TECH BRIEF: BUILDING BLOCKS OF LIFE-CYCLE THINKING

What Is Life-Cycle Thinking?

Life-cycle thinking (LCT) is a holistic approach to considering the economic, environmental, and social impacts across the complete life cycle of a product, system, or service. The application of LCT allows for improved decision-making that can lead to reduced costs, reduced environmental impacts, and more favorable social outcomes; in essence, the LCT philosophy works to employ sustainability strategies that minimize negative impacts and avoid unintended consequences.

As applied to pavements, LCT involves two key steps:

1. **Identifying the goals and performance metrics/priorities/values** (economic, environmental, and social) to be used in decision-making; for example, one agency goal might be to reduce life-cycle cost and negative environmental impacts while ensuring similar (or enhanced) performance.
2. **Defining the life-cycle stages** of the product or system being considered and conducting an analysis within the three pillars of sustainability (economic, environmental, and social) using the appropriate tools for each (see figure 1).

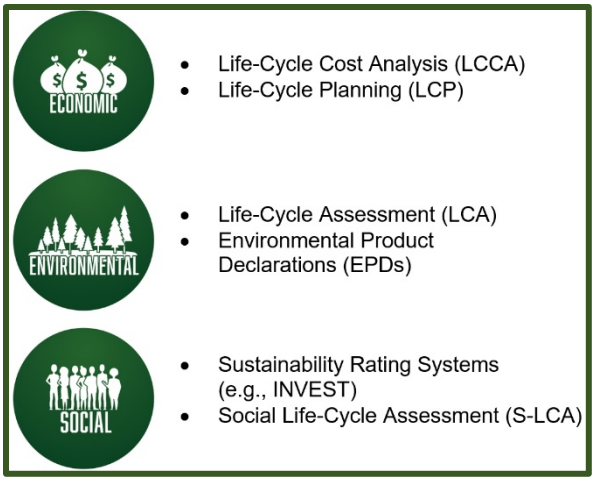

Figure 1. Pillars of sustainability with methods for measurement and communication.

Why Use LCT?

Consumers, owner agencies, and regulators are pressing for sustainability performance measures, and LCT provides a transparent methodology that can be used to support the decision-making processes for sustainability-related questions at the network, the conceptual design, the design, and the construction stages of project development (see examples provided in call-out box below). In many cases, LCT can be used to investigate the impact of a design change when compared to current practice, but it may also be used in performing a policy evaluation, in the development of a pavement material or product, or in the procurement of materials, products, and services.

Example Applications of LCT

- **At the Network Level:** Prioritizing network maintenance and preservation activities to minimize life-cycle costs and environmental impacts.
- **In the Conceptual Design Stage:** Evaluating the option of adding a truck-only lane compared to just increasing capacity to minimize life-cycle costs, reduce environmental impacts, and maximize safety.
- **In the Design Stage:** Selecting a pavement design alternative based on life-cycle costs and environmental impacts.
- **In the Construction Stage:** Procuring pavement materials that meet performance criteria based on environmental impacts.

What Should Be Considered In LCT?

It is important to consider the entire life cycle so that all consequences of decisions are included and not just the initial impacts. This helps to identify opportunities at various points in the life cycle where negative impacts can be reduced or to inform and guide decision makers who are setting priorities for change. In this way, more meaningful comparisons can be made between two materials that, for example, may have different initial impacts and varying performance lives. The consideration of the sustainability impacts over the complete life cycle of the pavement project allows for the determination of the material that offers the lowest negative consequences. Examples of some of the metrics/priorities/values that may be considered in each individual pavement life-cycle stage are provided in figure 2.

