CORRIM Report

Life Cycle Assessment of Glued Laminated Timbers Production – United States

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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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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 glued laminated timbers (glulam) produced in the United States (U.S.) (Figure 1) and the subsequent releases into the environment. Facilities included in this LCA are members of the American Wood Council (AWC), Softwood Lumber Board (SLB), 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 2023 calendar year. Inputs included lamstock, adhesive, fuels, energy, ancillary materials, and packaging materials used for producing glulam.

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).

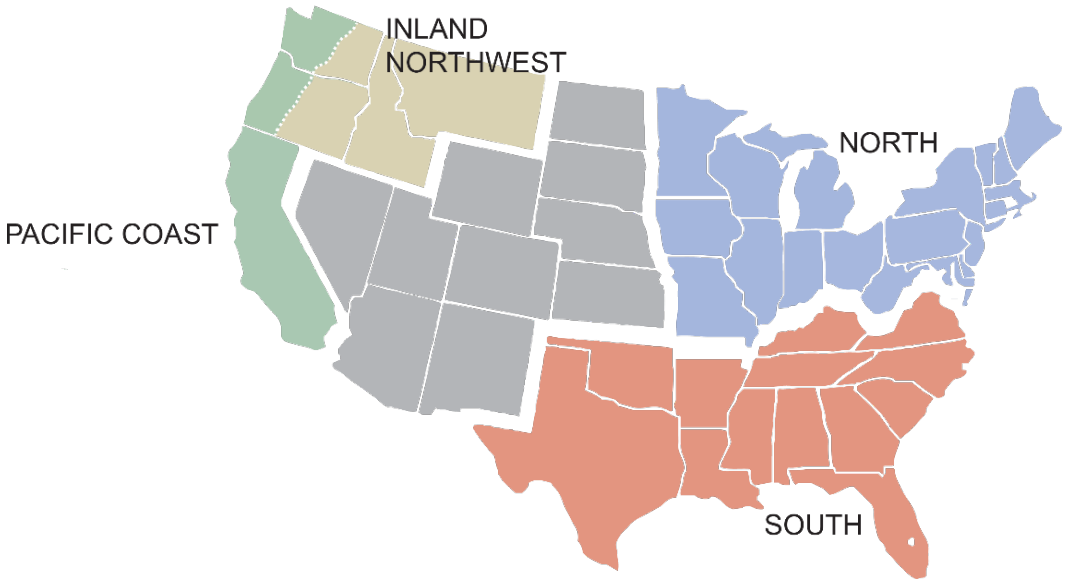


Figure 1. Geographical Regions of Glulam Production.

1 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.

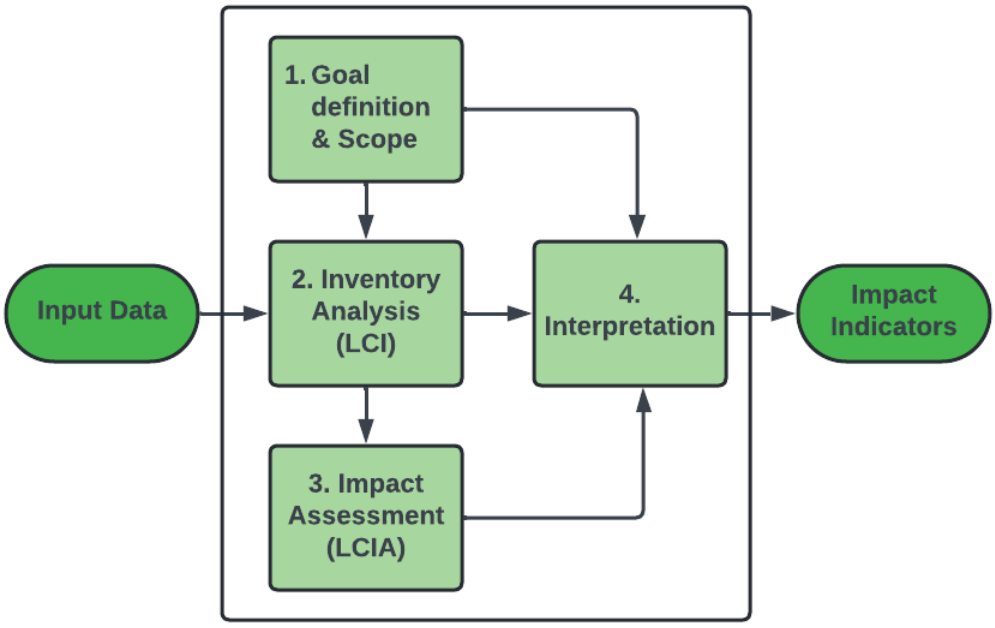


Figure 2. Steps Involved in a Life Cycle Assessment.

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.

2 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.

2.1 Goals and Objectives

2.1.1 Goals

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

2.1.2 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.

2.1.3 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.

2.2 Scope of Considered System

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

2.2.1 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 and ends with glulam 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; lamstock[1] production, and adhesive production (A_1); transportation of all resources and materials (A_2); and glulam 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 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 glulam products no doubt has a burden on the environment. However, the data collection required to properly

[1] Lamstock is defined as a special grade of wood used in constructing laminated timbers.

