LCA for Roadways and Bridges
Roadmap for greater adoption of LCA as a decision-support tool

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List of Abbreviations

LCI  Life cycle inventory
LCA  Life cycle assessment
LCCA Life cycle cost analysis
HMA  Hot mix asphalt
PCC  Portland cement concrete
FHWA Federal Highways Administration
SPTWG Sustainable Pavements Technical Working Group
EPD  Environmental product declaration
EPA  Environmental Protection Agency
PCR  Product category rules
GHG  Greenhouse gases
PVI  Pavement-vehicle interaction
WMA  Warm mix asphalt
Executive Summary

The National Research Council Canada (NRC) recognizes the value of life cycle assessment (LCA) to inform sustainability-focused decisions. NRC would like to facilitate the use of LCA as an evidence-based tool to support decisions by the stakeholders responsible for infrastructure investments in Canada. This study was commissioned to help NRC pursue that goal.

The objective of this study is to provide a roadmap towards an end state where LCA is used in the design and maintenance of roadways and bridges to reduce environmental impacts. We review the current state of practice, identify gaps that require addressing to achieve the desired end state, and propose strategies to move forward. The method for the study was an extensive literature review and multiple stakeholder interviews, addressing the use and readiness of LCA in Canada, the U.S. and abroad.

Roads and bridges are typically long-lived publicly-owned assets. Jurisdictions worldwide therefore have an incentive to understand and manage life cycle impacts of these assets. In fact, this is commonly practiced for costs: life cycle cost analysis (LCCA) is well-established in many transportation agencies in Canada and elsewhere. However, the application of a life cycle perspective to the environmental impacts of infrastructure is rarely practiced.

Life cycle assessment is an established scientific method for evaluating the lifetime environmental burden of a product or system. However, the application of LCA to roads and bridges is still evolving. Early studies were very limited in scope; they typically omitted traffic emissions from the use phase, for example. An important review in 2010 of existing studies and models highlighted significant shortcomings in data and methods that need addressing before roadway LCA results are reliable enough to encourage LCA uptake in practice and policy.

Since that time, the research community has responded to this call to action. First, there is now consensus (for the most part) that roadway LCA must be cradle-to-grave, although this introduces uncertainties around maintenance and rehabilitation timing, traffic use, and end-of-life circumstances. Meanwhile, a few key groups are filling in the gaps regarding data, methods and models, primarily at UC Davis, the US Federal Highways Administration, MIT, the University of Illinois Urbana-Champaign, and Louisiana State University. Several trade associations and manufacturers have generated data on pavement and bridge materials. The Athena Institute has developed an on-line simplified tool for Canada, “Pavement LCA,” with current material data and with MIT models for costing and for pavement-vehicle interactions. The University of Illinois has developed “Tollway LCA” for the Illinois Tollway Authority, with (limited) LCA metrics for roadways, bridges and other infrastructure, and tied to costing.

Roadway LCA data and models are now significantly improved, although work remains. For example, many researchers agree that the use-phase (i.e., vehicle-related impacts) is still not well-understood. In addition, research progress on bridge LCA lags behind pavements. But enough technical pieces are in place to support uptake in policy and practice, in theory.
Two transportation agencies in the US are LCA trend-setters. The Illinois Tollway Authority is an early adopter of LCA and has recently integrated it into their planning and procurement decision-making, with the Tollway LCA tool. The California Department of Transportation has also been actively exploring LCA for decision-support, which will likely escalate due to a recently-passed California bill requiring EPDs in procurement for some materials on state projects. Caltrans has engaged the UC Davis pavement group to develop an LCCA/LCA model.

In Canada, we did a temperature-check for LCA policy readiness with two provinces. Ontario’s recently-announced long-term infrastructure plan calls for the use of LCA in decision-making. The Ontario Ministry of Transportation is currently considering how to do that, given a lack of internal LCA technical capacity. The Alberta transportation ministry predicts LCA uptake in planning will require a link to LCCA.

Some policy activity in Europe offers potential examples for North America. The Swedish Transport Administration, with a policy objective to limit life cycle energy use and climate impact, has created LCA methods and tools for road and railway infrastructure. In the Netherlands, the ministry of infrastructure requires project bidders to include an “environmental cost” in their price and has developed an LCA-based software tool to enable that. Norway’s transportation agency regularly uses LCA in planning and is developing a software tool.

In our conversations with researchers, transportation agencies, and the materials industries, we heard several consistent messages about the hurdles to LCA uptake in policy and practice. These include: concerns about data quality and unintended consequences; no strong motivation to do LCA; and a need to integrate LCA with infrastructure design and costing processes.

Canada is probably ready for the first steps in LCA adoption for roadway and bridge decisions, recognizing that a slow step-by-step approach to policy implementation is advised, with low-risk early stages. Precedent examples of LCA adoption in other sectors (buildings, for example) show that it takes time to build awareness and confidence among all stakeholders, demonstrate value, and develop technical resources and capacity.

We recommend the following near-term actions which would serve to enable a greater rate of voluntary LCA usage, and would lay the groundwork for future incorporation of LCA in policy:

- Develop guidelines for the practice of LCA for roads and bridges
- Create outreach vehicles for awareness-building, education and network-building
- Initiate development of a national LCI database
- Provide LCA software tools specifically intended for use with roads and bridges
- Develop case studies to demonstrate value and feasibility
- Look for synergy with climate adaptation and resiliency mandates
1. Objective

The National Research Council Canada (NRC) recognizes the value of life cycle assessment (LCA) in providing data to inform sustainability-focused decisions. NRC would like to facilitate the use of LCA as an evidence-based tool to support decisions by the stakeholders responsible for infrastructure investments in Canada. This study was commissioned to help NRC pursue that goal.

The objective of this study is to provide a roadmap towards an end state where LCA is used in the design and maintenance of roadways and bridges to reduce environmental impacts. This study reviews the current state of practice, identifies gaps that require addressing to achieve the desired end state, and proposes strategies to move forward.

2. Method

In this study, we conducted an extensive literature review and multiple stakeholder interviews, addressing Canada, the U.S. and abroad. The intention was to characterize the evolution of LCA as applied to roads and bridges, the current state of practice in research and application, and the perspectives of stakeholders throughout the supply chain regarding current and future use of LCA in this context.

3. Introduction

Horizontal infrastructure is essential for supporting access and mobility. Our roads, bridges, tunnels and railways are a critical component of Canadian infrastructure. Building and maintaining this infrastructure is costly and resource-intensive, and it has a significant life cycle environmental footprint.

Roads and bridges are typically long-lived publicly-owned assets. Jurisdictions worldwide therefore have an incentive to understand and manage life cycle impacts of these assets. In fact, this is commonly practiced for costs: life cycle cost analysis (LCCA) is well-established in many transportation agencies in Canada and elsewhere (see Appendix for a detailed list). However, the application of a life cycle perspective to the environmental footprint of infrastructure is rarely practiced. LCA has not yet achieved the recognition of LCCA, although it is equally useful for reducing lifetime impacts of a project.

3.1. LCA background

Life cycle assessment is an established scientific method for evaluating the lifetime environmental burden of a product or product system. LCA is a cradle-to-grave accounting of all the flows to and from nature due to the product or product system, and an estimate of the ultimate impacts on air, land and water. As a rigorous measurement technique guided by international standards, LCA is an evidence-based approach to support more sustainable
business and policy decisions. When applied correctly, LCA can uncover unintended consequences of a product, product system or policy.