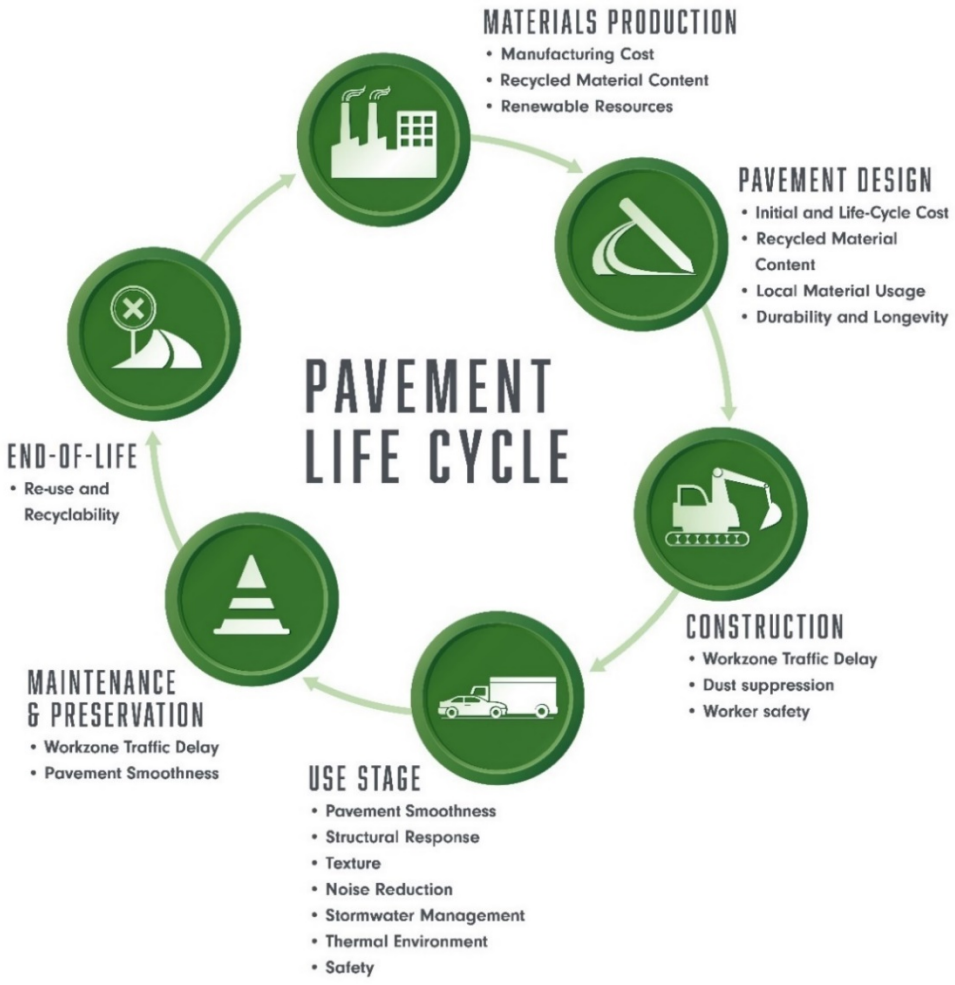

Figure 2. Example sustainability elements associated with pavement life-cycle stages.

What Tools Can Support LCT?

There are several methods of measurement that are used to quantify the three pillars of sustainability listed in figure 1; these include:

- Life-cycle planning (LCP), a network-level approach to managing transportation assets over their whole life.
- Life-cycle cost analysis (LCCA), which focuses on economic indicators.
- Life-cycle assessment (LCA), which focuses on environmental indicators.
  - Environmental product declarations (EPDs) are a format to communicate the results of LCAs for specific materials or products (e.g., asphalt, cement, asphalt mixture, concrete mixture, pavement interlayers, etc.).
- Social life-cycle assessment (S-LCA), which focuses on social LCA indicators.

Although LCP, LCCA, LCA, and S-LCA cannot be used to analyze and quantify all aspects of sustainability performance, these methods of measurement can provide quantitative support for a wide range of questions and decisions and can work in concert with more qualitative performance assessment and rating systems. Additional information on these tools is provided in the following sections.

Life-Cycle Planning (LCP)

Description

- LCP is a network-level approach to managing transportation assets over their whole life.
- For pavements, agencies would typically conduct an LCP analysis using their pavement management system.
- The objective of an LCP analysis is to determine the most cost-effective strategy of managing a pavement network over a selected time period that will enable an agency to achieve or sustain a defined state of good repair.

Typical Applications

- Provide a long-term view of pavement performance for an entire network or a subset of a network.
- Evaluate the impacts of a set of life-cycle strategies at various funding levels on pavement performance over a selected analysis period.
- Provide objective data to support investment decisions.
- Demonstrate good stewardship to internal and external stakeholders.

Life-Cycle Cost Analysis (LCCA)

Description

- LCCA is an analytical tool to provide cost comparisons between two or more competing alternatives on a project.
- For pavements, LCCA provides a way of measuring the economic consequences of changes in design, materials, construction techniques, maintenance schemes, and end-of-life treatments over a prescribed analysis period.
- LCCA should be used as one indicator in the decision-making process, along with other key factors that cannot be easily quantified monetarily (e.g., work zone safety, environmental impacts).
- Both direct agency costs and user costs can be considered and these may be expressed in terms of net present value (NPV) or equivalent uniform annual costs (EUAC).

Typical Applications

- Determine the pavement type or treatment strategy that results in the lowest overall life-cycle costs at the required level of performance.
- Demonstrate the benefits of various treatment strategies or construction sequencing on the traveling public (e.g., vehicle operating costs, user delay costs, crash costs, etc.).
- Estimate the initial costs and support future agency budget decisions for designing, constructing, and maintaining a pavement at a specified performance level over a predetermined time period.

Life-Cycle Assessment (LCA)

Description

- LCA is a technique for analyzing and quantifying the environmental impacts of a product, system, or process.
- An LCA is a comprehensive approach that examines material and energy inputs and outputs over the life cycle of the product or process, from raw material production to end-of-life.
- An LCA can be used to generate a range of environmental indicators, such as ozone depletion, acidification, eutrophication, and smog formation.
- LCA results are context specific and should not be compared to other LCA studies since an LCA is performed to address a specific question for a specific product or process that provides a specific function in a specific geographical location.

Typical Applications

- Document and benchmark the environmental impacts associated with current practices and materials and identify key areas for improvement to meet environmental goals.
- Determine the pavement structural and mixture design with the lowest environmental impacts.
- Evaluate the tradeoffs of implementing a policy such as requiring recycled materials in all pavement designs.
- Develop an EPD for a specific product (such as asphalt binder or portland cement).
- Demonstrate good environmental stewardship to internal and external stakeholders.

Environmental Product Declarations

Description

- EPDs are a transparent, verified report used to communicate the environmental impacts of a specific material (e.g., asphalt binder, portland cement) or product (e.g., asphalt mix, concrete mix).
- EPDs are needed to encourage the demand for, and supply of, those products that promote more sustainable use of finite resources and create less stress on the environment. Over time, periodic updates of EPDs can show progress being made by manufacturer or an industry, and agencies can use that information to track progress by their suppliers in meeting agency goals.
- EPDs are a life-cycle assessment developed by product manufacturers following the Product Category Rules (PCR) that are developed with industry stakeholders and LCA experts and subjected to a critical review process.
- EPDs can be issued for a specific product from a specific producer, but may also be issued for a generic product from a group of manufacturers (such as an association) that reflects the results of an industry-average LCA.
- EPDs using the same product category rules can be compared to identify materials with improved environmental performance in terms of various environmental and resource use impacts (e.g., energy use, air pollution, global warming, ozone layer depletion).