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

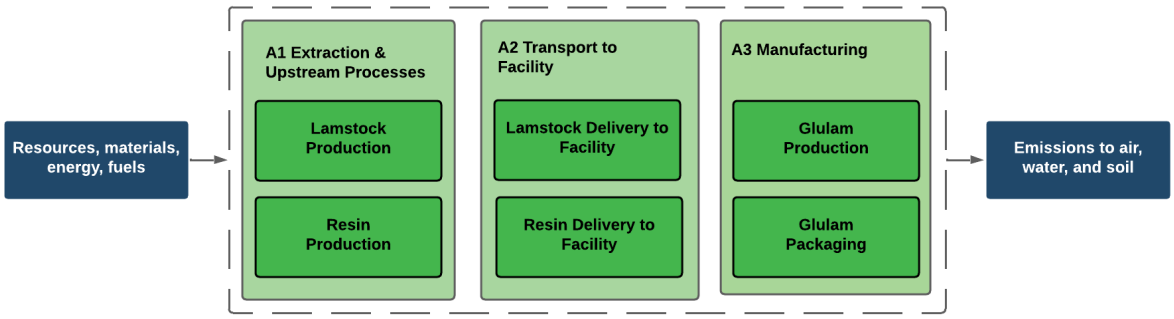


Figure 3. Cradle-to-Gate (A1-A3) System Boundary Glulam Production.

2.2.2 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.

2.2.3 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 with ISO 14044/Amd1:2017/Amd2:2020 standards. This study relied exclusively on 2023 production 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). Ten facilities from the Pacific Coast, Inland Northwest, Northern, and Southern regions participated in the survey (Figure 1).

Photo credit: APA – The Engineered Wood Association

2.2.4 Calculation Rules

Lumber inputs (lamstock) were provided in units of thousand board feet (MBF) and a ratio of nominal to actual BF was used to calculate actual wood volumes. This ratio was determined by weight-averaging the BF ratio of common sizes of lamstock used for glulam. The volume was converted to cubic meters (m^3) (1 BF = 0.0024 m^3) and the weight of the lamstock input was calculated with the weighted average density in 530 kg/m^3 (oven dry basis).

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 glulam 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 Glulam facility are calculated respectively as follows:

Example y_1, 10 facilities are represented

$$w_1 = y_1 / (y_1 + y_2 + y_3 \ldots y_{10}) = y_1 / Y_{total}$$

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

where:

Y_{total}	**Total Glulam production of all 11 facilities (m^3 basis)**
y_1	**Glulam production of facility 1 (m^3 basis)**
y_2	**Glulam production of facility 2 (m^3 basis)**
y_3	**Glulam production of facility 3 (m^3 basis)**
$\ldots y_{10}$	**Glulam production of facility 10 (m^3 basis)**

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.

2.2.5 Functional and Declared Unit

In accordance with the PCR, the declared unit for glulam is 1.0 m^3 of glulam 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, with 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.

2.2.6 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 glulam is lamstock. 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. Packaging inputs are not related to the by-products and are allocated 100% to the final product.

2.2.7 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 2), 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 2. **Note:** *Six impact indicators listed in Table 2, 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 2 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 2. 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-11 eq	TRACI 2.1 V1.08
Acidification potential of soil and water sources	AP	kg SO_2 eq	TRACI 2.1 V1.08
Eutrophication potential	EP	kg N eq	TRACI 2.1 V1.08
Formation potential of tropospheric ozone	SFP	kg O_3 eq	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

2.3 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[2]. 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)

[2] 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.

3 Description of Industry

Glulam is one of the original engineered wood products developed over 100 years ago by glueing stacks of lumber together. Structural glulam was created to fill the void left by the lack of large solid dimensional timbers from old growth forests. Glulam comes in a variety of sizes with their production based on nominal[3] board feet[4].

The glulam industry is a subset of the very broad engineered wood product (EWP) industry which also produces mass ply-panels, cross laminated timber, laminated veneer lumber, and other EWP products derived from trees. A distinction is often made between primary and secondary forest product industries with the former including products such as lumber and panels and the latter including products derived from lumber and panels such as glulam.

Glulam facilities are located in all the major wood producing regions in the U.S. (Figure 1). Glulam plants utilize either one of two laminating technologies, either cold curing (no added heat) or radio frequency (RF) curing. Emission control devices are required at these facilities since toxic gases are emitted to the air from the curing of melamine and formaldehyde resins.

3.1 Description of Product

Glulam is an engineered, stress-rated product that consists of two or more layers of lumber that are glued together with the grain of the layers parallel to the length of the beam or column. These layers are typically referred to as laminations as seen in Figure 2. Glulam is made from suitably selected and prepared pieces of wood either in a straight or curved form, with the grain of all pieces essentially parallel to the longitudinal axis of the member (Figure 2). The maximum lamination thickness permitted is 50 mm (2 in.), and the laminations are typically made of standard 25 or 50 mm (nominal 1 or 2 in.) thick lumber. The lumber is joined end to end, edge to edge, and face to face, so the size of glulam is limited only by the capabilities of the manufacturing plant and the transportation system. North American standards require that glulam be manufactured in an approved manufacturing plant.

Glulam produced by APA -The Engineered Wood Association members are certified with an APA trademark and are tested for compliance to ANSI/AITC Standard A190.1-2022 to verify quality in product manufacturing. All glulam properties are tested to adhere to ASTM D3737-18(2023)e1 Standard Practice for Establishing Allowable Properties for Structural Glued-Laminated Timber (Glulam).

[3] Nominal size - The size designation for most lumber. In lumber, the nominal size usually is greater than the actual dimension; a kiln dried 2x4 (nominal) is surfaced to 1-1/2 x 3-1/2 inches (actual).

[4] Board foot (BF) -The basic unit of measurement for lumber. One board foot is equal to a 1-inch board 12 inches in width and 1 foot in length.

