Challenges in Meeting Data Needs for Use of Environmental Product Declarations in Pavement Design and Construction: State of Practice and Future Scope

PUBLICATION NO. FHWA-HRT-20-022

FEBRUARY 2020

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

The work presented in this report is part of Federal Highway Administration's (FHWA's) ongoing efforts to support the development of datasets that will provide convenient access to comprehensive, reliable, and transparent lifecycle inventories for highway construction materials. The FHWA Sustainable Pavements Program has been working toward applying a lifecycle-assessment (LCA) methods for evaluating environmental impacts associated with pavement design and construction and has produced a framework that addresses the fundamental goal and scope of conducting pavement LCAs.(1) This framework has laid the foundation for the development of product category rules (PCRs) for pavement construction materials and use of environmental product declarations (EPDs) in communicating the impacts of cradle-to-gate LCAs. While this framework is a step in the right direction, it has exposed various challenges associated with producing consistent PCRs and using EPDs to reliably communicate environmental impacts of pavement construction materials.

This report documents these challenges and classifies them within technical and organizational contexts. In addition, this report documents the requirements of the recently passed California Assembly Bill 262 (AB 262) and the experience of the California Department of Transportation (Caltrans) as it prepares to address the challenges of adopting EPDs in practice as an implementing agency for AB 262 and as it prepares to pilot requiring EPDs for a wide range of pavement materials.(2) This report concludes with suggestions to best address identified challenges and facilitate the smooth adoption of EPDs. This report is intended for State transportation departments' LCA practitioners, PCR developers, and EPD producers.

Cheryl Allen Richter, Ph.D., P.E.
Director, Office of Infrastructure
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td>1. Report No.
FHWA-HRT-20-022</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Challenges in Meeting Data Needs for Use of Environmental Product Declarations in Pavement Design and Construction: State of Practice and Future Scope</td><td colspan="2">5. Report Date
February 2020</td></tr>
<tr><td colspan="2">6. Performing Organization Code
1YX01</td></tr>
<tr><td colspan="2">7. Author(s)
Amlan Mukherjee (ORCID: 0000-0001-8250-9246), Chaitanya Bhat (ORCID: 0000-0002-7173-1287), and John Harvey</td><td colspan="2">8. Performing Organization Report No.
PDC-0209-01</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Engineering & Software Consultants, Inc.
14123 Robert Paris Court
Chantilly, VA 20151

Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931</td><td colspan="2">10. Work Unit No. (TRAIS)</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
DTFH6111D00009/0209</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Office of Infrastructure Research and Development
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101-2296</td><td colspan="2">13. Type of Report and Period Covered
Final Report; August 2016–February 2018</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code
HRDI-20</td></tr>
<tr><td colspan="4">15. Supplementary Notes
Nadarajah Sivaneswaran (HRDI-20; ORCID: 0000-0003-0287-664X), Office of Infrastructure Research and Development, Turner-Fairbank Highway Research Center, served as the Contracting Officer's Representative.</td></tr>
<tr><td colspan="4">16. Abstract
The work presented in this report is part of Federal Highway Administration's (FHWA's) ongoing efforts to support the development of datasets that will provide convenient access to comprehensive, reliable, and transparent lifecycle inventories for highway construction materials. The FHWA Sustainable Pavements Program has been working toward applying a lifecycle-assessment (LCA) methods for evaluating environmental impacts associated with pavement design and construction and has produced a framework that addresses the fundamental goal and scope of conducting pavement LCAs.(1) This framework has laid the foundation for the development of product category rules (PCRs) for pavement construction materials and use of environmental product declarations (EPDs) in communicating the impacts of cradle-to-gate LCAs. While this framework is a step in the right direction, it has exposed various challenges associated with producing consistent PCRs and using EPDs to reliably communicate environmental impacts of pavement construction materials. This report documents these challenges and classifies them within technical and organizational contexts. In addition, this report documents the requirements of the recently passed California Assembly Bill (AB) 262 and the experience of the California Department of Transportation (Caltrans) as it prepares to address the challenges of adopting EPDs in practice as an implementing agency for AB 262 and as it prepares to pilot requiring EPDs for a wide range of pavement materials.(2) This report concludes with suggestions to best address identified challenges and to facilitate the smooth adoption of EPDs.</td></tr>
<tr><td colspan="2">17. Key Words
Pavement lifecycle assessment, construction materials lifecycle inventory, production category rules, environmental product declarations</td><td colspan="2">18. Distribution Statement
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.
http://www.ntis.gov</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
50</td><td>22. Price
N/A</td></tr>
</table>

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

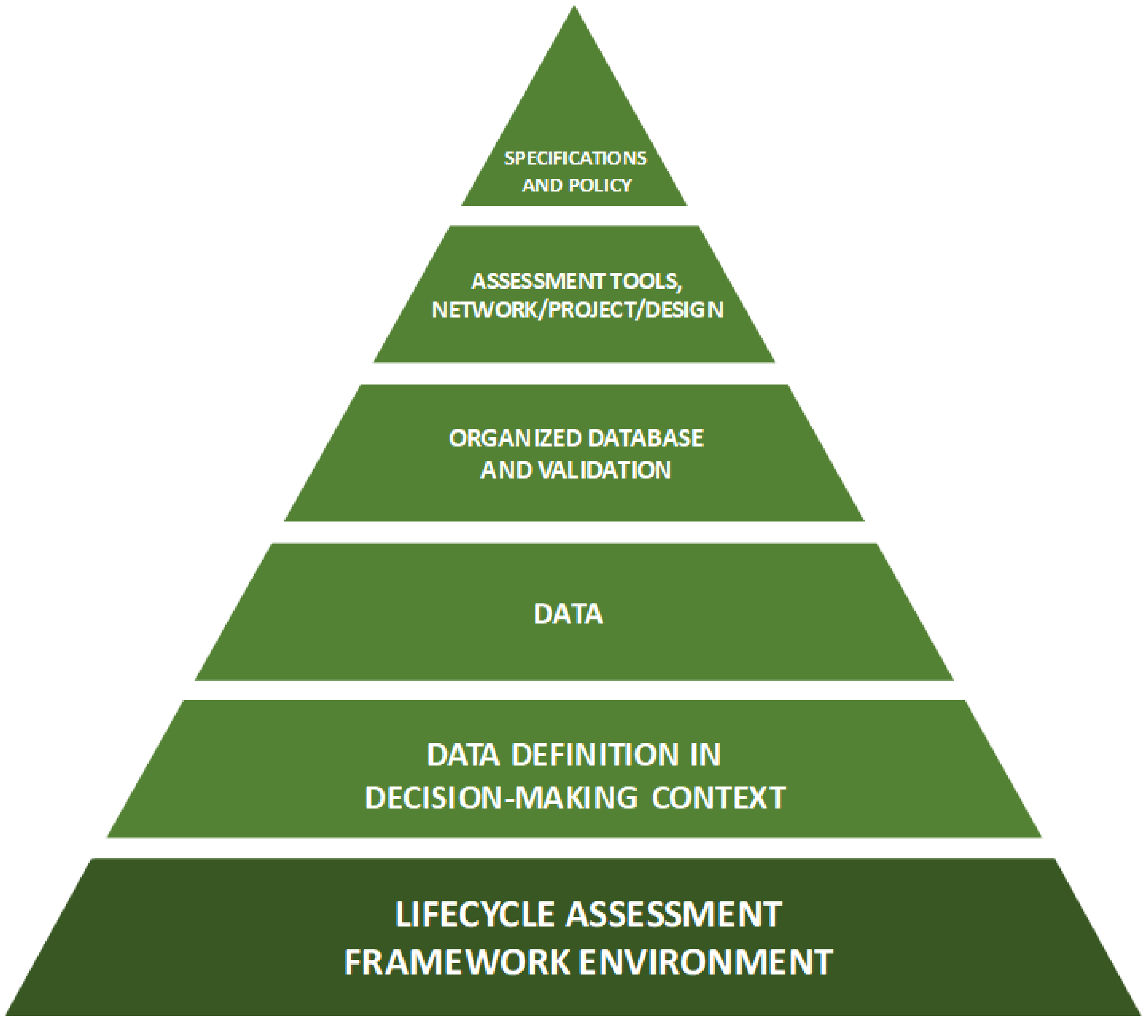
LIST OF ABBREVIATIONS AND ACRONYMS

AB	Assembly Bill
Caltrans	California Department of Transportation
DGS	Department of General Services
DOT	department of transportation
EN	European Norm
EPD	environmental product declaration
FHWA	Federal Highway Administration
GREET	greenhouse gases, regulated emissions, and energy use in transportation model
GWP	global-warming potential
ISO	International Organization for Standardization
IT	information technology
LCA	lifecycle assessment
LCI	lifecycle inventory
NAPA	National Asphalt Pavement Association
NREL	National Renewable Energy Laboratory
PCR	product category rule
PVI	pavement–vehicle interaction
USLCI	United States Life Cycle Inventory

CHAPTER 1. INTRODUCTION

The state of practice in the field of pavement lifecycle assessment (LCA) has come a long way since the inception of Federal Highway Administration's (FHWA's) Sustainable Pavements Program and the associated Sustainable Pavements Technical Working Group (TWG) in 2011.[3] FHWA's "Towards Sustainable Pavement Systems: A Reference Document" and *Pavement Life Cycle Assessment Framework* are useful resources for State, local, and Federal agencies to develop a better understanding of pavement LCA and its relationship to building sustainable pavements.[1,4] The pavement construction-materials industry has embraced pavement LCA methods, and the concrete and asphalt industries have developed environmental product declaration (EPD) programs that are International Organization for Standardization (ISO) 14025 and European Norm (EN) 15804 compliant.[5,6] Academic inquiry has supported these changes by helping develop industry product category rules (PCRs) and furthering models of the use phase of pavement LCA with emphases on topics such as pavement–vehicle interaction (PVI) and heat island effect.

A recent outcome of TWG discussions has been the development of a pyramid for implementation of pavement LCA (figure 1). This pyramid provides perspective on the implementation of FHWA's LCA framework through data organization, management, and eventual tool development.[1,7] At the very base of the pyramid is the development of pavement LCA framework.[1] The next levels are dependent on the different kinds of data that lie at the heart of a successful pavement LCA. The need for common protocols in developing LCAs and use of consistent data has laid the foundation for developing PCRs for pavement construction materials, empowering industry organizations to step in as program operators and develop industry-specific PCRs. It also encourages the use of EPDs to communicate the impacts of cradle-to-gate pavement LCAs. Indeed, recent legislation in California indicates EPDs may become the standard approach for reporting outcomes of pavement LCAs. Hence, the need to assess the roles played by PCRs and EPDs as standard instruments in the pavement construction-materials industry is imminent. Additionally, identifying associated challenges that the pavement construction-materials industry is likely to face in moving up this pyramid of implementation is critical. This report documents and discusses the challenges that have been exposed by the reliance of EPDs and PCRs on the quality, completeness, and availability of databases, which drive their credibility and usefulness.



Source: FHWA.

Figure 1. Diagram. The pyramid for implementation of pavement LCA.[(7)]

Identifying challenges to successfully delivering EPDs is particularly urgent because of the decentralized nature in which EPD programs in the pavement construction-materials industry have emerged in the last few years. In addition, in October of 2017, California Assembly Bill (AB) 262 was signed into law by the Governor of California, requiring successful bids to produce EPDs for a list of eligible materials before installing them.[(2)] The purpose of AB 262 is to set a maximum acceptable global-warming potential (GWP) for each category of eligible materials and produce materials that meet this requirement—thus reducing the GWP of the industry.[(2)] While AB 262 does not target the materials most commonly used in pavements, California Department of Transportation (Caltrans) is preparing to pilot requiring EPDs for a wide range of pavement materials it uses in parallel with implementing AB 262.[(2)] Caltrans's effort, which began more than a year before AB 262, to pilot requiring EPDs is aimed at gathering up-to-date and regionally applicable information on environmental impacts of pavement materials. These LCA outcomes can be used in pavement design, pavement management, and the development of specifications and other policies to reduce a number of environmental impacts, including GWP. Each of these efforts is a positive development toward implementation of pavement LCA. However, without appropriate coordination and preparation, these efforts could lead to unintended consequences that could impede the long-term adoption and appropriate use of EPDs. Time is of the essence, and the goal of this report is to provide suggestions for developing protocols for collecting and reporting LCA data for sustainable pavements.

