Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Forest Products Laboratory | Research Paper FPL–RP–718 | October 2023

Life-Cycle Assessment of Prefinished Engineered Wood Flooring in the Eastern United States

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Abstract

This study conducted a cradle-to-grave life-cycle assessment (LCA) of engineered wood flooring manufactured in the eastern United States. System boundaries in this study included the following information modules: raw material extraction (A1), raw material transportation (A2), product manufacturing (and packaging) (A3), product transportation (A4), installation (A5), product use (B1-B7), and end-of-life (C1-C4). Two disposal options were considered for flooring products at the end of useful life: landfilling and burning. The burning option captures heat, which displaces use of natural gas. A functional unit of 1 m^2 of flooring with a weighted average oven-dried mass of 18.9 kg/m^2 of flooring (for 75 years of estimated service life of the building) was used to present the LCA results. Surveys collected primary data along the supply chain including resource procurement, manufacturing, and logistics. The use and disposal stages of the flooring products were modeled with data from literature and industry experts. This LCA study followed the guidelines of the International Organization for Standardization standards and product category rules (Underwriters Laboratories-Environment Part A + Part B: Flooring EPD Requirements). Life-cycle impact assessments (LCIA) were estimated using the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, CML baseline, and cumulative energy demand. Among all segments of the life cycle (cradle-to-grave), the contributions of the use stage and, to a lesser extent, the product manufacturing module dominated the total cradle-to-grave environmental impacts of engineered wood flooring. The cradle-to-grave LCIA results showed that 39.3 kg CO_2eq were released during the life cycle of 1 m^2 of engineered wood flooring. Considering biogenic carbon emissions (i.e., carbon sequestration), the net global warming potential impact was decreased to 16.4 kg CO_2eq because carbon is stored in the landfill (82% of total waste disposed of in landfill). Each square meter of engineered wood flooring consumed 840.2 MJ of energy, and about 25.5% of the total primary energy used came from renewables, specifically on-site woody biomass. This study showed that engineered wood flooring can be considered a carbon-negative material that stores carbon (22.85 kg CO_2eq/m^2 flooring) for decades and thus can help to mitigate climate change.

Keywords: LCA, life-cycle inventory, wood, biogenic carbon, environmental impacts, ISO, PCR, product category rule, flooring

October 2023

Heidari, M.D.; Bergman, R.D.; Salazar, J.; Hubbard, S.S.; Bowe, S.A. 2023. Life-cycle assessment of prefinished engineered wood flooring in the eastern United States. Research Paper FPL-RP-718. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 34 p. https://doi.org/10.2737/FPL-RP-718.

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Executive Summary

Study Goal

The goal of this study was to summarize the environmental performance of engineered wood flooring in the United States using a cradle-to-grave life-cycle assessment (LCA). Further, this LCA report was used to develop the environmental product declaration (EPD) for engineering wood flooring. Engineered wood flooring is available in a wide range of dimensions and wood species. A comparative proclamation was not the goal of this study.

Methodology

This study followed the International Organization for Standardization (ISO) 14040 and 14044 standards and Underwriters Laboratories Environment (ULE) product category rules (PCR) for flooring (Part A (life cycle assessment calculation rules and report requirements) and Part B (flooring EPD requirements)) to develop life-cycle inventory (LCI) and to conduct a life-cycle impact assessment (LCIA). System boundaries in this study were cradle-to-grave. The system boundary included all stages of the product's life including resource extraction, logistics, manufacturing, installation, use, and end-of-life. The LCI was developed considering the unit process modeling approach, where all input and output quantities are assigned to a reference flow. A declared unit of 1 m^2 of flooring with a weighted average oven-dried mass of 18.9 kg/m^2 of flooring (for 75 years of estimated service life of the building) was used to present the LCA results. Primary data for this study (i.e., cradle-to-gate) were collected using a survey instrument administered to flooring manufacturers located in the eastern United States with dedicated production to engineered wood flooring. Secondary data were used from literature and public LCI databases. For the gate-to-grave portion, experts' opinions and secondary data from the literature were used to estimate LCIs. The surveys collected all raw material inputs, outputs (product and coproducts), related direct emissions to water and air, and solid waste generation. After analysis of the survey data by LCA experts, a mass balance was performed for data quality assurance. The mass-allocations approach was used to assign environmental impacts to the product (engineered wood flooring) and coproducts. The LCA modeling software, SimaPro (containing the DATASMART database) was used to construct the LCI and perform LCIA. The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) 2.1, CML-baseline, and cumulative energy demand (CED) methods were used to determine the LCIA results and primary energy consumption, respectively.

Life-Cycle Inventory

The LCI was developed considering the unit operation modeling approach, in which all input and output quantities were assigned to a reference flow. The product life stages within the boundary of the LCA included the following information modules: raw material extraction (A1), raw material transportation (A2), product manufacturing (and packaging) (A3), product transportation (A4), installation (A5), product use (B1-B7), and end-of-life (C1-C4). Two disposal options were considered: landfilling and burning. The burning option captures heat that displaces natural gas (D stage). The LCI flows listed raw materials consumed and emissions to nature such as air, water, and soil.

Life-Cycle Impact Assessment

Following the standards, ISO 21930, and the ULE PCR for North American structural and architectural wood products, we examined all required impact categories and analyzed

relevant LCIA methods to estimate the LCIA results. The main impact categories were global warming (kg CO_2eq), acidification (kg SO_2eq), eutrophication (kg Neq), ozone depletion (kg chlorofluorocarbons-11eq), photochemical smog (kg NOxeq), abiotic depletion potential for fossil resources (MJ), and fossil fuel depletion (MJ surplus). Additional information was provided, such as the use of primary energy resources [energy consumption from nonrenewable sources (fossil and nuclear fuels) and renewable sources (biomass; wind, solar, and geothermal; and hydro)], water use, and indicators describing waste.

Key Findings

Among all stages in the life cycle (cradle-to-grave), the use stage (B1-B7) contributed the most to the total cradle-to-grave environmental impacts of engineered wood flooring. The cradle-to-grave LCIA results (Table 1) showed that 39.3 kg CO_2eq were released during the life cycle of 1 m^2 of engineered wood flooring. Considering biogenic carbon emissions (negative carbon emissions or carbon sequestration), the net global warming impact was decreased to 14.6 kg CO_2eq because of carbon stored in the landfill (82% of total waste) and benefits from flooring waste (12% of total waste), which was burned to produce heat that displaced use of natural gas. Each square meter of engineered wood flooring consumed 840 MJ of energy, and about 25.5% of the total primary energy used came from renewables, especially on-site woody biomass.

Table 1—Cradle-to-grave life-cycle impact assessment for 1 m^2 of engineered wood flooring

Impact indicator	Unit	Total
Core mandatory		
Global warming potential – TRACI 2.1	kg CO_2eq	39.3
Global warming potential – w/ biogenic CO_2	kg CO_2eq	–22.9
Global warming potential – total	kg CO_2eq	16.4
Depletion potential of the stratospheric ozone layer	kg CFC11eq	7.45E–06
Acidification potential of soil and water sources	kg SO_2eq	0.25
Eutrophication potential	kg Neq	0.24
Formation potential of tropospheric ozone	kg O_3eq	3.24
Abiotic depletion potential for fossil resources	MJ, NCV	493
Fossil fuel depletion	MJ surplus	58.8
Energy consumption		
Renewable primary energy used as energy	MJ	215
Renewable primary energy used as material	MJ	31.5
Nonrenewable primary energy used as energy	MJ	626
Nonrenewable primary energy used as material	MJ	0.00

Sensitivity Analysis

A sensitivity analysis was completed per ISO 14040 to model the effects of input parameters. Among all input parameters, the assumption of vacuuming used for floor cleaning had the most significant impact on the results.

Interpretation

The results of this study provided the cradle-to-grave environmental impacts of engineered wood flooring. A significant part of the total impact comes from the use stage of the flooring considering the reference service life of the product (25 years) and the estimated service life of the building (75 years). The landfill option of disposal for the flooring stored a significant amount of carbon for the long term. However, burning of discarded flooring provided benefits by displacing the use of fossil fuels.

Acknowledgments

This project would not have been possible without the support of several organizations and individuals. Sincere thanks are given for their time and contributions to this study. This project was financially supported by a joint venture agreement between the USDA Forest Service, Forest Products Laboratory, and the U.S. Endowment for Forestry & Communities, Inc. (Endowment Green Building Partnership—Phase 1, no. 18-JV-11111137-021). We would also like to thank the Decorative Hardwoods Association and the National Wood Flooring Association for the sponsorship and promotion of this project. And, we greatly appreciate the participating companies and individual mill respondents from the flooring industry for their time and effort in providing the data needed to make this project a success.

Introduction

Climate change, environmental degradation, and resource scarcity are major global challenges in the 21st century (Naser 2012, Cavicchioli and others 2019). The recent COP26 (Conference of the Parties, 26th annual summit) underlined the urgent need to reduce greenhouse gas emissions (Turney and others 2020). The building industry and materials for buildings and construction account for ~40% and ~11% of total greenhouse gas emissions, respectively (UN Environment and International Energy Agency 2017, Gu and others 2021, UNEP 2021). The contribution of greenhouse gas emissions to climate change and climate-change-induced negative environmental impact on our planet have never been more elevated in the public's consciousness. Resources from forests provide renewable construction materials, pulp and paper, energy, bioproducts, and more (Jakes and others 2016, Sahoo and others 2019, Brashaw and Bergman 2021). Because of the carbon stored in harvested wood products (HWPs), the production and end use of HWPs can reduce greenhouse gas inventories (Bergman and others 2014, Johnston and Radeloff 2019, Prestemon and others 2022). It has been illustrated that carbon stored or sequestered in forests as well as in wood products has the greatest potential to mitigate climate change (Malmsheimer and others 2011, Sahoo and others 2019, Haight and others 2020, Brashaw and Bergman 2021). Considering carbon storage and carbon displacement by avoiding fossil-fuel-intensive construction materials, especially in buildings, is one of the most efficient options for mitigating climate change (Sathre and O'Connor 2010, Bergman and others 2014, Oliver and others 2014, Liang and others 2021). Recent years have seen an increase in the growth of environmental certifications and green building programs (Shi and Liu 2019). The latter, green building programs, seeks to reduce the environmental footprint of residential and commercial building construction through the selection of products and processes deemed energy efficient and environmentally benign. Careful attention is needed in evaluating the claims and selection criteria for building materials classified as "green" (Bergman and Taylor 2011, Ibáñez-Forés and others 2016, Durão and others 2020). Because of environmental awareness and regulations, documenting the environmental performance of building products using life-cycle assessment (LCA) is becoming widespread and is the new accepted approach. The LCA approach is one way to conduct fair and scientifically sound evaluations of environmental impacts of products and services (ISO 2006a,b). Quantifying environmental performance of structural wood products is one way to generate green building certifications (Bergman and Taylor 2011, Ritter and others 2011, Bergman and others 2012), provide scientific documentation (e.g., environmental product declarations (EPDs)), and provide information to stakeholders including consumers, regulating agencies, and policymakers. EPDs, based on the underlying LCA data, not only provide verified data on the environmental performance of products and services but can also identify the environmental hot spots for continuous improvements in a consumer-friendly format (ISO 2006b, 2017).

A full cradle-to-grave LCA considers the materials, energy, and wastes characteristic of a given product from the origin of its raw material extraction, through its manufacturing process and service life, to its eventual re-use or disposal (Bergman 2012, ISO 2017). This LCA study estimates environmental impacts by accounting for inputs, such as raw materials and energy, and outputs, such as generated emissions and wastes, from the production of engineered wood flooring. The life-cycle impact assessment (LCIA) results are useful for examining the environmental impacts including the global warming potential (GWP) of this popular wood product and also play a broader role by identifying hot spots and providing benchmarks for process improvements and tracking carbon flows (Bergman and others 2014, Sahoo and others 2019). This study is intended to become part of a larger effort connected to a scientific database managed by the U.S. Department of Agriculture, National Agriculture Library (USDA NAL) (USDA NAL 2023). The U.S. LCI database makes industry specific and general U.S. background data available through an open repository (NREL 2012). These two databases are a library or data warehouse for interested stakeholders to evaluate the comparative impacts of various building products and assemblies (Kahn and others 2022).

