WoodLife Environmental Consultants

# Cradle to Gate Life Cycle Assessment of North American Laminated Strand Lumber Production

Prepared for:
AWC – The American Wood Council

By:
CORRIM and WoodLife Environmental Consultants

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## Glossary of Terms[1]

***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***[2] - 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)***[3] – 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***[4] – A set of criteria that specifies which unit processes are part of a product system (adapted from ISO 104044)

[1] Baumann, H. and A-M. Tillman. 2004. The Hitch Hiker's Guide to LCA – An orientation in life cycle assessment methodology and application. Studentlitteratur AB, Lund, Sweden
[2] FP Innovations. Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD), For North American Structural and Architectural Wood Products June 2015.
[3] FP Innovations. Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD), For North American Structural and Architectural Wood Products. June 2015.
[4] FP Innovations. Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD), For North American Structural and Architectural Wood Products. June 2015.

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## Acronyms and Abbreviations

| | |
|---|---|
| CORRIM | Consortium for Research on Industrial Renewable Materials |
| Cubic foot | $ft^3$ |
| Cubic meter | $m^3$ |
| ECD | Emission Control Device |
| EFB | Electrified Filter Beds |
| EPDs | Environmental Product Declarations |
| FBC | Fluidized Bed Combustors |
| GWP | Global Warming Potential |
| ISO | International Organization for Standardization |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| LPG | Liquid Propane Gas |
| LSL | Laminated Strand Lumber |
| MDI | Methylene Diphenyl di-isocyanate resin |
| NE-NC | Northeast and north central regions of the United States |
| OSB | Oriented Strand Board |
| PCR | Product Category Rules |
| TOS | Thermal Oil System |
| TRACI | Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts |
| USDA | United States Department of Agriculture |
| VOCs | Volatile Organic Compounds |

## Addendum

This report was updated in November 2015 to comply with the updated Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015). All references to previous PCR version (FPInnovations 2015) have been updated. In accordance with the 2015 version of the PCR, an economic allocation LCA for LSL was required. Results are located in Appendix 12 of this report. In addition, there was a change made to renewable (solar, wind, hydroelectric, and geothermal) energy in Table 16 for mass allocation which is different from July 2015 release of this report.

# 1 Introduction

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.) The life cycle inventory data start 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 average North American production of Laminated Strand Lumber (LSL). Wood resources inputs for LSL production are sourced from the Northeast-North central U.S. and central Canada regions. The LCI data were used to conduct life cycle impact assessments (LCIA) using the North American impact method, TRACI 2.1 (Version 1.01 TRACI implementation in Simapro) (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare et al. 2011). The LCI and LCIA are in conformance with Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015) and ISO 14040/14044 standards (ISO 2006). This report follows data and reporting requirements as outlined in the PCR and will provide the guidance for preparation of North American wood product EPD's.

In recent years there has been a growing recognition that consumption of products affects both resources and the environment and that the manufacturing of a product impacts the environment, beginning with the extraction of raw materials, through processing, subsequent manufacturing, use and disposal, as well as all necessary transportation. Forest land owners and product manufacturers are facing increased environmental regulations and competition in the marketplace. The forest sector as a whole is challenged with re-thinking how they grow, manage, and produce products to efficiently meet expectations set forth by environmental regulations, government policies, and the public. These challenges provide an opportunity for change and create future "green" marketing opportunities. It is within this framework, that the American Wood Council (AWC) commissioned CORRIM to produce a cradle to gate LCA of North American Laminated Strand Lumber production.

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 LSL ready to be shipped at the mill gate.

As defined by the International Organization for Standardization (ISO 2006), 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 particular study.

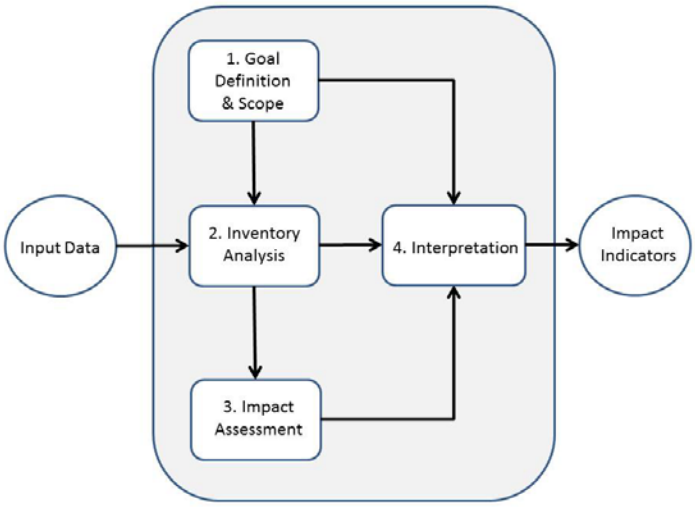


**Figure 1 Steps involved in a life cycle assessment**

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, carcinogenics, respiratory effects, eutrophication, ozone depletion, ecotoxicity, and smog. For assessing the environmental impacts of LSL production the TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) impact method was used. TRACI is a midpoint oriented LCIA methodology developed by the U.S. Environmental Protection Agency specifically for the U.S. using input parameters consistent with U.S. locations (Bare 2011). TRACI is available through the LCA software used for modeling LSL process (http://www.pre-sustainability.com/simapro).

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 in order to reach conclusions and recommendations. This final step in a 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 back to the inventory to determine which environmental flows are contributing to the high value, and which unit processes contribute to those outputs. This is also used as a form of *quality control*, and the results can be used to refine the scope definition to focus on the more important unit processes. This step also supports arriving at more certain conclusions and supportable recommendations.

# 2 Description of Product

Laminated strand lumber (LSL) is a structural building material that belongs to the general category of engineered wood products and to the more specific group of structural composite lumber. It is engineered to be stronger and demonstrate less variability in wood quality than solid sawn lumber of the same species, and therefore can easily serve as a substitute product for a wide variety of residential construction applications where traditional lumber is used. Most commonly LSL is used in headers and beams, wall stud applications, roof beams and rafters, truss chords, rim board, and stair stringers (Figure 2). It can be made from smaller diameter, low quality trees with the primary species used in North America being a mixture of aspen, birch, and maple. The material properties of LSL are dependent on the density of the panel, the strand species, and the orientation of strands.

**Figure 2 Specific applications for LSL in residential construction**

LSL uses small veneers cut directly from whole logs with an appearance similar to that of oriented strand board (Figure 3). The wood veneers are glued and compressed to form panels up to 3-1/2 inches (90-mm) thick. Waterproof adhesives are used in the manufacture of LSL. An isocyanate type of adhesive is sprayed on the strands and cured by steam injection. The manufacturing process starts with the whole log, excluding the bark, which is processed through the rotating knives of a stranding machine. LSL uses 8" to 10" strands. Strands that do not meet dimensional specifications are screened out and used as fuel for the production process. The longer length strands run parallel to the finished product's length. The strands are bonded together using a waterproof "formaldehyde free" adhesive which is sprayed onto the strands as they tumble inside a rotating drum. LSL panels are formed when the resins are cured with steam and pressure in a stationary steam injection press. The dryer and press remove moisture, producing an even density gradient all the way through the panels. Because moisture levels are carefully controlled through the manufacturing process, LSL has a 7 to 10 percent moisture content (dry basis). Production is measured on volume (cubic feet $ft^3$ or cubic meters $m^3$) at varying thicknesses, widths, and lengths (Table 1). The production of LSL is evaluated according to ASTM D 5456-07 – *Standard specifications for evaluation of structural composite lumber product* - which includes other structural composite lumber products such as laminated veneer lumber and parallel strand lumber (USDA 2010).

**Figure 3 Laminated Strand Lumber (LSL)**

**Table 1 Specifications and sizing for LSL**

| Use | Product specifications |
|---|---|
| Thickness | 1-1/2”, 1-3/4”, 3-1/2” |
| Widths | 3-1/2”, 4-3/8”, 5-1/2”, 7-1/4”, 8-5/8”, 9-1/4”, 9-1/2, 11-1/4, 11-7/8”, 14”, 18”, 20”, 22”, 24” |
| Grades | 1.35E, 1.55E, 1.75E |
| Framing | Same as lumber sizes |
| End sealed | Edges and ends are sealed for additional moisture protection |
| Moisture content | 7-10% (dry basis) |

## 2.1 Study goals and scope

The goal of this work is to determine energy and material inputs and outputs associated with the production of laminated strand lumber (LSL) representing average manufacturing practices in the U.S. and Canada. The data were obtained through a scientifically sound and consistent process established by the Consortium for Research on Renewable Industrial Materials (CORRIM), following ISO14040/140444 standards (ISO 2006) and Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015).

The scope of this study was to develop a cradle to gate LCA for the production of LSL from wood resources using practices and technology common to North America for LSL feedstock and manufacturing sectors. It covers the impacts in terms of input materials, fuels, and electricity through to the outputs of product, co-products, and emissions. Wood resources used in LSL production are obtained from hardwood logs from the northeast-north central (NE-NC) United States and Central Canadian regions. Data for the LCI are based on manufacturing gate to gate inputs and outputs surveyed directly from LSL mills and previous published data for cradle to gate forest resources LCI’s (Oneil et al. 2010, Athena 2012).

## 2.2 Intended audience

The primary audience for the LCA report is AWC – American Wood Council and the North American LSL mills.

## 2.3 Comparative assertions

The report does not consider how the wood was used which requires a comparison to the impact of substitute products. If future comparative studies are intended and disclosed to the public an internal critical review would be required to be consistent with the ISO 14040/44:2006 guidelines and principles and compliance with the Wood Products PCR (FPInnovations 2015).[5]

## 2.4 Functional and declared unit

In accordance with the PCR (FPInnovations 2015), the declared unit for LSL is one cubic meter (1.0 $m^3$). 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 cubic foot is equal to 0.02832 cubic meters. All input and output data were allocated to the declared unit of product based on the mass of products and co-products in accordance with International Organization for Standardization (ISO) protocol (ISO 2006). As the analysis does not take the declared unit to the stage of being an installed building product no service life is assigned.

## 2.5 System Boundaries

The system boundary begins with the planting, growth and harvest of trees in the NE-NC US and central Canada (Oneil et al. 2010, Athena 2012) and ends with LSL packaged to leave the mill gate (Figure 4). The production stage for LSL includes an extraction module ($A_1$), a transportation module ($A_2$), and a manufacturing module ($A_3$) (Figure 4). The extraction module includes forest regeneration and stand management, if any, felling the trees with a feller buncher, processing the trees by removing limbs, and cutting to shipping lengths, and transportation of logs to landing using a skidder. Excluded from the extraction module are maintenance and repair of equipment, and building and maintenance of logging roads, logging camps, and weigh stations. The transportation of logs ($A_2$) from the woods to the mill is accounted for with the LSL manufacturing ($A_3$) (Figure 4). The LSL manufacturing module ($A_3$) was modeled as a multi- unit process separating log yard operations and primary log breakdown with the production and final packaging of the LSL product. Outputs to the system boundary include 1 $m^3$ of LSL ready to be shipped, air and water emissions, solid waste and co-products. The co-products are no longer tracked once they leave the system boundary.

[5] If the LCA is used to develop an Environmental Product Declaration (EPD), internal and/or external critical review would be required.