OBJECTIVE

The primary objective of this report is to identify the challenges of developing a centralized approach to pavement LCA that will allow practitioners to have access to comprehensive, reliable, and transparent data on lifecycle inventory (LCI) on pavement construction materials. Specifically, this report presents such challenges as either technical or organizational. Technical challenges are problems that can relate directly to the development of new engineering heuristics about a specific product or process. Organizational challenges, on the other hand, are based in the need for creating new collaborative platforms and networks within which protocols and shared knowledge can support the practice of pavement LCAs.

According to Ferraro, Etzion, and Gehman, "collaborative organization is necessary to tackle grand institutional change and cannot be brought forth by any one participant alone."[8] Creating change requires a collective process that involves distributed action for implementing new technical solutions into practice. In the case of EPDs, given the nature of lifecycle flows across disparate industries, addressing the challenges of creating reliable and transparent databases for LCAs will require the creation of new collaborative networks between industries and agencies. Indeed, as this discussion will prove, technical and organizational challenges are tightly coupled and often a solution to one is necessary to support a solution to the other.

As a first step, a literature survey of the current state of PCRs and EPDs in the pavement construction-materials industry was conducted. A discussion of the processes around the development of PCRs and EPDs was included as part of this literature survey. Next, in an effort to generate knowledge through a collaboration, a workshop was conducted that involved multiple stakeholders from across the pavement construction-materials industry, agency, and academia, both nationally and internationally in September 2016 to identify some of the underlying challenges. The outcomes of this workshop are reported in chapter 3. In addition, chapter 4 provides a discussion of the challenges specific to Caltrans as it negotiates the new requirements set by AB 262.[2]

WORKSHOP REPORT

This report presents the outcomes of the workshop that was conducted to assess the prospects and obstacles for production of EPDs by industry and their use by public and private owners.

The workshop involved a series of presentations from public and private owners. The later part of the workshop involved group discussions about institutional barriers; technical gaps; human resource and capacity limitations; and cost constraints in developing uniform standards and approaches for collecting, organizing, and documenting data inventories in keeping with data quality standards outlined in ISO 14025 and its implementation in the European EN 15804 standard and recently published FHWA pavement LCA guidelines.[5,6,1]

CALTRANS'S EXPERIENCE

Chapter 4 discusses the specific challenges Caltrans is addressing with respect to AB 262, which was passed by the California Legislature and signed into law by the Governor on October 15, 2017.[(2)] The legislation was motivated by the State of California's need to respond to the challenges of climate change.

The objective of chapter 4 is to analyze the requirements of AB 262 and record the initial work of Caltrans, as one of three implementing State agencies, toward complying with it.[(2)] The challenges discussed reflect the outcomes of the workshop. This chapter specifically discusses technical and organizational challenges involved in complying with AB 262.

RECOMMENDATIONS AND THE ROAD AHEAD

In order to improve the reliability of EPDs and their usefulness in developing benchmark estimates for indicators like GWP, developing reliable, consistent, publicly available, and economic datasets is critical. Protocols to harmonize PCRs and ensure the use of background datasets for upstream processes across all public projects are also necessary. Hence, chapter 5 addresses both technical and organizational recommendations to ensure reliability of background datasets, collection of foreground data, and consistent use of PCRs—all of which are motivated by developing structured data definitions or information models that can be used easily across pavement LCAs.

CHAPTER 2. PCRS AND EPDS

Stakeholders' growing emphasis on sustainability has led to strong efforts to mitigate lifecycle environmental impacts of products and processes used in the built environment. In response, ISO has established standard processes and procedures for developing product labels that use pavement LCA methods to declare the environmental impacts of construction materials.(9) An EPD is a Type III environmental declaration that communicates the potential environmental impacts of a product or service using pavement LCA methods.(5) An EPD is a very useful instrument for communicating the outcomes of a pavement LCA. The specific strengths of EPDs lie in the rigorous process required by standards such as ISO 14025:2006 and EN 15804:2012.(5,6) Clearly defining the goal and scope of a PCR's underlying pavement LCA ensures consistent use of system boundaries and functional or declared units.

TYPES OF PAVEMENT LCA DATA

When conducting a pavement LCA, LCI data can be broadly classified as foreground or background. Broadly speaking, foreground data are collected through direct measurement or observation of processes that are immediately pertinent to the pavement LCA at hand. Data, such as the volume of natural gas used at an asphalt plant per year or the total energy consumed in drying aggregate, can be measured and collected through questionnaires, templates, and tools. Background data are defined as inventories describing upstream processes within the defined system boundaries of the pavement LCA but not within the scope of direct observation. These data can be obtained through either public databases, such as the United States Life Cycle Inventory's (USLCI's) National Renewable Energy Laboratory (NREL) data, or private databases.(12) The inventories for the extraction of crude oil and its transportation and refining to make gasoline, diesel, petroleum, and associated coproducts used for energy are an example of background data. Similarly, electricity production profiles by region and producer are also pertinent to most pavement LCAs. Needless to say, depending on the process, a specific data item (such as an inventory of impacts burning natural gas in a burner) can be either observed (foreground data) or found in an existing inventory database (background data).

A third category of pavement-LCA data is modeled data (i.e., data that are developed through the modeling and analysis of phenomena that are either within the lifecycle boundary or impact a process within it). For instance, the allocation percentages of impacts for different fractions in the petroleum distillation process are modeled based on the thermodynamics of the process and included in background data inventories for bitumen, diesel, petroleum, etc. Similarly, energy losses at the PVI interface are also modeled and used as inputs in the use phase of a pavement, utilizing parameters that are collected as foreground data. Hence, modeled data can be considered either foreground or background data depending on the application.

The data quality of each of these data categories, once collected, can be checked for compliance using the data-quality standards outlined in an ISO 14025:2016- or EN 15804:2012-compliant document.(5,6) These standards identify the dimensions of data quality, including temporal representativeness (age), technological representativeness, geographical representativeness (geography), precision, uncertainty, and completeness. However, they provide limited guidance regarding industry processes and practices and specific methods that ought to be used for data collection and reporting. PCRs can be as prescriptive as the program operator chooses in establishing these specifications. Data quality–assurance requirements for EPDs ensure foreground and background datasets are appropriately assessed for completeness and reported within specified, recent time periods. While some PCRs clearly identify background inventories to be used and the specificity and format in which foreground datasets need to be collected, other PCRs provide only a guideline for the choice of upstream inventories. This gap continues to be a critical and major impediment in making the use of pavement LCA methods, results, and technologies transparent and reliable for decision-support applications.

DISCUSSION OF EPDS AND PCRS

Similar to nutrition labels for processed foods, EPDs communicate the potential environmental impacts of a product or process based on a rigorous LCA. The rigor of the LCA is ensured using a set of PCRs that defines the rules, requirements, and guidelines for conducting the LCA for all products in a specific category. Hence, EPDs must be in compliance with a relevant PCR. The PCR ensures that the LCA supporting EPDs does the following:

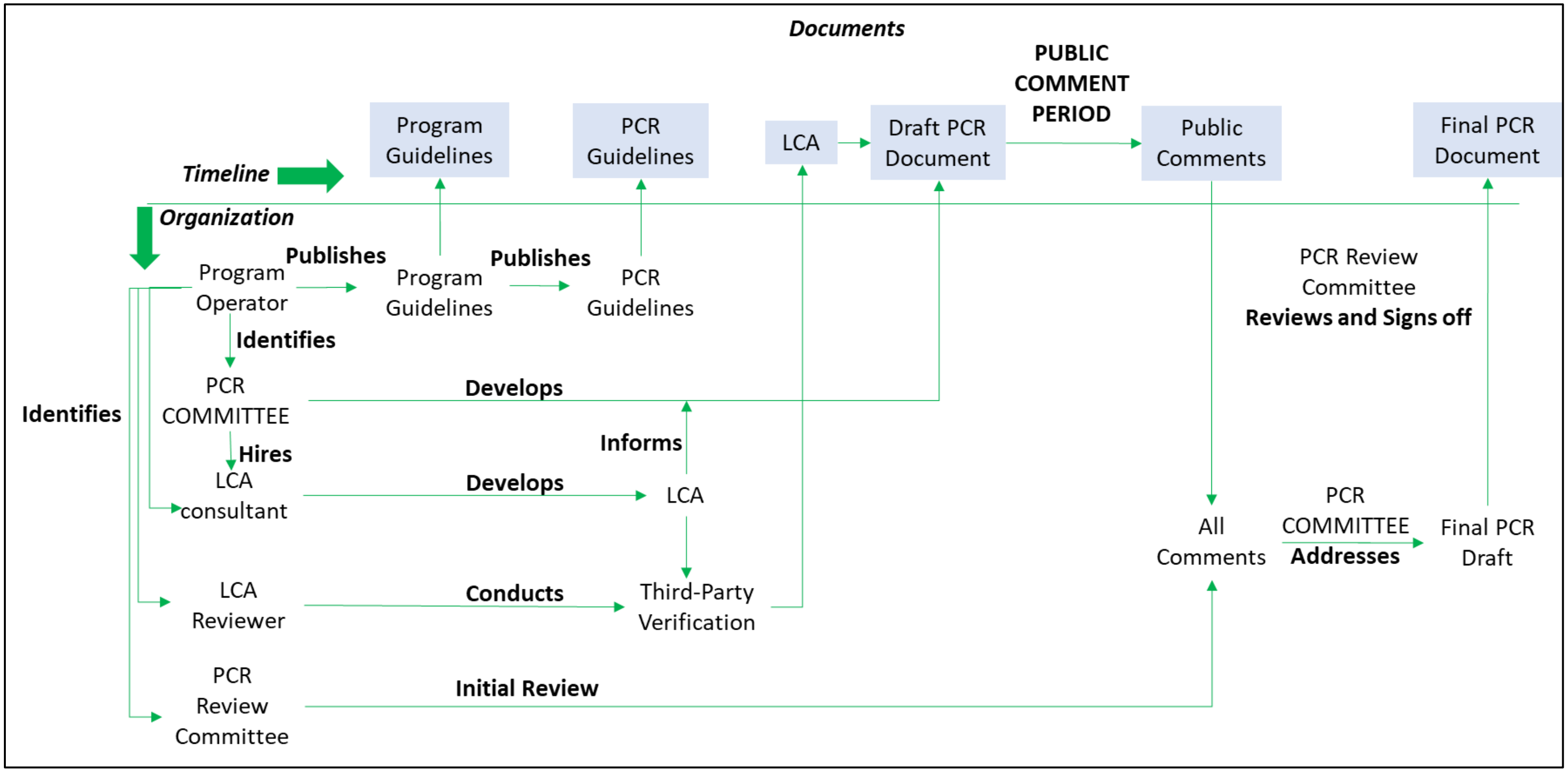
- Will use the same functional and declared units for a product.
- Will be conducted using the same goal, scope, and system boundaries to support the EPD.
- Will use the same guidelines for data collection and specification when developing the LCI, requiring reporting across a 12-mo period in the last 5 yr, reflecting technology in current use and ensuring the use of geographically pertinent data.
- Will use the same guidelines for ensuring the quality of the data collected (including tolerances) for conducting the underlying LCA.
- Will use the same guidelines for reporting environmental impacts across relevant product impact categories using appropriate characterization factors. Example categories are environmental impact indicators (such as GWP), total primary-energy consumption, and material-resource consumption.

Based on a given PCR, an EPD can be developed to convey information from business-to-business or from business-to-consumer (more commonly known as B-to-B (cradle-to-gate) and B-to-C (cradle-to-grave), respectively). To maintain the accuracy, reliability, and unbiased integrity of an EPD, multiple stakeholders are involved with peer review and third-party verification. Typically, an organization plays the role of a program operator. It develops industry-specific PCRs in compliance with ISO 14025.[5] The PCR-development process involves participation of industry stakeholders. In addition, an independent review panel provides a peer review of the developed PCR. Using their PCR of the product at hand, program operators, manufacturers, and producers can develop a specific EPD based on an LCA conducted using input data on materials and energy use specific to their operations and processes. A third party (or the program operator) must certify that the EPD is compliant with the PCR. ISO 14025 has defined specific requirements for the PCR review and EPD verification.[5] The following section describes the process involved in developing PCRs and EPDs.

