CORRIM Report

Life Cycle Assessment of Softwood Plywood Production – Western Region

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Table 3. Changed unit of Eutrophication potential from kg PO_4e to kg Ne

Table 27. Typo in A3 changed from 165.60 to 303.60 kg CO2e

Abbreviations

AP	Acidification Potential of Soil and Water Sources
CED	Cumulative Energy Demand
CFCs	Chlorofluorocarbons
CFC-11	Trichlorofluoromethane
EP	Eutrophication Potential
EPD	Environmental Product Declaration
FW	Consumption of Freshwater Resources
GWP	Global Warming Potential
GWP_{FOSSIL}	Global Warming Potential as an output from the TRACI impact methods. Does not include carbon dioxide released from biogenic sources
$GWP_{BIOGENIC}$	Global Warming Potential released from the combustion of biogenic materials (e.g., wood)
HLRW	High-level Radioactive Waste, Conditioned, to Final Repository
HWD	Hazardous waste Disposed
ILLRW	Intermediate- and Low-Level Radioactive Waste, Conditioned, to Final Repository
ISO	International Organization for Standardization
kg	Kilogram
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Low heat value (Net Caloric Value)
m^3	Cubic Meters
MC	Moisture Content
MJ	Megajoule
MBF	Thousand board foot
MSF	Thousand square foot
NCV	Net Caloric Value
NHWD	Non-Hazardous Waste Disposed
NRPRE	Non-Renewable Primary Energy Carrier Used as Energy
NRPRM	Non-Renewable Primary Energy Carrier Used as Material
O_3	Ozone
ODP	Depletion potential of the stratospheric ozone layer
OD	Oven-dry
PCR	Product Category Rules
RPRE	Renewable Primary Energy Carrier Used as Energy
RPRM	Renewable Primary Energy Carrier Used as Material
SFP	Formation Potential of Tropospheric Ozone
tkm	Metric-Tonne – Kilometers
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts

Glossary of Terms

Allocation – partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (14040:2006/Amd1:2020)

Biogenic Carbon-carbon derived from biomass ($CO_{2BIOGENIC}$) (ISO 21930:2017)

By-product- any of two or more products coming from the same unit process or product system (ISO 14040:2006/Amd1:2020)

CO_2 eq/Carbon dioxide equivalent/CO_2 equivalent. Unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide (ISO 14067)

Cradle-to-gate – Covers the mandatory production stage that includes the following information modules: extraction and upstream production (raw material supply), transport to factory and manufacturing (ISO 21930:2017)

Declared Unit - quantity of a construction product for use as a reference unit in an EPD based on LCA, for the expression of environmental information needed in information modules. When the precise function of the product or scenarios at the construction works level is not stated, or is unknown, a declared unit may be used instead of the functional unit (ISO 21930:2017)

Embodied Carbon- Carbon emissions associated with materials and construction process throughout the whole life cycle of a building or infrastructure (World Green Building Council)

Life cycle assessment (LCA) – compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle (14040:2006/Amd1:2020)

Life cycle inventory (LCI) phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (14040:2006/Amd1:2020)

Life cycle impact assessment (LCIA) – phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (14040:2006/Amd1:2020)

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).

System boundary – A set of criteria that specifies which unit processes are part of a product system (ISO 14044/Amd1:2017/Amd2:2020)

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1 Background

Producing all materials, renewable and non-renewable, has environmental impacts. Over the years, assessment of environmental burdens has evolved from not just considering site-specific impacts but to now including impacts of specific products' processes and use. The increased need for product specific environmental information has progressed the use of environmental product declarations (EPDs) as one tool for product selection.

Historically, a preferred environmental building product was one that was made from renewable or recycled resources. Today, building materials are held to a higher standard of transparency that goes beyond their natural attributes. Builders, designers, politicians, and the public are asking for the full suite of a material's environmental impacts to meet "green building" standards as well as state and national emission reduction benchmarks, just to name a few. Building materials that have low embodied carbon and energy are sought out, and other functional aspects such as structural performance, ease of installation, and product durability are also desired. Users of building materials are increasingly relying on science-based quantitative life cycle assessment (LCA) studies and EPDs that offer assurance that the material has the environmental attributes they seek.

LCAs will become increasingly important as they are used by all industries to inform product and process design, as well as build system development, as they seek to minimize energy consumption and carbon release. Going forward, the need for credible, scientific, LCA-based information will be greater than ever.

This report describes the cradle-to-gate energy and materials required for producing softwood plywood from the Western region in the United States (U.S.) and the subsequent releases into the environment. The Western region encompasses Washington, Oregon, Idaho, and Montana (Figure 1). This region was previously called the Pacific Northwest. Facilities included in this LCA are members of the American Wood Council (AWC) and/or APA – The Engineered Wood Association and voluntarily participated in AWC's online LCA survey, which collected primary data on each participating facility's material use and energy consumption for the 2022/2023 calendar year. Inputs included logs, veneer, adhesive, fuels, energy, ancillary materials, and packaging materials used for producing softwood plywood.

Data collection followed ISO 14040/10444 standards (ISO 2006a-c), ISO 21930 (ISO 2017), and the Product Category Rules (PCR) for North American Structural and Architectural Wood Products, Part B (UL 2020) and Part A: Life Cycle Assessment Calculations Rules and Report Requirements (UL 2018).

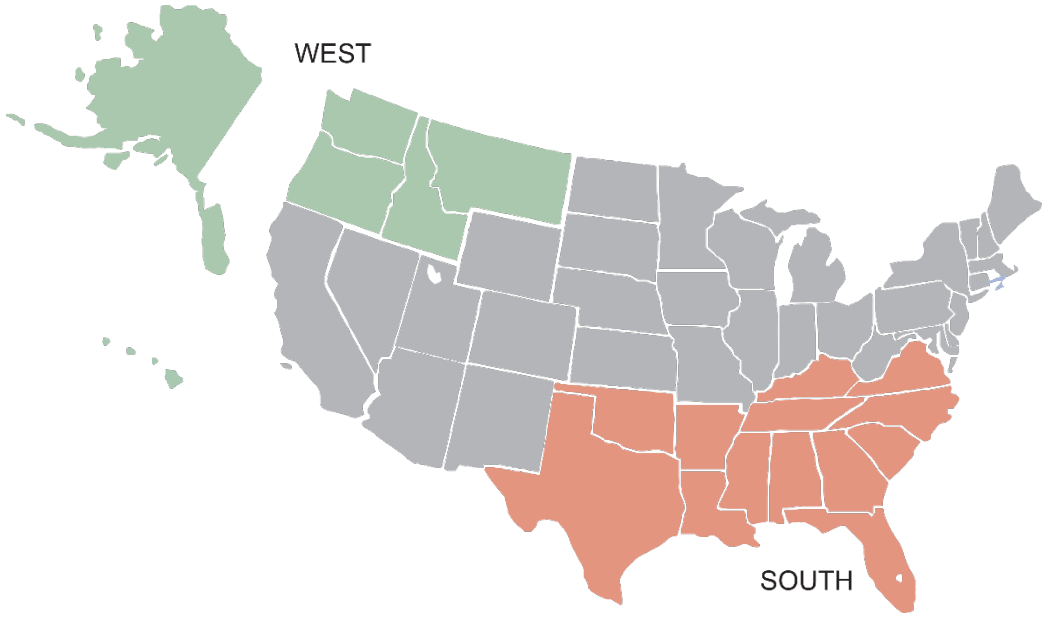


Figure 1. Geographical Distribution of Softwood Plywood Product Regions.

2 Life Cycle Assessment

Life-cycle assessment (LCA) has evolved as an internationally accepted method to analyze complex impacts and outputs of a product or process and the corresponding effects they might have on the environment. LCA is an objective process to evaluate a product's life cycle by identifying and quantifying energy and material use and wastes released to the environment; to assess the impact of those energy and materials uses and releases on the environment; and to evaluate and implement opportunities to effect environmental improvements. LCA studies can evaluate full product life cycles, often referred to as "cradle-to-grave," or incorporate only a portion of a products life cycle, referred to as "cradle-to-gate," or "gate-to-gate." This study is a cradle-to-gate LCA as it includes forestry operations through production of the product ready for shipment.

As defined by the International Organization for Standardization (ISO 2006a-b), LCA is a multiphase process consisting of a 1) Goal and Scope Definition, 2) Life Cycle Inventory (LCI), 3) Life Cycle Impact Assessment (LCIA), and 4) Interpretation (Figure 2). These steps are interconnected, and their outcomes are based on goals and purposes of a study.

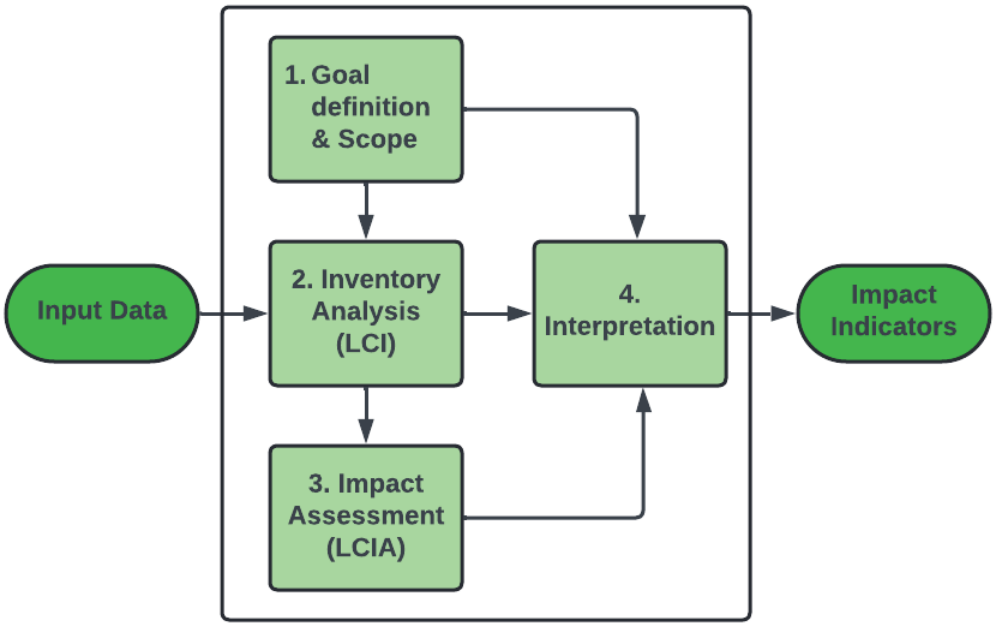


Figure 2. Steps Involved in a Life Cycle Assessment.

