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Life-Cycle Assessment of Solid Hardwood Flooring in the Eastern United States

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Abstract

This study conducted a cradle-to-grave life-cycle assessment (LCA) of solid hardwood 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 (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, which displaces natural gas (D stage). A functional unit of 1 m^2 of flooring with a weighted average oven-dried mass of 12.06 kg/m^2 of flooring (for 75 years of estimated service life of the building) was used to present the LCA results. Primary data were collected along the supply chain including resource procurement, manufacturing, and logistics using surveys. Data not available from the surveys, especially regarding use and disposal of the wood flooring, were supplemented from literature and industry experts. This LCA study followed the guidelines of the International Organization for Standardization standards and product category rules (PCR), Underwriters Laboratories-Environment Part A (Building-Related Products and Services) PCR and Part B (Flooring EPD Requirements) PCR. Life-cycle impact assessments (LCIA) were estimated using the tool for the reduction and assessment of chemical and other environmental impacts (TRACI), CML baseline, and cumulative energy demand. Among all segments of the life cycle (cradle-to-grave), the manufacturing module (37%) and use stage (57%) were the most substantial contributors to the total cradle-to-grave environmental impacts of solid hardwood flooring. The cradle-to-grave LCIA results showed that 26.65 kg CO_2eq were released during the life cycle of 1 m^2 of solid hardwood flooring. Considering biogenic carbon emissions, the net global warming potential impact was decreased to 12.27 kg CO_2eq as a result of carbon being stored in the landfill (82% of total waste disposed of in landfill). Each square meter of solid hardwood flooring consumed 610.5 MJ of energy, and about 20.3% of the total primary energy used came from renewables, especially biomass. This study showed that solid hardwood flooring has a low carbon footprint. It stored carbon (14.37 kg CO_2eq/m^2 flooring) for the long-term, which can help mitigate climate change.

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

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Executive Summary

Study Goal

The goal of this study was to summarize the environmental performance of solid hardwood flooring, including solid plank hardwood flooring, in the United States using a cradle-to-grave life-cycle assessment (LCA). Solid hardwood flooring is available in a wide range of dimensions and species. This study did not consider parquet or engineered wood flooring. 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 rule (PCR) for Building-Related Products and Services (Part A) and Flooring (Part B) to develop life-cycle inventory (LCI) and conduct a life-cycle impact assessment (LCIA). System boundaries in this study were cradle-to-grave. The system boundary included raw material extraction (A1), raw material transportation (A2), product manufacturing (A3), product transportation (A4), installation (A5), product use (B1-B7), and end-of-life (C1-C4). Two flooring disposal options were considered, landfilling and burning. The burning option captures heat, which displaces natural gas (D).

The LCI was developed considering the unit process modeling approach, where all input and output quantities were assigned to a reference flow. A declared unit of 1 m^2 of flooring with a weighted average oven-dried mass of 12.06 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 solid strip and solid plank hardwood flooring. Secondary data were used from literature and public LCI databases. For the gate-to-grave portion, we used expert opinions and secondary data from the literature to estimate LCIs.

The surveys collected data regarding all raw material inputs, outputs (product and coproducts) and related direct emissions to water and air, and generation of solid waste. After LCA experts analyzed the survey data, a mass balance was performed for data quality assurance. The mass-allocations approach was used to assign environmental impacts to the product (hardwood flooring) and coproducts. The LCA modeling software, SimaPro (containing the DATASMART database from Long Trail Sustainability, Huntington, Vermont, USA) 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 Impact Assessment

Several impact categories were examined as required by ISO 21930 and the ULE PCR for Building-Related Products and Services (Part A) and Flooring (Part B). The main impact categories were global warming (GW) (kg CO_2eq), acidification (kg SO_2eq), eutrophication (kg Neq), ozone depletion (kg chlorofluorocarbons-11-eq), photochemical smog (kg NOxeq), abiotic depletion potential for fossil resources (MJ), and fossil fuel depletion (MJ surplus). Additional information was provided such as the consumption of primary energy resources [energy consumption from nonrenewable (fossil fuels), nonrenewable (nuclear fuels), renewable (biomass), and renewable (wind, solar, hydro, and geothermal)], 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 substantially to the total cradle-to-grave environmental impacts of hardwood flooring. The cradle-to-grave LCIA results (Table 1) showed that 26.65 kg CO_2eq was released during the life cycle of 1 m^2 of hardwood flooring. Considering the benefits of burning the flooring after the end-of-life stage (D), the GW impact was decreased to 24.28 kg CO_2eq. Further considering biogenic carbon, GW potential was decreased to 12.27 kg CO_2eq because the wood resource was extracted from a sustainable source and reported per ISO 21930. In the long-term, each unit (1 m^2, 12.06 dry kg) of hardwood flooring stores 14.37 kg CO_2eq in the landfill.

Each 1 m^2 of hardwood flooring consumed 610.54 (124.14 + 486.40) MJ of energy, and about 79.67% of the total primary energy used came from nonrenewables, especially fossil sources.

Sensitivity Analysis

A sensitivity analysis was completed per ISO 14040 to model the effects of input parameters. Among all input parameters, reference service life of the products and 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 solid hardwood flooring. A significant part of the total impact comes from the use stage of the flooring considering the reference service life of the product (75 years) and the estimated service life of buildings (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.

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

Impact indicator	Unit	Total
Core mandatory		
Global warming potential – TRACI 2.1	kg CO_2eq	26.65
Global warming potential – with biogenic CO_2	kg CO_2eq	–14.37
Global warming potential – total	kg CO_2eq	12.27
Depletion potential of the stratospheric ozone layer	kg CFC11eq	4.73E–06
Acidification potential of soil and water sources	kg SO_2eq	0.17
Eutrophication potential	kg Neq	0.14
Formation potential of tropospheric ozone	kg O_3eq	1.90
Abiotic depletion potential for fossil resources	MJ, NCV	389.37
Fossil fuel depletion	MJ surplus	51.98
Energy consumption		
Renewable primary energy used as energy	MJ	124.14
Renewable primary energy used as material	MJ	236.30
Nonrenewable primary energy used as energy	MJ	486.40
Nonrenewable primary energy used as material	MJ	0.00

Acknowledgments

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Introduction

The earth is facing two major challenges: climate change and resource scarcity. The role of greenhouse gas emissions in global climate change and its projected negative impact on our planet has never been more elevated in the public's consciousness (Bergman and others 2012, UNEP 2021). Materials for buildings and construction account for ~40% of energy-related CO_2 emissions (UN Environment and International Energy Agency 2017, UNEP 2021). Resources from forests provide renewable construction materials, pulp and paper, energy, bioproducts, and more (Jakes and others 2016). Furthermore, carbon sequestered in forests and stored in wood products has great potential to mitigate climate change (Malmsheimer and others 2011, Sahoo and others 2019, Haight and others 2020, Brashaw and Bergman 2021). Combining carbon storage and carbon displacement by avoiding fossil-fuel-intensive construction materials, especially in buildings, is one of the most efficient options to mitigate climate change (Sathre and O'Connor 2010, Bergman and others 2014, Oliver and others 2014). Recent years have seen an increase in the growth of environmental certifications and green building programs (Shi and Liu 2019). The latter, green building, 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 others 2012). 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 (Bergman 2012). Quantifying environmental performance for 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 material extraction, through its manufacturing process and service life, to its eventual reuse or disposal (Bergman 2012, ISO 2017). This LCA study provides environmental impacts by accounting for the required raw materials, energy, and generated wastes to produce solid hardwood flooring. The 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) (NREL 2012). The database is a library or data warehouse for interested stakeholders to evaluate the comparative impacts of various building products and assemblies.

LCA studies have been conducted for various flooring materials including wood flooring. 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). Jönsson and others (1997) examined the environmental impacts of linoleum, vinyl, and untreated solid wood flooring in Sweden using LCA. Both primary and secondary data were utilized to construct the life-cycle inventories (LCIs), and the life-cycle impact assessment (LCIA) was estimated considering the functional unit, 1 m^2 of floor covering. Jönsson and others (1997) found that wood had the least emissions to air and water, generated less waste, and used the least amount of energy among the three floor coverings. Thus, it was reported that solid wood flooring was more environmentally sound because linoleum and vinyl both require extensive material inputs compared with wood. Vinyl was found to be the least environmentally sound (Jönsson and others 1997). Nebel and others (2006) conducted a similar study 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 and followed the ISO 14040/44 standards (ISO 2006a,b). The authors highlighted the need to understand the decision tradeoffs made in drying procedures and gluing and finishing choices, which can dramatically alter the observed results. Kiln-drying represents the most energy-intensive process, followed by the manufacturing of flooring. Options to reduce environmental impacts were the use of natural (solar, air, and wind) drying of the solid floor coverings before entry into the kiln and substituting water-based glues for those borne of solvents. The storage of carbon inherent in wood flooring coupled with energy production alternatives to fossil fuels realized by residual wood and postconsumer wood streams represent significantly reduced, perhaps even negative, GWP for these products (Nebel and others 2006). The literature on the LCA of flooring materials, especially wood flooring, is limited especially considering gate-to-grave life stages of flooring (Jönsson 1999; Hubbard and Bowe 2008, 2010; Bergman and Bowe 2010, 2011; Vjestica and others 2014). A previous study (Minne and Crittenden 2015) illustrated that the impact of cradle-to-grave, especially the use stage of flooring, has a significant contribution to the total life-cycle impact of flooring products. The objectives of the current study were to perform a cradle-to-grave LCA and quantify the environmental impacts of hardwood flooring produced and used in the eastern United States. This study expanded the boundary from cradle-to-gate to cradle-to-grave, which provides a holistic view of the environmental impacts of solid wood flooring including the use and end-of-life (EoL) stages. The benefits of energy generation and permanent storage of carbon at the EoL stage are also included, which may help in decision-making and policy-making.

The solid hardwood flooring industry in the United States is well established. Continued innovation makes product-specific estimates difficult. In addition to their historic inclusion with millwork and dimension data, the growing popularity of wide plank, recycled, parquet, and engineered wood flooring is exacerbating this hardship and making current industry census data for solid strip and solid plank hardwood flooring production difficult to decipher. In personal communications with company owners, industry experts, and scientists involved with this industry segment, we found that no single authoritative, comprehensive, and exhaustive source of concise demographic information exists. Information presented in this document represents a thorough treatment of data gathered from a variety of sources involved in tracking and reporting U.S. solid wood flooring activity. There are an estimated 100 to 150 manufacturing facilities in the United States with dedicated production to solid hardwood flooring (Hubbard and Bowe 2008). Annual production from these mills in 2006 was estimated to be 483 million ft^2 (44.9 million m^2) (Hubbard and Bowe 2008). Hardwood flooring production is located within states that have well-established transportation channels and proximity to the raw hardwood resource.

Abbreviations

BF	board feet
CED	cumulative energy demand
CFC	chlorofluorocarbons
CLR	cubic lumber recovery
CML	Centrum voor Millikunde Leiden
CORRIM	Consorium for Research on Renewable Industrial Materials
EoL	end-of-life
EPD	environmental product declaration
ESL	estimated service life
GW	global warming
GWP	global warming potential
HAP	hazardous air pollutant
ISO	International Organization for Standardization
LCA	life-cycle assessment
LCI	life-cycle inventory
LCIA	life-cycle impact assessment
LHV	lower heating value
LRF	lumber recovery factor
MBF	thousand board feet
MMBF	million board feet
MRO	Midwest Reliability Organization
NCV	net calorific value
NE/NC	northeast/north central
NHLA	National Hardwood Lumber Association
NPCC	Northeast Power Coordinating Council
NREL	National Renewable Energy Laboratory
NWFA	National Wood Floors Association
OD	oven-dry
PCR	product category rules
RFC	Reliability First Corporation
RNA	region North America
RSL	reference service life
S2S	surfaced two sides
SE	southeastern
SERC	SERC Reliability Corporation
tkm	metric tonne–kilometers
TRACI	tool for the reduction and assessment of chemical and other environmental impacts
ULE	Underwriters Laboratories Environment
USDA NAL	U.S. Department of Agriculture National Agriculture Library
UV	ultraviolet
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

Solid hardwood flooring is referenced by length, thickness, width, profile, finish, grade, species, or a combination of these. The National Hardwood Lumber Association (NHLA) has outlined rules and grading procedures for hardwood lumber (NHLA 2003, 2019). Traditional hardwood flooring manufacturers have made use of lower grade lumber including number 2A and 3A common lumber (Hosterman 2000). Number 1 common and higher lumber grades are not often used. Table 2 lists common dimensions used in hardwood flooring.

Solid hardwood flooring has three classifications: strip, plank, and parquet. Strip flooring dominates overall production. It is considered to have face widths less than 3 in. (76.2 mm) (NWFA 2022). Plank flooring is classified as having a face width between 3 and 5 in. (76.2 and 127 mm) (NWFA 2022). Wide plank flooring is classified as having a face width wider than 5 in. (127 mm). Alternatively, parquet flooring is a 1-ft-square (0.31-m-square) assemblage of thin wood strips that are in a geometric pattern as opposed to a linear orientation. Some typical patterns are chevron, herringbone, and traditional square-shaped finger-block patterns. Parquet flooring is not considered in this inventory. Both strip and plank flooring share traditional thicknesses of 0.75 in. (19.0 mm). Consumer preferences and technological innovation in milling equipment have made thicknesses ranging from 0.3 to 0.5 in. (7.62 to 12.7 mm) available (Hosterman 2000, Bergman 2012).