Typical Applications

- Select a product with reduced environmental impact as in green public procurement.
- Document the progress being made on reducing environmental impacts by an individual manufacturer or an industry when performed over time.
- Improve the ability of agencies to perform pavement LCAs with better data quality at a lower cost.
- Demonstrate commitment towards environmental stewardship.

Social Life-Cycle Assessment (S-LCA)

Description

- A social life-cycle assessment considers the actual and potential positive and negative social and sociological aspects of products in the life cycle.
- Relevant indicators of an S-LCA are context-sensitive and are defined in collaboration with groups of stakeholders that can include workers, consumers, local communities, and others at the beginning of the planning process where a need has been identified but a solution has not been determined.
- Current pavement sustainability rating systems (such as INVEST, ENVISION, and Greenroads) incorporate many topics that can be considered as part of an S-LCA.

Typical Applications

- Determine and communicate employment factors, such as employment creation (type and number of jobs) and quality of employment (wages vs. skill levels, working conditions).
- Communicate health indicators, such as safety, pollution exposure, and changes to active transportation.
- Estimate quality of life indicators, such as physical comfort (consideration of noise and temperature) and access to essential services (such as schools, child care, and health services).
- Evaluate other indicators that could include measures of transparency, good governance, inclusiveness in decision making, and investment equity.

Where Can I Learn More?

Some key resources that provide information on the various tools, techniques, and methodologies related to LCT are provided below. Additional information and resources can also be found on the sustainable pavements webpage.

- FHWA Life-Cycle Cost Analysis Primer Document (FHWA-IF-02-047).
- FHWA Sustainable Pavements Reference Document (FHWA-HIF-15-002).
- FHWA Tech Brief on Pavement Life Cycle Assessment (FHWA-HIF-15-001).
- FHWA Tech Brief on Pavement Sustainability (FHWA-HIF-14-012).
- FHWA Pavement Life-Cycle Assessment Framework (FHWA-HIF-16-014).
- FHWA Tech Brief on Environmental Product Declarations

Contact: For more information, contact:

Federal Highway Administration (FHWA)
Office of Preconstruction, Construction, and Pavements
Heather Dylla (Heather.Dylla@dot.gov)

Researcher: This Tech Brief was developed by Joep Meijer, John Harvey, Prashant Ram, and Kurt Smith and prepared under FHWA's Sustainable Pavements Program (DTFH61-15-D-00005). Applied Pavement Technology, Inc. of Urbana, Illinois served as the contractor to FHWA.

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LIFE-CYCLE COST ANALYSIS

What Is Life-Cycle Cost Analysis (LCCA)?

- LCCA is an analytical tool to provide cost comparisons between two or more competing alternatives on a project.
- For pavements, LCCA provides a way of measuring the economic consequences of changes in design, materials, construction techniques, maintenance schemes, and end-of-life treatments over a prescribed analysis period.

How Can LCCA Be Used?

- LCCA can be used to:
  - Determine the pavement type or treatment strategy that results in the lowest overall life-cycle costs at the required level of performance.
  - Demonstrate the benefits of various treatment strategies or construction sequencing on the traveling public (e.g., vehicle operating costs, user delay costs, crash costs, etc.).
  - Estimate the initial costs and support future agency budget decisions for designing, constructing, and maintaining a pavement at a specified performance level over a predetermined time period.
- LCCA should be used as one indicator in the decision-making process, along with other key factors that cannot be easily quantified monetarily (e.g., work zone safety, environmental impacts).
- Both direct agency costs and user costs can be considered, and these may be expressed in terms of net present value (NPV) or equivalent uniform annual costs (EUAC). User costs are those costs incurred by the users of the facility, such as vehicle operating costs and user delay costs.
- Many state highway agencies use LCCA to evaluate the cost-effectiveness of alternative pavement design approaches.

What Are the Steps Involved in an LCCA for Pavement Design?

Step 0: Establish LCCA Framework. Select analysis period for the LCCA. Determine how inflation will be addressed and establish discount rate to be used. Establish economic analysis indicators to be used for presenting results (e.g., NPV, EUAC).

Step 1: Establish Design Alternatives. Identify a range of possible design alternatives. Consider a minimum of two options that offer the same level of performance for a selected analysis period.

Step 2: Determine Activity Timing. Define the schedule of initial and future activities (e.g., construction, maintenance, rehabilitation, end-of-life) and their performance period for each selected pavement design alternative.

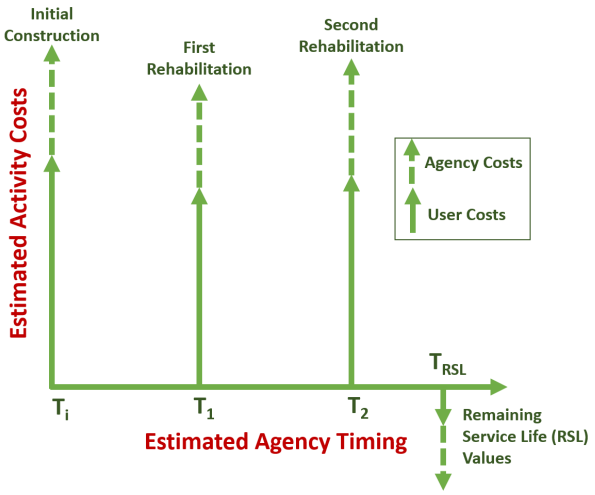

Figure 1. Example projected life-cycle cost stream diagram.