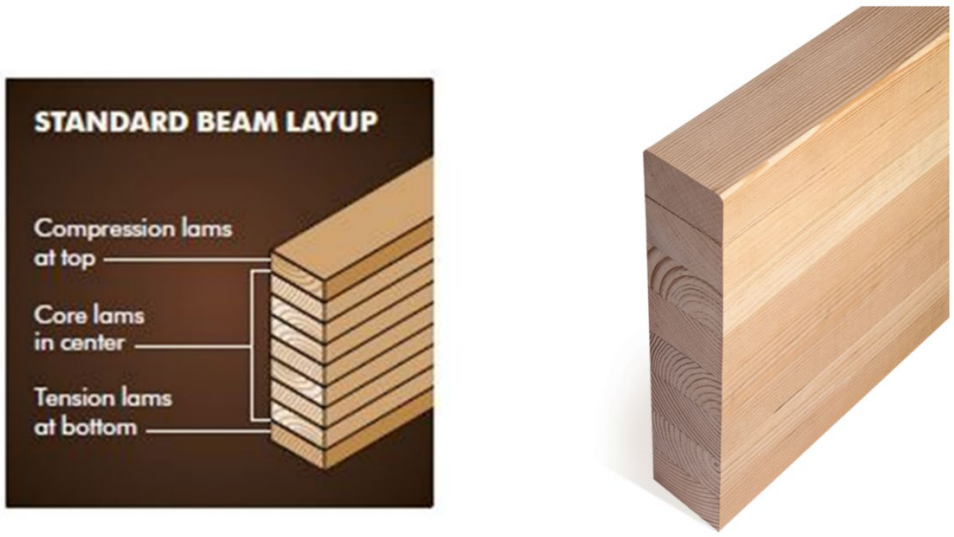


Figure 4. Glulam Assembly, Photo credit APA – The Engineered Wood Association.

Glulam beams are used as concealed or exposed structural beams and columns in residential and commercial construction, warehouse roof beams and purlins, church arches, and girders and deck panels for timber bridges. Glulam comes in a variety of sizes with production based on a volume basis, typically board feet (1 BF = 0.0024 m^3), and is sold by retailers on a linear basis.

Glulam is produced from softwood lumber called lamstock. Lamstock is defined as a special grade of lumber used in the construction of laminated timbers. Green lamstock cut from logs must be kiln-dried to a moisture content (MC) of 16 percent or less to minimize any additional dimensional changes. Lamstock that exceeds the 16 percent MC limit cannot be utilized and has to be re-dried, since this will prevent the laminations from properly adhering to each other in the following processes. Lamstock grading entails either one of two methods, either visual or machine grading. Visual grading is based upon the appearance of the material and any apparent flaws. Machine e-rated lamstock is graded by stiffness and visual characteristics.

NAICS product code 321213 is used in identifying products that can be labeled as engineered wood products like glued-laminated timbers. Additional classification codes for glulam are the United Nations Standard Products and Services Code (UNSPSC) – Engineered wood products/Glued laminated timber 111220 05 and Construction Specifications Institute (CSI) code for Heavy Timber Construction 06 13 00 and Glued-Laminated Construction 06 18 00.

Table 3. United Nations Standard Products and Services Code (UNSPSC) and Construction Specification Institute (CSI) MasterFormat Code for Glued-Laminated Timbers.

Classification Standard	Category	Subcategory	Product Code
UNSPSC	Engineered wood products	Engineered Wood Products	111220 00
		Glued Laminated Timber	111220 05
CSI/CSC		Heavy Timber Construction	06 13 00
		Glued-Laminated Construction	06 18 00
		Glued-Laminated Beams	06 18 13
		Glued-Laminated Columns	06 18 16
		Engineered Wood Products	06 11 13

3.1.1 Categories of Products and By-products

The primary product from glulam facilities is glulam. Other products (by-products) are also generated during the glulam production process. These by-products could include sawdust, end-cuts, and trim. Glulam facilities reported, on average, over 99 percent of the by-products produced sold and <1 percent used for on-site energy.

3.2 Annual Operating and Production Statistics of the Industry

In this LCA, participating glulam facilities (n=10) accounted for 44 percent of the 258 million board feet (MMBF) of glulam capacity in 2023 (FEA 2024). Of the reporting facilities, the annual production ranged from 1 – 22 MMBF, with a weighted average based on production of 20 MMBF (30,836 m^3).

3.3 General Types of Wastes and Emissions

Emission control devices are required at these facilities since toxic gases are emitted to the air from the curing of melamine and formaldehyde resins. The air emissions at glulam facilities may 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[5]. These emissions are reported in this LCA.

Most mills reported mill waste going to landfills, recycling, and/or incineration. Most common waste types reported were wood waste, oils and greases, and ash.

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

3.4 Wood Species

Southern pine dominated the species mix for glulam mill responses, representing 71 percent (Table 4), followed by Inland Northwest species (Douglas-fir, Hemlock, Spruce/Pine/Fir) (Puettmann 2025) at 24 percent and Pacific Coast Douglas-fir at 4 percent. Southern pine is a mixture of several species with similar characteristics. The species are primarily longleaf pine (*Pinus palustris*), loblolly pine (*P. taeda*), shortleaf pine (*P. echinata*), and slash pine (*P. elliottii*).

Table 4. Species and Representation for Glulam.

Lamstock Production Regions	Species Grouping	Scientific Name	Survey Composition
South	Southern Pine	*Pinus spp.*	71.34%
Inland Northwest	Douglas-fir/Hemlock/SPF	*Pseudotsuga menziesii, Tsuga heterophylla, Picea/Pinus/Abies spp.*	24.34%
Pacific Coast	Douglas-fir	*Pseudotsuga menziesii*	4.32%
			100%

3.5 Moisture Content

The weighted average moisture content of the glulam ready for shipment was 13 percent. Surveys reported a range of moisture contents for finished glulam from 12-15 percent. All wood moisture content values are reported on an oven-dry basis.