Typically, the life cycle of infrastructure is quite long and can be broken into distinct phases or life cycle activity stages (see Figure 1). A cradle-to-grave life cycle assessment for roads or bridges would include the following activity stages:

**Material manufacturing** includes raw material extraction, beneficication and acquisition to the point where materials and or products are ready to be used in initial construction or reconstruction as well as subsequent maintenance and rehabilitation of a roadway or bridge.

**Construction** (or reconstruction) entails the transportation and placement of materials and equipment used during construction/reconstruction operations.

**Maintenance and rehabilitation** encompasses the preservation and necessary rehabilitation activities associated with the roadway’s expected life and includes the use of equipment, various preservation and rehabilitation processes as well as the periodic transportation and placement of materials.

**Use** includes the effects of pavement or bridges on the operation of vehicles using the infrastructure as well as lighting.

**End-of-life** considers the removal and final disposition of materials – whether they are stockpiled for reuse, recycled or landfilled.

![Figure 1  Life cycle phases for a roadway](Image)

Source: Santero et. al. (10)
For further detail on LCA in general, see Trusty (28) and on the life cycle phases for pavement, see Harvey et. al. (11).

LCA can trace its origins back to the 1960s, but it wasn’t until the 1990s that international guidelines and standards first appeared. This means LCA is still evolving. With respect to long lived product systems such as infrastructure, many methodological questions remain. For example, LCA is challenging when life cycles are uncertain and when there spatial and temporal aspects to be considered.

As discussed in detail by Trusty (28), LCA is slowly becoming a factor in sustainable design, however there are significant hurdles to broad uptake in practice or in codes and policy. These include methodology questions, uncertainty in results, data quality and availability issues, lack of knowledge to practice and interpret LCA among stakeholders, and minimal market drivers.

3.2. Evolution of LCA for roads and bridges

Life cycle assessment of road pavements and bridges has been developing since the 1990s (1,2,3). Early on, much of the focus was on comparing pavement types (e.g., flexible vs rigid) or bridge structural materials (concrete vs. steel), and many of these studies were prepared or commissioned by material associations (1,4,5). These early studies typically confined the boundary of the LCA to cradle-to-gate or to the point of first construction. However, at the same time, numerous studies determined that traffic emissions during the use phase account for the majority of emissions in the pavement life cycle (6,7). But, because vehicle fuel consumption is largely a function of many factors other than pavement or bridge performance (8,9), traffic-related emissions were largely excluded in these earlier LCAs.

It is now acknowledged that this truncation of the system boundary before the use phase is a limitation. For example, it’s a significant oversight to exclude maintenance and rehabilitation, given the additional construction activities involved plus the queuing or traffic delays that occur during these rehabilitation cycles which may impact vehicle fuel consumption. End-of-life has also typically been ignored, on the assumption that roads and bridges are rarely retired, but this exclusion may not be justified.

There is currently general consensus in roadway LCA practice that the system boundary must be cradle-to-grave. While this introduces uncertainty associated with maintenance and rehabilitation timing and/or traffic use, it is required in order to understand the performance, durability or recyclability of products over the course of a roadway or bridge life cycle.

In 2010, Santero et. al. (10) prepared a critical review of existing literature and modeling tools related to life cycle assessment applied to pavements. The review found that the existing body of work exhibited “methodological deficiencies and incompatibilities” that serve as barriers to the widespread use of LCA by pavement engineers and policy makers. In many cases, the studies reviewed sought to compare pavement types by focusing on a single environmental indicator: global warming potential. Generally, the review showed a wide variation in approaches, and results that were sometimes contradictory. However, many of these variations were themselves
a result of a diverse array of goals and objectives in the reviewed studies. At that time, Santero et. al. identified five key issues in the current body of work:

- Inconsistent functional units;
- Improper or incomplete system boundaries;
- Imbalanced (poor) LCI data for asphalt and cement;
- Use of limited inventory and impact assessment categories; and
- Poor overall utility of models.

This review also identified common data and modeling gaps in pavement LCAs that should be addressed in future work. Specifically, there are issues in the use phase (rolling resistance, albedo, carbonation, lighting, leachate and tire wear and emissions), asphalt fumes, treatment of the feedstock of bitumen, traffic delay, the maintenance phase, and the end-of-life phase.

The Santero et. al. review served as a pivotal call to action for the North American academic community as well as for others interested in addressing pavement sustainability and, in turn, developing better decision-making frameworks for more sustainable pavements.

In 2010, the University of California Pavement Research Center (UCPRC) convened a pavement LCA conference in Davis, CA to begin the process of standardizing pavement LCA and to build greater understanding of LCA for stakeholders in the pavement sector (11). The conference resulted in LCA guidelines tailored to pavements and led to three more conferences: 2012 in Nantes, France; 2014 in Davis, CA; and 2017 in Champaign, IL. In addition, the US Federal Highways Administration (FHWA), via its Sustainable Pavements Technical Working Group (SPTWG), released a “Pavement Life-Cycle Assessment Framework” in 2016 (12). The framework documents the implementation and adoption of LCA principles in the pavement community within the U.S. It also provides guidance on the overall approach, methodology, system boundaries and current knowledge gaps concerning the application of LCA to pavements.

Meanwhile, industry associations and manufacturers have addressed some of the critical data vintage and gap issues by updating life cycle inventory (LCI) data for significant materials used in the construction of pavements and bridges. Here in Canada, the Cement Association of Canada, Canadian Ready Mixed Concrete Association, the Canadian Precast Prestressed Concrete Institute and the Canadian Steel Construction Institute have completed industry-average environmental product declarations (EPDs) for a wide range of products used in both pavement and bridge projects. Similar EPD efforts have occurred both in Europe and the U.S.

The recent and increasing activity worldwide in EPDs is very helpful to the availability and quality of LCI data. Note that EPDs are Type III environmental declarations and are based on a set product category rules (PCR). These rules are equivalent to a goal and scope statement that would accompany an LCA, and thus a PCR ensures all resulting EPDs are developed in a similar way and should be comparable. Note as well that the International EPD System has developed a global PCR for “Highways, Streets and Roads” as well as “Elevated Highways, Bridges and
Tunnels”. These PCRS will be useful in guiding and perhaps encouraging LCA for road and bridge projects.

A significant LCI data undertaking is also currently underway for bitumen as produced in North America. The Asphalt Institute is creating an industry-average cradle-to-gate LCI and LCA for asphalt binders representative of N. America, with 12 participating refineries (three from Canada) plus 10 participating distribution terminals. These updated data will be made publicly available as well as incorporated into the National Asphalt Pavement Association’s online EPD tool (“Emerald Eco-label”).

As LCA has matured, so has its application to infrastructure systems. Researchers are now considering more of the complexities of infrastructure design and life cycle performance such as traffic flow and delay or the effect of pavement types on vehicle operation (10) as well as radiative forcing, carbonation of concrete, albedo and accounting for uncertainty in both the timing of activities and LCI data itself (13). There is also a growing interest in, and body of work, combining LCA and LCCA to find the most cost-effective approach to reducing environmental impacts (14, 15).

