance Program, $27 billion for the Bridge Formula Program, $7 billion for the Carbon Reduction Program, and $300 million into the Highway Research and Development Program. A grand total $326 billion has been dedicated to roads, bridges and other major projects (Landrieu, 2022). These funds are allocated to recipients via various funding mechanisms including competitive grants, federal expenditures, formula grants, and cooperative agreements.

The Federal Highway Administration's (FHWA) Climate Challenge grant was amongst several programs initiated by BIL funding to facilitate the reduction of embodied carbon in pavement materials and practices. The objective of the grant was to motivate state DOTs and other public sector stakeholders to implement environmentally conscious practices for long-term reduction of greenhouse gas (GHG) emissions in pavement construction. A total of 27 state and local agencies were selected as recipients of this grant, as shown in Figure 1.1, with a minimum funding of $80,000 per state DOT and cumulative funding of $7.1 million across the US. The participants are encouraged to explore Life Cycle Assessment (LCA) to quantify the GHG emissions released throughout the life cycle of a pavement and report the GHG impacts through publicly available documents known as Environmental Product Declarations (EPDs). The availability of EPDs for construction materials is a crucial step in the adoption of low carbon materials in pavement construction. Another noteworthy program focused on is Every Day Counts' (EDC) EPDs for sustainable project delivery program. EDC-7, which is the latest edition of the EDC program, focuses on enabling the current procurement process for construction materials to be supplemented with environmental impact quantifications through life cycle assessment. More details on the program are available through FHWA (FHWA, 2024a).

In Missouri, there were a limited number of EPDs available for concrete and asphalt mixtures at the time of application for this grant. MoDOT also identified several gaps of knowledge and needs to be met to ensure participation by industry and other stakeholders in producing EPDs and adopting low carbon construction materials in pavement construction. These gaps were primarily related to the lack of technical knowhow and general awareness about EPDs and related literature. The creation of a facility-specific Type III EPD is a non-trivial task that includes following specific Product Category Rules (PCR) set by a program operator. For instance, the National Asphalt Pavement Association (NAPA) serves as the program operator for the asphalt mixture PCR. NAPA also provides an EPD tool, known as the Emerald Eco-Label, to create, verify and publish the EPDs. The Emerald Eco-Label tool taps into the existing public database which allows the user to compute the environmental impacts of an asphalt mixture produced in a specific plant. Similarly, for concrete mixtures the National Ready Mixed Concrete Association (NRMCA) and the American Concrete Pavement Association (ACPA) utilize another EPD software called Theta EPD. An auxiliary goal of this grant was to help Missouri public industries and MoDOT progress to the point where they could take advantage of large-scale grants, such as the Low Carbon Transportation Materials (LCTM) grant, to increase the adoption of low carbon construction materials without any compromise on pavement service life.

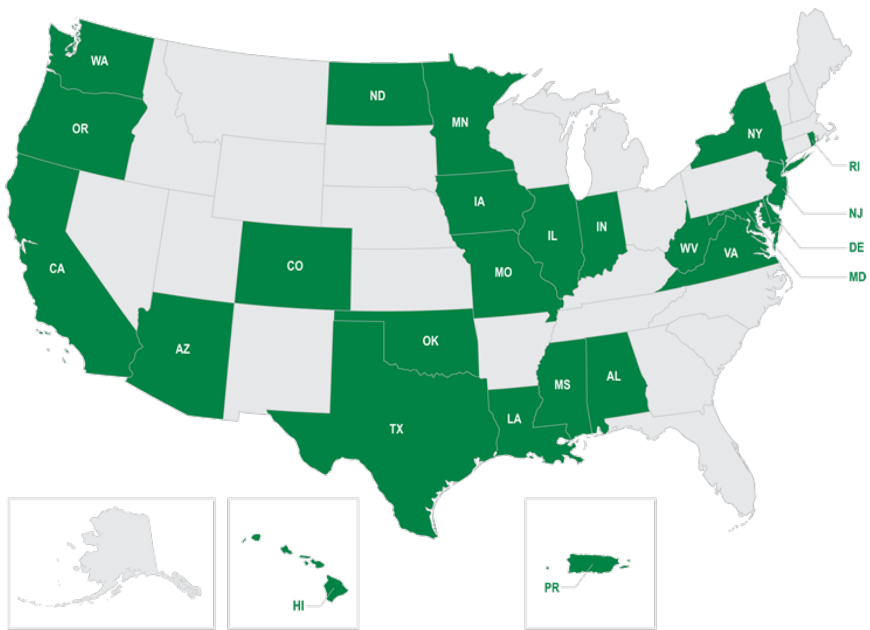


Figure 1.1. Climate Challenge participants (FHWA, 2024b)

1.2 Goals and Objectives

With a federal push for the adoption of substantially lower embodied carbon transportation materials, the collection of pertinent foreground and background data and the generation of accurate EPDs is expected to be critical. This grant's goal was primarily to get the construction industry up to speed with EPDs and other relevant information. To that end, this project had the following defined objectives:

a) To increase the knowledge of EPDs within the Missouri asphalt and concrete industry.
b) To assess the current state of Missouri EPDs and compare with appropriate regional and national benchmarks.
c) To provide recommendations for lowering the GWP of asphalt and concrete mixtures.
d) To disseminate relevant information to various stakeholders through presentations at key state and national conferences.

1.3 Organization of Report

This remainder of this report is organized in the following manner:

Chapter 2 – Quantifying Carbon Footprint

Chapter 3 – Material Specific Considerations

Chapter 4 – Benchmarks for Asphalt Mixtures

Chapter 5 – Benchmarks for Concrete Mixtures

Chapter 6 – Recommendations for Mixtures

Chapter 7 – Project Team Activity Summary

Chapter 8 – Summary and Recommendations

Chapter 2. Quantifying Carbon Footprint

2.1 Overview

This section encompasses the terminologies and components relating to life cycle assessment and environmental product declarations essential for GHG quantification and reporting. Additionally, various LCA software programs and databases applicable for pavement LCA were outlined.

2.2 Life Cycle Assessment and Environmental Product Declarations

Life cycle assessment is a systematic analytical tool or method to quantify the environmental impacts of the processes involved in a system or manufacturing of a product. Evaluation through LCA mainly consists of four different steps, namely, goal and scope definition, life cycle inventory assessment, life cycle impact assessment and life cycle interpretation (ISO, 2016). Environmental Product Declarations provide a means to publish and report the emissions quantified through a LCA, pertaining to a particular product (FHWA, 2020). ISO 14040 through ISO 14043 are the standards set by the International Organization for Standardization (ISO) corresponding to the principles and different stages of life cycle assessment. ISO 14025 is the standard that provides procedure for EPDs (ISO, 2006). To further implement standardization in the composition of EPDs, guidelines and requirements from documents known as product category rules (PCRs) are applied. PCRs are produced by designated entities or program operators respective to the product category and are compiled consistently with the aforementioned ISO standards. Along with the interpretations from conducting LCA analysis, other essential details from the LCA framework such as system boundaries, functional unit, environmental impact indicators, etc., are also included in EPDs, which allows decisionmakers to have region and product-specific information on the product (Rangelov et al., 2021). The parameters of LCA for a product can be tailored based on the needs of the entity generating the EPD. Based on the generating-entity, EPDs are generally classified as industry-wide, product specific, facility specific or supply-chain specific (Kardish, 2022; Waldman et al., 2020).

Some of the key considerations for LCA include the life cycle stages accounted for in the study (cradle-to-gate) and method of impact assessment to calculate different environmental categories. Most EPDs provide environmental impact quantifications for the material production stage (A1-A3) which can further be broken down into extraction and acquisition of raw materials (A1), the transportation phase (A2) and manufacturing of the product (A3). The stages succeeding the material production stage, namely, the construction, use, and end-of-life stages are often excluded. The LCA modules under each life cycle stage are shown in Figure 2.1 (Lewis 2021). The types of impact indicators in an EPD are dependent on the impact assessment method used in the LCA process. To name a few, Cumulative Energy Demand computes the total energy use in a life cycle, while TRACI 2.1, ReCiPe Midpoint and Endpoint, CML and eco-indicator 99 give a combination of the following impacts: global warming potential or climate change, acidification, resource depletion, ecotoxicity, eutrophication, human toxicity, ozone layer depletion, photochemical oxidation, ionizing radiation, and land use.