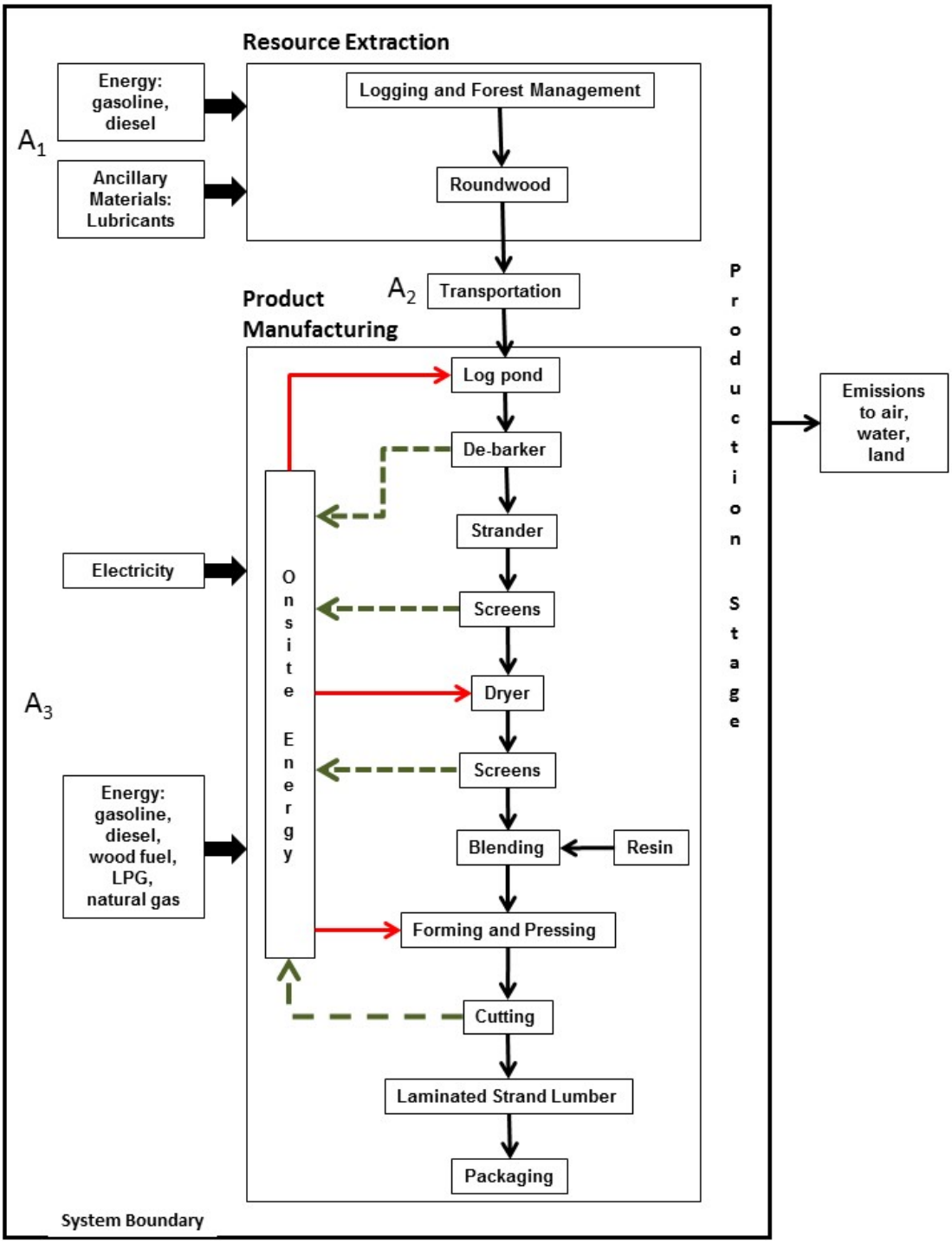


**Figure 4 Cradle to gate life cycle stages for Laminated Strands Lumber.**

## 2.6 Description of data/Process Description

### 2.6.1 Resource harvesting

Forest growth and harvesting system process begins in the forest and include the forestry activities that are customary to central Canada and NE-NC U.S. (Athena 2012, Oneil et al. 2010) and may include activities such as thinning, fertilizations, seedling growth, and replanting or natural regeneration and harvesting of trees. In most cases natural regeneration is used for the species used for LSL. The tree is cut down manually using a chainsaw, or mechanically using a harvester or feller-buncher. Tops and limbs are removed and then the log is cut to optimal length (bucking). The logs are them moved from the stump to the landing by skidders where they are loaded on trucks destined for the mill. Fuel consumption and energy use for all steps leading up to and including forest harvesting were calculated using the weighted average of LSL production in each region (Table 2).

**Table 2 Weighted average fuel consumption for regional hardwood forest resource management processes used in LSL.**

| Fuel | Unit | Fuel Consumption per m3 |
|---|---|---|
| Diesel | L | 4.4333 |
| Gasoline | L | 0.2446 |
| Lubricants | L | 0.1207 |
| LPG | L | 0.0332 |
| Electricity | kWh | 0.2090 |

### 2.6.2 Wood Product Manufacturing

The LSL manufacturing process is highly automated, process-controlled and fairly linear as illustrated in Figure 5. Once the logs reach the mill, the manufacturing process of LSL begins with a whole log, which is de-barked and then processed through the rotating knives of a stranding machine. Strands are screened, dried, and screened again in preparation for the bonding process. The strands are bonded together using a waterproof, urea formaldehyde free adhesive sprayed on the strands in a rotating drum. The strand/resin/adhesive mixture is cured using steam and pressure, and then the LSL panels are cut to size and receive a protective end or edge seal before packaging and shipping. All flow analyses of wood and bark in the process were determined on an oven-dry weight basis and a green specific gravity[6] of 0.39.

[6] Green specific gravity uses oven dry mass and green volume of the wood resource.

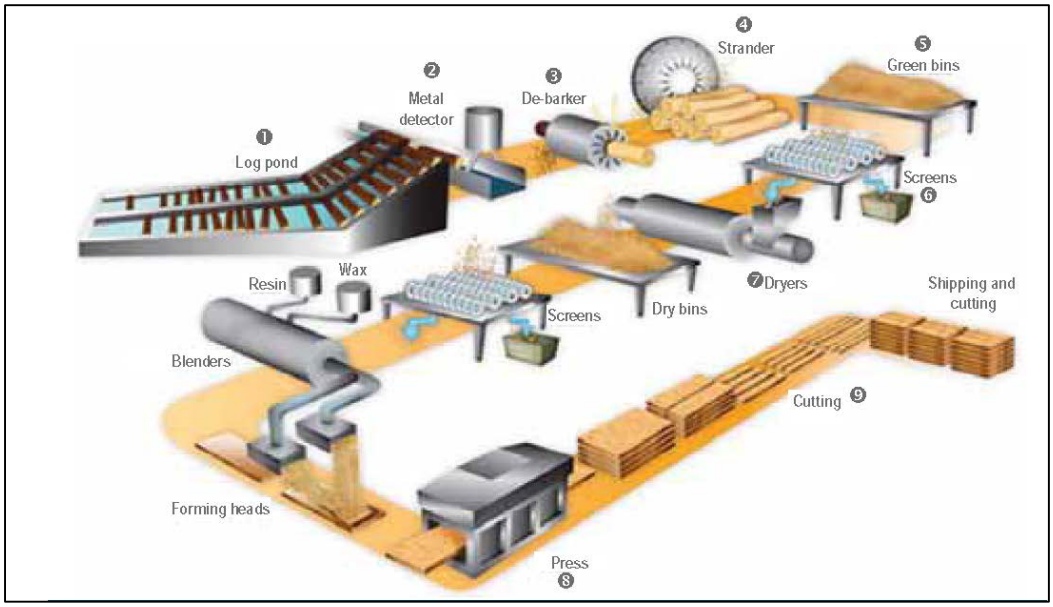


**Figure 5 Process flow for the production of LSL**

### *2.6.2.1 Transportation Process*

Hauling is the first process of product manufacturing (Figure 4). Logs are transported from the forest landing to LSL mill by truck. The average haul distance for logs is 225 km by truck and 161 km rail. The one-way delivery distances for logs, resin, and wax are shown in Table 3. These distances are weighted averages of the production of LSL (by volume produced) from survey data.

**Table 3 Average delivery distance (one-way) for materials to LSL mill, North American average.**

| Material delivered to mill | Delivery Distance | |
|---|---|---|
| | **km** | **miles** |
| **Hardwood Logs** | | |
| Truck | 225 | 140 |
| Rail | 161 | 100 |
| **Resin** | | |
| Truck | - | - |
| Rail | 2,712 | 1,685 |
| **Wax** | | |
| Truck | 1,422 | 884 |
| Rail | 372 | 231 |

### *2.6.2.2 Heat Energy*

Energy for the production of LSL comes from wood waste/hogged fuel and natural gas. Other fuels such as diesel, liquid propane gas (LPG), and gasoline are used to operate transport equipment within the mill. Electricity is used to operate equipment within the plant, including conveyors, refiners, fan motors, hydraulic press motors, sanders, pumps and emission control systems. Electricity is used throughout the process. The natural gas is used for start-up of Fluidized Bed Combustors (FBC) and supplemental heat for Thermal Oil System (TOS). Wood fuels are used for FBC that supply heat to dryers and TOS.

Emission control devices (ECD) such as cyclones, bag-houses and Electrified Filter Bed (EFB) are used throughout the LSL manufacturing process. These emission control devices are used to reduce particulate and chemical emissions with a trade-off of having greater electricity use to operate the ECD's. Electricity use for ECD is roughly 2% of the total mill use.

Wood fuel is the primary heating source used in the LSL process; it is used for providing process heat for drying strands, heating steam or oil for log ponds, and hot pressing. Wood fuel is mainly in the form of bark, wet and dry wood waste obtained after screening, and particulates collected in bag-houses. Bark and wood waste for energy generation was converted to oven dry moisture content, dry basis representing 20.9 MJ/kg of energy. The wood-based fuel mix was 47% wet wood waste, and 53% dry wood waste. The total fuel used for onsite process heat is 7,141 MJ/$m^3$ of which 99% is generated through the combustion of wood fuel (Table 4) and the other 1 % is from natural gas.

**Table 4 Onsite heat inputs per 1 $m^3$ LSL, North American average.**

| Fuel | Unit | Value (Unit/$m^3$) | HHV (MJ/kg) | MJ/$m^3$ of product |
|---|---|---|---|---|
| Wood waste, wet[7], oven dry | kg | 159.39 | 20.9 | 3,331.21 |
| Wood waste, dry, oven dry | kg | 179.39 | 20.9 | 3,756.47 |
| Natural gas[8] | $m^3$ | 1.39 | 54.4 | 52.93 |
| TOTAL Heat Energy – at LSL | MJ | - | - | 7,140.61 |

#### *2.6.2.3 Electricity and Fuel Use*

The source of fuel used to generate the electricity used in the manufacturing process helps determines the type and amount of impact in the overall LCA. The proportional breakdown of electricity used for the LSL by fuel source is given in Table 5.

**Table 5 Electricity fuel breakdown for LSL production**

| Electricity generation | Percent Contribution |
|---|---|
| Coal (bituminous) | 14.2% |
| Biomass (liquid, solid, gas) | 3.6% |
| Fuel oil | 2.6% |
| Hydropower | 12.9% |
| Natural gas | 35.6% |
| Nuclear | 29.5% |
| Solar and Wind | 0.5% |
| Other | 1.1% |

#### *2.6.2.4 Receiving, Log Pond, Debarking, and Stranding*

Round logs are delivered to the mill in long (tree length) form or shorter bolts ranging from 2.5-2.6 meters (8.2-8.5 feet) long. Wood is unloaded by large mobile equipment and stacked in the wood yard in a "first in first out" inventory method. Many mills have chosen to pave their wood yards in order to meet air-borne dust requirements or to reduce the quantity of dirt and grit entering the process. If the wood is

[7] Includes bark

[8] Density of natural gas 0.70 kg/$m^3$

tree length it is cut to shorter pieces either before or after debarking. Mills in the north typically utilize hot ponds to raise the temperature of the wood to about 20°C (68°F) prior to debarking. Debarking is done either by ring or drum debarkers and the bark is used by the mills as fuel or sold as a byproduct. The bolts of wood then move to the stranders which reduce them to thin strands 0.8-1.3mm (0.03-0.05 inches) thick, 300-330mm (11.8-13.0 inches) long, and 19-38mm (0.75-1.5 inches) wide. Some mills have disc screens installed after the stranders to remove small unacceptable particles before drying. These small particles are used for fuel or sold. The acceptable strands then go to the green bins (Boehner, 2014). Approximately 26% of the mills total electricity use is consumed in the log ponds, debarker, and strander.

