CORRIM Report

Life Cycle Assessment of Softwood Lumber Production – Northern Region

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

Table 22. Typo in A3 changed from 597.69 to 1,095.76 kg CO2e

Abbreviations

BF	Board Feet
CLR	Cubic Lumber Recovery
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)
LRF	Lumber Recovery Factor, expressed in board foot of Lumber per Cubic foot of logs
m^3	Cubic Meters
MC	Moisture Content
MJ	Megajoule
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 impact 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 releases. 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 lumber from the northern region in the United States (U.S.) and the subsequent releases into the environment. The northern region encompasses the states indicated in blue in Figure 1. This region was previously called the Northeast/North Central in CORRIM reports. Facilities included in this LCA are members of the American Wood Council (AWC) and/or the Northeastern Lumber Manufacturers Association (NELMA) 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 logs, fuels, energy, ancillary materials, and packaging materials used for producing dry planed softwood lumber.

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).

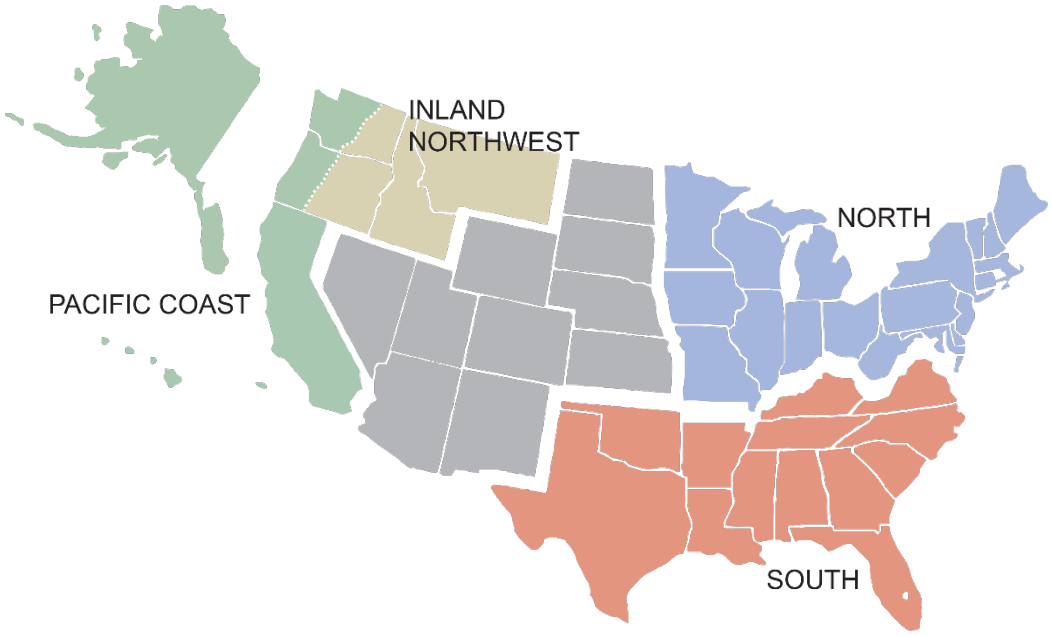


Figure 1. Geographical Distribution of Softwood Lumber Product Regions.

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 materials used 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 product's 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.

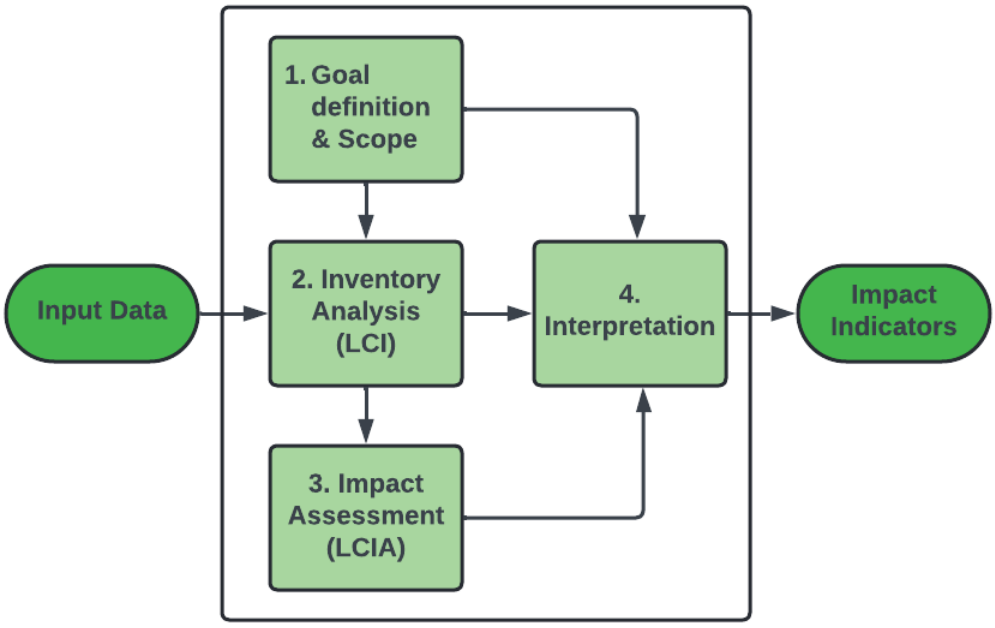


Figure 2. Steps Involved in a Life Cycle Assessment.

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 provide 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 construction grade softwood lumber. 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 and NELMA members and the participating facilities. The intended audience for the subsequent EPD includes AWC and NELMA and their members, 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 2. The system boundary begins with regeneration of the forest in the northern region and ends with planed dry lumber packaged at the plant gate. The system boundary includes forest operations (A_1), which 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; transportation of all resources and materials (A_2); and softwood lumber production (A_3) (Figure 3). The sawmill complex is divided into four processes: log yard/sawmill, kiln drying, energy generation, and planing. The recognized four processes are accounted for in module (A_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 lumber 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