4 Life Cycle Inventory Analysis

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

4.1 A1- Wood Inputs

Logs inputs for the production of lamstock were from manufacturers in the Southern, Pacific Coast, and Inland Northwest regions of the United States (Figure 1). Upstream impacts from forestry operations in each of these regions were reported by Oneil (2021), Oneil and Puettmann (2017), and Oneil (2022a, 2022b). Included are activities associated with establishment, growth, and harvest of trees specific to each region. 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.

The lamstock production process is similar to lumber production reported by Puettmann (2024a-c, 2025). It starts at the sawmill and includes debarking logs, sawing logs into rough-green lamstock, drying the lamstock and then transporting to glulam production facilities.

4.2 A1 – Adhesive

Facilities reported the use of melamine formaldehyde (MF), polymer emulsion polyurethane (PEP), and phenol resorcinol formaldehyde (PRF) resins. Other additives (hardeners, primers, catalysts, and caustic) represent around 12 percent of the total mass of adhesive inputs (8.55 kg) (Table 5). Production of adhesives was obtained from published LCA data (Athena 2022).

Table 5. Weighted Average Resin and Additive Inputs per cubic meter of Glulam, Unallocated.

Adhesive and Sealant Components	Component mass (kg)	Component Percent
	per m^3 of Glulam	
MF	3.27	38.21%
PEP	2.77	32.40%
PRF	1.52	17.75%
Hardeners	0.60	7.06%
Caustic	0.25	2.96%
Catalyst	0.12	1.39%
Primer	0.02	0.24%
Total	8.55	100.0%

A2 – Transport

The A2 module includes the transportation of resources and materials used in the production of glulam (Table 6). The distances are weighted averages based on glulam production surveys.

Table 6. Weighted Average Delivery Distance and Mode of Transport for Glulam.

Input Material	Mode of Transportation	Distance	
		km	Miles
Lamstock	Road	1,492.44	927.36
Adhesive & additives	Road	2,310.41	1,435.62
Lamstock	Rail	573.91	356.61

4.3 A3 – Glulam Manufacturing

4.3.1 Equipment: Type and Fuel Consumption

Diesel-powered loaders are typically used for moving materials and product. Electrically driven motors in the mill are used for material conveyors, finger jointing, and trims saws. Electricity is also used for running fans and pumps, and for operating emissions control equipment. Lifts for transporting products and materials in the mill are typically powered by electricity and liquefied propane gas. Natural gas and wood by-products are used to keep process facility at a required temperature to maintain moisture content and proper curing.

4.3.2 Onsite Energy Production

Heat energy from wood was used at glulam facilities. Of the wood fuel burned, 100 percent is produced on site. 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 landfilled.

4.3.3 Material Flows

Wood raw material for glulam production arrives in the form of lamstock (lumber). Table 7 lists the wood inputs and outputs from glulam production on an oven dry mass basis. Based on mass allocation, glulam product used over 85 percent of the wood input, with less than 15 percent left for by-products. Of the by-products produced, 99 percent were sold and <1 percent were used onsite for heat energy.

Table 7. Mass Balance of Raw Materials, By-products, and Products in the Glulam Manufacturing Process, Unallocated.

A3 Production	Value	Unit/m3	Allocation
Inputs			
Lamstock	614.05	kg	98.63%
Resin	8.55	kg	1.37%
Total	622.60	kg	100%
Outputs			
Glulam	529.49	kg	85.05%
By-Products, wood only	93.11	kg	14.95%
Total	622.60	kg	100%

4.3.4 Glulam Manufacturing

Once the lamstock input is at the necessary moisture content, the actual glulam manufacturing process can begin. Resins are the other primary material input at this stage.

4.3.4.1 End Jointing

Glulam beams are typically longer than the available lamstock. Lamstock can be joined end to end to extend the length of each lamination. The most common joint used to combine lumber end to end is a finger joint. The joints are cut on both ends of the lamstock, and resin is applied. A structural resin is used for finger joints and cured with RF drying or cold cure processes (Table 8). Curing occurs under pressure and heat for a strong and stable bond between the pieces. Manufacturers typically employ a continuous RF curing system for end finger jointing, so that they can quickly process the laminations before face bonding.

Table 8. Weighted Average Curing Process Used in Glulam Manufacturing.

Curing Process	Survey Response for Use
Finger Joint – Cold Cure	32%
Finger Joint – Radio Frequency	68%
Face bonding – Cold Cure	83%
Face bonding – Radio Frequency	17%

4.3.4.2 Face Bonding

During the face bonding process, the finger jointed lamstock is planed, and resin is applied to the face with a glue extruder. The laminations are then assembled into the required layup, and pressure is applied. Either cold cure or radio frequency curing are utilized during this process (Table 8). Glulam is allowed to cure until ready for finishing and fabrication.

4.3.4.3 Finishing and Fabrication

After pressing and curing, glulam is removed from the presses and the beams are planed to remove adhesive that had squeezed out during pressing. The remaining two faces of the member may be lightly planed or sanded. For premium and architectural classified glulam, knots and planer skips are covered up. Depending upon use, final cuts are made, holes are drilled, connectors are added, and a finish may be applied. Each glulam is wrapped for protection before shipping.

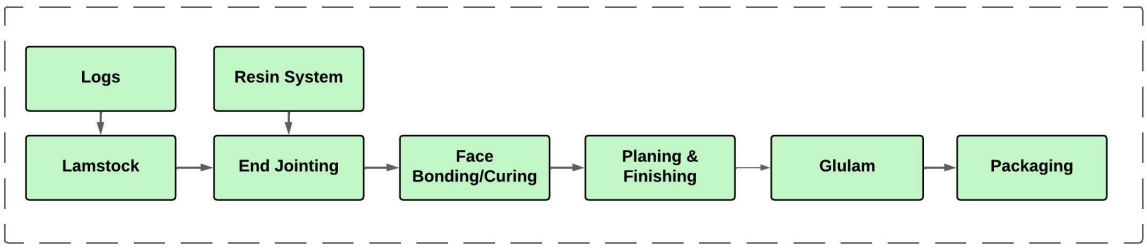


Figure 5. Process Flow for the Manufacturing of Glulam.