#### *2.6.2.5 Drying and Screening*

Strands are fed from the green bins to the dryers to reduce their moisture content. Depending on the species, green moisture content can range from 50% to over 100%, OD basis. The dryers reduce the moisture content of strands to less than 2 or 3%. The emissions from the dryers contain water, small wood particles, and volatile organic compounds (VOC's). The dryers in the LSL process are usually single pass rotary drum dryers. The dryer inlet temperature can range from 300-500°C (572-932 °F). Heated air is blown through the mass of strands until the desired moisture content is achieved which typically takes 20-25 minutes. Dry strands are sent to a dry storage bin where they are further processed by primary and secondary screens to sort them by size which are stored in separate bins. Undersized and otherwise unsuitable strands are sent to either the OSB storage bin or to the dry biomass storage bin for use as fuel. This process creates a significant amount of particulate matter which comprises much of the dry biomass fuel. OSB strands are sold and shipped to an OSB manufacturer (Boehner 2014). Drying and screening consume 14% of the mills total electricity use.

#### *2.6.2.6 Blending*

Screened strands are sent to rotary drum blenders where droplets of adhesive and wax are applied to the strand surfaces. Either a wax emulsion or slack wax (molten wax) is applied using spray nozzles. The adhesive is almost always MDI (methylene diphenyl diisocyanate). MDI is listed on the US Environmental Agency (EPA) Toxics Release Inventory[9]. For Canada[10], MDIs are a mandatory reporting substance when it is present at concentrations greater than 0.1%. Adhesive content is usually between 3-5%, and wax content is about 1% both being based on the ovendry weight of wood. The strands exit the blenders and are sent the forming bins (Boehner 2014). Less than 2% of mill electricity use is consumed during blending.

#### *2.6.2.7 Forming*

The blended furnish is fed onto conveyors at the infeed to the forming bin. These conveyors move from one side of the forming bin to the other in a regular motion. The purpose is to ensure uniform mass distribution side-to-side in the forming bins. The forming bins feed strands onto "orienteers" whose purpose is to orient the strands in the long direction of the product (machine direction). All strands in the composite are oriented in this direction. Mechanical weigh scales can be used to determine the variability of the mass distribution in both the machine and cross-machine directions. After the mat is formed a release agent is sprayed on the surfaces of the mat just before it enters the press to prevent it sticking to the press platens (Boehner 2014). Electricity use for forming was less than 2% of the total mill electricity use.

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[9] US Environmental Protection Agency, Toxics Release Inventory. http://www.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals. Accessed January 2016

[10] Environment Canada. Rick Mangement Scope for Methylenediphenyl diisocyantes (MDI). http://ec.gc.ca/ese-ees/7DDFCE16-9CF9-4D80-B797-81CB7EFEA195/RM%20Scope_Groupings-MDIs_EN.pdf. Accessed January 2016.

#### 2.6.2.8 Hot pressing

The LSL process uses a single opening steam injection press which allows the efficient curing of adhesive in thick products. A steam injection press has heated platens similar to an OSB hot press. Platen temperature is maintained between 375°C and 410°C (707°F - 770°F) by circulating hot oil through a labyrinth built into the platen. However, the unique feature of steam injection pressing is that the internal structure of the platens contains a second separate labyrinth of channels which allow the circulation of steam through the platen. The injection of steam allows extremely fast curing of the adhesive. Since LSL thicknesses greater than 75mm are commonly made the cycle times would be excessive if hot presses were used without the steam injection feature. Once the adhesive is sufficiently cured the press opens and the billet (product) is removed (Boehner 2014). Pressing requires about 10% of the mills total electricity use.

#### 2.6.2.9 Trimming, sanding, and packaging

After cooling, the billets are stacked for further processing. Depending on customer requirements finishing can be as simple as trimming the edges and ends, strapping, and shipping. Other products might require sanding (one or both sides), cutting to typical dimension lumber sizes, or cutting to special sizes requested by the customer. All trim and sander dust is usually used as fuel, but could be sold as a byproduct. Rejected billets are either sold at a discount or broken into small pieces and used as fuel. Packing materials represent only 0.73% of the cumulative mass of the model flow (Table 6). The wooden spacers make up the bulk of this mass, representing 86 percent of the total packaging material. The wrapping material, strap protectors, and strapping made up, 8, 4, and 2 percent of the packaging by mass. Fork lifts are used to load trucks or rail cars for shipping (Boehner 2014). Finishing the product for shipping consumes 14% of the mills total electricity use.

**Table 6 Materials used in packaging and shipping per $m^3$ LSL, North American average.**

| Material | Value | Unit |
|---|---|---|
| Wrapping Material – HDPE and LDPE laminated paper | 0.4601 | kg |
| PET Strapping | 0.0834 | kg |
| Cardboard strap protectors | 0.2002 | kg |
| Wooden spacers | 4.6721 | kg |

# 3 Cut-off rules

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). Under Title III of the Clean Air Act Amendments of 1990, the EPA has designated six HAPs that wood products facilities are required to report as surrogates for all HAPs. These are methanol, acetaldehyde, formaldehyde, propionaldehyde (propanal), acrolein, and phenol. If applicable to the wood product, all HAPS are reported in Table 12 (cut-off rule does not apply) and would be included in the impact assessment. Table 12 shows all air emissions to $10^{-4}$ to simplify and report on the dominant releases by mass. There were no cut-offs used in the impact assessment therefore a complete list of all air emissions (smaller than $10^{-4}$) is located in Section 13 (Appendix) of this report.

# 4 Data sources and averaging

The LCA for LSL contains two main system processes: 1) forest management and harvesting and 2) LSL production. Primary and secondary data is used in both systems. This section provides a brief description of the primary and secondary data sources used to complete the LCA.

## 4.1 Primary and secondary data sources

Forest management and harvesting LCI data was used in this study were derived from earlier studies (Athena 2012, Oneil et al. 2010). The original data included a weighted average of various harvesting and forest management methods used in both the NE-NC and central Canadian hardwood forest types in each region. The forestry system from each of these regions was weighted averaged to represent a common forestry system for LSL production.

Resource transportation for LSL mills was by diesel tractor-trailer truck or diesel locomotive. The LCA incorporated an appropriate diesel tractor-trailer and diesel locomotive LCI from the US LCI database (https://www.lcacommons.gov/nrel/) based on transportation distances and mass of logs for each mill location.

## 4.2 Data quality requirements

This study collected data from representative laminated strand lumber manufacturers in North America that use average technology for their regions. Primary data for the LCI were collected through surveys in accordance with CORRIM and ISO 14040 standards. The production facilities surveyed were selected to be representative of North American production practices. The mills provided data on a 2013 production year. The participating plants also provided information and data on the use of resins, wax, fuels, energy consumption, electricity use, and ancillary inputs (e.g. lubricants, oils, greases, packaging, paints, etc.). In 2013 the weighted average LSL capacity for North America was 316,456 $m^3$ (11,175,527 $ft^3$). Table 7 shows the secondary LCI data sources used in this LCA study.

## 4.3 Assumptions and limitations

Assumptions were made for the extraction of the wood resource. Databases with similar technology and geographical regions were used and adapted for LSL (Table 7). Primary data were not collected for the MDI resin. Data available in the USLCI was used, which has been adapted from Europe. Future work with engineered wood products that use MDI resin types should warrant a resin production survey for North America. Other data assumptions and substitutions are listed in Table 7.

**Table 7 Secondary LCI data sources used.**

| Technosphere Input | LCI data Source | Publication date |
|---|---|---|
| Diesel truck | USLCI data for "Transport, combination truck, diesel powered/US" | 2008 |
| Diesel locomotive | USLCI data for "Transport, train, diesel powered/US" | 2008 |
| Electricity | USLCI data for "Electricity, at Grid, NPCC, 2008/RNA U" | 2008 |
| Forestry and Harvesting | CORRIM data for NE-NC forestry operation; Athena data for central Canadian forestry operation adapted for OSB production | 2010, 2012 |
| Hydraulic fluid, Lubricants, motor oil, thermal fluid | USLCI data for "Gasoline, at refinery/l/US" without combustion emissions. | 2008 |
| MDI resin | USLCI data for "Methylene diphenyl diisocyanate, resin, at plant, CTR". | 2010 |
| Slack Wax | CORRIM data for Slack wax obtained from the USLCI | 2004 |
| Propane | USLCI data for "Liquefied petroleum gas, combusted in industrial boiler/US". Combustion emission removed if mill reported emissions | 2008 |
| Gasoline | USLCI data for "Gasoline, combusted in equipment/US". Combustion emission removed if mill reported emissions | 2008 |
| Diesel | USLCI data for "Diesel, combusted in industrial equipment/US." Combustion emission removed if mill reported emissions | 2008 |
| Natural gas | USLCI data for "Natural gas, processed, at plant/US." Combustion emission removed if mill reported emissions | 2008 |
| Release agent | EcoInvent data for potassium hydroxide modified for US electricity and energy. "Potassium hydroxide, at regional storage/RER U" | 2005 |

# 5 Life cycle inventory analysis

## 5.1 Data collection and calculation methods

Primary data for the LCI was collected through surveys in accordance with CORRIM and ISO 14040 protocols. This study relied almost exclusively on production inputs and emissions data provided by LSL producers in North America, with some secondary data from the US LCI database. All allocation was based on the mass of the products and co-products.

Laminated strand lumber is most commonly reported in cubic feet or cubic meters[11]. 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 database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 8+ (Pré Consultants 2012) was used as the accounting program to track all of the materials.

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

$w_1$ = weighing factor for LSL mill 1

[11] 1 cubic meter = 35.31467 cubic feet

$Y_{total}$ = total annual production of "y" LSL mills

$y_1$ = LSL annual production of Mill 1

$y_2$ = LSL annual production of Mill 2

$y_3$ = LSL 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 LSL 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.

All wood flows in the LSL process were determined on an oven-dry (OD) basis. Many coproducts are produced in the primary log breakdown and are reported both on dry and wet basis. The following formulas were applied to prepare the mass balance. The mass balance for LSL was within 2% of the wood input and output.

$$\%\ Moisture\ content\ (\ dry\ basis) = \frac{weight\ of\ water\ in\ wood}{weight\ of\ oven-dry\ \ wood}\ x\ 100 \qquad eq.2$$

$$\%\ Moisture\ content\ (\ wet\ basis) = \frac{weight\ of\ water\ in\ wood}{weight\ of\ wet\ wood}\ x\ 100 \qquad eq.3$$

$$\%\ Moisture\ content\ dry\ basis = \frac{MC\ wet\ basis}{100 - MC\ wet\ basis} x\ 100 \qquad eq.4$$

Table 8 provides a weighted average mass balance for North American LSL manufacturing per cubic meter ($m^3$) of LSL. The mass balance indicates that approximately 55% of the raw resource input ends up in LSL. Wood fuel for heat energy used onsite represents about 32% and sold OSB furnish and finished product represent approximately 8.3%. The remaining 4.7% is from bark and ash that is landfilled, and fuel sold.

**Table 8 Wood mass balance for North American LSL manufacturing per cubic meter of LSL.**

| Input/Output | Oven dry weight of wood, weighted average ($kg/m^3$) | Percent contribution |
|---|---|---|
| **Wood Input** | | |
| Roundwood with bark | 1036.41 | |
| **Wood Output** | | |
| LSL Finished Product | 570.28 | 55.02% |
| OSB Finished Product | 25.14 | 2.43% |
| OSB Furnished | 61.14 | 5.90% |
| Bark to Landfill | 13.50 | 1.30% |
| Ash to Landfill | 9.75 | 0.94% |
| Non-structural sold | 1.41 | 0.14% |

| | | |
|---|---|---|
| Hogged fuel green, sold | 16.26 | 1.57% |
| Hogged fuel dry, sold | 7.68 | 0.74% |
| Dust | 0.26 | 0.02% |
| Wood fuel used onsite | 331.00 | 31.94% |
| | 1036.41 | 100% |

## 5.2 Allocation Rules

If one or more co-products are generated during the production process, it is necessary to allocate the inputs and outputs using a standardized approach. The LCA on LSL follows the allocation rules in the PCR (FPInnovation 2015) which states that when the total revenues between the main product and co-products is more than 10%, allocation shall be based on the revenue [economic] allocation. The 10% rule is applied based on a per unit basis, in this case per $m^3$ of LSL. To ensure comparability with previous CORRIM wood product LCA's (http://www.corrim.org/pubs/reports.asp) this report also presents results based on mass allocation. Mass allocation results can be found in subsequent sections, while economic allocation results are located in Appendix 12 of this report.