Step 3: Estimate Costs. Estimate agency cost and user costs associated with the activities of each pavement design alternative being investigated over the selected analysis period.

Step 4: Compute Life-Cycle Costs. Calculate the total life-cycle cost agency and user costs for each design alternative considered.

- All costs are converted to present dollars using an established engineering economics technique known as “discounting” to account for the time value of money.
- All initial and future costs are summed to provide a an NPV for the entire analysis period. If different analysis periods are used, the costs may be expressed in terms of an EUAC.

Step 5: Analyze Results. Compare alternatives using a common metric such as the NPV or EUAC and determine the most influential parameters affecting the outcome (e.g., initial costs, future rehabilitation costs, etc.).

When Do Highway Agencies Use LCCA?

Highway agencies follow different approaches in applying LCCA on pavement projects; for example:

- The Michigan Department of Transportation conducts an LCCA when total project pavement costs exceed $1 million and when comparable asphalt and concrete design options are available to achieve the same project objectives.
- The Washington State Department of Transportation uses the FHWA RealCost tool to conduct LCCA for pavement type selection on all mainline pavement projects that are more than 1 lane-mi (1.6 lane-km) long or cost more than $1 million with the exception of chip-seal pavement surfaces.
- The California Department of Transportation has developed a detailed LCCA procedure manual and requires LCCA be performed on all projects that include a pavement cost component (with a few exceptions such as pavement preservation projects).

What Inputs Are Needed for an LCCA?

- Analysis period.
- Timing, performance, and cost of each activity (e.g., initial construction, maintenance, rehabilitation) to be performed over the analysis period.
- Discount rate.
- Current and projected traffic volumes.
- And if user costs are to be considered:
  - Construction work zone inputs (such as number of work zone lanes, work zone duration, work zone length, work zone speed limit, etc.).
  - User cost inputs (value of time of categories of vehicles using the pavement such as cars, single-unit trucks, combination trucks, etc.).

What Agency Resources Are Needed?

- Most highway agencies typically have in-house expertise to conduct LCCA.
- LCCA calculations can be performed using pencil and paper, calculator, or simple spreadsheet-based tools.
- Many state highway agencies have developed their own customized LCCA policy and software tools with agency specific inputs.

What Resources and Tools Are Available?

FHWA's 1998 Interim LCCA Technical Bulletin: A comprehensive document providing technical guidance and best practices for conducting an LCCA in pavement applications.

FHWA's RealCost software tool: A spreadsheet-based tool that can be used to incorporate life-cycle costs into the pavement investment decision-making process

OMB Circular A-94 Appendix C: A tabular listing of national discount rates for use in LCCA if state-specific data are not available.

Where Can I Get More Information?

- FHWA's LCCA Primer
- FHWA LCCA Factsheet
- FHWA LCCA Webpage

For additional information, contact:

Heather Dylla

Office of Preconstruction, Construction, and Pavements

202-366-0120

Heather.Dylla@dot.gov

https://www.fhwa.dot.gov/pavement/sustainability/

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LIFE-CYCLE ASSESSMENT

What Is Life-Cycle Assessment (LCA)?

- LCA is a technique for analyzing and quantifying the environmental impacts of a product, system, or process (see figure 1).
- An LCA examines material and energy inputs and outputs over the life cycle of the product or process, from raw material production to end-of-life.

How Can LCA Be Used?

- LCA can be used to:
  - Document and benchmark the environmental impacts associated with current practices and materials to identify key areas for improvement to meet environmental goals.
  - Determine the pavement structural and mixture design with the lowest environmental impacts.
  - Evaluate the tradeoffs of implementing a policy such as requiring recycled materials in all pavement designs.
  - Develop an EPD for a specific product (such as an asphalt binder or a portland cement).
- LCA should be used as one indicator in the decision-making process as there are a number of other key factors that should be considered (e.g., work zone safety, life-cycle agency costs, user costs, etc.).
- The results from different LCAs are context-specific and should not be compared to other LCA studies since an LCA is performed to address a specific question for a specific product or process that provides a specific function in a specific geographical location.

What Are The Steps Involved In An LCA?

Step 1: Define Goal and Scope. The relevant life-cycle stages, processes, and required levels of data for the analysis are first established for a defined goal. This includes defining the initial and future activities involved, using the same activity prediction data that are typically available for use in life-cycle cost analysis (LCCA).

Step 2: Perform Life-Cycle Inventory Assessment. The environmental flows (inputs of resources, and outputs of waste, emissions, and co-products) are estimated for each activity to produce the life-cycle inventory (LCI). Resource flows considered are energy and materials whereas emission flows are emissions to air, land and water.

Step 3: Conduct Impact Assessment. The resource and input and output flows from Step 2 are translated into selected impact category results, which can range from narrowly focusing on energy and greenhouse gas emissions to a broader set of impact categories. The most commonly used impact categories in the U.S. are based on the Environmental Protection Agency's (EPA) TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) impact assessment methodology.

Step 4: Conduct Interpretation. The overall results are summarized, and recommendations are developed for decision-making in accordance with the goal and scope definition. A review as part of steps 1 and 4 of the LCA process by a carefully chosen group of experts/ stakeholders is recommended to ensure that the assessment meets the standards as claimed.