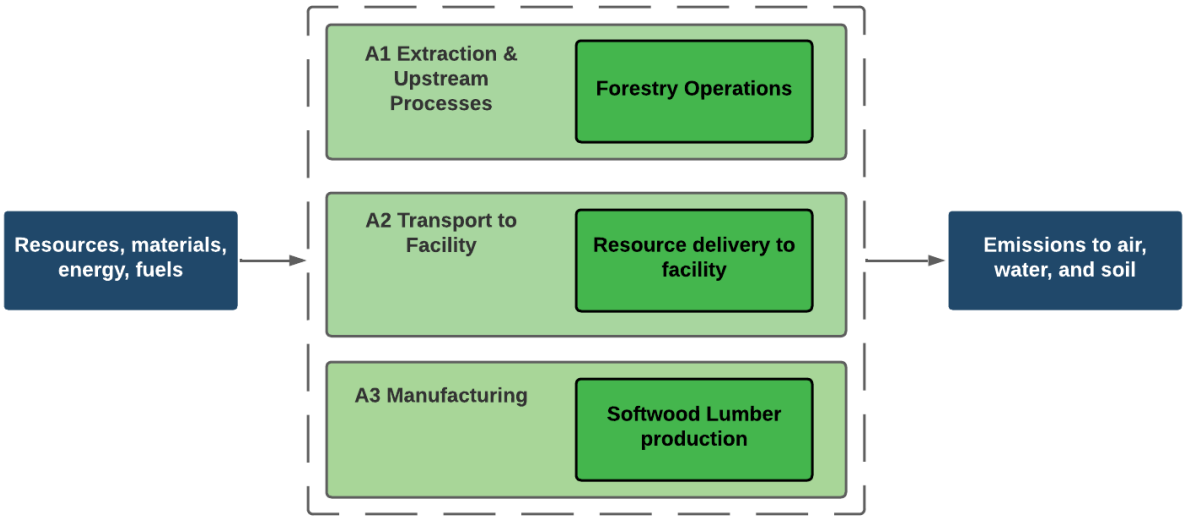


Figure 3. Cradle-to-Gate (A1-A3) System Boundary for Northern Softwood Lumber Production.

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 with ISO 14044/Amd1:2017/Amd2:2020 standards. This study relied almost exclusively on 2023 production and emissions data provided by each facility, with upstream secondary data on fuels and electrical grid inputs from the U.S. database (Datasmart 2023) and European datasets (Ecoinvent 3.8) (LTS 2023, Wernet et al. 2016). Nine facilities from the northern region participated in the survey.

3.2.4 Calculation Rules

Log consumption can be reported on a volume basis (e.g. International log scale in board feet) or on a mass basis. Log scale is a century-old method of measuring logs in which measurements of diameter and length are used to predict the board feet of lumber to be recovered from the log. Due to technology 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 0.0045 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 223.51 BF/m^3 (6.33 BF/ft^3) based on Winn et al. (2020).

Lumber was reported in board feet and converted to cubic meters using a regional average of 503 BF/m^3 actual lumber dimensions (2x6, nominal).

All flow analyses of the product and co-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 density of 443.27 kg per m^3.

The survey results for each unit process were converted to a production basis: per m^3 of rough green lumber for the sawmill, per m^3 of rough dry lumber for drying, and per m^3 of planed-dry lumber for planing. 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 sawmill complex that represents a composite of the mills surveyed and maintains confidentiality. SimaPro, version 9.6 (Pré Consultants 2024) was used as the accounting program to track material flows.

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

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

$$w_1 = y_1 / (y_1 + y_2 + y_3 \ldots y_{33}) = y_1 / Y_{total}$$

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

where:

Y_{total} **Total lumber production of all 9 facilities (m^3 basis)**
y_1 **Lumber production of facility 1 (m^3 basis)**
y_2 **Lumber production of facility 2 (m^3 basis)**
y_3 **Lumber production of facility 3 (m^3 basis)**
…
Y_9 **Lumber production of facility 9 (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.

3.2.5 Functional and Declared Unit

In accordance with the PCR, the declared unit for lumber is one cubic meter (1.0 m^3) of planed dry lumber 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. Weighted average specific gravity and density for northern lumber is reported in Table 2.

Table 2. Northern Weighted Average Specific Gravity and Density.

	Specific gravity			Density (kg/m3)		
Moisture content	Green	15%	0%, oven dry	51%	15%	0%, oven dry
	0.39	0.41	0.44	594.15	472.81	443.27

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 lumber is a round log with bark. Processing the log involves multiple steps with generation of by-products (e.g., sawdust, chips, bark). 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.*

U.S. 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-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
Biogenic Carbon Removal from Product	BCRP	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, co-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 with 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 emissions is characterized with 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 lumber industry is a subset of the very broad forest products industry which also produces plywood, fiberboard, particleboard, paper, cabinetry, furniture, millwork, and other 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 cabinets and furniture.

The lumber industry can be further segmented in other ways. For example, there are significant differences between processing hardwood logs and softwood logs into lumber, and there are very different markets for the products. There are also regional differences. The inputs and processing of softwood lumber from the northern and southern regions yield similar (but not identical) allocations of by-products, but the inputs come from completely different forest management regimes and the outputs go to different markets.

4.1 Location of Markets and Typical Transportation Methods

About 7 percent of the lumber produced in the northern part of the U.S. is sold in the northern states (Figure 1), 24 percent to the South, 12 percent to Pacific Coast, and 49 percent to Canada (AWC 2024). On average, northern softwood lumber is shipped by rail (84%) and truck (16%) but varies by destination region (AWC 2024).

4.2 Plant Geographical Distribution

Many sawmills have been in their current locations for many years; however, they have been continually 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 northern softwood lumber production region is represented by the states (in blue) in Figure 1. This production region considers the significantly different growth rates between adjacent regions (e.g., Southern region) 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

Lumber can include a variety of products ranging from boards to beams and timbers. Dimension lumber and studs (framing lumber) are the main products produced at the sawmills used in this study.

Dimension lumber is sold as 2”x4”, 2”x6”, 2”x8”, 2”x10”, and 2”x12”. Studs are sold as 2”x4” or 2”x6”. These numbers represent the nominal size of the lumber. The actual size of the lumber can vary depending on the stage of processing. For example, a 2x4 might be 41 mm in thickness and 94 mm in width (1.61” x 3.7”) when green. This condition is called “rough green” in this report. After drying the actual dimensions might change to 39 mm in thickness by 90 mm in width (1.55” x 3.55”). This condition is called “rough dry” in this report. The dimensions after final finishing (planing) are 38 mm in thickness by 89 mm in width, based on grading rules which specify (in inches) 1.5” x 3.5” as the final size. This condition is called “planed dry” in this report.

Figure 4. Softwood Lumber.

When converting lumber from board feet to cubic meters, the actual dimensions were used in this report. For the northern region, there are 0.0020 m^3/BF or 503 BF/m^3 planed dry lumber.