## 5.3 Gate-to-gate LCI of LSL manufacturing production system

Table 9 and Table 10 summarize the gate-to-gate LCI flows associated with North American LSL production. These flows are linked to the upstream processes for forestry operations, transportation, fuels, and electricity to calculate a complete cradle to gate profile for LSL. The inputs and outputs were modeled in SimaPro.

**Table 9 Unit process inputs/outputs primary log breakdown, 1 $m^3$ of LSL, North American average (Mass allocation).**

| Inputs/Outputs | Value | Unit/$m^3$ | Allocation |
|---|---|---|---|
| **Inputs** | | | |
| Electricity | 79.47 | kWh | |
| Wood fuel | 82.75 | kg | |
| Transport diesel truck | 85.25 | tkm | |
| Transport diesel train | 262.51 | tkm | |
| Roundwood | 2.30 | $m^3$ | |
| **Outputs (Products/co-products)** | | | |
| Strands | 570.28 | kg | 55% |
| OSB flakes, sold | 61.14 | kg | 6% |
| OSB flakes, to OSB | 25.14 | kg | 2% |
| Bark to landfill | 13.50 | kg | 1% |
| Ash to landfill | 9.75 | kg | 1% |
| Non Structural sold | 1.41 | kg | 0% |
| Hogged fuel sold | 23.90 | kg | 3% |
| Dust | 0.26 | kg | 0% |
| Wood fuel used onsite | 330.99 | kg | 32% |

From the primary log breakdown, 32% of log was used for generating heat energy on site at the LSL mills. When mass allocation was applied, 96% of the wood fuel was assigned to the product (Table 10). When an economic allocation was applied, 100% of the wood fuel was assigned to the LSL product.

**Table 10 Gate to gate weighed average LCI flows of 1 $m^3$ of LSL production, North American[12] (Mass allocation).**

| Inputs | Value | Unit/$m^3$ | Allocation |
|---|---|---|---|
| **Material/Fuels** | | | |
| Wood fuel, dry | 275.25 | kg | |
| OSB flakes, to OSB | 25.14 | kg | |
| Strands | 570.28 | kg | |
| Resin | 34.18 | kg | |
| Slack wax | 2.88 | kg | |
| Electricity | 238.41 | kWh | |
| Liquefied petroleum gas | 10.11 | L | |
| Gasoline | 0.10 | L | |
| Diesel | 3.18 | L | |
| Natural gas | 1.46 | m3 | |
| Liquefied petroleum gas | 0.08 | L | non combustion emissions |
| Diesel | 1.99 | L | non combustion emissions |
| Transport diesel truck | 3.23 | tkm | Transport wax |
| Transport diesel train | 92.68 | tkm | Transport resin |
| Transport diesel train | 0.22 | tkm | Transport wax |
| Hydraulic fluid | 0.08 | L | |
| Oils and grease | 0.01 | L | |
| Motor oil | 0.04 | L | |
| Thermal fluid | 1.60 | L | |
| Dunnage | 0.01 | $m^3$ | |
| Packaging materials | 1.00 | p | |
| Release agent | 1.17 | kg | |
| **Water Use** | **Value** | **Unit/$m^3$** | **Comments** |
| Water municipal | 146.41 | L | |
| Water well | 11.89 | L | |
| **Outputs** | | | |
| **Products and Co-products** | **Value** | **Unit/$m^3$** | **Comments** |
| Laminated Strand Lumber | 1.00 | $m^3$ | 95.78 |
| Oriented Strand Board | 25.14 | kg | 4.22% |
| **Emissions to Air[13]** | **Value** | **Unit/$m^3$** | **Comments** |
| Carbon dioxide, biogenic | 607.2080 | kg | Calculated based on percent of fuel used |
| Carbon dioxide, fossil | 4.5084 | kg | Calculated based on percent of fuel used |
| Carbon monoxide | 0.8865 | kg | |
| Methane | 0.0003 | kg | |
| Methane, biogenic | 0.0345 | kg | |
| Nitrogen oxides | 0.2461 | kg | |

[12] Based on data provided by North American LSL mills for 2013 reference year
[13] On-site process and fuel combustion only as reported by mills

| | | | |
|---|---|---|---|
| Sulfur dioxide | 0.0544 | kg | |
| Particulates, < 2.5 um | 0.1360 | kg | |
| Particulates, < 10 um | 0.1747 | kg | |
| Wood (dust) | 0.3284 | kg | |
| VOC, volatile organic compounds | 0.3430 | kg | |
| Methanol | 0.0766 | kg | |
| Formaldehyde | 0.0264 | kg | |
| Acetaldehyde | 0.0092 | kg | |
| Propionaldehyde | 0.0027 | kg | |
| Acrolein | 0.0011 | kg | |
| Phenol | 0.0033 | kg | |
| Methylene diisocyanate | 0.0043 | kg | |
| **Waste to Treatment** | | | |
| Wood waste | 9.9980 | kg | |
| Wood ash, to fertilizer | 10.4804 | kg | |
| Metal | 0.3572 | kg | |
| Plastic strapping | 0.0064 | kg | |
| Cardboard | 0.0284 | kg | |
| Wrapping paper | 0.0505 | kg | |

## 5.4 Life Cycle Inventory Results – Mass Allocation

Life cycle inventory results for LSL are presented for two life stages, 1) forestry operations and 2) LSL production (Table 11 -Table 14). The majority of the raw material energy consumption occurs during LSL production with only a very small portion arising from forestry operations. Raw material energy requirements are presented in Table 11 for 1 $m^3$ of LSL. Air emissions are reported in Table 12, water emissions are reported in Table 13 and solid waste emissions are reported in Table 14.

**Table 11 Raw material energy consumption per 1 $m^3$ of LSL, North American average (Mass allocation).**

| Fuel | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| | kg/$m^3$ | | |
| Coal, in ground | 33.9711 | 0.4879 | 33.4832 |
| Gas, natural, in ground | 30.5517 | 0.3434 | 30.2083 |
| Oil, crude, in ground | 44.6209 | 8.9749 | 35.6460 |
| Uranium oxide, in ore | 0.0032 | 0.0000 | 0.0031 |
| Uranium, in ground | 0.0000 | 0.0000 | 0.0000 |
| Wood waste | 339.1232 | 0.0000 | 339.1232 |

**Table 12 Air emissions released per 1 $m^3$ of LSL, North American average (Mass allocation).**

| Air Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| | kg/$m^3$ | | |
| Carbon dioxide, biogenic | 5.88E+02 | 7.54E-03 | 5.88E+02 |
| Carbon dioxide, fossil | 2.66E+02 | 2.82E+01 | 2.38E+02 |
| Carbon dioxide | 1.82E+00 | 0.00E+00 | 1.82E+00 |
| Sulfur dioxide | 1.26E+00 | 1.63E-02 | 1.24E+00 |
| Nitrogen oxides | 1.18E+00 | 1.30E-01 | 1.05E+00 |
| Carbon monoxide | 1.10E+00 | 3.45E-05 | 1.10E+00 |
| Carbon monoxide, fossil | 7.69E-01 | 3.47E-01 | 4.22E-01 |
| Methane | 5.56E-01 | 3.83E-02 | 5.18E-01 |
| Methane, fossil | 4.25E-01 | 3.11E-03 | 4.22E-01 |
| VOC, volatile organic compounds | 3.94E-01 | 6.53E-03 | 3.88E-01 |
| Wood (dust) | 3.15E-01 | 0.00E+00 | 3.15E-01 |
| Particulates, < 10 um | 2.04E-01 | 0.00E+00 | 2.04E-01 |
| Particulates, < 2.5 um | 1.40E-01 | 0.00E+00 | 1.40E-01 |
| Sulfur oxides | 1.30E-01 | 2.72E-02 | 1.03E-01 |
| NMVOC, non-methane volatile organic compounds, unspecified origin | 1.11E-01 | 1.77E-02 | 9.32E-02 |
| Isoprene | 1.08E-01 | 1.89E-04 | 1.08E-01 |
| Methanol | 7.34E-02 | 0.00E+00 | 7.34E-02 |
| Particulates, unspecified | 6.09E-02 | 2.80E-03 | 5.81E-02 |
| Methane, biogenic | 3.30E-02 | 0.00E+00 | 3.30E-02 |
| Sulfur monoxide | 3.16E-02 | 1.94E-03 | 2.96E-02 |
| Particulates, > 2.5 um, and < 10um | 2.81E-02 | 2.83E-03 | 2.53E-02 |
| Formaldehyde | 2.55E-02 | 4.08E-05 | 2.55E-02 |
| TOC, Total Organic Carbon | 2.42E-02 | 0.00E+00 | 2.42E-02 |
| Hydrogen chloride | 1.82E-02 | 8.85E-04 | 1.73E-02 |
| Barium | 1.12E-02 | 0.00E+00 | 1.12E-02 |
| Ammonia | 9.79E-03 | 1.83E-04 | 9.61E-03 |
| BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio | 9.65E-03 | 1.41E-04 | 9.51E-03 |
| Acetaldehyde | 8.88E-03 | 2.55E-05 | 8.86E-03 |
| Organic substances, unspecified | 7.09E-03 | 1.31E-06 | 7.09E-03 |
| Dinitrogen monoxide | 4.67E-03 | 1.30E-04 | 4.54E-03 |
| Radionuclides (Including Radon) | 4.49E-03 | 2.22E-05 | 4.46E-03 |
| Methylene diisocyanate | 4.12E-03 | 0.00E+00 | 4.12E-03 |
| Toluene | 3.61E-03 | 1.36E-05 | 3.59E-03 |
| Phenol | 3.18E-03 | 1.71E-12 | 3.18E-03 |
| Propanal | 2.59E-03 | 4.07E-11 | 2.59E-03 |
| Benzene | 2.47E-03 | 3.13E-05 | 2.44E-03 |
| Hydrogen fluoride | 2.14E-03 | 3.20E-05 | 2.11E-03 |
| Xylene | 2.10E-03 | 9.47E-06 | 2.09E-03 |

| Air Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| | kg/m$^3$ | | |
| N-Nitrodimethylamine | 1.33E-03 | 0.00E+00 | 1.33E-03 |
| Aldehydes, unspecified | 1.16E-03 | 3.65E-04 | 7.98E-04 |
| Acrolein | 1.09E-03 | 3.14E-06 | 1.08E-03 |
| Hydrocarbons, unspecified | 9.67E-04 | 4.78E-06 | 9.62E-04 |
| Particulates, > 10 um | 2.95E-04 | 0.00E+00 | 2.95E-04 |
| Potassium | 2.81E-04 | 0.00E+00 | 2.81E-04 |
| Propene | 2.27E-04 | 8.57E-05 | 1.41E-04 |
| Metals, unspecified | 2.08E-04 | 2.14E-14 | 2.08E-04 |
| Ammonium chloride | 1.67E-04 | 8.28E-07 | 1.67E-04 |
| Magnesium | 1.64E-04 | 2.35E-06 | 1.61E-04 |
| PFC (perfluorocarbons) | 1.57E-04 | 0.00E+00 | 1.57E-04 |

[1/] Due to large amount of air emissions, total emissions less than $10^{-4}$ are not shown. A complete list of all air emissions can be found in Section 13.

Waterborne emissions listed in Table 13 are produced all off-site, no water emissions were reported by LSL mills.