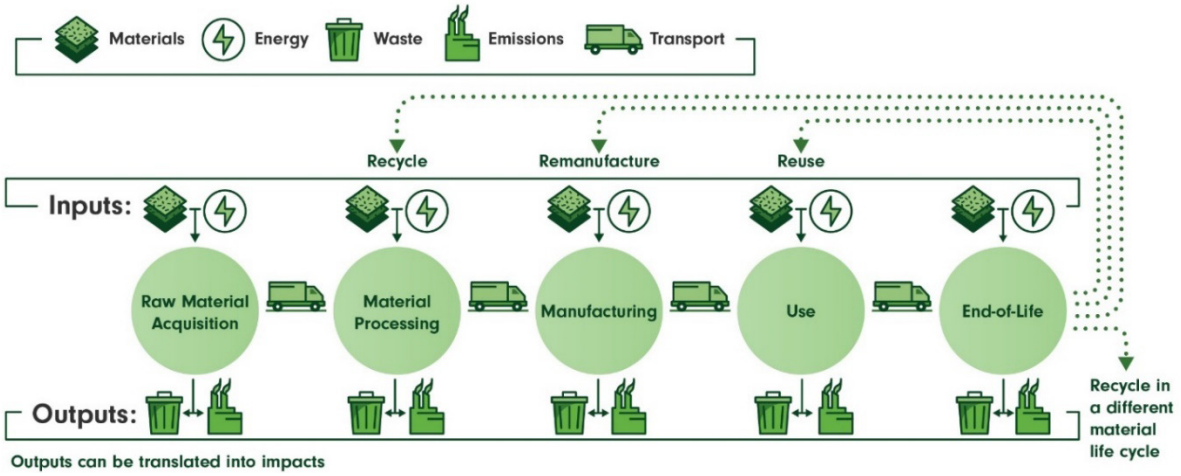

Figure 1. Generic life cycle of a production system for LCA.

What Are Examples Of LCA Use?

- The Illinois Tollway uses LCA tools to evaluate environmental impacts of materials, equipment, and construction operations, and uses that information in conjunction with LCCA and sustainability rating systems in the decision-making process.
- The California Department of Transportation and the Oregon Department of Environmental Quality are taking steps toward requiring Environmental Product Declarations (EPDs) for pavement and other transportation infrastructure materials for use in reporting, benchmarking, and LCA for design and asset management, but not yet as part of procurement. California requires that EPDs for steel used by state agencies be considered in procurement.

What Data Are Needed For Pavement LCAs?

Agency-Specific Data

- Analysis period.
- Timing, performance, and material quantities for each activity (e.g., initial construction, maintenance, rehabilitation) to be performed over the analysis period.
- Mix design data, including transportation distances for materials.
- Current and projected traffic volumes.
- Construction work zone inputs (such as work zone duration, work zone length, work zone speed limit, etc.).
- Construction site equipment usage (usage duration, fuel, electricity).
- Construction waste treatment.
- Transportation modes and distances involved in the construction process, along with fuel usage for trucks, rail, and barge.

Industry Data

- Background data sets for all materials used.
- Emission factors for categories of vehicles using the pavement such as cars, single-unit trucks, combination trucks, etc.
- Emission factors for construction equipment.
- Plant operation data (asphalt, concrete, etc.).
- EPDs (when available).

What Agency Resources Are Needed?

- Resources needed to complete an LCA vary with the use of the LCA, but they typically rely on the use of LCA expertise from dedicated internal staff or hired experts.
- There are a number of available LCA software tools (sophisticated commercial software and simple spreadsheet-based tools) that include life-cycle inventory (LCI) datasets for pavement that can be used as a starting point to develop LCA models.
- Some state highway agencies have developed their own customized LCA software tools with agency-specific default background data.

What Resources And Tools Are Available?

FHWA Pavement LCA Framework Document—This document presents a framework for performing an LCA specific to pavement systems along with guidance on the overall approach, methodology, and system boundaries.

Federal LCA Commons—This is a community of practice of LCA practitioners working within and for the Federal government to align and advance LCA research. It also maintains a repository dedicated to access to and long-term preservation of Federal LCA data, tools, and resources.

TRACI—This spreadsheet includes the EPA impact assessment models for use in the U.S.

FHWA Pavement LCA Benchmarking Tool—Expected to be available in 2020.

Where Can I Get More Information?

- FHWA Pavement LCA Framework
- FHWA Tech Brief on Pavement LCA
- FHWA Tech Brief on Life-Cycle Thinking
- FHWA Tech Brief on EPDs
- TRACI
  - Background
  - User's Guide

For additional information, contact:

Heather Dylla

Office of Preconstruction, Construction, and Pavements

202-366-0120

Heather.Dylla@dot.gov

https://www.fhwa.dot.gov/pavement/sustainability/

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ENVIRONMENTAL PRODUCT DECLARATIONS

What Is An Environmental Product Declaration (EPD)?

- An EPD is a transparent, verified report used to communicate the environmental impacts of a specific material (e.g., asphalt binder, portland cement) or product (e.g., asphalt mix, concrete mix).
- EPDs express the results of a life-cycle assessment (LCA) for a specific material or product. They show the environmental performance through the material production stage in terms of environmental and resource use.
- EPDs are developed with industry stakeholders and LCA experts and subjected to a critical review process following the industry standards described in the Product Category Rule (PCR) document. PCRs and EPDs are not required by law or federal regulations.
- EPDs that follow different PCRs cannot be compared.

How Are EPDs Used?