The global wood flooring market was valued at US$47.5 billion in 2021 and is expected to reach US$90 billion by 2031 (billion = $\times 10^9$) (Transparency Market Research 2022). Because of superior properties with respect to dimensional stability and durability (Blanchet and others 2003, Bergman and Bowe 2011, Fang and others 2012), engineered wood flooring has gained global popularity and makes up a significant portion of all flooring products. The engineered wood flooring industry in the United States is well established and continues to make innovation. In 2007, wood flooring manufacturers in the United States produced 36.36 million m^2 of engineered wood flooring and a total of 78.03 million m^2 of wood flooring overall (Bergman and Bowe 2011). LCA studies have been conducted for various wood flooring materials including solid wood and engineered wood. Wood flooring has been proposed as a renewable and low or negative carbon footprint material (Petersen and Solberg 2003, Geng and others 2017, Balasbaneh and others 2021). The literature (Jönsson 1999; Hubbard and Bowe 2008; Bergman and Bowe 2010, 2011; Vjestica and others 2014) on the LCA of flooring materials, especially wood flooring, is limited, especially with regard to the gate-to-grave life stages of flooring. Jönsson and others (1997) studied the environmental impacts of various flooring materials such as linoleum, vinyl, and untreated solid wood flooring in Sweden using LCA.

This study used both primary and secondary data to construct the life-cycle inventories (LCIs). The LCIA was estimated considering the functional unit, 1 m^2, of floor covering. Jönsson and others (1997) found that wood flooring had the least emissions to air and water, generated less waste, and used the least amount of energy among the studied floor coverings. A similar study (Nebel and others 2006) was conducted in Germany for four wood floor coverings including solid parquet (8, 10, and 22 mm), multilayer parquet, solid floor boards, and wood blocks. Several manufacturers participated in the study. Nebel and others (2006) highlighted the need to understand that decision tradeoffs made in drying procedures or glue and finishing choices, for example, can dramatically alter the observed results. The storage of carbon inherent in wood flooring coupled with energy production alternatives to fossil fuels realized by residual wood and post-consumer wood streams results in significantly reduced, perhaps even negative, GWP for these products (Nebel and others 2006). Bergman and Bowe (2011) conducted a cradle-to-gate LCIA of wood flooring manufactured in the eastern United States. The study illustrated that engineered wood flooring consumes a greater amount of energy compared with solid wood flooring. However, most of the energy in the manufacturing of wood flooring was from mill residues or wood waste generated in the sawmill. A previous study (Minne and Crittenden 2015) illustrated that the use stage has a significant contribution to the total life-cycle impact of flooring products. The objectives of this study were to perform a cradle-to-grave LCA and to quantify the environmental impacts of engineered wood flooring produced in the eastern United States and used in North America.

Abbreviations

BF	board feet
CFC	chlorofluorocarbons
CED	cumulative energy demand
CFC	chlorofluorocarbons
CLR	cubic lumber recovery
CML	Centrum voor Millikunde Leiden
CORRIM	Consortium for Research on Renewable Industrial Materials
EoL	end-of-life
EPA	U.S. Environmental Protection Agency
EPD	environmental product declaration
ESL	estimated service life
GWP	global warming potential
HAP	hazardous air pollutant
HWP	harvested wood products
ISO	International Organization for Standardization
LCA	life-cycle assessment
LCI	life-cycle inventory
LCIA	life-cycle impact assessment
LHV	lower heating values
LRF	lumber recovery factor
MBF	thousand board feet
MC	moisture content
MMBF	million board feet
MRO	Midwest Reliability Organization
NC	north central
NCV	net calorific value
NE	northeast
NPCC	Northeast Power Coordinating Council
NREL	National Renewable Energy Laboratory
NWFA	National Wood Flooring Association
OD	oven-dry
PCR	product category rules
PM10	particulate matter 10 microns or less in diameter
PVA	polyvinyl acetate
RFC	Reliability First Corporation
RNA	region North America
RSL	reference service life
SE	southeast
SERC	SERC Reliability Corporation
tkm	metric tonnes in kilometers
TRACI	tool for the reduction and assessment of chemical and other environmental impacts
UF	urea-formaldehyde
ULE	Underwriters Laboratories Environment
UNFCCC	United Nations Framework Convention on Climate Change
USDA NAL	U.S. Department of Agriculture, National Agriculture Library
UV	ultraviolet
VOC	volatile organic compound
WARM	waste reduction model

Glossary of Terms

Allocation: An approach that divides emissions and resource use among the different products of a process. The partitioning can be made on weight basis, energy content, or economic value.

Cradle-to-gate: Life-cycle assessment model that includes the upstream part of the product life cycle, i.e., all steps from raw material extraction to product at a factory gate.

Cradle-to-grave: Life-cycle assessment model that includes the upstream part of the product life cycle, i.e., all steps from raw material extraction through production, use, end-of-life treatment, recycling, and final disposal.

Declared unit: Quantity of a wood building product for use as a reference unit (e.g., mass or volume) in reporting aspects of environmental information needed in information modules.

Functional unit: Expresses the function of the studied product in quantitative terms and serves as the basis for calculations. It is the reference flow to which other flows in the LCA are related. It also serves as a unit of comparison in comparative studies.

Hog fuel: A combination of wood residues, including bark from multiple processing centers.

Kiln schedule: A set of parameters including temperature, humidity, and total drying time that have been developed for commercial hardwoods and that kiln operators use to determine how a charge of wood will be dried.

Life-cycle assessment (LCA): Method for the environmental assessment of products covering their life cycle from raw material extraction to waste treatment.

Life-cycle inventory (LCI): LCA study that goes as far as an inventory analysis but does not include impact assessment.

Life-cycle impact assessment (LCIA): Phase of an LCA study during which the environmental impacts of the product are assessed and evaluated.

Lumber recovery factor: The volume of lumber produced measured in the standard measurement of board feet to cubic feet of logs processed.

Overrun: The amount by which actual lumber recovery exceeds a log scale estimate.

Product category rules (PCR): Set of specific rules, requirements, and guidelines for the development of type III environmental declarations for one or more product categories (ISO 14025, ISO 21930).

System boundary: A set of criteria that specifies which unit processes are part of a product system (adapted from ISO 14044).

Description of Product

Engineered wood flooring is referenced by length, thickness, width, profile, finish, grade, species, or a combination of these. Table 2 lists common dimensions used in engineered wood flooring. All thicknesses listed for engineered wood flooring are readily available in both strip and plank flooring (Forbes 2023). Wood flooring has three classifications: strip, plank, and parquet. Plank flooring dominates overall production. Face width of plank flooring is between 3 and 5 in. (76.2 and 127 mm). Face width of strip flooring is less than 3 in. (76.2 mm). Both strip and plank share traditional thicknesses of 3/4 in. (19.0 mm).

Table 2—Common hardwood flooring dimensions

Flooring classification	Face widths (in. (mm))	Thickness (in. (mm))
Strip engineered wood	2.25 (57.2)	3/8 (9.52), 1/2 (12.7), 5/8 (15.87), 3/4 (19.0)
Plank engineered wood	3.0 (76.2), 6.0 (152.4)	3/8 (9.52), 1/2 (12.7), 5/8 (15.87), 3/4 (19.0)

Consumer preferences and technological innovation in milling equipment have made thicknesses ranging from 3/8 to 3/4 in. (9.52 to 19.0 mm) available (Hosterman 2000). Engineered wood flooring consists of several layers of veneer (solid wood) bonded together with an adhesive under heat, pressure, or both. Although layers or plies with two, three, five, seven, or nine sheets are available, three and five are the most common. Prefinishing of this wood flooring product protects the surface and includes the following operations: sanding, priming, staining, filling, curing, sealing, and topcoating. Sanding the wood prepares the surface for the rest of the finishing steps. Prefinished engineered wood flooring is one of many commercially available flooring products.

Methods

Goal

The goal of this study was to quantify the cradle-to-grave life-cycle impacts of engineered wood flooring. The life-cycle impacts include mandatory indicators as defined by the PCR (ULE 2018a,b) including environmental indicators and energy use. Further, this LCA report will be used to develop the industry average EPD for engineered wood flooring.

Scope and System Boundaries

The scope of this study covered the life-cycle stages of engineered wood flooring production in the eastern United States. The scope (Fig. 1) included raw material extraction (A1), raw material transportation (A2), and product manufacturing (and packaging) (A3), product transportation (A4), installation (A5), product use (B1-B7), end-of-life (EoL) (C1-C4), and potential benefits beyond system boundaries (D). All inputs (material, fuel, and energy), outputs (product and coproducts), and direct emissions to air, water, and land were included in the development of the LCI and LCIA. Indirect emissions from the consumption of materials were included in secondary data sets available with the LCA software (PRé Consultants 2021). The resources used in the production of flooring such as engineered wood (e.g., hardwood veneer) were considered to be produced in the eastern region of the United States. It was assumed that the engineered wood flooring was also produced in the eastern United States but was installed and used in any state in the United States. The gate-to-gate system boundary for the flooring mill is denoted by the innermost dotted lines in Figure 1. Combustion of fuels and associated electricity generation required to produce the final product are included.

The cradle-to-grave system boundary included cradle-to-gate and gate-to-grave. Gate-to-grave consists of product transportation, installation, use, and disposal at EoL (outer

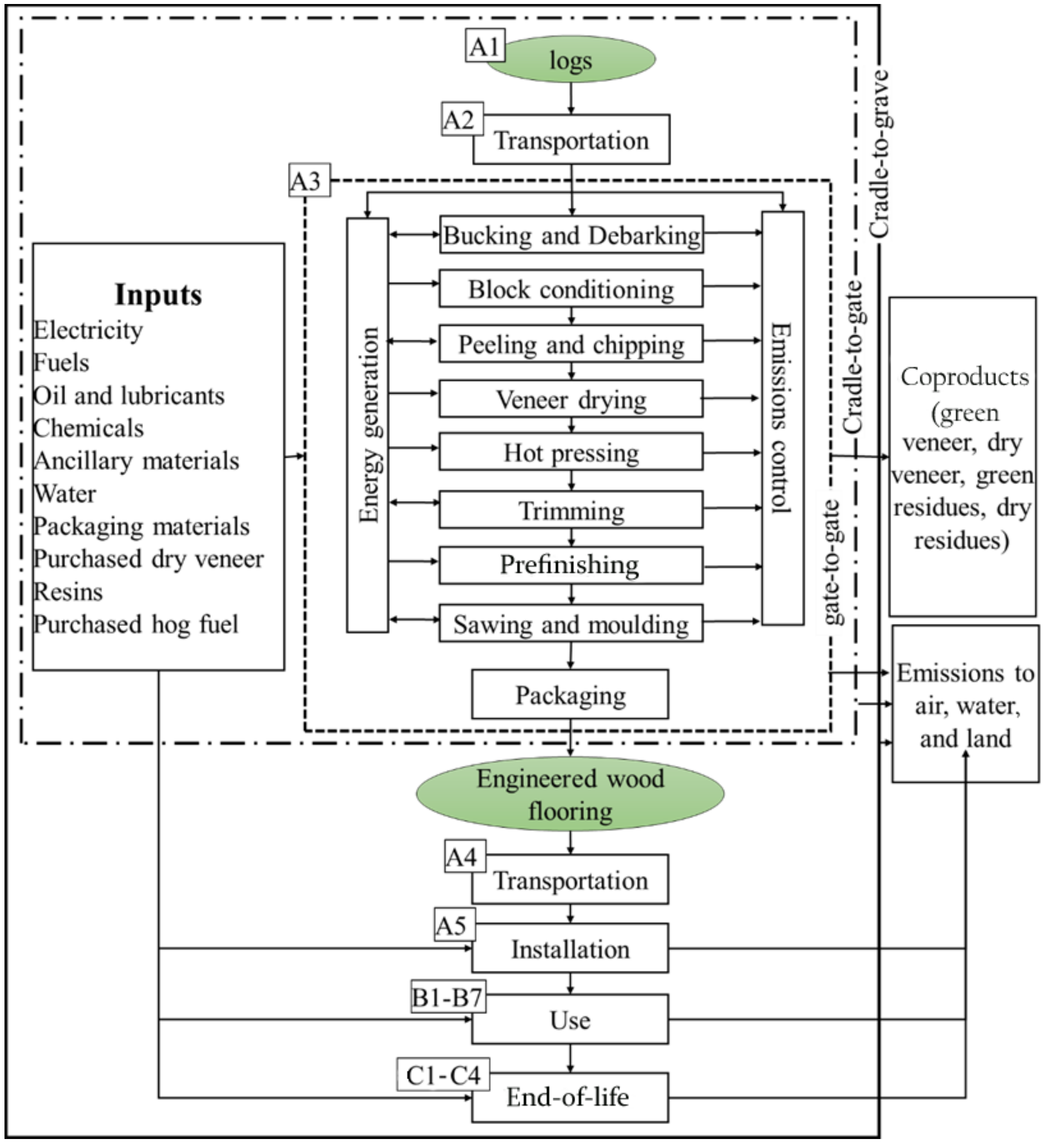

Figure 1—System boundaries for engineered wood flooring production in the eastern United States.

solid line in Fig. 1 includes both cradle-to-gate and gate-to-grave). The expanded gate-to-gate boundary is shown in Figure 2. This study examined the cumulative effects of producing strip and plank engineered wood flooring (by including the impacts associated with producing the engineered wood as well as the transportation required to deliver the veneer from the veneer mill to the flooring mill) and its downstream supply chain including installation, use, and disposal at EoL.

