# Cradle to Gate Life Cycle Assessment of North American Particleboard Production


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## Abbreviations

| | |
|---|---|
| Cubic meter | m3 |
| EPDs | Environmental Product Declarations |
| GWP | Global Warming Potential |
| ISO | International Organization for Standardization |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| MSF | thousand square feet |
| MUF | Melamine formaldehyde resin |
| PCR | Product Category Rules |
| odkg | oven dry weight of wood in kilograms |
| tkm | metric tonne – kilometers |

## Glossary of Terms

**Allocation -** A way of dividing emissions and resource use among the different products of a process. The partitioning can be made on weight basis, energy content, or economic value.

**Cradle-to-gate -** LCA model which includes upstream part of the product life cycle, i.e. all steps from raw material extraction to product at factory gate.

**Declared Unit -** Quantity of a wood building product for use as a reference unit, e.g. mass, volume, for the expression of environmental information needed in information modules.

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

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

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

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

**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 (adapted from ISO 104044)

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# 1 BACKGROUND

CORRIM, the Consortium for Research on Renewable Industrial Materials, has derived life cycle inventory (LCI) data for major wood products and wood production regions in the United States (U.S.) (www.corrim.org). The life cycle inventory data cover from forest regeneration through to final product at the mill gate. Research has covered nine major forest products including both structural and nonstructural uses and four major regions: in this report we focus on the North American (NA) (U.S., and Canada) production of particleboard. This report supersedes an LCI report by Wilson (2010) and a subsequent life cycle impact assessment (LCIA) (Puettmann et al. 2013).

# 2 INTRODUCTION

The Composite Panel Association (CPA) engaged CORRIM to complete a cradle-to-gate life cycle assessment of NA average particleboard production. The LCA included primary LCI data from particleboard producers that included all raw materials, resources, energy, and ancillary flows entering the particleboard production facility as well as emissions to air, water, and land association with the production of the finished product. The project a collaborative effort between CPA and CORRIM. CPA was responsible for identifying and engaging participants through their member mills while CORRIM was responsible for survey design, questionnaire validation, and final LCA report. Surveys were distributed to NA particleboard manufacturers in June 2017 and requested LCI input and output data for the 2016 production year.

The LCA follows data and reporting requirements as outlined in the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015) that will provide the guidance for preparation of a particleboard North American wood product EPD. The methodology outlined in the PCR document follows published ISO standard (14040, 14044, 21930, and 14025) that include general practices for LCA as well as specific reporting requirements and supported impact categories. This report does not include comparative assertions.

# 3 LIFE CYCLE ASSESSMENT METHODOLOGY

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 the products life cycle, referred to as "cradle-to-gate", or "gate-to-gate". This study can be categorized as a cradle-to-gate LCA as it includes forestry operations though the manufacturing of particleboard ready to be shipped at the mill gate.

As defined by the International Organization for Standardization (ISO 2006a, 2006b), 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 1). These steps are interconnected, and their outcomes are based on goals and purposes of a study.

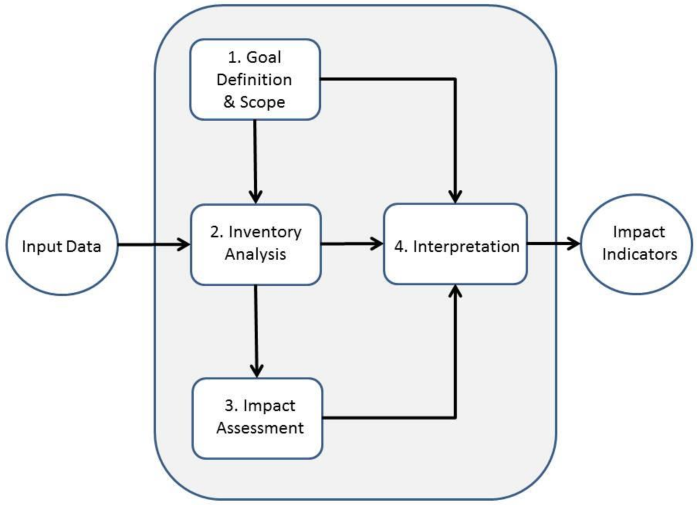


***Figure 1 Steps involved in a life cycle assessment.***

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 which 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, carcinogenic, respiratory effects, eutrophication, ozone depletion, ecotoxicity, 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.

# 4 GOAL AND SCOPE

It is the goal and scope that provide the plan for conducting the LCI including data collection, compilation, and interpretation.

## 4.1 GOAL AND OBJECTIVES

### 4.1.1 GOALS

The primary goal is to generate a gate-to-gate LCA of NA particleboard manufacturing and use this data to develop a cradle-to-gate profile of particleboard. The cradle-to-gate LCA will be follows data and reporting requirements as outlined in the PCR (FPInnovations 2015) that will provide the guidance for preparation of a business-to-business EPD.

### 4.1.2 INTENDED AUDIENCE

The primary audience for the results of this LCA report is primarily CPA, their member mills, and CORRIM LCA practitioners.

### 4.1.3 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 future comparative studies are intended and disclosed to the public, the LCA boundary would need to be expanded to include the use and end of life phases consistent with the ISO 14044:2006 (ISO 2006a) guidelines and principles and compliance with the Wood Products PCR (FPInnovations 2015).

## 4.2 SCOPE OF CONSIDERED SYSTEM

### 4.2.1 FUNCTIONAL AND DECLARED UNIT

In accordance with the PCR, the declared unit for particleboard is one cubic meter (1.0 m3). A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building product cannot be stated. For conversion of units from the US industry measure, 1.0 MSF (1000 square feet) is equal to 1.7698 m3. The inventory data is presented as unallocated flows, all input and output flows allocated to the main product. This analysis does not take the declared unit to the use stage no service life is assigned.

The cradle-to-gate LCI was generated by combing the particleboard manufacturing data collected by survey with previously published datasets for upstream manufacturing of wood, resins, fuels, electricity, and ancillary material use.

### 4.2.2 SYSTEM BOUNDARY

The system boundary begins with regeneration in the forest and ends with the particleboard product (Figure 2). The system boundary includes forest operations ($A_1$), which may include site preparation and planting seedlings, fertilization and thinning, final harvest, residue production, and resin production. Transportation of all resources and materials ($A_2$) to the particleboard facility, particleboard production ($A_3$) (Figure2). The particleboard production complex was modeled as a single unit process. The study recognized twelve steps ($A_3$) necessary to make particleboard. Excluded from the system boundaries are fixed capital equipment and facilities, transportation of employees, land use, delivery of particleboard to construction site, construction, maintenance, use, and final disposal.

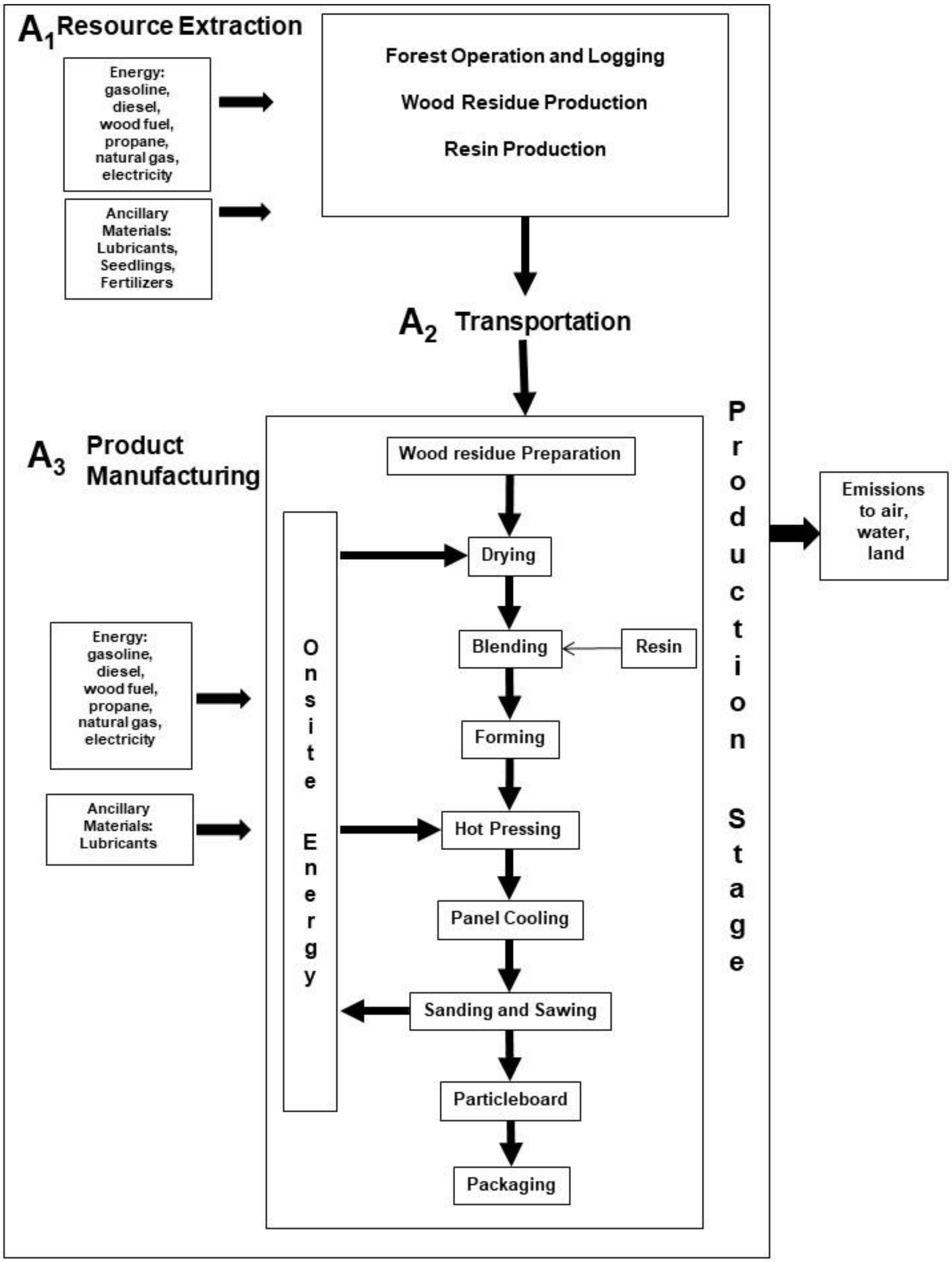


*Figure 2 Cradle-to-gate system boundary for particleboard product system*

The use phase, maintenance, and disposal of particleboard are not included within the scope of this study. Disposal of on-site waste from production manufacture is included in the system boundary. Table 1 lists the inclusions and exclusions within the system boundaries of this study.