An LCA begins with a project goal, scope, functional unit, system boundaries, any assumptions and study limitations, method of allocation, and the impact categories that will be used.

The key component is the LCI, which is an objective, data-based process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases occurring within the system boundaries. It is this information that provides a quantitative basis for comparing wood products, their manufacturing processes and, most importantly from the forest industry point of view, wood products' performance against competitors who use other resources to create alternative products.

The LCIA process characterizes and assesses the effects of environmental releases identified in the LCI into impact categories such as global warming, acidification, eutrophication, ozone depletion, and smog.

The life cycle interpretation is a phase of LCA in which the findings of either the LCI or the LCIA, or both, are evaluated in relation to the defined goal and scope to reach conclusions and recommendations. This final step in an LCA involves an investigation of significant environmental aspects (e.g., energy use, greenhouse gases), their contributions to the indicators under consideration, and which unit processes in the system are generating the emissions. For example, if the results of a LCIA indicate a particularly high value for the global warming potential indicator, the analyst could refer to the inventory to determine which environmental flows are contributing to the high value, and which unit processes contribute to those outputs. This is also used as a form of *quality control*, and the results can be used to refine the scope definition to focus on the more important unit processes. This step also supports arriving at more certain conclusions and supportable recommendations.

3 Goal and Scope

It is the goal and scope that provides the plan for conducting the LCI including data collection, compilation, and interpretation. The EPD developed from this LCA study is intended for use in Business to Business (B to B) communications.

3.1 Goals and Objectives

3.1.1 Goals

The primary goal is to generate a cradle-to-gate LCA of structural softwood plywood. The LCA will follow data and reporting requirements which provide guidance for preparation of a B-to-B EPD.

3.1.2 Intended Audience and Uses

The primary audience for the results of this LCA report is AWC/APA members and the participating facilities. The intended audience for the subsequent EPD includes AWC, APA, architectural and engineering professionals, government organizations, academia, policy makers, or other interested parties.

3.1.3 Comparative Assertions

The report does not include product use and end of life phases which are required for comparative assertions relative to substitute products. If comparative studies are intended and disclosed to the public, reporting will be consistent with the 14044:2006/Amd1:2017/Amd2:2020: guidelines and principles and ISO 21930:2017 core rules for EPDs (ISO 2006a-c, ISO 2017), and will follow the PCR for Building Products (Part A) and the PCR for Structural Wood Products (Part B) (UL 2018 and 2020). No comparative assertions are made in this LCA.

3.2 Scope of Considered System

This LCA follows the attributional approach as outlined in ISO 21930 Section 7.1.1.

3.2.1 System Boundary

Information modules included in the LCA are shown in Table 1. This LCA includes mandatory modules A1-A3 for a cradle-to-gate analysis. The cradle-to-gate system boundary is shown in Figure 3. The system boundary begins with regeneration of the forest in the Western region and ends with plywood packaged at the plant gate. The system boundary includes forest operations (A_1), which may include growing seedlings in a nursery, planting the seedlings, managing the forest (which may include pre-commercial and commercial thinning), fertilization, and final harvesting, with the logs brought to a landing and loaded on the truck ready for transportation to the manufacturing facility; adhesive production (A_1); transportation of all resources and materials (A_2); and veneer and plywood production (A_3) (Figure 3).

Both human activity and capital equipment were excluded from the system boundary. The environmental effects of manufacturing and installing capital equipment and buildings have generally been shown to be minor relative to the throughput of materials and components over the useful lives of the buildings and equipment. Human activity involved in the manufacturing of softwood plywood products no doubt has a burden on the environment. However, the data collection required to properly quantify human involvement is particularly complicated, and

allocating such flows to the production of materials as opposed to other societal activities was not feasible for a study of this nature. Typically, human activity is only considered within the system boundary of an LCA when value-added judgements or substituting capital for labour decisions are within the study scope. These types of decisions are outside the current goal and scope of this study.

Table 1. Description of System Boundary Modules.

PRODUCTION STAGE			CONSTRUCTION STAGE		USE STAGE							END-OF-LIFE STAGE				OPTIONAL BENEFITS
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Extraction and up-stream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Building Operational Energy Use During Product Use	Building Operational Water Use During Product Use	Deconstruction	Transport	Waste	Disposal	Reuse, Recycle, & Recovery benefits
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

MND – Module Not Declared

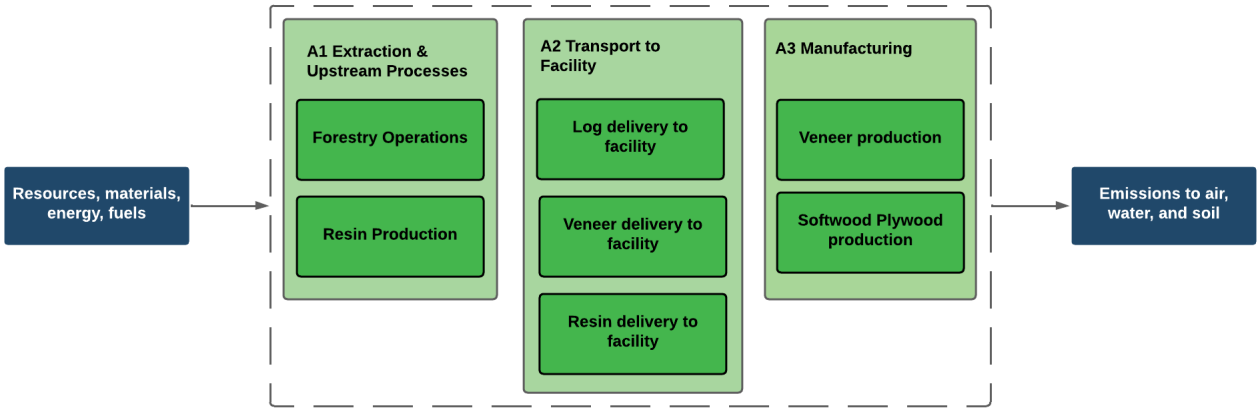


Figure 3. Cradle-to-Gate (A1-A3) System Boundary for Western Softwood Plywood Production.

3.2.2 Cut off Rules

The cut-off criteria for all activity stage flows considered within the system boundary conform with ISO 21930: 2017 Section 7.1.8. Specifically:

- All inputs and outputs for which data are available are included in the calculated effects and no collected core process data are excluded.
- A one percent cut-off is considered for a) renewable and non-renewable primary energy consumption and b) the total mass of inputs within a unit process. The sum of the total neglected flows does not exceed 5% of all energy consumption and mass of inputs.
- All flows known to contribute a significant impact or to uncertainty are included.
- The cut-off rules are not applied to hazardous and toxic material flows, all of which are included in the life cycle inventory.

No material or energy input or output was knowingly excluded from the system boundary.

3.2.3 Data Collection

Primary data from each facility was collected via an online LCA survey portal developed and managed by AWC. These data were used to develop the LCI in accordance ISO 14044/Amd1:2017/Amd2:2020 standards. This study relied almost exclusively on 2022/2023 production and emissions data provided by each facility, with upstream secondary data on fuels and electrical grid inputs from the US database (Datasmart 2023) and European datasets (Ecoinvent 3.8) (LTS 2023, Wernet et al. 2016). Twelve facilities from the Western region participated in the survey (9 plywood, 3 veneer).

3.2.4 Calculation Rules

Log consumption can be reported on a volume basis (e.g., Westside Scribner log scale in board feet), on a cubic feet basis, or on a mass basis. Due to technological changes and changes in average log diameter, log scale greatly underestimates the board feet currently recovered and there is a complicated relationship between log scale and actual volume (e.g., m^3). A regional average log conversion of 0.00586 cubic meters per BF was used based on conversions factors reported by Winn et al. (2020). The log scale quantities reported were converted to cubic volume using a factor of 170.66 BF/m^3 (4.83 BF/ft^3) based on Winn et al. (2020).

Plywood was reported on a thousand square foot (MSF) 3/8-inch basis (hereafter, 3/8-inch basis if referred to as 3/8”) and converted to a cubic meter volume using 1 MSF = 0.8849 m^3, 9.525-mm basis.

All flow analyses of the product and by-products in the process were determined on an oven-dry weight basis. An overall wood mass balance was determined for material input to material output using the weighted average oven-dry density of 507 kg per m^3.

The reported survey data was converted to a production basis: per m^3 of plywood. The values reported by each mill were combined into a production-weighted average for each input (see text box below). Thus, the value from a large mill had more weight. This approach resulted in a plywood complex that represents a composite of the mills surveyed and maintains confidentiality. SimaPro, version 9.6 (Pré Consultants 2023) was used as an accounting program to track material flows.

Averaging weighting factors for each softwood plywood facility are calculated respectively as follows:

Example y_1, 9 facilities are representative of the Pacific Coast region in this LCA

$$w_1 = y_1 / (y_1 + y_2 + y_3 \ldots y_9) = y_1 / Y_{total}$$

$$w_1 (\%) = (y_1 / Y_{total}) * 100$$

where:

Y_{total} Total plywood production of all 9 facilities (m^3 basis)
y_1 Plywood production of facility 1 (m^3 basis)
y_2 Plywood production of facility 2 (m^3 basis)
y_3 Plywood production of facility 3 (m^3 basis)
$\ldots y_9$ Plywood production of facility 9 (m^3 basis)

Note: Three additional facilities were included in this LCA that produced veneer only and used as the input resource when facilities reported green and dry veneer inputs to their plywood manufacturing.

Missing data is defined as data not reported in surveys. Whenever missing data occurred for survey items, they were checked with plant personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros.