DEVELOPMENT OF PCRS AND EPDS

A program operator is responsible for creating and maintaining a PCR document.[13] The program operator first publishes program guidelines followed to develop a PCR. A PCR committee involving stakeholders is then identified by the program operator. A PCR committee will first identify the product category, goal, and scope for the product under consideration. Only after that will it identify an existing LCA for the product category. In situations when the PCR committee is unable to identify an existing LCA, it will hire an LCA consultant to conduct LCA. This third party–verified LCA will act as a baseline to develop the draft PCR document. The LCA results will inform the drafting of the PCR document. The draft PCR document, prepared by the PCR committee, will then be open for public comment for a period of time (typically, 30 d). All public comments received need to be addressed by the PCR committee. A PCR review committee is a group identified by the program operator that consists of independent, external reviewers who will ultimately sign off on the PCR. This committee will review the responses to the comments. An approval by the PCR review committee will lead to the final PCR document. Industry-specific EPD programs could then be developed based on this PCR document. The audience for this document would be plant owners, agencies procuring material, and others.[5] Figure 2 provides a graphical workflow for developing a PCR document.

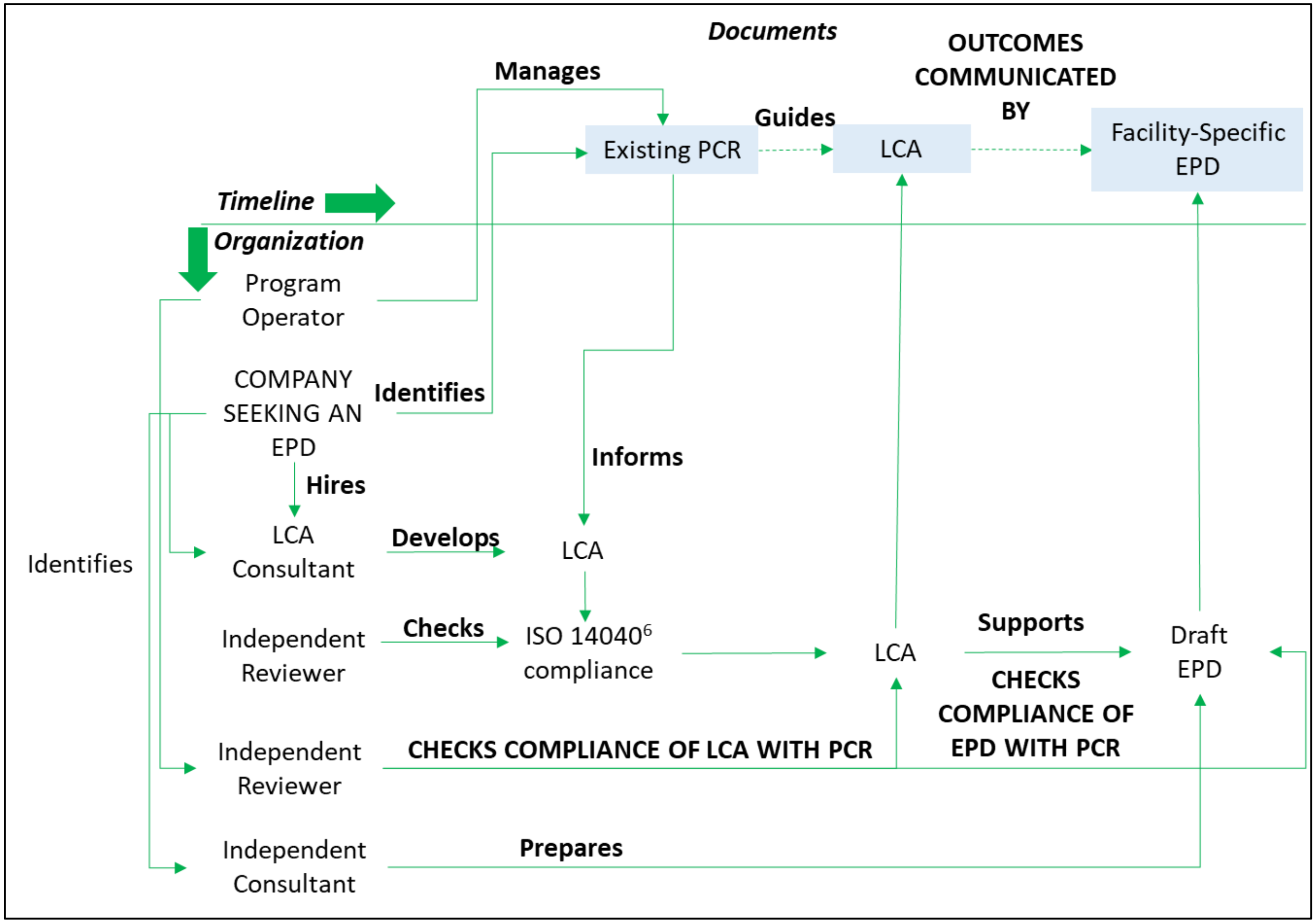
An organization willing to produce a facility-specific EPD will identify an existing PCR for the product category of interest. A facility, in the context of cradle-to-gate EPDs for construction materials, will indicate a material production plant. This PCR will be owned by a program operator. Based on this PCR, the organization may conduct an LCA with the aid of in-house staff or may hire an independent consultant to conduct an LCA. This LCA will be reviewed by a panel of independent critical reviewers for its compliance with ISO standard 14040.[9] Qualifications of critical reviewers include knowledge and expertise of LCA as well as the relevant domain. This critically reviewed LCA will aid in formulating a draft of the EPD. The organization may formulate this draft with the help of in-house staff or an independent consultant. The draft EPD along with the LCA study will be sent to the program operator for certification. At this stage, an independent reviewer identified by the program operator will check the compliance of both the LCA study and draft EPD with the base PCR and ISO and any other standards that the LCA and PCR claim to follow. The independent reviewer will approve the EPD document only if both the LCA study and draft EPD are in compliance with the base PCR. Figure 3 conveys the steps involved in an industry-specific EPD-verification process.



Source: FHWA.

Note: Bolded words refer to actions.

Figure 2. Flowchart. Workflow for PCR development.



Source: FHWA.

Note: Bolded words refer to actions.

Figure 3. Flowchart. EPD verification process.

RELIABILITY AND CONSISTENCY OF PCRS AND EPDS

The reliability and consistency of EPDs are a function of how the PCR is crafted. In this section, these terms are defined and potential systemic weaknesses that can compromise the reliability and consistency of the information communicated by EPDs are identified. Different aspects of the PCRs for asphalt mixtures and concrete in North America are used to inform the discussion.

The reliability of an EPD is a function of the data quality of both foreground and background data categories used in conducting the underlying LCA. Besides meeting the data quality–assurance criteria set forth by ISO 14025, the reliability of an EPD can be improved if the underlying LCA meets the following preferred characteristics:(5)

- Datasets used can be easily accessed, are transparent, and allow the LCA to be reproduced by independent parties.
- Proprietary background databases, when used, are externally reviewed, and preferably, the inventories are made available as a product system to ensure transparency.
- Foreground proprietary data are reported using statistical measures that characterize uncertainty with appropriate confidence intervals when appropriate. All assumptions used in the collection of the data should be clearly identified.
- Monte Carlo simulations are used as a tool for assessing uncertainty of LCA outcomes. Care should be taken to ensure that the underlying distributions being sampled have been characterized through empirical data and any variables that are expected to be correlated are sampled from correlated distributions. Parameter ranges should also be bounded to avoid sampling invalid values. In addition, tests should be conducted to identify if the simulation is introducing noise into the results. As an effective and useful alternative, sensitivity analysis based on meaningful case options can be considered.
- Proxy inventories to approximate missing data are avoided altogether as this practice is more likely to introduce errors. Instead, missing data should be clearly identified and a need for data collection and reporting should be established.

In the rest of this report, the word "reliability" is used as short hand for communicating these characteristics.

The consistency of an EPD is a function of how well the motivating PCR is harmonized with other related PCRs. The consistency of an EPD can be improved if the underlying PCR meets the following criteria:

- Allocation of upstream coproducts and recycled materials is consistent across the supply chain ensuring that double counting or exclusion of processes is avoided.
- When possible, background datasets are selected and specified in the PCR to reflect the underlying industrial processes. For instance, inventories for asphalt binder and diesel

should be ideally derived by using the same allocation coefficient to the petroleum refining process.

- Regionalized, facility-specific data are used when possible, and the lifecycle flows are identified as specifically as proprietary constraints will allow.

- Assumptions of allocation and choice of upstream data are consistent with the current PCR when EPDs from other PCRs are used as inputs.

Ultimately, the consistency of a PCR and the reliability of the underlying LCA are critical to the usefulness of the information communicated by an EPD. Of course, reliability and consistency are coupled concepts, and an EPD that is produced using EPD inputs from inconsistent PCRs is unreliable in what it communicates.

Discussion of Some Major PCRs

PCR committees play an important role in defining the consistency and reliability of EPDs. While the work done by each of these committees (often voluntary) is laudable, the disparate nature of the efforts and the limited coordination between industries often results in unintended consequences. This section discusses some of the choices made in current PCRs with an eye on the implications of agencies requesting EPDs for informational purposes.

The PCR for concrete provides clear guidelines on data quality, and an industry average EPD is available that illustrates the use of a set of LCIs spanning datasets that are proprietary and sourced from North America and Europe.(14,15) In this case, the proprietary nature of the data leaves direct review of underlying assumptions difficult to assess, even when the metadata are available. However, the reliability is improved because of the review process that most such inventories have gone through. The average EPD provides a guideline for practitioners even though the PCR does not specify the use of particular inventories. A literature survey of the spread of the background databases that have been used for the 16 EPDs published by the National Ready-Mix Concrete Association (NRMCA) program is summarized in table 1.(15)

The asphalt mixture PCR for North America clearly identifies the background datasets to be used for upstream processes, establishes a format for the collection of foreground data collected at asphalt plants, and specifies the desired level of data quality.(16) The inventories specified are all based on the open, freely available USLCI database provided by NREL.(12) Limited metadata are associated with the database, and it is not reviewed and updated regularly. The accompanying LCA adheres strictly to the specified background data and provides statistical margins to assess the reliability of the foreground data to be collected as a test of reliability. The limitations of the NREL database due to its incompleteness are established in the PCR, and a sensitivity analysis is provided using a proprietary USLCI database provided by EarthShare, showing a difference between the two at 25–30 percent.(17) While the background data are incomplete, their consistent use across all EPDs for asphalt mixtures will ensure that LCA practitioners consistently use the same upstream processes. The trade-offs for background data incompleteness are the benefits of low cost, easy availability, and direct access to the knowledge of the level of reliability of the data.

The contrast between the approaches taken by the North American PCRs for asphalt mixtures and concrete highlights alternative trade-offs.(16,14) While the former emphasizes consistency, free availability, and transparency in selection of background inventories for upstream processes, the latter leaves the choice of upstream inventories to the LCA practitioners, instead emphasizing the quality of the data used. Asphalt EPDs are more suitable for developing benchmarks, even if they are likely to be based on incomplete datasets and, therefore, potentially have limitations in the results. Developing benchmarks with concrete EPDs will require an examination of the underlying databases for each of the EPDs considered.

Table 1. Examples of background data inventories.