**Table 13 Emissions to water released per 1 m$^3$ of LSL, North American average (Mass allocation).**

| Water Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| Chloride | 9.70E+00 | 1.22E+00 | 8.48E+00 |
| Suspended solids, unspecified | 6.83E+00 | 1.95E-01 | 6.63E+00 |
| Solved solids | 3.59E+00 | 1.40E+00 | 2.19E+00 |
| Sodium, ion | 1.66E+00 | 3.19E-01 | 1.34E+00 |
| Sodium | 1.46E+00 | 2.43E-02 | 1.43E+00 |
| Dissolved solids | 1.15E+00 | 0.00E+00 | 1.15E+00 |
| Sulfate | 4.89E-01 | 2.81E-03 | 4.86E-01 |
| Calcium | 4.60E-01 | 7.67E-03 | 4.52E-01 |
| Calcium, ion | 2.86E-01 | 1.01E-01 | 1.85E-01 |
| Heat, waste | 1.84E-01 | 0.00E+00 | 1.84E-01 |
| Barium | 1.69E-01 | 3.97E-02 | 1.29E-01 |
| Magnesium | 1.68E-01 | 2.12E-02 | 1.46E-01 |
| Lithium | 1.29E-01 | 2.83E-04 | 1.28E-01 |
| COD, Chemical Oxygen Demand | 1.00E-01 | 1.17E-02 | 8.84E-02 |
| BOD5, Biological Oxygen Demand | 5.47E-02 | 6.17E-03 | 4.86E-02 |
| Bromide | 4.90E-02 | 7.22E-03 | 4.18E-02 |
| Potassium, ion | 3.34E-02 | 0.00E+00 | 3.34E-02 |
| Iron | 2.89E-02 | 5.79E-03 | 2.31E-02 |
| Aluminum | 1.39E-02 | 2.90E-03 | 1.10E-02 |
| Strontium | 1.28E-02 | 1.84E-03 | 1.09E-02 |

| Water Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| Lithium, ion | 8.43E-03 | 1.70E-03 | 6.73E-03 |
| Silicon | 7.70E-03 | 0.00E+00 | 7.70E-03 |
| Sulfur | 7.53E-03 | 8.93E-05 | 7.44E-03 |
| Oils, unspecified | 6.20E-03 | 7.81E-04 | 5.42E-03 |
| Ammonia | 4.52E-03 | 6.30E-04 | 3.89E-03 |
| TOC, Total Organic Carbon | 1.33E-03 | 0.00E+00 | 1.33E-03 |
| Manganese | 1.07E-03 | 3.80E-05 | 1.03E-03 |
| Phosphate | 1.04E-03 | 0.00E+00 | 1.04E-03 |
| Fluoride | 9.18E-04 | 2.88E-06 | 9.15E-04 |
| Iron, ion | 9.07E-04 | 0.00E+00 | 9.07E-04 |
| Boron | 7.98E-04 | 1.06E-04 | 6.92E-04 |
| DOC, Dissolved Organic Carbon | 5.14E-04 | 3.73E-13 | 5.14E-04 |
| Silver | 4.80E-04 | 7.08E-05 | 4.09E-04 |
| Benzene | 3.85E-04 | 5.66E-05 | 3.29E-04 |
| Toluene | 3.64E-04 | 5.34E-05 | 3.11E-04 |
| Zinc | 3.42E-04 | 6.71E-05 | 2.74E-04 |
| Chromium | 2.60E-04 | 7.63E-05 | 1.84E-04 |
| Benzoic acid | 2.36E-04 | 3.42E-05 | 2.02E-04 |
| Detergent, oil | 2.06E-04 | 2.84E-05 | 1.78E-04 |
| Xylene | 1.92E-04 | 2.87E-05 | 1.63E-04 |
| Nitrate | 1.61E-04 | 4.09E-14 | 1.61E-04 |
| Solids, inorganic | 1.55E-04 | 9.38E-12 | 1.55E-04 |
| Nitrogen, total | 1.13E-04 | 4.40E-07 | 1.13E-04 |
| Sulfide | 1.09E-04 | 1.65E-06 | 1.07E-04 |
| Lead | 1.09E-04 | 1.94E-05 | 8.95E-05 |
| Titanium, ion | 1.07E-04 | 2.59E-05 | 8.08E-05 |

[1/] Due to large amount of water emissions, total emissions less than $10^{-4}$ are not shown. A complete list of all air emissions can be found in Section 13.

Solid emissions include ash generated at the boiler and in the upstream processes, including from primarily fuels and resins used in LSL production (Table 14). ***Onsite*** waste for producing LSL represented only 20 kg/m$^3$, or 60 percent of the total waste generated from cradle-to-gate.

**Table 14 Waste to treatment per 1 m$^3$ of LSL, North American average (Mass allocation).**

| Waste to treatment | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| | kg/m$^3$ | | |
| Solid waste[14] | 33.45 | 0.45 | 33.00 |

[14] Includes all waste generated cradle-to-gate from raw materials, resin, wax, chemicals, fuels, and electricity.

# 6 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 in Table 15. Environmental impacts are determined using the TRACI method (Bare et al. 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (FPInnovations 2015).

**Table 15 Selected impact indicators, characterization models, and impact categories.**

| Impact Indicator | Characterization Model | Impact Category |
|---|---|---|
| Greenhouse gas (GHG) emissions | Calculate total emissions in the reference unit of $CO_2$ equivalents for $CO_2$, methane, and nitrous oxide. | Global warming |
| Releases to air decreasing or thinning of ozone layer | Calculate the total ozone forming chemicals in the stratosphere including CFC's HCFC's, chlorine, and bromine. Ozone depletion values are measured in the reference units of CFC equivalents. | Ozone depletion |
| Releases to air potentially resulting in acid rain (acidification) | Calculate total sulfur dioxide equivalent for releases of acid forming chemicals such as sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of $SO_2$ is used as a reference unit. | Acidification |
| Releases to air potentially resulting in smog | Calculate total substances that can be photo-chemically oxidized. Smog forming potential of $O_3$ is used as a reference unit. | Photochemical smog |
| Releases to air potentially resulting in eutrophication of water bodies | Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq. is used as a reference unit. | Eutrophication |

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 that no single indicator is given more or less value than any of the others. All are presented as equals. 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. Table 15 provides the environmental impact by category for LSL. In addition, energy and material resource consumption values and the waste generated are also provided.

Environmental performance results for global warming potential (GWP), 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 Table 16. For GWP, 90 percent of the $CO_2$ equivalent emissions come from producing LSL. Similar results are presented for acidification, eutrophication, and smog, representing 94, 89, and 90 percent contributed to LSL production, respectively.

Renewable biomass fuels represented the greatest proportion of energy consumed (54%) for total cradle to gate primary energy use. Non-renewable fossil fuels represented 35% of the total primary energy. Non-

renewable nuclear and renewable (solar/hydro/wind/etc.) represented 9 and 1 percent of the total primary energy. Overall, the manufacture of LSL in North America is roughly 99% energy self-sufficient with its *on-site use* of renewable biomass. Producing 1 $m^3$ of LSL results in the production of 295 kg of greenhouse gases, on a $CO_2$ equivalent basis, of which 90 percent can be traced to the LSL production process. The calculated GWP is limited to anthropogenic emissions of fossil carbon and does not include biogenic emissions.

**Table 16 Environmental performance of 1 $m^3$ LSL, North American average (Mass allocation).**

| Impact category | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Global warming potential (GWP) | kg $CO_2$ eq | 294.51 | 29.31 | 265.19 |
| Acidification Potential | kg SO2 eq | 2.28 | 0.14 | 2.14 |
| Eutrophication Potential | kg N eq | 0.0672 | 0.0072 | 0.0600 |
| Ozone depletion Potential | kg CFC-11 eq | 3.41E-06 | 1.24E-09 | 3.41E-06 |
| Smog Potential | kg $O_3$ eq | 32.22 | 3.26 | 28.96 |
| Total Primary Energy | MJ | 13,054.88 | 446.62 | 12,608.27 |
| *Non-renewable fossil* | *MJ* | *4595.00* | *439.81* | *4155.19* |
| *Non-renewable nuclear* | *MJ* | *1202.92* | *5.94* | *1196.98* |
| *Renewable (solar, wind, hydroelectric, and geothermal)* | *MJ* | *155.62* | *0.85* | *154.77* |
| *Renewable, biomass* | *MJ* | *7090.07* | *0.00* | *7090.07* |
| **Material resources consumption (Non-fuel resources)** | **Unit** | **Total** | **Forestry Operations** | **LSL Production** |
| Non-renewable materials | kg | 14.96 | 0.00 | 14.96 |
| Renewable materials | kg | 874.92 | 874.92 | 0.00 |
| Fresh water | L | 172.73 | 0.00 | 172.73 |
| **Waste generated** | **Unit** | **Total** | **Forestry Operations** | **LSL Production** |
| Solid waste | kg | 33.45 | 0.45 | 33.00 |

# 7 Treatment of Biogenic Carbon

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. Standards such as ASTM D7612, which are used in North America to define legal, responsible and/or certified sources of wood materials, are in place to provide assurances regarding forest regeneration and sustainable harvest rates that serve as proxies to ensure stable carbon balances in the forest sector. They are outside the accounting framework for this LCA.

This approach to the treatment of biogenic carbon was taken for the Norwegian Solid Wood Product PCR (Aasestad 2008), and the North American PCR has adopted an identical approach to ensure comparability and consistency. 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. For a complete list of emissions factors for the GWP method used, see Bare et al. (2011). Using this method, 295 kg $CO_2$e were released in the production of 1 $m^3$ of LSL. That same 1 $m^3$ of LSL stores 285 kg of carbon[15] or 1,046 kg $CO_2$e resulting in more carbon storage in the product then released during manufacturing (cradle to gate) (Table 17).

**Table 17 Carbon per 1 $m^3$ LSL, North American average.**

| | **kg $CO_2$ equivalent** |
|---|---|
| released forestry operations | 29.31 |
| released LSL manufacturing | 265.19 |
| $CO_2$ eq. stored in product[16] | 1,045.51 |

# 8 Conclusions

The cradle to gate LCA for laminated strand lumber (LSL) includes: 1) the LCI of forest resources that relies on secondary and tertiary data and 2) LSL LCI that relies on primary survey data and secondary data for process inputs such as natural gas, diesel, and electricity. The survey results for LSL were representative of the North American average with wood inputs representing central Canada and NE-NC.

Emissions from the forest resources LCI are small relative to LSL manufacturing. At the LSL mill emissions originate during debarking, stranding, drying, sanding and sawing. They are mainly a function of the fuel combusting and resin use. Renewable biomass fuels substantially reduces the global warming potential form the LSL mills, but does not eliminate the mills total GWP contribution due to the use of fossil fuels directly or indirectly via electricity and fossil fuel use.

The TRACI impact method does not count the contribution of wood-derived $CO_2$ emissions from burning wood fuel in the boiler towards the global warming impact estimate. This is consistent with the current US EPA ruling on wood emissions from stationary sources which considers the $CO_2$ taken up by the forest ecosystem when the tree grew as balancing any $CO_2$ emissions when it is burned. Using this method, 295 kg $CO_2$e were released in the production of 1 $m^3$ of LSL. That same 1 $m^3$ of LSL stores 1,046 kg $CO_2$e. In summary, the LSL product attains a positive carbon balance in its production – a finding worthy of communicating to users of LSL.

Recommendations for continuing LCA coverage of laminated strand lumber include, but not limited to, 1) modeling use and end of life life cycle phases, 2) different wood species 3) investigate the influence substituting the use of renewable biomass fuel on fossil fuels and how this may effect coproduct supply to other wood products (e.g. particleboard, medium density fiberboard).

# 9 Acknowledgments

The manufacturing survey was made possible with the financial assistance of the American Wood Council. Our special thanks are extended to those companies and their employees that participated in the surveys to obtain production data. Upstream forest resource and resin data were developed with financial and technical assistance provided by the USDA Forest Service, Forest Products Laboratory (USFS (JV11111137-084&094)), and completed by CORRIM's University members with subsequent updates by

[15] Assuming a 50% carbon content
[16] Assuming 44/12 molecular weight ratio of $CO_2$/C

CORRIM under prior American Wood Council contracts. Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the contributing entities.