In the United States, the most commonly used domestic hardwood species for solid flooring include red oak (*quercus rubra*), white oak (*quercus alba*), sugar maple (*acer saccharinum*), red maple (*acer rubrum*), ash (*fraxinus* spp.), birch (*betula* spp.), black walnut (*juglans nigra*), cherry (*prunus serotina*), American beech (*Fagus grandifolia*), and hickory (*Carya* spp.). Of these, red oak captures nearly 70% of the market.

Table 2—Common solid hardwood flooring dimensions

Flooring classification	Face widths (in. (mm))	Thickness (in. (mm))
Solid strip hardwood	1.5 (38.1), 2.25 (57.2)	5/16 (7.93), 3/8 (9.53) 1/2 (12.7), 3/4 (19.0)
Solid plank hardwood	3.0 (76.2), 5.0 (127)	5/16 (7.93), 3/8 (9.53) 1/2 (12.7), 3/4 (19.0)
Solid wide plank hardwood	6.0 (152.4), 8.0 (203.2)	5/16 (7.93), 3/8 (9.53) 1/2 (12.7), 3/4 (19.0)

Methods

Goal

The objective of this study was to quantify the cradle-to-grave life-cycle impacts of solid hardwood flooring. The life-cycle impacts include mandatory indicators as defined by the product category rules (PCR) (ULE 2018a,b) environmental indicators and energy use. Comparative assertions were not a goal of this study.

Scope and System Boundaries

The scope of this study was to cover the life-cycle stages of solid hardwood flooring products in the eastern United States. The scope (Fig. 1) covered raw material extraction (A1), raw material transportation (A2), product manufacturing (A3), product transportation (A4), installation (A5), product use (B1-B7), EoL (C1-C4), and potential benefits beyond system boundary (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 datasets available with the LCA software (PRé Consultants 2021).

The hardwood lumber used in the production of flooring was considered to be produced in the eastern region of the United States. Figure 2 shows the initial eastern region, which was divided into two subregions (the northeast shown in blue and the southeast shown in green).

It was assumed that the hardwood flooring was produced in the eastern United States but installed and used anywhere in the United States. For accounting purposes, boundary selection is a key aspect of all life-cycle studies. The gate-to-gate system boundary (A3) for the flooring mill is denoted by the inner dotted lines in Figure 1. The gate-to-gate system boundary of solid hardwood flooring from the point at which hardwood lumber arrives at the mill to the point it is converted and packaged as hardwood flooring was considered. Combustion of fuels and associated electricity generation required to produce the final product were included.

The cradle-to-gate system boundary included gate-to-gate and the upstream supply chain that consists of impacts of resource inputs including hardwood lumber manufacturing and its logistics (Bergman and Bowe 2008, 2012; Hubbard and others 2020; Heidari and others 2023). The cradle-to-grave system boundary included cradle-to-gate and gate-to-grave, which consists of product transportation, installation, use, and disposal at the end of life (outer solid line in Fig. 1). Figure 3 shows only the gate-to-gate system boundary (A3). This study examined cumulative effects of

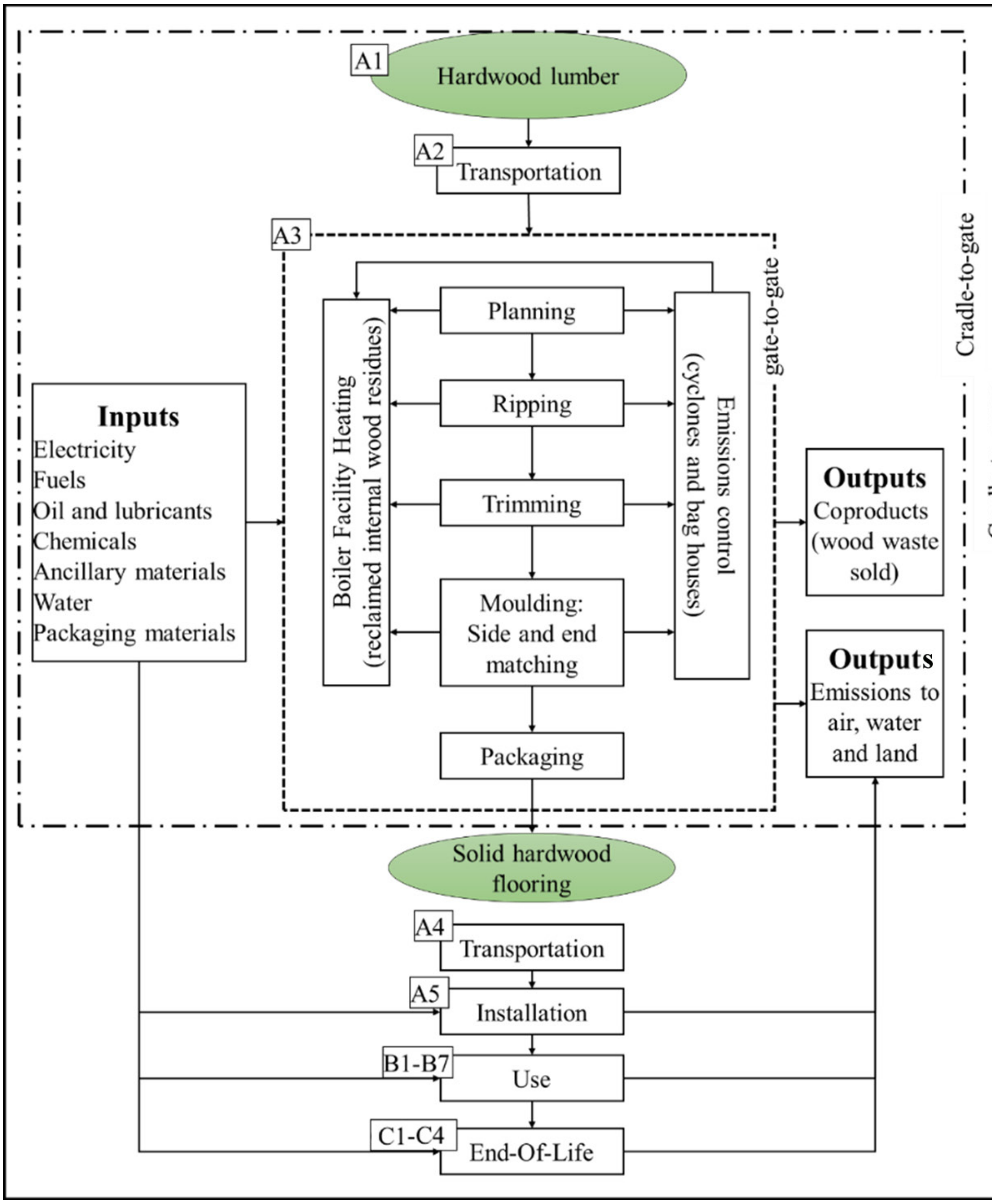

Figure 1—System boundaries for solid hardwood flooring production in the eastern United States.

producing solid hardwood flooring (by including the impacts associated with producing the hardwood lumber as well as the transportation burdens required to deliver the lumber from the sawmill 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 2018b) 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 quantifies the functions and performance characteristics of the product (ISO 2017). The main purpose

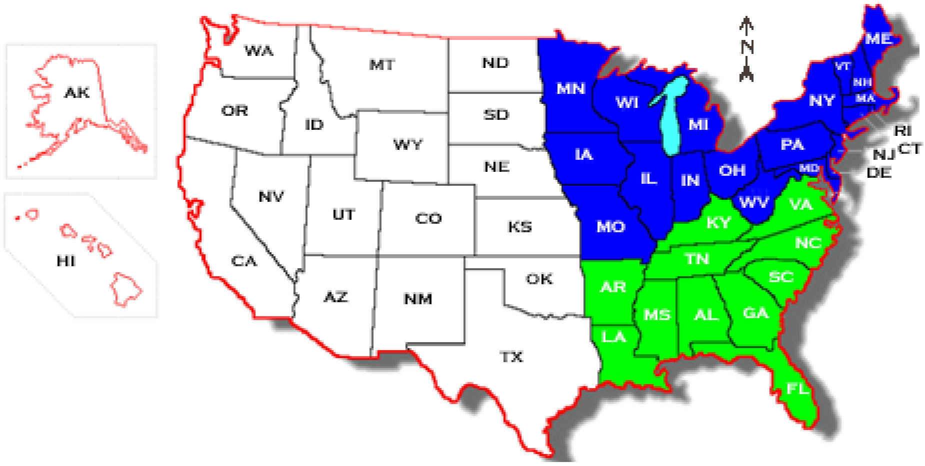

Figure 2—Northeast (blue) and southeast (green) U.S. manufacturing regions of hardwood lumber and hardwood flooring.

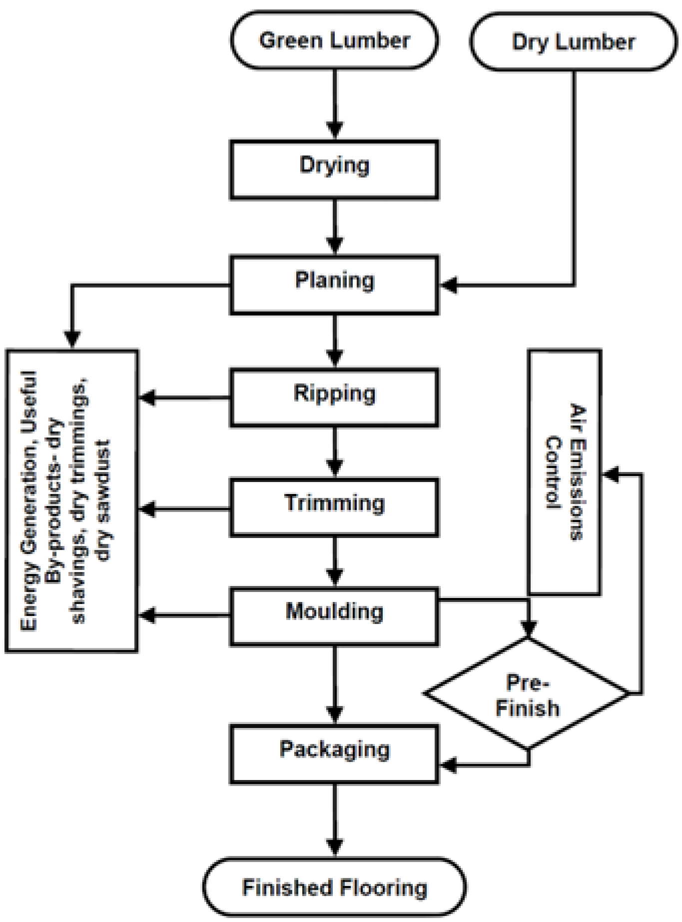

Figure 3—Simplified process flowchart of the manufacturing of hardwood flooring.

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). The functional unit for solid wood flooring is 1.0 m^2 of product. The reference service life (RSL) of hardwood flooring was varied based on multiple factors including wood species, use conditions, and environment (Coelho and others 2021). The RSL varied between 25 and 100 years from different manufacturers in North America. Coelho and others (2021) estimated the average life of solid flooring as 44 years. However, several EPDs (AFS 2023a,b) and flooring manufacturers have shown that the RSL of solid hardwood flooring can be far more than 44 years. This study considered 75 years as the RSL of solid hardwood flooring. The estimated service life (ESL) of a building was considered 75 years, and the hardwood flooring was used as a construction product in the building. Based on ESL (75 years) and RSL (75 years), the flooring products were calculated to be replaced 0 times during the full life of the building. But when RSL was considered as 44 years, the flooring products were calculated to be replaced 0.7 times during the full life of the building. One square meter of the hardwood flooring weighs about 12.06 dry kg assuming a thickness of 18.9 mm.

Intended Audience

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

Comparative Assertions

According to ISO 14044 (ISO 2006b) and the flooring PCR (ULE 2018a,b), the LCA boundary needs to be expanded to include the use and EoL stages if future comparative studies are intended to be disclosed to the public. This report included the use (B1-B7) and EoL (C1-C4) stages of products, which are required for comparative assertions relative to substitute products. Therefore, this study can be used for a comparative analysis of hardwood flooring with the alternatives if the LCA studies of alternative products also consider all stages of product life.

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 (ISO 2017). This analysis included all energy and mass flows for primary data. In the primary surveys, manufacturers were asked to report total hazardous air pollutants (HAPs) specific to their wood products' manufacturing process. Under Title III of the Clean Air Act Amendments of 1990, the EPA has designated HAPs that wood products 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, and no cut-off rules apply. There were no cut-offs used in the impact assessment.

Description of Processes and Life-Cycle Inventories

Module A1: Raw Material Extraction (Upstream Lumber Manufacturing)

The main raw materials examined in the LCI analysis were rough green and rough dry lumber. These inputs are the outputs of lumber mills, and the impacts of forest resources management, harvesting, transportation, and lumber manufacturing were considered. The various wood species of hardwood lumber used in the production of hardwood flooring are presented in Table 3. A weighted average

Table 3—Wood flooring conversion to oven-dry mass basis by species

Wood species	Green weight[a] (8% MC) (kg/m^3)	Oven-dry weight[b] (kg/m^3)	Reported volume for all mills (m^3)	Total weight-averaged volume contributions (%)	Oven-dry mass basis conversion (kg/m^3)
Red oak	648.15	600.14	190,052.22	62.26	373.62
White oak	680.56	630.14	72,138.55	23.63	148.91
Hickory	736.11	681.58	29,112.96	9.54	65
Beech	639.81	592.42	123.58	0.04	0.24
Walnut	562.04	520.4	209.78	0.07	0.36
Ash	582.41	539.27	461.33	0.15	0.81
Cherry	512.96	474.97	451.83	0.15	0.7
Hard maple	626.85	580.42	12,618.50	4.13	23.99
Birch	626.85	580.42	110.74	0.04	0.21
Total	—	—	—	—	613.84

[a]Nominal green weight values obtained from NHLA (2003, 2019).