Internationally, there are concerted efforts to incorporate LCA into design, procurement and selection of contractors for infrastructure projects (see section 4.4). In the U.S., the Illinois State Tollway Authority has developed an LCA system to complement its life cycle costing analysis. The California Department of Transportation has included network-level GHG LCA equations in its pavement management system (11) to identify network hotspots and aid in prioritizing maintenance. The western states of the U.S. have or are now contemplating passing bills requiring environmental product declarations to be used for procurement purposes. Here in Canada, Ontario’s Ministry of Infrastructure has committed to integrating LCA in its evidence-based infrastructure planning and delivery (33).

There is less progress in LCA for bridges, compared to roadways. From a review of the literature, it is clear that few studies apply LCA to bridges, and there doesn’t seem to be any concerted effort to do so here in N. America. The first studies were carried out by Horvath and Hendrickson (17) and Widman (18). Thereafter, other researchers assessed the environmental impact of bridges, but most did not include all life cycle stages and focused on just one (19, 20) or focused on a limited number of environmental indicators, usually CO2 and energy (21, 22). It wasn’t until Steele et.al. (23) that a complete LCA was carried out, and the majority of the more complete LCA studies are much more current. These recent LCAs divide the life cycle of the bridge into four stages: manufacturing, construction, use and end-of-life, and they typically

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1 These PCRs are publicly available at www.environdec.com
2 Personal communication with Mark Buncher, Director of Engineering, Asphalt Institute – 11/2017
3 California Assembly Bill 262, which was signed in October 2017, requires contractors for state-funded projects to obtain EPDs for certain products in order to demonstrate that selected products have lower-than-average carbon footprints. A similar bill proposed in the state of Washington in February 2018 did not progress through the legislature. A similar bill in the state of Oregon failed in 2017 but may be pursued again in 2019.
compare bridge design variants (24,25,26,27). The manufacturing stage is usually found to be the life cycle stage with the highest environmental impact and is driven by concrete, asphalt and steel material inputs.

4. State-of-Practice Review

The application of LCA in the context of infrastructure is still evolving, in terms of methods, data, tools, hurdles and incentives. This section reports the findings from our literature review and stakeholder interviews to better understand the state of LCA research, practice and policy as applied to infrastructure investments.

4.1. North American Research

A handful of research groups are the primary contributors to advancing the technical capacity of LCA applied to infrastructure in North America. We summarize their efforts here.

MIT Concrete Sustainability Hub

The MIT Concrete Sustainability Hub (CSHub) is an interdisciplinary team of researchers working on concrete and infrastructure science, engineering, sustainability and economics since 2009. Their work is funded by the Portland Cement Association and the Ready Mixed Concrete Research and Education Foundation. The CSHub applies a life cycle perspective to much of its work, and the team has developed considerable LCA and LCCA capacity. Essentially, their “Sustainable Pavements” guiding principle is to optimize pavement performance (use materials efficiently) at a reduced cost and environmental impact. Their pavement life cycle approach marries pavement design with a bill of activities (material quantities, construction and maintenance activities and timing and pay items) such that LCCA and LCA are concurrently assessed and iteratively inform the final design. The CSHub has also extensively studied pavement-vehicle interaction (PVI) – the excess fuel consumption of vehicles due to surface roughness and deflection (which is a function of design and maintenance) – and built it into their pavement LCA model. While most LCA and LCCA models are deterministic, the CSHub models now account for uncertainty based on probabilistic modeling of initial and future costs, environmental impacts, material quantities, pavement deterioration and excess fuel consumption. More recently, they have also incorporated more pavement use-phase elements into their LCA model – e.g., albedo, carbonation, lighting and traffic delay – to complement their use-phase PVI analysis. They have modelled both rigid and flexible pavement projects of various types (local, state and interstate) in various climate locations. They are currently extending their analysis capabilities to a network level to help allocate funds across a transportation department’s network to attain a certain pavement PVI performance. The CSHub’s inter-related models are certainly robust and informative but are not publicly available and are termed “breadboard tools” built in the MATLab software environment or in spreadsheets.

4 Full disclosure: The Athena Institute has a collaborative relationship and memorandum of understanding with the MIT CSHub regarding their use of the Institute’s LCI data. The Institute has also incorporated the CSHub’s PVI model and is currently incorporating their LCCA module in the Athena Pavement LCA tool.
The CSHubs Executive Director Jeremy Gregory believes a significant hurdle for the greater use of LCA is the fact that LCA is not integrated in pavement design tools such that it can be considered at the time when key make-up and performance decisions are made. He’d like to see pavement design, cost and environmental impact combined to inform and optimize life cycle performance of pavements, as opposed to current practice where LCA (if it is done at all) is performed separately and probably too late. By integrating all three – performance, cost and environmental burden – one can begin to optimize pavement decisions via iterative trade-off analysis. His experience suggests that LCA has achieved an adequate capability (data and tools) and, if applied consistently, can provide a reasonable result to guide decisions. However, Mr. Gregory believes data and tools could be improved – for example, data needs to more regionalized and tools need to be more context-sensitive to circumstances such as urban vs. rural pavements. Currently, he sees very little will on behalf of decision-makers (departments of transportation) to do LCA. He believes that until procurement requires LCAs to be completed, the uptake of LCA will remain relatively slow.

University of California Pavement Research Center, Davis
The UCPRC has long been a strong advocate of LCA and the standardization of the practice of LCA as applied to pavements. They have a strong body of LCA work published in various journals and with the National Center for Sustainable Transportation.

This group facilitated the development of LCA methodology guidelines tailored to pavements and have worked extensively with the California Department of Transportation to demonstrate the efficacy of LCA. Like MIT, they have investigated many facets of the pavement life cycle and have developed various databases and models across various pavement types at both the project and network level. They too are shifting to include more use-stage elements in their models (e.g, rolling resistance, the influence of albedo via their cool pavements model, various material recycling strategies and end-of-life treatments). An in-progress study *Life Cycle Assessment for Complete Streets: Framework and Pilot Studies* is developing socio-economic impact indicators and then testing this using several case studies. This project is intended to be the first step towards the development of standardized guidelines for conducting social and environmental LCAs for complete streets. The idea is to combine LCA with life cycle cost analysis to produce a complete, transparent and quantitative picture of a street project, including interdependencies between impacts. UCPRC is a strong advocate of using LCA and LCCA in tandem to minimize the environmental impact of pavements at a reduced cost.

University of Illinois Urbana-Champaign
The Illinois Center for Transportation has a long engineering history applied to civil and private works. In 2011, the Illinois Tollway Authority engaged the Center to first explore the application of LCA to its roadway infrastructure and then build a LCA model for the Tollway (see section 4.2 for more on this model). Since then, the Center has built a significant LCA capacity and has completed numerous LCA studies of varying complexity to address knowledge gaps concerning the application of LCA to pavement projects and networks; they are looking at issues such as
recycled materials, rolling resistance, and pavement design. In 2017, the Center hosted the International Pavement LCA Symposium.

The Center is now building LCA models for the Illinois Department of Transportation and the FHWA. Director of the Center Dr. Imad L. Al-Qadi believes that the use-phase is still not well understood and is still evolving from a LCA application perspective. He is not surprised that LCA has not been better integrated in state transportation planning or delivery decision-making, as there is little priority or mandate to do so – except in California. He sees awareness about LCA as a significant issue influencing its uptake.