Construction Works Life Cycle Information Within the System Boundary															Optional supplementary information beyond the system boundary
A1-A3			A4-A5		B1-B7					C1-C4				D
Production Stage			Construction Stage		Use Stage					End-Of-Life Stage				
A1	A2	A3	A4	A5	B1	B2	B3	B4[a]	B5	C1	C2	C3	C4	
Extractional upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance (incl. production, transport, and disposal of necessary materials)	Repair (incl. production, transport, and disposal of necessary materials)	Replacement (incl. production, transport, and disposal of necessary materials)	Refurbishment (incl. production, transport, and disposal of necessary materials)	Deconstruction / Demolition	Transport to waste processing or disposal	Waste processing	Disposal of waste	Potential net benefits from reuse, recycling, and/or energy recovery beyond the system boundary
			Scenario	*Scenario*	*Scenario*	*Scenario*	*Scenario*	*Scenario*	*Scenario*	*Scenario*	*Scenario*	*Scenario*	*Scenario*	*Scenario*
					B6 Operational Energy Use *Scenario*									
					B7 Operational Water Use *Scenario*									

[a] Replacement information module (B4) not applicable at the product level

Figure 2.1. Common life cycle stages and their information modules for construction products and construction works (FHWA, 2024c)

2.3 LCA Software

Various software systems exist to perform LCA for users of different levels, ranging from beginners to LCA experts. The appropriate LCA software for a user can depend on an array of factors, for instance, purpose of performing LCA, region of application, need for life cycle-cost assessment (LCCA), type of pre-existing LCA database in the software, and other software related features. SimaPro and GaBi are paid software that are amongst the most commonly used software in the construction materials industry. Other free and open-source software, particularly for pavements, are also available. OpenLCA and Athena are two examples. Different life cycle inventory databases can be added to these software programs with a few popular datasets like Ecoinvent, Agri-footprint and USLCI pre-embedded in some. Other LCA tools for specific purposes are also established by different industries, a good example of such a software is the LCA Pave Tool developed by the Federal Highway Administration (FHWA). This tool allows users to quantify and evaluate environmental impacts for diverse types of pavements.

Chapter 3. Material Specific Considerations

3.1 Overview

The implementation of EPDs is gradually increasing across the US. However, several challenges still exist in both the concrete and asphalt industry with respect to their efficiency and development. This section deals with the progress of EPDs in the US, their current state in Missouri, and their shortcomings respective to each industry.

3.2 Asphalt

3.2.1 State of Asphalt EPDs in the US

In the US, asphalt mixture EPDs follow the guidelines of the PCR structured by the National Asphalt Pavement Association (NAPA), the designated program operator for asphalt mixture PCR. The first version of the PCR was established in 2017 and was valid until January 2022, which is the typical period of validity for PCRs i.e., 5 years. The current version (version 2.0) was put into effect in April 2022, providing specifications to develop cradle-to-gate EPDs (A1-A3) for a ton of asphalt mixture, which is the declared unit (NAPA, 2022). As of 2024, NAPA has been effective in facilitating the generation of EPDs across fifty states in the US, with a varying number of asphalt mixtures from different plants for each state. Table 3-1 shows the progress of the thirty-eight states that have published EPDs through NAPA's Emerald Eco-Label tool at the end of 2023. NAPA has also made efforts to release an EPD simulator, an addition to the Emerald Eco-Label software, for educational purposes.

Table 3-1. EPDs per state in the US

-	2023		2024	
State	**Plant**	**EPDs**	**Plant**	**EPDs**
FL	20	326	24	446
PA	14	195	36	979
CA	21	135	33	215
CO	27	101	37	138
TX	14	79	21	103
NY	9	77	21	133
OR	11	58	11	59
OK	10	49	10	51
WA	10	49	12	52
AR	8	48	8	48
UT	8	48	8	47
MD	5	47	6	68
CT	4	46	4	46
MO	2	45	7	86
NJ	6	44	7	57
AZ	3	43	4	45
MA	4	40	7	91
OH	5	38	10	98
VA	7	28	18	182
NH	2	25	2	24
ID	3	23	6	22
IL	2	21	4	19
LA	5	20	5	21
AL	4	18	7	22
NC	3	16	4	26
ME	2	16	2	35
KY	2	13	3	14
IN	4	12	4	11
ND	2	10	2	10
WI	2	6	2	6
GA	2	4	2	4
NV	1	9	2	44
KS	1	2	8	9
MT	1	2	1	2
TN	1	2	1	30
WY	1	2	1	4
MN	1	1	1	21
SC	1	1	6	6

EPDs for asphalt mixtures present producer and product specific information and evaluations of life cycle impact categories computed through the TRACI v2.1 assessment method (Miller, 2017). TRACI impact categories include global warming potential, ozone depletion, eutrophication, acidification, and photochemical ozone creation (Bare, 2011). Presently, one of the more imperative environmental impacts focused on in various industries is the global warming potential (GWP), which measures the potency of GHG emissions relative to carbon dioxide. Its unit is kilograms of carbon dioxide per unit of material, in the case of asphalt mixture production, one ton of asphalt mixture (kg-CO_2e/ton). The mixture details available in most EPDs are mixture design proportions, mixture design method, gradation type, binder grade, nominal maximum aggregate size (NMAS), use of additives and modifiers, incorporation of recycled materials, and mixing temperature. For emissions corresponding to asphalt plant operations (A3), the current asphalt mixture PCR considers the average value of the total energy and fuel consumed per plant per year for all asphalt mixtures produced at a particular plant. Information such as the name and contact of the producing company, location of the asphalt plant, and a list of standards and organizations involved in compiling the EPD can also be found. Life cycle inventory (LCI) sources for asphalt mixtures are limited to FHWA's Federal LCA Commons and USLCI databases. The Pavement Life Cycle Assessment Framework by FHWA also serves as a supplementary guideline for LCA specific to asphalt and other pavement types (Harvey 2016).

3.2.2 State of EPDs in Missouri

As of 2024, Missouri is in the development stage of EDC-7's "EPDs for sustainable project delivery" implementation and is aiming to be in the demonstration stage by 2025 (FHWA, 2024a). In the asphalt industry, various organizations (FHWA, CDOT, NAPA, etc.) have clearly identified and defined the data gaps and problems in current EPDs and PCR. At present, EPDs from seven asphalt plants in Missouri are publicly available, with a total of eighty-six asphalt mixture EPDs. The number of EPDs in Missouri has nearly doubled since 2023. Approximately 50% of asphalt EPDs in Missouri have data gaps.

3.2.3 Limitations of Asphalt EPDs

NAPA is actively working on resolving several pertinent gaps within the asphalt mixture PCR. Some of the new developments include specifications on how to account for emissions pertaining to portable asphalt plants and more clarity on the type of mixture (NMAS, PG binder grade, etc.) Several gaps still need to be bridged in asphalt mixture LCA. Some of the noteworthy gaps and limitations are as follows:

- As the life cycle stages evaluated in EPDs are limited to the material production stage (A1-A3), the benefits of additives or modifiers that increase the durability and service life of asphalt pavements are not reflected in the EPDs. For example, polymer-modified asphalt mixtures are often used in areas with high traffic due to their enhanced performance, but with the current PCR considering only A1-A3 stages, those durability benefits are not taken into account.

- The absence of LCI data for certain modifiers/additives is a critical data gap. For example, ground tire rubber and waste plastics have seen tremendous growth in the asphalt industry in the past few years but data on these materials included in the current PCR is incomplete. Other materials such as cellulose and synthetic fibers also represent data gaps.
- For plant operations (A3), the use of a yearly average environmental impact or emission value for all asphalt mixture from a single asphalt plant could be disadvantageous for mixtures with lower heat and energy requirements such as warm-mixture asphalt, while also underestimating emissions of mixtures that are more energy and carbon intensive, such as mixtures with styrene-butadiene-styrene (SBS) and polyphosphoric acid (PPA) binder modifiers and higher binder grades.
- While drawing comparisons between asphalt EPDs in the US, it is important to take into account the differences in the source and quantity of mixture components, supplier locations, equipment efficiencies, etc. However, the standard use of NAPA's PCR in the asphalt industry does provide comparability within them as long as data gaps do not exist (Rangelov et al., 2021). Comparability can also be enhanced by using shared background datasets for processes common to all asphalt LCA systems (Mukherjee et al., 2020; Rangelov et al., 2020).
- For efficient use of asphalt mixture EPDs in the pavement procurement process, transparency and standardization in mixture composition terms and details are key. Existing asphalt EPDs require further clarity in the binder grading systems used for the mixture i.e., between performance grading (PG) or multiple stress creep recovery (MSCR) grading system. Providing information pertaining to aggregate and mineral filler types (e.g., lime filler, fly ash, slag, etc.) would also be more beneficial to appropriately assess and characterize mixtures.