Process	Background Data Source	Geography	Study
Reclaimed asphalt pavement	Ecoinvent 2.2	U.S.	Yang et al. 2014(18)
Asphalt binder	Yang (2014)	U.S.	Yang et al. 2015(19)
Aggregate	Stripple (2001)	Sweden	Chowdhury, Apul, and Fry 2010(20)
Aggregate	Ecoinvent 2.2	U.S.	Yang et al. 2015(19)
Aggregate	USCLI	U.S.	Argos Ready Mix South Central 2014(21)
Aggregate	CLF PCR Default	EU	CalPortland Company 2017(22)
Aggregate	Ecoinvent	Global	Cemex Environmental Product Declaration 2014(23)
Aggregate	Ecoinvent	Switzerland	Central Concrete 2013(24) CeraTech 2014(25)
Fly ash	Stripple (2001)	Sweden	Chowdhury, Apul, and Fry 2010(20)
Bottom ash	Stripple (2001)	Sweden	Chowdhury, Apul, and Fry 2010(20)
Recycled concrete	Stripple (2001)	Sweden	Chowdhury, Apul, and Fry 2010(20)
Portland cement	SimaPro Database	EU	Huntzinger and Eatmon 2009(26)
Portland cement	Portland Cement Association EPD USA Portland Cement, 2016	U.S.	CalPortland Company 2017(22)
Portland cement	USLCI	U.S.	Cemex Environmental Product Declaration 2014(23)
Portland cement	WBCSD-CSI tool for EPDs of concrete and cement - Background Report	China	CalPortland Company 2016(27)
Electricity	USLCI	U.S.	Chowdhury, Apul, and Fry 2010(20)
Electricity	Emissions and Generation Resources Integrated Databases (eGRID 2012)	U.S.	Al-Qadi et al. 2015(28)

Process	Background Data Source	Geography	Study
Electricity	Ecoinvent	U.S.	Argos Ready Mix South Central 2014[21]
Transportation	Stripple (2000, 2001)	Sweden	Chowdhury, Apul, and Fry 2010[20]
Transportation	USLCI	U.S.	CalPortland Company 2017[22]
Construction equipment	NONROAD	U.S.	Al-Qadi et al. 2015[28]
Admixtures	EFCA EcoProfiles (300, 301, 302, 303, 324, and 325)	EU	Argos Ready Mix South Central 2014[21]
Admixtures	CLF PCR Default	EU	CalPortland Company 2017[22]
Slag cement	Slag Cement Association N. America EPD Slag Cement, 2015	U.S.	CalPortland Company 2017[22]
Slag cement	Ecoinvent v3	U.S.	Cemex Environmental Product Declaration 2014[23]
Slag cement	Ecoinvent	Switzerland	Central Concrete 2013[24] CeraTech 2014[25]
Natural gas	USLCI	U.S.	Argos Ready Mix South Central 2014[21]
Diesel	USLCI	U.S.	Argos Ready Mix South Central 2014[21]

Reliability of PCRs

This section considers the challenges associated with functioning in an environment where PCRs are operated by multiple program operators, often independently of each other, for products that interact within the same industrial processes and product systems. The range of databases and inventories used when conducting LCAs using these PCRs—in the absence of a national inventory database—further compounds the challenge. As discussed in the section Discussion of some major PCRs, in the case of concrete and asphalt, PCRs and their effect on choice of data inventories (and databases) used can cause trade-offs between completeness, consistency, and reliability of LCAs. It is important to note that the reliability of a database, commercial or otherwise, is based on the underlying rigor used in its development and whether it has been externally reviewed. Underlying rigor and external review still do not assuage the challenges around using data that are collected using assumptions that are not always harmonized between databases or when using them for PCRs that do not have the same underlying assumptions.

Specifically, the use of inconsistent databases can become pertinent when an agency considers the use of EPDs as inputs to a decisionmaking process (i.e., using EPDs for construction materials to assess the GWP of a pavement system). Within a cradle-to-gate scope, the impacts as declared in facility-specific EPDs can be added to create an estimate for the system as a whole in theory. While this method is intended for use when developing benchmarks for pavement systems, it can cause double counting or exclusion of processes if the PCRs are not harmonized.

For instance, when considering recycled materials across different product streams, differing allocation protocols can introduce inconsistencies.

Consider the case of steel slag, a coproduct of the steel production process that is used as a supplementary cementitious material (SCM) that can help replace cement in concrete mixes, thus potentially reducing their environmental impacts. The North American PCR for slag cement requires EPDs to allocate impacts across all coproducts using system boundary expansion, a method that accounts for avoided burden due to the use of a waste material as a substitute for a virgin material.[(29)] The concrete PCR, meanwhile, allows a cut-off allocation for slag, thus inheriting no impact due to its production while reducing the impact due to the replaced cement.[(14)] Finally, the PCR for natural aggregate, crushed concrete, and iron/steel furnace slag suggests the use of economic allocation at the steel production plant.[(30)] Each of these methods is valid within the context of each individual PCR but can lead to inconsistencies when EPDs for each of the products are combined.

Similar inconsistencies can emerge when using LCIs from different databases. For instance, to achieve consistency, all the coproducts of the petroleum refining process, including aviation fuel, diesel, fuel oils, naphtha, and binder, should be based on a consistent allocation from the process with a trace back to the crude source. When inventories for each of these products come from different databases, they may lack underlying consistency with respect to process as well as the crudes from which they are originating, which can result in omission or double counting.

The discussion of cost and/or open access, while not pertinent to the scientific merit of the data, is nonetheless relevant to the adoption of EPDs into business processes. An open data inventory can be assessed by practitioners, and any incompleteness can be established easily and corrected over time. The NREL USLCI database is an example in which the gaps in the data are clearly identifiable and dummy inventories can be updated by a practitioner using other data sources (for instance, the electricity inventories can be updated and adapted using a combination of eGRID and greenhouse gases, regulated emissions, and energy use in transportation model (GREET) data).[(12)] The database does not require rigorous maintenance or updating and is freely available. In comparison, proprietary databases promise completeness through a rigorous methodology and review process and, therefore, come at a cost. While some of these databases do provide the metadata, that information is not always considered in the LCA reporting when the data are used. A need of public agencies and the construction industry generally is databases that are verifiable and reliable, undergo some form of open-access or review process, and are available at reasonable costs. This combination is difficult to find in the current climate.

A takeaway from this discussion is that, while the system of PCRs and EPDs has created a foundation for communicating and using LCA outcomes, considerable gaps in the availability and consistent use of databases still exist. When benchmarking the environmental impacts of products and processes, these inconsistencies can lead to erroneous estimates that can adversely impact long-term adoption and acceptance of the benchmarks into business processes.

State of Practice for PCRs and EPDs

An ongoing effort at Caltrans (discussed in detail in chapter 4) is looking at the readiness of each material industry mandated by AB 262 to provide EPDs. Carbon steel reinforcing bar, structural steel, flat glass, and mineral wool board insulation are the materials covered in AB 262.[(2)] Caltrans has an effort underway to require EPDs for a wide range of transportation materials, a large portion of which are pavement materials. This section looks at the state of PCRs for asphalt, aggregates, and concrete in addition to those of materials mentioned in AB 262. (All expiration dates and validity information are provided in figure 4.) The materials discussed in AB 262 are described as follows:

- **Concrete:** The program operator for the concrete PCR is Carbon Leadership Forum.[(14)] They have developed a North American PCR with the aid of the University of Washington and the NRMCA. This PCR aids in developing EPDs meeting ISO standard 14025 for Type-III EPDs.[(5)] NRMCA has developed multiple software tools to produce industry-specific EPDs in a cost-effective way. The PCR for concrete expired in December 2018.

- **Mineral Wool Board Insulation:** UL Environment is the program operator for mineral wool board insulation PCR. They have developed a building envelope thermal insulation PCR. Facility-specific EPDs have been developed by the North American Insulation Manufacturers Association as well as some individual companies.[(31)]

- **Flat Glass:** NSF International is the program operator for flat glass PCR. They published "Glass Association of North America (GANA) PCR for Flat Glass: UN CPC 3711."[(32)] This PCR is derived from the European PCR. The PCR covers processed and coated glass, including heat-treated, insulating, and laminated glass. It was valid until March 2019. At present, there are facility-specific EPDs for flat glass in California. However, the amount of data is limited.[(32)]

- **Carbon Steel Reinforcing Bar:** SCS Global Services is the program operator for the carbon steel reinforcing bar PCR. They have developed a North American PCR for designated steel construction products. Industry average EPDs are available in California, and only a few facilities have published specific EPDs. The validity period for their PCR is from May 5, 2015, to May 5, 2020.[(33)]

- **Structural Steel:** SCS Global Services is the program operator for structural steel PCR. They have developed a North American PCR for designated steel construction products. A numerous small bifurcation of materials such as hollow structural shapes, steel plates, and others exist under the broader umbrella of structural steel. Hence, it is feasible to develop EPDs for specific products. As of December 2017, there are no industry-specific EPDs for structural steel fabricators in California. The validity period for their PCR is from May 5, 2015, to May 5, 2020.[(33)]

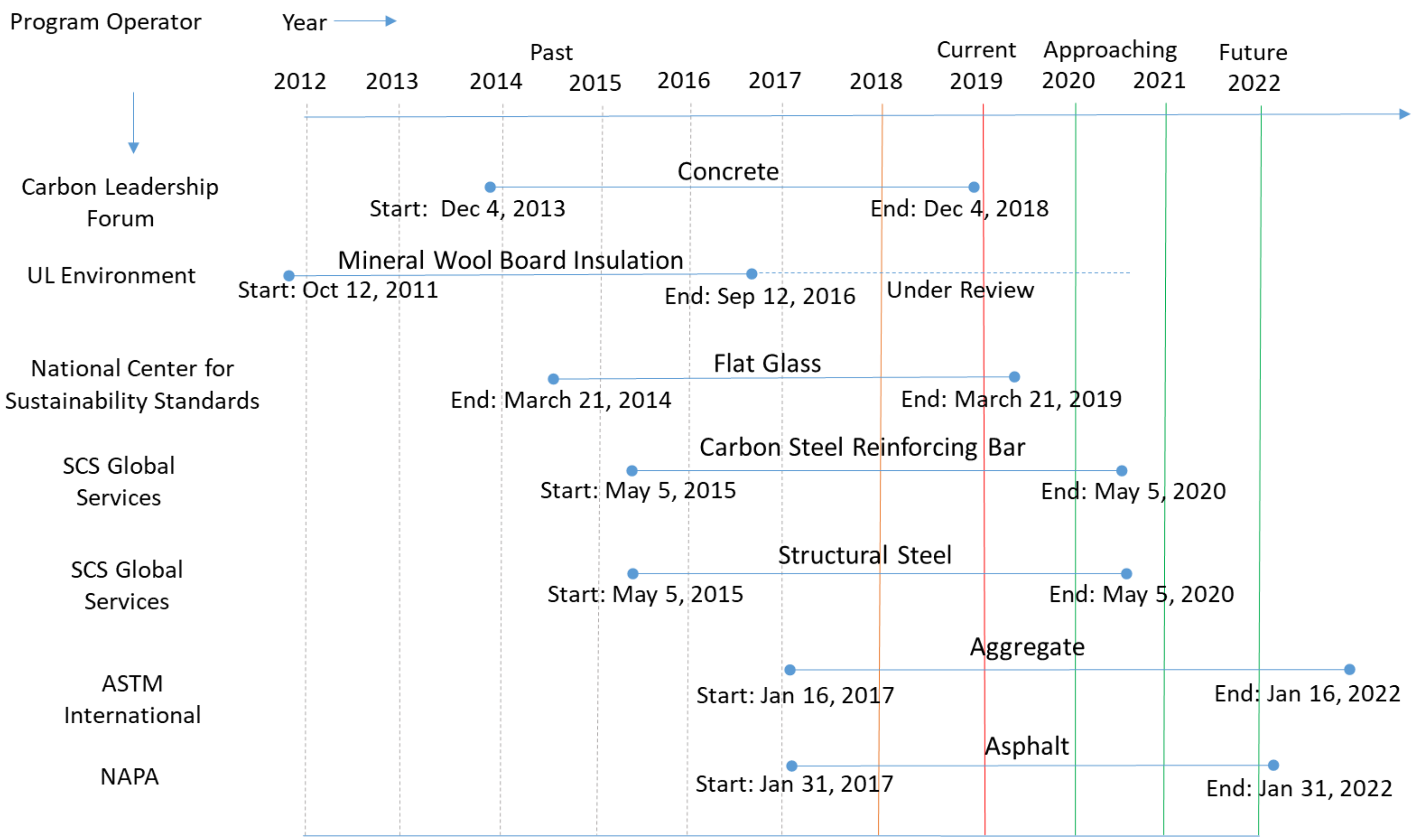
- **Aggregate:** The program operator for aggregates PCR is ASTM International. They published a PCR for construction aggregates comprising natural aggregates, crushed concrete, and iron/steel furnace slag. The validity period for their PCR is from January 2017 to January 2022. Particularly in California, a lot of facility-specific data are available. However, due to the large disparity in the availability of aggregates, proper care needs to be taken before comparing GWP between aggregates.[(30)]

- **Asphalt Mixture:** National Asphalt Pavement Association (NAPA) is the program operator for PCR of asphalt mixtures. They have established an EPD tool that can be used to develop facility-specific EPDs. The validity period for their PCR is from January 31, 2017, to January 31, 2022. There are no published EPDs for asphalt in California at this time.(16)

Table 2 provides the state of practice regarding industry-specific EPD programs based on these PCRs, and figure 4 presents the timelines for PCRs of materials considered in the present study.