# 10 Critical Review

## 10.1 Internal Review

This LCA is a product of work done by CORRIM in accordance with its agreement with the American Wood Council (AWC). If the LCA is used to develop an Environmental Product Declaration (EPD), internal and/or external critical review is needed to ensure compliance with ISO and PCR requirements.

## 10.2 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 the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 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:

Wade Stout EPD Project Manager
UL Environment
UL LLC
2211 Newmarket Parkway, Suite 106
Marietta, GA 30067 USA
Mobile: 678.469.3598; Office: 678.444.4046

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 the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015).

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# 12 Economic allocation results

Laminated strand lumber is a single-output process and thus no allocation was applied to the manufacturing gate-to-gate process. The wood fiber input (logs with bark) was also treated in this manner. When using economic allocation, the total environmental burden of the cradle-to-gate LSL manufacturing system is allocated to the main product (LSL). Tables 18-21 and Table 23 summarize the main LCA results for the production of 1 cubic meter of LSL using economic allocation

## 12.1 Life Cycle Inventory Results

Life cycle inventory results for LSL are presented for two life stages, 1) forestry operations and 2) LSL production (Table 18 – 21, 23). The majority of the raw material energy consumption occurs during LSL production with only a very small portion arising from forestry operations. Raw material energy requirements are presented in Table 18 for 1 $m^3$ of LSL. Air emissions are reported in Table 19, water emissions are reported in Table 20, and solid waste emissions are reported in Table 21.

**Table 18 Raw material energy consumption per 1 $m^3$ of LSL, North American average (Economic allocation).**

| Fuel | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| | kg/$m^3$ | | |
| Coal, in ground | 35.9890 | 0.4879 | 35.5011 |
| Gas, natural, in ground | 31.8961 | 0.3434 | 31.5527 |
| Oil, crude, in ground | 46.5836 | 8.9749 | 37.6086 |
| Uranium, in ground | 0.0034 | 0.0000 | 0.0033 |
| Wood waste | 361.2626 | 0.0000 | 361.2626 |
| Coal, in ground | 35.9890 | 0.4879 | 35.5011 |

**Table 19 Air emissions released per 1 $m^3$ of LSL, North American average (Economic allocation).**

| Air Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| | kg/$m^3$ | | |
| Carbon dioxide, biogenic | 6.14E+02 | 7.54E-03 | 6.14E+02 |
| Carbon dioxide, fossil | 2.80E+02 | 2.82E+01 | 2.52E+02 |
| Carbon dioxide | 1.91E+00 | 0.00E+00 | 1.91E+00 |
| Sulfur dioxide | 1.33E+00 | 1.63E-02 | 1.31E+00 |
| Nitrogen oxides | 1.24E+00 | 1.30E-01 | 1.11E+00 |
| Carbon monoxide | 1.15E+00 | 3.45E-05 | 1.15E+00 |
| Carbon monoxide, fossil | 7.96E-01 | 3.47E-01 | 4.49E-01 |
| Methane | 5.87E-01 | 3.83E-02 | 5.48E-01 |
| Methane, fossil | 4.45E-01 | 3.11E-03 | 4.42E-01 |
| VOC, volatile organic compounds | 4.12E-01 | 6.53E-03 | 4.05E-01 |
| Wood (dust) | 3.28E-01 | 0.00E+00 | 3.28E-01 |
| Particulates, < 10 um | 2.13E-01 | 0.00E+00 | 2.13E-01 |
| Particulates, < 2.5 um | 1.46E-01 | 0.00E+00 | 1.46E-01 |
| Sulfur oxides | 1.36E-01 | 2.72E-02 | 1.09E-01 |
| NMVOC, non-methane volatile organic compounds, unspecified origin | 1.16E-01 | 1.77E-02 | 9.86E-02 |
| Isoprene | 1.15E-01 | 1.89E-04 | 1.15E-01 |
| Methanol | 7.66E-02 | 0.00E+00 | 7.66E-02 |
| Particulates, unspecified | 6.44E-02 | 2.80E-03 | 6.16E-02 |
| Methane, biogenic | 3.45E-02 | 0.00E+00 | 3.45E-02 |
| Sulfur monoxide | 3.33E-02 | 1.94E-03 | 3.14E-02 |

| Air Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| Particulates, > 2.5 um, and < 10um | 2.97E-02 | 2.83E-03 | 2.69E-02 |
| Formaldehyde | 2.66E-02 | 4.08E-05 | 2.66E-02 |
| TOC, Total Organic Carbon | 2.53E-02 | 0.00E+00 | 2.53E-02 |
| Hydrogen chloride | 1.92E-02 | 8.85E-04 | 1.84E-02 |
| Barium | 1.17E-02 | 0.00E+00 | 1.17E-02 |
| Ammonia | 1.02E-02 | 1.83E-04 | 1.00E-02 |
| BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio | 1.02E-02 | 1.41E-04 | 1.01E-02 |
| Acetaldehyde | 9.27E-03 | 2.55E-05 | 9.25E-03 |
| Organic substances, unspecified | 7.40E-03 | 1.31E-06 | 7.40E-03 |
| Dinitrogen monoxide | 4.92E-03 | 1.30E-04 | 4.79E-03 |
| Radionuclides (Including Radon) | 4.78E-03 | 2.22E-05 | 4.76E-03 |
| Methylene diisocyanate | 4.30E-03 | 0.00E+00 | 4.30E-03 |
| Toluene | 3.76E-03 | 1.36E-05 | 3.75E-03 |
| Phenol | 3.31E-03 | 1.71E-12 | 3.31E-03 |
| Propanal | 2.70E-03 | 4.07E-11 | 2.70E-03 |
| Benzene | 2.57E-03 | 3.13E-05 | 2.54E-03 |
| Hydrogen fluoride | 2.27E-03 | 3.20E-05 | 2.24E-03 |
| Xylene | 2.19E-03 | 9.47E-06 | 2.18E-03 |
| N-Nitrodimethylamine | 1.39E-03 | 0.00E+00 | 1.39E-03 |
| Aldehydes, unspecified | 1.21E-03 | 3.65E-04 | 8.50E-04 |
| Acrolein | 1.13E-03 | 3.14E-06 | 1.13E-03 |
| Hydrocarbons, unspecified | 1.03E-03 | 4.78E-06 | 1.03E-03 |
| Particulates, > 10 um | 3.08E-04 | 0.00E+00 | 3.08E-04 |
| Potassium | 2.93E-04 | 0.00E+00 | 2.93E-04 |
| Propene | 2.33E-04 | 8.57E-05 | 1.48E-04 |
| Metals, unspecified | 2.17E-04 | 2.14E-14 | 2.17E-04 |
| Ammonium chloride | 1.78E-04 | 8.28E-07 | 1.78E-04 |
| Magnesium | 1.73E-04 | 2.35E-06 | 1.71E-04 |
| PFC (perfluorocarbons) | 1.64E-04 | 0.00E+00 | 1.64E-04 |

Waterborne emissions listed in Table 20 are produced all off-site, no water emissions were reported by LSL mills.

**Table 20 Emissions to water released per 1 $m^3$ of LSL, North American average (Economic allocation).**

| Water Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| Chloride | 1.02E+01 | 1.22E+00 | 8.96E+00 |
| Suspended solids, unspecified | 7.20E+00 | 1.95E-01 | 7.01E+00 |
| Solved solids | 3.74E+00 | 1.40E+00 | 2.34E+00 |
| Sodium, ion | 1.73E+00 | 3.19E-01 | 1.41E+00 |
| Sodium | 1.54E+00 | 2.43E-02 | 1.51E+00 |
| Dissolved solids | 1.20E+00 | 0.00E+00 | 1.20E+00 |
| Sulfate | 5.12E-01 | 2.81E-03 | 5.10E-01 |
| Calcium | 4.85E-01 | 7.67E-03 | 4.77E-01 |
| Calcium, ion | 2.98E-01 | 1.01E-01 | 1.97E-01 |
| Barium | 1.76E-01 | 3.97E-02 | 1.37E-01 |
| Magnesium | 1.76E-01 | 2.12E-02 | 1.55E-01 |

| Water Emissions | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| Lithium | 1.36E-01 | 2.83E-04 | 1.35E-01 |
| COD, Chemical Oxygen Demand | 1.05E-01 | 1.17E-02 | 9.33E-02 |
| BOD5, Biological Oxygen Demand | 5.74E-02 | 6.17E-03 | 5.12E-02 |
| Bromide | 5.15E-02 | 7.22E-03 | 4.43E-02 |
| Potassium, ion | 3.49E-02 | 0.00E+00 | 3.49E-02 |
| Iron | 3.03E-02 | 5.79E-03 | 2.45E-02 |
| Aluminium | 1.46E-02 | 2.90E-03 | 1.17E-02 |
| Strontium | 1.34E-02 | 1.84E-03 | 1.16E-02 |
| Lithium, ion | 8.80E-03 | 1.70E-03 | 7.10E-03 |
| Silicon | 8.04E-03 | 0.00E+00 | 8.04E-03 |
| Sulfur | 7.87E-03 | 8.93E-05 | 7.78E-03 |
| Oils, unspecified | 6.51E-03 | 7.81E-04 | 5.72E-03 |
| Ammonia | 4.74E-03 | 6.30E-04 | 4.11E-03 |
| TOC, Total Organic Carbon | 1.39E-03 | 0.00E+00 | 1.39E-03 |
| Manganese | 1.13E-03 | 3.80E-05 | 1.09E-03 |
| Phosphate | 1.09E-03 | 0.00E+00 | 1.09E-03 |
| Fluoride | 9.71E-04 | 2.88E-06 | 9.68E-04 |
| Iron, ion | 9.47E-04 | 0.00E+00 | 9.47E-04 |
| Boron | 8.38E-04 | 1.06E-04 | 7.32E-04 |
| DOC, Dissolved Organic Carbon | 5.37E-04 | 3.73E-13 | 5.37E-04 |
| Silver | 5.05E-04 | 7.08E-05 | 4.34E-04 |
| Benzene | 4.05E-04 | 5.66E-05 | 3.48E-04 |
| Toluene | 3.83E-04 | 5.34E-05 | 3.29E-04 |
| Zinc | 3.59E-04 | 6.71E-05 | 2.91E-04 |
| Chromium | 2.72E-04 | 7.63E-05 | 1.95E-04 |
| Benzoic acid | 2.48E-04 | 3.42E-05 | 2.14E-04 |
| Detergent, oil | 2.17E-04 | 2.84E-05 | 1.89E-04 |
| Xylene | 2.01E-04 | 2.87E-05 | 1.72E-04 |
| Nitrate | 1.68E-04 | 4.09E-14 | 1.68E-04 |
| Solids, inorganic | 1.62E-04 | 9.38E-12 | 1.62E-04 |
| Nitrogen, total | 1.20E-04 | 4.40E-07 | 1.20E-04 |
| Lead | 1.14E-04 | 1.94E-05 | 9.48E-05 |
| Sulfide | 1.14E-04 | 1.65E-06 | 1.12E-04 |
| Titanium, ion | 1.11E-04 | 2.59E-05 | 8.54E-05 |
| Zinc, ion | 1.04E-04 | 0.00E+00 | 1.04E-04 |

Solid emissions include ash generated at the boiler and in the upstream processes, including from primarily fuels and resins used in LSL production (Table 21). ***Onsite*** waste for producing LSL represented only 21 kg/m$^3$, or 60 percent of the total waste generated from cradle-to-gate.

**Table 21 Waste to treatment per 1 $m^3$ of LSL, North American average (Economic allocation).**

| Waste to treatment | Total | Forestry Operations | LSL Production |
|---|---|---|---|
| | kg/$m^3$ | | |
| Solid waste[17] | 35.26 | 0.45 | 34.80 |

## 12.2 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 in Table 22. Environmental impacts are determined using the TRACI method (Bare et al. 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (FPInnovations 2015).