[b]Oven-dry weight calculated using the standard formula with green weight at assumed 8% MC; i.e., OD wt = green wt/(1 + 0.08).

density for wood (oven-dry (OD) basis) was calculated for each wood species reported by respondent mills. In addition to wood species, Table 3 gives conversion values, volume, and percentage contribution by species. Values for nominal green weights used in calculating the OD weights by species are given by the NHLA (2003, 2019). The given values are reported at identical moisture content to that reported by mills for rough input lumber (8%), making this a logical source.

Reported wood volumes by species across all mills were obtained and totaled (Table 3). Recorded values for each species were then divided by this total to obtain a percentage contribution by species. Oven-dry averages for each species were computed by multiplying the percentage contribution of a given species by the OD weight for that species. Oven-dry averages were summed across all species to obtain a final OD mass basis of 613.84 kg/m^3 for hardwood flooring.

Module A2: Raw Material Transportation

Delivery of hardwood lumber (green and dry) from the sawmill to the flooring manufacturing facility was only by truck. None of the mills reported delivery by rail. The average one-way delivery distance for the lumber was 172 km. Mills reported that these trucks are empty on their backhaul. Burdens associated with this transportation were included in the cumulative system boundary but omitted from the on-site boundary analysis. Transportation data for packaging material were not reported and were not included in the analysis.

Module A3: Product Manufacturing

Hardwood flooring manufacturing is accomplished through a series of unit processes. A unit process may be thought of as a machining center, a work cell, 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 3 and includes the following sequence of activities: receiving lumber, drying lumber (if in the green state), planing, ripping, trimming, moulding (side and end-matching), prefinishing, and packaging. Prefinishing refers to the application of any final coating material such as stains or protective emulsions. Not all flooring manufacturers perform this unit process.

Coproducts associated with the process, including trimmings, edgings, planar shavings, wood flour, and sawdust, are considered useful and given careful attention (Table 4). Inputs of rough kiln-dried lumber and these associated coproducts were reported in the survey to have an average moisture content of 8%. Table 5 estimated that a representative flooring operation realizes yields of roughly 48% of the original raw lumber input.

Subsequent flows for wood in the process of flooring manufacture were determined on an OD basis. They may be sent to energy-producing systems for use in the plant or serve as raw material furnishes for other value-added wood products such as particleboard, animal bedding, or medium-density fiberboard. The unit processes illustrated in Figure 3 are discussed in the subsequent subsections.

Receiving Lumber

The first unit process entails unstacking lumber after its arrival at the mill, sorting it, and restacking it for proper storage. Lumber may arrive green or kiln-dried and is unbundled and sorted by species, dimension, and grade. Sorted lumber is restacked onto drying stickers and may be end-sealed and oriented in the mill yard such that air-drying of the lumber is optimized. Manual labor and fork trucks are used in this process. The output of this unit process is stacked green lumber ready for kiln-drying or kiln-dried lumber ready for planing. The impacts of this process are assumed in the transportation and total mill energy use contributions.

Drying

This unit process starts with stacked and stickered green lumber. The lumber is loaded into a conventional kiln and subjected to an optimal drying schedule for the given species. Wood used for flooring is typically dried to a final moisture content of between 6% and 9% OD basis (Bergman 2021).

Table 4—Raw material inputs, coproducts, and products for flooring manufacture[a]

Input materials[b]	Coproducts[c]	Products[d]
Rough kiln-dry hardwood lumber	Sawdust	Unfinished solid hardwood flooring
Steel strapping	Planer shavings	
Water, from ground	Edging strips	
	Trimmings	
	Wood flour	

[a]Fuels and electricity not included.
[b]Lumber is at 8% moisture content.
[c]Coproducts produced are at 8% moisture content.
[d]Solid strip and solid plank flooring; does not consider parquet or engineered flooring.

Table 5—Wood mass balance for 1.0 m^3 of solid hardwood flooring produced

	OD wood (kg/m^3)	Allocation (%)
Inputs		
Rough green hardwood lumber	662	52
Rough kiln-dry hardwood lumber	612	48
Total wood input	1,274	100
Outputs		
Solid hardwood flooring	614	48
Wood residue[a]	660	52
Total wood output	1,274	100

[a]Wood residue in the black box approach refers to any combination of planer shavings, sawdust, edgings, trimmings, and wood flour. The wood residue is used on-site for energy generation or sold off-site as value-added furnish.

Other activities included in the drying process are kiln and transportation maintenance, handling of kiln emissions (steam and water), and transport of the newly dried lumber. The output of this unit process is rough kiln-dried lumber. This unit process was not included in primary data collection. Impacts are reflected through data from a recently completed hardwood lumber LCI (Hubbard and others 2020, Heidari and others 2023).

Planing

A charge of freshly dried hardwood lumber can have variations in thickness. A planer brings lumber thicknesses into uniform tolerance limits while simultaneously producing smooth face surfaces, which helps with visual grading and sorting. Manually or with specialized machinery, the dried lumber is unstacked and destickered. Next, referred to as “flatting”, lumber is conveyed to, and passed through, either a knife planer or abrasive planer at which the widest faces of the piece are surfaced smooth. The output of this unit process is surfaced two sides (S2S) lumber ready for ripping and trimming. In addition, this process generates a useful class of byproduct: dry planer shavings.

Ripping

Ripping involves feeding dry, planed, random-width lumber along its length through a ripsaw to create a stock of desired and uniform widths. The fixed-width aspect of flooring often means that ripping is conducted before trimming, but some flooring manufacturers may reverse the order of their ripping and trimming unit processes. Generally, firms that trim first do so to optimize aspects of their component products. Ripsaws are classified as straight-line or multigrip. Both use circular saw blades but differ in the number of blades on a shaft. As the name implies, multigrip saws employ several blades running in parallel to execute multiple cuts in a single saw pass. During the ripping process, dry sawdust and edge trimmings are generated. Edgings may be used for value-added products such as moldings or parquet flooring furnish. In mills equipped with fuel conversion technologies, these byproducts also support energy generation for the plant. The output of the ripping process is a stock of uniform widths.

Trimming

The objective of the trimming process is to eliminate defects while cross-cutting the lumber into desired lengths using a chop saw. Many mills rely on a manual operator to determine and execute the cutting locations. Others have adopted optimization equipment with automated chop saws. The advantages of the latter approach include the potential for increased lumber yields, uniformity, and larger throughput. Removal of human operators reduces the likelihood of worker injury and variation in operator decisions across production shifts. Trim pieces generated by the cuttings serve as a useful byproduct and are often sent to in-house systems dedicated to energy production. The output of this process is a stock of desired lengths that are within defect tolerances required for the final flooring product.

Moulding: Side and End Matching

Because it changes the profile of the wood stock so drastically, the moulding process is among the most critical value-adding activities in secondary wood processing. The moulding process used in flooring has three main objectives. First, the lumber may be edge-matched. This is more commonly referred to as tongue and groove. Typically, a side-matcher modifies one edge of the wood blank lengthwise creating a protrusion. The opposite side is profiled such that a lengthwise gap is created. The protrusion face (tongue side) can now be received by the gap side (groove) of a similarly processed piece of wood. Most hardwood floors are installed by nailing down the alternating tongue and groove faces, and most flooring products also use an end-matcher to accomplish the same principle on the lumber ends (end matching). In this way, floor strips can be joined end to end over the length of a floor. Finally, although not featured in most finished flooring, a moulder can be used to put a lengthwise bevel along the top flooring face when the flooring is factory finished. Wood flour is generated and considered a byproduct, which can be used as fuel or a value-added furnish. Moulding profiles today are limited only by design and operator proficiency. Maintenance of the cutting heads can be time consuming and frequent. The output of the moulding process is unfinished, solid strip or plank, tongue and groove flooring.

Sorting

Sorting is a process that occurs throughout the production flow depicted in Figure 3. Because of the inherent character variations that normally occur in wood such as knots or color, sorting is conducted to ensure that flooring stock may realize its full potential value. As lumber is transformed into flooring during the manufacturing process, human operators or scanning technology organize the wood by visual characteristics, which ultimately determine the highest potential grade a piece of flooring may achieve. Manufacturers often differ in the number and location of sorts they perform. The intensity with which sorting is performed is often a direct result of species, lumber grade, and the final product mixes offered. The output of sorting units is uniformly grouped flooring stocks. The process may include manual labor, scanners, conveyor systems, and holding bins. Sorting was not included in the gate-to-gate LCI model. Sorting is labor intensive but does not consume significant material or energy inputs and outputs.

Prefinishing

Further value may be added to the flooring by applying a stain or protective coating to the wood. There are several common approaches to adding a finish. One method conveys the unfinished flooring through a series of spray booths where high-pressure air is used to distribute the coating over the wood. Because the spraying takes place in enclosed chambers, the excess coating material can be reclaimed for reuse and solvent emissions can be better captured. A second method makes use of large rollers similar to those used in residential or commercial painting. In this strategy, flooring passes beneath the rollers, which spread the coating. Vacuum coating represents a third approach. In this method, pressure differentials are used to force coatings into contact with the wood surface. Depending on the size and complexity of a particular manufacturer's product mix, combinations of these methods or hybrid forms of them may be used. Today's factory-applied finishes make use of sensors and scanning equipment to trigger precise amounts of desired coatings at equally precise start and stop times. After the flooring has received its finish, it is cured. Popular methods for curing include radiant heat, drying ovens, or exposure to ultraviolet (UV) light. Because it can cure stains and sealants in a matter of seconds, UV has become a desirable method. With changes in environmental regulations, coatings used to prefinish flooring have also evolved. Most notably, water-based coatings are gradually replacing traditional solvent-based finishes. In addition to application advantages, water-based coatings pose fewer burdens to the environment and human health. Prefinishing was not included in the initial gate-to-gate LCI because of problematic weighting and data quality. A subsequent LCI may be constructed for prefinished hardwood flooring using unfinished hardwood flooring as the product–material input.

Energy Generation

Energy generation refers to the process of combusting propane, wood, or natural gas to furnish useable on-site heat and electricity. This process is typically carried out with large boilers that produce hot water and steam, cogenerators that produce electricity, or a combination of the two. Outputs associated with energy generation include the produced energy as well as solid waste and emissions to air associated with combustion.

Emissions Control

This process captures wood dust, finishing gases, and other deleterious substances generated at a given unit process. Typical control devices include cyclones and baghouses. Finish and coating lines use closed spray booths to reclaim furnish and volatile organics. Emission control devices use fossil fuels, wood waste, electricity, and water to operate. Collected process emissions are re-used as input furnishes (e.g., wood dust to boiler fuel feedstock) or physically disposed of outside the mill.

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 lumber is realized into products, coproducts, and waste. A recovery of 48.2% was observed in this study. In other words, to produce 1.0 m^3 of solid hardwood flooring, 2.08 m^3, or 1,323 OD kg, of input lumber were needed. The remaining 1.08 m^3 of input lumber were classified as wood residue. The wood residue is sold off site or used on site as hogged fuel for heat generation. Values were obtained by dividing the weight of wood in hardwood flooring by the total weight of input lumber and multiplying by 100%. Findings here are consistent with previous yield studies reported for this product (Bond and others 2007, Hosterman 2000, Hubbard and Bowe 2008).

To account for all wood reported as input and output to flooring manufacturers, a mass balance was performed (Table 5). To yield 614 kg/m^3 (OD basis) of solid strip hardwood flooring, 1,274 kg of hardwood lumber was needed. A difference of 0.2 kg/m^3 was observed between the total recorded wood input and output. The unaccounted wood was <1% of the total wood input. This amount of unaccounted wood was considered excellent for a survey of this magnitude.

Production Energy

Energy Sources

Solid hardwood flooring production uses several energy sources. Purchased electricity is a key source and is used to operate conveyance and pneumatic equipment as well as saws, planers, molders (matches), and emission control devices. Thermal energy is used to operate kilns and for facility heating. For the on-site system boundary in this study, thermal energy is confined to facility heating. Energy use associated with kiln-drying the hardwood lumber is accounted for in the cumulative system boundary through a hardwood lumber production model input (Hubbard and others 2020, Heidari and others 2023, Bergman 2021). All mills except one used industrial boilers to combust wood residue (hogged fuel) generated on site to provide thermal energy. On-site forklifts, trucks, and carriers relied on gasoline, diesel fuel, and liquid propane gas.

Electrical Usage

Purchased electricity (off-site electrical grid) required to operate the machine centers was reported by 13 of the 16 respondent mills. For the on-site system boundary, to produce 1.0 m^3 of solid hardwood flooring (prefinishing stage), 224.9 kWh of electricity was consumed (Table 6).