Table 2. Approximate number of EPDs for materials of interest in North America.

Material	Number of EPDs
Concrete	16
Mineral wool board insulation	5
Flat glass	2
Carbon steel reinforcing bar	33
Structural steel	29
Aggregate	3
Asphalt mixture	0



Source: FHWA.

Figure 4. Diagram. Timeline for PCRs of materials of interest.

CHAPTER 3. WORKSHOP REPORT

This section presents the outcomes of the workshop that was conducted to assess the prospects and obstacles to the production of EPDs by industry and their use by public and private owners. The objectives of this workshop were the following:

- Globally benchmark the ability of industry to produce EPDs and the use of EPDs by owners.
- Identify institutional barriers, technical gaps, human resource and level of expertise capacity limitations, and cost constraints in developing uniform standards and approaches for collecting, organizing, and documenting data inventories in keeping with data quality standards outlined in ISO 14025 and its implementation in the European EN 15804 standard, and recently published FHWA pavement LCA guidelines.[5,6,1]
- Work together to produce a vision for future production and use of EPDs, including solutions for standardization, strategies to overcome barriers and gaps, and ideas for constraining costs.

The underlying questions this workshop addressed fall into two categories: technical and organizational (categories that are closely coupled).

The workshop consisted of invited plenary presentations to frame the issues and pose questions, followed by participatory workshop sessions to discuss and develop answers (and sometimes more questions), and on the final day, the outline of a draft road map for a way forward was discussed.

SUMMARY OF DISCUSSIONS ON DAY 1

On Day 1, the following presentations were made:

- Funding Process for Infrastructure projects, City of Detroit.
- Federal Highway's Sustainability Program.
- Framework for Sustainability.
- State of Life Cycle Inventory Data: Presentations from Michigan Department of Transportation (DOT), the Netherlands, Sweden, Spain.
- Broader Infrastructure: Presentations from City of Detroit, City of Austin, California High Speed Rail.
- Current Practices around Data Reporting: Presentations from NAPA, Massachusetts Institute of Technology, and Illinois Tollway.

The presentations were followed by a robust discussion that can be broken into three sections, which are expanded on in this section. The first section addressed the technical questions around the development of PCRs, the data used to conduct LCAs to support EPDs, and the technology frameworks that support the use of EPDs. The second section covered challenges to integrating the use of EPDs into current business processes, such as procurement, and the necessary policy support and frameworks. The third section considered the challenges to integrating EPDs in the decisionmaking process.

Technical Questions

This section outlines the discussion on issues inherent to the technical aspects of developing PCRs and conducting LCAs that support the EPD development process.

State of PCRs

In the last few years, multiple industries in the United States have become program operators and introduced PCRs for their products. The pavement construction-materials industry is in this group. The National Ready Mix Concrete Association and NAPA have become program operators for concrete and asphalt mixtures, respectively. As these relatively loosely coordinated efforts have begun, the industry has recognized that multiple components of a PCR apply broadly across different products and processes. For example, data quality–assurance requirements could be applied uniformly across all products. Similarly, the need has risen for coordination to ensure PCRs are harmonized and are using consistent principles for allocation of impacts to coproducts and recycled materials.

Speakers at the workshop representing European countries (the Netherlands, Spain, and Sweden) reported that some of the member countries have developed or are in the process of developing national PCRs managed by national program operators who are associated with the national government. Meanwhile, efforts at developing Europe-wide PCRs may supersede national PCRs.

The development of Europe-wide PCRs has led to the discussion of whether there needs to be a single PCR for the United States usable across all products and processes that could be governed by a consortium. ISO 21930 would establish a core set of requirements to be considered a core PCR to develop an EPD for any construction product or service.(34) This core PCR would identify the majority of rules (possibly 80 percent) that apply across all products and processes and highlight the need to develop special requirements for the factors that are product specific. The process of developing a common PCR could help identify discrepancies across PCRs for related products and harmonize them. The PCR would be akin to the core requirements definition for all construction and building materials as outlined in EN 15804. In keeping with the Part B specifications in EN 15804 that are specific to different products, the PCR could allow special provisions to cater to specific products.

The following new questions were raised in the discussion:

- Should the infrastructure materials industries adopt a “core PCR” that allows special provisions for a wide variety of materials?
- Who would be the operator for the program?

Recommendations for addressing these questions are discussed in the final chapter of this report.

System Boundary Definition

The FHWA Sustainable Pavements TWG has developed the Pavement LCA Framework.[(1)] It has identified the lifecycle system boundary for the entire pavement system. While this guide is useful, there are still questions to be addressed regarding possible exclusion or double counting of impacts when developing the subsystem boundaries for products and coproducts that are part of the pavement system. The following additional questions were raised in the discussion:

- When declared units are defined by mass, should they be normalized to reflect specific gravity of the material?
- How would an EPD be developed for a material with 100 percent recycled content?
- For pavement products and coproducts, what is the appropriate definition of a "gate"? For example, if the gate for asphalt binder is set to be the petroleum refinery, then there is a possibility of excluding the impacts of the terminals where the binder is transported to before making it to the asphalt plant. Similar dilemmas are relevant for products that are recycled-in-place or are precast or processed offsite.
- Should capital equipment in plants that produce construction materials be included explicitly in the system boundaries defined in the product PCRs?

Databases

Establishing data quality and assurance standards and ways of communicating data reliability and transparency, in keeping with standards such as ISO 14025, is a critical goal of this effort.[(5)] The presentations raised questions regarding the current state of reliable and transparent LCI databases available for highway infrastructure materials. Challenges exist for both foreground and background data. The workshop had various discussions regarding ways of ensuring reliability and transparency of background datasets and the reporting of foreground data.

Currently there are a few commercial providers of background data, and one U.S. public LCI.[(12)] While the former promises higher quality and completeness, it is usually proprietary and can be expensive. Public sources, conversely, are free to use and transparent but often incomplete. This circumstance creates a dilemma for industry operators when specifying background databases in their PCRs. On the one hand, State DOTs, which are often major customers for the highway infrastructure–materials industry, are looking for greater transparency in the use of upstream databases and want low-cost solutions. The high cost of upstream databases can be a deterrent to adoption of EPDs for industry. On the other hand, if industry operators do not specify the use of specific inventories, there is a risk of EPDs being produced using widely different and unreliable upstream data. In this context, it was reported that, in the Netherlands, LCA consultants created a single national database funded equally by industry and government. The best available data are used when available with an emphasis on using supplier-reported data. In the absence of supplier-reported data, very conservative industry average and third party reported data are used to indirectly penalize and encourage the suppliers to provide better data. Questions were raised regarding the suitability of similar situations in the United States.

Reporting foreground data presents similar challenges. Uncertainty in the observed data must be reported with careful characterization of variability across a significant number of observations. For example, average electricity use for a specific process must be reported with region specification and confidence intervals from more than a specified number of observations. Also, the sources of uncertainty should be sorted into their types: uncertainty resulting from lack of knowledge (epistemic) or uncertainty resulting from inherent randomness (aleatory). Efforts should also be made to correlate trends in data with underlying causal relationships that define processes. For example, the issue of correlation may exist while considering the trend of regional variations in energy and electricity used to dry aggregate and the correlation with ambient temperature and moisture.

Besides foreground and background data, LCAs also use modeled data in some instances. Modeled data are particularly relevant to use-phase considerations that relate impacts to modeled changes in system or product performance (e.g., the rate of change of vehicle fuel efficiency with respect to changes in pavement surface characteristics). Guidelines should be developed regarding how data from supporting models should be used and the necessary validation and documentation necessary to support such models.

In the course of the discussion in this section on using databases, the following ideas were considered beneficial:

- Develop rules for reporting and using upstream background data across all industries. Such rules are particularly important for upstream producers who are outside the immediate supply chain (e.g., upstream impacts of fuels, additives, and other chemicals).

- Encourage collaboration with allied industries (e.g., the chemical manufacturing industry) to develop transparent, reliable, and low-cost inventories.

- Strongly encourage use of the same proxy datasets for all LCAs when using upstream datasets that are incomplete.

- Develop guidelines for characterization of uncertainty in reported data.

- Develop guidelines for reporting data from models and establish necessary validation and documentation necessary to support such models.

- Develop benchmarks for processes to standardize across available databases and reported datasets.

Business and Organizational Processes

This section addresses the discussions regarding the challenges to delivering EPDs, including using novel technological frameworks and integrating them into existing construction-industry business processes.

Information Technology Frameworks

Identifying suitable information technology (IT) frameworks and platforms that can be used to integrate processes for creating EPDs and processes for using EPDs in the design, procurement, construction, and maintenance processes is necessary. For instance, one presentation reported a custom-made software system that takes the bill-of-materials as an input in Sweden. The information is directly extracted from the design documents and loaded into standardized templates that are compatible with an LCA calculation engine. The LCA is conducted using a built-in standardized LCA engine using the EPDs as inputs. This process produces an easily verifiable standardized report that provides a project-level view of the LCA impacts.

The following delivery possibilities were discussed:

- Have standardized software templates reflecting PCR categories so that EPDs can be easily uploaded and archived.
- Make available to local Governments simplified systems for tracking flows, including materials used, distances travelled in transporting them, and project-level procurement. These tools could be useful for tracking flows through current business processes providing decisionmakers an initial way to engage in lifecycle thinking.
- Develop EPD delivery tools tied to standardized databases and PCRs. These platforms would allow suppliers to keep their EPDs up to date using a verified, user-friendly software interface. The interface would allow suppliers to change and update their EPDs easily and economically as they change the list of ingredients and proportions per declared unit.

The discussion emphasized the need for good IT design that allows for integration with existing design and construction management software.

Critical Review Frameworks and Qualifications

Several rounds of third-party review occur when developing an ISO 14025 compliant EPD program and subsequently, for producers creating program, compliant EPDs.(5) The PCR must be reviewed and commented upon as does the LCA supporting the EPD to ensure its compliance with the PCR. The review process is critical to the reliability of EPDs as a way of communicating the environmental impacts of a product, yet currently, there is no standard best practice to define the review process. In this context, the following issues were discussed:

- The necessity of possible minimal requirements to be a critical reviewer.
- The need for a standardized critical review process for EPDs.

- The need for a mechanism to ensure that, if the procurement process were to use EPDs, there would be a way to vet the reviewers and/or create a list of verified reviewers to be used.

- The possibility of automated verification of EPDs using software as part of the technology frameworks discussed in the section, Information Technology Frameworks.

Use of EPDs in Procurement

There is potential for EPDs to be used by owners and agencies during the procurement phase. A contractual scenario can be limited to requiring EPDs on an informational basis to estimate the impacts of the materials being used in design and construction. Further, it can be extended to consideration of EPDs in the selection of materials in a design–bid–build (low-bid) environment. The California High Speed Rail Commission is asking for EPDs from material suppliers but limiting their use for informational purposes only. However, the Commission has set a goal for using EPDs provided by suppliers at the time of material delivery to the project (not during the bidding process) for procurement purposes.. Within this context, the discussion considered the following challenges and questions for State agencies using EPDs in the procurement process:

- There is limited LCA experience in agencies, and no best practices are established in reviewing the expertise involved in critical reviews of EPDs and the PCRs under which they were produced. Particularly, there is no benchmarking to identify differences in the scope, and so forth, of EPDs for materials produced under different PCRs (as discussed in the section, Reliability of PCRs in chapter 2).

- It is not clear if making EPDs a requirement could burden small businesses. If they are, could Government-supported programs be created to level the playing field?

- The success of EPD programs will depend on the availability of reliable and transparent LCI databases. Should a Government agency fund a targeted effort to fill gaps in public LCI data?

- There are currently no best practices for certification of EPDs for materials produced in other countries, which could become relevant for projects that procure material from overseas.

- Materials EPDs only extend to the gate of the producer and do not consider construction, use, and end-of-life phases. ISO rules state EPDs should not be used for comparison without consideration of the full lifecycle of the product system. The full lifecycle of a pavement material is highly dependent on how it is used in the structure, traffic conditions, climate, and other variables affecting performance. Thus, the use phase cannot be considered based on the materials properties alone in an LCA. Materials with lower impacts in the materials-production phase may produce greater impacts over the rest of the lifecycle and vice versa. Therefore, selection of materials within a pavement type and especially between different types based on material EPDs alone could result in increased impacts over the pavement's lifecycle if information from the design of the pavement structure and prediction of its performance are not considered.