**Louisiana State University (LSU)**
The Transportation Consortium of South-Central States (Tran-SET) Regional University Transportation Center at LSU has recently built a LCA/LCCA tool for the Louisiana State Department of Transportation based on EPDs available within the state. The tool is limited in its scope to consideration of material cradle-to-gate effects and transport to construction site, as it is primarily meant to inform pavement design. Currently, the tool supports only rigid or Portland cement concrete materials and designs, as they are awaiting more EPDs on asphalt materials. The Department of Transportation is using the tool to benchmark past and present pavement designs.

Tran-SET director Dr. Marwa Hassan cautions that, due to the poor alignment of product category rules across asphalt and concrete materials, comparisons of the two materials should not be made based on their EPDs alone. She sees the harmonization of PCRs as a significant issue going forward and would like to see either the EPD Program Operators or the FHWA address the issue at some point.

**The Athena Sustainable Materials Institute**
Established in 1997 in Ottawa, the Athena Sustainable Materials Institute is a membership-based not-for-profit research and consultancy group fostering the uptake of life cycle thinking by the construction sector. The Institute is probably best known for developing life cycle inventory data for North America, conducting LCAs on numerous building materials, and making available free software to the architectural, engineering and policy communities to facilitate the use of LCA by these non-LCA experts.

In 2012, with support from Environment Canada, the Cement Association of Canada and transportation engineers at Morrison Hershfield, the Athena Institute released the Impact Estimator for Highways software. This user-friendly LCA tool helps transportation and roadway designers to consider environmental implications of construction/reconstruction or various rehabilitation strategies. The tool provides results for materials manufacturing, roadway construction, use, and rehabilitation life cycle phases, covering nine regional locations in Canada. The software was renamed the Athena Pavement LCA tool in 2015. Three regional locations in the U.S. were added. Meanwhile, a web version of this tool was launched (with just the Canadian regions), with funding from the Cement Association of Canada and Athena Institute members.
The Pavement LCA tool includes a large equipment and materials database and the flexibility to specify unique pavement systems: sub-base and base granular materials as well as hot and warm mix asphalt and a host of user-specified concrete mix designs. Users can also input use-phase operating energy and apply built-in pavement vehicle interaction algorithms, if desired, to be included in the final LCA results. The software allows for quick and easy comparison of multiple design and rehabilitation options over a range of expected roadway lifespans. The Athena Institute is currently adding a life cycle cost analysis module to the software to complement the LCA component analysis, making for a more complete decision-support environment, and updating various background datasets. A new version of the Pavement LCA tool is scheduled to be released in March 2018\(^5\).

4.2. North American Transportation Agencies
In this section, we summarize notable activities in federal, state and provincial departments or ministries of transportation.

U.S. Federal Highway Administration (FHWA)
In 2010, the FHWA launched its “Sustainable Pavements Program” to advance the knowledge and practice of sustainability as related to pavements. To engage stakeholders, they also initiated the Sustainable Pavements Technical Working Group (SPTWG) with whom they developed a number of deliverables, some of which include\(^6\):

- A comprehensive reference document on sustainable pavement systems
- A framework document for pavement life cycle assessment (12)
- Five technical briefs:
  - Pavement Sustainability
  - Life-Cycle Assessment of Pavements
  - Climate Change Adaptation of Pavements (31)
  - Strategies for Improving Sustainability of Asphalt Pavements
  - Strategies for Improving Sustainability of Concrete Pavements
- Roadmap for the Sustainable Pavements Program (30)

The roadmap document describes the strategic direction for the Sustainable Pavements Program for the next five years (2015 -2020). The overarching goal of FHWA’s strategy is to develop a decision-making framework that collectively considers pavement performance, LCCA and LCA.

With respect to LCA specifically, the FHWA sees LCA’s intensive data requirements as an issue to be addressed and wants to facilitate a more robust and LCI data rich environment that is financially accessible to both public and private users. While these data issues are slowly being addressed.

\(^5\) More information on this tool and free access to both the desktop and web versions are here: [https://calculatelca.com/software/pavement-lca/overview/](https://calculatelca.com/software/pavement-lca/overview/)

\(^6\) These documents can be found at [https://www.fhwa.dot.gov/pavement/sustainability/](https://www.fhwa.dot.gov/pavement/sustainability/)
resolved with the advent of environmental product declarations, FHWA also sees a need for the development of LCA tools to facilitate implementation. Moreover, they believe these tools will work best when tied to existing databases within agencies that can easily provide LCA input information, such as pay items. The roadmap calls for more education, particularly to position LCA as part of value-engineering rather than an afterthought.

Heather Dylla, a pavement engineer at FHWA, believes the development of case studies would be helpful. Examples that demonstrate how the integration of pavement design, LCCA and LCA can deliver higher performing pavements at a reduced life cycle cost and environmental burden would go a long way towards creating awareness about the value of LCA. Similarly, these case studies would serve to underpin policy development going forward. The FHWA, working with its SPTWG, is planning to develop a spreadsheet LCA tool for use by state departments of transportation and municipalities. The tool will be based on EPDs and a simplified life cycle scope that will exclude the use-phase, which she believes is still not well understood. She expects the tool will be made available within the next three years.

Ontario Ministry of Transportation (MTO)
Ontario’s Long-Term Infrastructure Plan calls for the integration of LCA in infrastructure decision-making (33). MTO is slowly working to build capacity in this regard. Phil Hutton (Manager in the Design and Contract Standards office) foresees including an LCA requirement in their design/bid/build procurement requirements (rather than taking on the LCA work within the ministry). In the meantime, MTO has already put in place a few sustainability-focused policies. For example, MTO currently stipulates the use of warm mix asphalt (WMA) and a 10% reduction in cement usage for Portland cement concrete (PCC) projects, because these tactics have proven to be less energy intensive and hence, reduce CO₂ emissions. They are also adopting an LED-only policy for roadway lighting. In addition, they have addressed waste by recycling 95% of all materials removed from infrastructure projects. Mr. Hutton also recognizes the environmental side benefits for some cost-saving efforts such as “rapid bridge replacement.” In that example, a bridge is replaced in a weekend rather than over three months, which reduces congestion and the associated idling time, thereby avoiding considerable GHG emissions.

Mr. Hutton sees LCA as potentially useful for benchmarking pavement environmental performance to help set GHG targets going forward. In his view, the largest obstacle to better integration of LCA into MTO’s decision making is internal resources; because they don’t have in-house capacity to conduct LCA, they will most likely build it into the procurement process such that it is undertaken by project proponents. He appreciates the value of LCA but foresees it being applied only to major construction or reconstruction projects and suggests that capturing the full value for MTO will require developing internal LCA capacity. He has confidence in the current state-of-the-art for LCA methodology, data and tools.

Alberta Ministry of Transportation
Alberta Transportation does apply lifecycle cost analysis on its projects, and they do have the ability to account for reduced emissions at the broader project level (e.g. less congestion).
However, they do not formally apply environmental LCA to the level of component materials on a project basis. They have started to consider emissions when evaluating their materials requirements and design and construction standards.