Table 6—Survey data input to hardwood flooring model by type required to produce 1.0 m^3 of solid hardwood flooring

Inputs to the model	Quantity in SI units per 1.0 m^3	Weighted coefficient of variation (CoV_w) (%)
Materials		
Wood		
Rough green hardwood lumber	661 OD kg	11.13
Rough kiln-dry hardwood lumber	662 OD kg	9.3
Water		
From ground	153 L	127
Packaging		
Steel strapping, cold rolled	0.003 kg	
Fuels		
Electricity		
Purchased	225 kWh	128
Wood hogged fuel		
Wood residue produced on site	660 OD kg	96
Fossil		
Natural gas	4.76 m^3	98
On-site transportation		
Off-road diesel	2.93 L	49
Propane	0.83 L	39
Gasoline	0.08 L	43
Emissions		
To air		
Particulates, unspecified	0.024 kg	99
To water		
Discharged to sewer or surface	—	
To land		
Fly ash	0.30 kg	129

Mills were unable to provide a percentage allocation of electrical use per unit process. By comparison, electrical use for the cumulative system boundary, which included hardwood lumber production, was 344.9 kWh.

Thermal Usage

Wood residue produced on site is used to fuel on-site boilers. The extraneous wood residue is sold off site as value-added furnish. No mills in this study reported that they purchase wood residue because they can meet internal demands. Thermal energy (associated with the production of 1.0 m^3 of flooring) produced on site for facility heating required 497 OD kg/m^3 of wood residue.

Energy Requirements

Electricity is the most prevalent form of energy used in the system boundary for hardwood flooring manufacture. Thermal energy produced by combusting wood in on-site boilers is second followed by fossil fuels natural gas and fuel oil. The eastern region produces most of its electricity through a variety of fuel sources. Unlike the Pacific Northwest region, little is produced by hydropower. The average composition of off-site electrical generation was determined for the eastern region by averaging U.S. Department of Energy values given for the northeast–north central region and those reported for southeastern states (USEIA 2022). Table 6 includes electrical power requirements for both the on-site flooring system in isolation and with eastern hardwood lumber production (Bergman 2012, Heidari and others 2023).

On-Site Transportation Fuel Use

The on-site transport and handling of materials throughout a flooring mill are accomplished through the use of forklifts, trucks, skid steers, and other carriers. Three primary fuel sources power this machinery. These are off-road diesel fuel, propane, and gasoline. To produce the functional unit of hardwood flooring, off-road diesel was the fuel type with the largest contribution at 2.93 m^3/m^3, followed by propane and gasoline at 0.83 and 0.08 L/m^3, respectively (Table 6).

Water Consumption

Water use in the production of solid hardwood flooring can occur in three primary areas: human use, prefinishing operations use, and boiler use. Consistent with the system boundary and established protocol, human water use on site (bathrooms, drinking water, etc.) and water used in prefinishing operations were not included in this report. Therefore, the results presented in this report are based on the weighted-average amount of water used for on-site industrial boilers. The reader is reminded that only water required in boilers (maintenance and facility heating) is considered on site. Based on the weight-averaged responses for 16 mills, 152.88 L of groundwater was used in the production of 1.0 m^3 of solid flooring.

Water use is much higher when the production of lumber is included. This is due in large part to sprinkling systems or holding ponds used to control yard dust and sapstain fungi at sawmills. The hardwood lumber module introduces 28.57 L of water to the cumulative boundary flooring model. Table 6 shows the on-site data collected in the surveys that were input to the SimaPro model software. The data in the table do not include values for the production of hardwood lumber. Table 6 shows that hardwood flooring manufacture is a relatively straightforward process.

Module A4: Product Transportation

The A4 module consists of total distances between (i) the manufacturing facility to the distributor center and (ii) the distribution center to the installation sites (Khatri and others 2021). This study did not collect the transportation distance from the solid wood flooring manufacturing facility to the installation site. Therefore, we assumed a transport distance of 800 km (Table 7) from the solid wood flooring manufacturing facility to the installation site as recommended by the PCR (ULE 2018b). It was also assumed that solid wood flooring products were transported in diesel-powered trucks only.

Module A5: Installation

The A5 module consists of flooring installation in a building. Installation of hardwood flooring does not require many inputs such as electricity and consumables. The inventory (Balasbaneh and others 2021) for the installation of 1 m^2 of hardwood flooring (nailed only) is provided in Table 8.

During installation, between about 1.5% and 4.0% of mass loss occurred depending on the type of flooring product (Nebel and others 2006). In this study, it was assumed that about 1.5% mass loss of hardwood flooring occurred during installation (Nebel and others 2006). Both flooring waste and waste from packaging were considered to be disposed of in the landfill. Because we assumed no energy was used during installation of the hardwood flooring, we did not collect data for energy use during the installation process, based on the PCR guidelines (ULE 2018b).

Modules B1-B7: Use Stage

The use stage of the hardwood 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 and water in B6 and B7 were not relevant; therefore, these modules were omitted. Similarly, refurbishment (B5) was not considered due to 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 9) (Bergman 2012, Minne and Crittenden 2015, Ros-Dosdá and others 2019). The B4 stage was considered but because the RSL was 75 years, no replacement was needed.

Vacuuming is not a typical activity for hardwood solid flooring. However, if a vacuum was used, then it was assumed that hardwood flooring was vacuumed once a week. Energy use of 1.5 kW (Ros-Dosdá and others 2019) and vacuum time of 12 s/m^2 (Minne and Crittenden 2015) were assumed. Mopping is the typical activity to clean hardwood flooring. It was assumed that hardwood flooring was mopped once a month with water (0.1 L/m^2) and cleaning agents (0.0001 kg/m^2). The RSL of hardwood flooring was considered to be 75 years with a replacement cycle of 1 for the ESL of a building of 75 years. It was assumed repair of hardwood 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.

Modules C1-C4: End-of-Life Stage

At the end of its life, hardwood flooring is demolished (C1), waste is transported to the site of the disposal (C2), the waste is processed (C4), and the waste is disposed of (C4). Energy and fuel used during demolition of hardwood flooring are extremely low and thus were omitted from this study. It was considered that the demolished building waste (including flooring) is transported in trucks to the disposal site, which is assumed to be 161 km from the installation site (Table 10).

In the United States, 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 11).

Module D: Potential Benefits

The D stage provides the net benefits achieved during the disposal of a product. It was assumed that landfilled

Table 7—Transportation of solid hardwood flooring from the 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	667.21	Dry kg/m^3

Table 8—Installation of solid hardwood flooring at the site

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

Table 9—Life-cycle inventory for solid hardwood flooring in the use stage at the use site

Description	Value	Unit
Net freshwater consumption specified by water source and fate	0.09	m^3/m^2
Ancillary materials specified by type (e.g., cleaning agent)	0.09	kg/m^2
Electricity (vacuum)[a]	0 or18	kWh/m^2
Cleaning chemicals	0.09	kg/m^2
Maintenance coat (new coat of finish)	6.19	kg/m^2
Wax	2.48	kg/m^2
Electricity (coating)	0.31	kWh/m^2
Repair cycle	7.50	Cycles/RSL
Reference service life (RSL)	75.00	Years
Replacement cycle	1.00	Cycles/ESL

[a]No electricity was used when no vacuum was considered, and 18 kWh/RSL were used when the vacuum was considered.

Table 10—Transportation of solid hardwood flooring from installation site to disposal site

Description	Value	Unit
Vehicle type	Truck	—
Fuel type	Diesel	—
Transport distance	161.0	km

Table 11—Types of solid hardwood flooring disposal and quantity by type after flooring end-of-life

Description	Value	Unit
Landfill	9.87	kg/m^2 RSL
Used for fuel	2.19	kg/m^2 RSL

hardwood lumber flared the methane generated in the landfill and thus no benefits were achieved except for storing carbon in the landfill. Hardwood 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 purposes displaced about 0.483 m^3 of natural gas.

Data Collection, Quality, and Assumptions

Primary Data Collection

The survey instrument sent to flooring manufacturers contained a section devoted to detailed inputs and outputs specific to each unit process. A majority of responding mills indicated the level of detail in this section was too difficult to assess accurately and indicated 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. The National Wood Flooring Association identified representative mills and provided detailed contact information for each. Self-administered questionnaires were mailed, and 16 companies responded. The survey was externally reviewed by members of CORRIM, scientists at the University of Wisconsin-Madison, and employees at the USDA Forest Service, Forest Products Laboratory. It was then pretested with a large flooring manufacturer in the study region. The cover letter and complete survey are given in Appendixes 1 and 2. All participating companies were assured confidentiality and asked to fill out individual questionnaires for each mill with dedicated production to solid hardwood flooring.

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 the wood resources production, transport, adhesive, and wax production. Sources for secondary data are listed in Table 12.

Data Quality and Assumptions

The annual production of solid hardwood flooring for the entire United States in 2020 was an estimated 82.5 million m^2 (Feldman 2021). Regional production figures were not found. For the reporting year 2020, the amount of solid hardwood flooring produced by mills surveyed in this study totaled 305,280 m^2. This represents nearly 19.4% of total U.S. hardwood flooring production. 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 covers the reporting year 2019.
- Consistent with previous CORRIM studies (Bergman and Bowe 2008, 2011; Hubbard and Bowe 2008), 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:

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

  where $\overline{P}_{\text{weighted}}$ 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 NHLA (NHLA 2003, 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).
- A single density value for flooring and input lumber was derived by calculating the OD weight of weight-averaged species input for reported flooring production. Input lumber was not broken down by species in the survey and was assumed to correspond with weight-averaged contributions determined for flooring species. The calculated density value for flooring was 613.84 kg/m^3.

Table 12—Secondary data sources and data quality assessment

Input	LCI data source	Geography	Year	Data quality assessment
		A1: raw material extraction		
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
Rough dry lumber	Sawn lumber, hardwood, rough, kiln-dried, US SE-NE-NC/m^3 Sawn lumber, hardwood, rough, kiln-dried, at kiln, SE/m^3/RNA	US NE/NC, SE	2014	Technology: good; processes represent U.S. average production – modified with U.S. electricity Time: good; data are less than 5 years old Geography: good; data are U.S. specific
		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 represent 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: fair; data are representative of global processes

- Rough kiln-dry lumber input was reported in board feet and converted to cubic meters with the conversion factor of 2.36 (Briggs 1994). Conversion from the reported square footage of produced flooring to cubic meters was done in a commercial spreadsheet based on actually reported thicknesses for each flooring width classification.
- For the wood mass balance, 0.2 kg/m^3 (OD basis) was unaccounted for and was assumed to be fugitive wood waste. This unaccounted mass is <1% of the total mass.
- The energy content of fuels in this report is presented as their lower heating values (LHV). This method is preferred in the United States.
- Impacts associated with kiln-drying are included in an expanded gate-to-gate analysis through the hardwood lumber input to the flooring model developed in a parallel gate-to-gate inventory model for hardwood lumber production (Bergman and Bowe 2008). The hardwood lumber module documents four unit processes (sawing, energy generation, drying, and planing) required to produce hardwood lumber in the southeastern region of the United States (Bergman and Bowe 2008).

Secondary data for the hardwood flooring gate-to-gate LCI was processed using SimaPro life-cycle assessment software version 9.1.0.8 (PRé Consultants 2021). SimaPro utilizes internationally recognized standards for environmental management and standardized LCI 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

This LCA study was performed to create an average EPD that represents the solid hardwood flooring produced by several flooring manufacturers represented by the NWFA in the United States. Surveys were sent to all members of the NWFA located in the two subregions of the eastern United States: the northeast and the southeast (Fig. 2). Both email and postal mail were used to share and collect the surveys for the primary data collection. Sixteen members (solid wood flooring manufacturers) participated, which represented 19.4% of total U.S. hardwood flooring production. A weighted average method (Eq. (1)) was used to process all the input data and develop an 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.

Life-Cycle Impact Assessment

Method

The LCIA is the crucial phase of the LCA study. It establishes links between the LCI results and potential environmental impacts. This study used the TRACI, CED, and CML methods to determine environmental impacts (Bare 2011) associated with the production, use, and end-of-life of 1.0 m^2 of hardwood flooring in the eastern region of the United States. Reporting categories, indicator names, and measurement units are summarized (Table 13) (estimated based on the inventory-based approach).

Results

Cradle-to-Gate

Table 14 shows the cradle-to-gate life-cycle impacts of solid hardwood flooring. The LCIA results here do not have predictive power on category endpoints, safety margins, risk, or outcomes if thresholds are exceeded. Overall, hardwood flooring cradle-to-gate global warming (GW) impact was 9.79 kg CO_2eq/m^2 of flooring. Production of flooring (A3) contributed more than 50% of the total cradle-to-gate GW impact. Overall, hardwood flooring consumed 269.5 MJ of energy per square meter of hardwood flooring in which 41% was coming from burning biomass residues in the cogeneration boilers. The A1 module contributed substantially to other major environmental indicators, including acidification, smog formation, and water consumption.

Cradle-to-Grave

Table 15 presents the results for the cradle-to-grave life-cycle impacts with weighted average EoL treatment considered (82% landfill, 18% incineration). Tables 16 and 17 show the individual cradle-to-grave life-cycle impacts resulting from landfilling and incineration at EoL, respectively. Among all stages of hardwood flooring, the use stage had the largest GW impact (70% of cradle-to-grave GW impact), which mainly came from the finishing and refinishing chemicals (Table 15). The remaining stages, especially the production stage (A1-A3), contributed a significant (40% of total) GW impact. Each 1 m^2 of hardwood flooring consumed 610.54 (124.14 + 486.40) MJ of energy, and about 79.67% of the total primary energy used came from nonrenewable sources, especially fossil sources. Overall, cradle-to-grave GW impacts of hardwood flooring were 26.72 kg CO_2eq/m^2 considering landfill as the EoL option (Table 16). However, considering carbon storage (module C4), the overall GW impact was decreased to 9.16 kg CO_2eq/m^2.