Survey respondents provided data from 2023 on the material and resource inputs to glulam manufacturing at the mill and outputs such as product, by-products, resin use and transportation (Table 9). The data were production-weight averaged and are reported below per cubic meter (m^3) of finished glulam produced.

Table 9. Process Inputs/Outputs for Glulam Manufacturing to Produce 1 m^3, Unallocated.

A3 Production	Value	Unit/m^3	Allocation
A3 Glulam, m3, US	1.00	m^3	85.0%
A3 By-product, at Glulam, Sold, kg, US	92.50	kg	14.9%
A3 By-product, at Glulam, kg, US	0.60	kg	0.1%
Resources			
Water, unspecified	20.87	L	
Water, well	4.02	L	
Materials/fuels			
A1 – Lamstock	1.18	m3	
A1 – Adhesive & Additives	8.55	kg	
Transportation road (lamstock & resin)	297.12	tkm	
Transportation rail (lamstock)	3.15	tkm	
Diesel	0.5598	L	
Gasoline	0.3448	L	
Natural gas	2.91	m3	
Liquefied petroleum gas	0.8627	L	
Residual fuel oil	0.0016	L	
Wood Boiler	0.60	kg	
Process Waste, landfill	43.18	kg	
Process Waste, incineration	0.3079	kg	
Process Waste, recycling	0.3692	kg	
Electricity/heat			
Electricity-Total	69.85	kWh	
WECC	5.53	kWh	
SERC	64.10	kWh	
NPCC	0.22	kWh	
Emissions to air			
Acetaldehyde	4.22E-04	kg	
Formaldehyde	5.18E-03	kg	
HAPs	4.04E-01	kg	
Methanol	3.45E-02	kg	
Particulates, < 10 um	5.92E-02	kg	
Phenol	6.13E-01	kg	
VOC, volatile organic compounds, unspecified origin	4.33E-02	kg	

4.3.5 Packaging

Packing materials represent only 0.42 percent of the mass of the main product. Wrapping material and wood stickers make up the bulk of the mass, representing 99 percent of the total packaging (Table 10).

Table 10. Materials Used in Packaging and Shipping per m^3 Glulam.

Material	Unit	Value	Percent of Total Packaging
Wrapping Material	kg	0.2298	55.10%
Plastic strapping	kg	0.0022	0.54%
Cardboard protectors	kg	0.0033	0.79%
Stickers and battens	kg	0.1817	43.57%
TOTAL	kg	0.4170	100.00%

4.4 Secondary Data Sources

Secondary data is necessary for creating the full cradle-to-gate analysis. Tables 11, 12, and 13 list the secondary LCI data sources, geographical origin, age, and quality of the data used in this LCA study.

Table 11. Raw Material Supply Processes.

A1: Raw Material Inputs				
Inputs	**LCI Data Source**	**Geography**	**Year**	**Data Quality Assessment**
Resources	Database: CORRIM Softwood lumber,	US Pacific Coast, Southern, Inland Northwest, Norther	2024-20252024	- Technology: Good - Process models product specific technology - Time: Good update in the last 5 years - Geography: Good, Data specific to product
Resins	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 12. 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

Table 13. Manufacturing Processes

A3 Manufacturing				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Electricity	Database: Ecoinvent 3. Processes: Electricity, low voltage {WECC, US only} | market for electricity, low voltage | Cut-off, U; Processes: Electricity, low voltage {SERC, US only} | market for electricity, low voltage | Cut-off, U; Processes: Electricity, low voltage {NPCC, 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
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
Gasoline	Database: Datasmart v. 2023 Process: Gasoline, 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: Liquefied petroleum 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 5 years old - Geography: Good
Wood Fuel	CORRIM Database	United States	2020	- Technology: Good, process models average North American technology - Time: Good, Data is less than 5 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

5 Life Cycle Impact Assessment Results

5.1 A1-A3 - Cradle-to-Gate

This section discusses the cradle-to-gate results for the declared unit, one cubic meter of glulam. 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 glulam are presented for one cubic meter (Tables 14 -19).

The contribution impact results are in tables 17-19. Module A1 has the greatest contribution to the overall impact in nearly every impact category (except waste). The higher contribution in A1 module comes from the upstream impacts from the production of the lamstock and resins. Transportation accounted for a maximum of 20 percent and as low as 0.3 percent. While manufacturing glulam (A3) impact contribution was as low as 1.7 for renewable fuel use, it was as high as 56 percent of the cradle to gate impacts for waste (Tables 17-19, Figure 6).

Table 14. Cradle-to-Gate LCIA Results for 1 m^3 of Glulam – Absolute Basis.

Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{TOTAL} [kg CO_2 eq]	154.43	(1,051.64)	24.04	1,182.03
$GWP_{BIOGENIC}$ [kg CO_2 eq]	0.00	(1,141.43)	0.00	1,141.43
GWP_{FOSSIL} [kg CO_2 eq]	154.43	89.79	24.04	40.60
ODP [kg CF-11eq]	1.31E-05	1.26E-05	4.24E-08	3.58E-07
AP [kg SO_2 eq]	0.9674	0.7210	0.1335	0.1129
EP [kg N eq]	0.3487	0.2227	0.0107	0.1152
SFP [kg O_3 eq]	30.35	22.86	3.86	3.64
FFD [MJ, surplus]	284.86	172.78	45.16	66.93
ADP_{FOSSIL} [MJ, LHV]	2,149.32	1,309.33	300.77	539.22

Table 15. Cradle-to-Gate Resource use Results for 1 m^3 of Glulam – Absolute Basis.