It appears that if they were to explicitly address sustainability impacts, it would have to be in the context of life cycle costing – that is, the benefits and impacts would need an associated cost. “To fully account for emissions-related aspects at the component material level in a life cycle cost analysis, we would require some confidence in what the relative emissions would be over the lifecycle, and we would need to ascribe a value to those emissions that would ensure a fair and complete overall analysis of options,” says Des Williamson, Executive Director, Technical Services Branch, Alberta Transportation.

**Illinois Tollway Authority (ITA)**
The Illinois Tollway Authority is an early adopter of LCA and has recently integrated it into their planning and procurement decision-making. In 2011, the ITA launched “Move Illinois,” a 15-year $14 billion capital spending program with a tenet to deliver the “cleanest and greenest” program in the Tollway’s history. In order to meet that goal and adequately communicate progress, ITA was in search of quantitative tools (they had been using FHWA’s INVEST sustainable highways self-evaluation tool, which provides qualitative indicators). ITA engaged the University of Illinois to investigate LCA as a methodology for use in delivering the program. After an initial exploratory project to test the applicability of LCA, they asked the university to develop an LCA model to complement the Tollway’s LCCA methods and tool.

The resulting Tollway LCA tool addresses five infrastructure components: pavement, structures (including bridges), drainage, landscape and lighting. Each infrastructure type includes up to five phases: materials, construction, maintenance/rehabilitation, use (captured in pavement, drainage and lighting component models only) and end-of-life. All LCI data is built to reflect “pay items”; i.e., materials and services as purchased by the Tollway. Hence, they can measure impacts at different stages of a project (initial design estimate, contract bids and final invoice or as-built). The Tollway focuses on three environmental indicators: global warming potential, energy use, and a single point score which reflects a weighted outcome of numerous indicators based on an EPA methodology. These impacts are given a 10% weighting within their decision support analysis; life cycle cost is weighted 80% and constructability is the remaining 10%.

The Tollway is currently using the tool to back-test its past practices with its current practices and has so far documented considerable improvement overtime. Paul Kovacs of the ITA indicates that they have found a strong correlation between cost and environmental impact. Greening a project typically results in lower costs, and they have calculated that over the past ten years, greening their infrastructure has saved Illinois over $200 million. Going forward, Mr. Kovacs says the Tollway is committed to using LCA to help identify pavement design alternatives, inform material specifications and evaluate construction methods. They are equally committed to demonstrating “continuous improvement,” and Mr. Kovacs believes LCA is the tool to do this.
California Department of Transportation (Caltrans)
Caltrans, in partnership with UCPRC, has conducted a number of LCAs in the past and will ramp up its engagement with LCA given the recent signing of California State Bill No. 262 (“Buy Clean California Act”). This bill requires EPDs in the procurement of certain materials for state projects beginning in July 2019. A very limited number of products are currently affected, however this list is likely to grow.

Jacquelyn Wong at Caltrans has been reviewing and creating a library of EPDs as a possible source of information to support a LCA tool. Their primary focus has been on aggregates, asphalt, concrete, rebar and structural steel; the latter two are currently included in Bill 262. Starting this summer, she expects Caltrans to begin requesting EPDs from their suppliers. She also expects that their pavements and structures groups will be the first groups to utilize LCA.

Caltrans has included network-level GHG LCA equations in its pavement management system to identify network hotspots and aid in prioritizing maintenance. They have also engaged UCPRC to develop a LCCA/LCA model for their specific use going forward. Deepak Maskey of Caltrans indicates that the tool, likely available in the next 18 to 24 months, will include use-phase effects such as rolling resistance and traffic delay, but there is some reservation about whether these effects should be used within their decision-making framework. In fact, they are currently working on a method to transparently disclose how decisions will be made with respect to LCA outcomes; i.e., how much weight is given to cost vs. environmental measures. They use a design/bid/build procurement process and are moving to a 40-year design life for their pavements; this means there are many suppliers, contractors and Caltrans personnel involved in the life cycle of a pavement, all of whom need to be on the same page with respect to the knowledge of LCA – a considerable education hurdle.

4.3. North American Materials Sector
The industries that supply paving materials are a major stakeholder in the conversation about LCA and roadway or bridge construction. We capture some of their perspective in this section.

Cement Association of Canada (CAC)
CAC has long been an advocate of life cycle thinking. For example, CAC has been an Athena Institute member since its inception and has funded many research projects. They have spent considerable time and resources on documenting the life cycle advantages of rigid concrete pavements from both a life cost and environmental perspective. In 2016, the CAC published EPDs for both general use (GU) and Portland limestone cement (GUL) cements7 to support greater transparency on behalf of its members as well as to facilitate the development of Canadian concrete EPDs8. The Institute’s free LCA tools include these cement and concrete product profiles. The CAC is currently supporting the continued development of the Institute’s

7 The CAC EPDs are available here https://www.csaregistries.ca/epd/epd_label_e.cfm?No=747
8 Ready mix EPD is here: http://info.nsf.org/Certified/Sustain/ProdCert/EPD10092.pdf and precast EPDs are here: https://www.astm.org/CERTIFICATION/DOCS/351.EPD_for_Structural_Precast_Concrete_Industry_Wide_EP.pdf
Pavement LCA tool, with the addition of roller-compacted concrete as well as incorporating a LCCA module in the tool.

Sherry Sullivan of the CAC sees knowledge and awareness of LCA within and by ministries of transportation as a significant issue which needs to be overcome (see Ontario MTO discussion). As a supporter of LCA and tools, she wishes to see more uptake of LCA as a practice as well as a procurement philosophy. She also sees LCA methodology, data and its robustness as less of an issue, but more case studies documenting how LCA informed designs or decisions would also be most useful.

**Asphalt Institute/ National Asphalt Producers Association**

The Asphalt Institute is a trade association of petroleum asphalt producers, manufacturers and affiliated businesses. The Institute is currently undertaking a LCI and LCA of various asphalt binders produced by its members to support the National Asphalt Producers Association (NAPA) on-line EPD Program for mixtures, called the Emerald Eco-Label9. These binder data are expected to be added to the tool this spring, with an industry-average EPD created shortly thereafter that NAPA members can compare themselves to.

Mark Buncher at the Asphalt Institute believes that the application of LCA, while useful, may be moving too fast as decision-support tool. He is concerned about the quality, consistency and comparability of data both within and across industries and that “unintended consequences” may arise unless LCA is applied in a complete and consistent way.

**American Concrete Paving Association (ACPA)**

The ACPA has been a proponent of life cycle thinking and especially life cycle cost analysis. Typically, concrete pavements are initially more expensive than their asphalt counterparts, but this generally balances out or reverses over the life cycle. Leif Wathne of ACPA suggests LCA is the most meaningful way to make decisions regarding environmental impacts but believes comparing EPDs across various product categories is not meaningful due to different assumptions underlying different PCRs. In his dealings with state departments of transportation, he finds few have a sustainability point person or a mandate beyond recycling or using recycled materials. To his knowledge, most transportation agencies base their pavement decisions on initial cost and constructability. He believes more needs to be done to educate pavement designers about how LCA can inform their decisions and, in tandem with LCCA, reduce both costs and environmental impact.