**Table 22 Selected impact indicators, characterization models, and impact categories.**

| Impact Indicator | Characterization Model | Impact Category |
|---|---|---|
| Greenhouse gas (GHG) emissions | Calculate total emissions in the reference unit of $CO_2$ equivalents for $CO_2$, methane, and nitrous oxide. | Global warming |
| Releases to air decreasing or thinning of ozone layer | Calculate the total ozone forming chemicals in the stratosphere including CFC's HCFC's, chlorine, and bromine. Ozone depletion values are measured in the reference units of CFC equivalents. | Ozone depletion |
| Releases to air potentially resulting in acid rain (acidification) | Calculate total sulfur dioxide equivalent for releases of acid forming chemicals such as sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of SO2 is used as a reference unit. | Acidification |
| Releases to air potentially resulting in smog | Calculate total substances that can be photo-chemically oxidized. Smog forming potential of $O_3$ is used as a reference unit. | Photochemical smog |
| Releases to air potentially resulting in eutrophication of water bodies | Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq. is used as a reference unit. | Eutrophication |

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 that no single indicator is given more or less value than any of the others. All are presented as equals. 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.

[17] Includes all waste generated cradle-to-gate from raw materials, resin, wax, chemicals, fuels, and electricity.

Table 23 provides the environmental impact by category for LSL. In addition, energy and material resource consumption values and the waste generated are also provided.

Environmental performance results for global warming potential (GWP), 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 Table 23. For GWP, 91 percent of the $CO_2$ equivalent emissions come from producing LSL. Similar results are presented for acidification, eutrophication, and smog, representing 94, 90, and 90 percent contributed to LSL production, respectively. Over all impacts, 91% came from LSL production and 9% from forestry operations.

Renewable biomass fuels represented the greatest proportion of energy consumed (55%) for total cradle to gate primary energy use. Non-renewable fossil fuels represented 56% of the total primary energy. Non-renewable nuclear and renewable (solar/hydro/wind/etc.) represented 9 and <1 percent of the total primary energy. Overall, the manufacture of LSL in North America is roughly 57% energy self-sufficient with its *on-site use* of renewable biomass. Producing 1 $m^3$ of LSL results in the production of 295 kg of greenhouse gases, on a $CO_2$ equivalent basis, of which 90 percent can be traced to the LSL production process. The calculated GWP is limited to anthropogenic emissions of fossil carbon and does not include biogenic emissions.

**Table 23 Environmental performance of 1 $m^3$ LSL, North American average (Economic allocation).**

| Impact category | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Global warming potential (GWP) | kg $CO_2$ eq | 310.28 | 29.31 | 280.97 |
| Acidification Potential | kg SO2 eq | 2.41 | 0.14 | 2.27 |
| Eutrophication Potential | kg N eq | 0.0709 | 0.0072 | 0.0637 |
| Ozone depletion Potential | kg CFC-11 eq | 3.41E-06 | 1.24E-09 | 3.41E-06 |
| Smog Potential | kg $O_3$ eq | 34.05 | 3.26 | 30.79 |
| Total Primary Energy | MJ | 13,832.63 | 446.63 | 13,386.00 |
| *Non-renewable fossil* | *MJ* | *4,810.87* | *439.81* | *4,371.06* |
| *Non-renewable nuclear* | *MJ* | *1,281.70* | *5.94* | *1,275.75* |
| *Renewable (solar, wind, hydroelectric, and geothermal)* | *MJ* | *165.83* | *0.85* | *164.99* |
| *Renewable, biomass* | *MJ* | *7,574.23* | *0.03* | *7,574.21* |
| **Material resources consumption (Non-fuel resources)** | **Unit** | **Total** | **Forestry Operations** | **LSL Production** |
| Non-renewable materials | kg | 17.00 | 0.00 | 17.00 |
| Renewable materials | kg | 877.98 | 877.98 | 0.00 |
| Fresh water | L | 178.09 | 0.00 | 178.09 |
| **Waste generated** | **Unit** | **Total** | **Forestry Operations** | **LSL Production** |
| Solid waste | kg | 35.26 | 0.45 | 34.80 |

## 12.3 Sensitivity analysis mass vs. economic allocation

Figure 6 graphically displays the two allocation methodologies side by side across the LCIA indicators reported in this study. Since a no allocation approach was used for the economic allocation the resulted in

a 5 – 7 percent increase over the impact categories compared to mass allocation. More of the environmental burden is allocated to LSL production and not to the co-products produced that leave the system boundary.