***Table 1. System boundary inclusions and exclusion for the cradle-to-gate of particleboard production***

| Included | Excluded |
|---|---|
| • **Production of upstream processes for all resources, raw materials, fuels, and energy for particleboard production used in forestry operations, harvesting, feedstock production, and particleboard manufacturing** | • Fixed capital equipment and facilities |
| • **Transportation of materials throughout the cradle-to-gate manufacturing life stages.** | • Transportation of employees |
| • **Packaging** | • Construction, maintenance, use, and end of life treatment |

The particleboard production complex was modeled as a single process representing all the steps necessary to make particleboard: sorting of wood residue, digesting, refining, blending, drying, forming, hot pressing, conditioning, sanding, and sawing (Figure 4).

### 4.2.3 ALLOCATION RULES

Allocation is the method used to partition the environmental load of a process when several products or functions share the same process. particleboard is the only valuable output from the manufacturing facility and thus no allocation was applied to A3-product manufacturing.

The wood fiber raw material input is a product of multiple output processes, namely the milling of lumber in the different source regions. In these cases, mass allocation data for fibers was conservatively chosen. Wood fibers are a lower value coproduct than the primary product, lumber, and thus the impacts are higher for fibers in a mass allocation profile. Further, mass allocation data was available for all of the regions participating in this study.

### 4.2.4 CUT-OFF CRITERIA

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

In the primary surveys, manufacturers were asked to report total hazardous air pollutants (HAPS) specific to their wood products manufacturing process: these include formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde. If applicable to the wood product, HAPS are reported in Table 9 and are included in the impact assessment. There were no cut-offs used in the impact assessment.

### 4.2.5 DATA COLLECTION

Primary data for the LCI was collected through surveys in accordance with CORRIM and ISO 14040 protocols. This study relied almost exclusively on production and emissions data provided by particleboard producers in NA. The survey data represents particleboard production in terms of input materials, electricity, and fuel use, and emissions for the 2016 production year.

This study collected data from representative eight particleboard manufacturers in NA (4 U.S. and 4 Canadian). The wood residue to produce particleboard comes from a variety of co-products produced in both sawmills and plywood mills in the PNW, SE, and NE-NC regions of the U.S and national average data in Canada. Wood residues are in the form of wet and dry shavings, green chips, green sawdust, and panel trim. The wood residue is comprised of softwood species commonly used in lumber in production and plywood production in North America. In 2016, total north American production of particleboard was over 5.9 million $m^3$, with 4.2 from U.S. facilities and Canada producing an additional 1.8 m3 (CPA 2017). For this study of particleboard production mills responding to surveys represented 63 percent of total production North American production (Table 2).

***Table 2 Survey respondents representation to North American particleboard production.***

| Particleboard (cubic meters) | | | |
|---|---|---|---|
| | USA | Canada | North America |
| **Survey Data Production** | 2,607,872 | 1,153,150 | 3,761,022 |
| **Total production** | 4,149,997 | 1,804,749 | 5,954,746 |
| **Survey data representation of total of Production** | 63% | 64% | 63% |

### 4.2.6 CALCULATION RULES

Particleboard is most commonly reported in a thousand square foot (MSF) ¾ inch basis, which in SI units is equivalent to 1.77 m3. The survey results were converted to a unit production basis, 1 MSF (¾ inch basis) and a weighted average of input data was calculated based on production. This approach resulted in an particleboard complex that represents a composite of the mills surveyed but may not represent any mill in particular.

The survey results were converted to a unit production basis, 1 cubic meter and a weighted average of input data was calculated based on each mills production (eq. 1). The USLCI-TS and ecoinvent databases were used to assess off-site impacts associated with the materials and energy used. Gabi (v8.5) was used as the accounting program to track all of the materials and produce the cradle-to-gate LCI and LCIA results.

$$w_1 = \frac{y_1}{(y_1 + y_2 + y_3)} = \frac{y_1}{Y_{total}} \qquad eq. 1$$

$w_1$ = weighing factor for mill 1
$Y_{total}$ = total annual production of “y” mills
$y_1$ = annual production of Mill 1

$y_2$ = annual production of Mill 2
$y_3$ = annual production of Mill 3
$w_{total} = w_1 + w_2 + w_3 = 1.0$

Missing data is defined as data not reported in surveys by the particleboard facilities. 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. Any outliers were resolved by contacting mill personnel. Final particleboard product has an average dry density of 692 kg/$m^3$ (at a 5.9% moisture content, dry basis) representing 95 percent wood residue and 5 percent resin.

### 4.2.7 Data Quality

Data quality is achieved and measured by its precision (measured, calculated, or estimated), completeness (e.g. unreported emissions), and consistency in applied methodology and does the data represent the geographical scope of the study and data type (temporal and technological).

***Completeness***

Evaluating the LCA's completeness and consistency offers confidence in and the reliability of the LCA results. The completeness check process verifies whether information from the life cycle phases of a LCA are sufficient for reaching the goals and scope and conclusions of the study and making sound interpretations of the results. Three cradle-to-gate life cycle stages (A1: forestry operations, wood residue production, and resin production, A2: Transportation, and A3: particleboard manufacturing) were checked for data completeness including all input elements such as raw and ancillary materials input, energy input, transportation scenarios, water consumption, and outputs such as products and coproducts, emissions to air, water, land, and final waste disposals. All input and output data were found to be complete and no significant data gaps were identified.

***Consistency and Reproducibility***

To ensure consistency, only primary data as provided by the mill participants were used to model gate-to-gate processes (A3). All other secondary upstream data were consistently applied across particleboard system boundary. At various points in the study (data collection and modeling) a quality and consistency check were performed. The objective of these checks was to ensure that the data collection, the development of the LCI model, and the results remain consistent with the scope of the study, and that the study delivers the required information. The quality check process included a review of the precision and completeness of the collected primary data (e.g. mass and energy balance were performed), applicability of LCI datasets used, general model structure, and results plausibility (e.g. comparison to other similar reports). The data was found to be within acceptable ranges compared to internally and publicly available information.

***Temporal Coverage***

Primary data collected from the manufacturing facilities for their operational activities related to the product processes of interest are representative for the year 2016 (reference year). Additional data necessary to model base material production and energy use, etc. was adapted from various secondary databases (CORRIM datasets, USLCI-TS, and ecoinvent)

***Geographical Coverage***

The geographical coverage for this study is based on U.S. and Canadian system boundaries for all processes and products. Whenever North American background data was not readily available, European data (adjusted for N. American system boundaries) was used as a proxy.

# 5 DESCRIPTION OF PRODUCT

particleboard is a non-structural panel product developed in the 1970s to utilize industrial wood residue from the production of primary wood products such as softwood lumber and plywood. These wood residues were previously burned for energy or sent to landfill to dispose of them as waste material. Over the years the product has evolved into a highly engineered product designed to meet specific end-use requirements. particleboard is an industrial type panel used for making furniture, cabinets, tables, countertops, and millwork (Figure 3). The production of particleboard falls into the Standard Industrial Classification (SIC) Code 2493—reconstituted wood products—which includes other wood composite products such as hardboard, insulation board, particleboard, and oriented strand board (U.S. Census Bureau 2007).

***Figure 3 Particleboard***

Particleboard is produced from industrial wood residues such as shavings, sawdust, panel trim, and chips, and can be produced from chips, from logs, or directly from trees. The residues are refined to fibers or fiber bundles that are dried, blended with resin and wax, and then formed into a mat that is consolidated and cured under pressure and heat. Particleboard is produced in densities ranging from 600-800 kg/m3 (Figure 4) consistent with the material standards listed in the American National Standard ANSI A208.2-2016 (ANSI 2016). Average product density reported in surveys was 692 kg/$m^3$ at a 6 percent moisture content (oven dry basis).

Table 3 details the product composition for North American industry average particleboard production. In addition to the weighted average product composition that was the basis of this research, Table 3 also reports the statistical variation, median, minimum, and maximum values for these surveyed data.