- **Green Procurement**. An EPD encourages the demand for (and supply of) those products that promote the more sustainable use of finite resources and that create less stress on the environment.
- **Environmental Stewardship**. An EPD is a statement that the manufacturer is paying attention to the environmental aspects of sustainability.
- **Effective Communication**. An EPD provides verified and transparent life-cycle environmental impact data for materials or products that can be used in pavement LCAs.
- **Progress Measurement**. Periodic updating of EPDs can show the progress made by a manufacturer or an industry. Agencies can use this information to track progress by their suppliers in meeting agency goals.

How Are Agencies Using EPDs?

- The California Department of Transportation and the Oregon Department of Environmental Quality are taking steps toward requiring EPDs for pavement and other transportation infrastructure materials for use in reporting, benchmarking, and LCA for design and asset management, but not yet as part of procurement. California requires that EPDs for steel used by State agencies be considered in procurement.
- The Minnesota Department of Transportation (DOT) recently undertook an effort to educate stakeholders and decision makers on the purpose and application of EPDs.
- Louisiana State University developed a concrete EPD and cost database that can be used in conjunction with a decision-making tool to help the State DOT benchmark its current concrete pavement designs and practices.

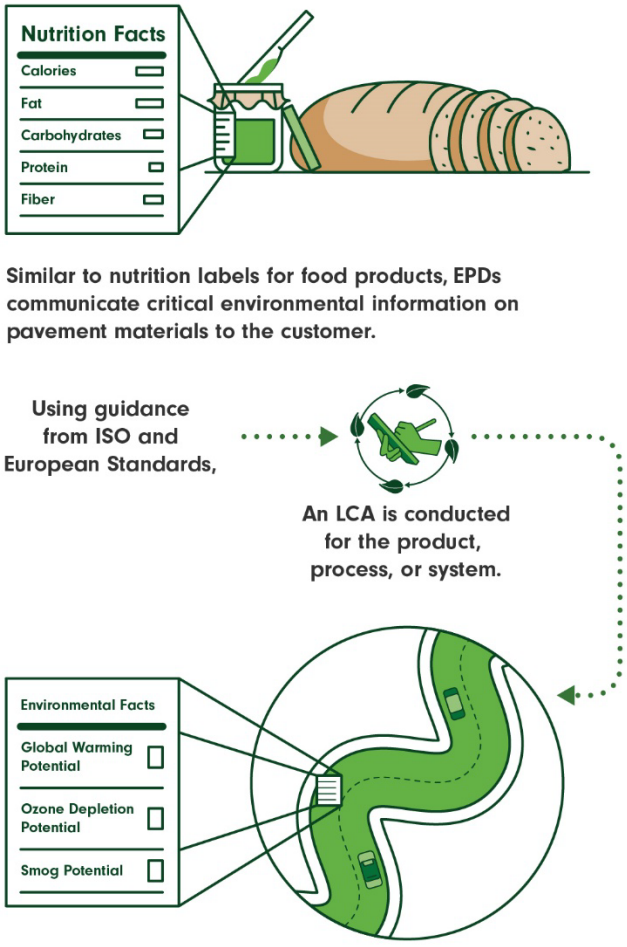

Figure 1. EPD Concepts.

What Agency Resources Are Recommended To Use EPDs?

- Agencies should develop sufficient expertise in LCA and EPDs or collaborate with other State agencies (such as various environmental departments) to ensure the content and production of EPDs is aligned with overarching agency goals, especially if the agency is considering the use of EPDs in green procurement.

How Can Agency Use EPDs Today?

- Establish a database with EPDs relevant to pavements.
- Encourage the development and use of EPDs by providing incentives to industries or manufacturers.
- Compile EPDs to track and communicate the progress being made toward the agency's sustainability goals.
- Use EPDs as inputs to the agency's use of LCA in pavement design, asset management, and in the development of specifications and policies.
- Conduct a pilot program to introduce the industry to EPDs and their applications.
- Participate as a stakeholder for creating PCRs (review or committee member) to ensure EPDs are produced in line with the public interests.
- Consider EPDs for materials procurement once harmonization efforts have created a sufficiently level playing field for competition.

How Are EPDs Developed?

- EPDs are published by a program operator, which can be a company or a group of companies, an industrial sector or trade association, public authorities or agencies, or an independent scientific body or other organization.
- EPDs are developed using standards defined in the PCR document, which is developed in conjunction with industry stakeholders and LCA experts.
- After review, EPDs are published and can be included in listing and database submittals to agencies.
- EPDs should be updated periodically, typically every 3 to 5 years (or more frequently if significant changes have occurred in the declared environmental performance).

The steps involved in the development of EPDs are outlined in figure 2.