3.3 Concrete

Concrete EPDs are generally divided into strength ranges including mixtures containing fly ash or slag across eight regions (see Figure 3.1). Table 3-1 shows the range of different mixtures from the NRMCA 2020 industry baseline EPD, not including the lightweight aggregate mixtures. Table 3-2 shows the mixture designs used for each concrete strength class baseline determination with the associated GWPs shown in Figure 3.2. The cementitious materials content for the baseline mixtures increases with increased strength class with the cementitious fraction accounting for around 85% of the A3 GWP for a particular mixture. About half of the remaining GWP is contributed to by the aggregate, admixtures, and water, and the other half is contributed to by the transportation to the concrete plant and plant production operations. Consequently, focusing on optimizing mixtures with appropriate cementitious amounts and significant inclusion of SCMs has the greatest impact on mixture GWP.

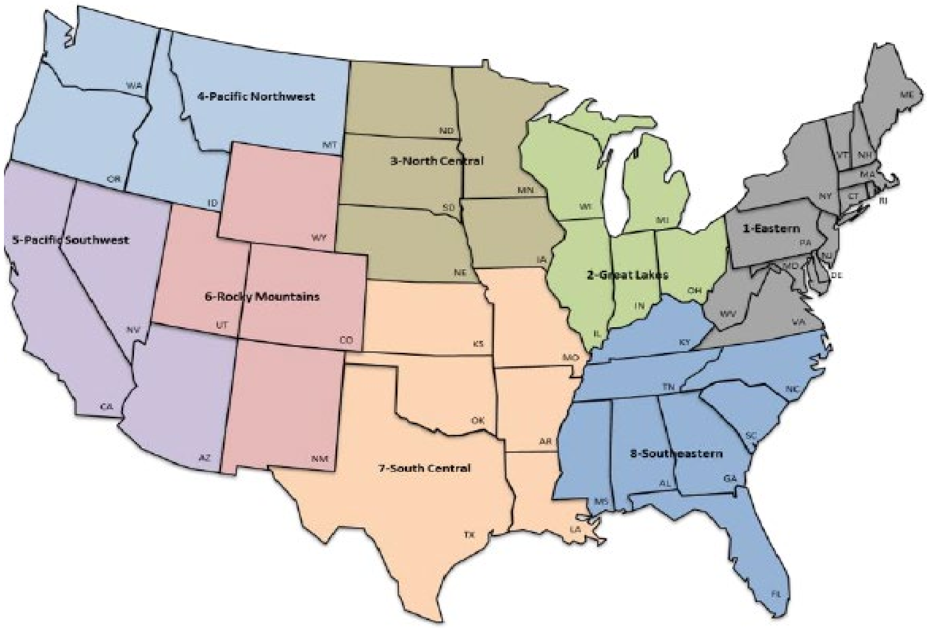


Figure 3.1. NRMCA Regions for EPD Benchmarking

Table 3-12. Product Range from NRMCA 2020 Industry Baseline Report

Table 1: Declared Product Range Classification		
Specified Compressive Strength Range	SCM Range (%)	Product Name
0-2500 psi (0-17.24 MPa)	0-19% Fly Ash and/or Slag	2500-00-FA/SL
	20-29% Fly Ash	2500-20-FA
	30-39% Fly Ash	2500-30-FA
	40-49% Fly Ash	2500-40-FA
	30-49% Slag	2500-30-SL
	40-39% Slag	2500-40-SL
	≥ 50% Slag	2500-50-SL
	≥ 20% Fly Ash and ≥ 30% Slag	2500-50-FA/SL
2501-3000 psi (17.25-20.68 MPa)	0-19% Fly Ash and/or Slag	3000-00-FA/SL
	20-29% Fly Ash	3000-20-FA
	30-39% Fly Ash	3000-30-FA
	40-49% Fly Ash	3000-40-FA
	30-39% Slag	3000-30-SL
	40-49% Slag	3000-40-SL
	≥ 50% Slag	3000-50-SL
	≥ 20% Fly Ash and ≥ 30% Slag	3000-50-FA/SL
3001-4000 psi (20.69-27.58 MPa)	0-19% Fly Ash and/or Slag	4000-00-FA/SL
	20-29% Fly Ash	4000-20-FA
	30-39% Fly Ash	4000-30-FA
	40-49% Fly Ash	4000-40-FA
	30-39% Slag	4000-30-SL
	40-49% Slag	4000-40-SL
	≥ 50% Slag	4000-50-SL
	≥ 20% Fly Ash and ≥ 30% Slag	4000-50-FA/SL
4001-5000 psi (27.59-34.47 MPa)	0-19% Fly Ash and/or Slag	5000-00-FA/SL
	20-29% Fly Ash	5000-20-FA
	30-39% Fly Ash	5000-30-FA
	40-49% Fly Ash	5000-40-FA
	30-39% Slag	5000-30-SL
	40-49% Slag	5000-40-SL
	≥ 50% Slag	5000-50-SL
	≥ 20% Fly Ash and ≥ 30% Slag	5000-50-FA/SL
5001-6000 psi (34.48-41.37 MPa)	0-19% Fly Ash and/or Slag	6000-00-FA/SL
	20-29% Fly Ash	6000-20-FA
	30-39% Fly Ash	6000-30-FA
	40-49% Fly Ash	6000-40-FA
	30-39% Slag	6000-30-SL
	40-49% Slag	6000-40-SL
	≥ 50% Slag	6000-50-SL
	≥ 20% Fly Ash and ≥ 30% Slag	6000-50-FA/SL
6001-8000 psi (41.38-55.16 MPa)	0-19% Fly Ash and/or Slag	8000-00-FA/SL
	20-29% Fly Ash	8000-20-FA
	30-39% Fly Ash	8000-30-FA
	40-49% Fly Ash	8000-40-FA
	30-39% Slag	8000-30-SL
	40-49% Slag	8000-40-SL
	≥ 50% Slag	8000-50-SL
	≥ 20% Fly Ash and ≥ 30% Slag	8000-50-FA/SL

Table 3-23. NRMCA Baseline Mix Designs

Compressive Strength	psi	2500	3000	4000	5000	6000	8000
Portland Cement	lbs	354	394	475	576	610	719
Fly Ash	lbs	62	69	83	101	107	126
Slag Cement	lbs	17	19	23	28	30	35
Mixing Water	lbs	305	305	305	315	341	341
Crushed Coarse Aggregate	lbs	1,126	1,115	1,083	1,029	1,061	1,018
Natural Coarse Aggregate	lbs	553	547	531	505	521	499
Crushed Fine Aggregate	lbs	169	167	162	154	159	152
Natural Fine Aggregate	lbs	1,282	1,270	1,233	1,171	1,208	1,159
Man.Lightweight Aggregate	lbs	0	0	0	0	0	0
Air %	%	6%	6%	6%	6%	6%	0
Air Entraining Admixture	oz	1	1	1	1	1	1
Plasticizer & Superplasticizer	oz	3	3	3	7	3	3
Set Accelerator	oz	25	20	15	10	25	20
Total Weight	lbs	3,867	3,886	3,895	3,878	4,037	4,049

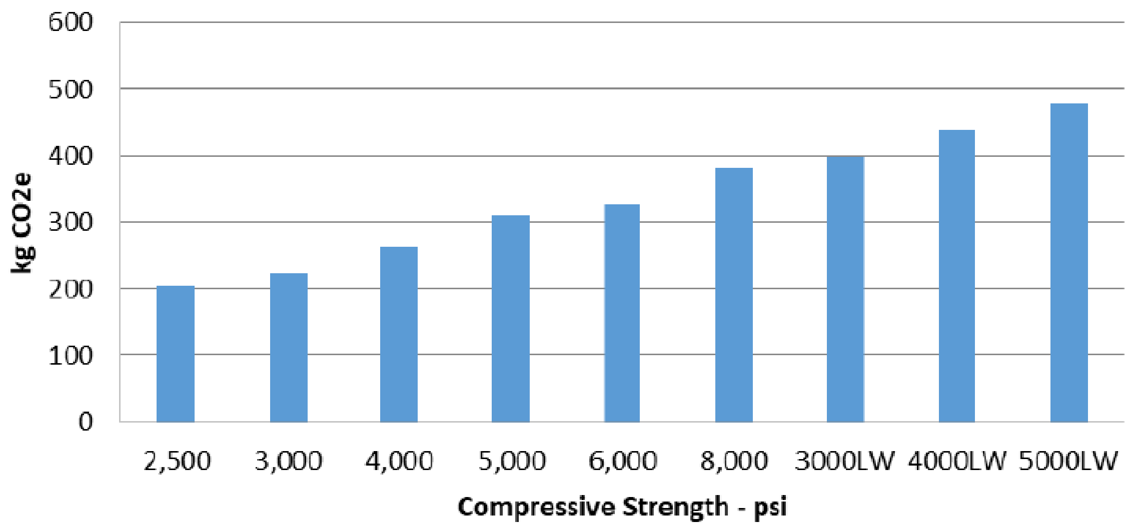


Figure 3.2. GWP for NRMCA Baseline Mixtures (GWP/yd^3)