***Table 3. Average Product Composition for Particleboard***

| Average Product Composition | | Weighted Avg. | Variance | Median | Minimum | Maximum |
|---|---|---|---|---|---|---|
| **Product Density** | kg/m3 | 691.61 | 7,344.93 | 708.02 | 662.00 | 816.94 |
| **Moisture Content** | % | 5.93% | 9.2E-05 | 6.00% | 5.00% | 8.00% |
| **Wood Component** | kg/m3 | 639.37 | 29134.77 | 631.45 | 605.92 | 1023.18 |
| **Resin Component** | kg/m3 | 52.23 | 471.52 | 61.60 | 31.72 | 78.70 |

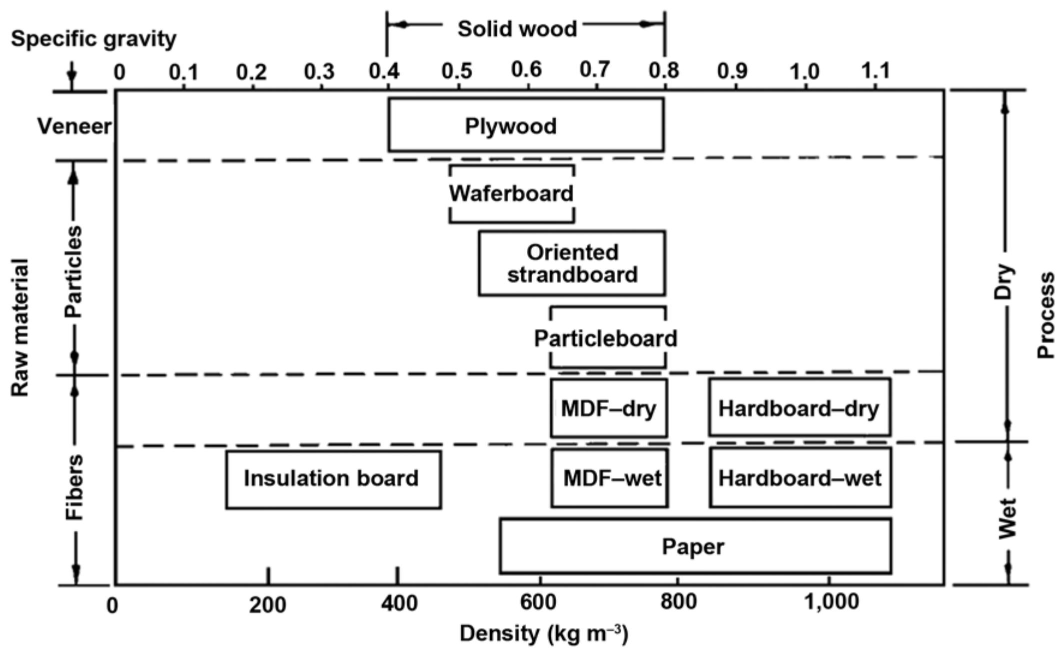


***Figure 4 Classification of wood composite panels by particle size, density, and process (Suchsland and Woodson 1986).***

Production is measured on a thousand square foot (MSF) ¾-inch basis (19.05 mm). Particleboard panels can be produced in thicknesses ranging from 3/8 inch (9.525 mm) to 1-1/4 inch (31.75 mm) and in widths from 4 to 5 feet (1.22 to 1.52 m) and lengths from 8 to 24 feet (2.44 to 7.32 m). Life cycle Inventory

# 6 Life Cycle Inventory

The life cycle inventory in this section presents the unit process flows 1 $m^3$. The LCI was calculated based on 2016 production and the corresponding flows of materials during that period. No data gaps were recorded.

## 6.1 A1 – Resource Extraction

The wood extraction stage (A1) provides estimates of the yield and emissions associated with management of representative softwood timber producing in the western, southern, and northeast/northcentral US and Canada (Oneil and Puettmann 2017, Johnson et al. 2005, Oneil et al. 2010, Athena SMI 2018)

Facilities reported the use of the following resins: urea formaldehyde (UF), melamine urea formaldehyde (MUF), methylene diphenyl di-isocyanate (MDI) and phenol formaldehyde (PF). UF resin represented the majority of the resin used by particleboard producers (71%). Alternatives to UF resin, MUF, MDI, and PF represented 12%, 4%, and 4% respectively. Other additives (urea, catalyst and wax) represent 9 percent of the total mass of resin inputs (52 kg).

Wood residue for particleboard production comes from primary softwood lumber and plywood facilities. The wood residue are coproducts generated and represent a mix of green or dry chips, sawdust, shavings, or trim. Data for these residues was generated in previous published LCI reports as listed in Table 4.

Wood residue attributes vary across the major production centers of the U.S and Canada. Residue from the U.S. include softwoods from the Southeast, Pacific Northwest, Northeast – North Central regions, and Inland Northwest. Green residues represented 50% with the majority being shavings and sawdust. Dry coproducts occurring after the primary wood product was dried represent 41% of the residue inputs for North America. Residues classified as dry and green shavings were the largest residue input from U.S. and Canadian producers (Table 5).

***Table 4 Residue source by region and representation***

| Particleboard Fiber Source | | Source of data |
|---|---|---|
| **Pacific Northwest** | 10.66% | Milota 2015a |
| **Southeast** | 45.22% | Milota 2015b |
| **Northeast – North central** | 3.88% | Puettmann et al. 2013<br>Bergman and Bowe 2010 |
| **Inland Northwest** | 9.57% | Puettmann et al. 2010 |
| **Canada** | 30.66% | Athena SMI 2018 |

*Table 5 Representation of residue type by region*

| | North America Average |
|---|---|
| **Green Chips** | 10% |
| **Green Sawdust** | 18% |
| **Green Shavings** | 23% |
| **Dry Chips** | 1% |
| **Dry Sawdust** | 3% |
| **Dry Shavings** | 37% |
| **Plywood Trim** | 3% |
| **Trim Ends** | 6% |
| **Total** | 100% |

## 6.2 A2 - Transportation Process

Delivery of wood residues and materials to the mills is by truck. Table 6 list average transport distances to particleboard facilities for US, Canadian, and North America.

*Table 6 Average delivery distance (one-way) for materials to particleboard facilities*

| Material delivered to mill | North America Average Delivery Distance (km) Road |
|---|---|
| **Wood Residues** | 39 |
| **UF** | 106 |
| **MUF** | 282 |
| **MDI** | 2 |
| **PF** | 45 |
| **Urea** | 191 |
| **Catalyst – Ammonium sulfate** | 716 |
| **Wax** | 232 |
| **Hydraulic fluid** | 40 |
| **Lubricating fluid** | 91 |
| **Motor oil** | 10 |
| **Greases** | 38 |
| **Antifreeze** | 3 |
| **Steel strapping** | 420 |
| **Plastic strapping** | 347 |

## 6.3 A3 - Particleboard Manufacturing

The particleboard manufacturing process is highly automated, process-controlled, and linear. The complete process is shown in Figure 2.

### 6.3.1 Energy use and generation

Energy for production of particleboard comes from both renewable and non-renewable sourced. Report energy and fuel use is from electricity, hog fuel, and natural gas. Other fuels such as diesel, propane, and gasoline are used to operate transport equipment within the mill. The electricity is used to operate equipment within the plant, including conveyors, refiners, fan motors, hydraulic press motors, sanders, and emission control systems. Electricity is used throughout the process and represent several grids in North America (Table 7).

Emission control devices (EMC) such as baghouses, multi cyclones, electrostatic precipitators, scrubbers, biofilters, and catalytic gas treatments, can be used throughout the mill. The emission control devices are used to reduce particulate and chemical emissions with a trade-off in that there is a large quantity of natural gas and electricity used to operate these EMC devices.

### 6.3.2 particleboard Production Process

***Wood Residue Sort and Store***

Wood residue is delivered to the mill normally by truck; the residue, referred to in the industry as furnish, consists of shavings, sawdust, panel trim, fines, and chips of various moisture contents. The residue is sorted by geometry and moisture content and then stored under cover. Incoming residue has a moisture content that ranges from 10 to 100% on an oven-dry weight-basis.

***Screening***

During screening the wood residue is passed through a set of screens that sort them by size, with oversize particles going to refining. Particles are sorted according to the desired sized for use in face and core layers, and undersized particles referred to as fines can either be put into the board which is the most common practice, or sometimes used as fuel for dryers.

***Refining***

After screening the wood residue is refined by mechanically reducing the residue geometry into uniform sizes of desired dimensions. This process is usually accomplished with the use of refiners, hammermills and occasionally flakers and hogs. Particulate emissions are addressed by baghouses and cyclones.

***Drying***

The fibers are sent through rotary dryers using either a single pass or triple pass configuration. The particles enter the dryers at moisture contents of 10-100% oven-dry wood basis and are dried to a targeted moisture content of about 3-5% depending on whether the particles will be used for face or core layers. The dryers are normally fired directly with natural gas, although some dryers also use sander dust that is recycled from a later process step. As wood dries at elevated temperatures in the dryers, particulates and air emissions of volatile organic compounds (VOCs) are released. Emissions from dryers go to cyclones and control devices such as regenerative thermal oxidizers (RTOs), catalytic regenerative oxidizers (RCOs), and biofilters.

*Blending*

This process distributes the resin, wax, catalyst, and scavenger onto the particles in the form of discrete droplets. Urea-formaldehyde (UF) is the most commonly used resin except for those products where moisture resistance is desired which are made with either melamine-urea-formaldehyde or PMDI.

*Forming*

The blended fibers are distributed into a flat mat in multiple layers of three or five consisting of face and core layers. The size of particles, their moisture and resin content are controlled for the face and core layers to obtain desire panel properties.

*Hot pressing*

The physical properties of the panel are controlled during pressing. The formed mats are conveyed into large stack presses with multiple openings, Presses operate at sufficient temperature 340°F (170°C) and duration to cure the resin, and sufficient pressure of approximately 750 psi (5.17 MPa) to consolidate the mat to a desired density of 37 to 50 lb/ft3 (593- 801 kg/m3). As a result of the elevated temperature and resin curing, particulates and air emissions of VOCs, HAPs, and other resin related emissions are generated. Emissions, if treated, go to control devices such as RTOs, RCOs, and biofilters

*Cooling*

The hot panels are placed on a cooling wheel to enable the temperature of the panels to drop below a value where the UF resin will start to break down with time and emit formaldehyde gas. Limited amounts of air emissions occur at this point.

*Sanding*

The panels are sanded on both major surfaces to targeted thickness and smoothness. Sander dust coming off this process can either be put back into residue prior to the blending process or used as fuel for the dryers.