**National Ready Mixed Concrete Association (NRMCA)**

Like NAPA, the National Ready Mixed Concrete Association acts as an EPD Program Operator on behalf of its members. Unlike NAPA, however, NRMCA doesn’t make an EPD tool available to its members. Instead, 3rd-party consultants prepare LCA background reports, EPDs and EPD tools for NRMCA members, all of which are externally reviewed and verified. Numerous NRMCA

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members are now using these pre-verified tools to produce EPDs “on demand” for project-specific customer needs. NRMCA became an EPD Program Operator to help its members benefit from an EPD incentive in LEED\textsuperscript{10}. To date, over 2,800 concrete mix designs have been verified via the NRMCA EPD program (although this activity has been oriented towards buildings rather than pavement or bridges).

Like other cement and concrete associations, NRMCA is a proponent of life cycle thinking. They have held sustainability conferences and workshops on LCA and have funded inclusion of their industry-average data in the Athena Institute building and pavement LCA tools. Brian Killingsworth of NRMCA believes there is still much work ahead before LCA is widely included in decision-support frameworks. He cites the industry’s LCCA efforts as a case in point: “We have been advocating for the use of LCCA as an informative method for making decisions for 30 years and to this day LCCA as applied is often still an issue”. He views LCCA and LCA as too easy to manipulate, and hence argues for more education, guidance and transparency surrounding both practices. He draws a parallel between “user costs” in LCCA and “use-phase” modeling in LCA, suggesting that since both can have a significant effect but also represent the high variability in results, considerable uncertainty remains as to the value of and confidence in LCCA and LCA.

4.4. European Research and Policy

Europe offers precedents and lessons regarding LCA in policy and the development of technical resources to support such policy, as reported in Zizzo et. al.\textsuperscript{(29)}. In this section, we provide details from the most notable examples.

Sweden

As described by Toller and Larsson\textsuperscript{(32)}, Sweden is actively applying a life cycle perspective to sustainability goals for its infrastructure, in compliance with Federal government mandate. The Swedish Transport Administration (STA), with a policy objective to limit life cycle energy use and climate impact, has given considerable attention to methodology and tools necessary to achieve its objective. As a result, STA developed a free web-based LCA software tool called “Klimatkalkyl” (“climate calculation”). The tool was first released in 2013 and is currently in version 4 (released in 2016).

Klimatkalkyl is applicable to road and railway infrastructure. It has a limited system boundary scope (construction, operation and maintenance) and focuses only on primary energy use (MJ) and greenhouse gas emissions (kgCO\textsubscript{2}e). Operation includes activities such as lighting, tunnel ventilation, and water pumping) but not vehicle traffic (there is another model that estimates energy use and greenhouse gas emissions associated with vehicles). The software uses cost or “pay items” in conjunction with energy and emission factors to estimate material and process energy use and climate effects. Since 2015, STA has been regularly using Klimatkalkyl as a decision-support tool during the planning phase for large projects.

\textsuperscript{10} LEED is a highly influential green building rating program administered by the US Green Building Council. Its current iteration, LEED v4, has a credit that encourages project teams to select products with EPDs. The intention of the credit is to motivate industry to perform LCA in the hope that this will eventually lead to environmental improvements in products.
In February 2016, STA put in place a requirement that all proposed projects greater than SEK 50 million ($7.9 million CDN) and that will be completed in 2020 or later must complete a Klimatkalkyl assessment during the planning process as well as during the procurement phase of the project. The requirement includes performance targets and incentives.

To date, the model has been applied to hundreds of projects. This has enabled STA to establish benchmark values for proposed new projects. The model has also been useful in assessing the climate change impact of Sweden’s transportation plan. The policy is motivating the development of EPDs, and it is hoped that the performance targets will motivate environmental improvements in materials. STA is studying reaction to the policy, monitoring the effects, and working on improvements to the model.

Netherlands
Zizzo et. al. (29) identify the Netherlands as a world-leader in bringing LCA into construction policy, and in establishing technical resources to support policy. The Netherlands has a national EPD database, a national standardized method for whole-building LCA, and three whole-building LCA tools that conform with the method and use the EPD database. New residential and office buildings over 100 square meters in area must report LCA results before receiving a building permit. Performance targets have been proposed but are not yet in place.

Regarding infrastructure, the Netherlands is addressing sustainability through procurement policy via Rijkswaterstaat (RWS), which is the Department of Public Works within the Dutch Ministry of Infrastructure and the Environment11. When reviewing tenders for infrastructure projects, RWS puts a price on environmental impacts and thereby creates an incentive to reduce those impacts.

To support the policy, RWS developed an LCA software tool called “DuboCalc”, which draws on the national EPD database and is consistent with the national LCA methodology. The tool calculates cradle-to-grave results for 11 environmental indicators and returns an “environmental cost indicator” which is included in tenders. DuboCalc appears to have initially been offered for free, but now seems to be managed and further developed by two private sector companies, who launched a web version and charge a licensing fee to use the tool.

RWS created a second instrument to support its green procurement policy. The “CO2 Ladder” is a certification system for companies that rewards energy efficiency and GHG reduction efforts within their own operations and their supply chains. Certification translates to a discount on tenders. Organizations can earn a certification rating from one to five; the higher the rating, the more advantage the organization has in tenders.

11 Our source for this section is a 2013 English-language briefing note found here: http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue36_Case_Study78_Rijkswaterstaat.pdf
Norway
Norway does not have a policy requirement to evaluate new or rehabilitation road or bridge projects using LCA but is nonetheless highly active in this area. The Norwegian Public Roads Administration (NPRA) is currently doing so through its “KraKK” project, a two-year effort that started in 2016.12

Five operating units within NPRA use LCA as a tool for systemizing the carbon reduction in detailed road planning. The KraKK project findings suggest that the materials and construction phase should receive the majority of the attention, as this typically accounts for two-thirds of the total carbon footprint. They find that this truncated scope reduces the assessment complexity and the results are easier to communicate to a non-LCA audience. In addition, they are generally finding a close correlation between the cost and the carbon footprint of projects.

Much of the early KraKK project results relied on product data from EPD-Norge (Norway’s national EPD program). NPRA is now developing “RoadLCA”, a software tool for LCA modeling of materials and construction processes in Norway. When completed, it will be used to help guide early planning and bidding processes as well as during the construction process. During this development phase of the software, it is already being used internally to help guide projects.

Our NPRA contact suggests that the price of CO2 needs to reach 100-200 Euros per ton to influence the costing of projects, which is considerably higher than the current EU carbon market price. In 2018, NPRA intends to set CO2 benchmarks for major materials used in Norwegian infrastructure and to award projects that beat the benchmark.

4.5. Discussion
The state-of-practice review helps us gauge Canada’s readiness for LCA uptake in infrastructure planning. Readiness is partly a function of technical capacity, risk management, perceived value, and policy-maker receptivity. It is our sense that the signals are good for initial steps in Canada.

Awareness of LCA and its practice is growing within the infrastructure community, particularly with respect to pavement. There is significant activity and interest among academia, design professionals, the materials sector, the construction sector, and the owner agencies. Various organizations across the public and private sector have contributed to the literature, hosted conferences, and formed working groups or committees to collectively tackle the gaps that impede LCA uptake and to advocate for LCA.

However, to date in North America, LCA applied to infrastructure has generally been limited to experimental investigations or demonstration projects. If we look to the precedent examples in Europe, slow uptake is not surprising. It takes time to build awareness, develop the necessary

12 We gathered information on this project through personal communication with Karl Sigurd Fredriksen Norwegian Public Roads Administration, January 2018.
technical resources to fully support policy, deliver education to help the target market understand the complexities of LCA, demonstrate value, and advocate for the meaningful inclusion of sustainability objectives in planning, designing, constructing and maintaining infrastructure assets.