Table 17 shows that the burning of hardwood flooring waste at EoL could provide benefits, but the fact that all carbon stored in the wood is released into the atmosphere must be considered. Overall, the GW impact of burning the waste (considering both fossil and biogenic) was 26.33 kg CO_2eq/m^2. However, considering the credit (–13.05 kg CO_2eq/m^2) from energy generated from burning the wood, the net GW impact (Stages A-D) was decreased to only 13.28 kg CO_2eq/m^2. In summary, the net cradle-to-grave

Table 13—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, total	GWP_{total}	kg CO_2eq
Core mandatory impact indicators	Global warming potential, fossil	GWP_{fossil}	kg CO_2eq
Core mandatory impact indicators	Global warming potential, biogenic	$GWP_{biogenic}$	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	Nonrenewable 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	CWNR	kg CO_2eq

GW impacts (Stages A-D) (fossil + biogenic) of solid wood flooring were 9.16 and 13.28 kg CO_2eq/m^2 for EoL as landfill and incineration, respectively. In addition, Tables 18 to 20 show the percentage contributions for each information module from cradle-to-grave for the weighted average treatment EoL, landfill EoL, and burning EoL, respectively.

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. Carbon removal is considered a negative emission (Bergman and others 2014, Brashaw and Bergman 2021). The biogenic carbon leaves the system (emission) as a product, as a byproduct, 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 of 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 (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 section 7.2.1 note 2 states the

Table 14—Cradle-to-gate environmental impacts of 1.0 m^2 of solid hardwood flooring

Impact indicator[a]	Unit	A1-A3	A1	A2	A3
Core mandatory					
GWP_{total}	kg CO_2eq	9.793	–47.854	0.769	56.878
GWP_{fossil}	kg CO_2eq	9.793	4.103	0.769	4.921
$GWP_{biogenic}$	kg CO_2eq	0.000	–51.957	0.000	51.957
ODP	kg CFC11eq	7.06E–07	1.79E–07	2.93E–11	5.27E–07
AP	kg SO_2eq	0.053	0.025	0.005	0.024
EP	kg Neq	0.038	0.014	0.000	0.023
SFP	kg O_3eq	0.997	0.557	0.125	0.315
ADP fossil	MJ, NCV	105.913	51.975	9.894	44.044
FFD	MJ surplus	12.652	6.118	1.474	5.060
Use of primary resources					
RPRE	MJ, NCV	112.027	44.451	0.000	67.577
RPRM	MJ, NCV	236.301	236.301	0.000	0.000
NRPRE	MJ, NCV	157.490	65.060	9.938	82.492
NRPRM	MJ, NCV	0.000	0.000	0.000	0.000
Secondary material, secondary fuel, and recovered energy					
SM	kg	0.000	0.000	0.000	0.000
RSF	MJ, NCV	130.601	0.000	0.000	130.601
NRSF	MJ, NCV	0.000	0.000	0.000	0.000
RE	MJ, NCV	0.000	0.000	0.000	0.000
Mandatory inventory parameters					
FW	m^3	0.019	0.011	0.000	0.008
Indicators describing waste					
HWD	kg	0.068	0.063	0.000	0.005
NHWD	kg	0.409	0.247	0.000	0.162
HLRW	m^3	0.000	0.000	0.000	0.000
ILLRW	m^3	0.000	0.000	0.000	0.000
CRU	kg	0.000	0.000	0.000	0.000
MR	kg	0.000	0.000	0.000	0.000
MER	kg	0.000	0.000	0.000	0.000
EE	MJ, NCV	0.000	0.000	0.000	0.000

[a]See Table 13 for definitions of abbreviations.

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." Canada and the United States UNFCCC annual reports table 6-1 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.). 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. Emissions other than CO_2 associated with biomass combustion (e.g., methane or nitrogen oxides) are characterized by their specific radiative forcing factors.

The Underwriters Laboratories Environment (ULE) PCR Part A (ULE 2018a) 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 emissions. The biogenic CO_2 component is shown in detail in Table 21.

Table 21 shows that the landfill scenario causes a net removal of biogenic carbon from the atmosphere equivalent to 17.55 kg CO_2eq. This is caused by the permanent storage of 92% of biogenic carbon that enters the landfill; only 8% of the wood decomposes (EPA 2022). ULE's wood product PCR adopted EPA's Waste Reduction Model (WARM)

Table 15—Environmental impacts of 1.0 m^2 of solid hardwood flooring – weighted 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	12.27	9.91	–12.32	0.91	0.17	0.00	12.26	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	8.20	–2.36
GWP_{fossil}	kg CO_2eq	26.65	24.28	9.79	0.91	0.17	0.00	12.26	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.47	–2.36
$GWP_{biogenic}$	kg CO_2eq	–14.37	–14.37	–22.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.74	0.00
ODP	kg CFC11eq	4.7E–06	4.7E–06	7.1E–07	1.5E–09	1.2E–09	0.0E+00	1.6E–06	2.4E–06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E–10	0.0E+00	5.9E–09	–5.0E–10
AP	kg SO_2eq	0.17	0.17	0.05	0.01	0.00	0.00	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EP	kg Neq	0.14	0.14	0.04	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
SFP	kg O_3eq	1.90	1.86	1.00	0.15	0.01	0.00	0.55	0.15	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.02	–0.04
ADP fossil	MJ, NCV	389.37	356.17	105.91	11.42	1.51	0.00	123.66	143.62	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.94	–33.20
FFD	MJ surplus	51.98	46.45	12.65	1.72	0.07	0.00	15.51	21.60	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.08	–5.52
Use of primary resources																		
RPRE	MJ, NCV	124.14	124.14	112.03	0.02	0.02	0.00	3.85	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.63	0.00
RPRM	MJ, NCV	236.30	236.30	236.30	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	486.40	449.52	157.49	12.30	1.64	0.00	157.48	153.98	0.00	0.00	0.00	0.00	0.00	2.48	0.00	1.04	–36.88
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	130.60	130.60	130.60	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
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	0.40	0.40	0.02	0.00	0.00	0.00	0.37	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.07	0.07	0.07	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	0.41	0.41	0.41	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
HLRW	m^3	2.0E–08	2.0E–08	5.3E–09	9.0E–11	1.5E–11	0.0E+00	1.4E–08	8.8E–10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E–11	0.0E+00	2.5E–11	–1.8E–11
ILLRW	m^3	5.2E–07	5.2E–07	4.4E–08	4.3E–10	7.1E–11	0.0E+00	6.5E–08	4.1E–07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.7E–11	0.0E+00	1.2E–10	–8.7E–11
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 13 for definitions of abbreviations.

Table 16—Environmental impacts of 1.0 m² of solid hardwood flooring – landfilling 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, landfill	D, landfill
Core mandatory																		
GWP_{total}	kg CO_2eq	9.16	9.16	−12.32	0.91	0.17	0.00	12.26	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	5.09	0.00
GWP_{fossil}	kg CO_2eq	26.72	26.72	9.79	0.91	0.17	0.00	12.26	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.54	0.00
$GWP_{biogenic}$	kg CO_2eq	−17.55	−17.55	−22.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.55	0.00
ODP	kg CFC11eq	4.7E−06	4.7E−06	7.1E−07	1.5E−09	1.2E−09	0.0E+00	1.6E−06	2.4E−06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E−10	0.0E+00	7.2E−09	0.0E+00
AP	kg SO_2eq	0.17	0.17	0.05	0.01	0.00	0.00	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EP	kg Neq	0.15	0.15	0.04	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00
SFP	kg O_3eq	1.89	1.89	1.00	0.15	0.01	0.00	0.55	0.15	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00
ADP fossil	MJ, NCV	389.11	389.11	105.91	11.42	1.51	0.00	123.66	143.62	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.68	0.00
FFD	MJ surplus	51.99	51.99	12.65	1.72	0.07	0.00	15.51	21.60	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.09	0.00
Use of primary resources																		
RPRE	MJ, NCV	116.53	116.53	112.03	0.02	0.02	0.00	3.85	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
RPRM	MJ, NCV	236.30	236.30	236.30	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	486.14	486.14	157.49	12.30	1.64	0.00	157.48	153.98	0.00	0.00	0.00	0.00	0.00	2.48	0.00	0.78	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	130.60	130.60	130.60	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
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	0.40	0.40	0.02	0.00	0.00	0.00	0.37	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.07	0.07	0.07	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	0.41	0.41	0.41	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
HLRW	m^3	2.0E−08	2.0E−08	5.3E−09	9.0E−11	1.5E−11	0.0E+00	1.4E−08	8.8E−10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E−11	0.0E+00	3.1E−11	0.0E+00
ILLRW	m^3	5.2E−07	5.2E−07	4.4E−08	4.3E−10	7.1E−11	0.0E+00	6.5E−08	4.1E−07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.7E−11	0.0E+00	1.5E−10	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 13 for definitions of abbreviations.

Table 17—Environmental impacts of 1.0 m² of solid hardwood flooring – incineration with energy recovery at end-of-life

Impact indicator[a]	Unit	A-C	A-D	A1-A3	A4	A5	B1-B5	B1-B6	B1-B7	B1-B8	B1-B9	B6-B7	B6-B8	C1	C2	C3	C4, incineration	D, incineration
Core mandatory																		
GWP_{total}	kg CO_2eq	26.33	13.28	–12.32	0.91	0.17	0.00	12.26	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	22.26	–13.05
GWP_{fossil}	kg CO_2eq	26.33	13.28	9.79	0.91	0.17	0.00	12.26	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.15	–13.05
$GWP_{biogenic}$	kg CO_2eq	0.00	0.00	–22.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.11	0.00
ODP	kg CFC11eq	4.7E–06	4.7E–06	7.1E–07	1.5E–09	1.2E–09	0.0E+00	1.6E–06	2.4E–06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E–10	0.0E+00	2.4E–12	–2.7E–09
AP	kg SO_2eq	0.17	0.16	0.05	0.01	0.00	0.00	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–0.01
EP	kg Neq	0.08	0.08	0.04	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SFP	kg O_3eq	1.95	1.71	1.00	0.15	0.01	0.00	0.55	0.15	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.07	–0.25
ADP fossil	MJ, NCV	390.56	207.39	105.91	11.42	1.51	0.00	123.66	143.62	0.00	0.00	0.00	0.00	0.00	2.30	0.00	2.13	–183.17
FFD	MJ surplus	51.90	21.43	12.65	1.72	0.07	0.00	15.51	21.60	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	–30.47
Use of primary resources																		
RPRE	MJ, NCV	158.55	158.53	112.03	0.02	0.02	0.00	3.85	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42.03	–0.03
RPRM	MJ, NCV	236.30	236.30	236.30	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	487.58	284.13	157.49	12.30	1.64	0.00	157.48	153.98	0.00	0.00	0.00	0.00	0.00	2.48	0.00	2.22	–203.45
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	130.60	130.60	130.60	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
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	0.02	0.00	0.00	0.00	0.37	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.07	0.07	0.07	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	0.41	0.41	0.41	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
HLRW	m^3	2.0E–08	2.0E–08	5.3E–09	9.0E–11	1.5E–11	0.0E+00	1.4E–08	8.8E–10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E–11	0.0E+00	0.0E+00	–9.9E–11
ILLRW	m^3	5.2E–07	5.2E–07	4.4E–08	4.3E–10	7.1E–11	0.0E+00	6.5E–08	4.1E–07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.7E–11	0.0E+00	0.0E+00	–4.8E–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 13 for definitions of abbreviations.

Table 18—Percentage contribution of various life-cycle stages on the total environmental impacts of 1.0 m² of solid hardwood 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}	–124	9	2	0	124	29	0	0	0	0	0	2	0	83	–24
GWP_{fossil}	40	4	1	0	50	12	0	0	0	0	0	1	0	2	–10
$GWP_{biogenic}$	154	0	0	0	0	0	0	0	0	0	0	0	0	–54	0
ODP	15	0	0	0	33	52	0	0	0	0	0	0	0	0	0
AP	32	3	0	0	53	13	0	0	0	0	0	1	0	1	–1
EP	28	0	2	0	24	4	0	0	0	0	0	0	0	41	0
SFP	54	8	0	0	29	8	0	0	0	0	0	2	0	1	–2
ADP fossil	30	3	0	0	35	40	0	0	0	0	0	1	0	0	–9
FFD	27	4	0	0	33	46	0	0	0	0	0	1	0	0	–12
Use of primary resources															
RPRE	90	0	0	0	3	0	0	0	0	0	0	0	0	6	0
RPRM	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRPRE	35	3	0	0	35	34	0	0	0	0	0	1	0	0	–8
NRPRM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary material, secondary fuel, and recovered energy															
SM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RSF	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRSF	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mandatory inventory parameters															
FW	5	0	0	0	91	5	0	0	0	0	0	0	0	0	0
Indicators describing waste															
HWD	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NHWD	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HLRW	26	0	0	0	69	4	0	0	0	0	0	0	0	0	0
ILLRW	8	0	0	0	12	79	0	0	0	0	0	0	0	0	0
CRU	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MER	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
EE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a]See Table 13 for definitions of abbreviations.