3.2.5 Functional and Declared Unit

In accordance with the PCR, the declared unit for plywood is one cubic meter (1.0 m^3) of plywood packaged for shipment. A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building cannot be stated (UL 2018). The inventory input data is presented as unallocated flows, all input and output flows allocated to the main product. This analysis does not take the declared unit to the use stage; therefore, no service life is assigned. Weighted average specific gravity and density for Western softwood plywood is reported in Table 2.

Table 2. Western Plywood Weighted Average Specific Gravity and Density.

	Specific gravity			Density (kg/m3)		
Moisture content	Green	7%	0% oven-dry	50%	7%	0% oven-dry
	0.447	0.496	0.507	687.94	537.97	507.39

3.2.6 Allocation Rules

Allocation is the method used to partition the environmental load of a process when several products or functions share the same process. The input material for producing softwood plywood is a round log with bark and veneer. Producing plywood involves multiple steps with generation of by-products along the production chain (e.g., bark, sawdust, chips, trim). Following the PCR, Parts A and B, allocation is based on physical properties (e.g., mass or volume). For this study, a mass allocation was used for the primary product and subsequent by-products. Some by-products used internally were used for on-site energy generation. Packaging inputs are not related to the by-products and are allocated 100% to the final product.

3.2.7 Impact Categories / Impact Assessment

The life cycle impact assessment (LCIA) phase establishes links between the LCI results and potential environmental impacts. The LCIA calculates impact indicators (Table 3), such as global warming potential and smog. ***These impact indicators provide general, but quantifiable, indications of potential environmental impacts.*** The target impact indicator, the impact category, and means of characterizing the impacts are summarized in Table 3. **Note:** *Six impact indicators listed in Table 3, global warming potential, ozone depletion potential, acidification potential, eutrophication potential, smog formation potential, and abiotic resource depletion potential of non-renewable (fossil) energy resources, are globally deemed mature enough to be included in a Type III environmental declaration. Other categories are being developed and defined and LCA should continue making advances in their development. However, with the results from this LCA as they appear in the subsequent EPDs, users shall not use additional measures for comparative purposes.*

US Environmental Protection Agency's (EPA) TRACI 2.1 v1.08 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare 2012) environmental impacts are determined using several methods obtained with the SimaPro software package and include the North American TRACI method (Bare 2012). Additional impact indicators were generated using the European CML Baseline, and Cumulative Energy Demand (CED, LHV, v.1.0) as well as several indicators calculated from the LCI results. This LCIA does not make value judgments about the impact indicators, meaning a comparison of indicator values is not valid. Additionally, each impact indicator value is stated in units that are not comparable to others. For the same reasons, indicators should not be combined or added. Additionally, the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Cumulative Energy Demand is based on fuels' lower heating values (LHV). Cumulative Energy Demand is calculated from data published by Ecoinvent and expanded by PRé for energy resources available in the SimaPro database. Characterization factors are given for six impact categories: 1. Non-renewable, fossil, 2. Non-renewable, nuclear, 3. Non-renewable, biomass, 4. Renewable, biomass, 5. Renewable, wind, solar, geothermal, and 6. Renewable, water. The primary fuels are categorized into non-renewable (fossil and nuclear) and renewable (biomass, geothermal, solar, wind, and hydro). Table 3 summarizes the source and scope of each impact category reported in this report, as required to be in conformance with the PCR (UL 2018, 2020) and ISO 21930.

Table 3. Selected Impact Category Indicators and Inventory Parameters.

Impact Indicators per ISO 21930	Abbreviation	Units	Method
Core Mandatory Impact Indicator			
Global warming potential, Total	GWP_{TOTAL}	kg CO_2 eq	$GWP_{BIOGENIC}$ + GWP_{FOSSIL}
Global warming potential, Biogenic	$GWP_{BIOGENIC}$	kg CO_2 eq	TRACI 2.1 V1.08+ LCI Indicatory
Global warming potential, Fossil	GWP_{FOSSIL}	kg CO_2 eq	TRACI 2.1 V1.08
Depletion potential of the stratospheric ozone layer	ODP	kg CF-11e	TRACI 2.1 V1.08
Acidification potential of soil and water sources	AP	kg SO_2e	TRACI 2.1 V1.08
Eutrophication potential	EP	kg PO_4e	TRACI 2.1 V1.08
Formation potential of tropospheric ozone	SFP	kg O_3e	TRACI 2.1 V1.08
Abiotic depletion potential (ADP fossil) for fossil resources;	ADPf	MJ, LHV	CML-IA Baseline V3.08
Fossil fuel depletion	FFD	MJ Surplus	TRACI 2.1 V1.08
Use of Primary Resources			
Renewable primary energy carrier used as energy	RPRE	MJ, LHV [a/]	CED (LHV) V1.00
Renewable primary energy carrier used as material	RPRM	MJ, LHV	LCI Indicator
Non-renewable primary energy carrier used as energy	NRPRE	MJ, LHV	CED (LHV) V1.00
Renewable primary energy carrier used as material	NRPRM	MJ, LHV	LCI Indicator
Secondary material, secondary fuel and recovered energy			
Secondary material	SM	kg	LCI Indicator
Renewable secondary fuel	RSF	MJ, LHV	LCI Indicator
Non-renewable secondary fuel	NRSF	MJ, LHV	LCI Indicator
Recovered energy	RE	MJ, LHV	LCI Indicator
Mandatory Inventory Parameters			
Consumption of freshwater resources;	FW	m^3	LCI Indicator
Indicators Describing Waste			
Hazardous waste disposed	HWD	kg	LCI Indicator
Non-hazardous waste disposed	NHWD	kg	LCI Indicator
High-level radioactive waste, conditioned, to final repository	HLRW	m^3	LCI Indicator
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	m^3	LCI Indicator
Components for re-use	CRU	kg	LCI Indicator
Materials for recycling	MR	kg	LCI Indicator
Materials for energy recovery	MER	kg	LCI Indicator
Recovered energy exported from the product system	EE	MJ, NCV	LCI Indicator
Additional Inventory Parameters for Transparency			
Biogenic Carbon Removal from Product	BCRP	kg CO2e	Manual
Biogenic Carbon Emission from Product	BCEP	kg CO2e	Manual
Biogenic Carbon Removal from Packaging	BCRK	kg CO2e	Manual
Biogenic Carbon Emission from Packaging	BCEK	kg CO2e	Manual
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	BCEW	kg CO2e	Manual

3.3 Biogenic Carbon

Wood is a biobased material and thus contains biogenic carbon. The accounting of biogenic carbon follows the requirements set out in ISO 21930:2017 section 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. The biogenic carbon leaves the system (emission) as a product, by-products, and directly to the atmosphere when combusted. These mass flows of biogenic carbon from and to nature are listed in the LCI and are expressed in kg CO_2.

In the LCIA, the LCI flow of biogenic carbon removal is characterized by a factor of -1 kg CO_2e/kgCO_2 of biogenic carbon in the calculation of the GWP[1]. Likewise, the LCI flow of biogenic carbon emission is characterized by a factor of +1 kg CO_2e/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 in the calculation of the GWP.

The UL PCR 2020 specifies TRACI as the default LCIA method for GWP (GWP_{FOSSIL}). The TRACI method does not account for the removals or emissions of biogenic CO_2. We have thus manually calculated the component of the global warming potential related to biogenic carbon separately. We have reported the GWP indicator both with and without the biogenic CO_2 component for maximum transparency.

The results for global warming potential (GWP) and biogenic CO_2 are as follows:

- GWP_{FOSSIL} includes greenhouse gases (GHG) emissions from the combustion of fossil resources, and GHG emissions other than CO_2 from the combustion of biogenic resources (TRACI method)
- $GWP_{BIOGENIC}$ adds the net emissions of biogenic carbon to the GWP (TRACI method + net biogenic carbon = GWP_{TOTAL})
- LCI flows of biogenic carbon emissions and removals (Section 7.2; Table 22)

[1] ISO 21930 requires a demonstration of forest sustainability to characterize carbon removals with a factor of -1 kg CO_2e/kg CO_2. ISO 21930 Section 7.2.1 Note 2 states the following regarding demonstrating forest sustainability: “Other evidence 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’s UNFCCC annual report Table 6-1 provides annual net GHG Flux Estimates for different land use categories. This reporting indicates non-decreasing forest carbon stocks and thus the source forests meet the conditions for characterization of removals with a factor of -1 kg CO_2e/kg CO_2.

4 Description of Industry

The US plywood industry produces and domestically uses construction and industrial plywood. Construction and industrial plywood have traditionally been made from softwoods such as Douglas-fir. However, true firs, western hemlock, spruce, and western pines are also used. Phenol formaldehyde resin is the primary adhesive type used in construction and industrial plywood. Plywood is categorized by exposure capability and grade using Voluntary Product Standard PS 1–22 (NIST 2023). Construction and industrial plywood are classified as either Exposure 1 or Exterior in Voluntary Product Standard PS 1–22. The majority of construction and industrial plywood sold in North America is of Exposure 1 classification. Exposure 1 panels may undergo rain-wetting during building construction but will be protected from wetting after the building is enclosed, while Exterior plywood is suitable for long term exposure to weather such as repeated wetting (USDA 2021).

4.1 Location of Markets and Typical Transportation Methods

According to an internal study by AWC (2024) on wood products distribution (A4), finished plywood is distributed either by the manufacturer or by customer pickup. Volumes shipped by the manufacturer range from 67-88% of annual production while customer pickups range from 12-33% of annual production volumes. Shipments by the manufacturer can be by truck (26-72% of annual production) averaging 359 miles or by rail (28-74% of annual production) with an average distance of 945 miles. Customer pickups were by truck and averaged less than 200 miles.

4.2 Plant Geographical Distribution

Many plywood facilities have been on site for many years; however, they are typically periodically updated to remain competitive. Over the years, log size has changed, and facilities have had to upgrade their technology to process these smaller logs at the highest efficiency.

The Western softwood plywood production region is represented by Oregon, Washington, Idaho, and Montana (Figure 1). This production region considers the significantly different growth rates between regions (e.g., southern) which include different forest management intensities and activities, as well as accounting for the different species of trees, and different wood properties within the same species of trees that are found in this region.