3.3.1 State of Concrete EPDs in the US

Concrete can be utilized for a wide variety of products compared to asphalt, which is only utilized for pavement. While many concrete EPDs exist, very few are directly applicable for MoDOT applications. As of November 29, 2023, GSA reported over 68,000 concrete EPDs, 1,500 for asphalt, 15 for glass, and 137 for steel. Figure 3.3 shows the range of GWPs for 67,576 US concrete mixtures coded for paving, with an average GWP of 293 kgCO2e per cubic yard as reported by the EC3 tool from Building Transparency. Table 3-4 shows the range of GWP (kg-CO_2e /yd^3) for all US paving mixtures with strengths between 3,000-5,000 psi.

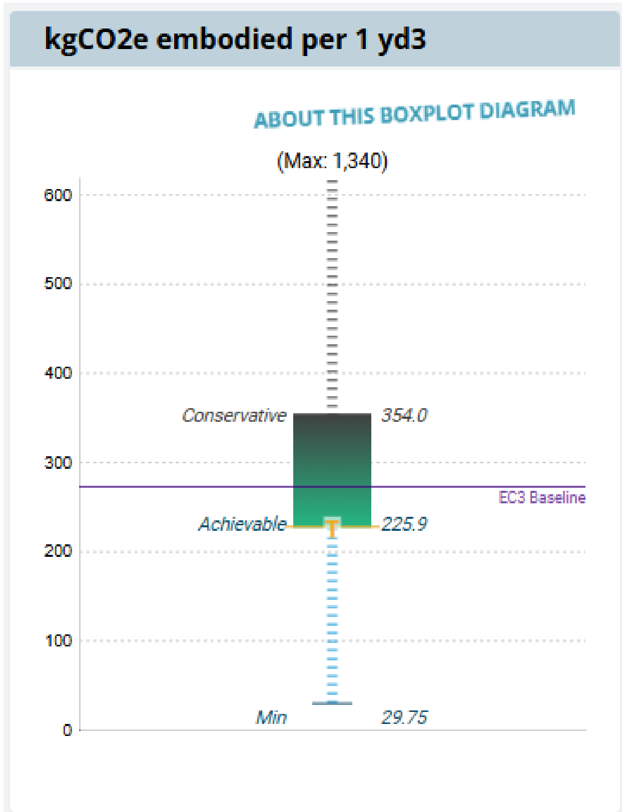


Figure 3.3. GWP for US Paving Mixtures Across All Strength Ranges

Table 3-34. Summary of U.S. Paving Mixtures (GWP/yd^3)

Strength Category	Number of EPDs	Average (kg-CO2e)	Achievable Low (kg-CO2e)	Conservative High (kg-CO2e)
3,000 psi	11,036	260	206	311
4,000 psi	19,975	289	229	346
5,000 psi	17,901	311	247	371

3.3.2 State of Concrete EPDs in Missouri

At the time of this report development, Missouri had 17 EPDs available with one for 3,500 psi, eight for 4,000 psi, five for 4,500 psi, and three for 5,000 psi concrete. Figure 3.4 shows the range of GWPs for the Missouri concrete mixtures coded for paving. Of those EPDs, nine were for portable plants and eight were for fixed locations. The average GWP for Missouri concrete mixtures is 256 kgCO2e per cubic yard, which already meets the top 20% limit established for the 4,000 psi category by GSA. The performance by strength category is shown in Table 3-5.

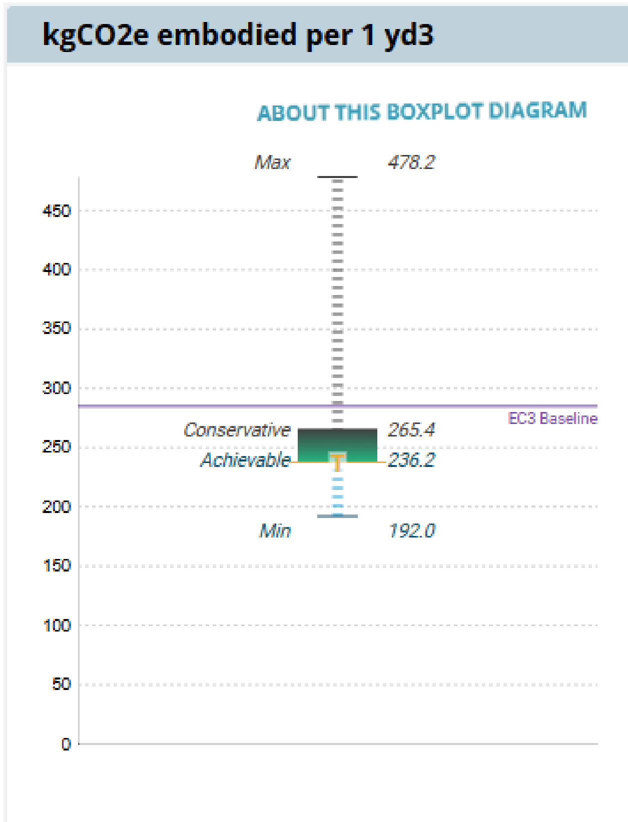


Figure 3.4. GWP for Missouri Concrete Mixtures

Table 3-45. Summary of Missouri Paving Mixtures (GWP/yd^3)

Strength Category	Number of EPDs	Average (kg-CO2e)	Achievable Low (kg-CO2e)	Conservative High (kg-CO2e)
3,500 psi	1	237	237	237
4,000 psi	8	238	224	256
4,500-5,000 psi	8	277	243	273

3.3.3 Data Gaps in Concrete EPDs

The biggest obstacle for more broad application of EPDs in Missouri, for decision making purposes, is the lack of applicable EPDs. The currently available EPDs are likely already more sustainable mixtures and only include St. Louis and Kansas City markets. Those locations have cementitious materials locally available and have newer, more energy-efficient plants. Significantly more mixtures are required which represent more geographically diverse and distant plants from population centers.

Concrete EPDs are not required to list the application, exposure condition, or any other information besides strength. As such, the data input into EPD comparison tools are reliant on the data supplier. For instance, all Missouri concrete mixtures were coded as paving mixtures, however, the names of several indicated the mixtures were non-entrained and not suitable for paving. The following are some data gaps for EPDs for concrete that would be useful to report:

- ACI exposure class
- Application
- Cement type and cementitious materials
- Water to cement ratio
- Bulk resistance

Chapter 4. Benchmarks for Asphalt Mixtures

4.1 Overview

National GWP benchmarks have been established for the asphalt industry as a standardized method to define low carbon asphalt mixtures. This section presents an outline of the Environmental Protection Agency's (EPA) and NAPA's benchmarking systems for asphalt mixtures, followed by a benchmarking study conducted for Missouri asphalt mixtures. Overall and per-phase GWP benchmarks were quantified based on Missouri asphalt EPDs published through the Emerald Eco-Label portal.

4.2 Interim Determination on Low-Embodied Carbon Asphalt Materials

Under the Inflation Reduction Act (IRA), the U.S. Environmental Protection Agency (EPA) and the General Services Administration (GSA), issued an interim determination in 2023, with product-specific GWP thresholds for low embodied carbon asphalt materials. With the possibility of EPDs becoming a nationwide requirement in the future, these benchmarks will dictate the incentives and reimbursements received by asphalt mixture producers for using substantially lower embodied carbon materials (NAPA, 2024a). Additionally, the GSA interim benchmarks will serve as a frame of reference for participants of the LCTM project as well.