Allocation Procedure

A production system can produce more than one product, and this is common in manufacturing systems. Therefore, an LCA study needs to select an allocation method for assigning environmental impacts on each product. Mass, energy, and economic allocation approaches are generally used for allocating various impacts to each output from a manufacturing system. The flooring PCR (ULE 2018a,b) requires using a mass allocation approach. All inputs and direct emissions were allocated to various outputs (i.e., main product and its coproducts) based on their respective mass.

Functional Unit

The functional unit quantified functions and performance characteristics of the product (ISO 14040 and ISO 21930 (ISO 2006a, 2017)). The main purpose of the functional unit is to provide a reference to which all inputs and outputs are related and quantify the service delivered by the product system (ULE 2018a,b). A functional unit of 1 m^2 of flooring with a weighted average oven-dried (OD) mass of 18.9 kg/m^2 of flooring (for 75 years of estimated service life (ESL) of the building) was used to present the LCA results.

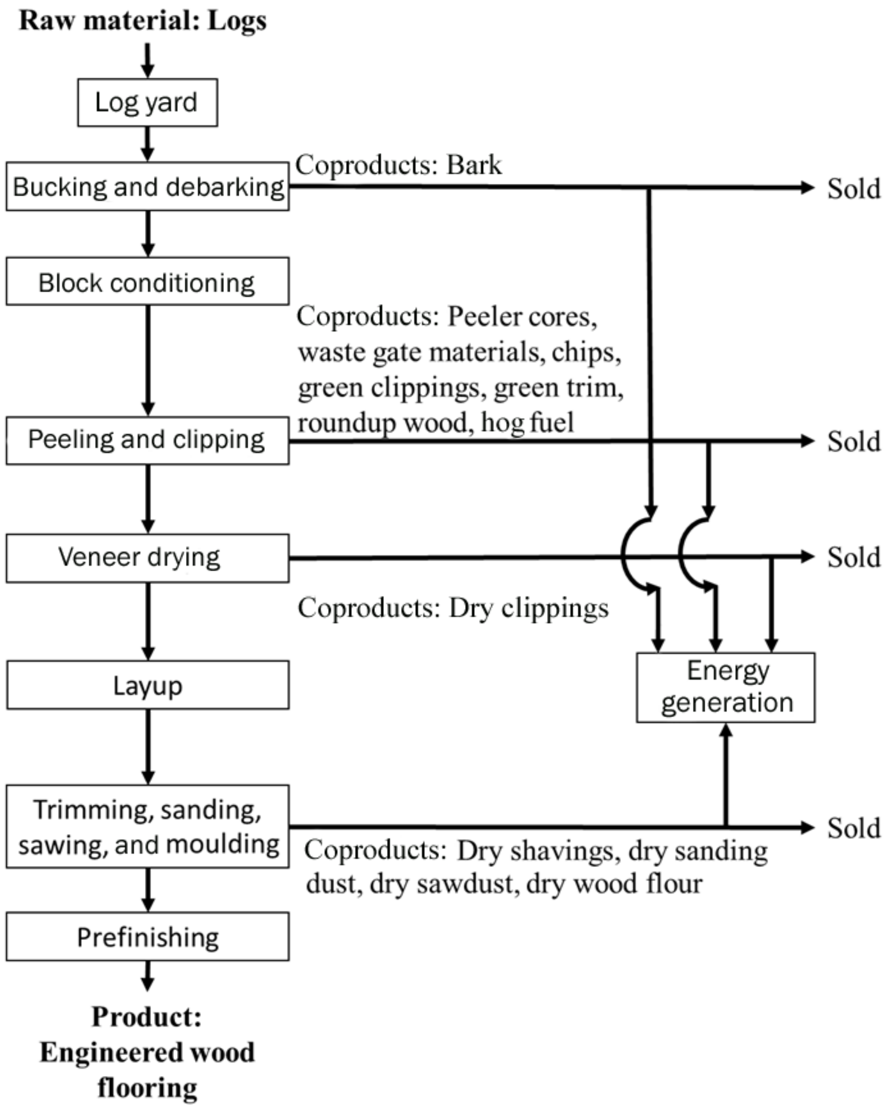

Figure 2—Expanded gate-to-gate system boundary of engineered wood flooring manufacture.

The reference service life (RSL) of engineered wood flooring varied based on multiple factors including wood species, use conditions, and environment (Coelho and others 2021, Bergman 2021). The RSL varied between 10 and more than 40 years from different manufacturers in the United States. Based on the literature, this study considered 25 years as the RSL for engineered wood flooring (Coelho and others 2021). The ESL of a building was 75 years, and the engineered wood flooring was used as a building product. Based on ESL and RSL, the flooring products were calculated to be replaced two times during the full life of the building. One square meter of engineered wood flooring weighs about 6.3 OD kg dry, assuming a thickness of 3/4 in. (19.0 mm).

Intended Audience

The primary audience for this LCA report includes engineered wood flooring manufacturers, National Wood Flooring Association (NWFA), building developers and owners, architects, and other LCA practitioners.

Comparative Assertions

According to ISO 14044 (ISO 2006b), ULE Part A, and flooring PCR (ULE 2018a,b), the LCA boundary needs to include the use and EoL stages if future comparative studies are intended to be disclosed to the public. Because this report included the use (B1-B7) and EoL (C1-C4) stages of products, this study can be used in the future for a comparative analysis of engineered wood flooring with alternative products if the LCA studies of the alternative products also considered all stages of product life in the LCA and are aligned with the functional unit.

Cut-Off Rules

According to ISO 21930, if the mass–energy of a flow is less than 1% of the cumulative mass–energy of the model flow, it may be excluded, provided its environmental relevance is minor. This analysis included all energy and mass flows for primary data.

In the primary survey, manufacturers were asked to report total hazardous air pollutants (HAPs) specific to the manufacturing processes of their wood products. Under Title III of the Clean Air Act Amendments of 1990, the U.S. Environmental Protection Agency (EPA) designated HAPs that wood product facilities are required to report as surrogates for all HAPs. These are methanol, acetaldehyde, formaldehyde, propionaldehyde (propanol), acrolein, and phenol. All HAPS are included in the LCI; no cut-off rules apply. Also, there were no cut-offs used in the impact assessment.

Description of Processes and Life-Cycle Inventories

Module A1: Raw Material Extraction

Module A1 includes the cradle-to-gate production of logs that are used in engineered wood flooring. The upstream resource extraction includes forest resource management and log harvesting. A1 also includes reforestation processes that include nursery operations (which include fertilizer, irrigation, energy for greenhouses if applicable, etc.), site preparation, as well as planting, fertilization, thinning, and other management operations. A number of commercial hardwood species are used for engineered wood flooring in the eastern region (such as red oak, white oak, hard maples).

Module A2: Raw Material Transportation

Module A2 includes average or specific transportation of raw materials (including secondary materials and fuels) from extraction site or source to manufacturing site (including any recovered materials from source to be recycled in the process). An average one-way haul distance for hardwood log (including bark) transportation of 201 km with 100% empty backhaul was calculated from primary mill data. Mill average log moisture content (MC) was 45.9% wet basis (85% MC dry basis). Transportation data for packaging material were not reported and were not included in the analysis.

Module A3: Product Manufacturing and Packaging

Engineered wood flooring manufacturing is accomplished through a series of unit processes. A unit process is a machining center or a specific operational task that both requires and modifies a material input in some way. A representative approach to flooring production appears in Figure 2 and includes the following sequence of activities: log yard, debarking and bucking, block conditioning, peeling and clipping, veneer drying, layup, trimming, sanding, sawing and moulding, prefinishing, and packaging. Prefinishing refers to the application of any final coating materials including stains or protective emulsions. Not all flooring manufacturers perform this unit process. If this step is not done during the manufacturing, flooring installers must perform this on site.

Coproducts associated with the process (bark, peeler cores, waste gate material, green chips, green clippings, green trim, roundup wood, green hog fuel, dry clippings, dry sawdust, dry shavings, and dry sanding dust) are considered useful and were given careful attention in this assessment. Raw wood inputs of green logs and purchased dry veneer and associated coproducts (trimmings, edging strips, planer shavings, wood flour, and sawdust) were reported in the survey to have an average moisture content of 8%. Table 3 estimated that a representative flooring operation realizes yields of 578 OD kg/m^3, roughly 39% of the original raw wood inputs. Given that the raw inputs included purchased green veneer, the actual conversion efficiency from using green logs only to flooring would be lower.

Log Yard

The log yard unit process begins with logs at the veneer mill and includes the following operations: transporting veneer logs from forest landing to log yard, sorting veneer logs by grades and size, storing logs either wet or dry, depending on season and species, transporting logs in-yard from point of

Table 3—Wood mass balance for 1.0 m^3 of engineered hardwood flooring produced

	Wood mass balance (kg/m^3)			
Material	In	Out	Boiler fuel	Sold
Green logs (white wood only)	1,255	—	—	—
Green logs (bark only)	66.9	—	—	—
Dry veneer (purchased)	177	—	—	—
Green bark	—	66.9	6.0	60.9
Green roundup wood	—	2.8	2.8	0.0
Green peeler cores	—	0.2	0.0	0.2
Green veneer clipping	—	0.6	0.6	0.0
Green trim	—	0.6	0.6	0.0
Green chips	—	532.8	0.1	532.7
Green hog fuel	—	175.3	175.3	0.0
Green waste gate material	—	0.1	0.0	0.1
Dry clipping	—	7.6	4.6	3.1
Dry sawdust	—	106	2.7	103
Dry shavings	—	11.1	0.8	10.3
Dry sanding dust	—	17.8	0.2	17.6
Engineered wood flooring	—	578	—	—
Sum	1,499	1,499	194	728

unloading to log deck storage, and transporting logs in-yard from log deck storage to the veneer mill infeed and debarker and log bucking saw. Inputs include fossil fuel for the log haulers and water and electricity for the sprinklers. No coproducts are generated. Water emissions are released during the log wetting process.

Debarking and Bucking

The debarking and bucking unit process begins with logs at the debarker and includes the following operations: mechanically removing the bark from the logs and cutting long veneer logs to make wood "blocks" for peeling (cut-off saw). Inputs include electricity to operate debarker and saw and diesel fuel for the log haulers. Coproducts generated include green bark and some green wood waste including material lost during end splitting of the log. The green wood residues are either ground into wood fuel burned on site or sold as mulch.

Block Conditioning

Wood blocks are heated in vats with either hot water or direct steam to soften the log to improve the quality of the peeled veneer. Inputs include steam (hot water) and electricity for the vats and fossil fuel for equipment to load and unload vats. No coproducts are produced. Emissions associated with this unit process include air emissions from the boilers providing heat for the vats.

Peeling and Clipping

A rotary lathe slices the hot, softened veneer blocks into thin veneer sheets, and a clipper clips the sheets to proper size. Inputs include electricity to run the lathes, conveyors, clippers, hog fuel grinders, and waste gate equipment and fossil fuel to transport veneer sheets to veneer dryers. Coproducts include green roundup wood, green peeler cores, green wood chips, green waste gate material, and green veneer clippings. Green roundup wood and green veneer clippings are ground into wood fuel that is burned on site. Ground green wood fuel is also listed as hog fuel. Green peeler cores, green chips, and green waste gate material are sold.

Veneer Drying

Jet dryers dry the green veneer sheets down to between 0% and 4% MC dry basis. Inputs include electricity to run fans, steam or hot oil for heating the coils inside the dryers, and fossil fuel for forklifts and transport to and from veneer drying process. The material is clipped after drying. Coproducts include dry clippings. As the wood dries and temperature rises, air emissions occur. This unit process generates air emissions including the largest amount of volatile organic compounds (VOCs) compared with the other unit processes because of the drying wood and hot temperatures. Other emissions associated with this unit process include air emissions from the boilers or direct-fired burners providing heat for the dryers.

Layup

The layup unit process involves gluing thin veneer sheets also called plies together to form panels. The resins include urea-formaldehyde (UF) and polyvinyl acetate (PVA). The plies are stacked on top of each other with the wood grain oriented perpendicularly to each subsequent sheet for dimensional stability. Depending on the resin, pressure and heat applied to the sheets cure the resin and bond the sheets to form veneer panels. For engineered wood flooring, 3- to 5-ply veneer panels are common. Inputs include heat and electricity to apply the resin and run the presses and fossil fuel for forklifts to transport material to the trimming, sawing, and moulding unit process. No coproducts are generated from this unit process. Air emissions are released from the pressing and heating processes as the resin cures. In addition, emissions associated with this unit process include air emissions from the boilers providing heat for the panel presses.