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	3,524.07	3,463.73	0.69	59.66
RPRM [MJ, LHV]	11,066.34	11,066.34		
NRPRE [MJ, LHV]	2,497.04	1,450.40	305.18	741.46
NRPRM [MJ, LHV]	252.04	252.04	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]	0.8739	0.6864	0.0027	0.1849

Table 16. Cradle-to-Gate Output Flows for 1 m^3 of Glulam – Absolute Basis.

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	1.56E-01	1.29E-01	1.07E-02	1.64E-02
NHWD [kg]	9.74E+00	5.33E+00	1.95E+00	2.46E+00
HLRW [m^3]	3.78E-07	1.66E-07	0.00E+00	2.12E-07
ILLRW [m^3]	3.37E-06	1.48E-06	1.39E-08	1.88E-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 17. Cradle-to-Gate LCIA Results for 1 m^3 of Glulam – Relative Basis.

Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{FOSSIL} [kg CO_2 eq]	100%	58.1%	15.6%	26.3%
ODP [kg CF-11eq]	100%	96.9%	0.3%	2.7%
AP [kg SO_2 eq]	100%	74.5%	13.8%	11.7%
EP [kg N eq]	100%	63.9%	3.1%	33.1%
SFP [kg O_3 eq]	100%	75.3%	12.7%	12.0%
FFD [MJ, surplus]	100%	60.9%	14.0%	25.1%
ADP_{FOSSIL} [MJ, LHV]	100%	60.7%	15.9%	23.5%

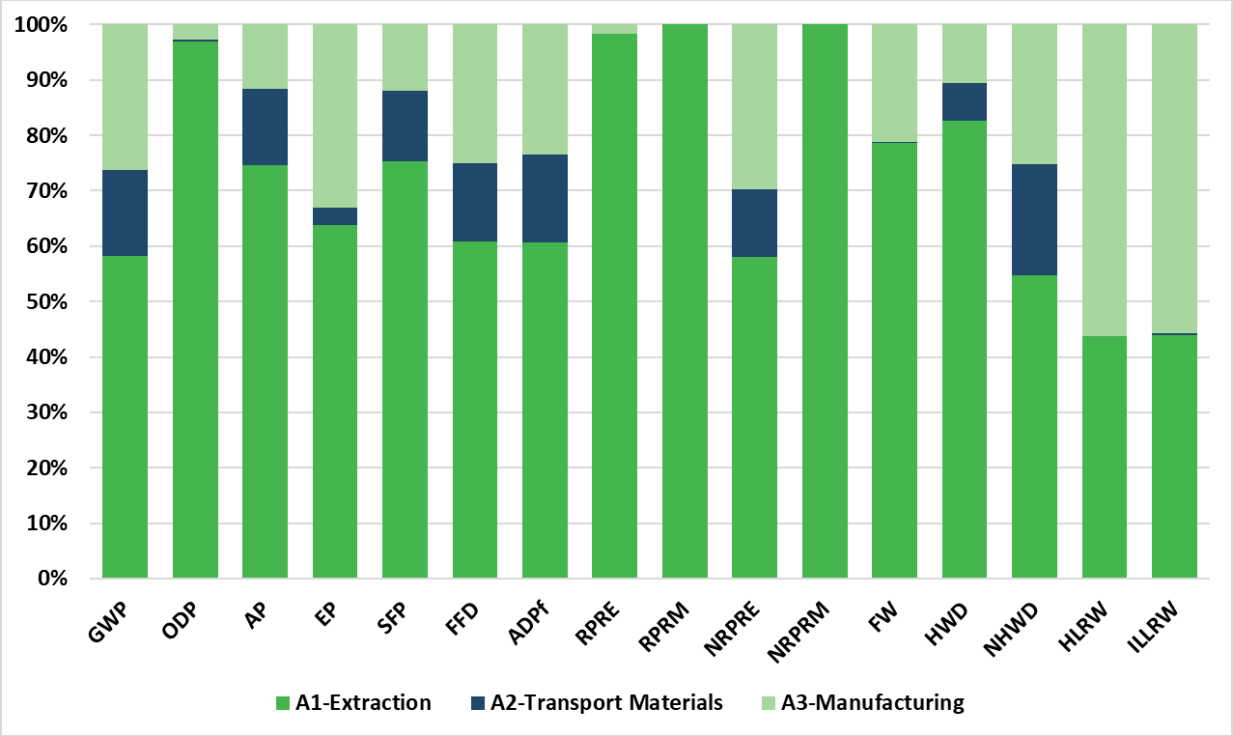
Table 18. Cradle-to-Gate LCIA Results for 1 m^3 of Glulam – Relative Basis.

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	100%	98.3%	0.0%	1.7%
RPRM [MJ, LHV]	100%	100.0%	0.0%	0.0%
NRPRE [MJ, LHV]	100%	58.1%	12.2%	29.7%
NRPRM [MJ, LHV]	100%	100.0%	0.0%	0.0%
FW [m^3]	100%	78.5%	0.3%	21.2%

Table 19. Cradle-to-Gate LCIA Results for 1 m^3 of Glulam – Relative Basis.