Three different GWP thresholds, also referred to as limits, were established as follows and are shown in Table 4-1: 1. Top 20th percentile, best-performing mixtures, 2. 40th percentile, best-performing mixtures and 3. Better than average mixtures (GSA, 2023a). Figure 4.1 describes EPA's interpretation of the GWP benchmarks.

Table 4-1. GSA interim benchmarks for low embodied carbon asphalt

EPD-Reported GWPs (kg-CO_2e/t)		
Top 20% limit	**Top 40% limit**	**Better than average limit**
55.4	64.8	72.6

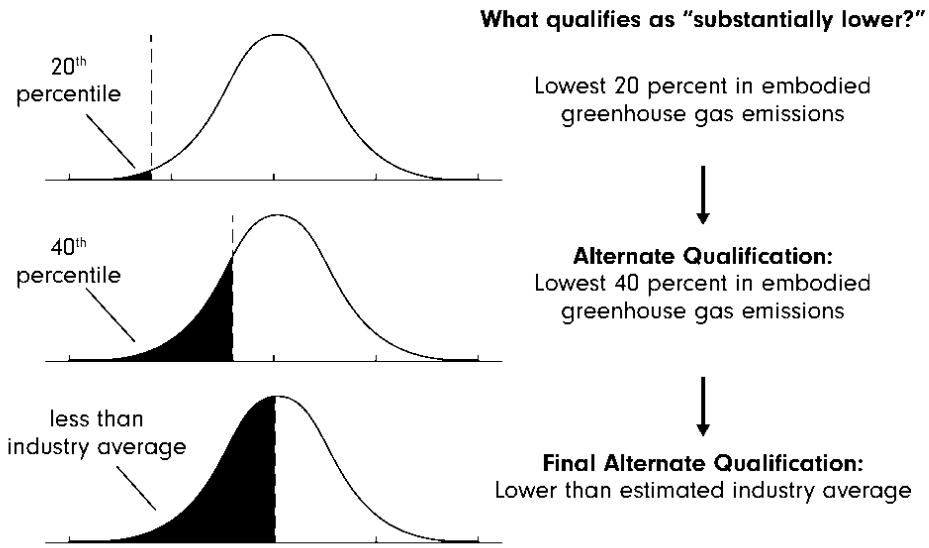


Figure 4.1. EPA's interpretation of low-embodied carbon materials (FHWA, 2024c)

4.3 National Benchmarks for Asphalt Mixtures

Recently, NAPA has released two significant documents regarding the carbon footprint of asphalt mixtures and pavements, namely, SIP-108 and 109 (NAPA, 2024c) (NAPA, 2024a). These documents were developed in accordance with NAPA's PCR and ISO 21678, the international standard for indicators and benchmarks for civil engineering sustainability. SIP-108 proposed a statistical method to determine per-phase (A1, A2, A3) GWP benchmarks for asphalt mixtures, rather than using an overall A1-A3 GWP as specified by GSA. The data used in the study was obtained from industry surveys via the Emerald Eco-Label tool from asphalt producers across the country. The GWP values of the A1 phase are entirely dependent on the asphalt mixture design and mixture ingredients, therefore, state-wise, or region-specific benchmarks were not determined for this life cycle phase. Instead, industry average GWP benchmarks were provided for common mixture ingredients such as aggregates, neat binder, SBS-modified binder, lime, and RAP.

As opposed to the carbon intensity of the material acquisition (A1) phase, the A2 and A3 thresholds were provided on a region-specific basis, where the benchmarks are more sensitive to influencing factors such as geology, climatic conditions, and resource availability. This ensures that stakeholders from different parts of the U.S. are appropriately represented according to their regional circumstances. This guidance could help MoDOT set region-specific GWP benchmarks and help Missouri choose eligible, substantially lower embodied carbon asphalt materials in LCTM grant implementation.

SIP-109 deals with outlining the major sources of GHG emissions in the entire life cycle of asphalt pavements. It provides detailed strategies that can be employed to reduce the carbon footprint of asphalt pavements and is targeted towards the overall decarbonization of the asphalt industry. Furthermore, the GHG emissions associated with common asphalt mixture technologies and potential long-term carbon reductions in the asphalt pavement life cycle were presented from various published literature sources.

4.4 Benchmark study for Missouri Asphalt Mixtures

Benchmarks specific to the state of Missouri are not available in NAPA's EPD benchmarking effort. Hence, this study set out to evaluate GWP benchmarks for Missouri asphalt mixtures, derived from eighty-six existing NAPA-verified EPDs. The asphalt EPD data was obtained from NAPA's Emerald Eco-Label tool, while Microsoft Excel was used for data organization and analysis purposes.

GWP values in terms of kilograms of carbon dioxide equivalent per ton of asphalt mixture were considered from the EPDs, for the impacts associated with acquisition of materials (A1), transportation (A2) and mixture production (A3) of the asphalt mixtures. In accordance with GSA and NAPA's system of benchmarking, the top 20%, 40% and industry average thresholds were computed using the published EPDs.

4.4.1 A1 GWP Benchmarks

To establish the benchmarks for A1, the mixtures were categorized based on the ingredients or combination of ingredients present in the mixtures. Table 4-2 shows the GWP benchmarks for the A1 phase, where six unmodified or virgin mixtures, 45 RAP mixtures, and 18 RAP with PPA mixtures were accounted for. As expected, mixtures containing RAP exhibited lower GWP values due to the reduced use of virgin binder and aggregates in the mixture. The reduction in the average GWP values of the RAP mixtures compared to the virgin mixtures was 16%. While mixtures with RAP and PPA exhibited GHG emissions higher than those exclusively with RAP, they maintained emission levels lower than virgin or unmodified mixtures, by 6%. Benchmarks for mixtures containing SBS, lime filler (LF), and recycled asphalt shingles (RAS) were not established due to insufficient data. These mixtures consisted of 18% of the total number of mixtures included in the study.

Table 4-2. A1 GWP benchmarks by mixture ingredients (kg CO_2-eq/ton)

Mixture type	Top 20%	Top 40%	Top 50%	Average
Virgin	30.9	31.5	32.5	32.4
With RAP	23.7	26.2	27.5	27.1
With RAP, PPA	28.2	29.6	30.5	30.4

In addition to GWP benchmarks, NAPA released state-wise reference values (RV) in their recently revised SIP-108 (NAPA, 2024b). Their method of quantification for the reference values are similar to the GWP benchmarks, where top 20%, 40%, 50% best-performing limits and average values are computed based on the GWP data from asphalt EPDs in each state. NAPA's reference values (RVs) for Missouri were quantified for asphalt mixtures with NMAS sizes of 12.5 mm and below. Table 4-3 shows NAPA's reference values and the reference values calculated in this study for the respective NMAS category.

Table 4-3. A1 GWP reference values (RVs) for NMAS <= 12.5 mm (kg-CO_2e/ton)

	Top 20%	Top 40%	Top 50%	Average
NAPA's RVs	28.1	29.8	30.7	39.5
Calculated RVs	27.5	28.8	30.1	37.1

4.4.2 A2 and A3 GWP Benchmarks

For the A2 and A3 phases, the benchmarks were determined based on all eighty-six asphalt EPDs from Missouri. Table 4-4 compares Missouri's best-performing GWP benchmarks computed in this study, to the GWP benchmarks and the newly established wet-freeze reference values presented in NAPA's SIP-108. As per AASHTO's climate zones, Missouri falls within the wet-freeze zone and consequently, the appropriate GWP benchmarks were considered to analyze the A3 benchmarks for Missouri. Missouri's A2 GWP benchmarks are only marginally higher than NAPA's benchmark for all states collectively (excluding Florida and Louisiana) and the reference value for the wet-freeze zone. This could be attributed to a standard practice amongst Missouri contractors, who source majority of their mixture ingredients from local sources. With respect to A3, EPDs from only seven asphalt plants were available in the Emerald Eco-Label tool. The influence of having limited data points for the GWP benchmarks associated with asphalt plant operations is evident in Table 4-4, where the 40^{th} and 50^{th} percentile are equal.

Table 4-4. A2 and A3 GWP benchmarks (kg CO_2-eq/ton)

Life cycle stage	Climatic region	Top 20%	Top 40%	Top 50%	Average
A2	**All states**	1.0	2.1	3.0	4.6
	Wet Freeze RV	1.4	2.6	3.4	5.4
	Missouri	2.1	3.2	3.6	4.5
A3	**Wet Freeze**	20.9	22.8	23.6	24.7
	Missouri	28.3	40.3	40.3	36.9

4.4.3 Overall GWP Benchmarks

Total GWP benchmarks for the total mixture production (A1-A3) stage were also quantified from the asphalt EPDs available for the state of Missouri. Table 4-5 presents the GWP benchmarks for Missouri along with GSA's interim determination benchmarks.