In summary, it may be too early to use EPDs for procurement given the challenges discussed here. However, the use of EPDs in procurement would yield better incentive. Requiring material EPDs, which can be used as input to evaluation of pavement-structure designs, is a more likely early goal. (Note: This discussion regarding procurement is a reflection of the workshop and precedes the AB 262 discussion in time.[2] Hence, it presents a limited understanding of what procurement could look like as discussed later in the context of AB 262).

Decisionmaking

Ultimately the goal of EPDs is to produce better information to support the decisionmaking process and move decisions toward more sustainable outcomes. The role of decisionmakers in improving the long-term sustainability of infrastructure is important at all levels: local, State, and Federal. The workshop attendees provided perspectives from all three levels. While at the Federal level, there are efforts at advancing best practices and informing policy, the States can provide leadership in benchmarking and implementing LCAs in projects. At the local level (city and municipality), the scope of sustainable decisionmaking is quite broad with decisionmakers encountering many situations that can be better informed by lifecycle thinking (comparison of flows from the inventory phase of LCA rather than full-impact assessment). At the local level, the performance of pavement systems is also often affected by other infrastructure, such as storm-water systems and utility maintenance.

The dilemma lies in appropriately using EPDs during the decisionmaking process. All indicators reported in an EPD may not have the same scope, and depending on the level at which decisions are being made, the weighting may vary. For instance, while GWP is of universal concern, local indicators, such as eutrophication, smog formation, and water use, may carry different weights in different locations. In addition, as these indicators are summed across the lifecycle of a product or process, it may be difficult to establish the geographical scope of the impacts. The economic aspect of decisionmaking must also be considered, and there are potential challenges with monetizing impacts.

SUMMARY OF ACTIVITIES ON DAY 2

The second day was dedicated to group work. Groups were formed to reflect the diversity of the stakeholders. Each team was assigned a facilitator and a scribe.

The LCA checklist from FHWA’s *Pavement Life Cycle Assessment Framework* was provided as a reference for discussion.[1] The groups discussed and responded to a set of questions that were technical, organizational, and pertinent to decisionmaking. The questions and the group responses are listed in the next section.

SUMMARY OF DISCUSSIONS ON DAY 2

The following summary shows the key outcomes from the responses from all of the groups under each question put to them.

Technical Questions

Technical Question 1: What factors should be kept in mind when developing a checklist/guideline for EPD data collection and organization?

- A checklist is necessary for pavement LCAs. While the FHWA checklist, originally developed at the University of California Pavement Research Consortium workshop, has been useful, it needs to be redesigned. One suggestion is to reorganize it to reflect the EN 15804 framework.

- Data collection should be organized by lifecycle phases, and material suppliers and contractors should be incentivized to develop EPDs. Data collection and organization should be considered within the context of network, project, and design/execution levels.

Technical Question 2: How do EPDs integrate at different levels: the conceptual–program description and project and network levels?

- When implementing EPDs at the project level, all EPD-related information should be managed through the prime or general contractors.

- There should be greater emphasis on collecting material flow data at the local-Government level.

- IT frameworks are necessary for seamless reporting of EPDs across project delivery systems.

Technical Question 3: How about roadmaps, challenges, and gaps?

- Identify significant data gaps in LCIs for upstream impacts of (including but not limited to) project-level material flows, aggregates, additives (various), polymers, fibers, lime, transportation, and asphalt binder. Develop further guidelines on handling capital equipment impacts and handling recycled material.

- Improve industry knowledge regarding PCRs and EPDs. Identify how they can best be produced and develop rules and best practices for use.

- Determine where the gaps and conflicts are in PCRs and EPDs. Find common areas and conflicts (lateral and vertical), and prioritize gaps.

- Develop a funding plan for curating transparent and reliable public datasets.

- Continue to update the FHWA LCA framework through improved information and consensus on best practice, eventually leading to requirements instead of just recommendations.(1)

- Produce guidelines for agencies. Determine how to manage and use EPDs through management of information and benchmarking quantities and impacts, use in design, procurement, and interpretation in decisionmaking.

Technical Question 4: Would developing a roadmap highlighting challenges and gaps in data be the first step to a "single PCR"?

- A single PCR can be developed for materials, but there are uncertainties associated with the development of single PCR for the complete pavement system.

- A phased approach should be considered starting with PCRs for individual products, followed by PCRs for each lifecycle phase before merging into single PCR in the long run. Through this process, as more stakeholders get more experience in handling EPDs, the "single PCR" development process will be smooth.

Organizational Questions

What are the recommendations for collecting and organizing data?

- In the long run, create a single governmental (or Government-controlled) operator or an effective consortium of industry operators.
    - Appeal to ISO for a change so that procurers can select the PCR they want to use to prevent small, unqualified organizations from staking a claim with a PCR and forcing everyone to wait until it expires even though it is an incomplete or poorly prepared PCR.

    - Perform data collection and organization at State level or through the consortium of States that would lead in this effort and local Governments if there is no Federal mandate for national effort.

- There is a need and a demand to develop a centralized, comprehensive, easily accessible, reliable, and transparent database, which might come from collaboration of allied industry and agency groups.

- A Governing body comprising people from industry, academia, State transportation agencies, and FHWA should be formed to examine the critical-review process. Reviewers should have some years of experience in the field of LCA. There should be uniformity in the process followed by PCR program operators.

- When developing rules relating to EPD implementation, consider how they will drive behavior, and evaluate the potential for unintended consequences.

- Outline types of tools needed tied to IT.
    - Standard templates for pulling data into EPDs, tied to existing pay and other tracking systems because local Governments need tools for tracking flows.

    - Standard reporting templates for EPDs so information can be pulled into LCA tools and other database and reporting tools.

    - Tools for producing EPDs as proportions of basic ingredients and additives change.

DECISIONMAKING QUESTIONS

What steps should be taken to understand uncertainty in data (variability and epistemic) and its impact on decisionmaking?

- Uncertainty analysis should be considered in case of significant variability in the results obtained. Sensitivity analysis should be carried out in most of the lifecycle phases; however, more data are needed before these analyses can really be performed. There is no point in doing sensitivity analysis if there are no data regarding variability.

- It is desirable to consider all the impact indicators specified by FHWA's framework (tool for reduction and assessment of chemical and other environmental impacts from the U.S. Environmental Protection Agency), but in most cases, it is practical to consider the indicators that are significant to the decisionmaking organization.(1)

SUMMARY OF DISCUSSIONS ON DAY 3

A round-table discussion was conducted on day 3 from 8 to 11 a.m. The highlights of the discussion raised the following needs:

- To understand, review, and harmonize existing and newly developing PCR efforts.

- To understand the role of the ISO 21930 working group, which has the goal of producing a single, industry-wide PCR as it takes shape.(34)

- To identify and fill knowledge gaps in databases: What data need to be collected? What are the standards for data-quality assurance?

- To identify how each of the organizational and technical challenges aligns with decisionmaking workflows.

The next step that has been identified is to try to benchmark a project with a leading State DOT (State DOT which would pioneer the effort) to understand the scope of the challenges of using EPDs as input in the design phase of a project. That experience will provide information regarding challenges in the use of EPDs for procurement.A brief summary of recommendations as discussed at the workshop, which outlines a three-stage implementation plan for agencies in the use of EPDs, follows:

1. Develop rules and then require reporting; move toward standardization of EPDs (1–2 yr).
    a. Pilot project for requirements for EPDs for informational purposes (a process Caltrans has begun).
    b. Pilot project for using EPDs for various other purposes (not yet to procurement, Caltrans).
    c. Take lessons learned and provide information to other lead States.
    d. Identify alternative plans for and gaps in steps 2 and 3.

2. Require use of standardized PCRs (3–5 yr).
    a. Identify a single operator or consortium in 1–2 yr.
    b. Produce a single PCR with appendices for additional requirements for specific materials.
    c. Fill gaps in public databases.
    d. Develop processes to handle characterization of performance (must have for procurement).
    e. Implement reward system similar to Dutch for quality (plant-specific data versus use of industry averages) of EPDs submitted.
    f. Use this better information in pavement design.

3. If desirable and sufficient progress has been made, consider using the following for procurement:
    a. EPDs of materials if design-bid-build.
    b. LCAs of pavements, including the construction stage, if design–build.
    c. LCAs of full lifecycle if design–build–maintain.

Chapter 5 discusses the overall recommendations of this report.

CHAPTER 4. EXPERIENCE OF CALTRANS

This chapter discusses the specific challenges Caltrans is addressing with respect to AB 262, which was passed by the California Legislature and signed into law by the Governor on October 15, 2017.(2) The legislation was motivated by the State of California's need to respond to the challenges of climate change. The bill focuses only on procurement and aims to reduce the GWP of infrastructure materials through establishing requirements for maximum allowable GWP as documented through EPDs. The California Department of General Services (DGS) is responsible for implementation of the bill and is working with other State departments that are the awarding authorities buying the materials covered by the bill.

The objective of this chapter is to analyze the requirements of AB 262 and record Caltrans's response to it.(2) The challenges discussed here directly reflect the outcomes of the workshop. This chapter specifically discusses the technical and organizational challenges within the context of AB 262. Some of the material is intentionally repetitive so that each chapter can be read independently. This chapter does not cover the effort by Caltrans to require facility-specific EPDs for pavement materials for use as inputs to LCA analyses that are done to reduce GWP and other emissions through pavement design, pavement management, and policy development. That effort was begun before passage of AB 262 and is continuing in parallel with AB 262 implementation through pilot projects beginning in 2018.

THE REQUIREMENTS OF AB 262

The bill broadly requires awarding authorities (such as Caltrans) to do the following:(2)

- Require submission of EPDs by successful bidders before the installation of any "eligible material."(2) A list of eligible materials has been provided, and a project with any eligible material in it is considered an "eligible project."(2)
- Accept EPDs that are compliant with "International Organization for Standardization (ISO) standard 14025, or similarly robust life cycle assessment methods that have uniform standards in data collection consistent with ISO standard 14025, industry acceptance, and integrity, for each eligible material."(2)

In addition, DGS responsibilities will include the following:

- Setting a "maximum acceptable global warming potential as a number that states the maximum acceptable facility-specific global warming potential" for each eligible material by January 1, 2019. The estimates will be based on industry averages by consulting, "nationally or internationally recognized databases of environmental product declarations."(2)
- Review the maximum acceptable GWP by January 1, 2022, and every 3 yr thereafter, and revise it downward to reflect industry improvements to ensure continuous improvement.

Based on discussions in the California Senate Appropriations Committee, various fiscal impacts on the State were identified. In the short term, it would cost the DGS "up to the hundreds of thousands of dollars" to create and publish the maximum acceptable GWP for each category of eligible materials.[2] Additional ongoing costs in the range of $100,000 to $200,000 per yr would be required to review and analyze EPDs submitted on projects. Ongoing costs in the range of millions of dollars would be necessary to support State agencies contracting eligible projects. In the long run, there is a possibility of these costs being reflected in higher bid prices.

The discussions at the committee also identified a potential for unknown significant costs in the implementation of the bill and determining the maximum acceptable GWP for eligible materials. The discussion ended with the note that there may be additional costs in establishing the "effectiveness of these provisions in reducing global warming potential."[2] A direct impact of the fiscal burdens was limiting the list of eligible materials to carbon steel rebar, flat glass, mineral wool board insulation, and structural steel. The concrete and asphalt industries, despite having EPD programs in place, were exempt from the list.

The language of the bill requires awarding authorities "to strive to continuously reduce emissions over time."[2] At the same time, it also asserts that only "successful bidders" produce an EPD before being allowed to install an eligible material.[2]

CHALLENGES FOR CALTRANS

AB 262 affects six California agencies: DGS (the Real Estate Services Division), DOT (Caltrans), Department of Water Resources, California State University, University of California, and Air Resources Board.[2] While the legislative intent of AB 262 is clear, its impact on current business processes within agencies that are directly involved in the procurement of eligible materials on eligible infrastructure projects remains unclear. Caltrans is an example of such an agency. In effect, it directly relates back to both the technical and organizational challenges in implementing EPDs in the decisionmaking process as discussed in the previous chapter of this report.