Construction lumber is categorized by United Nations Standard Products and Services Code (UNSPSC) 111220 00 and Construction Specifications Institute (CSI) codes for wood framing 06 11 00 (Table 4). In addition, Structural Solutions products fall into the North American Industry Classification System (NAICS) Code 321113— and the Standard Industrial Classification (SIC) Code 2421—Sawmills and Planing Mills, General

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

Classification Standard	Category	Subcategory	Product Code
UNSPSC	Structural Products	Framing Lumber	30103603
CSI	Sawn timber (Lumber)	Wood Framing	06 11 00

4.3.1 Categories of Products and By-Products

The primary product from northern softwood sawmills is construction grade lumber. Other products (by-products) are also made when logs, which are round in cross section, are processed into lumber, which is rectangular in cross section. These by-products typically include hog fuel, chips, sawdust, and shavings. Chips are typically used for pulp, while sawdust and shavings are typically used for panels, paper, or fuel. Logs arrive at the mill with much of the tree's bark intact. The bark is removed and used as hog 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 biomass boiler or is sold. Northern lumber facilities reported 44 percent of the by-products produced in the sawmill were sold and 48 percent of the by-product produced during the planing process was sold.

4.4 Annual Operating and Production Statistics of the Industry

Northern regional mills accounted for 3 percent of the 45,567 million board feet (MMBF) of U.S. softwood lumber capacity in 2023 (Forisk 2024). The northern region's capacity is 1,535 MMBF. Participating facilities for the LCA represented over 63 percent (971 MMBF) of the regional capacity.

Of the reporting facilities (n=9), the annual production ranged from approximately 24 MMBF to 176 MMBF with a weighted average of 130 MMBF. Table 5 lists the number of participating sawmills per production class in the northern region compared with the regional production capacity.

Table 5. Production by Northern Softwood Lumber Sawmills.

Survey Sawmills		Survey Sawmills Representation	
Million BF / year	Number	%	Million BF
< 100	5	37%	357
100-150	1	13%	123
150-200	3	51%	491
	9	100%	971

4.5 Conversion Efficiencies

The fraction of log cubic volume recovered as lumber is call the cubic recover ratio (CRR). It is an accurate and consistent measure of the conversion efficiency used in scanners in sawmills to measure the log and lumber dimensions. As log diameter increases, the fraction of the log recovered as rough green lumber increases, and the fraction of by-products decreases. The weighted average CRR for northern sawmills was 0.437 m^3_{lumber}/ m^3_{log} for rough green lumber. When the overall process is considered (to produce planed-dry lumber), the CRR was 0.380 m^3_{lumber}/m^3_{log}. Another measure of mill efficiency is the lumber recovery factor (LRF) which measures the amount of recovered lumber in board feet divided by the cubic volume of log. LRF is more sensitive to product mix than the CRR. As mills have adapted to cutting smaller diameter logs, it is possible to produce more board feet of dimension lumber out of a log than larger timbers, increasing the LRF while lowering the CRR. The weighted average LRF for northern softwood lumber is 5.837 (BF_{lumber}/ft3 $_{log}$).

4.6 Typical Emission Control Measures

Facilities reported processing steps (such as debarking, sawmilling, pneumatic transfer equipment and kiln) and quantities of material moving through each process. The process of sawing of green lumber had no pollution control except a bag house on certain equipment. There were no emissions control devices on the dry kilns. Boilers most commonly had an electrostatic precipitator (wet or dry) often followed by a baghouse. Emissions control at the planing process consisted of baghouses at all mills where dry lumber was planed.

4.7 General Types of Wastes and Emissions

No dangerous substances were reported by industry that fall under ISO 21930 (ISO 2017). The air emissions reported include 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 EPA's HAPs list. If boilers are included, then there are some sulfur dioxide and oxides of nitrogen emitted. Emissions to air for each facility were provided by the National Council for Air and Stream Improvement (NCASI) and reported for each unit process (see Tables 10-12).

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

4.8 Wood Species

Spruce, pine, and fir dominate the species mix in northern softwood sawmills, with red pine dominating the individual species group. The weighted average specific gravity was 0.39 green and 0.44 dry.

Table 6. Species and Representation for the Northern Region.

Species Grouping	Scientific Name	Survey Composition
Spruce-Pine-Fir (SPF)	*Picea, Pinus, and Abies spp.*	49%
Red Pine	*Pinus resinosa*	34%
White Pine	*Pinus strobus*	8%
White Spruce	*Picea glauca*	4%
Jack Pine	*Pinus banksiana*	3%
Balsam Fir	*Abies balsamea*	2%
		100%

4.9 Moisture Content

The average moisture content of the lumber leaving the sawmill was 51 percent dry basis. After drying, the grading rules specify that the lumber moisture content is 19 percent or less. Mills reported dry moisture contents between 12 and 19 percent. For all dry lumber,15 percent was assumed as an average.

5 Life Cycle Inventory Analysis

The life cycle inventory in this section presents the unit process flows for 1 m^3 of planed dry lumber. The LCI was calculated based on 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 lumber in the North 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 through to maturity, and to harvest the merchantable logs from the stand (Oneil 2021).

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 lumber mill. Non-merchantable slash is generally left at a landing to decay in-situ.

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.

Northeast/North Central forests generate approximately 7% of the U.S. softwood products and nearly 60% of U.S. hardwood forest products from 32% of U.S. timberland (Oswalt et al. 2019). Nearly 75% of total softwood harvests in the region come from only four states (Maine, Michigan, Wisconsin, and Minnesota), and 88% of total softwood harvests come from these four states plus New Hampshire, New York and Vermont (Table 7).

Table 7. Harvest Allocation by State and Subregion (Oneil 2021)

Subregion	State	Harvest (1,000 ft^3/year)	Percent of Total
Northeast	Maine	224,147	34%
North Central	Michigan	109,961	17%
North Central	Wisconsin	73,320	11%
North Central	Minnesota	70,509	11%
Northeast	New Hampshire	38,529	6%
Northeast	New York	34,641	5%
Northeast	Vermont	26,940	4%
Northeast	Maryland	19,205	3%
Northeast	Pennsylvania	16,396	3%
North Central	Ohio	10,969	2%
North Central	Missouri	8,779	1%
Northeast	West Virginia	7,837	1%
Northeast	Massachusetts	5,307	1%
North Central	Indiana	2,668	0%
Northeast	Delaware	2,363	0%
Northeast	Connecticut	911	0%
North Central	Illinois	689	0%
Northeast	New Jersey	469	0%
Northeast	Rhode Island	169	0%
North Central	Iowa	90	0%
Total		653,899	100%

5.2 A2 – Transport

The A2 module includes the transportation of resources and materials used in the production of softwood lumber. The distances are weighted averages based on lumber production volume. Incoming roundwood resources (logs) are transported by road within 130 kilometers (81 miles) of the landing. Other transportation for ancillary materials and purchased wood fuel are also part of this module (Table 10).

