

Natural Resources Research Institute

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NRRI TECHNICAL REPORT

PRELIMINARY LIFE-CYCLE ASSESSMENT OF HENNEPIN COUNTY BRIDGE 27C53

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EXECUTIVE SUMMARY

The University of Minnesota Duluth Natural Resources Research Institute (NRRI) completed a preliminary, screening cradle-to-gate life-cycle assessment (LCA) of Hennepin County, MN bridge 27C53, which was constructed on County Road 202 in the Elm Creek Park Reserve. The LCA utilized data from the bill of materials (BOM) and construction drawings, which were provided by Dr. Brian Brashaw of the USDA Forest Service, Forest Products Laboratory (FPL).

The system boundary included material and fuel consumption for timber and structural steel materials fabrication; material and fuel consumption for fabrication of steel hardware, bituminous overlay, and related components; and transport of materials to the construction site. Because this preliminary screening LCA study was cradle-to-gate, use phase activities and disposal/recycling of the timber bridge were excluded. The majority of the life-cycle inventory data was secondary data from the DATASMART life-cycle inventory (LCI) database. This study also used the cut-off approach method for recycling and utilized the LTS 2019 method to translate the LCI data into environmental impacts; this method combines the ReCiPe Endpoint (H) v1.03 method with three endpoint categories (Human Health, Ecosystems, Resources) and the Cumulative Energy Demand, Climate Change, and Water Use impact categories.

It was found that the bituminous (asphalt) overlay generally accounted for the largest impact in most impact categories, ranging from 9% to 46%, while the nail-laminated deck panels contributed 18% to 24% of the impacts in five of the six impact categories. The steel hardware, structural steel, and copper naphthenate (CuNap)-treated solid timber components contributed an average of 25%, 8%, and 5% of the impacts in each impact category, respectively.

INTRODUCTION

The University of Minnesota Duluth Natural Resources Research Institute (NRRI) completed a preliminary, screening cradle-to-gate life-cycle assessment (LCA) of Hennepin County, MN bridge 27C53, which was constructed on County Road 202 in the Elm Creek Park Reserve. The LCA utilized data from the bill of materials (BOM) and construction drawings, which were provided by Dr. Brian Brashaw of the USDA Forest Service, Forest Products Laboratory (FPL).

The system boundary included material and fuel consumption for timber and steel structural materials fabrication; material and fuel consumption for fabrication of steel hardware, bituminous overlay, and related components; and transport of materials to the construction site. Because this preliminary screening LCA study was cradle-to-gate, use phase activities and disposal/recycling of the timber bridge were excluded. The majority of the life-cycle inventory (LCI) data was secondary data from the DATASmart LCI database (LTS 2019a). This study also used the cut-off approach method for recycling and utilized the LTS 2019 method (LTS 2019b) to translate the LCI data into environmental impacts, which combines the ReCiPe Endpoint (H) v1.03 method's (Huijbregts et al. 2017) three endpoint categories (Human Health, Ecosystems, Resources) with the Cumulative Energy Demand, Climate Change, and Water Use impact categories.

A screening LCA is helpful to identify where in the product life cycle the majority of environmental impacts occur, as well as which environmental areas are most impacted. This helps in the definition of the goal and scope of future work, if desirable. The screening LCA may also serve as a guide for a full LCA and allow for the refinement of the goal and scope moving forward, while forming the basis of the model for a full LCA. Since a screening-level LCA may use simplified assumptions, the results are only as accurate as those assumptions.

This study was modeled using *SimaPro v9.0* LCA software (Pré 2016) and follows International Organization for Standardization (ISO) 14044 guidelines (ISO 2006a) for internal screening LCAs; however, this LCA is not ISO-approved and is not suitable for external statements or documentation. Screening-level LCAs are used for gathering and analyzing internal information and allow for assumptions and the use of proxy data and do not usually include the exhaustive sensitivity, consistency, or uncertainty analyses required to comply with ISO 14044 guidelines for public disclosure.

GOAL AND SCOPE DEFINITION

The first phase of an LCA defines the goal and scope of the study. According to ISO 14044, the goal of the study should clearly specify the intended application, reasons for carrying out the study, the intended audience, and whether the results are intended to be disclosed to the public. The scope of the study describes the most important aspects of the study, including the functional unit, system boundaries, cut-off criterion, allocation, impact assessment method, assumptions, and limitations.

Objective

The objective of this study was to determine the potential environmental impacts of Hennepin County, MN bridge 27C53. The results could be used to inform the Minnesota Department of Transportation (MnDOT) and their stakeholders of the environmental profile of the bridge.