*Sawing*

Sanded, conditioned panels are sawn to their final dimensions during this step in the manufacturing. Typical dimensions are panel widths of 4 or 5 feet and lengths of 8 or 9 feet and sometimes longer lengths. Panel trim is hammermilled into particles and sent back into the process prior to the former. The panels are then stacked and prepared for shipping.

The gate-to-gate process inputs for particleboard production are listed in Table 7. All inputs and outputs are based on weighted average survey data from participating facilities. Values are references to 1 $m^3$ of finished particleboard. Data in Table 7 does not include upstream inputs for forestry operations, residue production, and resin production.

***Table 7 Unit process inputs/outputs to produce 1 m³ of particleboard, North American average***

| | Units | North America Average |
|---|---|---|
| Material Inputs | | |
| Total Wood Inputs | odkg | 739.44 |
| ***Green Chips*** | odkg | *71.70* |
| ***Green Sawdust*** | odkg | *133.19* |
| ***Green Shavings*** | odkg | *168.25* |
| ***Dry Chips*** | odkg | *7.59* |
| ***Dry Sawdust*** | odkg | *19.85* |
| ***Dry Shavings*** | odkg | *271.35* |
| ***Plywood Trim*** | odkg | *21.64* |
| ***Trim Ends*** | odkg | *45.87* |
| Total Resin Inputs | kg solids | 52.23 |
| ***UF Resin*** | *kg solids* | *37.17* |
| ***MUF Resin*** | *kg solids* | *6.14* |
| ***PMDI Resin*** | *kg solids* | *1.89* |
| ***PF Resin*** | *kg solids* | *2.26* |
| ***Urea*** | *kg solids* | *2.90* |
| ***Ammonium Sulfate (Catalyst)*** | *kg solids* | *0.53* |
| ***Wax*** | *kg solids* | *1.35* |
| Ancillary Material Inputs | | |
| **Hydraulic fluid** | l | 8.26E-02 |
| **Lubricating fluid** | l | 3.25E-02 |
| **Motor oil** | l | 3.15E-03 |
| **Greases** | kg | 3.96E-02 |
| **Antifreeze** | l | 6.17E-03 |
| Packaging Inputs | kg | 9.27E-02 |
| Water Inputs | l | 377.79 |
| Energy Inputs | | |
| **Electricity** | kWh | 194.95 |
| ***MRO*** | *kWh* | *7.56* |
| ***SERC*** | *kWh* | *76.56* |
| ***TRE*** | | *11.60* |
| ***WECC*** | *kWh* | *39.45* |
| ***CA-NB*** | *kWh* | *6.53* |
| ***CA-ON*** | *kWh* | *7.85* |
| ***CA-QC*** | *kWh* | *45.39* |
| **Natural Gas** | m3 | 27.78 |
| **Diesel** | l | 0.46 |
| **Gasoline** | l | 0.01 |
| **Propane** | l | 0.43 |
| **Hog Fuel** | odkg | 16.94 |

| | Units | North America Average |
|---|---|---|
| Transportation Inputs | | |
| **Wood Inputs** | tkm | 28.63 |
| **Resin Inputs** | tkm | 11.96 |
| **Ancillary Material Inputs** | tkm | 7.41E-03 |
| **Packaging Inputs** | tkm | 2.66E-02 |
| Waste Outputs | | |
| **Total Waste** | kg | 9.22 |
| ***Wood Waste*** | *kg* | *7.66* |
| ***Boiler Ash Waste*** | *kg* | *1.42* |
| ***Grease Waste*** | *kg* | *0.03* |
| ***Plastic Waste*** | *kg* | *0.04* |
| ***Steel Waste*** | *kg* | *0.07* |
| Process Air Emissions | | |
| **Particulates <2.5** | kg | 6.98E-02 |
| **Particulates 2.5-10** | kg | 1.05E-01 |
| **Particulates >10** | kg | 1.74E-01 |
| **Nitrogen Oxides** | kg | 5.16E-01 |
| **Hydrocarbons** | kg | 1.24E-01 |
| **Sulfur Oxides** | kg | 1.27E-02 |
| **Carbon Monoxide** | kg | 3.14E-01 |
| **Aldehydes** | kg | 4.64E-03 |
| **Methane** | kg | 5.40E-03 |
| **VOCs** | kg | 4.16E-01 |
| **Acetaladehyde** | kg | 3.27E-03 |
| **Acrolein** | kg | 7.85E-04 |
| **Formaldehyde** | kg | 1.21E-01 |
| **Methanol** | kg | 2.81E-02 |
| **Phenol** | kg | 3.74E-03 |
| **HAPS (other)** | kg | 2.10E-02 |
| **Ammonia** | kg | 1.52E-02 |
| **Hydrogen Fluoride** | kg | 4.16E-06 |
| **Lead** | kg | 4.26E-05 |
| **Mercury** | kg | 5.74E-07 |
| **Chlorine** | kg | 8.66E-05 |
| Water Emissions | | |
| **COD** | kg | 1.45E-03 |
| **Suspended Solids** | kg | 1.85E-03 |

***Packaging***

***Table 8 Materials used in packaging and shipping per m³ particleboard, North American average***

| Material | Value | North America Average |
|---|---|---|
| **Steel strapping** | kg | 1.61E-02 |
| **Plastic strapping** | kg | 7.66E-02 |
| **TOTAL** | kg | 9.27E-02 |

Packing materials represent only 0.01% of the cumulative mass of the model flow.

## 6.4 Secondary Data Sources

Table 9 list the secondary LCI data sources used in this LCA study for raw material inputs, ancillary materials and packaging, transportation of materials and resources, fuels and energy for manufacturing, water sources, and waste streams.

***Table 9 Secondary Data Sources and Data Quality Assessment***

| **A1: Raw Material Inputs** | | | | |
|---|---|---|---|---|
| **Inputs** | **LCI Data Source** | **Geography** | **Year** | **Data Quality Assessment** |
| **Wood Residues** | CORRIM and Athena Publications (See Table 4) | North America – Region Specific | 2010 - 2018 | **Technology**: very good<br>Process models region-specific technology.<br><br>**Time**: good<br>Data is less than 10 years old<br><br>**Geography**: very good<br>Data is representative of regional production. |
| **Urea Formaldehyde Resin** | ecoinvent 3.3 Database: ROW: urea formaldehyde resin production. | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |
| **Melamine Urea Formaldehyde Resin (MUF) Resin** | ecoinvent 3.3 Database: RoW: melamine formaldehyde resin production | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |
| **Polymeric Methylene Diphenyl Diisocyanate (PMDI) Resin** | ecoinvent 3.3 Database: RoW: methylene diphenyl diisocyanate production | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |
| **Phenol Formaldehyde Resin** | ecoinvent 3.3 Database: RoW: urea formaldehyde resin production | Global | 2016 | Technology: very good<br>Process models average global technology<br><br>Time: very good<br>Data is less than 5 years old<br><br>Geography: very good<br>Data is representative of global processes. |

| | | | | |
|---|---|---|---|---|
| **Urea Scavenger** | ecoinvent 3.3 Database:<br>RoW: urea production, as N | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |
| **Ammonium Sulphate (Catalyst)** | ecoinvent 3.3 Database:<br>RoW: ammonium sulfate production | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |
| **Wax** | USLCI-TS (Full US) Database:<br>US: Slack wax, at plant, US SE | United States | 2018 | **Technology**: very good<br>Process models average US technology<br><br>**Time**: Fair<br>Data is less than 10 years old<br><br>**Geography**: very good<br>Data is representative of US processes. |
| **Ancillary Materials and Packaging** | **LCI Data Source** | **Geography** | **Year** | **Data Quality Assessment** |
| **Hydraulic Fluid and Lubricants** | USLCI-TS (Full US) Database:<br>US: Diesel, at refinery | North America | 2018 | **Technology**: very good<br>Process models average North American technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of North American processes. |
| **Antifreeze** | ecoinvent 3.3 Database:<br>RoW: ethylene glycol production | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |

| | | | | |
|---|---|---|---|---|
| **Steel Strap** | ecoinvent 3.3 Database: RoW: steel production, chromium steel 18/8, hot rolled | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |
| **Plastic Strap** | ecoinvent 3.3 Database: RoW: polyethylene production, high density, granulate | North America | 2018 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global processes. |
| **A2: Raw Material Transportation** | | | | |
| **Inputs** | **LCI Data Source** | **Geography** | **Year** | **Data Quality Assessment** |
| **Trucking** | USLCI-TS (Full US) Database: US: Single unit truck transport, diesel powered, short haul; | North America | 2018 | **Technology**: very good<br>Process models average North American technology<br><br>**Time**: good<br>Data is less than 10 years old<br><br>**Geography**: very good<br>Data is representative of North American trucking. |
| **A3: Manufacturing** | | | | |
| **Energy Inputs** | **LCI Data Source** | **Geography** | **Year** | **Data Quality Assessment** |
| **Electricity** | ecoinvent 3.3 Database: US egrid and Canadian gird market for electricity, low voltage | North America – Region Specific egrid | 2018 | **Technology**: very good<br>Process models average electricity technology specific to regional grids<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of regional electricity generation. |
| **Natural Gas** | USLCI-TS (Full US) Database: Natural gas, combusted in industrial boiler | North America | 2018 | **Technology**: very good<br>Process models average North American technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of North American natural gas production and consumption. |

| | | | | |
|---|---|---|---|---|
| **Liquid Propane** | USLCI-TS (Full US) Database: Liquefied petroleum gas, combusted in industrial boiler | North America | 2018 | **Technology**: very good<br>Process models average North American technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of North American propane production and combustion. |
| **Diesel** | USLCI-TS (Full US) Database: Diesel, combusted in industrial boiler | North America | 2018 | **Technology**: very good<br>Process models average North American technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of North American diesel production and combustion. |
| **Biomass Combustion** | CORRIM Data | North America | 2015 | **Technology:** very good<br>Process represents combustion of biomass in an industrial boiler.<br><br>**Time:** very good<br>Data is within two years<br><br>**Geography:** very good<br>Data is representative of North American biomass combustion. |
| **Water** | **LCI Data Source** | **Geography** | **Year** | **Data Quality Assessment** |
| **Municipal Water** | Modeled as elementary flow | N/A | N/A | N/A |
| **Waste** | **LCI Data Source** | **Geography** | **Year** | **Data Quality Assessment** |
| **Solid waste and liquid waste landfilled** | ecoinvent 3.3 Database: ROW: Process-specific burden, sanitary landfill. | Global | 2016 | **Technology**: very good<br>Process models average global technology<br><br>**Time**: very good<br>Data is less than 5 years old<br><br>**Geography**: very good<br>Data is representative of global production. |

# 7 LIFE CYCLE IMPACT ASSESSMENT

The life cycle impact assessment (LCIA) phase establishes links between the life cycle inventory results and potential environmental impacts. The LCIA calculates impact indicators, 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 below. Environmental impacts are determined using the TRACI method (Bare et al. 2011). Five impact categories (IC) and characterization factors (CF) are reported consistent with the requirement of the wood products PCR.