5.3 A3 – Lumber Manufacturing

5.3.1 Equipment: Type and Fuel Consumption

The equipment used in the manufacturing process falls into two broad categories: stationary machines and rolling stock (wheeled machinery, such as forklifts, for moving materials within a production facility). Stationary machinery in the sawing unit process includes debarkers, merchandisers, headrigs, resaws, edgers, sorters, scanners, stackers, and conveyors and other handling equipment. Stationary equipment in the planing unit process includes unstackers, moisture meters, planers, trim saws, sorters, scanners, stackers, conveyors, and other handling equipment. Some stationary equipment is powered electrically.

Rolling stock, such as loaders and cranes, are used to move logs in the log yard and to move packages of lumber from one -unit process to another and to load the final product for transport. Rolling stock is mainly powered by diesel but also by a smaller amount of gasoline and propane.

5.3.2 Onsite Energy Production

Heat energy is used in the drying process and is generated on site from a wood-fired or natural gas boiler. The gas boiler produced 6 percent of the energy for the dryers and onsite generated wood waste supplied the remaining 94 percent.

Of the wood fuel burned, 100 percent was produced on site. The fuel supplied to the boiler is a mix of bark, hog fuel, planer shavings, and dry wood waste. Thermal energy is created when the wood is combusted and makes steam in a boiler (indirect-heated kilns), or direct-fired kilns heated by wood waste or natural gas. Wood boilers produce ash in addition to steam. Boiler ash is sent to composting, recycling (fertilizer use), or incineration.

Lumber manufacturing was divided into three-unit processes: log yard/sawing, drying, and planing. The wood boiler represents a fourth process that provides steam for drying. Figure 6 shows the relationship between the processes and the woody inputs to and from each process.

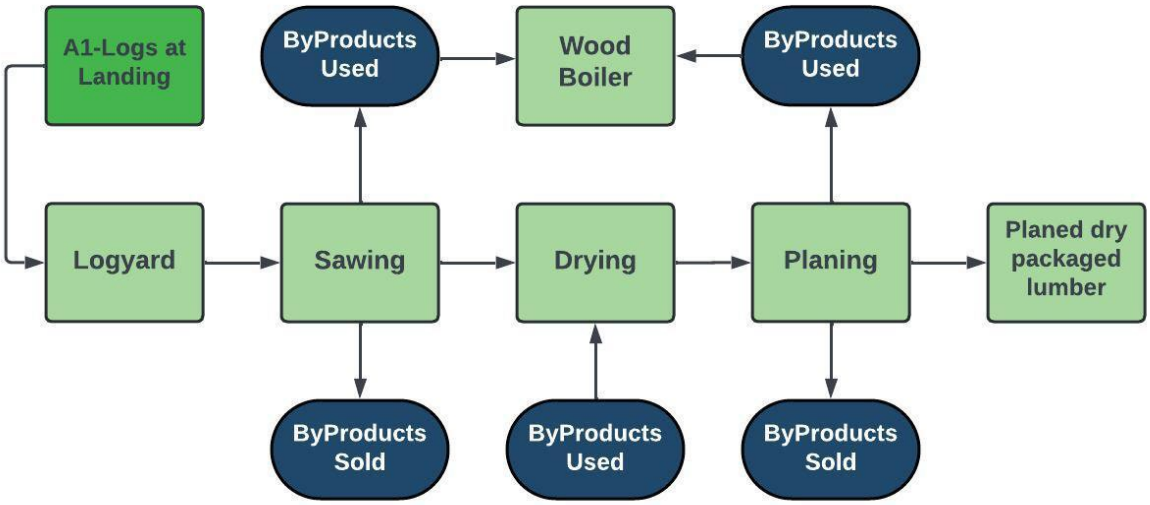


Figure 5. Sawmill Unit Processes from Roundwood to Planed Dry Lumber from Logs.

5.3.2.1 Log yard and Sawmill

The log yard unit process begins with logs plus the attached bark on a truck at the harvest site and ends with debarked and merchandised logs delivered to the infeed sawing process. Transportation of the logs from the forest road is included. Log trucks arrive at the log yard and are unloaded by diesel-powered wheeled loaders with log grapples (also referred to as on-site loaders and haulers or rolling stock). The unloading machines are a part of the log yard unit process. The log truck might be weighed in and out; however, all mills reported log input on a volume basis, either board feet or cubic feet. When the log trucks are unloaded the logs are either stacked in a storage deck or they are spread out, graded visually, then transferred to the deck. The logs are stored in the decks for anywhere from immediate use to months later. Having an inventory in the decks allows the mill to keep running even when log deliveries are temporarily interrupted due to weather, fire season, or supply issues. The logs are then removed from the deck and taken to the debarker and merchandiser at the infeed of the sawmill and cut into bolts.

Water is used in the log yard for sprinkling log decks to prevent stain, insect infestations and log dry out. Diesel, gasoline, and liquefied petroleum gas are used as fuel for rolling stock (wheeled machinery, such as loaders, forklifts, and lumber carriers) for log unloading and moving logs through the process.

The sawing process begins when bolts are received from the debarker and merchandiser and ends when rough sawn green lumber is stacked on stickers and transported to the dryer. Additionally, chips, sawdust, bark, and hog fuel are created in the sawing process, all in the green condition. Table 8 shows the products from and inputs to this process. By-product masses are given on an oven dry basis. Allocation was based on oven dry mass.

After sawing, the flow from all machine centers typically goes to a single sorting line. Here the pieces are scanned and trimmed to length. The pieces are then sorted by thickness, width, and length for drying. Finally, the lumber is stacked on stickers (spacers) in units that are removed

from the sawmill by mobile equipment that typically uses diesel fuel or propane. Lumber was reported as board feet and converted to cubic meters as described in section 3.2.4.

One m^3 of wood was produced from 2.6 m^3 of logs. Products are more accurately measured than logs, and the lumber is 44 percent of the wood leaving the sawmill. The balance of the wood leaving is chips, sawdust, bark, wood fuel, and hog fuel (Table 8).

All water use was allocated to the log yard/sawmill process. Diesel, gasoline, and liquefied petroleum gas are used as fuel for rolling stock for moving lumber from the process. Electricity is used in the sawmill to operate motors, instrumentation, and lighting, 25 kWh/m^3 with 0.71 kWh/m^3 sold back to the grid (Table 8) .

Table 8. Unit Process Inputs/Outputs for Log Yard and Sawmill Activities to Produce 1 m^3 of Rough Green Lumber, Northern Region, Unallocated.