Table 19—Percentage contribution of various life-cycle stages on the total environmental impacts of 1.0 m² of solid hardwood flooring – landfilling at end-of-life

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}	–134	10	2	0	134	31	0	0	0	0	0	2	0	56	0
GWP_{fossil}	37	3	1	0	46	11	0	0	0	0	0	1	0	2	0
$GWP_{biogenic}$	126	0	0	0	0	0	0	0	0	0	0	0	0	–26	0
ODP	15	0	0	0	33	52	0	0	0	0	0	0	0	0	0
AP	31	3	0	0	52	12	0	0	0	0	0	1	0	0	0
EP	25	0	2	0	22	4	0	0	0	0	0	0	0	46	0
SFP	53	8	0	0	29	8	0	0	0	0	0	2	0	1	0
ADP fossil	27	3	0	0	32	37	0	0	0	0	0	1	0	0	0
FFD	24	3	0	0	30	42	0	0	0	0	0	1	0	0	0
Use of primary resources															
RPRE	96	0	0	0	3	1	0	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	32	2	0	0	32	32	0	0	0	0	0	0	0	0	0
NRPRM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary material, secondary fuel, and recovered energy															
SM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RSF	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRSF	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mandatory inventory parameters															
FW	5	0	0	0	91	5	0	0	0	0	0	0	0	0	0
Indicators describing waste															
HWD	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NHWD	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HLRW	26	0	0	0	69	4	0	0	0	0	0	0	0	0	0
ILLRW	8	0	0	0	12	79	0	0	0	0	0	0	0	0	0
CRU	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MER	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
EE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a]See Table 13 for definitions of abbreviations.

Table 20—Percentage contribution of various life-cycle stages on the total environmental impacts of 1.0 m² of solid hardwood flooring – incineration with energy recovery at end-of-life

Impact indicator[a]	A1-A3	A4	A5	B1-B5	B1-B6	B1-B7	B1-B8	B1-B9	B6-B7	B6-B8	C1	C2	C3	C4, incineration	D, incineration
Core mandatory															
GWP_{total}	–93	7	1	0	93	22	0	0	0	0	0	1	0	168	–99
GWP_{fossil}	74	7	1	0	93	22	0	0	0	0	0	1	0	1	–99
$GWP_{biogenic}$	–100	0	0	0	0	0	0	0	0	0	0	0	0	100	0
ODP	15	0	0	0	33	52	0	0	0	0	0	0	0	0	0
AP	33	3	0	0	54	13	0	0	0	0	0	1	0	2	–6
EP	47	1	4	0	42	8	0	0	0	0	0	0	0	0	–1
SFP	59	8	0	0	32	9	0	0	0	0	0	2	0	4	–14
ADP fossil	51	5	1	0	60	69	0	0	0	0	0	1	0	1	–89
FFD	59	8	0	0	73	101	0	0	0	0	0	2	0	0	–143
Use of primary resources															
RPRE	71	0	0	0	2	0	0	0	0	0	0	0	0	27	0
RPRM	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRPRE	56	4	1	0	56	54	0	0	0	0	0	1	0	1	–72
NRPRM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary material, secondary fuel, and recovered energy															
SM	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RSF	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NRSF	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mandatory inventory parameters															
FW	5	0	0	0	91	5	0	0	0	0	0	0	0	0	0
Indicators describing waste															
HWD	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NHWD	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HLRW	26	0	0	0	69	4	0	0	0	0	0	0	0	0	0
ILLRW	8	0	0	0	12	79	0	0	0	0	0	0	0	0	0
CRU	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MER	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
EE	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[a]See Table 13 for definitions of abbreviations.

Table 21—Biogenic carbon inventory indicators for solid hardwood flooring

Additional inventory parameter	Unit	A1	A3	C4 landfill scenario	C4 incineration scenario	C4 avg.
Biogenic carbon removal from product	kg CO_2	–51.96	—	—	—	—
Biogenic carbon emission from product	kg CO_2	—	29.85	4.55	22.11	7.74
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 scenario	kg CO_2	–17.55				
Net biogenic carbon emission incineration scenario	kg CO_2	—				
Average end-of-life treatment	kg CO_2	–17.55				

estimations and published those assumptions under addendum 1 as a part of the PCR.

Scenario Analysis

The RSL of the products and the assumptions of vacuuming used for floor cleaning were among the input parameters that had significant impacts on the results. Tables 22, 23, and 24 show the cradle-to-grave life-cycle impacts of solid hardwood flooring for three scenarios (Scenario 1 was RSL = 75, vacuuming = yes; Scenario 2 was RSL = 44, vacuuming = no; Scenario 3 was RSL = 44, vacuuming = yes). Scenarios 2 and 3 require a partial replacement of 0.7 m^2 over the ESL of 75 years (B4). Compared with the base case, assuming vacuuming for solid hardwood flooring once a week can increase the GW impact by 46% to 38.91 kg CO_2eq (Table 22). Similarly, considering the lower RSL (i.e., 44 years) of the solid hardwood flooring, the GW impacts increased by 85% compared with the base case (Table 23). Also compared with the base case, the GW impact increased by about 2.6 times when the lower RSL and vacuuming were considered (Table 24).

Completeness and Consistency Checks

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

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

Conclusion

This study provides a cradle-to-grave LCA of the production of solid hardwood flooring in the eastern United States. The primary goal of this LCA was to develop LCI data and impact assessment results for solid hardwood flooring that could be used to develop an EPD. System boundaries in this study included all stages of the life cycle, starting with raw material extraction and ending with disposal of the product after its useful life. A functional unit of 1 m^2 of flooring (for 75 years of ESL) was considered to present the LCA results. This study followed the guidelines of the ISO standards and PCR, ULE Part A (Building-Related Products and Services) PCR and Part B (Flooring EPD Requirements) PCR. Primary data were collected along the supply chain using surveys. Data not available from the surveys were supplemented from literature and industry experts. The cradle-to-grave life-cycle GWP was estimated to be 26.65 kg CO_2eq per 1 m^2 of solid hardwood flooring. Considering biogenic carbon emissions, the net GWP was decreased to 12.27 kg CO_2eq as a part of carbon stored in the landfill. Every square meter of solid hardwood flooring consumed 610.5 MJ of energy, and only 20.3% of the total primary energy used came from biomass. This study showed that solid hardwood flooring is a low carbon footprint material. It stored carbon (14.37 kg CO_2eq/m^2 flooring) in the long-term, which can help mitigate climate change. This LCA report provides all required impact assessment results and LCI parameters. The cradle-to-grave LCA incorporates the necessary scope to develop a "business-to-consumer" EPD in accordance with the ULE PCR Part A and Part B.

Table 22—Environmental impacts of 1.0 m² of solid hardwood flooring – average end-of-life treatment (Scenario 1: RSL = 75, vacuuming = yes)

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	24.54	22.18	–12.32	0.91	0.17	0.00	24.52	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	8.20	–2.36
GWP_{fossil}	kg CO_2eq	38.91	36.55	9.79	0.91	0.17	0.00	24.52	2.86	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.47	–2.36
$GWP_{biogenic}$	kg CO_2eq	–14.37	–14.37	–22.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.74	0.00
ODP	kg CFC11eq	5.7E–06	5.7E–06	7.1E–07	1.5E–09	1.2E–09	0.0E+00	2.6E–06	2.4E–06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E–10	0.0E+00	5.9E–09	–5.0E–10
AP	kg SO_2eq	2.1E–01	2.1E–01	5.3E–02	5.0E–03	6.2E–04	0.0E+00	1.3E–01	2.1E–02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E–03	0.0E+00	9.3E–04	–1.8E–03
EP	kg Neq	2.4E–01	2.4E–01	3.8E–02	4.7E–04	3.2E–03	0.0E+00	1.3E–01	6.1E–03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.4E–05	0.0E+00	5.6E–02	–2.0E–04
SFP	kg O_3eq	2.21	2.16	1.00	0.15	0.01	0.00	0.85	0.15	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.02	–0.04
ADP fossil	MJ, NCV	521.80	488.60	105.91	11.42	1.51	0.00	256.09	143.62	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.94	–33.20
FFD	MJ surplus	60.74	55.22	12.65	1.72	0.07	0.00	24.28	21.60	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.08	–5.52
Use of primary resources																		
RPRE	MJ, NCV	135.42	135.42	112.03	0.02	0.02	0.00	15.12	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.63	0.00
RPRM	MJ, NCV	236.30	236.30	236.30	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	685.71	648.83	157.49	12.30	1.64	0.00	356.79	153.98	0.00	0.00	0.00	0.00	0.00	2.48	0.00	1.04	–36.88
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	130.60	130.60	130.60	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
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	0.46	0.46	0.02	0.00	0.00	0.00	0.43	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.07	0.07	0.07	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	0.41	0.41	0.41	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
HLRW	m^3	5.3E–08	5.3E–08	5.3E–09	9.0E–11	1.5E–11	0.0E+00	4.7E–08	8.8E–10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E–11	0.0E+00	2.5E–11	–1.8E–11
ILLRW	m^3	7.8E–07	7.8E–07	4.4E–08	4.3E–10	7.1E–11	0.0E+00	3.2E–07	4.1E–07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.7E–11	0.0E+00	1.2E–10	–8.7E–11
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 13 for definitions of abbreviations.

Table 23—Environmental impacts of 1.0 m² of solid hardwood flooring – average end-of-life treatment (Scenario 2: RSL = 44, vacuuming = no)

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	11.18	6.93	–12.32	0.91	0.17	0.00	12.94	3.18	–2.10	0.00	0.00	0.00	0.00	0.18	0.00	8.20	–4.26
GWP_{fossil}	kg CO_2eq	37.05	32.80	9.79	0.91	0.17	0.00	12.94	3.18	9.40	0.00	0.00	0.00	0.00	0.18	0.00	0.47	–4.26
$GWP_{biogenic}$	kg CO_2eq	–25.87	–25.87	–22.11	0.00	0.00	0.00	0.00	0.00	–11.50	0.00	0.00	0.00	0.00	0.00	0.00	7.74	0.00
ODP	kg CFC11eq	5.5E–06	5.5E–06	7.1E–07	1.5E–09	1.2E–09	0.0E+00	1.7E–06	2.6E–06	5.7E–07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E–10	0.0E+00	5.9E–09	–9.0E–10
AP	kg SO_2eq	2.3E–01	2.3E–01	5.3E–02	5.0E–03	6.2E–04	0.0E+00	9.4E–02	2.3E–02	5.1E–02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E–03	0.0E+00	9.3E–04	–3.2E–03
EP	kg Neq	2.3E–01	2.3E–01	3.8E–02	4.7E–04	3.2E–03	0.0E+00	3.5E–02	7.7E–03	8.8E–02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.4E–05	0.0E+00	5.6E–02	–3.6E–04
SFP	kg O_3eq	2.96	2.88	1.00	0.15	0.01	0.00	0.58	0.17	1.01	0.00	0.00	0.00	0.00	0.03	0.00	0.02	–0.08
ADP fossil	MJ, NCV	505.21	445.45	105.91	11.42	1.51	0.00	130.58	153.38	99.17	0.00	0.00	0.00	0.00	2.30	0.00	0.94	–59.76
FFD	MJ surplus	66.07	56.13	12.65	1.72	0.07	0.00	16.38	22.92	11.91	0.00	0.00	0.00	0.00	0.35	0.00	0.08	–9.94
Use of primary resources																		
RPRE	MJ, NCV	247.83	247.82	112.03	0.02	0.02	0.00	4.06	0.78	123.29	0.00	0.00	0.00	0.00	0.00	0.00	7.63	–0.01
RPRM	MJ, NCV	236.30	236.30	236.30	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	647.94	581.56	157.49	12.30	1.64	0.00	166.30	165.17	141.52	0.00	0.00	0.00	0.00	2.48	0.00	1.04	–66.38
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	235.08	235.08	130.60	0.00	0.00	0.00	0.00	0.00	104.48	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	0.44	0.44	0.02	0.00	0.00	0.00	0.39	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.12	0.12	0.07	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NHWD	kg	0.74	0.74	0.41	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HLRW	m^3	2.6E–08	2.6E–08	5.3E–09	9.0E–11	1.5E–11	0.0E+00	1.5E–08	1.3E–09	4.4E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E–11	0.0E+00	2.5E–11	–3.2E–11
ILLRW	m^3	5.9E–07	5.9E–07	4.4E–08	4.3E–10	7.1E–11	0.0E+00	6.8E–08	4.4E–07	3.6E–08	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.7E–11	0.0E+00	1.2E–10	–1.6E-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 13 for definitions of abbreviations.