Function

The function of the bridge is to support automobile, pedestrian, and bicycle traffic over Elm Creek in the Elm Creek Park Reserve.

Functional Unit

A functional unit identifies the primary function(s) of a system based on which alternative systems are considered functionally equivalent (ISO 2006b). This facilitates the determination of reference flows for each system, which in turn facilitates the comparison of two or more systems. Based on the identified function, the following functional unit was used to determine the reference flows: one steel and timber bridge with a width of 40 ft and a length of 68 ft.

System Boundaries

System boundaries are established in LCA in order to include the significant life-cycle stages and unit processes, as well as the associated environmental flows in the analysis. This lays the groundwork for a meaningful assessment where all important life-cycle stages, and the flows associated with each alternative, are considered. Included in the system boundary of this study are:

- Material and fuel consumption for timber and steel materials fabrication;
- Material and fuel consumption for fabrication of steel hardware and related components;
- Material and fuel consumption for bituminous overlay; and
- Transport of materials to the construction site.

Excluded Processes

Because this preliminary screening LCA study is cradle-to-gate, use-phase activities and disposal/recycling of the bridge components are excluded. Materials packaging is also excluded from the study. Typically in an LCA, some aspects within the set boundaries are excluded due to statistical insignificance or irrelevancy to the goal and scope. Thus, the following impacts were also excluded from the scope and boundaries for this study:

- Human activities (e.g., employee travel to and from work); and
- Services (e.g., the use of purchased marketing, consultancy services and business travel).

Cut-off Criteria

Cut-off criteria are often used in LCA practice for the selection of processes or flows to be included in the system boundary. The processes or flows below these cut-offs or thresholds are excluded from the study. Several criteria are used in LCA practice to decide which inputs are to

be considered, including mass, energy and environmental relevance. In the current study, every effort was made to include all the flows associated with the processes studied. During the interpretation phase, we used 1% of environmental load as a cut-off.

Allocation and Recycling

While conducting an LCA, if the life cycles of more than one product are connected, allocation of the process inputs should be avoided by using the system boundary expansion approach. If allocation cannot be avoided, an allocation method – based on physical causality (mass or energy content, for example) or any other relationship, such as economic value – should be used (ISO 2006a). All allocations were completed based on mass.

This study used the cut-off approach method for recycling. According to this approach, the first life of a material bears the environmental burdens of its production (e.g., raw material extraction and processing) and the second life bears the burdens of refurbishment (e.g., collection and refining of scrap). The burdens from waste treatment are taken by the life after which they occur (Frischknecht 2010). Given that DATASMART LCI data (LTS 2019a) uses the cut-off approach for recycling, it is considered a reasonable default.

Impact Assessment Method

Impact assessment methods are used to convert LCI data (environmental emissions and raw material extractions) into a set of environmental impacts. ISO 14044 (ISO 2006a) does not dictate which impact assessment method to use for a comparative assertion; however, the chosen method needs to be an internationally-accepted method if the results are intended to be used to support a comparative assertion disclosed to the public.

The impact assessment method used for this study was the LTS 2019 method (LTS 2019b), which combines the ReCiPe Endpoint (H) *v1.03* method's (Huijbregts et al. 2017) three endpoint categories (Human Health, Ecosystems, Resources) with the Cumulative Energy Demand (CED) *v1.11* (Frischknecht et al. 2007), Climate Change IPCC 2013 GWP 100a *v1.03* (IPCC 2013), and Water Use (Huijbregts et al. 2017) impact categories. These six categories have been found to be of interest and readily understandable to readers of LCA reports. The LTS 2019 impact assessment method (LTS 2019b) is summarized in Table 1.

Impact Category	Method	Unit
Human Health	ReCiPe 2016 Endpoint (H) <i>v1.03</i>	DALY
Ecosystems	ReCiPe 2016 Endpoint (H) <i>v1.03</i>	species*yr
Resources	ReCiPe 2016 Endpoint (H) <i>v1.03</i>	\$
Cumulative Energy Demand	CED <i>v1.11</i>	MJ
Climate Change	IPCC 2013 GWP 100a <i>v1.03</i>	kg CO ₂ eq.
Water Use	ReCiPe 2016 Endpoint (H) <i>v1.03</i>	m ³

Table 1. LTS 2019 impact assessment method (LTS 2019b).