4.3 Description of Product

Structural plywood is a strong, durable, and versatile engineered wood product widely used in construction and industrial applications. Made by bonding multiple layers (or plies) of wood veneer together with adhesives, structural plywood is designed to provide high strength, stability, and resistance to environmental factors. The grain direction of each layer is alternated, enhancing its dimensional stability and reducing the risk of warping, splitting, or shrinking.

One of the primary advantages of structural plywood is its load-bearing capacity, making it ideal for flooring, roofing, wall sheathing, and formwork in concrete construction. It meets strict manufacturing standards, such as PS 1-22, ensuring reliability and performance under heavy loads and varying weather conditions. It can be treated for added moisture, fire, or insect resistance, further expanding its applications. Additionally, it is available in various grades and thicknesses to suit different construction needs.

Although plywood is produced in different grades and thickness, a commonly used unit of volume in the industry is one thousand square feet (MSF) 3/8” (0.885 cubic meters) (Briggs 1994). Plywood is also used as a component in other engineered wood products and systems in applications such as prefabricated I-joists, box beams, stressed-skin panels, and panelized roofing

Plywood is a panel product built up wholly or primarily of sheets of veneer called plies (Figure 4). Softwood plywood in the U.S. is produced by peeling logs into veneer sheets, drying the veneer, applying adhesive (phenol-formaldehyde) to the veneer sheets, and stacking sheets together, typically with alternating grain orientation. The veneer stacks are put into a hot press where pressure and heat are used to provide contact and curing, and the cured panel is then removed and sawn to standard sizes, with 1.22 × 2.44 meters (4 × 8 feet) sheets being the most common.

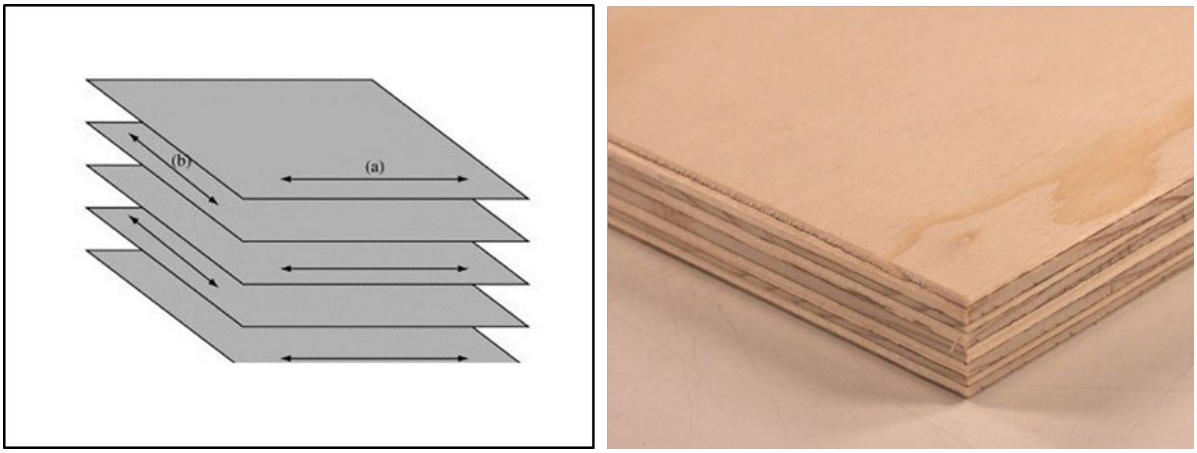


Figure 4. Softwood Plywood. Arrangement of Veneer Plies in Plywood (L) and the Finished Product (R)

Softwood plywood is categorized by United Nations Standard Products and Services Code (UNSPSC) 111220 01 and Construction Specifications Institute (CSI) codes for sheathing 06 16 00, 06 16 23 for subflooring, and 06 16 26 for underlayment (Table 4).

Table 4. United Nations Standard Products and Services Code (UNSPSC) and Construction Specification Institute (CSI) MasterFormat Code for Softwood Plywood.

Classification Standard	Category	Subcategory	Product Code
UNSPSC	Engineered wood products	Plywood	111220 01
CSI/CSC	Plywood (Softwood)	Sheathing	06 16 00
		Subflooring	06 16 23
		Underlayment	06 16 26

4.3.1 Categories of Products and By-products

The primary product from Western softwood plywood facilities is structural plywood. Some of the facilities in this LCA only produce veneer (n=3) where their primary products are green

veneer and dry veneer. Other products (by-products) are also made when logs, which are round in cross section, are debarked, bucked, and peeled into veneer. By-products are also generated during forming and trimming of plywood. These by-products could include bark, peeler cores, chips, sawdust, trim, and hogged fuel and wood waste. Logs arrive at the mill with much of the tree's bark intact. The bark is removed and used for fuel or sold for landscaping. Another product of the mill is hog fuel, which can be bark or a mix of bark and wood depending on how individual mills classify it. Hog fuel goes to a boiler for energy and heat generation or is sold. Western plywood facilities reported 38 percent of the by-products produced sold and 62 percent used for on-site energy and heat generation.

4.4 Annual Operating and Production Statistics of the Industry

Western regional mills accounted for 25 percent of the 7.90 million MSF 3/8" of U.S. softwood plywood capacity in 2022 (FEA 2024). The Western region's capacity is 2.93 million MSF, 3/8". Participating facilities in this LCA represented over 68 percent of the regional capacity.

Of the reporting facilities (n=9), the annual production ranged from 107,521 MSF, 3/8" to 415,080 MSF, 3/8" with a weighted average based on production of 269,083 MSF, 3/8".

4.5 Typical Emission Control Measures

Common emission control devices are regenerative thermal oxidizers (RTOs) for the reduction of volatile organic compounds (VOC's) and electrostatic precipitators (ESPs) for the removal of particulate matter or particle pollution (PM). Regenerative thermal oxidizers can remove more than 99.9 percent of VOCs, but release nitrogen oxides by burning natural gas or liquefied petroleum gas. Electrostatic precipitators are used to collect particulate matter (PM) pollution but are not effective in reducing volatile organic compounds (VOC's) or hazardous air pollutants (HAP) emissions.

4.6 General Types of Wastes and Emissions

Drying and pressing processes contribute to the production of emissions during plywood manufacturing. The air emissions reported by most mills include dust, particulate matter (PM), volatile organic compounds (VOCs), and hazardous air pollutants (HAPs). Mills classed as major sources under EPA rules are required to report methanol, formaldehyde, phenol, acetaldehyde, propionaldehyde, and acrolein which are on the US Environmental Agency (EPA)Toxics Release Inventory. These emissions are reported in this LCA.

Emissions to air for each facility were provided by the National Council for Air and Stream Improvement (NCASI). On-site water emissions are typically recycled and/or disposed of and treated under specific local regulations.

Most mills reported mill waste going to landfills, recycling, and/or incineration with and without energy recovery. Most common waste types reported were ash, oils and greases, metals, and wood waste.

4.7 Wood Species

Douglas-fir dominates the species mix in Western plywood mills responses, representing 92 percent (Table 5), followed by white fir at 3 percent, and several other species make up the remaining 5 percent. The weighted average (based on production) species-specific gravity was 0.45 green and 0.51 dry.

Table 5. Species and Representation for the Western Plywood Region.

Species Grouping	Scientific Name	Survey Composition
Douglas-fir	*Pseudotsuga menziesii*	91.89%
White Fir	*Abies concolor*	3.26%
Western Larch	*Larix occidentalis*	2.85%
Ponderosa Pine	*Pinus ponderosa.*	1.12%
Spruce	*Picea spp.*	0.54%
Western Hemlock	*Tsuga heterophylla*	0.35%
		100%

4.8 Moisture Content

The weighted average moisture content of the plywood leaving ready for shipment was 6.53 percent. Surveys reported a range of moisture contents for finished plywood from 5-8 percent. All wood moisture content values are reported as oven-dry basis.

5 Life Cycle Inventory Analysis

The life cycle inventory in this section presents the unit process flows for 1 m^3 of finished plywood. The LCI was calculated based on 2022/2023 production and the corresponding flows of materials during that period. No data gaps were recorded.

5.1 A1- Resource Extraction

Logs used in the production of softwood plywood in the Western region include in their life cycle the upstream activities associated with establishment, growth, and harvest of trees (Figure 1). This group of activities is collectively referred to as forest resource extraction. The forest resource extraction life cycle stage includes the efforts required to establish a forest stand, to treat that stand to maturity, and to harvest the merchantable logs from the stand (Oneil and Puettmann 2017, Oneil 2022).

Forest resource extraction includes growing seedlings, site preparation, planting, fertilization (where applicable), and final harvest. These activities have been divided into three specific processes: seedling production, stand management, and harvesting. Seedling production involves greenhouse operations and planting. Stand management includes precommercial thinning (where applicable) and fertilization. Harvesting includes felling, skidding, processing, and loading for both commercial thinning and final harvest operations. The primary output product for this analysis is a log at a landing destined for the mill. Non-merchantable slash is generally left at a landing to decay in-situ or for controlled burns.

Resource extraction and the associated impacts will change based on both past and prospective technologies, evolving forest management procedures, and market demands. Given that productivity gains are not confirmed or well developed, this assessment was based on data representing the current state of the art. It does not discount future operations or estimate potential productivity gains from future technologies. Product output, consumed resources, and

emissions associated with resource extraction were developed as a weighted average across the hectares managed for timber production. Weighted averages consider inherent differences in site productivity, management practices, and energy usage.

Western plywood facilities source their logs from two forest regions, the Pacific Coast (58%) and the Inland Northwest (42%) (Oneil and Puettmann 2017, Oneil 2022).

5.2 A1 – Adhesive

Facilities reported the use of phenol formaldehyde (PF). Other additives (fillers and extenders, catalysts, and soda ash) represent around 18 percent of the total mass of adhesive inputs (14.18 kg) (Table 6). Production of adhesives was obtained from published LCA data (Athena 2022). Phenol and formaldehyde are listed on the EPA Toxics Release Inventory[2].