Table 24—Environmental impacts of 1.0 m² of solid hardwood flooring – average end-of-life treatment (Scenario 3: RSL = 44, vacuuming = yes)

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	24.14	19.88	–12.32	0.91	0.17	0.00	25.90	3.18	–2.10	0.00	0.00	0.00	0.00	0.18	0.00	8.20	–4.26
GWP_{fossil}	kg CO_2eq	50.01	45.75	9.79	0.91	0.17	0.00	25.90	3.18	9.40	0.00	0.00	0.00	0.00	0.18	0.00	0.47	–4.26
$GWP_{biogenic}$	kg CO_2eq	–25.87	–25.87	–22.11	0.00	0.00	0.00	0.00	0.00	–11.50	0.00	0.00	0.00	0.00	0.00	0.00	7.74	0.00
ODP	kg CFC11eq	6.6E–06	6.6E–06	7.1E–07	1.5E–09	1.2E–09	0.0E+00	2.7E–06	2.6E–06	5.7E–07	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E–10	0.0E+00	5.9E–09	–9.0E–10
AP	kg SO_2eq	2.7E–01	2.6E–01	5.3E–02	5.0E–03	6.2E–04	0.0E+00	1.3E–01	2.3E–02	5.1E–02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E–03	0.0E+00	9.3E–04	–3.2E–03
EP	kg Neq	3.3E–01	3.3E–01	3.8E–02	4.7E–04	3.2E–03	0.0E+00	1.4E–01	7.7E–03	8.8E–02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.4E–05	0.0E+00	5.6E–02	–3.6E–04
SFP	kg O_3eq	3.28	3.20	1.00	0.15	0.01	0.00	0.90	0.17	1.01	0.00	0.00	0.00	0.00	0.03	0.00	0.02	–0.08
ADP fossil	MJ, NCV	645.06	585.30	105.91	11.42	1.51	0.00	270.43	153.38	99.17	0.00	0.00	0.00	0.00	2.30	0.00	0.94	–59.76
FFD	MJ surplus	75.33	65.39	12.65	1.72	0.07	0.00	25.64	22.92	11.91	0.00	0.00	0.00	0.00	0.35	0.00	0.08	–9.94
Use of primary resources																		
RPRE	MJ, NCV	259.74	259.73	112.03	0.02	0.02	0.00	15.97	0.78	123.29	0.00	0.00	0.00	0.00	0.00	0.00	7.63	–0.01
RPRM	MJ, NCV	236.30	236.30	236.30	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	858.40	792.03	157.49	12.30	1.64	0.00	376.77	165.17	141.52	0.00	0.00	0.00	0.00	2.48	0.00	1.04	–66.38
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	235.08	235.08	130.60	0.00	0.00	0.00	0.00	0.00	104.48	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	0.51	0.51	0.02	0.00	0.00	0.00	0.45	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicators describing waste																		
HWD	kg	0.12	0.12	0.07	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NHWD	kg	0.74	0.74	0.41	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HLRW	m^3	6.1E–08	6.1E–08	5.3E–09	9.0E–11	1.5E–11	0.0E+00	4.9E–08	1.3E–09	4.4E–09	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.8E–11	0.0E+00	2.5E–11	–3.2E–11
ILLRW	m^3	8.6E–07	8.6E–07	4.4E–08	4.3E–10	7.1E–11	0.0E+00	3.4E–07	4.4E–07	3.6E–08	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.7E–11	0.0E+00	1.2E–10	–1.6E–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 13 for definitions of abbreviations.

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Appendix 1—Cover Letter Sent with Survey

PRE-FINISHED SOLID STRIP HARDWOOD FLOORING LIFE CYCLE ANALYSIS

By flooring, we mean solid strip hardwood flooring. We are not collecting information for engineered, cork, bamboo, or parquet flooring in this study. 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 unfinished strip flooring)

Part 2: Pre-finishing and packaging (primary output prefinished and packaged 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 Solid Hardwood Flooring Production

PART 1 - Hardwood strip flooring mill questionnaire

SOLID STIP HARDWOOD FLOORING LIFE CYCLE INVENTORY SURVEY

PART 1: Solid Hardwood Strip/Plank Flooring Manufacture (this part of the survey covers all manufacturing up to, but excluding, prefinished packaging)

Please complete this worksheet on the basis of 2018 calendar year production ____ 1000 sq ft 3/4"basis

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(:		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

____

TOTAL HARDWOOD LUMBER CONSUMED — **Please provide species & quantity for lumber input to your mill**

(Total lumber purchased during the reporting year; the sum of the "Amount" column should equal total lumber input for reporting year)

Example: Name	*e.g Red Oak*	*Amount*	*20,000*	*MBF*	*% Green*	*20%*	*% Dry*	*80%*	*Dry MC*	*12%*
Name		Amount		MBF	% Green		% Dry		Dry MC	
Name		Amount		MBF	% Green		% Dry		Dry MC	
Name		Amount		MBF	% Green		% Dry		Dry MC	
Name		Amount		MBF	% Green		% Dry		Dry MC	
Name		Amount		MBF	% Green		% Dry		Dry MC	
Name		Amount		MBF	% Green		% Dry		Dry MC	
Name		Amount		MBF	% Green		% Dry		Dry MC	
Name		Amount		MBF	% Green		% Dry		Dry MC	
Add more rows if required.		TOTAL:	0							

Average # of miles lumber trucks travel to your mill to deliver hardwood lumber:		Miles	**Total % of Lumber delivered by:**	Truck %	
Average number of miles trains travel to your mill to deliver hardwood lumber:		Miles		Rail %	
Average number of miles ships travel to your mill to deliver hardwood lumber:		Miles		Ship %	

TOTAL HARDWOOD LUMBER VOLUME PROCESSED IN 2018

Hardwood Lumber ____ **MBF (1,000 board foot measure)**

OTHER MATERIAL INPUTS USED IN 2018:

	Quantity	Units *(change units if required)*		Quantity	Units
Hydraulic fluid		gallons	Greases		gallons
Lubricating fluid		gallons	Antifreeze		gallons
Motor oil		gallons	Steel strapping		pounds
Shrink wrap		pounds	Plastic strapping		pounds
Paint		gallons	Other		

CO-PRODUCTS PRODUCED — **Co-product use and final disposition (please fill in)**

	Quantity	Units	% MC	% Sold	% Used Internally as Fuel	% Landfilled	% Other (specify)
Sawdust		tons					
Planer shavings		tons					
Hog fuel		tons					
Other (specify)		tons					
Other (specify)		tons					

WATER USAGE *Please indicate source and receiver of water (river, lake, municipal supply, or ground (well) water)

Water Intake:		gallons	Primary Source of Water:*	
Water Output:		gallons	Primary Receiver of Water:*	

PROCESS ENERGY USE IN FLOORING MILL

	Unit	Total Used	% Used in Milling	% used in Kiln-drying	Kiln Capacity: Capacity
Purchased Electricity	kWh		%	%	Kiln 1:
Natural gas	m^3		%	%	Kiln 2:
Diesel fuel	gallons		%	%	Kiln 3:
Gasoline	gallons		%	%	Kiln 4:
Propane	gallons		%	%	Kiln 5:
Hog fuel (oven dry)	tons		%	%	Kiln 6:
Other (specify)			%	%	Kiln 7:

(Add rows if necessary)

If you purchase steam from off-site please complete purchased steam information below

Purchased Steam	lb.		psi	Fuel used to generate steam:

We assume that purchased steam is used to kiln dry green lumber. Please specify if it is used otherwise

If any hogfuel is purchased from off-site sources to fire on-site boilers, please indicate the quantities by type below

Boiler fuel Input	Quantity	Units	%MC	Transport distance to mill (mi)	Mode
Example: planer shavings	*1,000*	*kg*	*5*	*110*	*Truck*

Please describe any boilers used on-site below

Boiler	Size (btu/hr, HP or lbs of steam/hr)	Boiler Type	Fuel Type	Fuel Quantity/yr.
Example: #1	*200,000 btu/hr*	*dutch oven*	*hog fuel*	*20,000 od kg*
#1				
#2				

2018 STRIP/PLANK HARDWOOD FLOORING OUTPUT ______ **1,000 sq ft 3/4"basis**

(Total of sales and inventory increase)

Percent of total unfinished:		Notes	
Percent of total transferred to pre-finishing:		Notes	

Annual Production by species, width and thickness

	Species & Type (strip or plank)	Total Square Feet	Strip <3" Width (inch)	Plank = 3" wide or greater
Example:	*Red Oak*	*200,000*	*2.5*	*0.75*

(add rows if necessary)

Complete this part on the basis of the production volume reported on page 1 (2018 calendar year)
If basis other than 2018, describe here:
Note: we expect that this sheet will not be relevant or completed for some processes - please provide any data that you may have

WASTE MATERIALS (do not include internally recycled materials)

Indicate fate of material (%)

			% Landfilled	% sold for recycling or reuse	Burned w/ energy recovery	Other
Wood Waste(including o		tons	%	%	%	
Boiler Ash		tons	%	%	%	
Ancillary Materials (by material type)						
Grease		tons	%	%	%	
Motor Oil		gallons	%	%	%	
Hydraulic & lubricating f		gallons	%	%	%	
add rows if required						

ATMOSPHERIC EMISSIONS (controlled PROCESS emissions only, if possible)

Particulates*		tons	Odorous Sulfur		tons
Nitrogen Oxides		tons	Ammonia		tons
Hydrocarbons		tons	Hydrogen Fluoride		tons
Sulfur Oxides		tons	Lead		tons
Carbon Monoxide		tons	Mercury		tons
Aldehydes		tons	Chlorine		tons
Other Organics		tons	Other (Specify)		tons
Methane		tons	Other (Specify)		tons

Please indicate whether reported emissions include boiler emissions that cannot be separated out from process emissions:

* Particulates — Describe size distribution of particulates if known. eg %PM10, %<PM10, %PM2.5, %<PM2.5

Emission Controls — **Describe any emission control equipment (and numbers) in place on-site - bag house, cyclone, multi-cyclone, etc.**

Example: ***2 bag houses and 4 cyclones***

WATERBORNE WASTES (controlled PROCESS wastes only)

Fluorides		tons	Chromium		tons
Dissolved Solids		tons	Iron		tons
BOD		tons	Aluminum		tons
COD		tons	Nickel		tons
Phenol		tons	Mercury		tons
Sulfides		tons	Lead		tons
Oil		tons	Phosphates		tons
Suspended Solids		tons	Zinc		tons
Acid		tons	Ammonia		tons
Metal Ion		tons	Other (Specify)		tons
Cyanide		tons	Other (Specify)		tons

Describe on-site wastewater treatment, if any. Also, if discharging to treatment plant, please indicate:

PART 2 Hardwood Strip/Plank Flooring finishing Plant

This is Part 2 of the survey. It covers the finishing process and packaging of solid strip/plank hardwood flooring

Please complete this worksheet based on 2018 calendar year production [ ] e.g 2018 1000 sq ft 3/4"basis
basis other than 2018 calendar year production, describe here ____

GENERAL INFORMATION

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

TOTAL SOLID FLOORING INPUT (species & quantity information for flooring input to finishing line)
(sum of all rows should equal total lumber input for reporting year)

	Species	Quantity	Units of sq. ft.	Width (inches)	Thickness (inches)
Example:	*e.g Red Oak*	*200,000*	*ft²*	*2.25*	*0.75*
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		

(add more rows if needed)

Please indicate method to apply coatings
(check applicable box(es) below)
[ ] roller applicator
[ ] spray booth
[ ] other (specify)

Please indicate method used to cure coatings
(check applicable box(es) below)
[ ] UV
[ ] Gas oven
[ ] IF
[ ] other (specify)

Average unfinished flooring transportation distance to finishing plant (miles) [ ] Miles mode [ ] (truck, rail, etc.)

TOTAL HARDWOOD FLOORING PROCESSED IN 2018

Hardwood flooring [ ] 1,000 sq. ft. % of which is solid wood flooring [ ] %

OPERATIONS, FINISHING & PACKAGING MATERIAL INPUTS USED IN 2018

General Operations	Quantity	Units		Quantity	Units	*(change units if required)*
Hydraulic fluid		gallons	Greases		kg	*(add rows if required)*
Lubricating fluid		gallons	Antifreeze		gallons	
Motor oil		gallons	Other (specify)		?	
Packaging Inputs						
Shrink wrap		tons	Plastic strapping		tons	
Cardboard		tons	kraft paper		tons	
Steel strapping		tons	Other (specify)		?	

Finishing Inputs

Coating Type Used	Brand of Coatings	Total Annual Volume of Coatings Used (L)	% Solids Content of Coating	List any Catalysts Used	Brand/Manufacturer of Catalysts	% Solids Content of Catalysts	Total Volume of Catalysts Used (L)

CO-PRODUCTS PRODUCED

	Quantity	Units	% Sold	% Used as Fuel	% Landfilled	% Other (specify)
			Co-product use and final disposition			
Trim ends						
Off-specification product						
Other (specify)						

NET WATER USED

Water Intake: [ ] gallons Primary Source of Water:* [ ]
Water Output: [ ] gallons Primary Receiver of Water:* [ ]

*Please indicate source and receiver of water (river, lake, municipal supply, or ground (well) water)

PROCESS ENERGY USE IN FINISHING PLANT 2018

	Unit	Total Used
Purchased Electricity	kWh	
Natural gas	m^3	
Diesel fuel	gallons	
Gasoline	gallons	
Propane	gallons	
Hog fuel (oven dry)	tons	
Other (specify)	?	