ReCiPe is one of the most recent and updated impact assessment methods available to LCA practitioners. The method addresses a number of environmental concerns at the midpoint level and then aggregates the midpoints into a set of three endpoint categories. Endpoint characterization models the impact on Areas of Protection (i.e., on human health, ecosystems, and resources). In other words, endpoint is a measure of the damage – at the end of the cause-effect chain – caused by a stressor in terms of human life-years lost and the years lived disabled, species disappeared, and resources lost.

The Cumulative Energy Demand (CED) of a product is the direct and indirect energy use throughout the life cycle, including the energy consumed during the extraction, manufacturing, and disposal. The CED method considers both renewable and non-renewable energy and the direct and indirect energy consumption.

The IPCC 2013 method for assessing the Global Warming Potential (i.e., Climate Change) was developed by Intergovernmental Panel on Climate Change (IPCC). It is one of the most widely used methods to estimate climate change potential of global warming gases in LCA studies. The global warming factors have been developed for 20-, 100-, and 500-year time horizons to address the global warming potential of emissions in the short as well as long term. This study uses the climate change factors for the 100-year time horizon.

Endpoint Categories

- **Human Health.** In this category, the damage analysis links the six midpoint categories (Climate Change, Human Toxicity, Photochemical Oxidant Formation, Particulate Matter Formation, Ionizing Radiation, and Ozone Depletion) to the Disability Adjusted Life Years (DALYs). The DALY tool is primarily a disability weighting scale of 0 – 1, where 0 represents perfect health and 1 represents death.
- **Ecosystems.** The damage to ecosystems is measured by calculating the species that disappear in a given time period and area. The unit of damage assessment is species lost in one year (species*yr). The midpoint impact potentials that apply to ecosystem quality are: Climate Change, Terrestrial Acidification, Freshwater Eutrophication, Ecotoxicity, Agricultural Land Occupation, Urban Land Occupation, and Natural Land Transformation.
- **Resources.** The two midpoint categories contributing to the resources category are Fossil Depletion and Metal Depletion. The quantification of the damage is based on the marginal increase of cost due to the extraction of resources, measured as dollars per kilogram (\$/kg).

Midpoint Categories

- **Cumulative Energy Demand.** This category includes non-renewable (fossil and nuclear) and renewable (biomass, water, solar, wind, and geothermal) energy sources. Characterization factors are based on the upper (or higher) heating value. Characterization factors are expressed as equivalent megajoules (MJ).

- **Climate Change.** There are several gaseous emissions that cause global warming, including carbon dioxide, methane, nitrous oxides, and fluorinated gases. This category combines the effect of the periods of time that the various greenhouse gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. The global warming potential is measured as kg equivalents of radiation CO₂ (i.e., the relative global warming potential of a gas as compared to CO₂). The IPCC model with a 100-year time horizon is used for characterization. The uptake of CO₂ from the air (i.e., sequestration of CO₂ by plants) and the subsequent emission of biogenic CO₂ (from the burning of biomass) is not included.
- **Water Use.** Water use is based on water consumption, which is the use of water in such a way that the water is evaporated, incorporated into products, transferred to other watersheds, or disposed into the sea (Falkenmark et al. 2004). Water that has been consumed, therefore, is no longer available in the watershed of origin for humans nor for ecosystems.

Limitations of the Study

This is a cradle-to-gate screening LCA using mainly secondary data. To make external claims per ISO 14044 (ISO 2006a), this study would need to be expanded to include:

- Cradle-to-grave system boundary (to include distribution transport, use, and end-of-life phases);
- Primary data for key processes;
- Additional sensitivity analyses;
- Data quality requirements and indicators; and
- Critical review.

Limitations of LCA Methodology

LCA's ability to consider the entire life cycle of a product makes it an attractive tool for the assessment of potential environmental impacts. Nevertheless, like other environmental management analysis tools, LCA has several limitations.

With current availability of data, it is nearly impossible to follow the entire supply chain associated with the product life in a company- or manufacturer-specific way. Instead, almost all processes within the supply chains are modeled using average industry data with varying amounts of specificity (e.g., data on a more-or-less specific technology or region). This makes it difficult to accurately determine how well the unit process data actually represents the actual factors in the products' life cycle. It also makes it difficult to know in which region the processes are found.

Furthermore, LCA is based on a linear extrapolation of emissions with the assumption that all the emissions contribute to an environmental effect. This is contrary to threshold-driven environmental and toxicological mechanisms. Thus, while the linear extrapolation is a

reasonable approach for more global and regional impact categories such as Global Warming Potential (GWP) and Acidification, it may not accurately represent the actual on-the-ground human- and ecotoxicity-related impacts.