Each impact indicator is a measure of an aspect of a potential impact. This LCIA does not make value judgments about the impact indicators, meaning comparison indicator values are 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.

The primary fuels categorized into non-renewable fossil, non-renewable nuclear, non-renewable biomass, renewable biomass, hydroelectric, and other (wind, solar, geothermal). Table 10 summarizes the source and scope of each impact category reported in this report.

- **Global warming (IC) -** TRACI uses global warming potentials (CF), a midpoint metric proposed by the International Panel on Climate Change (IPCC) for the calculation of the potency of greenhouse gases relative to $CO_2$. The 100-year time horizons recommended by the IPCC and used by the United States for policy making and reporting are adopted within TRACI. Global warming potential (GWP) – the methodology and science behind the GWP calculation can be considered one of the most accepted LCIA categories. GWP100 will be expressed on equivalency basis relative to $CO_2$ – i.e., equivalent $CO_2$ mass basis.

- **Ozone depletion (IC) -** Stratospheric ozone depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substances. International consensus exists on the use of Ozone Depletion Potentials (CF), a metric proposed by the World Meteorological Organization for calculating the relative importance of CFCs, hydrochlorofluorocarbons (HFCs), and halons expected to contribute significantly to the breakdown of the ozone layer. TRACI is using the ozone depletion potentials published in the Handbook for the International Treaties for the Protection of the Ozone Layer (UNEP-SETAC 2000), where chemicals are characterized relative to CFC-11.

- **Acidification (IC) -** As per TRACI, acidification comprises processes that increase the sulfur dioxide ($SO_2$) of water and soil systems from acid forming chemicals such as sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification is a more regional rather than global impact effecting fresh water and forests as well as human health when high concentrations of $SO_2$ are attained. The Acidification potential (CF) of an air emission is calculated based on the number of $SO_2$ which can be produced and therefore is expressed as potential $SO_2$ equivalents per kg of contributing emission.

- **Photochemical smog (IC) -** Photochemical ozone formation potential (CF) – Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The "smog" indicator is expressed on a mass of equivalent ozone ($O_3$) basis.

- **Eutrophication (IC) -** In TRACI, eutrophication is defined as the fertilization of surface waters by nutrients that were previously scarce. This measure encompasses the release of mineral salts and their nutrient enrichment effects on waters – typically made up of phosphorous and nitrogen compounds and organic matter flowing into waterways. The result is expressed on an equivalent mass of nitrogen (N) basis. The characterization factors estimate the eutrophication potential of a release of chemicals containing N or P to air or water, per kilogram of chemical released, relative to 1 kg N discharged directly to surface freshwater.

- **Total primary energy (IC) –** Total primary energy is the sum of all energy sources which are drawn directly from the earth, such as natural gas, oil, coal, biomass or hydropower energy. The total primary energy contains further categories namely non-renewable and renewable energy, and fuel and feedstock energy. Non-renewable energy includes all fossil and mineral primary energy sources, such as natural gas, oil, coal and nuclear energy. Renewable energy includes all other primary energy sources, such as hydropower and biomass. Feedstock energy is that part of the primary energy entering the system which is not consumed and/or is available as fuel energy and for use outside the system boundary. Total primary energy is expressed in mega joules (MJ).

***Table 10 Selected impact indicators required for reporting***

| Impact category | Unit | Method | Level of site specificity |
|---|---|---|---|
| **Global warming** | kg $CO_2$ eq | TRACI 2.1 v1.01 | Global |
| **Smog** | kg $SO_2$ eq | TRACI 2.1 v1.01 | North America |
| **Acidification** | kg N eq | TRACI 2.1 v1.01 | North America |
| **Ozone depletion** | kg CFC-11 eq | TRACI 2.1 v1.01 | North America |
| **Eutrophication** | kg $O_3$ eq | TRACI 2.1 v1.01 | North America |
| **Total energy** | MJ | Gabi | Global |
| ***Non-renewable fossil*** | MJ | Gabi | Global |
| ***Non-renewable nuclear*** | MJ | Gabi | Global |
| ***Renewable woody biomass*** | MJ | Gabi | Global |
| ***Other renewables**** | MJ | Gabi | Global |

∗ solar, wind, hydro, geothermal

Cradle-to-gate environmental performance results for global warming, acidification, eutrophication, ozone depletion and smog, energy consumption from non-renewables, renewables, wind, hydro, solar, and nuclear fuels, renewable and nonrenewable resources, and solid waste are shown in Tables 11-13. The LCIA results in these tables show the absolute values for A1-Resource extraction, A2-Transportation, and A3-particleboard production (Table 11). Tables 12 and 13 further show the breakdown of impacts with the A1 (Table 12) and A3 (Table 13) phases.

***Table 11. Cradle-to-gate particleboard LCIA Results for A1-Resource extraction and residue and resin production, A2-Transporation, and A3-particleboard Production, no allocation, absolute basis, North America.***

| *Impact category* | Unit | Total | A1 | A2 | A3 |
|---|---|---|---|---|---|
| **Global warming** | kg CO2 eq | 402.46 | 228.17 | 4.29 | 170.00 |
| **Acidification** | kg SO2 eq | 6.34 | 4.90 | 0.05 | 1.39 |
| **Eutrophication** | kg N eq | 1.39 | 0.55 | 0.00 | 0.84 |
| **Smog** | kg O3 eq | 133.95 | 111.78 | 1.27 | 20.90 |
| **Ozone depletion** | kg CFC-11 eq | 3.41E-05 | 2.45E-05 | 1.82E-10 | 9.57E-06 |
| *Energy Consumption* | | | | | |
| **Total primary energy** | MJ | 8928.27 | 5479.85 | 61.27 | 3387.14 |
| ***Non-renewable fossil*** | MJ | *5,939.77* | *3,662.89* | *60.72* | *2,216.16* |
| ***Non-renewable nuclear*** | MJ | *634.11* | *131.03* | *0.56* | *502.52* |
| ***Renewable biomass*** | MJ | *1,936.18* | *1,560.54* | *0.00* | *375.64* |
| ***Renewable (solar, wind, hydroelectric and geothermal)*** | MJ | *418.21* | *125.39* | *0.00* | *292.82* |
| *Material Resources Consumption* | | | | | |
| **Non-renewable materials** | kg | 28.95 | 22.77 | 0.00 | 6.17 |
| **Renewable materials** | kg | 798.85 | 796.63 | 0.00 | 2.22 |
| **Fresh water** | l | 1,242.29 | 662.45 | 0.00 | 579.84 |
| *Waste Generation* | | | | | |
| **Hazardous waste generated** | kg | 0.00 | 0.00 | 0.00 | 0.00 |
| **Non-hazardous waste generated** | kg | 9.22 | 0.00 | 0.00 | 9.22 |

***Table 12 Cradle-to-gate particleboard LCIA Results for A1-Resource extraction (other) and residue and resin production, no allocation, absolute basis, North America.***

| *Impact category* | Unit | Total | Residues | Resins | Other |
|---|---|---|---|---|---|
| **Global warming** | kg CO2 eq | 228.14 | 74.92 | 152.99 | 0.23 |
| **Acidification** | kg SO2 eq | 4.90 | 1.39 | 3.51 | 0.00 |
| **Eutrophication** | kg N eq | 0.55 | 0.05 | 0.50 | 0.00 |
| **Smog** | kg O3 eq | 111.79 | 17.08 | 94.70 | 0.01 |
| **Ozone depletion** | kg CFC-11 eq | 2.45E-05 | 3.83E-07 | 2.41E-05 | 4.95E-09 |
| *Energy Consumption* | | | | | |
| **Total primary energy** | MJ | 5479.85 | 2365.04 | 3108.23 | 6.58 |
| ***Non-renewable fossil*** | MJ | 3,662.89 | 713.58 | 2,943.44 | 5.87 |
| ***Non-renewable nuclear*** | MJ | 131.03 | 37.56 | 93.04 | 0.43 |
| ***Renewable biomass*** | MJ | 1,560.54 | 1,528.29 | 32.19 | 0.06 |
| ***Renewable (solar, wind, hydroelectric and geothermal)*** | MJ | 125.39 | 85.61 | 39.56 | 0.22 |
| *Material Resources Consumption* | | | | | |
| **Non-renewable materials** | kg | 22.77 | 0.00 | 22.74 | 0.03 |
| **Renewable materials** | kg | 796.63 | 790.16 | 6.46 | 0.01 |
| **Fresh water** | l | 662.45 | 40.78 | 243.55 | 378.11 |
| *Waste Generation* | | | | | |
| **Hazardous waste generated** | kg | 0.00 | 0.00 | 0.00 | 0.00 |
| **Non-hazardous waste generated** | kg | 0.00 | 0.00 | 0.00 | 0.00 |