If you purchase steam from off-site please complete purchased steam information below:

Purchased Steam lb. ______ psi   Fuel used to generate steam: ______

We assume that purchase steam is used to dry flooring, please specify if it is used otherwise

If any hogfuel is purchased from off-site sources to fire on-site boilers, please indicate quantities by type below

	Boiler fuel Input	Quantity	Units	%MC	Transport	Transport Mode
Example	*flooring rejects*	*1000*	*kg*	*5%*	*45*	*Truck*

Please describe any boilers used on-site below

	Boiler	Size (btu/hr, HP or lbs of steam/hr)	Boiler Type	Fuel Type	Fuel Quantity/yr.
Example	*#1*	*200,000 btu/hr*	*dutch oven*	*hog fuel*	*20,000 od kg*
	#1				
	#2				
	#3				

2018 SOLID WOOD HARDWOOD FLOORING OUTPUT ______ **1,000 sq ft 3/4"basis**

Percent of total strip and plank ______ % Notes ______

Percent of total other flooring (e.g., engineered) ______ % Notes ______

Total solid wood flooring production by species, width and thickness

(these quantities should be less degrade and off-spec materials)

	Species & Type (strip or plank)	Total Square Feet	Width (inch)	Thickness (inches)
Example	*e.g., Red Oak (strip)*	*200,000*	*2.5*	*0.75*

(insert more rows if necessary)

Complete this worksheet on the basis of the production volume reported on page 1 (2018 calendar year)

(If basis other than 2018, describe here:) ______

Note: we expect that this sheet will not be relevant or completed for some or all processes - please provide any data that you may have

WASTE MATERIALS (do not include internally recycled materials)

	Land- filled	Units	Sold for recycling or reuse	Burned for energy recovery	Other (describ e)
Wood Waste (including off-specs)		tons			
Boiler Ash		tons			
Ancillary Materials (by material type)					
Grease		tons			
Motor Oil		gallons			
Hydraulic & lubricating fluids		gallons			

(add rows if required)

ATMOSPHERIC EMISSIONS (controlled PROCESS emissions only, if possible)

Do you report emissions to provincial or federal departments? If so attach 2018 filings

Particulates*		tons	Odorous Sulfur		tons
Nitrogen Oxides		tons	Ammonia		tons
Hydrocarbons		tons	Hydrogen Fluoride		tons
Sulfur Oxides		tons	Lead		tons
Carbon Monoxide		tons	Mercury		tons
Aldehydes		tons	Chlorine		tons
Other Organics		tons	Other (Specify)		tons
Methane		tons	Other (Specify)		tons

Indicate whether reported emissions include boiler emissions that cannot be separated out from process emissions: ______

* Particulates   Describe size distribution of particulates if known.   *eg*   *%PM10, %<PM10, %PM2.5, %<PM2.5*

Emission Controls   **Describe any emission control equipment in place (bag house, cyclone, multi-cyclone, etc.).**

	Device	How Many	Equipment controlled	Type of emission controlled
Example	*cyclone*	*1*	*boiler*	*particulates*

WATERBORNE WASTES (controlled PROCESS wastes only)

Fluorides		tons	Chromium		tons
Dissolved Solids		tons	Iron		tons
BOD		tons	Aluminum		tons
COD		tons	Nickel		tons
Phenol		tons	Mercury		tons
Sulfides		tons	Lead		tons
Oil		tons	Phosphates		tons
Suspended Solids		tons	Zinc		tons
Acid		tons	Ammonia		tons
Metal Ion		tons	Other (Specify)		tons
Cyanide		tons	Other (Specify)		tons

Describe on-site wastewater treatment, if any. Also, if discharging to treatment plant, please indicate.

Page 5 of 5

END OF SURVEY. THANK YOU! PLEASE REMEMBER TO SAVE and SEND AS ATTACHMENT IN AN EMAIL TO: hfsllc@zoho.com

WATER USAGE — ***Please indicate source and receiver of water (river, lake, municipal supply, or ground (well) water)**

Water Intake:		gallons	Primary Source of Water:*	
Water Output:		gallons	Primary Receiver of Water:*	

PROCESS ENERGY USE IN FLOORING MILL

	Unit	Total Used	% Used in Milling	% used in Kiln-drying	Kiln Capacity	Capacity
Purchased Electricity	kWh		%	%	Kiln 1:	
Natural gas	m^3		%	%	Kiln 2:	
Diesel fuel	gallons		%	%	Kiln 3:	
Gasoline	gallons		%	%	Kiln 4:	
Propane	gallons		%	%	Kiln 5:	
Hog fuel (oven dry)	tons		%	%	Kiln 6:	
Other (specify)			%	%	Kiln 7:	

(Add rows if necessary)

If you purchase steam from off-site please complete purchased steam information below

Purchased Steam	lb.		psi	Fuel used to generate steam:

We assume that purchased steam is used to kiln dry green lumber. Please specify if it is used otherwise

If any hogfuel is purchased from off-site sources to fire on-site boilers, please indicate the quantities by type below

Boiler fuel Input	Quantity	Units	%MC	Transport distance to mill (mi)	Mode
Example: planer shavings	*1,000*	*kg*	*5*	*110*	*Truck*

Please describe any boilers used on-site below

Boiler	Size (btu/hr, HP or lbs of steam/hr)	Boiler Type	Fuel Type	Fuel Quantity/yr.
Example: #1	*200,000 btu/hr*	*dutch oven*	*hog fuel*	*20,000 od kg*
#1				
#2				

2018 STRIP/PLANK HARDWOOD FLOORING OUTPUT ______ **1,000 sq ft 3/4"basis**
(Total of sales and inventory increase)

Percent of total unfinished:		Notes	
Percent of total transferred to pre-finishing:		Notes	

Annual Production by species, width and thickness

	Species & Type (strip or plank)	Total Square Feet	Strip <3" Width (inch)	Plank = 3" wide or greater
Example:	*Red Oak*	*200,000*	*2.5*	*0.75*

(add rows if necessary)

Complete this part on the basis of the production volume reported on page 1 (2018 calendar year)
If basis other than 2018, describe here: ______
Note: we expect that this sheet will not be relevant or completed for some processes - please provide any data that you may have

WASTE MATERIALS (do not include internally recycled materials)

Indicate fate of material (%)

			% Landfilled	% sold for recycling or reuse	Burned w/ energy recovery	Other
Wood Waste(including o		tons	%	%	%	
Boiler Ash		tons	%	%	%	
Ancillary Materials (by material type)						
Grease		tons	%	%	%	
Motor Oil		gallons	%	%	%	
Hydraulic & lubricating f		gallons	%	%	%	
add rows if required						

ATMOSPHERIC EMISSIONS (controlled PROCESS emissions only, if possible)

Particulates*		tons	Odorous Sulfur		tons
Nitrogen Oxides		tons	Ammonia		tons
Hydrocarbons		tons	Hydrogen Fluoride		tons
Sulfur Oxides		tons	Lead		tons
Carbon Monoxide		tons	Mercury		tons
Aldehydes		tons	Chlorine		tons
Other Organics		tons	Other (Specify)		tons
Methane		tons	Other (Specify)		tons

Please indicate whether reported emissions include boiler emissions that cannot be separated out from process emissions: ______

* Particulates — Describe size distribution of particulates if known. eg %PM10, %<PM10, %PM2.5, %<PM2.5

Emission Controls — **Describe any emission control equipment (and numbers) in place on-site - bag house, cyclone, multi-cyclone, etc.**

Example: ***2 bag houses and 4 cyclones***

WATERBORNE WASTES (controlled PROCESS wastes only)

Fluorides		tons	Chromium		tons
Dissolved Solids		tons	Iron		tons
BOD		tons	Aluminum		tons
COD		tons	Nickel		tons
Phenol		tons	Mercury		tons
Sulfides		tons	Lead		tons
Oil		tons	Phosphates		tons
Suspended Solids		tons	Zinc		tons
Acid		tons	Ammonia		tons
Metal Ion		tons	Other (Specify)		tons
Cyanide		tons	Other (Specify)		tons

Describe on-site wastewater treatment, if any. Also, if discharging to treatment plant, please indicate:

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PART 2 Hardwood Strip/Plank Flooring finishing Plant

This is Part 2 of the survey. It covers the finishing process and packaging of solid strip/plank hardwood flooring

Please complete this worksheet based on 2018 calendar year production ______ e.g 2018 1000 sq ft 3/4"basis
If basis other than 2018 calendar year production, describe here ______

GENERAL INFORMATION

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

TOTAL SOLID FLOORING INPUT (species & quantity information for flooring input to finishing line)
(sum of all rows should equal total lumber input for reporting year)

	Species	Quantity	Units of sq. ft.	Width (inches)	Thickness (inches)
Example:	*e.g Red Oak*	*200,000*	*ft²*	*2.25*	*0.75*
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		
			ft²		

(add more rows if needed)

Please indicate method to apply coatings
(check applicable box(es) below)
- ☐ roller applicator
- ☐ spray booth
- ☐ other (specify)

Please indicate method used to cure coatings
(check applicable box(es) below)
- ☐ UV
- ☐ Gas oven
- ☐ IF
- ☐ other (specify)

Average unfinished flooring transportation distance to finishing plant (miles) ______ **Miles** **mode** ______ **(truck, rail, etc.)**

TOTAL HARDWOOD FLOORING PROCESSED IN 2018

Hardwood flooring ______ 1,000 sq. ft. % of which is solid wood flooring ______ %

OPERATIONS, FINISHING & PACKAGING MATERIAL INPUTS USED IN 2018

General Operations	**Quantity**	**Units**		**Quantity**	**Units**
Hydraulic fluid		gallons	Greases		kg
Lubricating fluid		gallons	Antifreeze		gallons
Motor oil		gallons	Other (specify)		?
Packaging Inputs					
Shrink wrap		tons	Plastic strapping		tons
Cardboard		tons	kraft paper		tons
Steel strapping		tons	Other (specify)		?

(change units if required)
(add rows if required)

Finishing Inputs

Coating Type Used	Brand of Coatings	Total Annual Volume of Coatings Used (L)	% Solids Content of Coating	List any Catalysts Used	Brand/Manufacturer of Catalysts	% Solids Content of Catalysts	Total Volume of Catalysts Used (L)

CO-PRODUCTS PRODUCED

	Quantity	Units	% Sold	% Used as Fuel	% Landfilled	% Other (specify)
Trim ends						
Off-specification product						
Other (specify)						

(Co-product use and final disposition: % Sold, % Used as Fuel, % Landfilled, % Other (specify))

NET WATER USED

Water Intake:		gallons	Primary Source of Water:*	
Water Output:		gallons	Primary Receiver of Water:*	

*Please indicate source and receiver of water (river, lake, municipal supply, or ground (well) water)

PROCESS ENERGY USE IN FINISHING PLANT 2018

	Unit	Total Used
Purchased Electricity	kWh	
Natural gas	m^3	
Diesel fuel	gallons	
Gasoline	gallons	
Propane	gallons	
Hog fuel (oven dry)	tons	
Other (specify)	?	

If you purchase steam from off-site please complete purchased steam information below:

Purchased Steam lb. psi Fuel used to generate steam:

We assume that purchase steam is used to dry flooring, please specify if it is used otherwise

If any hogfuel is purchased from off-site sources to fire on-site boilers, please indicate quantities by type below

	Boiler fuel Input	Quantity	Units	%MC	Transport	Transport Mode
Example	*flooring rejects*	*1000*	*kg*	*5%*	*45*	*Truck*

Please describe any boilers used on-site below

	Boiler	Size (btu/hr, HP or lbs of steam/hr)	Boiler Type	Fuel Type	Fuel Quantity/yr.
Example	*#1*	*200,000 btu/hr*	*dutch oven*	*hog fuel*	*20,000 od kg*
	#1				
	#2				
	#3				

2018 SOLID WOOD HARDWOOD FLOORING OUTPUT **1,000 sq ft 3/4"basis**

Percent of total strip and plank % Notes

Percent of total other flooring (e.g., engineered) % Notes

Total solid wood flooring production by species, width and thickness

(these quantities should be less degrade and off-spec materials)

	Species & Type (strip or plank)	Total Square Feet	Width (inch)	Thickness (inches)
Example	*e.g., Red Oak (strip)*	*200,000*	*2.5*	*0.75*

(insert more rows if necessary)

Complete this worksheet on the basis of the production volume reported on page 1 (2018 calendar year)

(If basis other than 2018, describe here:)

Note: we expect that this sheet will not be relevant or completed for some or all processes - please provide any data that you may have

WASTE MATERIALS (do not include internally recycled materials)

	Land- filled	Units	Sold for recycling or reuse	Burned for energy recovery	Other (describe)
Wood Waste (including off-specs)		tons			
Boiler Ash		tons			
Ancillary Materials (by material type)					
Grease		tons			
Motor Oil		gallons			
Hydraulic & lubricating fluids		gallons			

(add rows if required)

ATMOSPHERIC EMISSIONS (controlled PROCESS emissions only, if possible)

Do you report emissions to provincial or federal departments? If so attach 2018 filings

Particulates*		tons	Odorous Sulfur		tons
Nitrogen Oxides		tons	Ammonia		tons
Hydrocarbons		tons	Hydrogen Fluoride		tons
Sulfur Oxides		tons	Lead		tons
Carbon Monoxide		tons	Mercury		tons
Aldehydes		tons	Chlorine		tons
Other Organics		tons	Other (Specify)		tons
Methane		tons	Other (Specify)		tons

Indicate whether reported emissions include boiler emissions that cannot be separated out from process emissions:

* Particulates Describe size distribution of particulates if known. *eg* *%PM10, %<PM10, %PM2.5, %<PM2.5*

Emission Controls **Describe any emission control equipment in place (bag house, cyclone, multi-cyclone, etc.).**

	Device	How Many	Equipment controlled	Type of emission controlled
Example	*cyclone*	*1*	*boiler*	*particulates*

WATERBORNE WASTES (controlled PROCESS wastes only)

Fluorides		tons	Chromium		tons
Dissolved Solids		tons	Iron		tons
BOD		tons	Aluminum		tons
COD		tons	Nickel		tons
Phenol		tons	Mercury		tons
Sulfides		tons	Lead		tons
Oil		tons	Phosphates		tons
Suspended Solids		tons	Zinc		tons
Acid		tons	Ammonia		tons
Metal Ion		tons	Other (Specify)		tons
Cyanide		tons	Other (Specify)		tons

Describe on-site wastewater treatment, if any. Also, if discharging to treatment plant, please indicate.

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END OF SURVEY. THANK YOU! PLEASE REMEMBER TO SAVE and SEND AS ATTACHMENT IN AN EMAIL TO: hfsllc@zoho.com