Trimming, Sanding, Sawing, and Moulding

Veneer panels are cut into unfinished wood flooring and trimmed to standard dimensions (4 by 8 ft (1.22 by 2.44 m)). Trimmed panels are sawn into individual boards and sanded. After sanding, boards are moulded into tongue and groove flooring of standard lengths. Inputs include electricity for trim saw, gang rip saw, sanders, hog fuel grinder, and conveyor and fossil fuel to transport material to the prefinishing unit process. Coproducts include dry trim material, dry sanding dust, dry sawdust, and dry shavings.

Prefinishing

Prefinishing of the wood flooring is performed next to protect the surface. This unit process includes the following operations: sanding, priming, staining, filling, curing, sealing, and topcoating. Sanding the wood prepares the surface for the remaining operations. The primer coat promotes adhesion of the other materials and is ultra violet (UV)-cured. Staining material includes a mixture of water-based, solvent-based, and UV-cured types. Rollers typically apply the stain, filler, sealer, and topcoat. Solvents clean the rollers. All the fillers, sealers, and topcoats are UV-cured. Aluminum oxide added to the finish increases surface durability. The prefinished engineered wood is packed into small cardboard boxes for shipment. Inputs include steam for the stain drying ovens; electricity for UV-curing ovens, conveyors, and wood dust collectors; and cardboard for boxing up flooring. Air emissions released include sanding dust, particulate matter 10 microns or less in diameter (PM10), HAPs, and VOCs.

Energy Generation

The auxiliary process of energy generation provides heat for use in other parts of the veneer mill and flooring plant. A fuel such as wood, propane, or natural gas is burned. Green wood residue from peeling and clipping and dried wood residue from sanding, trimming, sawing, and moulding generates most of the thermal energy used at the plant. The thermal energy is typically in the form of steam used for the presses, jet dryers, ovens, and facility heating. In addition, emissions from grid electricity are released off site. Each cubic meter of engineered wood flooring consumes 194 dry kg of mill residues (biomass), 0.27 kg of natural gas, 5.37 L of propane, and 1,114 kWh of electricity. About 11.27 L of diesel, 0.57 L of gasoline, and 6.28 L of propane are used as transportation fuel for on-site logistics.

Emission Controls

The auxiliary process of emission control reduces the amount of air emissions released to the atmosphere. Wood dust collectors collect particulate and PM10 from sanding and finishing operations. Input includes electricity.

Packaging

Packaging provides a final chance to sort and grade the end-product. Once organized, the flooring is stacked and bundled using conventional packaging straps and wraps of plastic or steel. The packaged material is conveyed to a staging area or loaded directly on trucks.

Product yields observed in the survey allowed for examination of how the input wood is realized into products, coproducts, and waste. With incoming bark and purchased dry ignored, a recovery of 46% (578 ÷ 1,255 × 100%) was observed in this study (Table 3). In other words, to produce 1 m^3 of engineered wood flooring, 2.08 m^3 of input logs were needed. The remaining 1.08 m^3 of input logs were classified as wood residue. The wood residue was sold off site or used on site as hogged fuel for heat generation. Values were obtained by dividing the weight of wood in engineered wood flooring by the total weight of input lumber and multiplying by 100%.

Module A4: Product Transportation

The A4 module consists of total transportation distances from (i) the manufacturing facility to the distribution center and (ii) the distribution center to the installation sites. Several studies (Sahoo and others 2021a,b; Khatri and others 2021) provided detailed analysis on how to consider product transportation for redwood lumber, cellulosic fiberboard, and laminated strand lumber. These studies did not collect the transportation distance from the engineered flooring manufacturing facility to the installation sites. Therefore, we assumed a transport distance of 800 km (Table 4) from the engineered flooring manufacturing facility to the installation sites as recommended by the PCR (ULE 2018a). It was also assumed that engineered wood flooring products were transported in diesel-powered trucks only.

Module A5: Installation

The A5 module consists of the flooring installation in a building. Installation of engineered wood flooring is easy and does not require many inputs such as electricity and consumables. The inventory (only nail (Balasbaneh and others 2021)) for installation of 1 m^2 of engineered wood flooring is provided in Table 5.

During installation, about 1.5% and 4.0% of mass loss occurred based on the type of flooring products (Nebel and others 2006). It was assumed that about 1.5% of the mass loss of engineered wood flooring occurred during installation (Nebel and others 2006). Both flooring waste and the waste from the packaging were considered to be disposed of in the landfill. Because we did not collect the data for energy use during the installation of the flooring product, based on the PCR guidelines (ULE 2018a) , we assumed no energy was used during the installation of the engineered wood flooring.

Module B1-B7: Product Use

The use stage of engineered wood flooring includes use (B1), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5), operational energy use (B6), and operational water use (B7). In this study, the use of energy in B6 and B7 were not relevant and were thus excluded. Similarly, refurbishment was not considered because of the absence of actual data collection. However, based on the literature, we considered the energy and material inputs during the B1 to B3 stages (Table 6) (Bergman 2012, Minne and Crittenden 2015, Ros-Dosdá and others 2019).

Vacuuming is not a usual activity for wood flooring. However, if vacuum was used, then it was assumed that engineered wood flooring was vacuumed once a week (a vacuum of power 1.5 kW (Ros-Dosdá and others 2019) and vacuum time of 12 s/m^2 (Minne and Crittenden 2015)). It was also assumed that engineered wood flooring was mopped once a month with water (0.1 L/m^2) and cleaning agents (0.0001 kg/m^2). The RSL of engineered wood flooring was considered to be 25 years with a replacement

Table 4—Transportation of engineered wood flooring from manufacturing plant to the installation site

Description	Value	Unit
Vehicle type	Truck	—
Fuel type	Diesel	—
Transport distance (plant to the building site)	800.0	km
Capacity utilization (including empty runs, mass-based)	100.0	%
Gross density of products transported	718.48	kg/m^3

Table 5—Installation of 1 m^2 engineered wood flooring at the building site

Description	Value	Unit
Nail	0.05	kg/m^2
Product loss	1.5	%
Packaging waste	4.89E–06	kg/m^2

Table 6—Life-cycle inventory for the engineered wood flooring in use stages at the site

Description	Value	Unit
Net freshwater consumption specified by water source and fate	0.030	m^3/m^2-RSL
Ancillary materials specified by type (e.g., cleaning agent)	0.030	kg/m^2-RSL
Electricity (vacuum)	0 or 6.0[a]	kWh/m^2-RSL
Cleaning chemicals	0.030	kg/m^2-RSL
Maintenance coat (new coat of finish)	2.063	kg/m^2-RSL
Wax	0.825	kg/m^2-RSL
Electricity (coating)	0.313	kWh/m^2-RSL
Repair cycle	2.50	Cycles/RSL
Reference service life (RSL)	25.00	Years
Replacement cycle	2.00	Cycles/ESL

[a]No electricity used when no vacuum was considered. 6.0 kWh/RSL when vacuum was considered.

of two times to correspond with the ESL of a building of 75 years. It was assumed repair of engineered wood flooring included waxing, which consumes wax (0.33 kg/m^2) and electricity (0.125 kWh/m^2) to run the equipment for making the surface smooth.

Module C1-C4: End-of-Life

At EoL, engineered wood flooring is demolished (C1), waste is transported to the site of the disposal (C2), waste is processed (C3), and waste is disposed of (C4). The energy and fuel used during the building demolition and removal of engineered wood flooring are extremely low and thus were excluded from this study. It was considered that the demolished building (included flooring) waste was transported in trucks to the disposal site, which was 161 km (ULE 2018a,b) from the installation site (Table 7).

In the United States, the waste wood is either disposed of in a landfill or burned to capture heat (EPA 2020). About 82% and 18% of the total woody materials were landfilled and burned for energy capture, respectively (Table 8).

Module D: Potential Net Benefits

The potential net benefits in stage D are achieved during the disposal of a product. It was assumed that landfilled waste from engineered wood flooring flared the methane generated in the landfill and thus no benefits were achieved except for storing carbon in the landfill. Also, part of the engineered wood flooring waste used for burning and capturing heat was considered to displace natural gas. It was estimated that each kilogram of wood waste burned for energy capture displaced about 0.483 m^3 of natural gas.

Data Collection, Quality, and Assumptions

Primary Data Collection

The survey (Appendixes 1 and 2) sent to flooring manufacturers contained a section devoted to detailed inputs

Table 7—Transportation of engineered wood flooring from installation site to disposal site

Description	Value	Unit
Vehicle type	Truck	—
Fuel type	Diesel	—
Transport distance (plant to the building site)	161.0	km

Table 8—Types of engineered wood flooring disposal and quantity after end-of-life

Description	Value	Unit
Landfill	5.15	kg/m^2-RSL
Fuel	1.14	kg/m^2-RSL

and outputs specific to each unit process. A majority of responding mills indicated that the level of detail in this section was too difficult to assess accurately and that responses were best guess estimates. Most mills were unable to complete this section of the survey and left it blank. To more accurately account for all input and output flows, this inventory was modeled using a system approach.

Between December 2019 and January 2020, primary data were collected from flooring mills considered representative of the industry. Surveyed mills were mid- to large-size manufacturing facilities. Eight self-administered questionnaires were completed. All participating companies were assured confidentiality and were asked to fill out individual questionnaires for each mill.

Secondary Data Collection

Databases with similar technology and geographical regions were used in this study. Primary data were not collected for various resource inputs including wood resource production, transport, adhesive production, and wax production. Sources for secondary data are listed in Table 9.

Data Quality and Assumptions

Data quality was considered very good for this study based on mill representativeness, peer review, and captured production. Additional assumptions and considerations include the following:

- All survey data for this report cover the reporting year 2019.
- Consistent with previous CORRIM studies (Hubbard and Bowe 2008, 2010; Bergman and Bowe 2008, 2011), survey data were weight-averaged across all mills by determining each mill's production relative to the total production captured for all mills in the survey. This is represented by the following equation:

$$\overline{P}_{\text{weighted}} = \frac{\sum_{i=1}^{n} P_i x_i}{\sum_{i=1}^{n} x_i} \tag{1}$$

Table 9—Secondary data sources and data quality assessment

Inputs	LCI data source	Geography	Year	Data quality assessment
		A1: raw material extraction		
Roundwood sawlog	Roundwood sawlog, hardwood, green, at logyard, m³, SE/kg/RNA Roundwood sawlog, hardwood, green, at logyard, m³, US SE-NE-NC	US NE/NC, SE	2016	Technology: very good; processes represent Pacific Northwest average production Time: very good; data are less than 5 years old Geography: very good; data are specific to the Pacific Northwest
Rough green lumber	Sawn lumber, hardwood, rough, green, at sawmill, SE/kg/RNA Sawn lumber, hardwood, green, rough, US SE-NE-NC	US NE/NC, SE	2016	Technology: very good; processes represent Pacific Northwest average production Time: very good; data are less than 5 years old Geography: very good; data are specific to the Pacific Northwest
		A2: raw material transportation, A4: product transportation, C2: waste transportation		
A2 road	USLCI: single unit truck transport, diesel-powered, short haul US avg.	North America	2014	Technology: very good; processes represent U.S average transportation profiles Time: fair; data are within 10 years Geography: good
A4 road	USLCI: transport, combination truck, long-haul, diesel-powered/tkm/RNA	North America	2014	Technology: very good; processes represent U.S average transportation profiles Time: fair; data are within 10 years Geography: good
		A3: product manufacturing (and packaging), C4: disposal		
Electricity	ecoinvent 3.7: Electricity, medium voltage, at grid (MRO, SERC, RFC, NPCC)	US NE/NC, SE	2018	Technology: very good; process represents production of electricity in Oregon Time: fair/good; electricity production data are within 10 years; production breakdown based on 2015 primary data Geography: very good
Biomass combustion	CORRIM database: wood-fired boiler (Puettmann and Milota 2017)	North America	2015	Technology: very good; process represents combustion of biomass in an industrial boiler Time: good; data are within 2 years Geography: good
Natural gas	USLCI: natural gas, combusted in industrial boiler NREL/US (LTS 2021)	North America	2014	Technology: very good; process represents combustion of natural gas in an industrial boiler Time: fair; data are within 10 years Geography: good
Diesel	USLCI: diesel, combusted in industrial boiler NREL/US (LTS 2021)	North America	2014	Technology: very good; process represents combustion of diesel in industrial equipment Time: fair; data are within 10 years Geography: good
Liquefied propane gas	USLCI: liquefied petroleum gas, combusted in industrial boiler NREL/US (LTS 2021)	North America	2014	Technology: very good; process represents combustion of LPG in industrial boiler Time: fair; data are within 10 years Geography: good
Plastic straps	USLCI: polypropylene resin, at plant NREL/RNA (LTS 2021)	North America	2014	Technology: very good; process represents production of polypropylene lumber wrap Time: fair; data are within 10 years Geography: good
Hydraulic fluid, lubricants, motor oil, and greases	USLCI: diesel, at refinery/L NREL/US (LTS 2021)	North America	2014	Technology: very good; data represents the production of petroleum products for the North American market Time: fair; data are within 10 years Geography: good
Waste landfilling	Ecoinvent 3.7: process-specific burden, sanitary landfill {RoW}| processing | Alloc Def, U (Wernet and others 2016)	Global	2018	Technology: very good; process models average global technology Time: good; data are less than 5 years old Geography: very good; data are representative of global processes

where $\overline{P}_{weighted}$ is the weighted average of the values reported by the mills, P_i is the reported mill value, and x_i is the fraction of the mill's value to total production for that specific value.