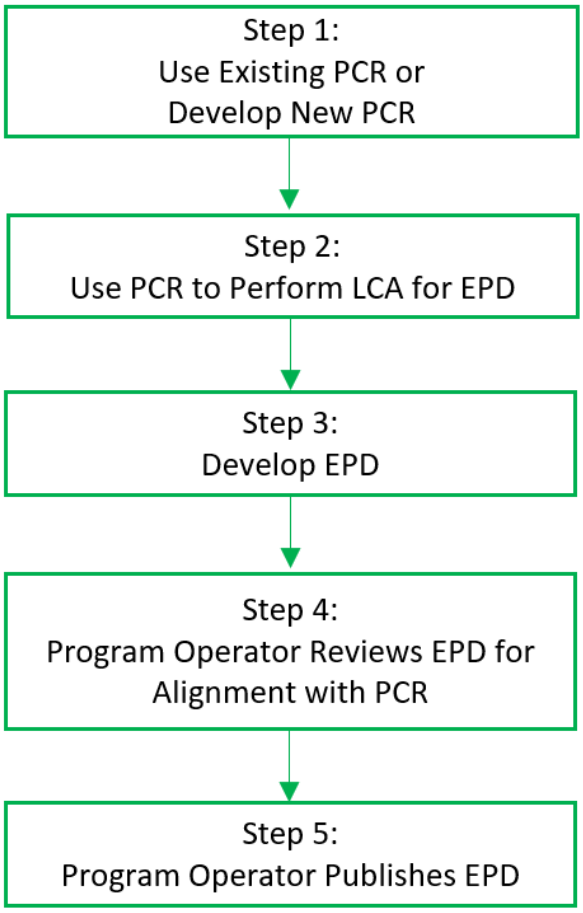

Figure 2. Steps in the development of EPDs.

What Data Are Considered?

- Most EPDs cover the "cradle-to-gate" stages of the life cycle, meaning that they include flow data up to the point the product leaves the control of the producer, but can also include other stages of the life cycle when a specific application is defined.
- EPDs can be produced using two types of data:
  - Plant-Specific EPD. Uses manufacturer's data on the production of the material or product, such as annual consumption of materials, electricity, natural gas, transportation fuels, reported emissions, waste generated, etc.
  - Industry-average EPDs. Uses data from participating manufacturers and sometimes multiple plants from different manufacturers.

Data from the literature are used for processes that are not owned or controlled by the specific facility.

What Is The Current State Of Practice For EPDs For Pavement Materials?

- Limited collaboration between program operators has resulted in some PCRs that are not consistent across areas. Harmonization efforts can improve consistency.
- The FHWA is working on documenting best practices for developing PCRs for EPDs of pavement materials.

What Are Best Practices For EPD Implementation?

A three-stage implementation plan based on the results of an FHWA-supported workshop on EPDs is summarized below:

Stage 1: Reporting (1 to 2 Years)

- Develop policies and reporting practices as a move toward standardization of EPDs.
- Use pilot projects for requesting EPDs to refine the specification for the EPDs and for using EPDs, including development of tools that use EPDs as inputs.

Stage 2: Standardization of PCRs (3 to 5 Years)

- Work with other agencies and industries to push for harmonization of PCRs and work to fill gaps in public databases.
- Implement rewards for plant-specific EPDs versus industry averages.
- Continue to improve the use of EPDs in pavement design and asset management.

Stage 3: Procurement (> 3 Years)

- Consider using EPDs along with costs in selecting materials to meet given performance requirements once sufficient progress has been made toward accounting for materials performance and improving the quality of EPDs.
- Consider EPDs for constructed pavement systems, or for longer-term maintenance and rehabilitation of a highway network as follows:
  - EPDs of materials (design-build).
  - EPDs of pavements to site (design-build).
  - EPDs of full life-cycle (design-build-maintain).

Where Can I Find EPDs?

Material	Source
Blended Cement	Portland Cement Association / ASTM Slag Cement Association
Portland Cement	Portland Cement Association / ASTM
Steel	Concrete Reinforcing Steel Institute
Hot Mix Asphalt	National Asphalt Pavement Association
Concrete	National Ready Mixed Concrete Association
Aggregates	ASTM

An example EPD for a concrete mixture design is shown in figure 3 and illustrates the type of environmental impact data that can be reported.

ENVIRONMENTAL IMPACTS

Declared Product:
Mix 3EAE75Z1 • Queens Lane (wet) Plant
3 IN LN 0.40 W/C 1" EF70 3-5 SL
Compressive strength: 5000 psi at 28 days

Declared Unit: 1 m^3 of concrete

Global Warming Potential (kg CO_2-eq)	229
Ozone Depletion Potential (kg CFC-11-eq)	7.5E-06
Acidification Potential (kg SO_2-eq)	1.69
Eutrophication Potential (kg N-eq)	0.30
Photochemical Smog Creation Potential (kg O_3-eq)	38.4
Total Primary Energy Consumption (MJ)	2,266
Nonrenewable (MJ)	2,195
Renewable (MJ)	70.8
Total Concrete Water Consumption (M^3)	2.28
Batching Water (m^3)	0.16
Washing Water (m^3)	0.02
Nonrenewable Material Resource Consumption (kg)	2,134
Renewable Material Resource Consumption (kg)	1.50
Hazardous Waste Production (kg)	0.01
Nonhazardous Waste Production (kg)	2.1

Product Components: crushed aggregate (ASTM C33), natural aggregate (ASTM C33), slag cement (ASTM C989), Portland cement (ASTM C150), fly ash (ASTM C618), batch water (ASTM C1602), admixture (ASTM C494)

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Figure 3. Example EPD for a Concrete Mix Design.

Where Can I Get More Information?

- FHWA Sustainable Pavements Reference Document
- FHWA Pavement LCA Framework
- FHWA Tech Brief on Pavement LCA
- FHWA Tech Brief on Life-Cycle Thinking
- FHWA Tech Brief on EPDs

For additional information, contact:

Heather Dylla

Office of Preconstruction, Construction, and Pavements

202-366-0120

Heather.Dylla@dot.gov

https://www.fhwa.dot.gov/pavement/sustainability/

Note: Unless otherwise indicated, all images in the document are from FHWA.

FHWA-HIF-19-027-c

PRODUCT CATEGORY RULES

What Is A Product Category Rule (PCR)?