***Table 13 Gate-to-gate particleboard LCIA Results for A3-particleboard production, no allocation, absolute basis, North America.***

| *Impact category* | Unit | Total | Nat Gas | Electricity | Other |
|---|---|---|---|---|---|
| **Global warming** | kg CO2 eq | 169.60 | 66.80 | 97.59 | 5.20 |
| **Acidification** | kg SO2 eq | 1.39 | 0.57 | 0.36 | 0.46 |
| **Eutrophication** | kg N eq | 0.84 | 0.01 | 0.80 | 0.03 |
| **Smog** | kg O3 eq | 20.84 | 1.46 | 2.66 | 16.72 |
| **Ozone depletion** | kg CFC-11 eq | 9.58E-06 | 3.95E-11 | 9.57E-06 | 6.37E-09 |
| *Energy Consumption* | | | | | |
| **Total primary energy** | MJ | 3387.14 | 1065.40 | 1912.31 | 409.43 |
| ***Non-renewable fossil*** | MJ | 2,216.16 | 1,062.11 | 1,107.40 | 46.66 |
| ***Non-renewable nuclear*** | MJ | 502.52 | 3.29 | 498.17 | 1.06 |
| ***Renewable biomass*** | MJ | 375.64 | 0.00 | 14.50 | 361.14 |
| ***Renewable (solar, wind, hydroelectric and geothermal)*** | MJ | 292.82 | 0.00 | 292.26 | 0.57 |
| *Material Resources Consumption* | | | | | |
| **Non-renewable materials** | kg | 6.17 | 0.00 | 6.17 | 0.00 |
| **Renewable materials** | kg | 2.22 | 0.02 | 2.20 | 0.00 |
| **Fresh water** | l | 579.84 | 0.00 | 579.82 | 0.02 |
| *Waste Generation* | | | | | |
| **Hazardous waste generated** | kg | 0.00 | 0.00 | 0.00 | 0.00 |
| **Non-hazardous waste generated** | kg | 0.00 | 0.00 | 0.00 | 9.22 |

# 8 Interpretation

As defined by ISO (2006), the term life cycle interpretation is the phase of the LCA that the findings of either the LCI or the LCIA, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations. This phase in the LCA reports the significant issues based on the results of the presented in LCI and the 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.

## 8.1 Identification of the Significant Issues

The objective of this element is to structure the results from the LCI or the LCIA phases to help determine the significant issues found in the results and presented in previous sections of this report. A contribution analysis was applied for the interpretation phase of this LCA study. Contribution analysis examines the contribution of life cycles stages (A1 and A3), unit process contributions in a multi-unit manufacturing process, or specific substances which contribute an impact.

## 8.2 Life Cycle Phase Contribution Analysis

For global warming impact, 42 percent of the $CO_2$ equivalent emissions come from producing particleboard (A3), with 57 and 1 percent assigned to extraction, wood residue and resin production

(A1) and transportation (A2), respectively (Table 14) (Figure 5). Resource extraction (A1) represented the highest impacts in four impact categories (GWP, acidification, smog, and ozone depletion) primarily due to resin production (Table 15). Resin production represented 67-98 percent in all of the impact categories (Table 15) (Figure 6). While resin production consumed the most primary energy in the A1 life cycle stage (57%) (Table 15) 38 percent the cradle-to-gate energy requirement is consumed in particleboard production (A3) from cradle-to-gate (Table 14). Cradle-to-gate, fresh water use was shared between A1 and A3 life cycle stages at 53 and 47 percent, respectively (Table 14).

Non-renewable fuels represented the greatest proportion of energy consumption (74%) over all life cycle stages with the raw material production (a1) using 62% of non-renewable fuels and and particleboard production(A3) phase using 37 percent of the non-renewable fuel(Table 14). The majority of the renewable biomass for energy was for feedstock production (A1) off-site of particleboard facilities. Renewable biomass is the primary fuel used in drying, conditioning, and pressing process in wood residue production (A1). Resin production consumed about half of the total energy in the A1 life cycle process (Table 15).

Total energy, which includes fuel for process heat and equipment and electricity, comes from fossil fuels (67%) wood fuel (22%), non-renewable nuclear (7%), and other renewable (5%) (Table 14). The non-wood energy component represents an opportunity for improving sustainability by substituting for it with sustainably grown wood fuel. During residue production (A1), 65 percent of the energy used in production was biomass while non-renewable fossil fuels was the primary fuel consumed in resin production (95%) (Table 15). Figure 6 shows the LCIA for the A1 phase of the cradle-to-gate system boundary where resin production dominates the impacts and energy production.

During particleboard production (A3), electricity generation and use dominates the impacts with the exception of smog (Table 16) (Figure 7). Natural gas combustion is also a significant driver of impacts. The biomass energy consumed at the production facilities account for most of the “Other” impacts.

***Table 14 Cradle-to-gate particleboard LCIA Results for A1-Resource extraction and residue and resin production, A2-Transporation, and A3-particleboard Production, no allocation, percent basis, North America.***

| *Impact category* | Unit | Total | A1 | A2 | A3 |
|---|---|---|---|---|---|
| **Global warming** | kg CO2 eq | 100.0% | 57% | 1% | 42% |
| **Acidification** | kg SO2 eq | 100.0% | 77% | 1% | 22% |
| **Eutrophication** | kg N eq | 100.0% | 40% | 0% | 60% |
| **Smog** | kg O3 eq | 100.0% | 83% | 1% | 16% |
| **Ozone depletion** | kg CFC-11 eq | 100.0% | 72% | 0% | 28% |
| *Energy Consumption* | | | | | |
| **Total primary energy** | MJ | 100.0% | 61% | 1% | 38% |
| ***Non-renewable fossil*** | MJ | *100.0%* | 62% | 1% | 37% |
| ***Non-renewable nuclear*** | MJ | *100.0%* | 21% | 0% | 79% |
| ***Renewable biomass*** | MJ | *100.0%* | 81% | 0% | 19% |
| ***Renewable (solar, wind, hydroelectric and geothermal)*** | MJ | *100.0%* | 30% | 0% | 70% |
| *Material Resources Consumption* | | | | | |
| **Non-renewable materials** | kg | 100% | 79% | 0% | 21% |
| **Renewable materials** | kg | 100% | 100% | 0% | 0% |
| **Fresh water** | l | 100% | 53% | 0% | 47% |
| *Waste Generation* | | | | | |
| **Hazardous waste generated** | kg | 0% | 0% | 0% | 0% |
| **Non-hazardous waste generated** | kg | 100% | 0% | 0% | 100% |

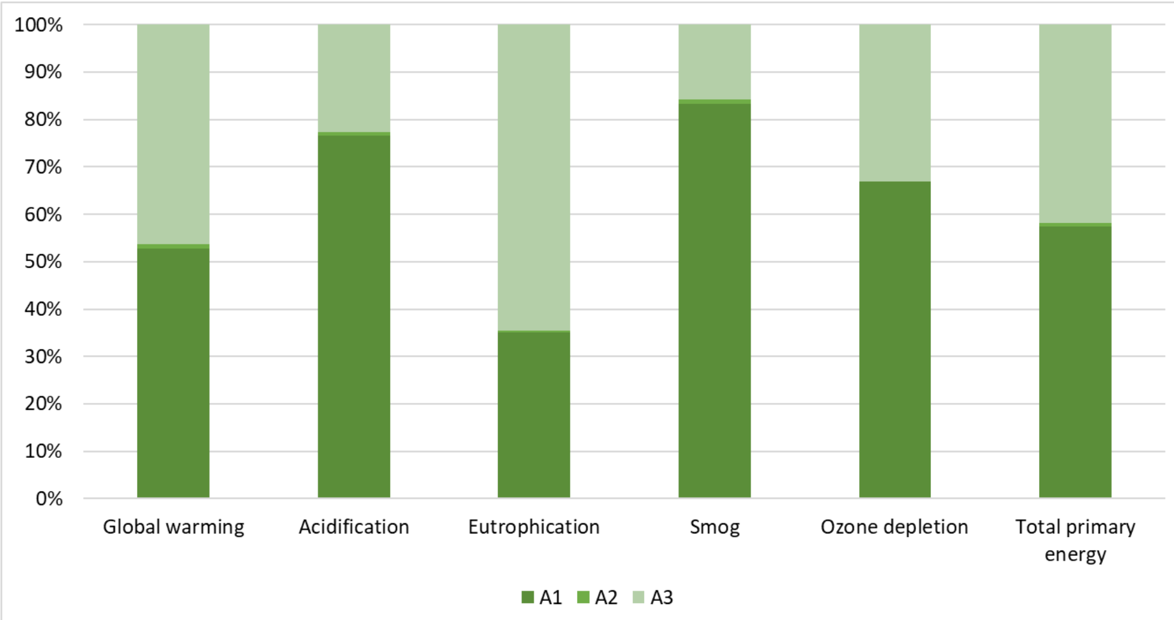


***Figure 5 Cradle-to-gate particleboard LCIA Results for A1-Resource extraction and residue and resin production, A2-Transporation, and A3-particleboard Production, no allocation, percent basis, North America.***