The technical support system is important and in need of more work, but good progress has been achieved. LCA practice for infrastructure has evolved beyond the limitations of the early studies (inconsistent system boundaries, omitting some life phases, focusing only on a small set of indicators, and so forth). LCA practice in this application is now much more standardized, and the underlying data is much improved. Robust and accessible data is the result of industry stakeholders responding to a market demand (for example, via procurement specifications) for EPDs. Having said that, however, EPDs are imperfect. While they are valued for delivering transparent LCA information, EPDs are still fairly new in the marketplace and not quite yet standardized enough. This raises questions about quality, consistency and comparability of the data. We expect those concerns to diminish as standards evolve and the practice matures. It is helpful to this cause that there are now product category rules for roadways and bridges. For further discussion on EPDs in this context, please see the appendix.

The use-phase of infrastructure remains a significant technical gap. Academia is working on gaining a better understanding of this phase so that it can be better modeled.

Transportation agencies are responsible for most roadway and bridge assets, and therefore uptake of LCA depends on their receptivity. Agencies need to see value in LCA and may need internal LCA capacity. Some early adopter agencies in the U.S. are now using LCA within their design and pavement management systems and have developed their own LCA tools. Here in Canada, there appears to be limited awareness of LCA within the provincial agencies and, by extension, little or no LCA capacity among internal personnel. However, this may not be a serious hurdle, given that LCCA is well-entrenched; agencies are already applying a life cycle perspective. If LCA can be demonstrated to provide confident results, and if it can be linked with LCCA, then implementation by Canadian transportation agencies may not be much of a burden.

There is now a good body of literature demonstrating the value of LCA in optimizing roadway design, material selection, and maintenance for best life cycle performance and functionality. LCCA and LCA used together have been shown to additionally optimize costs, maintenance, and rehabilitation outcome. Recent studies reveal findings that can help agencies most effectively reduce GHG emissions by focusing on what matters most. For example, newer studies have shown that maintaining smoother pavement on high-volume roadways reduces GHG emissions, while for low-volume roadways it is the material and construction effects that emit the greater portion of the GHGs.

For bridges, there is still little information available – we found minimal LCA references for bridges. But the literature and the Illinois Tollway recent experience indicate that the environmental impact of this type of infrastructure is concentrated in the materials and
construction phases of its life cycle, which suggest a simpler system boundary than for roadways. These means implementing LCA for bridge applications may be relatively easy.

5. Recommendations

In this section we provide our recommendations as to how NRC might best facilitate the use of LCA for decision-support by the stakeholders responsible for infrastructure investments in Canada.

Ultimately, LCA uptake will happen as a result of policy. In Zizzo et. al. (29), based on their observations of precedent policies in Europe, a slow step-by-step approach to policy implementation is advised, with low-risk early stages. We therefore recommend the following near-term actions which would serve to 1) enable a greater rate of voluntary LCA usage, and 2) lay the groundwork for future incorporation of LCA in policy:

- Develop guidelines for the practice of LCA for roads and bridges
- Create outreach vehicles for awareness-building, education and network-building
- Initiate development of a national LCI database
- Provide LCA software tools specifically intended for use with roads and bridges
- Develop case studies to demonstrate value and feasibility
- Look for synergy with climate adaptation and resiliency mandates

We propose these actions in response to the gaps and hurdles identified in the literature, as, for example, in Trusty (28) and Harvey et al (11). Until many of the gaps and hurdles are addressed, it will be difficult to secure the confidence in LCA among all stakeholders (industry, policy-makers, design professionals, etc.) that will be required prior to broad uptake in practice and policy. We discuss our recommended actions further below. The FHWA roadmap document (30) is a valuable resource, and we have drawn on it for much of the discussion here.

Methodology and guidelines

LCA is a complicated calculation with many variables and assumptions, that can be conducted with different approaches and that relies on data of varying quality, all of which leads to uncertainty in the results. This in turn raises questions on credibility and comparability of results. The problem is largely addressed by establishing a standard method for LCA practice in this context, with engagement from all stakeholders. This is particularly important for earning acceptance from stakeholders who may push back (for example, material industries that see a threat to market share if LCA shows their products to be less attractive). A robust and fair approach to LCA (combined with a robust database) will be key. LCA issues such as system boundary, impact assessment method and data sources are defined by the standard method and explained to users in guidelines. Consider adopting the FHWA reference and guidance documents for pavement LCA and possibly adapting them to include bridges. A Canadian representative could consider joining the FHWA Sustainable Pavements Technical Working Group and/or organizing such a stakeholder group here in Canada.
Outreach and advocacy
Many stakeholders see a widespread lack of basic LCA awareness and knowledge as a major obstacle to its uptake in roadway decision-making. A number of outreach activities would assist in this and could be implemented immediately. In fact, it would be prudent to initiate awareness-building in Canada as soon as possible – if we look to the history of LCA uptake in the buildings sector, it took years of awareness-building before LCA appeared in green building rating programs, codes and policy. Outreach activities will help create a path to receptivity while the technical components of an LCA initiative are being put in place. Consider developing LCA communication vehicles such as educational literature, webinars and perhaps a conference geared to Canadian roadway stakeholders. A key underlying objective is to position LCA as a value-engineering methodology and not just an add-on.

Data
LCA is data-intensive, and these data are expensive to develop and maintain. Furthermore, these data are not always consistently developed nor aligned across industry sectors or regions. The availability of high-quality and inexpensive life cycle inventory data on roadway and bridge materials and processes is critical to the ease and credibility of LCA in this application. The existence of national databases in Europe appears to be very helpful in supporting LCA uptake and in motivating development of data and EPDs. Creation of a regionalized national Canadian LCI database is recommended. The database should be consistent with international standards to enable cross-border utility, including, of course, with the U.S. (perhaps leading eventually to a unified North American database, depending on what action the U.S. takes to evolve or replace its current LCI database). A Canadian LCI database could be established fairly quickly.

Tools
Ultimately, tools are required to make LCA more accessible to non-LCA practitioners and to operationalize LCA as a decision-support mechanism. A simplified LCA tool intended specifically to support roadway and bridge decisions would have the standard method and data “baked in” – in other words, the tool will serve to standardize LCA practice and deliver reliable, credible, comparable results. The Athena Institute’s “Pavement LCA” tool is already in place as a free, “national” tool – which means, the most cost-effective and low-risk way forward in the area of tools is to extend the capacity and utility of this existing tool. The Athena Institute could ensure that Pavement LCA aligns with evolving standards and methodologies (for example, perhaps the use-phase is optionally excluded until there is consensus on modeling). For bridges, perhaps the pavement tool is extended. We have heard consistent messages that LCA should be integrated with LCCA; note that we just added an LCCA component to the Pavement LCA tool. Consider linking LCA and LCCA within infrastructure design tools currently in use by transportation agencies, perhaps via a “pay item” approach, thus minimizing user input requirements and improving the utility of the decision-support framework.