- Product Category Rules (PCR) are industry consensus standards and guidelines that are used in developing and reporting Environmental Product Declarations (EPDs), which are transparent, verified reports used to communicate the environmental impact of a specific material or product. PCRs and EPDs are not required by law or federal regulations.

What Is The Purpose of PCRs?

PCRs serve as the foundation for the development of meaningful EPDs in terms of:

- **Consistency**. Different practitioners using the same PCR to assess the EPDs of products belonging to the same category should produce consistent results.
- **Transparency**. PCRs outline the basis for the development of the EPDs, making it clear and transparent to all stakeholders as to how they were created.

What Should The Agency's Role Be In Ensuring High Quality PCRs?

- **Contribute to PCR Development**. Agencies can be involved in the PCR committee that is responsible for developing the PCR.
- **Review of PCRs**. Agencies can participate in the open stakeholder process to review the draft PCR and provide feedback.
- **Request EPDs Based on Published PCRs**. When PCRs are published, agencies can request their suppliers provide EPDs for their products using the published PCRs.
- **Encourage Harmonization of PCRs**. Agencies can be advocates for harmonization of PCRs as well as market drivers for harmonization through the standards they may set for EPD acceptance.

What Key Questions Should Agencies Ask When Assisting In PCR Development?

- Are the selected impact assessment categories in line with the agency's goals?
- Is the product defined adequately with the proper performance tests required by the agency's specifications?
- Are background datasets prescribed to limit variability caused by generic data inputs?

How Are PCRs Developed?

The general steps for PCR development are outlined in figure 1.

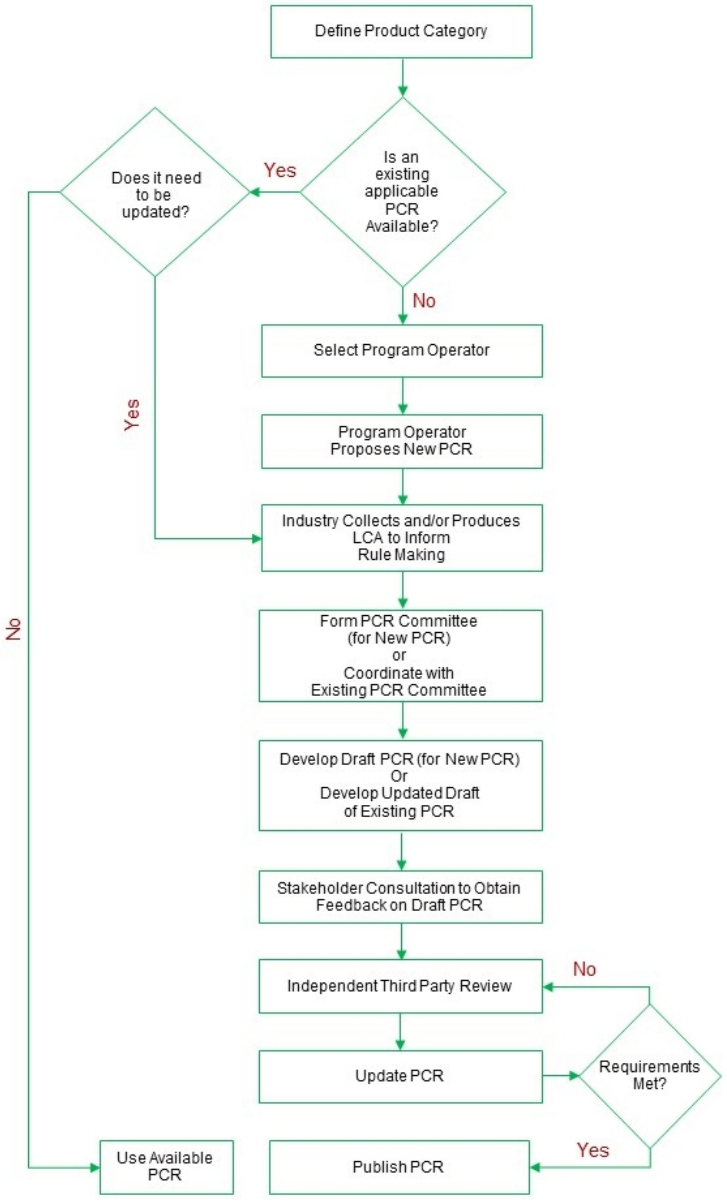

Figure 1. Steps in the development of PCRs.

What Is The Current State Of Practice For PCRs For Pavement Materials?

- A current challenge for the industries that produce the materials used in pavement construction is to bring harmonization between different PCRs. There is no overarching organization governing and overseeing harmonization between PCRs. FHWA is working on documenting best practices for creating PCRs for EPDs of pavement materials.
- Limited collaboration between program operators has resulted in some guidelines and requirements that are not consistent across areas. Recent initiatives working to bridge this gap are the Program Operator Consortium and the American Center for Life Cycle Assessment.
- More and more PCRs are expected to become available in the coming years as several industries are working to develop new PCRs or update existing ones.

Where Can I Find PCRs?

Industries that have published PCRs for pavement materials or are working toward the publication of one are listed in the table below:

Material	PCR Producer/Program Operator
Portland Cement	ASTM
Slag Cement	ASTM
Hot Mix Asphalt	National Asphalt Pavement Association
Ready Mix Concrete	Carbon Leadership Forum / NRMCA
Steel	SCS Global Services
Aggregates	ASTM

Where Can I Get More Information?

- FHWA Sustainable Pavements Reference Document
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- FHWA Tech Brief on Life-Cycle Thinking
- FHWA Tech Brief on EPDs

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