- Missing or questionable data were addressed by follow-up correspondence with survey respondents. Where missing data could not be resolved, care was taken to omit it from the averaging. In this way, zeros were not mistakenly included in the calculations.
- Density values for wood species reported by flooring manufacturers were obtained from the National Hardwood Lumber Association (NHLA 2019). This source provides a concise tabular breakdown of salient data acknowledged to be taken from the *Wood Handbook: Wood as an Engineering Material* (FPL 2010) and from *Hardwoods of North America* (Alden 1995).
- The energy content of fuels in this report is presented as their lower heating values (LHV). This method is preferred in the United States.

Secondary data for the engineered wood flooring gate-to-gate LCI was processed using SimaPro life-cycle analysis software version 9.1.0.8 (PRé Consultants 2021). SimaPro uses internationally recognized standards for environmental management and standardized life-cycle inventory formats to record and analyze the model data. Additionally, SimaPro provides sensitivity analyses for a given product (PRé Consultants 2021).

Average Environmental Product Declarations for Groups of Similar Products

The results of the LCA study of engineered wood flooring are the basis for developing a sector-specific EPD (ISO 2017, NWFA 2022). The input data and results represent the engineered wood flooring manufacturing plants located in the eastern United States (Fig. 3) and U.S. flooring manufacturers affiliated with NWFA. Surveys were sent to members of NWFA by email and postal mail. Seven mills participated and provided primary data for this LCA study. Based on the survey data, the cumulative production of engineered wood flooring was 2.03 million m^2 in 2019, which represented 13% of the total U.S. engineered wood flooring production (Feldman 2021). However, the contribution is much higher for the study region considering the smaller number of hardwood flooring manufacturers in this region of the United States. A weighted average method (Eq. (1)) was used to process all the input data and develop the LCI for this study. Major inputs such as electricity usage were estimated as weighted average values considering the individual grids and the location of the manufacturing plant belonging to the electricity grid. Thus, the input data used in this study represent geographic coverage, technology, and manufacturing practices for the production of engineered wood flooring.

Life-Cycle Impact Assessment Method

The LCIA is the crucial phase of the LCA study. The LCIA phase establishes links between the LCI results and potential environmental impacts. This study used the TRACI (Bare 2011), CED, and CML methods to determine environmental impacts associated with the production, use, and EoL of 1 m^2 of engineered wood flooring in the eastern region of the United States. Target impact indicators and their reporting categories are given in Table 10.

Results

Cradle-to-Gate Results

Table 11 shows the cradle-to-gate life-cycle impacts of engineered wood flooring (A1-A3). A3 dominates most of the results. The LCIA results from this study do not have predictive power on category endpoints, safety margins, risk, or outcomes if thresholds are exceeded.

Figure 3—Eastern U.S. manufacturing region of engineered wood flooring (in gray).

Table 10—Selected impact indicators and reporting categories

Reporting category per tables E1-E5 in ISO 21930:2017	Indicator name	Abbreviation	Unit
Core mandatory impact indicators	Global warming potential, with biogenic	GWP	kg CO_2eq
Core mandatory impact indicators	Global warming potential, fossil	GWP	kg CO_2eq
Core mandatory impact indicators	Depletion potential of the stratospheric ozone layer	ODP	kg CFC11eq
Core mandatory impact indicators	Acidification potential of soil and water sources	AP	kg SO_2eq
Core mandatory impact indicators	Eutrophication potential	EP	kg PO_4eq
Core mandatory impact indicators	Formation potential of tropospheric ozone	SFP	kg O_3eq
Core mandatory impact indicators	Abiotic depletion potential for fossil resources	ADP fossil	MJ, NCV
Core mandatory impact indicators	Fossil fuel depletion	FFD	MJ surplus
Use of primary resources	Renewable primary energy carrier used as energy	RPRE	MJ, NCV
Use of primary resources	Nonrenewable primary energy carrier used as energy	NRPRE	MJ, NCV
Use of primary resources	Renewable primary energy carrier used as material	NRPRM	MJ, NCV
Secondary material, secondary fuel and recovered energy	Secondary material	SM	kg
Secondary material, secondary fuel and recovered energy	Renewable secondary fuel	RSF	MJ, NCV
Secondary material, secondary fuel and recovered energy	Nonrenewable secondary fuel	NRSF	MJ, NCV
Secondary material, secondary fuel and recovered energy	Recovered energy	RE	MJ, NCV
Mandatory inventory parameters	Consumption of freshwater resources	FW	m^3
Indicators describing waste	Hazardous waste disposed	HWD	kg
Indicators describing waste	Nonhazardous waste disposed	NHWD	kg
Indicators describing waste	High-level radioactive waste, conditioned, to final repository	HLRW	kg or m^3
Indicators describing waste	Intermediate- and low-level radioactive waste, conditioned, to the final repository	ILLRW	kg or m^3
Indicators describing waste	Components for reuse	CRU	kg
Indicators describing waste	Materials for recycling	MR	kg
Indicators describing waste	Materials for energy recovery	MER	kg
Indicators describing waste	Recovered energy exported from the product system	EE	MJ, NCV
Additional inventory parameters	Biogenic carbon removal from product	BCRP	kg CO_2eq
Additional inventory parameters	Biogenic carbon emission from product	BCEP	kg CO_2eq
Additional inventory parameters	Biogenic carbon removal from packaging	BCRK	kg CO_2eq
Additional inventory parameters	Biogenic carbon emission from packaging	BCEK	kg CO_2eq
Additional inventory parameters	Biogenic carbon emission from combustion of waste from renewable sources used in production processes	BCEW	kg CO_2eq
Additional inventory parameters	Carbon emissions from combustion of waste from nonrenewable sources used in production processes	CWNR	kg CO_2eq

Cradle-to-Grave Results

Table 12 presents the results for the cradle-to-grave life-cycle impacts considering the weighted average EoL treatment (82% landfill, 18% incineration). Among all segments of the life cycle (cradle-to-grave), the contributions of the use stage (B) and, to a lesser extent, the production stage (A1-A3) dominated the total cradle-to-grave environmental impacts of engineered wood flooring. The cradle-to-grave LCIA results showed that 39.3 kg CO_2eq were released during the life cycle of 1 m^2 of engineered wood flooring. Considering biogenic carbon emissions (i.e., carbon sequestration), the net GWP impact was decreased to 16.4 kg CO_2eq because carbon is stored in the landfill (82% of total waste disposed of in landfill). Each square meter of engineered wood flooring consumed 840.2 MJ of energy, and about 25.5% of the total primary energy used came from renewables, specifically on-site woody biomass. This study showed that engineered wood flooring can be considered a carbon-negative material that stores carbon (22.85 kg CO_2eq/m^2 flooring) for decades and thus can help to mitigate climate change. Tables 13 and 14 show the individual cradle-to-grave life-cycle impacts resulting from landfilling and incineration at EoL.

Table 11—Cradle-to-gate environmental impacts of 1.0 m^2 of engineered wood flooring

Impact indicator[a]	Unit	A1-A3	A1	A2	A3
Core mandatory					
GWP_{total}	kg CO_2eq	6.849	–30.192	0.666	36.375
GWP_{fossil}	kg CO_2eq	6.849	0.215	0.666	5.968
$GWP_{biogenic}$	kg CO_2eq	0.000	–30.407	0.000	30.407
ODP	kg CFC11eq	1.13E–06	8.84E–12	2.54E–11	1.13E–06
AP	kg SO_2eq	0.040	0.003	0.004	0.033
EP	kg Neq	0.030	0.000	0.000	0.029
SFP	kg O_3eq	0.709	0.093	0.108	0.508
ADP fossil	MJ, NCV	63.869	2.980	8.565	52.323
FFD	MJ surplus	5.907	0.444	1.276	4.187
Use of primary resources					
RPRE	MJ, NCV	53.253	0.000	0.000	53.253
RPRM	MJ, NCV	31.494	31.494	0.000	0.000
NRPRE	MJ, NCV	91.732	2.876	8.604	80.253
NRPRM	MJ, NCV	0.000	0.000	0.000	0.000
Secondary material, secondary fuel, and recovered energy					
SM	kg	0.00	0.00	0.00	0.00
RSF	MJ, NCV	39.208	0.000	0.000	39.208
NRSF	MJ, NCV	0.00	0.00	0.00	0.00
RE	MJ, NCV	0.00	0.00	0.00	0.00
Mandatory inventory parameters					
FW	m^3	0.007	0.005	0.000	0.001
Indicators describing waste					
HWD	kg	0.002	0.000	0.000	0.002
NHWD	kg	0.127	0.006	0.000	0.122
HLRW	m^3	3.06E–09	1.08E–09	2.68E–11	1.95E–09
ILLRW	m^3	1.58E–10	9.74E–12	1.29E–10	1.89E–11
CRU	kg	0.00	0.00	0.00	0.00
MR	kg	0.00	0.00	0.00	0.00
MER	kg	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.00	0.00	0.00	0.00

[a]See Table 10 for definitions of abbreviations.

Contribution Analysis

Tables 15 to 17 present the contribution of each life-cycle stage on the total net cradle-to-grave environmental impacts of engineered wood flooring. Module C4 shows how varying the EoL treatment changes the baseline results and the results from other information modules. The EoL treatments considered were 100% landfill with flaring methane and 100% burn with energy capture, which avoids natural gas consumption (energy recovery).

Biogenic Carbon Balance

Wood is a biobased material and thus contains biogenic carbon. The accounting of biogenic carbon follows the requirements set out in ISO 21930:2017, sections 7.2.7 and 7.2.12. Per ISO 21930, biogenic carbon enters the product system (removal) as primary or secondary material. The carbon removal is considered a negative emission (ISO 2017). The biogenic carbon leaves the system (emission) as product, by-product, or directly to the atmosphere when combusted. These mass flows of biogenic carbon from and to nature are listed in the LCI and expressed in kilograms CO_2.