Additionally, even if the study has been critically reviewed, it should be noted that, as for any LCA, the impact assessment results generated for this study are relative expressions and do not predict impacts on category midpoints, exceeding thresholds, or risks. It should also be noted that, even though LCA covers a wide range of environmental impact categories, some types of environmental impacts (e.g., noise, social, and economic impacts) are typically not included in LCA.

LIFE-CYCLE INVENTORY

The second phase of an LCA is to collect life-cycle inventory (LCI) data. LCI data contains the details of the resources flowing into a process and the emissions flowing from a process to air, soil, and water.

LCI Data Collection

As previously noted, secondary inventory data was used in this study for most processes, with most it readily available in the DATASMART LCI database (LTS 2019a).

Treated solid timber production

The spreader beams, spreader beam splices, rail posts, post blocks, transition blocks, curbs, scuppers, and edge strips were all manufactured from copper naphthenate (CuNap)-treated solid timber. These materials were assumed to be manufactured from kiln-dried softwood. Selected life-cycle inventory data for the CuNap-treated solid timber are listed in Table 2.

Description	LCI Data Source	Quantity	Unit
Water	Water, unspecified natural origin, US	1.3×10^0	gal
LPG	Liquefied petroleum gas, combusted in industrial boiler NREL/US U	7.9×10^{-1}	gal
Diesel	Diesel, combusted in industrial equipment NREL/US U	1.9×10^1	gal
Gasoline	Gasoline, combusted in equipment NREL/US U	1.6×10^0	gal
Waste wood	Wood waste, unspecified, combusted in industrial boiler NREL/US U	5.5×10^3	lb
Transport	Transport, lorry 3.5-16t, fleet average/US- US-EI U	7.3×10^3	ton- mi
Copper naphthenate	LCA model	6.0×10^2	lb
Solid timber	Sawn Lumber, softwood, planed, kiln dried, at planer mill, INW/m ³ /RNA	1.0×10^3	ft ³
Natural gas	Natural gas, combusted in industrial boiler NREL/US U	2.0×10^3	ft ³
Electricity	Electricity, medium voltage, at grid, 2015/US US-EI U	9.2×10^2	kWh

Table 2. Selected life-cycle inventory data for 1,000 ft³ of CuNap-treated solid timber.

Treated glulam railing production

The glulam railings were manufactured from CuNap-treated glued timber (glulam) designed for outdoor use. The glulam was assumed to be manufactured from softwood at 20% moisture content and bonded with a melamine formaldehyde resin. Selected life-cycle inventory data for the CuNap-treated glulam are listed in Table 3.

Description	LCI Data Source	Quantity	Unit
Water	Water, unspecified natural origin, US	1.3×10^0	gal
LPG	Liquefied petroleum gas, combusted in industrial boiler NREL/US U	7.9×10^{-1}	gal
Diesel	Diesel, combusted in industrial equipment NREL/US U	1.9×10^1	gal
Gasoline	Gasoline, combusted in equipment NREL/US U	1.6×10^0	gal
Waste wood	Wood waste, unspecified, combusted in industrial boiler NREL/US U	5.5×10^3	lb
Transport	Transport, lorry 3.5-16t, fleet average/US- US-EI U	7.3×10^3	ton-mi
Copper naphthenate	LCA model	6.0×10^2	lb
Glulam	Glued laminated timber, outdoor use, at plant/US- US-EI U	1.0×10^3	ft ³
Natural gas	Natural gas, combusted in industrial boiler NREL/US U	2.0×10^3	ft ³
Electricity	Electricity, medium voltage, at grid, 2015/US US-EI U	9.2×10^2	kWh

Table 3. Selected life-cycle inventory data for 1,000 ft³ of CuNap-treated glulam.

CuNap-treatment process

LCI data was not available for CuNap in the DATASMART LCI database, so a new process was created based on previous literature (Bolin and Smith 2011; Tsang et al. 2014). It was assumed that the yield of treated wood was 100%. The life-cycle inventory data for the CuNap preservative are listed in Table 4.

Description	LCI Data Source	Quantity	Unit
Oxygen	Oxygen, in air	63.96	g
Copper	Copper oxide, at plant/US- US-EI U	79.545	g
Methylcyclopentane	Methylcyclopentane, from naphtha, at plant/US- US-EI U	168.324	g

Table 4. Life-cycle inventory data for 293.85 g of copper naphthenate.