A3 Production – Log yard & Sawing Process	Value	Unit	Allocation
Sawn lumber, softwood, rough, green	1.00	m3	44%
Bark, sold, softwood, green	78.77	kg	7%
Chips, sold, softwood, green,	387.02	kg	34%
Sawdust, sold, softwood, green	51.22	kg	4%
Wood fuel, softwood, green, kg	130.07	kg	11%
Resources			
Water	80.67	L	
Materials/fuels			
Sawlog with bark, softwood	2.60	m3	
Diesel	1.11	l	
Gasoline	0.0299	l	
LPG	0.1595	l	
A2 Truck Road Transport, Log	181.78	tkm	
A2 Truck Rail Transport Logs	13.78	tkm	
Electricity/heat			
Electricity	25.02	kWh	
Emissions to air			
Particulates, < 2.5 um	7.91E-04	kg	
Particulates, < 10 um	9.17E-04		
VOC, volatile organic compounds	8.70E-03	kg	

5.3.2.2 Drying

The drying process begins with rough sawn green lumber placed at the dryer and ends with rough sawn dry lumber delivered to the planer. The water loss during drying results in approximately 4-5 percent volume loss due to shrinkage with a corresponding increase in specific gravity.

Kilns are chambers that are 16 to 40 m in length, typically with two independent tracks running parallel to the chamber so lumber can be rolled through the kiln on carts on either track. Fans circulate air around and through the lumber stacks. Steam heat exchangers (heating coils) provide the energy to heat the air to the prescribed drying schedule temperature. The humidity is controlled by ventilators which open to release moist warm air and intake ambient air. The maximum drying temperature typically ranges from 80 to 100°C.

Diesel, gasoline, and liquefied petroleum gas are used as fuel for forklifts and modified front end loaders that move lumber into the kiln, out of the kiln, and to the planer. Electricity, 19.52 kWh/m^3 with 0.56 kWh/m^3 sold back to the grid (Table 9), is used in the dryer to operate motors, instrumentation, and lighting. Kiln emissions result when wood is heated and VOC are released.

Photo Credit. Fontaine Lumber – Stratton Mill.

Table 9. Unit Process Inputs/Outputs for Drying Activities to Produce 1 m^3 of Rough Dry Lumber, Northern Region, Unallocated.

A3 Production – Kiln Process	Value	Unit	Allocation
Sawn lumber, softwood, rough, green	1.00	m3	100%
Materials/fuels			
Sawn lumber, softwood, rough, green	1.00	m3	
Diesel	0.2735	l	
Gasoline	0.0233	l	
LPG	0.1245	l	
Electricity/heat			
Electricity	19.52	kWh	
Natural gas	4.33	m3	
Wood fuel	117.93	kg	
Emissions to air			
Particulates, unspecified	2.06E-02	kg	
Particulates, < 2.5 um	1.67E-02	kg	
Particulates, < 10 um	2.94E-02	kg	
Particulates, unspecified	5.63E-03	kg	
VOC, volatile organic compounds, unspecified origin	1.55E-01	kg	
Carbon monoxide, biogenic	3.86E-02	kg	
Sulfur oxides	9.17E-03	kg	
Nitrogen oxides	1.85E-02	kg	
Methanol	1.53E-02	kg	
Formaldehyde	4.14E-03	kg	
Acetaldehyde	2.91E-03	kg	
Acrolein	6.97E-04	kg	
Propanol	1.16E-04	kg	
Phenol	7.05E-04	kg	
Carbon dioxide, biogenic	1.39E+01	kg	

5.3.2.3 Planing

The planing process begins with rough dry lumber placed at the infeed to the planer and ends with packaged planed dry lumber loaded for shipment (Table 10). Sawdust, planer shavings, and other wood waste are generated in the planing process, all in dry condition (average 15% MC). By-products are expressed as oven dry masses. The planed lumber is graded, trimmed, sorted, and stacked before packaging.

The product is packaged in units that are composed of lumber of a single thickness, width, and sometimes variable length. The units are typically covered with waterproof coated paper wrap and banded with plastic or steel banding. Runners may be banded under the units to allow access for the forklift tines. The packaged units are then placed on the transport vehicle.

Diesel, gasoline, and liquefied petroleum gas are used as fuel for rolling stock for moving lumber from the process to truck, rail, or ships. Wrapping material, strapping, and cardboard are used to package the product. Electricity, 12.32 kWh/m^3 with 0.35 sold back to the grid, is used in the planer to operate motors, instrumentation, and lighting.

Table 10. Unit Process Inputs/Outputs for Drying Activities to Produce 1 m^3 Rough Dry Lumber, Northern Region, Unallocated.

A3 Production – Planing Process	Value	Unit	Allocation
Sawn lumber, softwood, planed, dry	1.00	m3	87.4%
Planer shavings, sold, dry	51.08	kg	10.1%
Chips, sold, dry	2.02	kg	0.4%
Trim, sold, dry	1.59	kg	0.3%
Wood fuel, dry	9.11	kg	1.8%
Materials/fuels			
Sawn lumber, softwood, rough, dry	1.14	m3	
Diesel	0.1727	l	
Gasoline	0.0147	l	
LPG	0.3518	l	
Packaging	2.54	kg	
Waste to Landfill	2.25	kg	
Waste to Recycling	0.1606	kg	
Waste to Compost	1.26	kg	
Waste to Incineration	1.85	kg	
Electricity/heat			
Electricity	12.32	kWh	
Emissions to air			
Particulates, unspecified	1.92E-04	kg	
Particulates, < 2.5 um	1.72E-07	kg	
Particulates, < 10 um	8.38E-05	kg	
Particulates, unspecified	5.21E-05	kg	
VOC, volatile organic compounds, unspecified origin	4.01E-04	kg	

5.3.3 Packaging

Packing materials represent only 0.57 percent of the mass of the main product. The wood stickers and runners make up the bulk of the mass, representing 89 percent of the total packaging (Table 11). The wrapping materials represent 9 percent, followed by the strapping and cardboard at 2 percent of the total packaging mass.

Table 11. Materials Used in Packaging and Shipping per m^3 Northern Softwood Lumber.

Material	Unit	Value	Percent of Total Packaging
Wrapping Material	kg	0.2241	8.83%
Plastic strapping	kg	0.0281	1.11%
Cardboard protectors	kg	0.0166	0.65%
Dunnage & Stickers (wood)	kg	2.2704	89.41%
TOTAL	kg	2.5392	100.00%

5.4 Secondary Data Sources

Secondary data is necessary for creating the full cradle-to-gate. Tables 12, 13, and 14, list the secondary LCI data sources, geographical origin, age, and quality of the data used in this LCA study.