Case studies
As support to outreach and advocacy tasks, we recommend the development of case studies that demonstrate how LCA is applied to decision-making, and, most importantly, how LCA
delivers value. It may be particularly effective to publish a few studies where LCA and LCCA are used together during the design stage of a project to determine the most cost-effective approaches to reducing environmental impacts. In fact, these projects are often a “win-win” – the result is low-cost and low-impact infrastructure. Case studies will require collaboration with a partner (the asset owner). We suggest approaching the Ontario Ministry of Transportation. MTO has a mandate to pursue LCA but has limited resources to do so itself. This could be an excellent opportunity to collaborate for multiple objectives, including pilot testing guidelines and tools, developing benchmarks, demonstrating value and “success stories”, and gathering lessons to help other provinces if they wish to duplicate.

Synergy with adaptation and resiliency
Climate change implications for pavements are a topic of increasing interest to research (see FHWA 2015 (31) for a summary). It may be helpful to LCA advocacy if it can be linked with adaptation and resiliency. The Trusty paper (28) discusses in detail potential synergies – for example, that LCA can help find the most environmentally effective design choice in resiliency/adaptation design – but he was unable to identify any specific supporting research in the literature. Perhaps fundraising for the development of LCA resources for infrastructure would be easier if a benefit towards resiliency were identified.

References


32. Toller, S. and M. Larsson. 2107. Implementation of life-cycle thinking in planning and procurement at the Swedish Transport Administration. In proceedings Pavement Life-Cycle Assessment, Champaign, IL.

Appendix 1: Pavement LCCA adoption in Canada and the U.S.

The Table below provides a recent snapshot of LCCA practice in various transportation agencies plus two pavement associations.

Source: Stantec Consulting Group 2017 A review and Recommendations for Canadian LCCA Guidelines. Proceeding of the Transportation Association of Canada conference, St. John’s, NL.

<table>
<thead>
<tr>
<th>Location</th>
<th>LCCA Input Parameters</th>
<th>Economic Evaluation Method</th>
<th>Residual Value</th>
<th>User Costs</th>
<th>LCCA Computational Approach</th>
<th>LCCA Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alberta</td>
<td>User-defined (Up to 80 years)</td>
<td>Real discount rate: 4 %</td>
<td>NPW, IRR, B/C Ratio, Break Even Point, PW Costs, PW Benefits</td>
<td>Considered</td>
<td>All three user cost components considered</td>
<td>Deterministic Sensitivity Analysis (optional)</td>
</tr>
<tr>
<td>British Columbia</td>
<td>25 years</td>
<td>Real discount rate: 6%</td>
<td>NPW BC Ratio</td>
<td>Considered</td>
<td>All three user cost components considered</td>
<td>Deterministic (with Sensitivity Analysis)</td>
</tr>
<tr>
<td>Manitoba</td>
<td>50 years</td>
<td>Real discount rate: 3%</td>
<td>NPW</td>
<td>Considered</td>
<td>Not considered</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Nova Scotia</td>
<td>40 years</td>
<td>Real discount rate: 4 %</td>
<td>NPW</td>
<td>Not considered</td>
<td>Not considered</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Ontario</td>
<td>50 years</td>
<td>Nominal social discount rate: 4.5% (0 to 30 yrs., 4% (31 to 75 yrs.)</td>
<td>NPW</td>
<td>Considered</td>
<td>Not considered</td>
<td>Deterministic Probabilistic</td>
</tr>
<tr>
<td>Quebec</td>
<td>50 years</td>
<td>Real discount rate: 5%</td>
<td>NPW</td>
<td>Considered</td>
<td>Only user delay costs considered</td>
<td>Probabilistic</td>
</tr>
<tr>
<td>Saskatchewan</td>
<td>60 years</td>
<td>Real discount rate: 4%</td>
<td>NPW EACF</td>
<td>Not considered</td>
<td>Not considered</td>
<td>Deterministic</td>
</tr>
<tr>
<td>FHWA</td>
<td>Minimum of 35 years</td>
<td>Real discount rate based on OMB</td>
<td>NPW (preferred), EUAC (also accepted)</td>
<td>Considered</td>
<td>Work zone user costs (VOC and delay) plus crash costs considered</td>
<td>Probabilistic</td>
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<tr>
<td>ACPA</td>
<td>45-50+ years</td>
<td>Real discount rate based on OMB</td>
<td>NPW EUAC</td>
<td>Considered</td>
<td>All three user cost components considered</td>
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<td>APA</td>
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<td>NPW</td>
<td>Considered</td>
<td>Only user delay costs considered</td>
<td>Deterministic Probabilistic</td>
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</table>
Appendix 2: Limitations in using EPDs for LCA

The publication of environmental product declarations (EPDs) is a relatively new trend in North America that has been escalating rapidly. This is likely motivated by a general interest in “transparency” in the sustainability community, and by market incentives like a credit in LEED for projects that accumulate enough EPDs.

An EPD is a summary of the LCA results for a product, intended for public release. Underpinning this typically short document is an extensive LCA study and a typically lengthy full LCA report with all of the technical details and the LCI data not included in an EPD. Full LCA reports are less frequently made available to the public.

Market demand and policy, particularly in Europe, have resulted in over 5,000 EPDs currently available globally13, most of which are easily accessible from on-line sources. As a consequence, EPDs are seen as a convenient source for LCA data – they are sometimes used as a short-cut route to LCA for a complex assembled product like a whole building. This is problematic for a number of reasons.

The limitations of EPDs as a data source for LCA modeling stems from the fact that EPDs are static documents: they represent a fixed snapshot for the product at a particular time, for a particular functional unit, electricity grid, location and LCA method. Each EPD is based on a specific methodology and scope as defined in its respective product category rules (PCR).

For example, both concrete and asphalt have their own PCRs, which differ in declared unit, scope and methods. This means concrete and asphalt EPDs cannot be compared to each other. Both PCRs are similarly limited to the production of each material type and therefore are truncated LCAs offering an incomplete LCA. In addition, the National Asphalt Pavement Association’s PCR explicitly excludes the feedstock value of bitumen in its reporting of “primary energy use”, which contradicts ISO 14040/44 LCA standards, and thus the indicators reported in any two EPDs may not have the same scope. Furthermore, the concrete PCR uses a higher heating value (HHV) basis for reporting energy use while the asphalt PCR uses lower heating value. Currently, NAPA’s PCR generally complies with EN 15804, while the carbon leadership forum’s ‘s PCR for concrete is currently being revised to comply with ISO 21930. Going forward, the methods and indicator reporting under each PCR will diverge further making comparability more difficult. Until PCRs are harmonized, the value of EPDs will be limited to intra-industry analysis – i.e., procurement within a specific product type or category.

Material EPDs, by their nature, offer a simple summary of a truncated LCA. They do not report life cycle inventory flow data and therefore are not adjustable to take into consideration regional differences, differing data quality and sources, or varying product compositions. To conduct a full LCA of a complete roadway or bridge – design, build and maintain – using EPDs for the materials will introduce multiple sources of potential error. Because the EPDs are each built

13 This statistic is from the blog of Jane Anderson, a UK-based LCA expert who tracks EPDs: https://constructionlca.wordpress.com/
on different upstream data sources using inconsistent LCA methodologies, which is then all combined with varying, additional downstream data sources, the results will be highly uncertain and possibly in error, potentially leading to unintended consequences. A full cradle-to-grave LCA model requires a consistent overarching methodology with an equally consistent background, foreground and downstream scenario database for it to provide meaningful results.