Caltrans is developing a plan for the implementation of LCAs and EPDs, which includes implementation of AB 262 in addition to a separate but related effort to require EPDs for use in LCA in pavement design, management, and policy.[2] Implementation of AB 262 includes the development of contractual language through specifications for collecting EPD information and setting up Caltrans's administrative and organizational infrastructure and technical know-how. In addition, this chapter considers the challenges in establishing processes for long-term benchmarking, and development of maximum acceptable GWP estimates (responsibilities of DGS). These challenges to the implementation of AB 262 are discussed within broad technical and organizational contexts.

Technical Challenges

The primary technical challenge to be addressed while implementing AB 262 is the establishment of maximum acceptable facility-specific GWP estimates for each of the eligible materials.[2] The bill suggests the use of "national or internationally recognized databases of environmental product declarations."[2] The timeline for completion of this task is January 1, 2019.

Currently, there are few EPDs that can be used by Caltrans to develop the acceptable GWP estimates. While EPD programs for the eligible materials have been in place, it is uncertain whether a reasonable number of EPDs are available for each material that can be used to benchmark the process. Even when EPDs are compliant with the same PCR, they may not be suitable for aggregation if the same (or similar) background databases and inventories are not used. Similarly, uniformity is needed in meeting the data-quality requirements for foreground-data collection. The level of granularity of the data collected at a facility matters when reporting foreground data. Energy mixes for electricity should be consistently recorded to reflect regional mixes, sourcing of nonrenewable fossil fuels, as well as renewable energies. Hence, a challenge for Caltrans will be establishing some agreement on the quality of background-data sources being used and consistent collection and reporting of foreground data to ensure all EPDs are developed consistently.

A significant challenge lies in the aggregation method used in estimating maximum acceptable limits for GWP. Aggregating based on GWPs reported in existing EPDs may pose challenges as they do not always furnish all the details and assumptions regarding the choice of background- and foreground-data collection. While the bill expects to make comparisons to national averages, a more suitable approach may be to develop averages of GWP across a representative sample of regional facilities using the same assumptions for foreground and background data.(2) As per data-quality requirements in ISO 14025, foreground data should be collected over a continuous period of 12 mo in the last 5 yr.(11) A statistical analysis of the data should be conducted to identify the sensitivity of the average to regional variations in climate, energy demands, sourcing, and upstream inventories used. An example of an industry average EPD for concrete materials as published by NRMCA can be studied for guidance.(15)

Finally, all the challenges with the current status of PCRs and limitations of databases and their impact on the reliability of EPDs, as discussed in chapter 2, will directly apply to technical challenges.

Organizational Challenges

Organizational challenges of using EPDs are closely coupled with technical challenges, and the resolution of each is, therefore, dependent on the other. For instance, improving collaboration across industries to adopt common data-collection protocols and harmonization of PCRs can significantly improve the reliability of inventory databases. Loosely organized systems, systems such as a consortium of program operators that reflect supply-chain linkages cutting across the silos within which industries function, can help document flows of materials between industries as products, coproducts, and recycled materials (e.g., chemical additives). Such organizational platforms can help different industries communicate with each other on developing common protocols (e.g., on allocation). Hence, some organizational solutions can pave the way for creating technical solutions. However, despite this close coupling, other organizational challenges must be addressed after the technical challenges have been resolved. These challenges have to do with the contexts in which EPDs are requested, what they communicate, and how they are used to support business processes.

To pave the path for addressing organizational challenges, system boundaries for EPDs must be very clearly specified by Caltrans, and decisionmakers must be cognizant of the limits to which the midpoint indicators provided by an EPD can be meaningfully used. Per ISO 14025, EPDs that are not based on an LCA covering all lifecycle phases have limited comparability.(11) Given that most EPDs of eligible materials, as identified by AB 262, are cradle-to-gate, they have limited comparability and should be used with caution for procurement-related purposes unless rules for comparability have been satisfied.(2)

The use of EPDs for informational purposes to benchmark the impacts associated with a specific design is an acceptable use of EPDs but, given the present state of practice, must also be conducted with caution. Performance of the material and its intended uses must be accounted for when aggregating the outcomes. Hence, when establishing maximum acceptable estimates for GWPs, care should be taken to classify subtypes of materials based on performance scenarios and functional equivalence rather than developing a single number that averages across all cases. In addition, while the emphasis of AB 262 is on GWP, other midpoint indicators, such as eutrophication, smog, and particulate matter, may be of equal or greater concern when considering alternatives.(2)

Careful consideration of the decision contexts within which EPD information is being used is important. Understanding of the margins of error that are acceptable when developing estimates for specific design alternatives is limited. Hence, when making comparisons, even under the fairest of conditions (for instance, between two estimates of the same class of materials made at 3-yr intervals), knowing the level of significance due to a difference in GWPs between two options can be difficult. For instance, if the acceptable error margins for benchmarking GWPs for two similar options are +/-*X*% and +/-*Y*% respectively, then for some range that is a function of *X*% and *Y*%, the options should be considered effectively equivalent.(35) The existence of error margins also establishes the necessity of appropriate statistical aggregation and analysis in the development of averages and maximum acceptable limits. A specific context in which the existence of error margins directly applies is in the comparison of a facility-specific EPD to a national industry average. Given the climatic diversity in North America as well as differences in regional materials and preferences, such a comparison can only be conducted fairly after developing confidence intervals, regional factors, and reasonable margins of error.

A final organizational challenge will be to ensure the EPDs being collected by Caltrans are appropriately vetted through the third-party review process. At present, standards and qualifications for identifying suitable pavement LCA reviewers are limited. The American Center for Life Cycle Assessment certifies LCA professionals through a process that combines experience and standardized testing. This certification is one possible criterion for reviewers to meet in addition to knowledge and experience in the field of pavement materials, design, and construction. Program operators also provide lists of reviewers and consultants who can conduct the underlying LCAs and serve as reviewers. Building on these resources for the future, there is an opportunity to establish some criteria for expertise (combination of experience and qualification) that a reviewer should possess.

SUMMARY

In summary, some of the challenges identified from Caltrans's experience in implementing AB 262 are as follows:(2)

- Ensure consistent reporting of foreground data and use of background inventories.
- Ensure harmonization across PCRs. Even though AB 262 is only operating within each PCR, the lack of harmonization of PCRs can result in material flows being excluded from accounting or, in some cases, double counted—thus reducing the reliability of the EPDs produced.(2)
- Develop infrastructure to appropriately use EPDs, including the development of the maximum acceptable limits for GWP and the contexts in which they are applied.

As discussed in the section, Challenges for Caltrans, these challenges need to be solved collaboratively with the recognition that they involve interdependent technical and organizational components.

A discussion of how the implementation of AB 262 is likely to impact the market of materials producers is beyond the scope of this report.(2) However, communication with all stakeholders regarding how the information provided in the EPDs will be used to inform business processes will improve industry and agency outcomes. A plan for appropriate use of EPDs along with clear communication of outcomes of an EPD can go a long way in ensuring long-term adoption of EPDs in practice.

CHAPTER 5. RECOMMENDATIONS AND THE ROAD AHEAD

An EPD can be an instrument for communicating environmental impacts of the lifecycle of a product—the outcomes of an LCA. The specific strengths lie in the rigorous process required by standards such as ISO 14025 and EN 15804.[5,6] The clear definition of the goal and scope of the underlying LCA in the PCR ensures consistent use of system boundaries and functional or declared units. Data quality–assurance requirements also ensure foreground and background datasets are appropriately assessed for completeness and reported within specified, recent time periods. While some PCRs clearly identify background inventories to be used and the specificity and format in which foreground datasets need to be collected, other PCRs provide only a guideline for the choice of upstream inventories. Within the broader context of the reliability provided by EPDs, inconsistent use of background inventories can result in a weakness in the system as use of different databases can lead to inconsistent use of data collected with differing assumptions. The potential bias created by such incomplete datasets can be reflected in the EPDs.

In order to improve the reliability of EPDs and their usefulness in developing estimates for maximum acceptable limits for indicators like GWP, developing reliable, consistent, publicly available, and economic datasets is critical. Protocols that harmonize PCRs and ensure the use of consistent background datasets for upstream processes across all public projects are necessary. This recommendation involves technical and organizational aspects.

LCA–INFORMATION MODEL DEVELOPMENT

The goal of the following recommendations is to improve the reliability of background databases, collection of foreground data, and consistent use of PCRs. They are motivated by developing structured data definitions or information models that can be used easily across pavement LCAs. An information model is defined as a way to formally structure the relationships between different entities in a system, reflecting the underlying relationships. In LCAs, an information model is akin to developing a product system that relates as a network of all the inputs and outputs associated with subprocesses. Information models should be modular blocks that can be used to additively build on each other. Hence, information models, when populated by default data inputs, can become easy-to-use building blocks for conducting pavement LCAs.

Upstream processes, such as crude oil extraction, petroleum refining, transportation, and electricity generation, that are common information models and used in all LCAs should be developed consistently with regionalized data from public sources, such as GREET. Such practice will prove to be a reliable data source that can be freely accessed, easily updated from time to time, and easily used as a module by LCA practitioners who will not have to worry about the reliability of these basic and important data sources.

Consider the example of an information model for an asphalt mixture. Developing an LCA information model for asphalt mixtures would require the following steps:

1. Develop a metadata structure outlining the lifecycle phases scoped and relating the upstream processes and plant production processes as defined in the system boundaries of the PCR for asphalt mixtures. Outline in the metadata important assumptions regarding the module while specifying parameters, such as allocation coefficients and protocols used.

2. Include inventories for upstream processes as part of the data in the information model as the PCR already specifies them. Ensure consistent use of upstream inventories across related supply chains and build on other similar information models for upstream products and processes. For example, instead of rebuilding the inventories for asphalt binders, use an information model for asphalt binders. Similarly, use regionalized modules for energy, electricity, and transportation.

3. Develop guidelines for foreground-data collection at asphalt-production plants, and when necessary, include statistically justifiable ranges for data items and suggested defaults. For example, per the underlying, supporting LCA for the asphalt mixture EPD program, ranges for plant electricity and energy use can be included.(17)

4. Create a product-system module for the asphalt mixture that can be easily customized by plant-specific foreground data and used as a building block for a pavement LCA.

The recommendation is to develop a library of similar LCA information models in a modular format and make them available for free use to LCA practitioners.

The next step is the development of LCA information models using FHWA's *Pavement Life-Cycle Assessment Framework* as the foundation.(1) Then, develop a metadata structure that classifies all processes in the pavement lifecycle system boundary as defined by FHWA's "Towards Sustainable Pavement Systems: A Reference Document" in the following categories: lifecycle phase; nature of the data when conducting a pavement LCA; the specific stakeholder responsible for reporting the dataset; the protocol for collecting the data and reporting uncertainty for the dataset; and the relationship to indicators and what aspects of design, construction, and performance are defined by it.(1,36) Each of the following will be identified and defined for each dataset:

- The level of granularity at which primary data need to be collected. For example, for an asphalt plant, is it enough to collect annual energy-use data and distribute the data uniformly over the total mixture production tonnage, or should a daily energy-use profile be generated and allocated by individual processes involved (drying, mixing, conveyor belt, etc.)?

- Protocols for ensuring a level of transparency and ways to enforce reliability for public inventories of upstream processes (fossil fuel extraction and refining, electricity generation, transportation, various chemicals from different parts of the supply chain, etc.).

- Statistical-analysis methods for defining confidence intervals to assess the reliability of reported primary data.

- Protocols for using and sharing averages and other metrics defined using proprietary data without sacrificing competitive advantage.

- Protocols for allocation of coproducts and recycled material from upstream inventories to avoid double counting and ensure harmony between products that share a supply chain.

- Methods of defining margins of tolerance when reporting LCA outcomes, and relevant benchmarks/contexts in which the model can be used appropriately.

It is critical to disseminate these methods through open-source platforms and, eventually, through a software interface that is easy to use.

DEVELOPMENT OF ORGANIZATIONAL INFRASTRUCTURE

The development of LCA information models will improve the transparency, consistency, and reliability of data sources used to conduct LCAs to support PCRs and EPDs. In addition, the organizational component of the problem must be addressed to ensure consensus around development of PCRs and the use of EPDs. This component requires the development of collaborative platforms for effective knowledge sharing across industry and agency networks.