***Table 15 Cradle-to-gate particleboard LCIA Results for A1-Resource extraction (other) and residue and resin production, no allocation, percentage basis, North America.***

| *Impact category* | Unit | Total | Residues | Resins | Other |
|---|---|---|---|---|---|
| **Global warming** | kg CO2 eq | 100% | 33% | 67% | 0% |
| **Acidification** | kg SO2 eq | 100% | 28% | 72% | 0% |
| **Eutrophication** | kg N eq | 100% | 9% | 91% | 0% |
| **Smog** | kg O3 eq | 100% | 15% | 85% | 0% |
| **Ozone depletion** | kg CFC-11 eq | 100% | 2% | 98% | 0% |
| *Energy Consumption* | | | | | |
| **Total primary energy** | MJ | 100% | 43% | 57% | 0% |
| ***Non-renewable fossil*** | MJ | 100% | 19% | 80% | 0% |
| ***Non-renewable nuclear*** | MJ | 100% | 29% | 71% | 0% |
| ***Renewable biomass*** | MJ | 100% | 98% | 2% | 0% |
| ***Renewable (solar, wind, hydroelectric and geothermal)*** | MJ | 100% | 68% | 32% | 0% |
| *Material Resources Consumption* | | | | | |
| **Non-renewable materials** | kg | 100% | 0% | 100% | 0% |
| **Renewable materials** | kg | 100% | 99% | 1% | 0% |
| **Fresh water** | l | 100% | 6% | 37% | 57% |
| *Waste Generation* | | | | | |
| **Hazardous waste generated** | kg | 0% | 0% | 0% | 0% |
| **Non-hazardous waste generated** | kg | 0% | 0% | 0% | 0% |

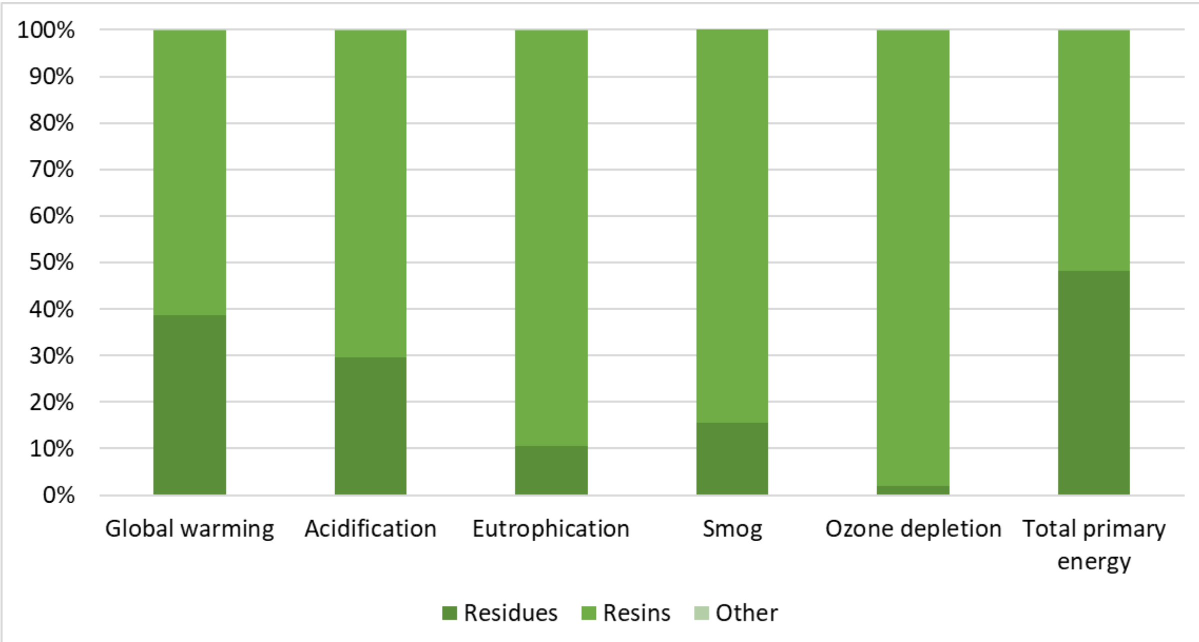


***Figure 6 Cradle-to-gate particleboard LCIA Results for A1-Resource extraction (other) and residue and resin production, no allocation, percentage basis, North America.***

***Table 16 Gate-to-gate particleboard LCIA Results for A3-particleboard production, no allocation, percent basis (North America).***

| *Impact category* | Unit | Total | Nat Gas | Electricity | Other |
|---|---|---|---|---|---|
| **Global warming** | kg CO2 eq | 100% | 39% | 58% | 3% |
| **Acidification** | kg SO2 eq | 100% | 41% | 26% | 33% |
| **Eutrophication** | kg N eq | 100% | 1% | 96% | 3% |
| **Smog** | kg O3 eq | 100% | 7% | 13% | 80% |
| **Ozone depletion** | kg CFC-11 eq | 100% | 0% | 100% | 0% |
| *Energy Consumption* | | | | | |
| **Total primary energy** | MJ | 100% | 31% | 56% | 12% |
| ***Non-renewable fossil*** | MJ | 100% | 48% | 50% | 2% |
| ***Non-renewable nuclear*** | MJ | 100% | 1% | 99% | 0% |
| ***Renewable biomass*** | MJ | 100% | 0% | 4% | 96% |
| ***Renewable (solar, wind, hydroelectric and geothermal)*** | MJ | 100% | 0% | 100% | 0% |
| *Material Resources Consumption* | | | | | |
| **Non-renewable materials** | kg | 100% | 0% | 100% | 0% |
| **Renewable materials** | kg | 100% | 1% | 99% | 0% |
| **Fresh water** | l | 100% | 0% | 100% | 0% |
| *Waste Generation* | | | | | |
| **Hazardous waste generated** | kg | 0% | 0% | 0% | 0% |
| **Non-hazardous waste generated** | kg | 100% | 0% | 0% | 100% |

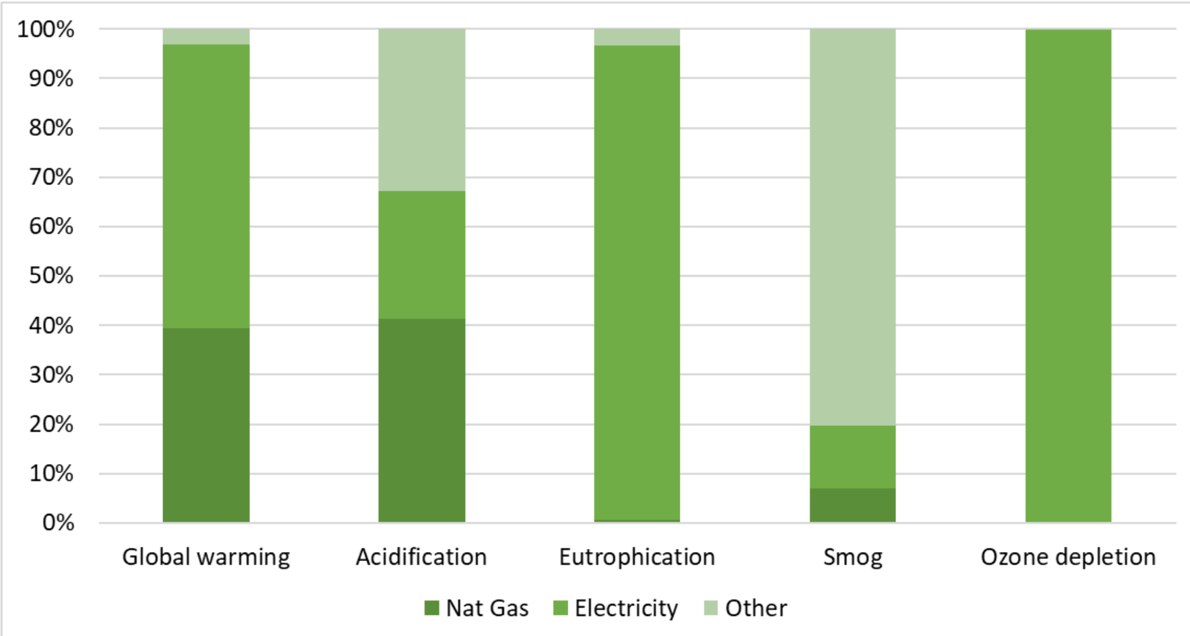


***Figure 7 Gate-to-gate particleboard LCIA Results for A3-particleboard production, no allocation, percent basis (North America).***

## 8.3 Uncertainty Analysis

Some degree of uncertainty is present in the results due to the variation amongst different data providers. Table 17 provides several statistics for the modeling parameters found to be most significant in the previous section. The significant parameters are residue input, resin input, natural gas use, and electricity use. The standard deviation for each of these parameters was calculated based on the sample data and was used to perform sensitivity analysis on these parameters.

***Table 17: Survey Data Statistics for Significant Parameters***

| Average Product Composition | | Weighted Avg. | Variance | Std. Deviation | Median | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| *A1 Inputs* | | | | | | | |
| **Residue Input** | kg | 739.44 | 33,694.72 | 183.56 | 730.28 | 605.92 | 1,183.32 |
| **Resin Input** | kg | 52.23 | 471.52 | 21.71 | 61.60 | 31.72 | 78.70 |
| *A3 Inputs* | | | | | | | |
| **Electricity** | kWh | 194.95 | 3,035.30 | 55.09 | 189.72 | 154.40 | 316.15 |
| **Natural Gas** | m3 | 27.78 | 833.03 | 28.86 | 15.73 | 0.00 | 93.55 |

Table 18 shows sensitivity analysis in which the original input amount (see Table 7) was multiplied by 1 + the standard deviation calculated for each parameter. For example, the standard deviation of the residue response was found to be 183.56 kg – which is 25% of the baseline model amount of 739.44. The sensitivity scenario thus represents 125% of the original residue amount.