Table 12. Raw Material Supply Processes.

A1: Raw Material Inputs				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Logs	Database: CORRIM	US Northeast	2021	-Technology: Good Process models product specific technology. -Time: Good, updated in the last 5 years -Geography: Good, Data specific to product

Table 13. 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 14. Manufacturing Processes.

A3 Manufacturing				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Electricity	Database: Ecoinvent 3.9 Processes: Electricity, low voltage {MRO, 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	North America	2023	-Technology: Good, process models average North American technology

A3 Manufacturing				
	Process: Natural gas, combusted in industrial boiler NREL/US U			-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
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	203	-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.	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; Process-specific burdens, municipal waste incineration {RoW}| market for process-specific burdens, municipal waste incineration | Cut-off, U; Compost {GLO}| market for compost | 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 northern softwood lumber. 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 co-products is done according to mass allocation principles (ISO 2006 a, b). The cradle-to-gate (A1-A3) LCIA results for lumber are presented for one cubic meter (Tables 15-21).

The contribution analysis for modules A1-A3 is in Tables 18-20 and Figure 6.

Table 15. Cradle-to-Gate LCIA Results for 1 m^3 of Northern Softwood Lumber – Absolute Basis.

Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{TOTAL} [kg CO_2 eq]	73.15	(2,097.35)	9.45	2,161.04
$GWP_{BIOGENIC}$ [kg CO_2 eq]	0.00	(2,115.94)	0.00	2,115.94
GWP_{FOSSIL} [kg CO_2 eq]	73.15	18.59	9.45	45.10
ODP [kg CF-11eq]	2.43E-07	2.98E-09	1.67E-08	2.23E-07
AP [kg SO_2 eq]	0.5805	0.2540	0.0541	0.2724
EP [kg N eq]	0.3169	0.0153	0.0043	0.2973
SFP [kg O_3 eq]	16.55	8.05	1.57	6.92
FFD [MJ, surplus]	114.75	38.85	17.75	58.16
ADP_{FOSSIL} [MJ, LHV]	904.67	260.71	118.22	525.73

Table 16. Cradle-to-Gate Resource use Results for 1 m^3 of Northern Softwood Lumber – Absolute Basis.

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	2,690.08	0.02	0.27	2,689.80
RPRM [MJ, LHV]	12,979.34	12,979.34	0.00	0.00
NRPRE [MJ, LHV]	986.87	260.81	119.96	606.09
NRPRM [MJ, LHV]	0.00	0.00	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]	0.3742	0.0001	0.0011	0.3730

Table 17. Cradle-to-Gate Output Flows for 1 m^3 of Northern Softwood Lumber – Absolute Basis.

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	4.63E-03	7.03E-06	7.55E-05	4.55E-03
NHWD [kg]	4.42E+00	4.99E-02	8.52E-01	3.52E+00
HLRW [m^3]	1.64E-09	5.45E-11	9.37E-10	6.44E-10
ILLRW [m^3]	7.88E-09	2.63E-10	4.51E-09	3.10E-09
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 18. Cradle-to-Gate LCIA Results for 1 m^3 of Northern Softwood Lumber – Relative Basis.

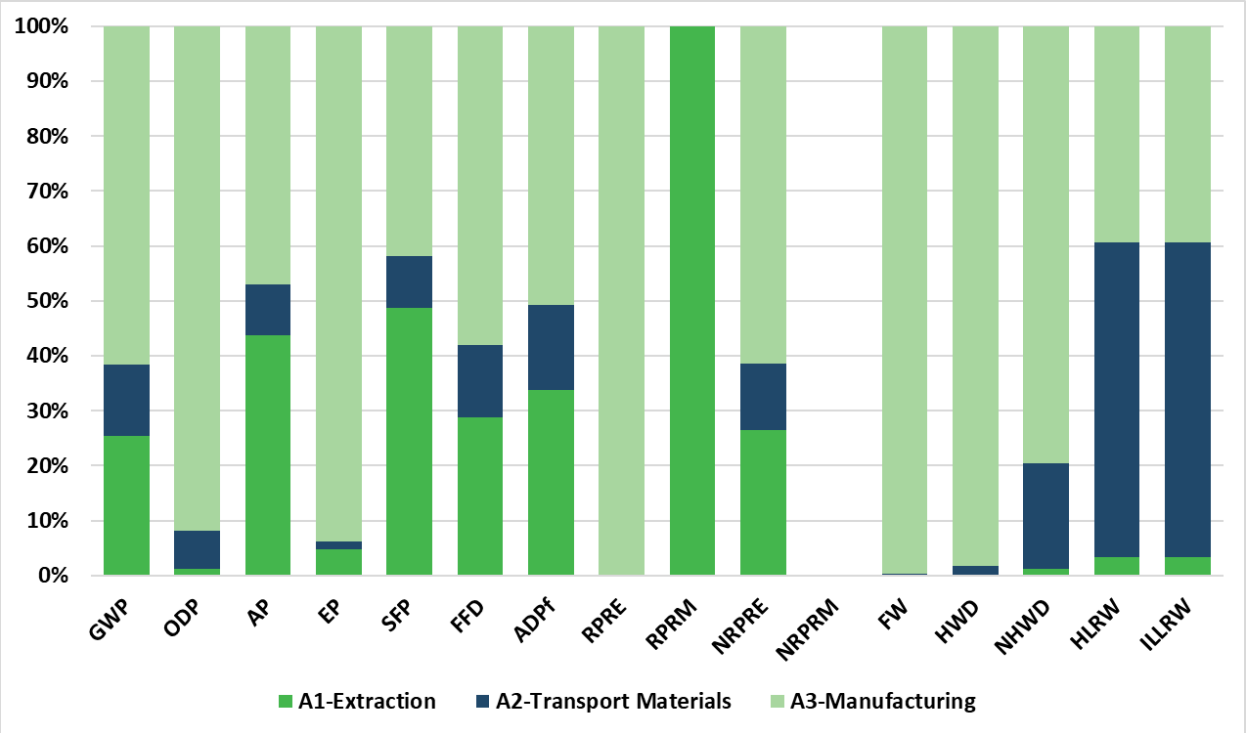
Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{FOSSIL} [kg CO_2 eq]	100%	25%	13%	62%
ODP [kg CF-11eq]	100%	1%	7%	92%
AP [kg SO_2 eq]	100%	44%	9%	47%
EP [kg N eq]	100%	5%	1%	94%
SFP [kg O_3 eq]	100%	49%	10%	42%
FFD [MJ, surplus]	100%	29%	13%	58%
ADP_{FOSSIL} [MJ, LHV]	100%	34%	15%	51%

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

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	100%	0%	0%	100%
RPRM [MJ, LHV]	100%	100%	0%	0%
NRPRE [MJ, LHV]	100%	26%	12%	61%
NRPRM [MJ, LHV]	0%	0%	0%	0%
FW [m^3]	100%	2%	0%	97%

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

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	100%	0%	2%	98%
NHWD [kg]	100%	1%	19%	80%
HLRW [m^3]	100%	3%	57%	39%
ILLRW [m^3]	100%	3%	57%	39%



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
ADPf	Abiotic depletion potential (ADP fossil) for fossil resource	NHWD	Non-hazardous waste disposed
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 Northern Softwood Lumber – Relative Basis.