Nail-laminated deck panel production

The nail-laminated deck panels (nail-lam) were manufactured from CuNap-treated solid timber, as described in Table 2, and 3/8-in diameter galvanized steel nails. (The length of the nails was either 11 or 15 in, depending on the size of the finished panel.)

Structural steel

The rail splice plates, guardrail transition plates, post plate assemblies, and internal steel plates were assumed to be manufactured from hot-rolled sheet steel with a density of 490 lb/ft³, which was then galvanized.

Waterproof membrane

The waterproof reinforcing membrane for the bridge deck was assumed to be manufactured from butadiene styrene sheeting with a weight of 0.26 lb/ft². Selected life-cycle inventory data for the waterproof membrane are listed in Table 5.

Description	LCI Data Source	Quantity	Unit
Sand	Sand (in ground)	5.3×10^{-1}	kg
Shale	Shale (in ground)	6.8×10^{-1}	kg
Pitch	Proxy_Pitch 100#/CN	1.8×10^0	kg
Pitch	Proxy_Pitch 10#/CN	2.1×10^{-1}	kg
Styrene butadiene styrene	Proxy_SBS/CN	2.5×10^{-1}	kg
Polyester	Proxy_Polyester materials/CN	7.9×10^{-1}	kg
Insulation	Proxy_Glass wool heat insulation/CN	2.6×10^{-1}	kg
Polyethylene	Proxy_PE film/CN	1.1×10^0	g
Transport	Transport, train, average/CN U	1.1×10^{-1}	ton-km
Transport	Transport, lorry, 2-5t, suburb, average/CN S	1.0×10^{-1}	ton-km
Coal	Hard coal supply mix/CN US-EI U	3.9×10^{-1}	kg
Electricity	Electricity mix/CN US-EI U	9.5×10^{-2}	kWh

Table 5. Selected life-cycle inventory data for 1 kg of waterproof membrane.

Bituminous overlay

The bituminous overlay was assumed to be asphalt with a density of 145 lb/ft³. 646 ft³ of asphalt was required to cover the bridge (with a 3-in thickness); however, asphalt for the bridge approaches was excluded from the study. Selected life-cycle inventory data for the bituminous overlay are listed in Table 6.

Description	LCI Data Source	Quantity	Unit
Bitumen	Bitumen, at refinery/US* US-EI U	8.0×10^{-2}	kg
Diesel	Diesel, burned in building machine/GLO US-EI U	2.2×10^{-2}	MJ
Electricity	Electricity, medium voltage, at grid/CH* US-EI U	2.8×10^{-2}	kWh
Heat	Heat, light fuel oil, at industrial furnace 1MW/US* US-EI U	1.5×10^0	MJ
Limestone	Limestone, milled, packed, at plant/US* US-EI U	2.6×10^{-1}	kg
Sand	Sand, at mine/US* US-EI U	6.6×10^{-1}	kg
Transport	Transport, freight, rail/US- US-EI U	1.6×10^{-2}	ton-km
Transport	Transport, lorry 20-28t, fleet average/US* US-EI U	5.4×10^{-2}	ton-km

Table 6. Selected life-cycle inventory data for 1 kg of bituminous overlay (mastic asphalt).

Steel hardware

All bolts, nuts, washers, and connectors were manufactured from galvanized low-alloyed steel.

Electricity Mixes

The electricity usage was modeled using the 2015 average U.S. electricity grid process from the DATASMART LCI database (LTS 2019a). (These values are taken from 2015 U.S. Energy Information Administration (EIA) data.) The electricity grid mix is a mix of domestic production from various sources, and the average grid mix for the electricity datasets used in this study is shown in Table 7.

Electricity source	2015
Hard coal	33.17%
Oil	0.69%
Natural gas	32.70 % (47% shale)
Industrial gas	0.16%
Petroleum coke	0.16%
Nuclear	19.55%
Hydro	6.11%
Cogen	0.103%
Geothermal	0.39%
Solar PV	0.61%
Wind	4.68%
Canadian imports	0.31%
Mexican imports	0.03%

Table 7: Average electricity grid mix for the U.S.

Data Quality

The quality of the data used in this preliminary LCA is considered to be reasonably accurate and representative of the processes modeled. However, Data Quality Requirements and Indicators (DQI) have not been assigned to this study. (This includes evaluation of data reliability, completeness, geographical correlations, further technological correlation, and sample size using the Pedigree Matrix (Weidema and Wesnaes 1996; Frischknecht *et al.* 2004).)