In the LCIA, the LCI flow of biogenic carbon removal is characterized with a factor of –1 kg CO_2eq/kg CO_2 of biogenic carbon in the calculation of the GWP. Likewise, the LCI flow of biogenic carbon emission is characterized with a factor of +1 kg CO_2eq/kg CO_2 of biogenic carbon in the calculation of the GWP. ISO 21930 requires a demonstration of forest sustainability to characterize carbon removals with a factor of –1 kg CO_2eq/kg CO_2. ISO 21930

Table 12—Environmental impacts of 1.0 m^2 of engineered wood flooring – average end-of-life treatment

Impact indicator[a]	Unit	A-C	A-D	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Core mandatory																		
GWP_{total}	kg CO_2eq	16.44	12.58	–4.87	0.48	0.15	0.00	12.26	3.28	0.68	0.00	0.00	0.00	0.00	0.10	0.00	4.36	–3.86
GWP_{fossil}	kg CO_2eq	39.29	35.43	6.85	0.48	0.15	0.00	12.26	3.28	15.91	0.00	0.00	0.00	0.00	0.10	0.00	0.25	–3.86
$GWP_{biogenic}$	kg CO_2eq	–22.85	–22.85	–11.72	0.00	0.00	0.00	0.00	0.00	–15.24	0.00	0.00	0.00	0.00	0.00	0.00	4.10	0.00
ODP	kg CFC11eq	7.4E–06	7.4E–06	1.1E–06	8.1E–10	9.1E–10	0.0E+00	1.6E–06	2.5E–06	2.3E–06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E–10	0.0E+00	3.2E–09	-8.1E–10
AP	kg SO_2eq	0.25	0.24	0.04	0.00	0.00	0.00	0.09	0.02	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EP	kg Neq	0.24	0.24	0.03	0.00	0.00	0.00	0.03	0.01	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
SFP	kg O_3eq	3.24	3.17	0.71	0.08	0.01	0.00	0.55	0.17	1.71	0.00	0.00	0.00	0.00	0.02	0.00	0.01	–0.07
ADP fossil	MJ, NCV	493.33	439.16	63.87	6.06	1.48	0.00	123.66	148.22	148.31	0.00	0.00	0.00	0.00	1.22	0.00	0.51	–54.17
FFD	MJ surplus	58.77	49.76	5.91	0.91	0.07	0.00	15.51	21.90	14.24	0.00	0.00	0.00	0.00	0.18	0.00	0.04	–9.01
Use of primary resources																		
RPRE	MJ, NCV	214.57	214.56	53.25	0.01	0.02	0.00	3.85	0.99	152.30	0.00	0.00	0.00	0.00	0.00	0.00	4.15	–0.01
RPRM	MJ, NCV	31.49	31.49	31.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRPRE	MJ, NCV	625.71	565.54	91.73	6.52	1.60	0.00	157.48	160.90	205.60	0.00	0.00	0.00	0.00	1.31	0.00	0.57	–60.17
NRPRM	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Secondary material, secondary fuel, and recovered energy																		
SM	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSF	MJ, NCV	117.62	117.62	39.21	0.00	0.00	0.00	0.00	0.00	78.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRSF	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mandatory inventory parameters																		
FW	m^3	0.41	0.41	0.01	0.00	0.00	0.00	0.37	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NHWD	kg	0.38	0.38	0.13	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HLRW	m^3	2.5E–08	2.5E–08	3.1E–09	4.8E–11	1.3E–11	0.0E+00	1.4E–08	2.0E–09	6.3E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.6E–12	0.0E+00	1.4E–11	–2.9E–11
ILLRW	m^3	4.9E–07	4.9E–07	1.6E–10	2.3E–10	6.5E–11	0.0E+00	6.5E–08	4.2E–07	1.2E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.6E–11	0.0E+00	6.7E–11	–1.4E–10
CRU	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MR	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MER	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]See Table 10 for definitions of abbreviations.

Table 13—Environmental impacts of 1.0 m^2 of engineered wood flooring – landfilling at end-of-life treatment

Impact indicator[a]	Unit	A-C	A-D	A1-A3	A4	A5	B1	B2	B3	B4	B5	B7	B8	C1	C2	C3	C4, landfill	D, landfill
Core mandatory																		
GWP_{total}	kg CO_2eq	11.41	11.41	–4.87	0.48	0.15	0.00	12.26	3.28	–2.70	0.00	0.00	0.00	0.00	0.10	0.00	2.71	0.00
GWP_{fossil}	kg CO_2eq	39.33	39.33	6.85	0.48	0.15	0.00	12.26	3.28	15.91	0.00	0.00	0.00	0.00	0.10	0.00	0.29	0.00
$GWP_{biogenic}$	kg CO_2eq	–27.91	–27.91	–11.72	0.00	0.00	0.00	0.00	0.00	–18.61	0.00	0.00	0.00	0.00	0.00	0.00	2.41	0.00
ODP	kg CFC11eq	7.4E–06	7.4E–06	1.1E–06	8.1E–10	9.1E–10	0.0E+00	1.6E–06	2.5E–06	2.3E–06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E–10	0.0E+00	3.9E–09	0.0E+00
AP	kg SO_2eq	0.25	0.25	0.04	0.00	0.00	0.00	0.09	0.02	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EP	kg Neq	0.25	0.25	0.03	0.00	0.00	0.00	0.03	0.01	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
SFP	kg O_3eq	3.23	3.23	0.71	0.08	0.01	0.00	0.55	0.17	1.71	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00
ADP fossil	MJ, NCV	493.18	493.18	63.87	6.06	1.48	0.00	123.66	148.22	148.31	0.00	0.00	0.00	0.00	1.22	0.00	0.37	0.00
FFD	MJ surplus	58.78	58.78	5.91	0.91	0.07	0.00	15.51	21.90	14.24	0.00	0.00	0.00	0.00	0.18	0.00	0.05	0.00
Use of primary resources																		
RPRE	MJ, NCV	210.43	210.43	53.25	0.01	0.02	0.00	3.85	0.99	152.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RPRM	MJ, NCV	31.49	31.49	31.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRPRE	MJ, NCV	625.57	625.57	91.73	6.52	1.60	0.00	157.48	160.90	205.60	0.00	0.00	0.00	0.00	1.31	0.00	0.42	0.00
NRPRM	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Secondary material, secondary fuel, and recovered energy																		
SM	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSF	MJ, NCV	117.62	117.62	39.21	0.00	0.00	0.00	0.00	0.00	78.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRSF	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mandatory inventory parameters																		
FW	m^3	0.41	0.41	0.01	0.00	0.00	0.00	0.37	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NHWD	kg	0.38	0.38	0.13	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HLRW	m^3	2.5E–08	2.5E–08	3.1E–09	4.8E–11	1.3E–11	0.0E+00	1.4E–08	2.0E–09	6.3E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.6E–12	0.0E+00	1.7E–11	0.0E+00
ILLRW	m^3	4.9E–07	4.9E–07	1.6E–10	2.3E–10	6.5E–11	0.0E+00	6.5E–08	4.2E–07	1.2E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.6E–11	0.0E+00	8.1E–11	0.0E+00
CRU	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MR	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MER	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]See Table 10 for definitions of abbreviations.

Table 14—Environmental impacts of 1.0 m² of engineered wood flooring – incineration with energy recovery at end-of-life

Impact indicator[a]	Unit	A-C	A-D	A1-A3	A4	A5	B1	B2	B3	B4	B5	B7	B8	C1	C2	C3	C4, incineration	D, incineration
Core mandatory																		
GWP_{total}	kg CO_2eq	39.12	17.83	–4.87	0.48	0.15	0.00	12.26	3.28	15.91	0.00	0.00	0.00	0.00	0.10	0.00	11.80	–21.28
GWP_{fossil}	kg CO_2eq	39.12	17.83	6.85	0.48	0.15	0.00	12.26	3.28	15.91	0.00	0.00	0.00	0.00	0.10	0.00	0.08	–21.28
$GWP_{biogenic}$	kg CO_2eq	0.00	0.00	–11.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.72	0.00
ODP	kg CFC11eq	7.4E–06	7.4E–06	1.1E–06	8.1E–10	9.1E–10	0.0E+00	1.6E–06	2.5E–06	2.3E–06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E–10	0.0E+00	1.3E–12	–4.5E–09
AP	kg SO_2eq	0.25	0.23	0.04	0.00	0.00	0.00	0.09	0.02	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02
EP	kg Neq	0.21	0.21	0.03	0.00	0.00	0.00	0.03	0.01	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SFP	kg O_3eq	3.27	2.86	0.71	0.08	0.01	0.00	0.55	0.17	1.71	0.00	0.00	0.00	0.00	0.02	0.00	0.04	–0.40
ADP fossil	MJ, NCV	493.97	195.12	63.87	6.06	1.48	0.00	123.66	148.22	148.31	0.00	0.00	0.00	0.00	1.22	0.00	1.16	–298.85
FFD	MJ surplus	58.73	9.02	5.91	0.91	0.07	0.00	15.51	21.90	14.24	0.00	0.00	0.00	0.00	0.18	0.00	0.00	–49.71
Use of primary resources																		
RPRE	MJ, NCV	233.28	233.24	53.25	0.01	0.02	0.00	3.85	0.99	152.30	0.00	0.00	0.00	0.00	0.00	0.00	22.86	–0.04
RPRM	MJ, NCV	31.49	31.49	31.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRPRE	MJ, NCV	626.35	294.41	91.73	6.52	1.60	0.00	157.48	160.90	205.60	0.00	0.00	0.00	0.00	1.31	0.00	1.21	–331.94
NRPRM	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Secondary material, secondary fuel, and recovered energy																		
SM	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSF	MJ, NCV	117.62	117.62	39.21	0.00	0.00	0.00	0.00	0.00	78.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRSF	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mandatory inventory parameters																		
FW	m^3	0.41	0.41	0.01	0.00	0.00	0.00	0.37	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NHWD	kg	0.38	0.38	0.13	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HLRW	m^3	2.5E–08	2.5E–08	3.1E–09	4.8E–11	1.3E–11	0.0E+00	1.4E–08	2.0E–09	6.3E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.6E–12	0.0E+00	0.0E+00	–1.6E–10
ILLRW	m^3	4.9E–07	4.9E–07	1.6E–10	2.3E–10	6.5E–11	0.0E+00	6.5E–08	4.2E–07	1.2E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.6E–11	0.0E+00	0.0E+00	–7.8E–10
CRU	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MR	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MER	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]See Table 10 for definitions of abbreviations.

Table 15—Percentage contribution of various life-cycle stages on the total environmental impacts of 1.0 m^2 of engineered wood flooring – average end-of-life treatment

Impact indicator[a]	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Core mandatory															
GWP_{total}	–39	4	1	0	97	26	5	0	0	0	0	1	0	35	–31
GWP_{fossil}	19	1	0	0	35	9	45	0	0	0	0	0	0	1	–11
$GWP_{biogenic}$	51	0	0	0	0	0	67	0	0	0	0	0	0	–18	0
ODP	15	0	0	0	21	33	30	0	0	0	0	0	0	0	0
AP	16	1	0	0	36	9	37	0	0	0	0	0	0	0	–1
EP	12	0	0	0	14	4	57	0	0	0	0	0	0	13	0
SFP	22	2	0	0	17	5	54	0	0	0	0	0	0	0	–2
ADP fossil	15	1	0	0	28	34	34	0	0	0	0	0	0	0	–12
FFD	12	2	0	0	31	44	29	0	0	0	0	0	0	0	–18
Use of primary resources															
RPRE	25	0	0	0	2	0	71	0	0	0	0	0	0	2	0
RPRM	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRPRE	16	1	0	0	28	28	36	0	0	0	0	0	0	0	–11
NRPRM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary material, secondary fuel, and recovered energy															
SM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RSF	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
NRSF	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mandatory inventory parameters															
FW	2	0	0	0	90	5	4	0	0	0	0	0	0	0	0
Indicators describing waste															
HWD	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
NHWD	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
HLRW	12	0	0	0	55	8	25	0	0	0	0	0	0	0	0
ILLRW	0	0	0	0	13	86	0	0	0	0	0	0	0	0	0
CRU	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MER	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
EE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a]See Table 10 for definitions of abbreviations.

section 7.2.1 note 2 states the following regarding demonstrating forest sustainability: “Other evidences such as national reporting under the United Nations Framework Convention on Climate Change (UNFCCC) can be used to identify forests with stable or increasing forest carbon stocks.” Table 6-1 in the annual reports of Canada and the United States UNFCCC provides annual NET GHG flux estimates for different land use categories. This reporting indicates nondecreasing forest carbon stocks and thus the source forests meet the conditions for characterization of removals with a factor of –1 kg CO_2eq/kg CO_2. Emissions other than CO_2 associated with biomass combustion (e.g., methane or nitrogen oxides) are characterized by their specific radiative forcing factors.

The ULE PCR Part A specifies TRACI as the default LCIA method for GWP. The TRACI method does not account for the removals or emissions of biogenic CO_2. We have thus manually calculated the component of the GWP related to biogenic carbon separately and reported the GWP indicator both with (GWP_{BIO}) and without (GWP_{TRACI}) biogenic carbon. The biogenic CO_2 component is shown in detail in Table 18. The landfill scenario causes a net removal of biogenic carbon from the atmosphere equivalent to 27.9 kg CO_2eq. This is caused by the permanent storage of 92% of

Table 16—Percentage contribution of various life-cycle stages on the total environmental impacts of 1.0 m^2 of engineered wood flooring – landfilling end-of-life treatment

Impact indicator[a]	A1-A3	A4	A5	B1	B2	B3	B4	B5	B7	B8	C1	C2	C3	C4, landfill	D, landfill
Core mandatory															
GWP_{total}	–43	4	1	0	107	29	–24	0	0	0	0	1	0	24	0
GWP_{fossil}	17	1	0	0	31	8	40	0	0	0	0	0	0	1	0
$GWP_{biogenic}$	42	0	0	0	0	0	67	0	0	0	0	0	0	–9	0
ODP	15	0	0	0	21	33	30	0	0	0	0	0	0	0	0
AP	16	1	0	0	36	9	37	0	0	0	0	0	0	0	0
EP	12	0	0	0	14	4	55	0	0	0	0	0	0	15	0
SFP	22	2	0	0	17	5	53	0	0	0	0	0	0	0	0
ADP fossil	13	1	0	0	25	30	30	0	0	0	0	0	0	0	0
FFD	10	2	0	0	26	37	24	0	0	0	0	0	0	0	0
Use of primary resources															
RPRE	25	0	0	0	2	0	72	0	0	0	0	0	0	0	0
RPRM	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRPRE	15	1	0	0	25	26	33	0	0	0	0	0	0	0	0
NRPRM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary material, secondary fuel, and recovered energy															
SM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RSF	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
NRSF	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mandatory inventory parameters															
FW	2	0	0	0	90	5	4	0	0	0	0	0	0	0	0
Indicators describing waste															
HWD	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
NHWD	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
HLRW	12	0	0	0	55	8	25	0	0	0	0	0	0	0	0
ILLRW	0	0	0	0	13	86	0	0	0	0	0	0	0	0	0
CRU	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MER	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
EE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a]See Table 10 for definitions of abbreviations.