The challenge in developing such a collaborative platform will arise from the need to create collaboration among industries and agencies that traditionally relate to each other in adversarial and competitive environments. This development requires a transformation in mindset, akin to a move from design–bid–build to design–build project-delivery methods. Creation of ad-hoc collaborative networks, such as the FHWA Sustainable Pavements TWG is a good example for generating and sharing knowledge in consensus-seeking environments. Taking advantage of interagency relationships and building up platforms, such as the Federal LCA Commons, can significantly help development and curation of the LCA information models. Without creating a need for long-term funding of such systems, existing efforts, such as GREET, in the public sphere and the use of crowd sourced (crowd of professionals) solutions should be leveraged when possible.

A critical role of the collaborative platform will also be to serve as a platform for education of stakeholders on all matters related to pavement LCA, PCRs, and EPDs. Engagement with legislatures and ensuring interested parties are fully aware of how EPDs are used in the decisionmaking process will be critical for long-term adoption and use. It is expected greater awareness will lead to better preparedness for implementation of legislation such as AB 262 in California.(2)

CONCLUSION

In summary, this report identifies the primary challenges to the adoption and implementation of EPDs, such as the following: Lack of reliable, transparent, and easily accessible background datasets and protocols for collecting and reporting foreground data.

- Lack of consistency in allocation protocols and other assumptions across PCRs of materials from related industries, resulting in processes being either neglected or, on occasion, double counted.
- Lack of careful consideration of the decisionmaking contexts in which to appropriately use EPDs for supporting design and construction.
- Lack of any collaborative organizational efforts that can lead to resolving the underlying technical problem through knowledge sharing across industry and agency networks.

This report specifies the coupled nature of technical and organizational challenges need to be recognized and a two-pronged approach for supporting the development of LCA information models needs to be followed while fostering a collaborative community (e.g., the Federal LCA Commons that has been created and maintained by the U.S. Department of Agriculture Agricultural Research Service National Agricultural Library for collecting, reviewing, and communicating such models).[(37)]

REFERENCES

1. Harvey, J.T., Meijer, J., Ozer, H., Al-Qadi, I.L., Saboori, A., and Kendall, A. (2016). *Pavement Life-Cycle Assessment Framework*, Report No. FHWA-HIF-16-014, Federal Highway Administration, Washington, DC.

2. State of California. (2017). "Assembly Bill 262." Buy Clean California Act, California: Legislative Counsel Bureau, Sacramento, CA.

3. Federal Highway Administration. (2019). "Sustainable Pavements Program." (website) FHWA, Washington, DC. Available online: https://www.fhwa.dot.gov/pavement/sustainability/, last accessed September 25, 2019.

4. Van Dam, T.J., Harvey, J.T., Muench, S. T., Smith, K.D., Snyder, M.B., Al-Qadi, I.L., Ozer, H., et al. (2015). *Towards Sustainable Pavement Systems: A Reference Document*, Report No. FHWA-HIF-15-002, Federal Highway Administration, Washington, DC.

5. International Organization for Standardization. (2015). "ISO 14025:2006: Environmental Labels And Declarations -- Type III Environmental Declarations -- Principles And Procedures." ISO, Geneva, Switzerland. Available online: https://www.iso.org/standard/38131.html, last accessed September 25, 2019.

6. European Standards. (2019). "EN 15804—2012 Sustainability of Construction Works, Environmental Product Declarations, Core Rules for the Product Category of Construction Products U.S. Green Building Council." EN, Pilsen, Czech Republic. Available online: https://www.usgbc.org/resources/en-15804%E2%80%942012-sustainability-construction-works-environmental-product-declarations-core-ru, last accessed September 25, 2019.

7. Ram, P.V., Harvey, J., Muench, S.T., Al-Qadi, I.L., Flintsch, G.W., Meijer, J., Ozer, H., et al. (2017). *Sustainable Pavements Program Road Map Draft Document*, Report No. FHWA-HIF-17-029, Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/pavement/sustainability/hif17029.pdf, last accessed September 25, 2019.

8. Ferraro, F., Etzion, D., and Gehman, J. (2015). "Tackling Grand Challenges Pragmatically: Robust Action Revisited." *Organization Studies*, *36*(3), pp. 363–390, DOI: 10.1177/0170840614563742.

9. International Organization for Standardization. (2016). "ISO 14040:2006: Environmental Management -- Life Cycle Assessment -- Principles and Framework." ISO, Geneva, Switzerland. Available online: https://www.iso.org/standard/37456.html, last accessed September 25, 2019.

10. International Organization for Standardization. (2016). "ISO 14044:2006: Environmental Management -- Life Cycle Assessment -- Requirements and Guidelines," ISO, Geneva, Switzerland. Available online: https://www.iso.org/standard/38498.html, last accessed September 25, 2019

11. International Organization for Standardization. (2015). “ISO 14025:2006: Environmental Labels and Declarations -- Type III Environmental Declarations -- Principles and Procedures,” ISO, Geneva, Switzerland. Available online: https://www.iso.org/standard/38131.html, last accessed September, 25 2019

12. National Renewable Energy Laboratory. (2018). “NREL: U.S. Life Cycle Inventory Database Home Page.” (website) NREL, Golden, CO. Available online: https://www.nrel.gov/lci/, last accessed September 25, 2019.

13. Ingwersen, W. and Subramanian, V. (2013). “Guidance for Product Category Rule Development: Process, Outcome, and Next Steps.” *The International Journal of Life Cycle Assessment*, *19*(3), pp. 532–537, Springer, Basel, Switzerland. DOI: 10.1007/s11367-013-0659-0.

14. Carbon Leadership Forum. (2019). “Concrete Product Category Rule - Carbon Leadership Forum.” CLF, Seattle, WA. Available online: http://www.carbonleadershipforum.org/projects/concrete-product-category-rule/, last accessed September 30, 2019.

15. National Ready Mixed Concrete Association. (2018). “NRMCA Sustainability.” (website) NRMCA, Silver Spring, MD. Available online: https://www.nrmca.org/sustainability/EPDProgram/, last accessed October 30, 2018.

16. National Asphalt Pavement Association. (2016). *Product Category Rules for Asphalt Mixtures*, NAPA, Lanham, MD.

17. Mukherjee, A. (2016). “Life Cycle Assessment of Asphalt Mixtures in Support of an Environmental Product Declaration.” National Asphalt Pavement Association, Lanham, MD. Available online: https://www.asphaltpavement.org/PDFs/EPD_Program/LCA_final.pdf, last accessed September 25, 2019

18. Yang, R., Ozer, H., Kang, S., and Al-Qadi, I.L. (2014). “Environmental Impacts of Producing Asphalt Mixtures with Varying Degrees of Recycled Asphalt Materials.” *Proceedings of the International Symposium on Pavement Life-Cycle Assessment*, pp. 14–16, University of California, Davis, CA. Available online: http://www.ucprc.ucdavis.edu/P-LCA2014/media/pdf/Papers/LCA14_Producing%20Asphalt%20Mix%20Recycled%20Matls.pdf, last accessed September 25, 2019.

19. Yang, R., Kang, S., Ozer, H., and Al-Qadi, I.L. (2015). “Environmental and Economic Analyses of Recycled Asphalt Concrete Mixtures Based on Material Production and Potential Performance.” *Resources, Conservation and Recycling*, *104*, pp. 141–151, Elsevier, Amsterdam, Netherlands. DOI:10.1016/j.resconrec.2015.08.014.

20. Chowdhury, R., Apul, D., and Fry, T. (2010). “A Life Cycle Based Environmental Impacts Assessment of Construction Materials Used In Road Construction.” *Resources, Conservation and Recycling*, *54*(4), pp. 250–255, Elsevier, Amsterdam, Netherlands. DOI: 10.1016/j.resconrec.2009.08.007.

21. Argos Ready Mix South Central. (2014). “Environmental Product Declaration (EPD) for Concrete.” National Ready Mixed Concrete Association, Silver Spring, MD. Available online: https://www.nrmca.org/sustainability/EPDProgram/Downloads/20141119-Argos-Panama-EPD.pdf, last accessed September 25, 2019.

22. CalPortland Company. (2017). “Environmental Product Declaration (EPD) For Concrete Produced At 12 CalPortland California Facilities.” National Ready Mixed Concrete Association, Silver Spring, MD. Available online: https://www.nrmca.org/sustainability/EPDProgram/Downloads/CalPortland_EPD20171228.pdf, last accessed September 25, 2019.

23. Cemex Environmental Product Declaration. (2014). “Environmental Product Declaration (EPD) For 12 Concrete Mixes Produced By CEMEX At The Pier 92 Plant In San Francisco, California.” National Ready Mixed Concrete Association, Silver Spring, MD.

24. Central Concrete. (2013). “Environmental Product Declaration (EPD) for 1479 Concrete Mixes Produced For 7 Different Service Areas At 8 Concrete Plants.” National Ready Mixed Concrete Association, Silver Spring, MD.

25. CeraTech. (2014). “Environmental Product Declaration (EPD) For Industry Average Ekkomaxx™ Cement Concrete Mixes.” National Ready Mixed Concrete Association, Silver Spring, MD.

26. Huntzinger, D.N. and Eatmon, T.D. (2009). “A Life-Cycle Assessment of Portland cement Manufacturing: Comparing the Traditional Process with Alternative Technologies.” *Journal of Cleaner Production*, *17*(7), pp. 668–675, Elsevier, Amsterdam, Netherlands. DOI: 10.1016/j.jclepro.2008.04.007.

27. CalPortland Company. (2016). “Environmental Product Declaration for Dupont, Duwamish and Tumwater WA Plants Ready-Mixed Concrete.” National Ready Mixed Concrete Association, Silver Spring, MD. Available online: https://www.nrmca.org/sustainability/epdprogram/Downloads/CalPortlandEPD.pdf, last accessed September 25, 2019.

28. Al-Qadi, I.L., Yang, R., Kang, S., Ozer, H., Ferrebee, E., Roesler, J.R., Salinas, A et al. (2015). “Scenarios Developed for Improved Sustainability of Illinois Tollway.” *Transportation Research Record*, *2523*, pp. 11–18. Transportation Research Board, Washington, DC. DOI: 10.3141/2523-02.

29. ASTM International. (2014). “Product Category Rules for Slag Cement UN CPC 3744.” ASTM International, West Conshohocken, PA.

30. ASTM International. (2017). “Product Category Rules for preparing an Environmental Product Declaration for construction aggregates: natural aggregate, crushed concrete, and iron/steel furnace slag.” ASTM International, West Conshohocken, PA.

31. UL Environment. (2011). “Product Category Rule for Building Envelope Thermal Insulation.” UL, Northbrook, IL.

32. National Center for Sustainability Standards. "Product Category Rules for Flat Glass UN CPC 3711." NSF International, Ann Arbor, MI. Available online: https://www.nsf.org/newsroom_pdf/GANA_Flat_Glass_PCR.pdf, last accessed September 25, 2019.

33. SCS Global Services. (2015). "North American Product Category Rule for designated steel construction products." SCS Global Services, Emeryville, CA. Available online: https://www.scsglobalservices.com/files/standards/scs_pcr_steel-products_050515_final.pdf, last accessed September 25, 2019.

34. International Organization for Standardization. (2017). "ISO 21930:2017: - Sustainability in Buildings and Civil Engineering Works - Core Rules for Environmental Product Declarations of Construction Products And Services." ISO, Geneva, Switzerland. Available online: https://www.iso.org/standard/61694.html, last accessed September 25, 2019.

35. Bhat, Chaitanya G., and Amlan Mukherjee. 2019. "Sensitivity of Life-Cycle Assessment Outcomes to Parameter Uncertainty: Implications For Material Procurement Decision-Making." *Transportation Research Record*, DOI:10.1177/0361198119832874.

36. Bhat, C., Mukherjee, A. and Meijer, J. (2019). *Mapping of Unit/Product System Processes for Pavement Life-Cycle Assessment*, Federal Highway Administration, Washington, DC.

37. United States Department of Agriculture. (2018). "Federal LCA Commons: Life Cycle Assessment Commons." National Agricultural Library, Beltsville, MD. Available online: https://www.lcacommons.gov/, last accessed September 25, 2019.

Recycled
Recyclable

HRDI-20/02-20(WEB)E