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	100%	50.7%	1.9%	47.3%
NHWD [kg]	100%	63.6%	12.3%	24.2%
HLRW [m^3]	100%	38.6%	0.0%	61.4%
ILLRW [m^3]	100%	40.6%	0.6%	58.8%

Most of the renewable fuels were used in the A1 life-cycle stage (Table 18, 20-23, Figure 6). Biomass energy from A1 comes from the drying processes in lumber production (lamstock) (Puettmann 2024a-c, 2025). Renewable fuels represented 59 percent of energy consumption cradle-to-gate (A1-A3) (Table 23) and 70 percent within the A1 stage (Table 23). Non-renewable fuel consumption made up 30 percent of the A1 energy use, nearly 100 percent for transportation (A2), and 93 percent in the A3 stage (Table 23). In summary, cradle-to-gate total energy for producing glulam, which includes fuel for heat energy and equipment and electricity, comes from 36 percent fossil fuels, 6 percent nuclear, 57 percent renewable biomass fuel, and 1 percent other renewable (Table 20).



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 Glulam – Relative Basis.

Table 20. Cradle-to-Gate Cumulative Energy Demand (CED) Results for 1 m^3 of Glulam – Absolute Basis.

Impact category	A1-A3	A1	A2	A3
Nonrenewable, fossil	2,150.02	1,309.77	300.78	539.47
Non-renewable, nuclear	347.01	140.63	4.40	201.98
Non-renewable, biomass	0.01	0.01	0.00	0.00
Renewable, biomass	3,434.15	3,401.40	0.14	32.61
Renewable, wind, solar, geothermal	41.65	29.63	0.15	11.87
Renewable, water	48.27	32.69	0.40	15.17
Total	6,021.11	4,914.13	305.87	801.11

Table 21. Cradle-to-Gate Renewable and Non-Renewable Energy Use Results for 1 m^3 of Glulam – Absolute Basis.

Impact category	A1-A3	A1	A2	A3
Renewable Energy	3,524.07	3,463.73	0.69	59.66
Non-renewable Energy	2,497.04	1,450.40	305.18	741.46
Total	6,021.11	4,914.13	305.87	801.11

Table 22. Contribution Analysis for Cradle-to-Gate Renewable and Non-Renewable Energy Use Results for 1 m^3 of Glulam by Module – Relative Basis.

Impact category	A1-A3	A1	A2	A3
Renewable Energy	100%	98.29%	0.02%	1.69%
Non-renewable Energy	100%	58.08%	12.22%	29.69%
Total	100%	81.61%	5.08%	13.31%

Table 23. Contribution Analysis for Cradle-to-Gate Renewable and Non-Renewable Energy Use Results for 1 m^3 of Glulam by Module Total – Relative Basis.

Impact category	A1-A3	A1	A2	A3
Renewable Energy	58.53%	70.49%	0.23%	7.45%
Non-renewable Energy	41.47%	29.51%	99.77%	92.55%
Total	100%	100.00%	100.00%	100.00%

5.2 Biogenic carbon

Table 24 shows additional inventory parameters related to biogenic carbon removal and emissions. All carbon dioxide flows (kg CO_2e) presented in Table 24 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[6]. 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 14, results from Total GWP_{FOSSIL} and Total GWP_{TOTAL} are equal.

Using the method described earlier in this report, -1,141 kg CO_2 (reported in A1-Extraction) were removed in the production of 1 m^3 of glulam (unallocated). One cubic meter of glulam stores 265 kg of carbon or +971 kg CO_2 eq (reported in C3/C4-End-of-Life). The by-products leaving the system boundary account for an additional +168 kg CO_2 (reported in A3-Manufacturing) for a total "emission" in wood product leaving the system boundary of +1,139 kg CO_2. The combustion of wood fuel emitted 3 kg of CO_2. Packaging resulted in removal of -0.38 kg CO_2 and an emission of +0.38 kg CO_2. In summary, total removals was -1,141 kg CO_2 and total "emissions" was +1,141 kg CO_2 from cradle-to-gate (A1-A3 of the LCA system boundary).

Table 24. Biogenic Carbon Inventory Parameters for 1 m^3 of Glulam, Unallocated.

	A1	A2	A3	A5	C3/C4	Total
BCRP [kg CO_2]	(1,141.43)	0.00	0.00	0.00	0.00	(1,141.43)
BCEP [kg CO_2]	0.00	0.00	167.79	0.00	970.73	1,138.53
BCRK [kg CO_2]	0.00	0.00	(0.38)	0.00	0.00	(0.38)
BCEK [kg CO_2]	0.00	0.00	0.00	0.38	0.00	0.38
BCEW [kg CO_2]	0.00	0.00	2.91	0.00	0.00	2.91

Glulam 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, glulam stores more carbon than is released during manufacturing (A1-A3) by containing 971 kg CO_2e in the final product while emitting 154 kg CO_2e from cradle-to-gate (A1-A3) (Table 14). In summary, the carbon balance of glulam is -816 kg CO_2e/m^3.

[6] 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.

6 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.

6.1 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 25 provides statistics for electricity and adhesive.

Table 25. Summary of Selected Survey Data Statistics for 1 m^3 Glulam

Parameter	Weighted Average	Max	Min.	Std. Dev.	Median
Electricity	69.85	156.40	46.70	33.86	87.62
Adhesive & Additives	8.55	18.74	3.74	4.38	9.27

In the sensitivity analysis, significant inventory parameters can be altered to investigate the effect on the LCIA results. In the case of glulam production, a decision was made to look at the impact of transportation of resources. Based on the road transport distances for lamstock reported in this LCA (2 to 1,207 km) these distances were doubled for every facility. This increased the total weighted mileage from 1,492 to 3,018 km

Increasing the resource road distances by 100 percent increased the A1-A3 GWP impact by only 18 percent and the non-renewable energy (NRPRE) use by 6 percent (Table 26).

Table 26. Sensitivity Analysis Around Road Transportation for Glulam, Cradle to Gate.