Table 17—Percentage contribution of various life-cycle stages on the total environmental impacts of 1.0 m² of engineered wood flooring – incineration with energy recovery end-of-life treatment

Impact indicator[a]	A1-A3	A4	A5	B1	B2	B3	B4	B5	B7	B8	C1	C2	C3	C4, incineration	D, incineration
Core mandatory															
GWP_{total}	–27	3	1	0	69	18	89	0	0	0	0	1	0	66	–119
GWP_{fossil}	38	3	1	0	69	18	89	0	0	0	0	1	0	0	–119
$GWP_{biogenic}$	–100	0	0	0	0	0	0	0	0	0	0	0	0	100	0
ODP	15	0	0	0	21	33	30	0	0	0	0	0	0	0	0
AP	17	1	0	0	38	10	39	0	0	0	0	0	0	1	–7
EP	14	0	0	0	16	5	65	0	0	0	0	0	0	0	–1
SFP	25	3	0	0	19	6	60	0	0	0	0	1	0	1	–14
ADP fossil	33	3	1	0	63	76	76	0	0	0	0	1	0	1	–153
FFD	65	10	1	0	172	243	158	0	0	0	0	2	0	0	–551
Use of primary resources															
RPRE	23	0	0	0	2	0	65	0	0	0	0	0	0	10	0
RPRM	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRPRE	31	2	1	0	53	55	70	0	0	0	0	0	0	0	–113
NRPRM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary material, secondary fuel, and recovered energy															
SM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RSF	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
NRSF	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mandatory inventory parameters															
FW	2	0	0	0	90	5	3	0	0	0	0	0	0	0	0
Indicators describing waste															
HWD	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
NHWD	33	0	0	0	0	0	67	0	0	0	0	0	0	0	0
HLRW	12	0	0	0	55	8	25	0	0	0	0	0	0	0	–1
ILLRW	0	0	0	0	13	87	0	0	0	0	0	0	0	0	0
CRU	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MER	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
EE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a]See Table 10 for definitions of abbreviations.

Table 18—Biogenic carbon inventory indicators

Additional inventory parameters	Unit	A1 all scenarios	A3 all scenarios	C4 landfill scenario	C4 incineration scenario	C4 avg.
Biogenic carbon removal from product	kg CO_2	–91.22	—	—	—	—
Biogenic carbon emission from product	kg CO_2	—	56.07	7.24	35.16	12.30
Biogenic carbon removal from packaging	kg CO_2	—	—	—	—	—
Biogenic carbon emission from packaging	kg CO_2	—	—	—	—	—
Biogenic carbon emission from combustion of waste from renewable sources used in production	kg CO_2	—	—	—	—	—
Total biogenic CO_2 removals and emissions						
Net biogenic carbon emission landfill	kg CO_2	–27.91				
Net biogenic carbon emission incineration	kg CO_2	0.00				
Average end-of-life treatment	kg CO_2	–27.91				

the biogenic carbon that enters the landfill; only 8% of the wood decomposes as per the EPA waste reduction model (WARM) (EPA 2023). The wood product PCR from ULE adopted WARM estimations and published those assumptions under addendum 1 as a part of the PCR (ULE 2018b).

Scenario Analysis

The input parameter that had the most significant impact on the results was the assumption of vacuuming used for floor cleaning. Table 19 shows the cradle-to-grave life-cycle impacts of engineered hardwood flooring considering that vacuuming activity occurs to clean the flooring. Compared with the base case, assuming vacuuming once a week for engineered hardwood flooring can increase the GWP impact by 34.6% compared with the base case (no vacuuming) scenario.

Completeness and Consistency Checks

Evaluating the study's completeness, consistency, and sensitivity helps to establish and enhance confidence in, and reliability of, the results of the LCA study, including the significant issues identified in the interpretation.

The objective of the completeness check is to ensure that all relevant information and data needed for the interpretation are available and complete. The data were checked for completeness including all elements such as raw and ancillary material input; energy input; transportation; water consumption; product and coproduct outputs; emissions to air, water, and land; and waste disposal. All the input and output data were found to be complete, and no data gaps were identified.

The objective of the consistency check is to determine whether the assumptions, methods, models, and data are consistent with the goal and scope of the study. Through a rigorous process, consistency is ensured to fulfil the goal of the study in terms of assumptions, methods, models, and data quality including data source and age, accuracy, time-related coverage, technology, and geographical coverage.

Conclusion

This study provides a cradle-to-grave LCA of the production of engineered wood flooring in the eastern United States. The primary goal of this LCA was to develop LCI data and impact assessment results for engineered wood flooring that could be used to develop an EPD. This LCA project report provides all required impact assessment results and LCI parameters. This cradle-to-grave LCA does incorporate the necessary scope to develop a "business-to-consumer" EPD in accordance with the ULE PCR Part A and Part B.

Among all segments of the life cycle (cradle-to-grave), the contributions of the use stage (B) and, to a lesser extent, the product manufacturing stage (A1-A3) dominated the total cradle-to-grave environmental impacts of engineered wood flooring. The cradle-to-grave LCIA results showed that 39.3 kg CO_2eq were released during the life cycle of 1 m^2 of engineered wood flooring. Considering biogenic carbon emissions (i.e., carbon sequestration), the net GWP impact was decreased to 16.4 kg CO_2eq because carbon is stored in the landfill (82% of total waste disposed of in landfill). Each square meter of engineered wood flooring consumed 840.2 MJ of energy, and about 25.5% of the total primary energy used came from renewables, specifically on-site woody biomass. This study showed that engineered wood flooring can be considered a carbon-negative material that stores carbon (22.85 kg CO_2eq/m^2 flooring) for decades and thus can help to mitigate climate change.

Table 19—Environmental impacts of 1.0 m² of engineered wood flooring (considering vacuuming)

Impact indicator[a]	Unit	A-C	A-D	A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Core mandatory																		
GWP_{total}	kg CO_2eq	28.70	24.84	–4.87	0.48	0.15	0.00	24.52	3.28	0.68	0.00	0.00	0.00	0.00	0.10	0.00	4.36	–3.86
GWP_{fossil}	kg CO_2eq	51.56	47.70	6.85	0.48	0.15	0.00	24.52	3.28	15.91	0.00	0.00	0.00	0.00	0.10	0.00	0.25	–3.86
$GWP_{biogenic}$	kg CO_2eq	–22.85	–22.85	–11.72	0.00	0.00	0.00	0.00	0.00	–15.24	0.00	0.00	0.00	0.00	0.00	0.00	4.10	0.00
ODP	kg CFC11eq	8.5E–06	8.5E–06	1.1E–06	8.1E–10	9.1E–10	0.0E+00	2.6E–06	2.5E–06	2.3E–06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E–10	0.0E+00	3.2E–09	–8.1E–10
AP	kg SO_2eq	0.28	0.28	0.04	0.00	0.00	0.00	0.13	0.02	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EP	kg Neq	0.34	0.34	0.03	0.00	0.00	0.00	0.13	0.01	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
SFP	kg O_3eq	3.54	3.47	0.71	0.08	0.01	0.00	0.85	0.17	1.71	0.00	0.00	0.00	0.00	0.02	0.00	0.01	–0.07
ADP fossil	MJ, NCV	625.76	571.59	63.87	6.06	1.48	0.00	256.09	148.22	148.31	0.00	0.00	0.00	0.00	1.22	0.00	0.51	–54.17
FFD	MJ surplus	67.53	58.52	5.91	0.91	0.07	0.00	24.28	21.90	14.24	0.00	0.00	0.00	0.00	0.18	0.00	0.04	–9.01
Use of primary resources																		
RPRE	MJ, NCV	225.85	225.84	53.25	0.01	0.02	0.00	15.12	0.99	152.30	0.00	0.00	0.00	0.00	0.00	0.00	4.15	–0.01
RPRM	MJ, NCV	31.49	31.49	31.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRPRE	MJ, NCV	825.02	764.85	91.73	6.52	1.60	0.00	356.79	160.90	205.60	0.00	0.00	0.00	0.00	1.31	0.00	0.57	–60.17
NRPRM	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Secondary material, secondary fuel, and recovered energy																		
SM	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RSF	MJ, NCV	117.62	117.62	39.21	0.00	0.00	0.00	0.00	0.00	78.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRSF	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mandatory inventory parameters																		
FW	m^3	0.47	0.47	0.01	0.00	0.00	0.00	0.43	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NHWD	kg	0.38	0.38	0.13	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HLRW	m^3	5.8E–08	5.8E–08	3.1E–09	4.8E–11	1.3E–11	0.0E+00	4.7E–08	2.0E–09	6.3E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.6E–12	0.0E+00	1.4E–11	–2.9E–11
ILLRW	m^3	7.5E–07	7.5E–07	1.6E–10	2.3E–10	6.5E–11	0.0E+00	3.2E–07	4.2E–07	1.2E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.6E–11	0.0E+00	6.7E–11	–1.4E–10
CRU	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MR	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MER	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	MJ, NCV	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]See Table 10 for definitions of abbreviations.

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Appendix 1—Cover Letter Sent with Survey

PRE-FINISHED ENGINEERED WOOD FLOORING LIFE CYCLE ANALYSIS

The survey appears in a spreadsheet format. If you need a different format, contact the name listed below. When you open the spreadsheet file you will see the questions are divided into parts. It is important to complete all parts. Where data is requested for a given question, a black outlined box (spreadsheet cell) appears. Simply type your response directly into the box.

IMPORTANT: Be sure to save your answers when you are finished or if you leave the survey for a break and come back to it later.

The survey looks long and complicated at first. The level of detail is required for an accurate picture of your industry and to stand up to product comparisons and claims. We understand that you may not have information for all the questions we ask. Just do the best you can. If you have company reports like stack tests for emissions, you may provide those if it is easier for those sections. Many people that have participated in studies like this in the past find that the survey is not difficult. Some even find that by compiling the information we are asking for they can get a better picture of their own company!

Part 1: Milling (includes kiln drying, primary output Pre-Finished Engineered Wood Flooring)

Part 2: Pre-finishing and packaging (primary output prefinished and packaged engineered hardwood flooring)

Add comments or clarifications directly on the questionnaire if needed. **Thank you for your valuable time and careful effort to fill in all the blanks**. It should be easier than it looks to complete.