Table 6. Western Softwood Plywood Adhesive System, Unallocated

Adhesive component	kg/m3	Component representation
PF Resin	11.57	81.57%
Fillers & Extenders	2.02	14.22%
Catalyst	0.31	2.21%
Soda ash	0.28	1.99%
Total adhesive system	14.18	100.00%

5.3 A2 – Transport

The A2 module includes the transportation of resources and materials used in the production of softwood plywood (Table 7). The distances are weighted averages based on plywood production weighted volume.

Table 7. Weighted Average Delivery Distance and Mode of Transport for Western Plywood.

Material	Mode of Transportation	Distance	
		km	Miles
Logs - plywood	Road	114.33	71.04
Logs - veneer	Road	219.23	136.23
Adhesive	Road	413.37	256.87
Dry veneer	Road	175.07	108.79
Dry veneer	Rail	737.69	458.40
Dry veneer	Water	1,764.53	1,096.48
Green veneer	Road	63.86	39.68

[2] US Environmental Protection Agency, Toxics Release Inventory. http://www.epa.gov/toxics-release-inventory-tri-program/tri-listedchemicals. Accessed February 2025.

5.4 A3 – Plywood Manufacturing

5.4.1 Equipment: Type and Fuel Consumption

Diesel-powered loaders are typically used in the mill yard to move logs. Electrically driven cranes may also be used. Electrically driven motors in the mill are used for debarkers, peeling lathes, material conveyors and trims saws. Log conditioning, veneer driers, and presses can be powered by natural gas or self-generated wood fuel. The emissions controls equipment is powered by electricity or natural gas. Lifts for transporting products and materials in the mill are typically powered by electricity and liquefied propane gas. Electricity is used for running fans and pumps, and for operating emissions control equipment. Natural gas and wood by-products are used for boiler fuel and emission control equipment, and propane fuel is used in forklifts.

5.4.2 Onsite Energy Production

Heat energy is used for conditioning logs prior to peeling, veneer dryers, and plywood presses. Heat energy can be generated either by natural gas or wood waste. Gas boilers produce 26 percent of the onsite heat energy and wood fuel provided the remaining 74 percent.

Of the wood fuel burned, 70 percent is produced on site, while 30 percent is purchased. The fuel supplied to the boiler is a mix of bark, hog fuel, chips, plywood/veneer trim, sawdust, and wood waste. The combustion of wood and its emissions is factored into this LCA (Puettmann and Milota 2017). Wood boilers produce ash in addition to steam. Boiler ash is sent to composting, recycling (fertilizer use), or incineration. For the veneer only facilities, 88 percent of wood fuel is produced on site, while 12 percent is purchased.

5.4.3 Material Flows

Most wood raw material for plywood production arrives in the form of roundwood (logs) and is converted to finished plywood on-site. In some instances, veneer (green or dry) can be a by-product as well as a purchased a raw material for plywood production. Table 8 lists the wood inputs and outputs from plywood production on oven dry mass basis. The wood flow for the veneer production facilities is in Table 9.

Table 8. Mass Balance of Raw Materials , By-products, and Products in the Plywood Manufacturing Process for the Western Region, Unallocated.

A3 Production	Value	Unit/m3	Allocation
Inputs			
Logs	512.74	kg	65.92
Dry veneer	154.41	kg	19.85%
Green veneer	110.72	kg	14.23%
Total	777.84	kg	100%
Outputs			
Plywood	507.39	kg	65.23%
Bark	25.83	kg	3.12%
Chips, dry	36.60	kg	4.71%
Chips, green	68.53	kg	8.81%
Peeler core	45.15	kg	5.80%
Sawdust	0.43	kg	0.05%
Trim	36.82	kg	4.73%
Hogged fuel	17.55	kg	2.26%
Sander dust	3.26	kg	0.42%
Wood Waste	2.04	kg	0.07%
Veneer	36.05	kg	4.63%
Structural composite Lumber	0.05	kg	0.01%
Laminated Veneer Lumber	1.22	kg	0.16%
Total	777.87	kg	100%

Table 9. Mass Balance of Raw Materials , By-products, and Products in the Veneer Only Manufacturing Process for the Western Region, Unallocated.

A3 Production	Value	Unit/m3	Allocation
Inputs			
Logs	661.50	kg	100%
Total	661.50	kg	100%
Outputs			
Dry veneer	98.37	kg	14.87%
Green veneer	235.13	kg	35.55%
Bark	45.97	kg	6.95%
Chips, green	95.87	kg	14.49%
Peeler core	77.52	kg	11.72%
Sawdust	6.50	kg	0.98%
Hogged fuel	102.13	kg	15.44%
Total	661.49	kg	100%

5.4.4 Plywood Manufacturing

Plywood manufacturing can be divided into six-unit processes: log debarking, log conditioning, veneer peeling, veneer drying, layup and pressing, and final trimming and packaging. The wood boiler represents a seventh process that provides heat energy. Figure 6 shows the relationship between the processes and the wood inputs to and from each process. Table 10 further describes the wood flow in and out of each unit process and type of energy input needed. Table 10 and Figure 6 are reported as information only on the general production processes of plywood. The data was collected by facility and not by unit process.

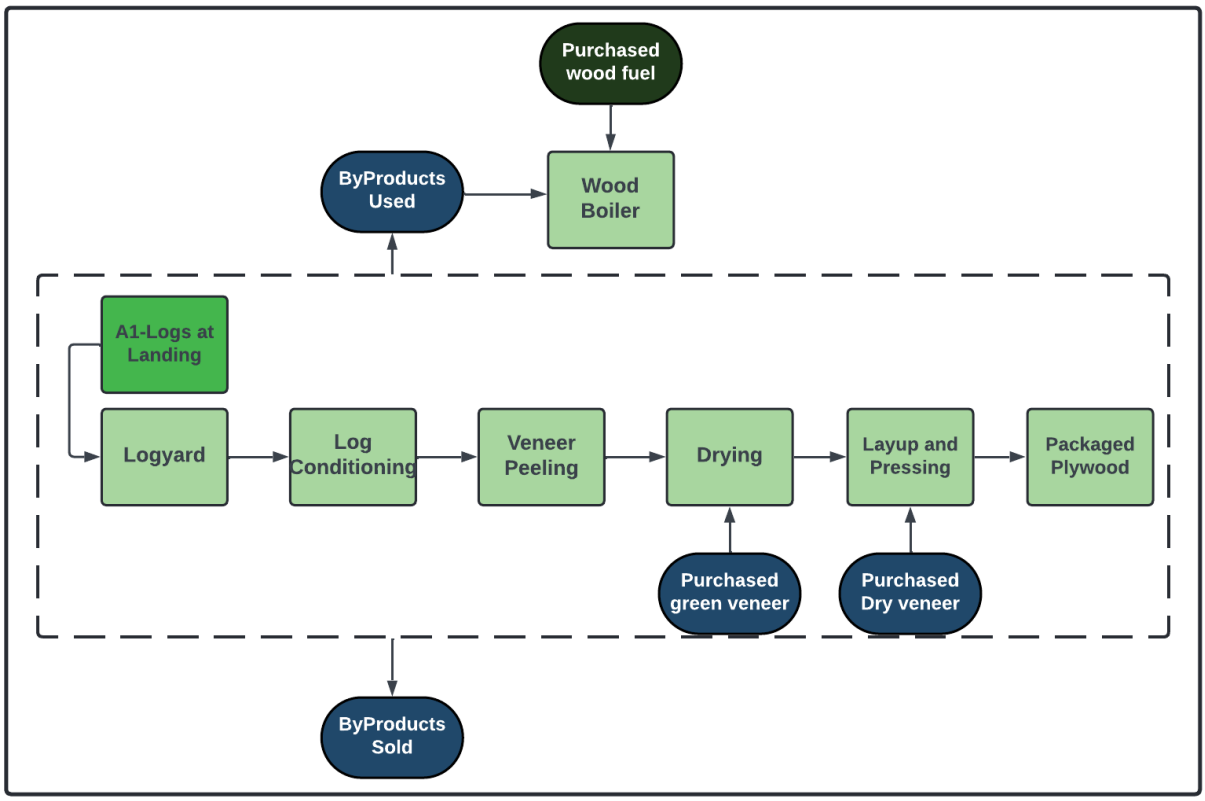


Figure 5. Plywood Unit Processes from Roundwood to Packaged Plywood.

Table 10. Description of the production flow of plywood and the associated inputs and outputs of each unit process.

Unit Process		Inputs	Outputs
1. Log/Yard & Debarking	Logs are bucked (cut to length) on the log yard. Logs are debarked.	• Logs • Fossil fuels • Electricity	• Debarked logs • Wood waste
2. Conditioning	Conditioning of debarked logs with hot water or steam.	• Debarked logs • Thermal energy • Water	• Conditioned logs
3. Veneer Peeling	Logs are peeled in the lathe to make veneer. Veneer is clipped to size and sorted by moisture content.	• Conditioned logs • Electricity	• Veneer (green) • Peeler cores • Veneer clippings and trim (downfall)
4. Drying	Veneers are dried to 4-6% MC. The re-drying rate for processed veneer is 2-18%, according to the surveys.	• Veneer (green) • Thermal energy • Electricity	• Veneer (dry) • Water vapor • Air emissions
5. Layup and Press	The adhesive is applied on the veneers, and the veneers are cross-laminated in a mat, and the mat is pressed.	• Veneer (dry) • Adhesive • Thermal heat • Electricity	• Plywood • Layup scrap • Water vapor • Air emissions
6. Trimming, sawing, packaging	The plywood panels are sawn to appropriate dimensions. Packaging material consists of wrapping, strapping, and spacers.	• Plywood • Electricity • LPG	• Sawn plywood • Plywood trim • Sawdust • Wood waste

Survey respondents provided data from 2022 or 2023 on the material and resource inputs to plywood manufacturing at the mill and outputs such as product, by-products, and air emissions (Table 11). The data were production-weight averaged and are reported below per cubic meter (m^3) of finished plywood produced. The veneer production process is shown in Table 12.

Table 11. Process Inputs/Outputs for Plywood Manufacturing to Produce 1 m3 of Western Plywood, Unallocated.