RESULTS OF LIFE-CYCLE IMPACT ASSESSMENT

The following sections summarize the key characterized results of the LCA including contribution analyses.

Bridge Life Cycle

Table 8 presents the life-cycle impacts for the completed 27C53 bridge.

Damage Category	Unit	27C53 Bridge
Human Health	DALY	0.171
Ecosystems	species*yr	2.36×10^{-4}
Resources	\$	5.95×10^3
Cumulative Energy Demand	MJ	8.11×10^5
Climate Change	kg CO ₂ eq.	4.11×10^4
Water Use	m ³	579

Table 8. Life-cycle impacts of the 27C53 bridge using the LTS 2019 method (LTS 2019b).

Contribution Analysis

Contribution analyses identify the environmental hot-spots within the bridge system, which are the processes that contribute disproportionately to the overall life-cycle impacts of the system. The identification of hot-spots provides a deeper understanding of what is driving the environmental performance of the completed bridge, and also allows for the identification of opportunities for process improvement. The contribution analysis for the completed bridge is shown in Figure 1.

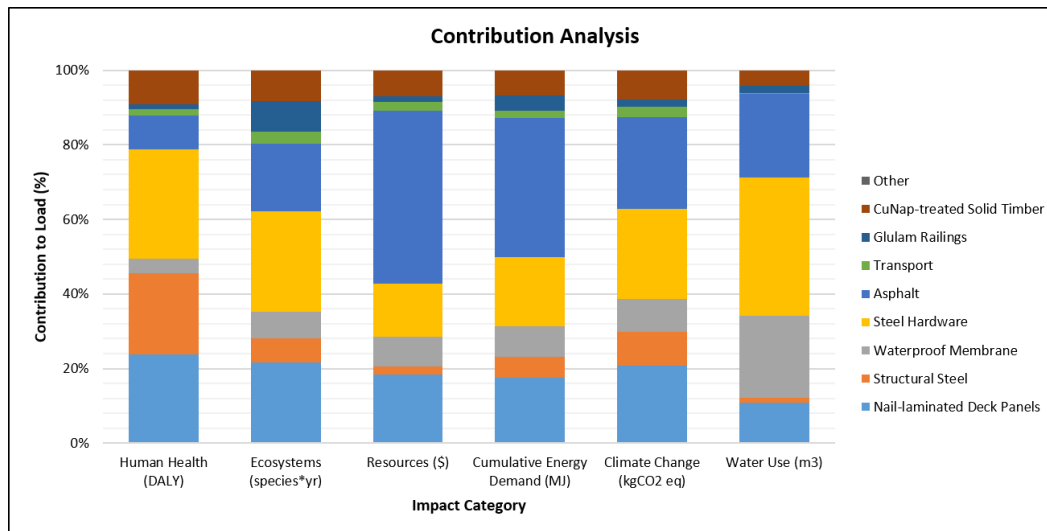


Figure 1. Contribution analysis for the completed 27C53 bridge using the LTS 2019 method (LTS 2019b).

As shown, the bituminous (asphalt) overlay accounted for the largest portion of the impacts in most impact categories, contributing 18%, 46%, 37%, 25%, and 22% of the impacts in the Ecosystems, Resources, Cumulative Energy Demand, Climate Change, and Water Use impact categories, respectively. Production and use of the steel hardware also contributed a large portion of the impacts in each impact category, accounting for 14% to 37% of total impacts. The nail-laminated deck panels accounted for 24%, 22%, 18%, 18%, and 21% of the impacts in the Human Health, Ecosystems, Resources, Cumulative Energy Demand, and Climate Change impact categories, respectively. The structural steel accounted for less than 10% of the total

impact in each impact category, except for Human Health, where it accounted for 22% of impacts. Likewise, the waterproof membrane accounted for less than 10% of the total impact in each impact category, except for Water Use, where it contributed 22% of impacts. The glulam railings, CuNap-treated solid timber components, and transport contributed less than 10% to each impact category.

CONCLUSIONS

The objective of the study was to understand the environmental impacts of the 27C53 bridge on a cradle-to-gate basis. The bituminous (asphalt) overlay generally accounted for the largest impact in most impact categories, ranging from 9% to 46%, while the nail-laminated deck panels contributed 18% to 24% of the impacts in five of the six impact categories. The steel hardware, structural steel, and CuNap-treated solid timber components contributed an average of 25%, 8%, and 5% of the impacts in each impact category, respectively.

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