Table 4-5. A1-A3 GWP benchmarks (kg CO_2-eq/ton)

Benchmarks	Top 20%	Top 40%	Top 50%
GSA Interim	55.4	64.8	72.6
Missouri	63.3	70.7	71.5

Additionally, the average GWP values of Missouri's asphalt mixtures were analyzed to identify high embodied carbon mixture types. Overall, the asphalt mixtures had an average GWP value of 76.5 kg-CO_2e/ton, with a 30% coefficient of variation. Figure 4.2 represents a box and whiskers chart of the GWP values for the various asphalt mixtures in this study, classified based on the mixture ingredients. The line across the box plot signifies the median or 50th percentile, while the '×' indicates the average GWP value of the mixture. The whiskers indicate the maximum and minimum values in the dataset, if they are not within the interquartile range.

It can be seen in Figure 4.2 that asphalt mixtures with a combination of SBS and LF exhibited exceedingly higher GWP values in comparison to the other mixtures in the study, with an average GWP of 183 kg-CO_2e/ton. Furthermore, all mixture categories containing LF had average GWP values higher than 90 kg-CO_2e/ton. As discussed earlier, mixtures solely with RAP exhibited the lowest GWP values, with an average of 65 kg-CO_2e/ton. SBS and PPA modified mixtures exhibited GWP values approximately between 82-92 kg-CO_2e/ton. It is important to note that the following mixture categories had less than five EPDs or data points available for analysis: - 1. SBS, 2. PPA, 3. LF, 4. SBS, LF, 5. PPA, LF, 6. RAP, PPA, LF and 7. RAP, RAS.

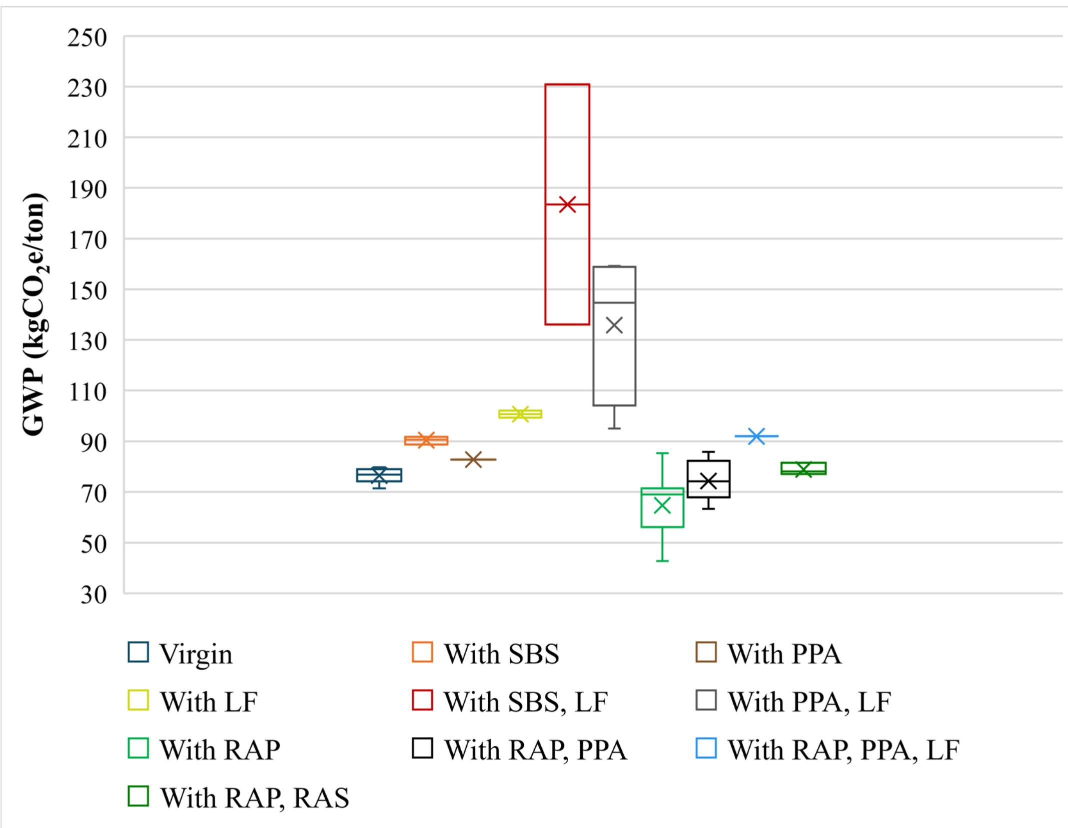


Figure 4.2. Total GWP of Missouri asphalt mixtures

Chapter 5. Benchmarks for Concrete Mixtures

5.1 Overview

This section presents an outline of EPA and NRMCA's benchmarking systems for cement and concrete mixtures, followed by a benchmarking study conducted for Missouri concrete mixtures.

5.2 Interim Determination on Low-Embodied Carbon Materials

Three different GWP thresholds for low-embodied carbon cement, also referred to as limits, were established in GSA's interim determinations. These are shown in Table 5-1 for cement and Table 5-2 for concrete across similar strength categories as NRMCA (GSA, 2023b). For reference, the Type I/II from the Central Plains Cement Company Sugar Creek Plant is 883 kgCO2e/t and the Type IL from that plant is 814 kgCO2e/t. From Holcim Ste. Genevieve the Type I/II is 748 kgCO2e/t and the Type IL is 724 kgCO2e/t. Holcim Ste. Genevieve also markets ASTM C595 Type IT which contains 6% limestone and 25% natural pozzolan, with 608 kgCO2e/t. (Note, 1 m^3 = 1.3097 yd^3).

Table 5-1. GSA interim benchmarks for low embodied carbon Cement

	EPD-Reported GWP (kg-CO_2e/t)	
Top 20% limit	**Top 40% limit**	**Better than average limit**
751	819	858

Table 65-2. GSA GWP Limits for Concrete (GWP/m^3)

	GSA IRA Limits for Low Embodied Carbon Concrete (EPD-Reported GWPs, in kilograms of carbon dioxide equivalent per cubic meter - kgCO_2e/ m^3)		
Specified concrete strength class (compressive strength [f'c] in pounds per square inch [PSI])	**Top 20% Limit**	**Top 40% Limit**	**Better Than Average Limit**
≤2499	**228**	**261**	**277**
3000	**257**	**291**	**318**
4000	**284**	**326**	**352**
5000	**305**	**357**	**382**
6000	**319**	**374**	**407**
≥7200	**321**	**362**	**402**
Add 30% to these numbers for GWP limits where high early strength[1] concrete mixes are required for technical reasons.			

For comparison, Missouri is located in the NRMCA South Central Region. The 2020 reported baseline GWP values are shown in Table 5-3. The NRMCA average baseline values exceed the top 40% GSA limits for strengths of 5,000psi or less but do not achieve better than average limits for 7,200psi and above. (Note Table 5-2 has units of m^3 and Table 5-3 yd^3 and m^3)

Table 75-3. NRMCA South Central EPD Baselines

Specified Concrete Strength Class (psi)	GWP (kg CO2e/yd^3)	GWP (kg CO2e/m^3)
2,500	190	249
3,000	208	272
4,000	243	318
5,000	286	374
6,000	303	396
8,000	348	455

Chapter 6. Project Team Activity Summary

6.1 Overview

A key element of Missouri's Climate Challenge Project was to socialize the key concepts underlying EPDs across Missouri while the study was being conducted. The following section provides a list of activities undertaken by members of the research team during calendar years 2023-2024.