A3 Production	Value	Unit/m3	Allocation
A3-Plywood, softwood, m3, Western	1	m3	65.23%
A3-Coproducts, softwood, at plywood, sold, kg, Western	103.61	kg	13.12%
A3-Coproducts, softwood, at plywood, kg, Western	168.41	kg	21.65%
Resources			
Water, process, surface	485.69	L	
Water, process, well	9.72	L	
Water, process, municipal	386.23		
Water, process unspecified	1.70	L	
Materials/fuels			
Sawlog with bark, softwood	1.01	m3	
A1 - Veneer, dry, at veneer plant, m3, Western	0.3043	m3	
A1 - Veneer, green, at veneer plant, m3, Western	0.2182	m3	
Phenol formaldehyde adhesive system	14.18	kg	
Transportation	158.51	tkm	
Diesel	1.52	l	
Gasoline	0.02	l	
Natural gas	29.63	m3	
Liquefied petroleum gas	1.48	l	
Wood Boiler	148.93	kg	
Process Waste, landfill	8.39	kg	landfill
Process Waste, incineration	0.03	kg	incineration % of total waste disposal
Process Waste, recycling	0.08	kg	recycling management % of total waste disposal
Electricity/heat			
Electricity	126.24	kWh	
Emissions to air			
Particulates, unspecified	1.01E-02	kg	
Particulates, < 2.5 um	2.51E-03	kg	
Particulates, < 10 um	2.57E-03	kg	
Particulates, unspecified	4.44E-02	kg	
VOC, volatile organic compounds, unspecified origin	1.44E-02	kg	
Carbon monoxide	3.61E-02	kg	
Sulfur oxides	4.19E-05	kg	
Nitrogen oxides	6.10E-03	kg	
Methanol	6.72E-03	kg	
Formaldehyde	1.12E-03	kg	
Acetaldehyde	1.48E-03	kg	
Acrolein	1.04E-04	kg	
Phenol	2.57E-03	kg	
Propanol	1.65E-05	kg	
Benzene	1.49E-05	kg	
Xylene	3.15E-07	kg	

Table 12. Process Inputs/Outputs for Plywood Manufacturing to Produce 1 m3 of Western Veneer, Unallocated.

A3 Production	Value	Unit/m3	Allocation
A1 - Veneer, green, at veneer plant, m3, Western	0.4864	m3	14.87%
A1 - Veneer, dry, at veneer plant, m3, Western	0.2035	m3	35.55%
A1 - Bark, at veneer plant, kg, Western	45.97	kg	6.95%
A1- Chips, at veneer plant, kg, sold, Western	95.87	kg	14.495
A1 - Peeler core, at veneer plant, kg, sold, Western	77.52	kg	11.72%
A1 - Sawdust, at veneer plant, kg, sold, Western	6.5	kg	0.98%
A1 - Hogged fuel, at veneer plant, kg, Western	102.13	kg	15.44%
Resources			
Water, process, surface	12.01	L	
Water, process, municipal	336.85	L	
Materials/fuels			
Sawlog with bark, softwood	1.37	m3	
Transportation	105.99	tkm	
Diesel	2.30	l	
Gasoline	0.002	l	
Natural gas	29.63	m3	
Liquefied petroleum gas	1.48	l	
Wood Boiler	212.45	kg	
Process Waste	0.1268	kg	landfill % of total waste disposal
Process Waste	5.2116	kg	recycling management % of total waste disposal
Electricity/heat			
Electricity	60.60	kWh	

5.4.5 Packaging

Packing materials represent only 0.59 percent of the mass of the main product. The wood stickers and runners make up the bulk of the mass, representing 96 percent of the total packaging (Table 13). The wrapping materials represent <1 percent and strapping and cardboard at 3.4 percent of the total packaging mass.

Table 13. Materials Used in Packaging and Shipping per m^3 Western Softwood Plywood.

Material	Unit	Value	Percent of Total Packaging
Wrapping Material	kg	0.027	0.94%
Steel strapping	kg	0.015	0.53%
Plastic strapping	kg	0.034	1.18%
Cardboard protectors	kg	0.049	1.72%
Stickers and battens	kg	2.746	95.63%
TOTAL	kg	2.871	100.00%

5.5 Secondary Data Sources

Secondary data is necessary for creating the full cradle-to-gate. Tables 14, 15, and 16 list the secondary LCI data sources, geographical origin, age, and quality of the data used in this LCA study.

Table 14. Raw Material Supply Processes.

A1: Raw Material Inputs				
Inputs	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Logs	Database: CORRIM	US Pacific Northwest	2021	- Technology: Good - Process models product specific technology - Time: Good updated in the last 5 years - Geography: Good, Data specific to product
Phenol formaldehyde Resin	Database: Athena Processes: Wood Resins 2021	United States	2021	- Technology: Good - Process models product specific technology - Time: Fair, updated in the last 2 years - Geography: Good, Data specific to product

Table 15. Transportation Processes.

A2: Raw Material Transportation				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Road	Database: Datasmart v. 2023 Process: Transport, combination truck, Diesel powered NREL/US U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: good
Rail	Database: Datasmart v. 2023 Process: Transport, train, diesel powered NREL/US U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: good
Water	Database: Datasmart v. 2023 Process: Transport, ocean freighter, average fuel mix NREL/US U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: good

Table 16. Manufacturing Processes

A3 Manufacturing				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Electricity	Database: Ecoinvent 3.9 Processes: Electricity, low voltage {WECC, US only} | market for electricity, low voltage | Cut-off, U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: Good
Natural gas	Database: Datasmart v. 2023 Process: Natural gas, combusted in industrial boiler NREL/US U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: Good
Gasoline	Database: Datasmart v. 2023 Process: Gasoline, combusted in equipment NREL/US U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: Good
Diesel	Database: Datasmart v. 2023 Process: Diesel, combusted in industrial equipment NREL/US U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: Good
LPG	Database: Datasmart v. 2023 Process:	North America	2023	- Technology: Good, process models average North American technology

A3 Manufacturing				
	Liquefied petroleum gas, combusted in industrial boiler NREL/US U			- Time: Good, Data is less than 2 years old Data is less than 5 years old - Geography: Good
Wrapping Materials	Database: Datasmart v. 2023 Processes: High density polyethylene resin, at plant NREL/RNA U Low density polyethylene resin, at plant NREL/RNA U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 2 years old - Geography: Good
Carboard protectors	Database: Datasmart v. 2023 and CORRIM Databases Cardboard	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 5 years old - Geography: Good
Strapping	Database: Datasmart v. 2023 Processes: Polyethylene, HDPE, granulate, at plant/US- US-EI U. Chromium steel 18/8, at plant/US- US-EI U	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 5 years old - Geography: Good
Waste	Database: Ecoinvent 3.9 Processes: Process-specific burdens, sanitary landfill {RoW} | market for process-specific burdens, sanitary landfill | Cut-off, U;	North America	2023	- Technology: Good, process models average North American technology - Time: Good, Data is less than 2 years old Data is less than 5 years old - Geography: Good

6 Life Cycle Impact Assessment Results

6.1 A1-A3 - Cradle-to-Gate

This section discusses the cradle-to-gate results for the declared unit, one cubic meter of Western softwood plywood. The TRACI, CML, and CED LCIA methods were used to characterize the flows to and from the environment. Allocation of environmental burdens to siding and its by-products is done according to mass allocation principles (ISO 2006 a, b). The cradle-to-gate (A1-A3) LCIA results for plywood are presented for one cubic meter (Tables 17-23). Results present in the LCIA section include veneer production in A1, A2, and A3.

The contribution impact of transportation of resource materials (A2) accounts for 8 percent or less of the impact in all impact categories (Tables 20-22, Figure 6).

Table 17. Cradle-to-Gate LCIA Results for 1 m^3 of Western Softwood Plywood – Absolute Basis.

Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{TOTAL} [kg CO_2 eq]	224.17	(1,524.73)	17.92	1,730.98
$GWP_{BIOGENIC}$ [kg CO_2 eq]	-	(1,572.89)	-	1,572.89
GWP_{FOSSIL} [kg CO_2 eq]	224.17	48.16	17.92	158.09
ODP [kg CF-11eq]	0.00	0.00	0.00	0.00
AP [kg SO_2 eq]	1.22	0.49	0.10	0.63
EP [kg N eq]	0.54	0.16	0.01	0.36
SFP [kg O_3 eq]	33.05	12.43	2.89	17.73
FFD [MJ, surplus]	449.73	115.77	33.66	300.30
ADP_{FOSSIL} [MJ, LHV]	3,188.38	866.95	224.19	2,097.24

Table 18. Cradle-to-Gate Resource use Results for 1 m^3 of Western Softwood Plywood – Absolute Basis.

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	4,997.62	44.35	0.51	4,952.76
RPRM [MJ, LHV]	15,743.37	15,743.37		
NRPRE [MJ, LHV]	3,383.44	905.70	227.48	2,250.26
NRPRM [MJ, LHV]	387.76	387.76	0.00	0.00
SM [kg]	0.00	0.00	0.00	0.00
RSF [MJ, LHV]	0.00	0.00	0.00	0.00
NRSF [MJ, LHV]	0.00	0.00	0.00	0.00
RE [MJ, LHV]	0.00	0.00	0.00	0.00
FW [m^3]	2.2418	0.8062	0.0020	1.4336

Table 19. Cradle-to-Gate Output Flows for 1 m^3 of Western Softwood Plywood – Absolute Basis.

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	1.66E-02	3.33E-03	1.14E-04	1.31E-02
NHWD [kg]	2.27E+01	2.51E+00	1.29E+00	1.89E+01
HLRW [m^3]	1.65E-07	1.95E-09	0.00E+00	1.63E-07
ILLRW [m^3]	1.88E-06	4.24E-08	5.59E-09	1.83E-06
CRU [kg]	0.00	0.00	0.00	0.00
MR [kg]	0.00	0.00	0.00	0.00
MER [kg]	0.00	0.00	0.00	0.00
EE [MJ, LHV]	0.00	0.00	0.00	0.00

Table 20. Cradle-to-Gate LCIA Results for 1 m^3 of Western Softwood Plywood – Relative Basis.

Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{FOSSIL} [kg CO_2 eq]	100%	21%	8%	71%
ODP [kg CF-11eq]	100%	81%	1%	18%
AP [kg SO_2 eq]	100%	40%	8%	52%
EP [kg N eq]	100%	31%	1%	68%
SFP [kg O_3 eq]	100%	38%	9%	54%
FFD [MJ, surplus]	100%	27%	7%	66%
ADP_{FOSSIL} [MJ, LHV]	100%	26%	7%	67%

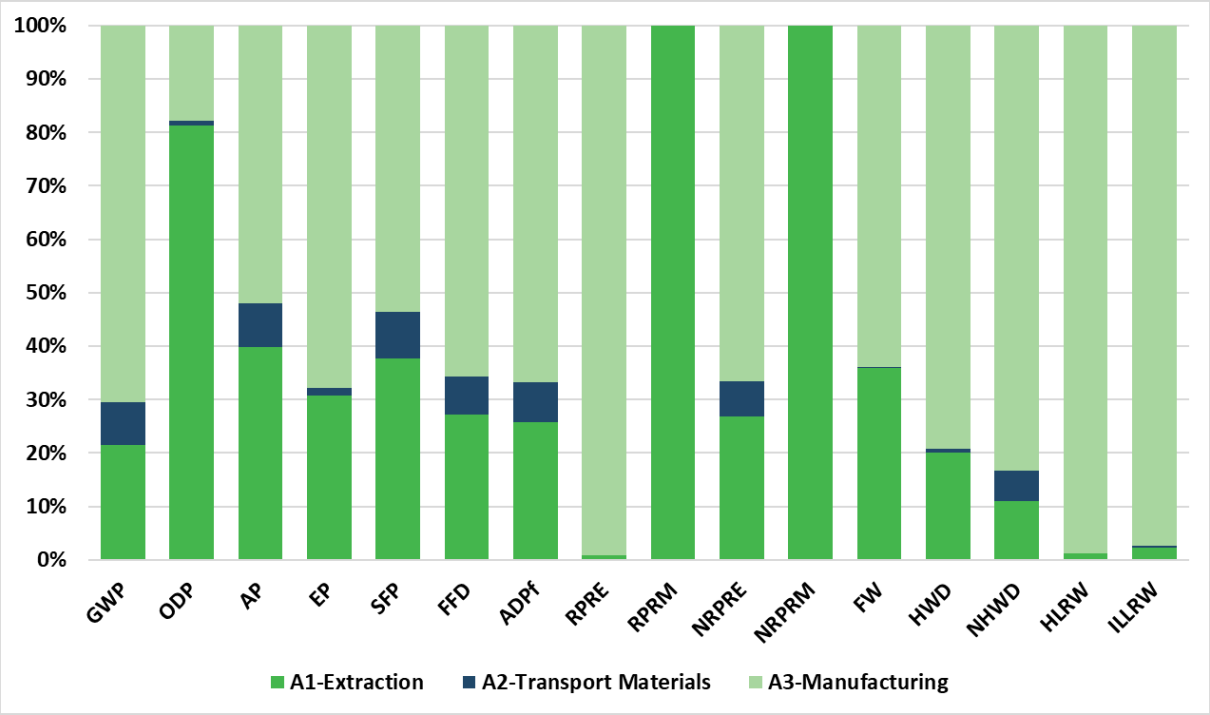
Table 21. Cradle-to-Gate LCIA Results for 1 m^3 of Western Softwood Plywood – Relative Basis.

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	100%	1%	0%	99%
RPRM [MJ, LHV]	100%	100%	0%	0%
NRPRE [MJ, LHV]	100%	27%	7%	67%
NRPRM [MJ, LHV]	100%	100%	0%	0%
FW [m^3]	100%	36%	0%	64%

Table 22. Cradle-to-Gate LCIA Results for 1 m^3 of Western Softwood Plywood – Relative Basis.

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	100%	20%	1%	79%
NHWD [kg]	100%	11%	6%	83%
HLRW [m^3]	100%	1%	0%	99%
ILLRW [m^3]	100%	2%	0%	97%

Most of the renewable fuels were used in the A3 life-cycle stage (Table 23-26). Biomass energy is used in log conditioning, veneer drying, and pressing panels (A3). Renewable fuels represented 60 percent of energy consumption cradle-to-gate (A1-A3) (Table 26) and 99 percent within the A3 stage (Table 25). Non-renewable fossil fuel consumption made up 95 percent of the A1 energy use, nearly 100 percent for transportation (A2), and 31 percent in the A3 stage (Table 25-26). In summary, cradle-to-gate total energy for producing Western softwood plywood, which includes fuel for heat energy and equipment and electricity, comes from 38 percent fossil fuels, 2 percent nuclear, 57 percent renewable biomass fuel, and 2 percent other renewable (Table 23).



GWP	Global warming potential	RPRM	Renewable primary energy carrier used as material
ODP	Depletion potential of the stratospheric ozone layer	NRPE	Non-renewable primary energy carrier used as energy
AP	Acidification potential of soil and water sources	NRPRM	Renewable primary energy carrier used as material
EP	Eutrophication potential	FW	Consumption of freshwater resources
SFP	Formation potential of tropospheric ozone	HWD	Hazardous waste disposed of
ADPf	Abiotic depletion potential (ADP fossil) for fossil resource	NHWD	Non-hazardous waste disposed of
FFD	Fossil fuel depletion	HLRW	High-level radioactive waste, conditioned, to final repository
RPRM	Renewable primary energy carrier used as energy	ILLRW	Intermediate- and low-level radioactive waste, conditioned, to final repository

Figure 6. Cradle-to-Gate LCIA Results for 1 m^3 of Western Softwood Plywood – Relative Basis.

Table 23. Cradle-to-Gate Cumulative Energy Demand (CED) Results for 1 m^3 of Western Softwood Plywood – Absolute Basis.

Impact category	A1-A3	A1	A2	A3
Nonrenewable, fossil	3,188.96	224.20	2,097.55	2,097.55
Non-renewable, nuclear	194.16	3.28	152.71	152.71
Non-renewable, biomass	0.32	0.00	0.01	0.01
Renewable, biomass	4,757.72	0.10	4,724.05	4,724.05
Renewable, wind, solar, geothermal	115.35	0.11	112.07	112.07
Renewable, water	124.55	0.30	116.64	116.64
Total	8,381.06	227.99	7,203.02	7,203.02

Table 24. Cradle-to-Gate Renewable and Non-Renewable Energy Use Results for 1 m^3 of Western Plywood, Absolute Basis.

Impact category	A1-A3	A1	A2	A3
Renewable Energy	4,997.62	44.35	0.51	4,952.76
Non-renewable Energy	3,383.44	905.70	227.48	2,250.26
Total	8,381.06	950.05	227.99	7,203.02

Table 25. Contribution Analysis for Cradle-to-Gate Renewable and Non-Renewable Energy Use Results for 1 m^3 of Western Plywood, by A1-A3 Total, Relative Basis.

Impact category	A1-A3	A1	A2	A3
Renewable Energy	100%	0.89%	0.01%	99.10%
Non-renewable Energy	100%	26.77%	6.72%	66.51%
Total	100%	11.34%	2.72%	85.94%

Table 26. Contribution Analysis for Cradle-to-Gate Renewable and Non-Renewable Energy Use Results for 1 m^3 of Western Plywood by Module Total, Relative Basis.

Impact category	A1-A3	A1	A2	A3
Renewable Energy	59.63%	4.67%	0.23%	68.76%
Non-renewable Energy	40.37%	95.33%	99.77%	31.24%
Total	100.00%	100.00%	100.00%	100.00%

6.2 Biogenic carbon

Table 27 shows additional inventory parameters related to biogenic carbon removal and emissions. All carbon dioxide flows (kg CO_2e) presented in Table 27 are unallocated to include by-products leaving the system boundary in module A3. Even though the system boundary for this LCA only includes modules A1-A3, in accordance with ISO 21930, emission from packaging (BCEK) is reported in A5-Construction and emission from the main product (BCEP) is reported in C3/C4-End-of-Life[3]. The net biogenic carbon emission across the cradle-to-gate life cycle is zero. It is assumed that all carbon removed from the atmosphere is eventually emitted to the atmosphere as CO_2.

Total $GWP_{BIOGENIC}$ includes biogenic carbon emissions and removals from the information modules A1-A3, A5, and C3/C4, leading to a net zero contribution of biogenic carbon to $GWP_{BIOGENIC}$. Therefore, in Table 17, results from Total GWP_{FOSSIL} and Total GWP_{TOTAL} are equal.

Using the method described earlier in this report, -1,573 kg CO_2 (reported in A1-Extraction) were removed in the production of 1 m^3 of plywood (unallocated). One cubic meter of Western softwood plywood stores 254 kg of carbon or +930 kg CO_2 eq (reported in C3/C4-End-of-Life). The by-products leaving the system boundary account for an additional +165 kg CO_2 (reported in A3-Manufacturing) for a total "emission" in wood product leaving the system boundary of +1,234 kg CO_2. The combustion of wood fuel emitted 339 kg CO_2. Packaging resulting in removal of -5.15 kg CO_2 and an emission of +5.15 kg CO_2. In summary, total removals was -1,573 kg CO_2 and total "emissions" was +1,573 kg CO_2 from cradle-to-gate (A1-A3 of the LCA system boundary).

Table 27. Biogenic Carbon Inventory Parameters for 1 m^3 of Western Softwood Plywood, Unallocated.