Indicator Name	Units	Base Case	100% increase in distance	Percent increase
Global warming (GWP_{FOSSIL})	kg CO_2 eq	154.43	181.56	17.57%
Non-Renewable Energy	MJ, LHV	2,497.04	2,497.04	5.73%

6.2 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 glulam in this LCA was compared to the previous LCA on Pacific Northwest and Southeast Glulam (Tait et al. 2020), and the North American Glulam EPD (2020) (Table 27).

Table 27. Energy Consumption of Glulam – Comparison of this LCA to Other Times/Regions.

Product	Total	A1 Extraction	A2 Raw Material Transport	A3 Manufacturing	Reference
	MJ/m^3				
Glulam 2023 data	6,021.11	4,914.13	305.87	801.11	This LCA
Pacific Northwest Glulam, 2012 data	7,919.55	6,504.14	275.47	1,139.94	Tait et al. 2020
Southeast Glulam, 2012 data	6,454.45	4,833.43	329.86	1,291.17	Glulam EPD, North American, 2020
North American EPD, 2012 data	6,799.76	5,205.02	308.08	1,286.66	Glulam 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.

7 Additional Information

Glulam production facilities in the U.S. 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 glulam mill must have a system in place that verifies their feedstock (or the logs used to produce lamstock) 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 ten facilities represented in this regional LCA reported on average, 100% of the fiber entering their mills to be non-controversial (legal), 96.5% to be responsible (following a certified procurement standard), and 39.5% from independently certified forests.

8 Conclusions

This study provides a comprehensive cradle-to-gate LCA of the production glued laminated timbers (glulam) produced and sourced in the United States. The primary goal of this LCA was to develop life cycle inventory data and impact assessment results for glulam 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).

9 Critical Review

9.1 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
- Tyler Congleton, Product Engineering Technical Manager, Boise Cascade Company

9.2 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:

Photo credit: APA – The Engineered Wood Association

10 References

ASTM Standard D7612-21. 2021. “Standard Practice for Categorizing Wood and Wood-Based Products According to Their Fiber Sources.” ASTM International, West Conshohocken, PA, 2021. DOI: 10.1520/D7612-21.

Athena Sustainable Materials Institute. 2022. A cradle-to-gate life cycle assessment of North American Wood Products Resin Systems. 93pp. https://www.athenasmi.org/wp-content/uploads/2022/03/Wood_Resins_LCA_Report_Final_Athena_With_CRS_Feb_2022.pdf (Accessed March 6, 2025)

AWC - American Wood Council. 2020. Environmental Product Declaration North

Bare, J. 2012. Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) - Software Name and Version Number: TRACI version 2.1 - User’s Manual. Washington, D.C.: U.S. EPA.

International Organization for Standardization ISO. 2006a. Environmental management—Life-cycle assessment—Requirements and guidelines. ISO 14044:2006/Amd1:2017/Amd:2:2020. International Organization for Standardization, Geneva, Switzerland. 46 pp/8 pp/12 pp/.

International Organization for Standardization ISO. 2006b. Environmental management—Life-cycle assessment—Principles and framework. ISO 14040. International Organization for Standardization, Geneva, Switzerland. 14040:2006/Amd1:2020. 20 pp/8 pp.

International Organization for Standardization ISO. 2006c. Environmental labels and declarations—Type III environmental declarations—Principles and procedures. ISO 14025. International Organization for Standardization, Geneva, Switzerland. 25 pp.

International Organization for Standardization ISO. 2017. Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services. International Organization for Standardization. Second edition (ISO 21930:2017-07) 80pp.

LTS. 2023 Datasmart LCI Package http://ltsexperts.com/services/software/datasmart-life-cycleinventory/

Oneil, E. and M. E. Puettmann. 2017. Life-Cycle Assessment of Forest Resources of the Pacific Northwest, USA, Forest Products Journal 67(5-6): 316-330.

Oneil, E. 2021. Life-Cycle Assessment of US Regional Forest Resources - US Northeast/Northcentral. 26pp. https://corrim.org/wp-content/uploads/2021/12/CORRIM_NENC_Forest_Resources_LCA_Report.pdf. (Accessed April 22, 2025)

Oneil, E. 2021. Cradle to gate life cycle assessment of US regional forest resources – US Southern Pine Forests. 41pp. https://corrim.org/wp-content/uploads/2021/12/CORRIM_SE_Forest_Resources_LCA_Report.pdf. (Accessed June 16, 2025).

Oneil, E. 2022. Cradle to gate life cycle assessment of US regional forest resources – US Inland Northwest. 29pp. https://corrim.org/wp-content/uploads/2022/05/CORRIM-INW-Forest-Resources-Report.pdf. (Accessed May 2024)

Puettmann, M. 2024. CORRIM Report. Life cycle assessment of softwood lumber production – Pacific Coast Region. 47pp.

Puettmann, M. 2024. CORRIM Report. Life cycle assessment of softwood lumber production – Inland Northwest Region. 45pp

Puettmann, M. 2024. CORRIM Report. Life cycle assessment of softwood lumber production – Southern Region. 46pp.

Puettmann, M. 2024. CORRIM Report. Life cycle assessment of softwood lumber production – Northern Region. (under review) 43pp.

Pré Consultants, B.V. 2023. SimaPro 9.5.0 Life-Cycle Assessment Software Package. Plotter 12, 3821 BB Amersfoort, The Netherlands. Http://www.pre.nl/.

UL. 2018. Product Category Rules for Building-Related Products and Services - Part A: Life Cycle Assessment Calculation Rules and Report Requirements, UL 10010, v.3.2.

UL. 2020. Product Category Rule Guidance for Building-Related Products and Services, Part B: Structural and Architectural Wood Products, EPD Requirements UL 10010-9 v.1.0.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016) The Ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, 21, 1218–1230.

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