When you have completed the survey please attach it to an email and send it to:

hfsllc@zoho.com

Questions about the survey or the study should be directed to:

Steve Hubbard Email: hfsllc@zoho.com or Phone: 608-445-1477

Appendix 2—Survey for Eastern Prefinished Engineered Wood Flooring Production

ENGINEENERED WOOD FLOORING LIFE CYCLE INVENTORY SURVEY

PART 1: Operational Overview

Please complete this worksheet on the basis of 2018 calendar year production
If production basis is not for the 2018 calendar year, please describe here: [ ]

GENERAL INFORMATION

Prepared by:		Contact Phone Number:	( )
Company Name:		Email:	
Facility Location(s) :		Date Prepared:	

Age of Facility [ ] **Years**

Type of kilns (if any) [ ]

Number of employees at this facility [ ]

Please describe any equipment or technology updates to this mill in the last 10 years

[ ]

We are collecting information for both your veneer manufacturing and flooring manufacturing

1. Veneer mill type (please check one):

Rotary veneer		% production		thousand ft^2 3/8" basis/year	
Sliced veneer		% production		thousand ft^2 3/8" basis/year	
Dry solid-sawn		% production		thousand ft^2 3/8" basis/year	

Average log diameter if logs are processed:		inches
Average final core size if logs are rotary peeled:		inches
Initial green veneer moisture content (MC%):		%
Final dry veneer moisture content (MC%):		%

2. Flooring Production (please write in amount for reporting year indicated above):

Volume of incoming veneer:		thousand ft^2 3/8" basis/year
Volume of incoming lumber:		thousand bf (MBF)
Annual production of engineered wood flooring produced:		ft^2
Percent of engineered wood flooring that is pre-finished:		%

PART II: TOTAL MILL MATERIAL & ENERGY INPUTS & OUTPUTS

A. VENEER MILL (annual production for reporting year; if no veneer mill go to page 7)

Please indicate log scale used by checking the appropriate box:

Doyle	
Scribner	
International 1/4	
Weight based	

Please indicate the type of veneer dryer you mill uses by checking the appropriate box:

Jet
Rotary

Total volume of incoming hardwood logs: ____ **thousand BF/year**
Total volume of incoming softwood logs if any: ____ **thousand BF/year**
Total volume of incoming hardwood lumber: ____ **thousand BF/year**
Total volume of incoming green veneer: ____ **thousand ft^2 3/8” basis/year**
Total volume of veneer produced on-site: ____ **thousand ft^2 3/8” basis/year**
Total volume of hardwood lumber produced on-site (if any): ____ **thousand BF/year**
Total volume of hardwood lumber kiln-dried on-site (if any): ____ **thousand BF/year**
Average moisture content into dryer: ____ **% MC**
Average moisture content out of dryer: ____ **% MC**
Percent of re-dry: ____ **%**

Please complete the following table:(breakdown of the individual tree species, approximate sizes processed by your mill by species, and average log diameter)
If less than 2% of total, use category labeled “Other

Species	% of total log input into veneer mill	Log Diameter* (in)
Total	**100%**	

***Please provide individual log diameters if known otherwise please state the average or range of logs processed at your facility in bottom row under Log Diameter**

TOTAL TRANSPORTATION FUEL USE ON-SITE (includes all fuels for yard equipment, forklifts, and carrier

Type	Amount	Units
On-road diesel (between facilities)		Gallons
Off-road diesel		Gallons
Fuel Oil #6		Gallons
Propane		Gallons
Gasoline		Gallons
Total	**100%**	

TOTAL MILEAGE: (Raw materials delivery to your manufacturing facility)

Over the Road ____ % By Rail ____ %
Total number of log deliveries made to this facility annually: ____ # / year
Average one-way mileage travel to this facility to deliver logs: ____ miles
Total number of lumber deliveries made to this facility annually: ____ # / year
Average one-way mileage travel to this facility to deliver lumber: ____ miles
Total number of green veneer deliveries made to this facility annually: ____ # / year
Average one-way mileage travel to this facility to deliver green veneer: ____ miles

TOTAL WATER USE:

Ground (municipal/well) water ____ gallons or ft^3 ____ percent recycled
Surface water ____ gallons or ft^3 ____ percent recycled

TOTAL (NON-TRANSPORTATION) FUEL USE (boilers, cogeneration units, etc.)

Wood:

On-site wood boiler fuel ____ tons @ ____ % MC
Purchased wood boiler fuel ____ tons @ ____ % MC

Fossil Fuel:

Natural Gas		thousand cubic feet (ft3)
Fuel oil #1(kerosene)		gallons
Fuel oil #2 (heating oil)		gallons
Fuel oil #6		gallons
Propane		gallons
Other		
Electricity for entire facility		kilowatt-hours (kWh)

Electricity for the following processes (Estimation is ok)

Process	kWh	% of total
1. Bucking & Debarking		
2. Block Conditioning		
3. Peeling & Clipping		

Process	kWh	% of total
4. Veneer Drying		
5. Energy Generation		
6. Emissions control		

TOTAL WOOD CO-PRODUCT/BY-PRODUCT OUTPUT

For each material, please indicate the percentages of total production for the reporting period that are sold (shipped) to other users, used internally (such as fuel), landfilled, or inventoried for future use. Select whatever category best fits your mill's situation. Please state units if other than tons such as cubic yards.

Co-products and By-Products	Moisture Content (wet basis) %	Sold (Shipped)	Used Internally (as fuel)	Used Internally (other uses)	Landfilled	Inventory	Total	
		tons	tons	tons	tons	tons	tons	(%)
Bark, green								
Roundup wood, green								
Peeler cores, green								
Veneer clippings, green								
Trim, green								
Chips, green								
Hogged material								
Waste gate material								
Clippings, dry								
Other								

TOTAL INDUSTRIAL (SOLID) WASTE (material requiring disposal outside of mill)

Type	Tons/Pounds	Percent Landfilled %
Pallets (not re-used)		
Fly Ash		
Bottom ash		
General refuse (do not include above materials)		
Recycled material		

TOTAL BOILER AIR EMISSIONS: (Provide stack test if available)

Emission	Amount	Units
Dust		pounds
Particulate		pounds
PM10		pounds
Hazardous Air Pollutants (HAPS)		pounds
Volatile organics		pounds
Nitrous oxide (N_20)		pounds
Nitrogen oxide (NO)		pounds
Sulfur oxides (S_xO)		pounds
Carbon monoxide (CO)		pounds
Carbon dioxide (CO_2)		pounds
Others (please list all known):		units

EMISSIONS CONTROL EQUIPMENT

If your facility has emission control devices, please complete the table below. For air emissions include devices such as cyclones, bag houses, and electric static precipitators (ESPs). For water emissions, explain how runoff or other water discharges from the boiler and mill are controlled (i.e. settling pond, city sewer, septic; annual basis). Please list ALL devices. If your facility has more than one of the same device please indicate the total number for that type of device.

Type of Emission Control Device (cyclone, bag house, esp, etc.)	How Many?	Equipment Controlled	Type of Emissions (gas, liquid, solid)	Electrical Usage For Device kWh (annual basis)

B. ENGINEERED WOOD FLOORING PLANT

TOTAL MATERIAL INPUTS

			% of the total
Total volume of incoming dry veneer		thousand ft^2 3/8" basis/year	
Wood species			
Wood species			
Wood species			
Wood species			
Wood species			
Wood species			
Wood species			
Total volume of cardboard cartons		cubic feet/year	
Total volume of sandpaper		cubic feet/year	

TOTAL (NON-TRANSPORTATION) FUEL USE

Wood:

On-site wood boiler fuel		tons	@		% MC
Purchased wood boiler fuel		tons	@		% MC

Fossil Fuel:

Natural Gas		thousand cubic feet (ft3)
Fuel oil #1(kerosene)		gallons
Fuel oil #2 (heating oil)		gallons
Fuel oil #6		gallons
Propane		gallons
Other		
Electricity for entire facility		kilowatt-hours (kWh)

Electricity for the following processes (Estimation is ok)

Process	kWh	% of total
6. Hot Pressing		
7. Trimming		
8. Pre-finishing		

Process	kWh	% of total
9. Sawing & Moulding		
10. Packaging		
11. Emissions control		

TOTAL TRANSPORTATION FUEL USE ON-SITE (includes all fuels for yard equipment, forklifts, and

Type	Amount	Units
On-road diesel (between facilities)		Gallons
Off-road diesel		Gallons
Fuel Oil #6		Gallons
Propane		Gallons
Gasoline		Gallons
Total	**100%**	

TOTAL MILEAGE: (Raw materials delivery to your manufacturing facility)

By truck		%	By Rail		%

Total number of dry veneer deliveries made to this facility annually:		# / year
Average one-way mileage travel to this facility to deliver dry veneer:		miles
Total number of lumber deliveries made to this facility annually:		# / year
Average one-way mileage travel to this facility to deliver lumber:		miles
Total number of adhesive deliveries made to this facility annually:		# / year
Average one-way mileage travel to this facility to deliver adhesives:		miles
Total number of stains, coatings, and related products deliveries:		# / year
Average one-way mileage to deliver stains, coatings, and related products:		miles
What is the percentage that leave your mill empty (no backhaul):		%

TOTAL WATER USE:

Ground (municipal/well) water		gallons or ft^3		percent recycled
Surface water		gallons or ft^3		percent recycled

TOTAL ADHESIVE INPUTS (glues used for hot pressing veneer plies)

Volume of adhesive used:		Solid	or		Wet-based		tons or gallons /year

Please list names and percentage of all adhesives used:

Urea Formaldehyde (UF):		tons or gallons /year		Percent of total	
Polyvinyl acetates (PVA):		tons or gallons /year		Percent of total	
Phenol formaldehyde (PF):		tons or gallons /year		Percent of total	
Melamine-urea-formaldehyde (MUF):		tons or gallons /year		Percent of total	
Phenol resorcinol (PR):		tons or gallons /year		Percent of total	
Phenol resorcinol formaldehyde (PFR):		tons or gallons /year		Percent of total	
Other(s):		tons or gallons /year		Percent of total	

Volume of other components used:

	Amount	
Volume of filler used in glues		tons or gallons /year
Volume of water used in glues		tons or gallons /year
Volume of other used in glues (please spec		tons or gallons /year

Volume of catalysts used in adhesives

List types and percentage of all catalysts used:

Type			Percent of total	
Type			Percent of total	

TOTAL FINISHING INPUTS (used for staining and coating)

Total volume of stains used in finishing ______ tons or gallons /year

List names and percentage of all stains used:

Solvent-based	tons or gallons /year		Percent of total	
Water-based	tons or gallons /year		Percent of total	
UV-cured	tons or gallons /year		Percent of total	

Total volume of clear coats used in finishing

Polyurethane lacquer	tons or gallons /year		Percent of total	
Acid-curing lacquer	tons or gallons /year		Percent of total	
UV-curing lacquer	tons or gallons /year		Percent of total	
Oil treatment	tons or gallons /year		Percent of total	
Melamine	tons or gallons /year		Percent of total	
Water-borne lacquer	tons or gallons /year		Percent of total	

List weights and percentage of all clear coats used:

Name of coat		tons or gallons /year		Percent of total	
Name of coat		tons or gallons /year		Percent of total	
Name of coat		tons or gallons /year		Percent of total	
Name of coat		tons or gallons /year		Percent of total	
Name of coat		tons or gallons /year		Percent of total	

TOTAL WOOD CO-PRODUCT/BY-PRODUCT OUTPUT

For each material, please indicate the percentages of total production for the reporting period that are sold (shipped) to other users, used internally (such fuel or), landfill, or inventoried for future use. Select whatever category best fits your mill's situation. Please state units if other than tons like cubic yards.

Co-products and By-Products	Moisture Content %	Sold (Shipped)	Used Internally for Fuel	Used Internally (other uses)	Landfilled
		tons	tons	tons	tons
Clippings, dry					
Sawdust, dry					
Shavings, dry					
Sanding dust, dry					
Wood flour[1]					
Other					

[1] Wood flour refers to wood particles smaller than sawdust like moulder or profiling off-fall

TOTAL INDUSTRIAL (SOLID) WASTE (material requiring disposal outside of mill)

Type	Tons/Pounds	Percent Landfilled %
Pallets (not re-used)		
Adhesive mixed with wood waste		
Fly Ash		
Bottom ash		
General refuse (not above materials)		
Recycled material		

TOTAL BOILER AIR EMISSIONS: (Provide stack test if available)

Emission	Amount	Units
Dust		pounds
Particulate		pounds
PM10		pounds
Hazardous Air Pollutants (HAPS)		pounds
Volatile organics		pounds
Nitrous oxide (N20)		pounds
Nitrogen oxide (NO)		pounds
Sulfur oxides (SxO)		pounds
Carbon monoxide (CO)		pounds
Carbon dioxide (CO2)		pounds
Others (please list all known):		units

EMISSIONS CONTROL EQUIPMENT

If your facility has emission control devices, please complete the table below. For air emissions include devices such as cyclones, bag houses, and electric static precipitators (ESPs).
For water emissions, explain how runoff or other water discharges from the boiler are controlled (i.e. settling pond, city sewer, septic). Please list ALL devices.

Type of Emission Control Device (cyclone, bag house, esp, etc.)	How Many?	Equipment Controlled	Type of Emissions (gas, liquid, solid)	Electrical Usage For Device kWh (annual basis)

TOTAL EMISSIONS FOR FINISHING LINE PROCESS

Emission	Amount	Units
Dust		pounds
Particulate		pounds
PM10		pounds
Hazardous Air Pollutants (HAPS)		pounds
Volatile organics (VOC's)		pounds
Nitrous oxide (N20)		pounds
Nitrogen oxide (NO)		pounds
Sulfur oxides (SxO)		pounds
Carbon monoxide (CO)		pounds
Methane (CH4)		pounds
Carbon dioxide (CO2)		pounds
Others (please list all known):		units

END OF SURVEY. THANK YOU! PLEASE SAVE YOUR ANSWERS, ATTACH IN AN EMAIL TO: hfsllc@zoho.com