Table 21. Cradle-to-Gate Cumulative Energy Demand (CED) Results for 1 m^3 of Northern Softwood Lumber – Absolute Basis.

Impact category	A1-A3	A1	A2	A3
Nonrenewable, fossil	923.84	260.71	118.23	544.90
Non-renewable, nuclear	63.02	0.10	1.73	61.19
Non-renewable, biomass	0.00	0.00	0.00	0.00
Renewable, biomass	2,601.89	0.00	0.06	2,601.83
Renewable, wind, solar, geothermal	70.14	0.00	0.06	70.08
Renewable, water	18.05	0.01	0.16	17.89
Total	3,676.95	260.83	120.23	3,295.89

6.2 Biogenic carbon

Table 25 shows additional inventory parameters related to biogenic carbon removal and emissions. All carbon dioxide flows (kg CO_2e) presented in Table 22 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[2]. The net 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, -2,116 kg CO_2 (reported in A1-Extraction) were removed in the production of 1 m^3 of northern softwood lumber. One cubic meter of northern softwood lumber stores 222 kg of carbon or +813 kg CO_2 eq (reported in C3/C4-End-of-Life). The by-products produced during lumber production account for an additional +598 kg CO_2 (reported in A3-Manufacturing) for a total "emission" in wood product leaving the system boundary of +1,908 kg CO_2. The combustion of wood fuel emitted 208 kg CO_2. Packaging resulted in removal of -4.19 kg CO_2 and an emission of +4.19 kg CO_2. In summary, total removals was -2,116 kg CO_2 and total "emissions" was +2,116 kg CO_2 from cradle-to-gate (A1-A3 of the LCA system boundary).

Table 22. Biogenic Carbon Inventory Parameters for 1 m^3 of Northern Softwood Lumber, Unallocated.

	A1	A2	A3	A5	C3/C4	Total
BCRP [kg CO_2]	(2,115.94)	0.00	0.00	0.00	0.00	(2,115.94)
BCEP [kg CO_2]	0.00	0.00	1,095.76	0.00	812.66	1,908.42
BCRK [kg CO_2]	0.00	0.00	(4.19)	0.00	0.00	(4.19)
BCEK [kg CO_2]	0.00	0.00	0.00	4.19	0.00	4.19
BCEW [kg CO_2]	0.00	0.00	207.52	0.00	0.00	207.52

Northern softwood lumber 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, northern softwood lumber stores more carbon than is released during manufacturing (A1-A3) by containing 813 kg CO_2e in the final product while emitting 73 kg CO_2e from cradle-to-gate (A1-A3). In summary, the carbon balance of northern lumber is -740 kg CO2e/m^3.

[2] 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.

6.3 A3 – Gate-to-Gate Northern Softwood Lumber Manufacturing

The surveys did not collect fuel and energy inputs by unit process. Softwood lumber LCAs allocations were based on the previous LCA by Puettmann (2020) (Table 23). Results shown in Tables 24, 25, 26, and Figure 7 are for the A3 manufacturing module by unit process. The kiln drying unit process carried the higher allocation of the impacts in all impact categories.

Table 23. Unit Processes Allocations Used for Fuels and Energy Inputs.

	Log yard/Sawmill	Kiln	Planer	Total
Diesel, Gasoline, LPG, and Electricity	44.00%	34.33%	21.67%	100%
Wood Fuel and Natural gas		100%		100%

Table 24. Gate-to-Gate LCIA Results for Selected Impact Categories (TRACI) for 1 m^3 of Northern Softwood Lumber – Absolute Basis.

		A3 Total	Sawmill	Kiln	Planer
Ozone depletion potential	kg CFC-11 eq	2.16E-07	3.53E-08	1.46E-07	3.50E-08
Global warming potential	kg CO2 eq	44.42	6.406	31.726	6.286
Smog potential	kg O3 eq	6.85	0.409	6.024	0.418
Acidification potential	kg SO2 eq	0.27	0.027	0.216	0.027
Eutrophication potential	kg N eq	0.30	0.059	0.180	0.058

Wood fuel (renewable biomass) is used almost exclusively in the A3 Manufacturing module (100%) and represents 79 percent of all energy used in the A3 (Table 25)

Table 25. Gate-to-Gate Cumulative Energy Demand (CED) Results for 1 m^3 of Northern Softwood Lumber – Relative Basis.

	Sawmill	Kiln	Planer	
Nonrenewable, fossil	13%	74%	13%	100.00%
Non-renewable, nuclear	20%	60%	20%	100.00%
Non-renewable, biomass	17%	57%	25%	100.00%
Renewable, biomass	0%	100%	0%	100.00%
Renewable, wind, solar, geothermal	21%	59%	20%	100.00%
Renewable, water	20%	60%	20%	100.00%