6.2 Summary of Activities

The following presentations, meetings, and activities were conducted in fulfillment of the dissemination of knowledge objectives of this project:

- Kevern, J.T. "Sustainability and All Things Environmental," Concrete Promotional Group and Midwest Concrete Industry Board Annual Concrete School, January 4, 2023, Kansas City, MO.
- Rath P. "Recycling in Asphalt Pavements," MAPA St. Louis Chapter Lunch and Learn, February 24, 2023.
- Kevern, J.T. "EPDs and the Road to Net Zero," Missouri Concrete Conference, April 25, 2023, Rolla, MO.
- Kevern, J.T. "The Global Concrete Industry and Road to Net Zero," Invited Seminar at the Cape Peninsula University of Technology and University of the Western Cape, May 22, 2023, Cape Town, South Africa.
- Kevern, J.T. "The Global Concrete Industry and Road to Net Zero," Invited Seminar at the Stellenbosch University, May 26, 2023, Stellenbosch, South Africa.
- Kevern, J.T. "Environmental Product Declarations and Low Hanging Fruit," Presentation to GSA Region 6, June 6, 2023, Kansas City, MO.
- Kevern, J.T. "Concrete Sustainability," 57th Annual Concrete Industry School, KC Concrete Promotional Group, January 5, 2024, Kansas City, MO.
- Rath, P. "Sustainable Asphalt Pavements," Solid Waste Utilities Volunteer Teams Appreciation Lunch & Learn, January 20, 2024, Columbia, MO.
- Kevern, J.T. "The Road to Net Zero: How to Implement Low Carbon Infrastructure Materials," ERTC3/MCTI Webinar, February 21, 2024.
- Kevern, J.T. "Missouri's FHWA Climate Challenge Approach," Missouri Concrete Conference, Rolla, MO, April 23, 2024.
- Rath, P., and Buttlar, W. "Infrastructure Sustainability," Focus Group Meeting – Energy, Sustainability, and Resilience, Hanson Professional Services Inc. (online), July 9, 2024.
- Buttlar, W. "Innovative Solutions for Sustainable Transportation Infrastructure: Asphalt Pavements," Sustain Mizzou, University of Missouri, Columbia, November 15, 2024.
- Gettu, N. "FHWA Climate Challenge: Missouri," 65th Missouri Asphalt Conference, December 3, 2024, Rolla, MO.

- Buttlar, W. "Update on EPD Research for Both HMA and PCCP," 26th Annual Association of General Contractors (AGCMO)/MoDOT Co-op Meeting, December 5, 2024, Lake of the Ozarks, MO.

<u>In attendance:</u>

- FHWA Sustainable Pavement Technical Working Group (SPTWG) Meeting, Delaware, April 2023.
- FHWA Sustainable Pavement Technical Working Group (SPTWG) Meeting, Louisiana, April 2024.
- FHWA CPM Stakeholder Feedback Meeting on LCTM Program, St. Charles, Missouri, October 2024.

Chapter 7. Summary and Recommendations

7.1 Overview

This report overviewed initial GWP benchmarks for asphalt and concrete mixtures for the MoDOT.

7.2 Asphalt

Overall A1-A3 and per phase GWP benchmarks were established for Missouri asphalt mixtures based on publicly available asphalt mixture EPDs. The benchmarking framework was implemented as per NAPA's SIP-108, to determine the top 20%, 40% and 50% best-performing mixture thresholds. A1 GWP benchmarks were evaluated for mixture types that had sufficient EPDs availability, namely, virgin, or unmodified mixtures, mixtures with RAP, and mixtures with RAP and PPA. Assessing the average A1 GWPs of the aforementioned mixture types, it was evident that the incorporation of RAP into asphalt mixtures can result in GWP reductions of 6-16%. Additionally, NAPA recently revised SIP-108 which disclosed newly established reference values for Missouri asphalt mixtures with NMAS sizes of 12.5 mm and lower. The GWP reference values quantified in this study were consistent with NAPA's reference values.

The GWPs of asphalt mixtures associated with the A2 and A3 phases are mainly influenced by geological and climatic factors. Consequently, NAPA established A2 and A3 benchmarks based on AASHTO's four climatic regions, with Missouri belonging to the wet-freeze zone. Missouri's asphalt mixtures exhibited A2 GWP benchmarks only marginally higher than the nationally reported GWP limits by NAPA; this could potentially be an outcome of the locally sourced mixture ingredients. The A3 GWP benchmarks determined for asphalt mixtures in this study were higher than the A3 GWP benchmarks for the wet-freeze zone. However, a noteworthy limitation of this data analysis is that the GWP thresholds reflect asphalt mixtures produced from only seven plants which are not adequate to be representative of all the regions.

One key lesson learned from the analysis conducted is that the use of recycled content, primarily RAP, could help drive the GWP of the asphalt mixtures down. The potential reduction in GWP impacts is attributed to the reduced use of virgin aggregates as well as virgin asphalt binder in the mixture. There are several other strategies that could be employed and need to be evaluated for implementation in order to produce good-performing mixtures in terms of durability and environmental impacts. The recent announcement of the LCTM grant being awarded to Missouri, along with the efforts to implement BMD throughout the state by MoDOT, will likely drive innovation in asphalt mixtures to not only include more RAP but also to evaluate other effective and upcoming technologies and recyclates. To achieve better-performing and lower-embodied carbon asphalt mixtures, the following recommendations could have the highest impact:

- Increase the use of RAP in the state and improve RAP stockpile quality to produce durable asphalt mixtures,

- Investigate other available technologies such as warm mix asphalt, rejuvenators, and other methods to produce mixtures at lower temperatures,
- Evaluate local sources for coarse and fine aggregates, as well as mineral fillers.

7.3 Concrete

As previously discussed, the limited Missouri-specific mixture EPD data indicates those mixtures have lower GWP values than the GSA top 20% limits which is consistent with the NRMCA 2020 baseline values. However, it is difficult to confidently determine if the geographical diversity of construction locations impacting transportation contributions and the older, less energy efficient plants in Missouri will significantly impact the GWP values such that mixtures from those locations would no longer meet GSA benchmarks. For MoDOT the easiest mechanism for lowering GWP will be lowering the amount and adjusting the makeup of the cementitious materials. Aggregate GWP makes up less than 10% of the overall A3 GWP of the mixture as does plant contributions. While reducing cementitious materials will require volumetrically more aggregate, the changes are insignificant for the precision of this assessment. Likewise, more efficient plants will reduce A3 GWP, however MoDOT does not possess the ability to require upgrading to more efficient plants and that contribution is less than that of the aggregate phase.

Using 2020 concrete mixtures provided by MoDOT, average A1 contributions for the cementitious materials were determined for B, B1, B2, MB2, and PCCP mixtures for which more than 30 mix designs were on file and represent the vast majority of all concrete produced for MoDOT. Table 7-1 shows the average cementitious materials for the five mixture classes. All contained fly ash and only one B-1 mixture contained slag cement. The weighted average A1 contribution of the cementitious fraction of all mixtures in 2020 was 219 kgCO2e which is 85% of the A3 Missouri average for all mixtures with strength class 4,000 psi or greater. The remaining 15% contribution includes all of the A1 for aggregate, water, and admixtures, A2 for transportation of the materials to the concrete production facility, and the A3 for the production facility itself.

Table 7-81. Summary of MoDOT 2020 Baseline Mixtures

Mixture Class	# of mixes	Cement (pcy)	Fly Ash (pcy)	Slag (pcy)	A1 Cementitious kgCO2eq/yd3	Est. A3 kgCO2eq/yd3	Est. A3 kgCO2eq/m3
B w/air	31	470	63	0	189	222	290
B-1 w/air	45	542	86	3	218	256	335
B-2 w/air	31	669	44	0	268	316	413
MB-2 w/air	31	489	142	0	196	231	302
PCCP	43	552	74	0	221	261	341

Of the 2020 baseline mixtures for Missouri, none met the criteria for the GSA top 20% classification of <284 kgCO2e. B w/air and MB-2 w/air met the top 40% classification of <326 kgCO2e, and all but B-2 w/air met the better than average classification of <352 kgCO2e. Since 2020 the majority of Missouri concrete mixtures now contain ASTM C595 Type IL cement instead of ASTM C150 meeting Type I and Type II classification. In Missouri, on average Type IL results in a 4.5% reduction in GWP compared to the parent Type I/II, although it is plant dependent. Table 7-2 shows the same 2020 baseline mixture GWP assuming the inclusion of Type IL cement. The B mixtures now meet the top 20% classification with MB-2 close. B-1 and PCCP meet the top 40% classification, and B-2 still does not meet the better than average limit for 4,000 psi or 5,000 psi.