***Table 18: Sensitivity Analysis on Significant Parameters***

| *Impact category* | | Baseline | 25% Additional Residues | 42% Additional Resins | 28% Additional Electricity | 103% Additional Nat. Gas |
|---|---|---|---|---|---|---|
| **Global warming** | kg CO2 eq | 402.46 | 421.06 | 466.06 | 485.34 | 531.08 |
| **Acidification** | kg SO2 eq | 6.34 | 6.69 | 7.80 | 6.66 | 7.45 |
| **Eutrophication** | kg N eq | 1.39 | 1.40 | 1.60 | 2.19 | 1.40 |
| **Smog** | kg O3 eq | 133.95 | 138.19 | 173.32 | 136.61 | 136.76 |
| **Ozone depletion** | kg CFC-11 eq | 3.41E-05 | 3.42E-05 | 4.41E-05 | 3.99E-05 | 3.41E-05 |
| *Energy Consumption* | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total primary energy** | MJ | 8,928.27 | 9,515.37 | 10,220.45 | 10,341.51 | 10,980.39 |
| ***Non-renewable fossil*** | MJ | 5,939.77 | 6,116.91 | 7,163.45 | 6,854.79 | 7,985.56 |
| ***Non-renewable nuclear*** | MJ | 634.11 | 643.43 | 672.79 | 970.70 | 640.44 |
| ***Renewable biomass*** | MJ | 1,936.18 | 2,315.56 | 1,949.56 | 1,971.82 | 1,936.18 |
| ***Renewable (solar, wind, hydroelectric and geothermal)*** | MJ | 418.21 | 439.47 | 434.66 | 544.19 | 418.21 |
| *Material Resources Consumption* | | | | | | |
| **Non-renewable materials** | kg | 28.95 | 28.95 | 38.40 | 33.38 | 28.95 |
| **Renewable materials** | kg | 798.85 | 995.00 | 801.54 | 803.99 | 798.89 |
| **Fresh water** | l | 1,242.29 | 1,252.41 | 1,343.54 | 1,745.92 | 1,242.29 |
| *Waste Generation* | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Hazardous waste generated** | kg | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Non-hazardous waste generated** | kg | 9.22 | 9.22 | 9.22 | 9.22 | 9.22 |

### 8.4 Limitations

This EPD was created using industry average data for upstream materials. Variation can result from differences in supplier locations, manufacturing processes, manufacturing efficiency and fuel type used.

This LCA does not report all of the environmental impacts due to manufacturing of the product, but rather reports the environmental impacts for those categories with established LCA-based methods to track and report. Unreported environmental impacts include (but are not limited to) factors attributable to human health, land use change, and habitat destruction. In order to assess the local impacts of product manufacturing, additional analysis is required.

This LCA report documents the results of a 'cradle-to-gate' analysis and is not a comparative assertion, defined as an environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function. This LCA does not make any statements that the product covered by the LCA is better or worse than any other product.

# 9 Treatment of Biogenic Carbon

The treatment of biogenic carbon in this LCA follows the requirements set out in the reference PCR. The requirements in the PCR were adapted from EN 16485. Modifications to the methodology from EN 16485 include the specification that carbon storage in products is to be excluded in the calculation of global warming potential in cradle-to-gate LCA. All other changes to the text in EN 16485 were done to remove references to European countries and to align the formatting with the rest of this PCR. Example 2 from EN 16485 was merged into Example 1.

Forests are understood as a natural system with multiple functions, the production function of timber being one of them. Therefore, natural growth and decay processes including natural disturbances, etc., are not attributable to the production function of forests and are therefore not considered in LCA.

Harvesting operations lead to temporal decreases in forest carbon pools in the respective stand. Impacts on forest carbon pools resulting from the sustainable or unsustainable management of forests, however, cannot be defined or assessed on stand level but requires the consideration of carbon pool changes on landscape level, i.e., the level based on which management decisions are made. Resulting from the fundamental principle of sustainable forest management to preserve the production function of forest, total forest carbon pools can be considered stable (or increasing) under sustainable forest management. This is due to the fact that temporal decreases of forest carbon pools resulting from harvesting on one site are compensated by increases of carbon pools on the other sites, forming together the forest area under sustainable forest management.

It is acknowledged that excessive extraction of slash, litter or roots for the purpose of bioenergy generation can lead to decreases in forest carbon pools. These activities, however, are not causally linked to the extraction of timber for the material use of wood. Effects on forest carbon pools related to the extraction of slash, litter or roots are not attributable to the material use of wood and are therefore not considered in this document.

In order to reflect the biogenic nature of wood, its renewability and its potential carbon neutrality, the system boundary between nature and the product system under study is defined as follows:

- Wood entering the product system from nature accounts for the energy content and the biogenic carbon content as material inherent properties.
- All technical processes related to forestry operations intended to produce timber, (e.g. stand establishment, tending, thinning(s), harvesting, establishment and maintenance of forest roads) are considered within the system boundary and are subject to co-product allocations as outlined in the reference PCR.
- Potential implications due to the unknown origin of wood or unsustainably produced timber are considered.
- Human induced impacts on forest carbon pools resulting in deforestation are included.

As the degradation of forest carbon pools resulting from unsustainable management of forests cannot be attributed to a specific log but is a process on landscape level, the effect of forest degradation is taken into account by not assuming carbon neutrality. In the case of land-use changes from forests to other land uses (e.g., deforestation), the loss of carbon in the forest carbon pools are to be taken into account.

Consideration of the biogenic carbon neutrality of wood is valid for North American wood products as national level inventory reporting shows overall increasing and/or neutral forest carbon stocks in recent years[1].

The North American PCR approach is followed here for GWP reporting therefore the default TRACI impact assessment method was used. This default method does not count the $CO_2$ emissions released during the combustion of woody biomass during production. Other emissions associated from wood combustion, e.g., methane or nitrogen oxides, do contribute to and are included in the GWP impact category. Using this method, 367 kg $CO_2e$ were released in the production of 1 $m^3$ of particleboard. That same 1 $m^3$ of particleboard stores 346 kg of carbon or 1,268 kg $CO_2e$ resulting in more carbon storage in the product then released during manufacturing (cradle-to-gate) (Table 19).

***Table 19 Carbon emission per 1 $m^3$ particleboard, North American average.***

| | Unit | Total |
|---|---|---|
| **Stored in product** | kg CO2 eq | -1,267.95 |
| **Extraction – A1** | kg CO2 eq | 193.45 |
| **Transportation – A2** | kg CO2 eq | 3.83 |
| **particleboard Manufacturing – A3** | kg CO2 eq | 170 |
| **Cradle-to-gate Net Total** | kg CO2 eq | -900.67 |

[1] National forest carbon stocks are reported under the United Nations Framework Convention on Climate Change. See Table 7.1 for United States forest carbon stocks and Table 7.1 for Canadian forest carbon stocks. Canadian forest carbon stocks have fluctuated near net neutrality in recent years (ranging from -98 Tg to +69 Tg since 1990) while United States forest carbon stocks have shown annual stock increases of 600-900 Tg annually since 1990.

# 10 CONCLUSIONS

This study provides a comprehensive cradle-to-gate LCA of the production of particleboard produced in North America in accordance 2015 FPInnovations Product Category Rules. The cradle to gate LCA for particleboard includes: Upstream production inputs for forestry and residue and resin production (A1), transportation of all materials and resources into the particleboard production boundary (A2) and gate-to-gate production for particleboard (A3). The survey results for particleboard were representative of north American average with wood inputs representing the PNW, SE, NE-NC regions of the U.S and Canada. Representative facilities represented 63 percent of the total North American particleboard production.

Emissions from transportation (A2) represented a small contribution over-all impact factors and energy consumption. Resource extraction and residue and resin production (A1) had the greatest contributions to global warming potential, acidification, smog, ozone depletion, and total energy. While particleboard production (A3) contributed highest to eutrophication potential impact. Most of the non-renewable materials were consumed in the A1 stage fresh water was consumption was spilt nearly equally between A1 and A3.

Renewable biomass represented 23 percent of the total energy consumption for all stages of production (A1-A3), with only 20 percent of the biomass energy used during particleboard production (A3). The use of non-renewable fossil fuels dominated the total energy consumption profile for particleboard production at 5,556 of the 8,564 MJ/$m^3$ (65%). Extraction of resources and residue and resin production were dominated by fossil use (65%). Electricity use in particleboard production (A3) represented more than half (56%) of the total 3,587 MJ/$m^3$ energy for this phase. Natural gas use during particleboard production represented 22 percent of the total energy for A3 and the remainder picked by ancillary material use.

Treatment of biogenic carbon is consistent with the Intergovernmental Panel for Climate Change (IPCC 2006) inventory reporting framework in that there is no assumption that biomass combustion is carbon neutral, but that net carbon emissions from biomass combustion are accounted for under the Land-Use Change and Forestry (LUCF) Sector and are therefore ignored in energy emissions reporting for the product LCA to prevent double counting. Using this framework, 367 kg $CO_2$e were released in the production of 1 $m^3$ of particleboard (cradle-to-gate). That same 1 $m^3$ of particleboard stores 346 kg of carbon or 1,268 kg $CO_2$e resulting in more carbon storage in the product then released during manufacturing. The scale for this credit far outweighs the global warming impacts caused by fossil fuel use within the cradle-to-gate product system for producing particleboard.

# 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 to for external review. The technical and editorial comments of the reviewers were carefully considered and, in most instances, incorporated into the final document. CORRIM addressed the internal review comments, as appropriate, and maintains a record of all comments and responses for future reference.

## 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 2006) and the Product Category Rules for North American Structural and Architectural Wood Products (FPInnvovations 2015). Following CORRIM's internal review evaluation, documents were submitted to UL Environment (ULE) for independent external review. The independent external review performed by ULE was conducted by James Mellentine, Ramboll.

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