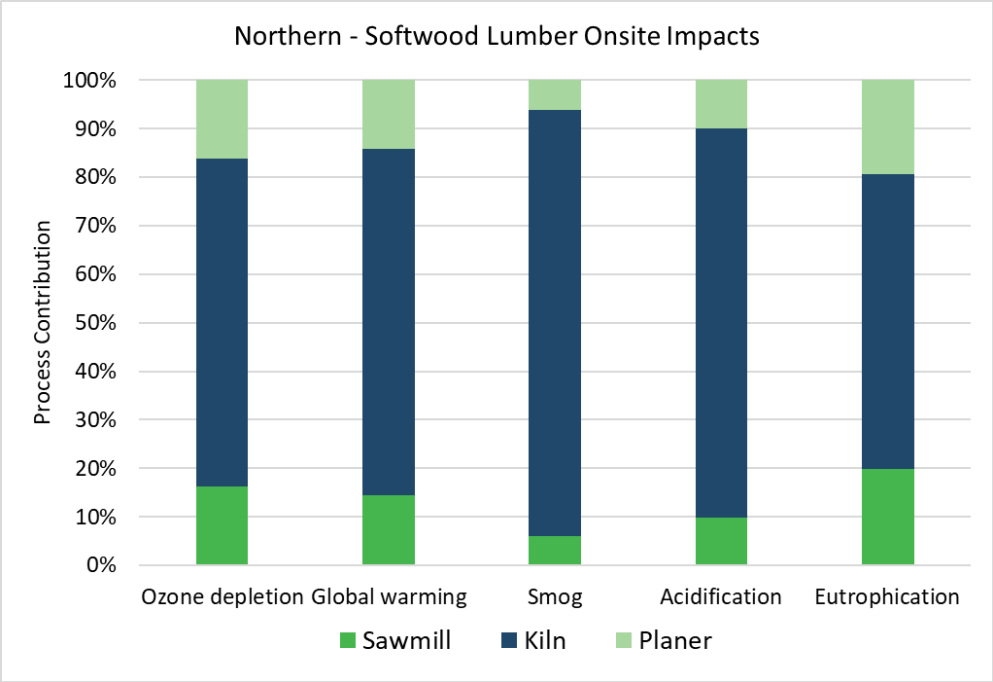


Figure 7. Contribution Analysis for A3-Manufacturing: Gate-to-Gate LCIA Results for 1 m^3 of Lumber through Each Unit Process – Relative Basis.

Table 26. Contribution Analysis for A3-Manufacturing: Gate-to-Gate Renewable and Energy Use Results for 1 m^3 of Northern Lumber, Relative Basis.

Energy Type	A3- Manufacturing	
	MJ	
Renewable	2,670.86	82%
Non-Renewable	586.36	18%
TOTAL	3,257.22	100%

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, and 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 of production facilities. Some degree of uncertainty is present in the results due to the variation amongst different data providers. Table 27 provides statistics for lumber recovery and cubic recovery ratio. Since this LCA is based on a mass allocation, the CRR is the allocation of the primary product and therefore a main driver in the percent impact the main product has over the entire manufacturing process.

Table 27. Survey Data Statistics for Northern Lumber Recovery Factor (LRF) and Cubic Lumber Recovery (CLR).

Parameter		Weighted Average	Min	Max.	Std. Dev.	Median
LRF	BF lumber/ft^3 of logs	5.837	4.52	10.11	2.35	5.01
CRR	Rough green Lumber m^3/ m^3 logs	0.437	0.33	0.84	0.21	0.37

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. In module A3, in the kiln drying process, the LCA model was run with no wood fuel and the equivalent energy content was substituted for natural gas. Natural gas used increased from 4.34 m^3 to 71.71 m^3 to supply the same amount of energy the wood fuel generated. The increase resulted in a 220 percent increase in the embodied carbon (GWP_{FOSSIL}) and a 229 percent increase in nonrenewable fossil fuels (Table 28).

Table 28. Sensitivity Analysis – Substituting Wood Fuel for Natural Gas.

Indicator Name	Units	Base	Substitution	Percent change
Ozone depletion	kg CFC-11 eq	2.43E-07	2.38E-07	-1.86%
Global warming (GWP_{FOSSIL})	kg CO_2 eq	73.15	234.22	220.22%
Smog	kg O_3 eq	16.55	16.06	-2.92%
Acidification	kg SO_2 eq	0.58	0.58	0.73%
Eutrophication	kg N eq	0.32	0.25	-19.71%
Nonrenewable, fossil	MJ, LHV	923.84	3,190.09	245.31%
Non-renewable, nuclear	MJ, LHV	63.02	51.81	-17.79%
Non-renewable, biomass	MJ, LHV	2.72E-03	2.01E-03	-26.17%
Renewable, biomass	MJ, LHV	2,601.89	189.77	-92.71%
Renewable, wind, solar, geothermal	MJ, LHV	70.14	54.16	-22.78%
Renewable, water	MJ, LHV	18.05	14.35	-20.49%

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 northern softwood lumber was compared to the previous LCA on Northeast/North Central softwood lumber (2020), and the North American softwood lumber EPD (2020) (Table 29).

Table 29. Energy Consumption of Lumber Products – Comparison of this LCA to Other Times/Regions.

Product	Total	A1-Extraction	A2-Raw Material Transport	A3-Manufacturing	Reference
	MJ/m^3				
Northern Lumber, this LCA	3,676.95	260.83	120.23	3,295.89	This LCA
NE/NC Lumber, 2020	2814.74	163.41	128.81	2,522.52	Puettmann 2020
North American EPD	3,380.67	148.81	137.40	3,094.45	Softwood Lumber 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 fulfil 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 co-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 northern softwood lumber. The primary goal of this LCA was to develop life cycle inventory data and impact assessment softwood lumber 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 lumber 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 lumber from the northern region was 3,677 MJ, which differs from the 2020 report by 31% (2,815 MJ, Puettmann 2020) (Table 30). Renewable biomass fuels increased by 30 percent in this LCA, and use of nonrenewable fossil fuels increased by 21 percent.

Table 30. LCIA Comparison Between this LCA and the 2020 LCA on Softwood Lumber Production in the Northern Region, U.S.

Impact category	Unit	This LCA[1/]	Puettmann 2020[2/]	Percent change
Global warming potential, fossil	kg CO_2 eq	73.15	46.78	56.36%
Eutrophication Potential	kg N eq	0.32	0.07	385.99%
Smog Potential	kg O_3 eq	16.55	12.57	31.63%
Non-renewable fossil	MJ, LHV	923.84	671.58	37.56%
Non-renewable nuclear	MJ, LHV	63.02	310.24	-79.69%
Renewable (solar, wind, hydroelectric, & geothermal)	MJ, LHV	88.19	43.00	105.10%
Renewable, biomass	MJ, LHV	2,601.89	1,789.92	45.36%
Fresh water	L	374.16	253.66	47.50%
Solid waste (hazardous & non-hazardous)	kg	4.43	6.01	-26.30%

[1/] Based on 2023 production data
[2/] Based on 2017 production data

9 Additional Information

Northern lumber production facilities 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 lumber 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 nine facilities represented in this regional LCA reported, on average,100 percent of the fiber entering their mills to be non-controversial (legal), 70 percent to be responsible (following a certified procurement standard), and 47 percent from independently certified forests.

10 Conclusions

This study provides a comprehensive cradle-to-gate LCA of the production softwood lumber produced and sourced in the northern region of the United States. The primary goal of this LCA was to develop life cycle inventory data and impact assessment results for northern lumber 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
- Jacob Odekirk, Division Environmental Manager, PotlatchDeltic Corporation

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:

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