	A1	A2	A3	A5	C3/C4	Total
BCRP [kg CO_2]	(1,572.89)	0.00	0.00	0.00	0.00	(1,572.89)
BCEP [kg CO_2]	0.00	0.00	303.60	0.00	930.22	1,233.82
BCRK [kg CO_2]	0.00	0.00	(5.15)	0.00	0.00	(5.15)
BCEK [kg CO_2]	0.00	0.00	0.00	5.15	0.00	5.15
BCEW [kg CO_2]	0.00	0.00	339.07	0.00	0.00	339.07

Western plywood production facilities obtain their wood fiber from sources that are legally and sustainably sourced. The carbon that is part of the molecular composition of wood is derived from the carbon dioxide removed from the atmosphere by the growing of trees that produce wood. The carbon content of wood, in general, is 50 percent. The GWP_{FOSSIL} accounts for the green house gas emissions released through manufacturing (embodied carbon). In this LCA, plywood stores more carbon than is released during manufacturing (A1-A3) by containing 930 kg CO_2e in the final product while emitting 224 kg CO_2e from cradle-to-gate (A1-A3). In summary, the carbon balance of Western plywood is -706 kg CO_2e/m^3.

[3] These products are reported in modules outside the scope of this LCA system boundary to provide reference for EoL waste and emissions if a full cradle-to-grave LCA were to be performed.

7 Interpretation

As defined by ISO (2006a), the term life cycle interpretation is the phase of the LCA in which the findings of either the LCI or the LCIA, or both, are combined consistent with the defined goal and scope to reach conclusions and recommendations. This phase in the LCA reports the significant issues based on the results presented in the LCI and LCIA of this report. Additional components report an evaluation that considers completeness, sensitivity, and consistency checks of the LCI and LCIA results, conclusions, limitations, and recommendations.

7.1 Uncertainty and Sensitivity Analysis

The uncertainty and sensitivity analysis aims to assess the reliability of the final results. The uncertainty analysis investigates input data variations within the sample production facilities. Some degree of uncertainty is present in the results due to the variation amongst different data providers. Table 28 provides statistics for electricity, natural gas, and wood fuel.

Table 28. Summary of Selected Survey Data Statistics for 1 m^3 of Western Softwood Plywood.

Parameter	Weighted Average	Max	Min.	Std. Dev.	Median
Electricity	126.24	305.29	32.68	89.88	133.03
Natural gas	29.60	126.93	0.00	40.95	33.25
Wood fuel	148.93	287.69	26.01	97.31	123.14

In the sensitivity analysis, significant inventory parameters are altered to investigate the effect on the LCIA results. Wood fuel was substituted 100 percent for natural gas and natural gas substituted for 100 percent wood fuel as the total energy source onsite. Natural gas increased from 29.60 m^3 to 114.68 m^3 to supply the same amount of energy the wood fuel generated. The increase resulted in a 50 percent increase in the embodied carbon (GWP_{FOSSIL}) and a 49 percent increase in nonrenewable fossil fuels (Table 29).

Table 29. Sensitivity Analysis – Substituting Natural Gas for all the Onsite Heat Energy Requirement.

Indicator Name	Units	Base	Substitution	Percent change
Ozone depletion	kg CFC-11 eq	3.23E-06	3.14E-06	-2.57%
Global warming (GWP_{FOSSIL})	kg CO_2 eq	2.24E+02	3.36E+02	49.93%
Smog	kg O_3 eq	3.31E+01	2.98E+01	-9.99%
Acidification	kg SO_2 eq	1.22E+00	1.13E+00	-7.25%
Eutrophication	kg N eq	5.35E-01	4.62E-01	-13.61%
Nonrenewable, fossil	MJ, LHV	3,188.96	4,759.20	49.24%
Non-renewable, nuclear	MJ, LHV	194.16	163.00	-16.05%
Non-renewable, biomass	MJ, LHV	0.32	0.32	-0.41%
Renewable, biomass	MJ, LHV	4,757.72	1,643.37	-65.46%
Renewable, wind, solar, geothermal	MJ, LHV	115.35	91.68	-20.52%
Renewable, water	MJ, LHV	124.55	100.16	-19.58%

7.2 Completeness and Consistency Checks

Life cycle assessment reports must be reviewed for completeness, consistency, and data sensitivity. Evaluation 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 energy use (MJ/m^3) of Western softwood plywood in this LCA was compared to the previous LCA on Pacific Northwest softwood plywood (Puettmann et al. 2020), and the North American softwood plywood EPD (2020) (Table 30).

Table 30. Energy Consumption of Plywood Products – Comparison of this LCA to Other Times/Regions.

Product	Total	A1-Extraction	A2-Raw Material Transport	A3-Manufacturing	Reference
	MJ/m^3				
Western Plywood, 2022/2023 data	8,381.06	950.05	227.99	7,203.02	This LCA
Pacific Northwest Plywood, 2012 data	7,997.50	1,425.02	149.30	6,423.18	Puettmann et al. 2020
North American EPD, 2012 data	7,462.44	1,608.42	135.29	5,718.73	Softwood Plywood EPD, North American, 2020

The objective of the consistency check is to determine whether the assumptions, methods, models, and data are consistent with the goal and scope of the study. Through a rigorous process, consistency is ensured to 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.

The completeness check is performed 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 by-products 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.

8 Discussion

This study provides a comprehensive cradle-to-gate LCA of the production of Western softwood plywood. The primary goal of this LCA was to develop life cycle inventory data and impact assessment softwood plywood that would be used to develop a Type III Environmental Product Declaration (EPD). In addition to the impact assessment results, the life cycle inventory elements are also provided. Including the LCI elements enables the resource use inventory elements and waste flows as required by the PCR to be included in the EPDs. This cradle-to-gate LCA does incorporate the necessary scope to develop a “business-to-business” EPD for softwood plywood in accordance with the Product Category Rule Guidance for Building-Related Products and Services, Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL 2018) and Part B: Structural and Architectural Wood Products EPD Requirements (UL 2020).

As noted earlier, total energy for producing 1 cubic meter of softwood plywood from the Western was 8,381 MJ, which differs from the 2020 report by 4.8 percent (7,997.50 MJ, Puettmann et al. 2020) (Table 31). Renewable fuels use differences between the LCAs is around 2 percent (1.8%) (Table 31).

Table 31. LCIA Comparison Between this LCA and the 2020 LCA Report on Softwood Plywood Production in the Western Region.

Impact category	Unit	This LCA[1/]	Puettmann et al. 2020[2/]	Percent change
Global warming potential, fossil	GWP_{FOSSIL} [kg CO_2 eq]	224.17	176.09	27.30%
Ozone depletion potential	ODP [kg CF-11eq]	3.23E-06	7.58E-06	-57.42%
Acidification potential	AP [kg SO_2 eq]	1.2204	0.9465	28.93%
Eutrophication potential	EP [kg N eq]	0.5352	0.778	-31.21%
Smog potential	SFP [kg O_3 eq]	33.05	24.33	35.85%
Non-renewable fuels	MJ, LHV	3,383.44	3,088.07	9.57%
Renewable fuels	MJ, LHV	4,997.62	4,909.43	1.80%
Fresh water	L	2,241.81	1,059	111.69%
Solid waste (hazardous & non-hazardous)	kg	22.69	43.69	-48.07%

[1/] Based on 2022/2023 production data
[2/] Based on 2012 production data

9 Additional Information

Plywood production facilities in the U.S. West obtain their wood fiber from sources that are legally and sustainably sourced. Participating facilities reported Fiber Sourcing data for the three sourcing categories established in ASTM-D7612: Standard Practice for Categorizing Wood and Wood-Based Products According to Their Fiber Sources (ASTM 2021). The standard provides criteria for differentiating wood products into three categories:

1. Non-controversial Sources of Forest Products,
2. Responsible Sources of Forest Products, and
3. Certified Sources of Forest Products.

Fiber from non-controversial, or legal, sources are from geographic areas with a low risk of illegal activity and are compliant with legal or other proprietary standards. Products from responsible sources are produced with wood fiber acquired according to an independently certified procurement standard or are from jurisdictions with regulatory or quasi-regulatory programs to implement best management practices. Independently certified procurement standards include FSC Controlled Wood and SFI Fiber Sourcing. To qualify for either standard, a plywood mill must have a system in place that verifies their logs are coming from areas in compliance with forestry best management practices to protect air and water quality and ensure all fiber comes from known and legal sources. Products from certified sources are independently certified to an internationally recognized forest management certification standard, such as those from the Sustainable Forestry Initiative (SFI), Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), American Tree Farm System (ATFS), or the Canadian Standards Association (CSA).

The twelve facilities represented in this regional LCA reported, on average, 100% of the fiber entering their mills to be non-controversial (legal), 89.6% to be responsible (following a certified procurement standard), and 37.9% from independently certified forests.

10 Conclusions

This study provides a comprehensive cradle-to-gate LCA of the production softwood plywood produced and sourced in the Western region of the United States. The primary goal of this LCA was to develop life cycle inventory data and impact assessment results for Western plywood that could be used to develop a product Environmental Product Declaration (EPD). In addition to the impact assessment results, the life cycle inventory elements are also provided. Including the LCI elements enables the resource use inventory elements and waste flows as required by the Product Category Rule (PCR) to be included in the EPD. This cradle-to-gate LCA does incorporate the necessary scope to develop a “business-to-business” EPD in accordance with the PCR Guidance for Building-Related Products and Services, Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL 2018) and Part B: Structural and Architectural Wood Products EPD Requirements (UL 2020).

11 Critical Review

11.1 Internal Review

The purpose of the LCA Report internal review is to check for errors and conformance with the PCR prior to submittal for external review. The technical and editorial comments of the reviewers were carefully considered and, in most instances, incorporated into the final document. CORRIM and the American Wood Council addressed the internal review comments, as appropriate, and maintains a record of all comments and responses for future reference.

- Anna Ostrander, Manager, Sustainability Data, American Wood Council
- AWC – Plywood Review Committee (representatives from industry)

11.2 External Review

The external review process is intended to ensure consistency between the completed LCA and the principals and requirements of the International Standards on LCA (ISO 2006a) and ISO 21930 -Sustainability in Buildings and Civil Engineering Works - Core Rules for Environmental Product Declarations of Construction Products and Services (ISO 2017), the Product Category Rules for North American Structural and Architectural Wood Products Part B (UL 2020) and Part A: Life Cycle Assessment Calculations Rules and Report Requirements (UL 2018).

Following the internal review evaluation, documents were submitted to ASTM International for an independent external review. The independent external review performed by ASTM was conducted by:

- Dr. Thomas Gloria, Industrial Ecology Consultants

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