Table 7-2. Summary of MoDOT Baseline Mixtures Assuming TIL Cement

Mixture Class	# of mixes	T1L Cement (pcy)	Fly Ash (pcy)	Slag (pcy)	A1 Cementitious kgCO2eq/yd3	Est. A3 kgCO2eq/yd3	Est. A3 kgCO2eq/m3
B w/air	31	470	63	0	178	210	274
B-1 w/air	45	542	86	3	206	242	317
B-2 w/air	31	669	44	0	254	298	390
MB-2 w/air	31	489	142	0	186	218	286
PCCP	43	552	74	0	209	246	322

The class of mixture which has the highest CO2 embodiment is B-2. However, the modified B-2 (MB-2) is already allowed in all instances and has a substantially lower total cementitious content and SCM requirement. Consequently, the average MB-2 mixtures have 27% less CO2eq than the B-2 mixture. Assuming performance and constructability are acceptable, eliminating the B-2 mixtures would result in significant CO2 reductions, while likely improving durability due to the higher SCM requirement.

Overall, the utilization of SCMs in the 2020 baseline mixtures was very low with B1 (6%), PCCP and B (12%), B-1 (14%), and MB-2 (22%) with only one B-1 mixture containing slag. The most obvious pathway to decarbonization within the current specifications is to increase the amount of SCMs. While nationally fly ash availability is limited, in Missouri, it is anticipated that a consistent supply will be available as new SCMs, such as reclaimed ash and more metakaolin, come online over the next few years.

Table 7-3 shows an example for the baseline mixtures when increasing the fly ash replacement to 30%. By making that change, all mixture classifications meet or exceed the GSA threshold for top 20%. It is well-understood that ternary mixtures containing both slag cement and fly ash produce excellent durability and performance (Kevern et al., 2016). In Missouri the mixture optimization protocol for the City of Kansas City, Missouri showed excellent performance in sidewalk applications for 50% replacement (Kevern and King, 2023). Table 7-4 shows the GWP performance for 50% cement replacement using 25% fly ash and 25% slag. In this scenario all mixtures are well below the lowest GSA limit.

Table 7-3. Summary of MoDOT Baseline Mixtures Assuming Increased Fly Ash

Mixture Class	TIL Cement (pcy)	Fly Ash (pcy)	A1 Cementitious kgCO2eq/yd3	Est. A3 kgCO2eq/yd3	Est. A3 kgCO2eq/m3
B w/air	374	160	138	163	213
B-1 w/air	442	189	163	192	252
B-2 w/air	499	214	184	217	284
MB-2 w/air	442	189	163	192	251
PCCP	438	188	162	191	249

Table 7-4. Summary of MoDOT Baseline Mixtures Assuming 50% Replacement Ternary Mix

Mixture Class	T1L Cement (pcy)	Fly Ash (pcy)	Slag (pcy)	A1 Cementitious kgCO2eq/yd3	Est. A3 kgCO2eq/yd3	Est. A3 kgCO2eq/m3
B w/air	267	133	133	104	123	160
B-1 w/air	316	158	158	123	145	190
B-2 w/air	356	178	178	139	164	214
MB-2 w/air	315	158	158	123	145	190
PCCP	313	156	156	122	144	188

One additional consideration in Missouri is implementing AASHTO R101 for performance engineered concrete paving mixtures (PEMs). The PEM process reduces the cementitious materials by optimizing the aggregate gradation and utilizing performance testing to demonstrate long-term durability. Table 7-5 shows the results for a lightly optimized mixture containing 520 pcy of total cementitious material with the previously utilized replacement rates. This results in a 46% CO2eq/yd^3 reduction from the 2020 baseline mixture and would result in reduced cost and improved durability.

Table 7-5. Summary of MoDOT Baseline Mixtures Assuming 50% Replacement Ternary Mix

Mixture Class	T1L Cement (pcy)	Fly Ash (pcy)	Slag (pcy)	A1 Cementitious kgCO2eq/yd3	Est. A3 kgCO2eq/yd3	Est. A3 kgCO2eq/m3
PCCP	260	130	130	102	120	156

To achieve better-performing and lower-embodied carbon concrete mixtures, the following recommendations could have the highest impact:

- Generate and collect EPDs for MoDOT concrete mixtures to expand EPD database for Missouri,
- Eliminate B-2 as a mixture option under standard pavement applications and typical circumstances,
- Increase the minimum SCM replacement rate to replace higher-carbon cement with lower carbon waste materials that yield more durable mixes,
- Implement performance engineered concrete mixtures for pavements which are accepted, industry-wide, as being more durable and used in 28 other state DOTs.
- Incentivize ternary mixtures (a combination of 3 SCMs) on all projects and require ternary mixtures for those applications with the highest exposure conditions, such as mainline pavement, since ternary mixtures are accepted industry-wide as the most durable, resilient, and sustainable mixes.

References

Bare, J. (2011). *TRACI 2.0: The tool for the reduction and assessment of chemical and other environmental impacts 2.0*. Clean Technologies and Environmental Policy.

FHWA. (2020, July). *Tech Brief: Environmental Product Declarations, Communicating Environmental Impact for Transportation Products. FHWA-HIF-19-087*. Sustainable Pavements Program, U.S. Department of Transportation.

FHWA. (2024a). *Every Day Counts: Innovation for a Nation on the Move. EDC-7 Progress Report #1*. Federal Highway Administration (FHWA), U.S. DoT, Washington, DC.

FHWA. (2024b). *Quantifying Emissions of Sustainable Pavements*. https://www.fhwa.dot.gov/infrastructure/climatechallenge/projects/index.cfm

FHWA. (2024c, May). *What is the EPA Interim Determination? FHWA-HIF-24-052*.

GSA. (2023a, December). *Low Embodied Carbon Asphalt Requirements*. U.S. General Services Administration, Inflation Reduction Act.

GSA. (2023b, December). *Low Embodied Carbon Concrete Requirements*. U.S. General Services Administration, Inflation Reduction Act.

Harvey, J., Meijer, J., Ozer, H., Al-Qadi, I., Saboori, A., & Kendall, A. (2016, July). *Pavement Life Cycle Assessment Framework -FHWA-HIF-16-014*. US Department of Transportation, FHWA.

ISO. (2006). *ISO 14025 Environmental labels and declarations—Type III environmental declarations—Principles and procedures*. International Organisation for Standardisation.

ISO. (2016). *ISO 14040: 2016 -Environmental management – Life Cycle Assessment – Principles and Framework. International Organization for Standardization*. International Organisation for Standardisation.

Kardish, C. (2022, November). *A Building Block for Climate Action: Reporting on Embodied Emissions*. Center for Climate and Energy Solutions.

Landrieu, M. (2022, May). *Building a Better America: A Guidebook to the Bipartisan Infrastructure Law for State, Local, Tribal, and Territorial Governments, and Other Partners*. The White House, Washington.

Lewis, M., Huang, M., Waldman, B., Carlisle, S., & Simonen, K. (2021). *Environmental Product Declaration Requirements in Procurement Policies*. Carbon Leadership Forum, Universityy of Washington, Seattle, WA.

Miller, L. (2017, April). *Emerald Eco-Label EPD Tool Instructions*. Trisight.

Mukherjee, A., Bhat, C., & Harvey, J. (2020, February). *Challenges in meeting data needs for use of environmental product declarations in pavement design and construction: State of practice and future scope. Report No. FHWA-HRT-20-022*. US Department of Transportation, FHWA.

NAPA. (2022). *Product Category Rules (PCR) for Asphalt Mixes -Version 2.0*. National Asphalt Pavement Association.

NAPA. (2024a). *EPD benchmark for asphalt mixtures* (No. SIP-108). National Asphalt Pavement Association.

NAPA. (2024b). *EPD Benchmark for National Asphalt Pavement Association. Version 2.0* (No. SIP-108).

NAPA. (2024c). *The carbon footprint of asphalt pavements: A reference document for decarbonization* (No. SIP-109). National Asphalt Pavement Association.

Rangelov, M., Dylla, H., Davies, J., & Sivaneswaran, N. (2020, June). *Integration of Life Cycle Assessment into Planning and Project Delivery for Pavements in the USA*. The International Journal of Life Cycle Assessment. https://doi.org/10.1007/s11367-020-01777-x

Rangelov, M., Dylla, H., Mukherjee, A., & Sivaneswaran, N. (2021). *Use of Environmental Product Declarations (EPDs) of Pavement Materials in the United States of America (U.S.A.) to Ensure Environmental Impact Reductions*. Journal of Cleaner Production 283. https://doi.org/10.1016/j.jclepro.2020.124619

Waldman, B., Huang, M., & Simonen, K. (2020, September). *Embodied carbon in construction materials: A framework for quantifying data quality in EPDs*. Buildings & Cities. DOI: 10.5334/bc.31