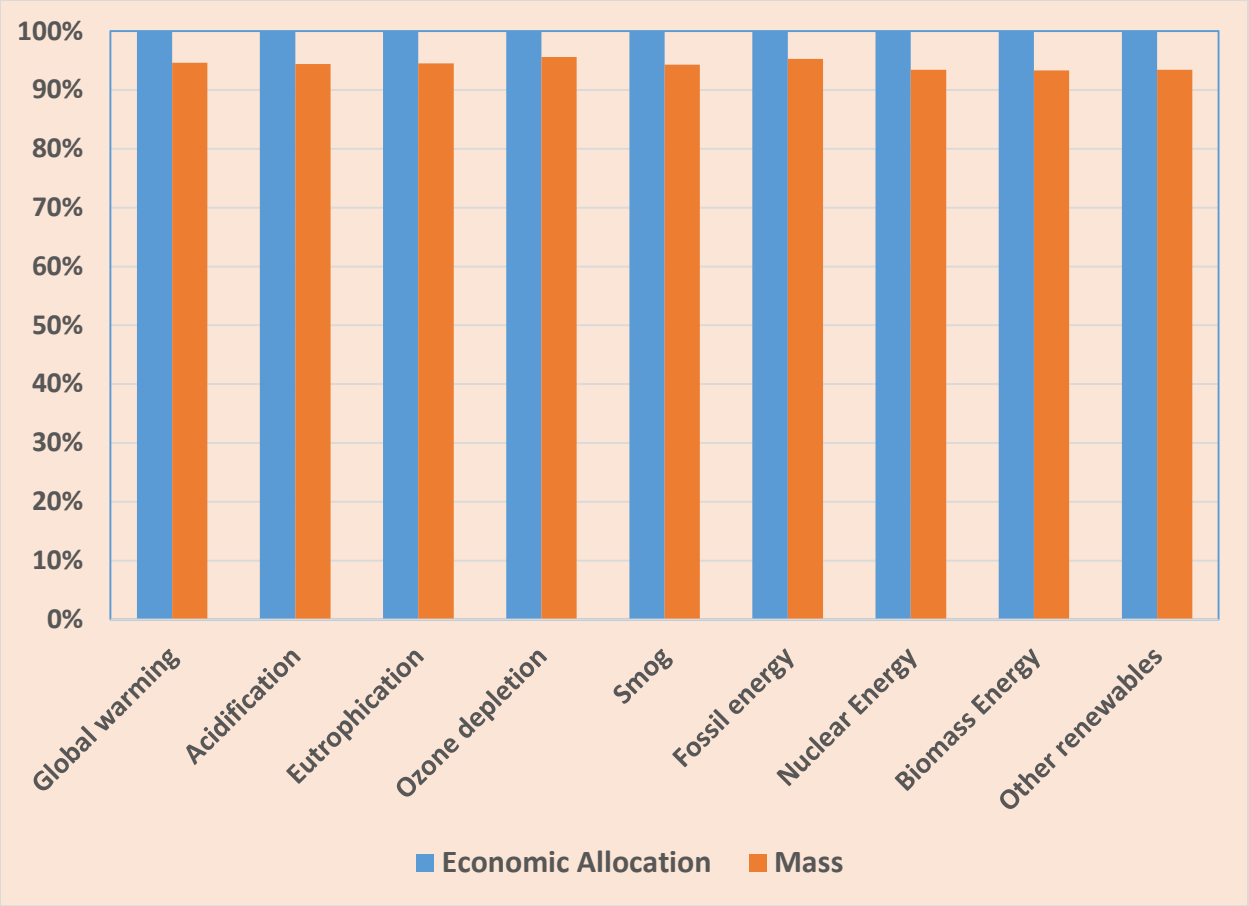


**Figure 6. Sensitivity Analysis Results - Mass vs. Economic Allocation**

# 13 Appendix

## 13.1 Air Emissions

**Table 24 Air emissions released per 1 $m^3$ of dry LSL North American average (Mass allocation).**

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| 1,4-Butanediol | kg | 2.54E-11 | 0.00E+00 | 2.54E-11 |
| 1-Butanol | kg | 9.19E-14 | 0.00E+00 | 9.19E-14 |
| 1-Pentanol | kg | 3.53E-14 | 0.00E+00 | 3.53E-14 |
| 1-Pentene | kg | 2.67E-14 | 0.00E+00 | 2.67E-14 |
| 1-Propanol | kg | 3.55E-12 | 0.00E+00 | 3.55E-12 |
| 2,4-D | kg | 1.31E-09 | 0.00E+00 | 1.31E-09 |
| 2-Aminopropanol | kg | 6.10E-15 | 0.00E+00 | 6.10E-15 |
| 2-Butene, 2-methyl- | kg | 5.91E-18 | 0.00E+00 | 5.91E-18 |
| 2-Chloroacetophenone | kg | 2.58E-09 | 7.50E-13 | 2.58E-09 |
| 2-Methyl-1-propanol | kg | 7.21E-14 | 0.00E+00 | 7.21E-14 |
| 2-Methyl-4-chlorophenoxyacetic acid | kg | 2.45E-11 | 0.00E+00 | 2.45E-11 |
| 2-Nitrobenzoic acid | kg | 1.09E-14 | 0.00E+00 | 1.09E-14 |
| 2-Propanol | kg | 4.75E-07 | 0.00E+00 | 4.75E-07 |
| 5-methyl Chrysene | kg | 3.16E-10 | 4.70E-12 | 3.12E-10 |
| Acenaphthene | kg | 7.33E-09 | 1.09E-10 | 7.22E-09 |
| Acenaphthylene | kg | 3.59E-09 | 5.34E-11 | 3.54E-09 |
| Acetaldehyde | kg | 8.88E-03 | 2.55E-05 | 8.86E-03 |
| Acetic acid | kg | 1.13E-06 | 0.00E+00 | 1.13E-06 |
| Acetochlor | kg | 1.82E-08 | 0.00E+00 | 1.82E-08 |
| Acetone | kg | 6.10E-07 | 0.00E+00 | 6.10E-07 |
| Acetonitrile | kg | 2.33E-10 | 0.00E+00 | 2.33E-10 |
| Acetophenone | kg | 5.53E-09 | 1.61E-12 | 5.53E-09 |
| Acrolein | kg | 1.09E-03 | 3.14E-06 | 1.08E-03 |
| Acrylic acid | kg | 1.23E-09 | 0.00E+00 | 1.23E-09 |
| Alachlor | kg | 1.79E-09 | 0.00E+00 | 1.79E-09 |
| Aldehydes, unspecified | kg | 1.16E-03 | 3.65E-04 | 7.98E-04 |
| Aluminium | kg | 4.24E-05 | 0.00E+00 | 4.24E-05 |
| Ammonia | kg | 9.79E-03 | 1.83E-04 | 9.61E-03 |
| Ammonium carbonate | kg | 8.64E-11 | 0.00E+00 | 8.64E-11 |
| Ammonium chloride | kg | 1.67E-04 | 8.28E-07 | 1.67E-04 |
| Aniline | kg | 2.90E-13 | 0.00E+00 | 2.90E-13 |
| Anthracene | kg | 3.02E-09 | 4.48E-11 | 2.97E-09 |
| Anthranilic acid | kg | 7.97E-15 | 0.00E+00 | 7.97E-15 |
| Antimony | kg | 3.67E-07 | 3.84E-09 | 3.64E-07 |
| Arsenic | kg | 7.70E-06 | 6.08E-07 | 7.09E-06 |
| Arsine | kg | 1.43E-14 | 0.00E+00 | 1.43E-14 |
| Ash | kg | 2.55E-05 | 0.00E+00 | 2.55E-05 |
| Atrazine | kg | 3.54E-08 | 0.00E+00 | 3.54E-08 |
| Barium | kg | 1.12E-02 | 0.00E+00 | 1.12E-02 |
| Bentazone | kg | 1.44E-10 | 0.00E+00 | 1.44E-10 |
| Benzal chloride | kg | 6.59E-17 | 0.00E+00 | 6.59E-17 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Benzaldehyde | kg | 1.22E-10 | 0.00E+00 | 1.22E-10 |
| Benzene | kg | 2.47E-03 | 3.13E-05 | 2.44E-03 |
| Benzene, 1,2-dichloro- | kg | 2.36E-13 | 0.00E+00 | 2.36E-13 |
| Benzene, 1-methyl-2-nitro- | kg | 9.39E-15 | 0.00E+00 | 9.39E-15 |
| Benzene, chloro- | kg | 8.10E-09 | 2.36E-12 | 8.09E-09 |
| Benzene, ethyl- | kg | 7.10E-07 | 1.01E-11 | 7.10E-07 |
| Benzene, hexachloro- | kg | 1.12E-10 | 0.00E+00 | 1.12E-10 |
| Benzene, pentachloro- | kg | 1.38E-11 | 0.00E+00 | 1.38E-11 |
| Benzo(a)anthracene | kg | 1.15E-09 | 1.71E-11 | 1.13E-09 |
| Benzo(a)pyrene | kg | 4.81E-09 | 8.11E-12 | 4.80E-09 |
| Benzo(b,j,k)fluoranthene | kg | 1.58E-09 | 2.35E-11 | 1.56E-09 |
| Benzo(g,h,i)perylene | kg | 2.74E-10 | 7.58E-13 | 2.73E-10 |
| Benzo(ghi)perylene | kg | 1.14E-10 | 5.01E-12 | 1.09E-10 |
| Benzyl chloride | kg | 2.58E-07 | 7.50E-11 | 2.58E-07 |
| Beryllium | kg | 7.20E-07 | 3.68E-07 | 3.52E-07 |
| Biphenyl | kg | 2.44E-08 | 3.63E-10 | 2.41E-08 |
| Boron | kg | 1.45E-06 | 0.00E+00 | 1.45E-06 |
| Boron trifluoride | kg | 1.96E-16 | 0.00E+00 | 1.96E-16 |
| Bromine | kg | 1.04E-07 | 0.00E+00 | 1.04E-07 |
| Bromoform | kg | 1.44E-08 | 4.18E-12 | 1.44E-08 |
| Bromoxynil | kg | 3.17E-10 | 0.00E+00 | 3.17E-10 |
| BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio | kg | 9.65E-03 | 1.41E-04 | 9.51E-03 |
| Butadiene | kg | 3.43E-06 | 1.30E-06 | 2.13E-06 |
| Butane | kg | 1.20E-05 | 0.00E+00 | 1.20E-05 |
| Butene | kg | 1.13E-07 | 0.00E+00 | 1.13E-07 |
| Butyrolactone | kg | 7.34E-12 | 0.00E+00 | 7.34E-12 |
| Cadmium | kg | 2.36E-06 | 3.94E-07 | 1.97E-06 |
| Calcium | kg | 2.48E-06 | 0.00E+00 | 2.48E-06 |
| Carbofuran | kg | 2.71E-10 | 0.00E+00 | 2.71E-10 |
| Carbon dioxide | kg | 1.82E+00 | 0.00E+00 | 1.82E+00 |
| Carbon dioxide, biogenic | kg | 5.88E+02 | 7.54E-03 | 5.88E+02 |
| Carbon dioxide, fossil | kg | 2.66E+02 | 2.82E+01 | 2.38E+02 |
| Carbon dioxide, land transformation | kg | 1.12E-05 | 0.00E+00 | 1.12E-05 |
| Carbon disulfide | kg | 6.59E-06 | 1.39E-11 | 6.59E-06 |
| Carbon monoxide | kg | 1.10E+00 | 3.45E-05 | 1.10E+00 |
| Carbon monoxide, biogenic | kg | 2.85E-06 | 0.00E+00 | 2.85E-06 |
| Carbon monoxide, fossil | kg | 7.69E-01 | 3.47E-01 | 4.22E-01 |
| Chloramine | kg | 1.36E-13 | 0.00E+00 | 1.36E-13 |
| Chloride | kg | 3.30E-09 | 5.78E-12 | 3.30E-09 |
| Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified | kg | 1.91E-07 | 0.00E+00 | 1.91E-07 |
| Chlorine | kg | 2.96E-05 | 0.00E+00 | 2.96E-05 |
| Chloroacetic acid | kg | 2.92E-11 | 0.00E+00 | 2.92E-11 |
| Chloroform | kg | 2.29E-08 | 6.32E-12 | 2.28E-08 |
| Chlorosilane, trimethyl- | kg | 1.63E-10 | 0.00E+00 | 1.63E-10 |
| Chlorosulfonic acid | kg | 6.98E-14 | 0.00E+00 | 6.98E-14 |
| Chlorpyrifos | kg | 2.08E-09 | 0.00E+00 | 2.08E-09 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Chromium | kg | 8.45E-06 | 4.53E-07 | 8.00E-06 |
| Chromium VI | kg | 1.21E-06 | 1.69E-08 | 1.19E-06 |
| Chrysene | kg | 1.44E-09 | 2.14E-11 | 1.42E-09 |
| Cobalt | kg | 4.44E-06 | 1.79E-07 | 4.26E-06 |
| Copper | kg | 4.90E-06 | 7.26E-07 | 4.18E-06 |
| Cumene | kg | 5.38E-08 | 5.68E-13 | 5.38E-08 |
| Cyanazine | kg | 3.12E-10 | 0.00E+00 | 3.12E-10 |
| Cyanide | kg | 9.76E-07 | 2.68E-10 | 9.76E-07 |
| Cyanoacetic acid | kg | 5.72E-14 | 0.00E+00 | 5.72E-14 |
| Dicamba | kg | 1.84E-09 | 0.00E+00 | 1.84E-09 |
| Diethylamine | kg | 1.32E-13 | 0.00E+00 | 1.32E-13 |
| Dimethenamid | kg | 4.34E-09 | 0.00E+00 | 4.34E-09 |
| Dimethyl ether | kg | 3.27E-05 | 0.00E+00 | 3.27E-05 |
| Dimethyl malonate | kg | 7.17E-14 | 0.00E+00 | 7.17E-14 |
| Dinitrogen monoxide | kg | 4.67E-03 | 1.30E-04 | 4.54E-03 |
| Dioxin, 2,3,7,8 Tetrachlorodibenzo-p- | kg | 1.43E-09 | 1.26E-11 | 1.41E-09 |
| Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin | kg | 2.62E-18 | 0.00E+00 | 2.62E-18 |
| Dipropylamine | kg | 8.08E-14 | 0.00E+00 | 8.08E-14 |
| Dipropylthiocarbamic acid S-ethyl ester | kg | 2.97E-09 | 0.00E+00 | 2.97E-09 |
| Ethane | kg | 4.48E-05 | 0.00E+00 | 4.48E-05 |
| Ethane, 1,1,1,2-tetrafluoro-, HFC-134a | kg | 1.27E-06 | 0.00E+00 | 1.27E-06 |
| Ethane, 1,1,1-trichloro-, HCFC-140 | kg | 1.00E-08 | 8.44E-10 | 9.16E-09 |
| Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113 | kg | 5.83E-11 | 0.00E+00 | 5.83E-11 |
| Ethane, 1,1-difluoro-, HFC-152a | kg | 8.57E-11 | 0.00E+00 | 8.57E-11 |
| Ethane, 1,2-dibromo- | kg | 4.42E-10 | 1.29E-13 | 4.42E-10 |
| Ethane, 1,2-dichloro- | kg | 4.53E-08 | 4.29E-12 | 4.53E-08 |
| Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114 | kg | 1.72E-09 | 0.00E+00 | 1.72E-09 |
| Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123 | kg | 1.22E-06 | 0.00E+00 | 1.22E-06 |
| Ethane, chloro- | kg | 1.55E-08 | 4.50E-12 | 1.55E-08 |
| Ethane, hexafluoro-, HFC-116 | kg | 2.80E-08 | 0.00E+00 | 2.80E-08 |
| Ethanol | kg | 4.99E-08 | 0.00E+00 | 4.99E-08 |
| Ethene | kg | 4.68E-06 | 0.00E+00 | 4.68E-06 |
| Ethene, chloro- | kg | 1.93E-08 | 0.00E+00 | 1.93E-08 |
| Ethene, tetrachloro- | kg | 7.26E-07 | 7.76E-08 | 6.49E-07 |
| Ethene, trichloro- | kg | 4.51E-13 | 0.00E+00 | 4.51E-13 |
| Ethyl acetate | kg | 2.20E-06 | 0.00E+00 | 2.20E-06 |
| Ethyl cellulose | kg | 4.46E-09 | 0.00E+00 | 4.46E-09 |
| Ethylamine | kg | 8.87E-14 | 0.00E+00 | 8.87E-14 |
| Ethylene diamine | kg | 8.66E-13 | 0.00E+00 | 8.66E-13 |
| Ethylene dibromide | kg | 5.60E-08 | 0.00E+00 | 5.60E-08 |
| Ethylene oxide | kg | 1.98E-09 | 0.00E+00 | 1.98E-09 |
| Ethyne | kg | 7.13E-07 | 0.00E+00 | 7.13E-07 |
| Fluoranthene | kg | 1.02E-08 | 1.52E-10 | 1.01E-08 |
| Fluorene | kg | 1.31E-08 | 1.94E-10 | 1.29E-08 |
| Fluoride | kg | 2.02E-05 | 2.32E-08 | 2.02E-05 |
| Fluorine | kg | 1.31E-07 | 0.00E+00 | 1.31E-07 |
| Fluosilicic acid | kg | 2.80E-08 | 0.00E+00 | 2.80E-08 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Formaldehyde | kg | 2.55E-02 | 4.08E-05 | 2.55E-02 |
| Formamide | kg | 6.45E-14 | 0.00E+00 | 6.45E-14 |
| Formic acid | kg | 4.32E-09 | 0.00E+00 | 4.32E-09 |
| Furan | kg | 5.10E-10 | 9.78E-13 | 5.09E-10 |
| Glyphosate | kg | 3.91E-09 | 0.00E+00 | 3.91E-09 |
| Helium | kg | 3.06E-07 | 0.00E+00 | 3.06E-07 |
| Heptane | kg | 1.12E-06 | 0.00E+00 | 1.12E-06 |
| Hexane | kg | 2.66E-06 | 7.18E-12 | 2.66E-06 |
| Hydrazine, methyl- | kg | 6.25E-08 | 1.82E-11 | 6.25E-08 |
| Hydrocarbons, aliphatic, alkanes, cyclic | kg | 9.08E-10 | 0.00E+00 | 9.08E-10 |
| Hydrocarbons, aliphatic, alkanes, unspecified | kg | 5.80E-06 | 0.00E+00 | 5.80E-06 |
| Hydrocarbons, aliphatic, unsaturated | kg | 9.27E-07 | 0.00E+00 | 9.27E-07 |
| Hydrocarbons, aromatic | kg | 1.85E-06 | 0.00E+00 | 1.85E-06 |
| Hydrocarbons, chlorinated | kg | 2.39E-08 | 0.00E+00 | 2.39E-08 |
| Hydrocarbons, unspecified | kg | 9.67E-04 | 4.78E-06 | 9.62E-04 |
| Hydrogen | kg | 4.24E-05 | 0.00E+00 | 4.24E-05 |
| Hydrogen chloride | kg | 1.82E-02 | 8.85E-04 | 1.73E-02 |
| Hydrogen fluoride | kg | 2.14E-03 | 3.20E-05 | 2.11E-03 |
| Hydrogen peroxide | kg | 3.30E-09 | 0.00E+00 | 3.30E-09 |
| Hydrogen sulfide | kg | 6.34E-06 | 1.87E-13 | 6.34E-06 |
| Indeno(1,2,3-cd)pyrene | kg | 8.77E-10 | 1.30E-11 | 8.64E-10 |
| Iodine | kg | 6.21E-08 | 0.00E+00 | 6.21E-08 |
| Iron | kg | 9.60E-06 | 0.00E+00 | 9.60E-06 |
| Isocyanic acid | kg | 3.28E-09 | 0.00E+00 | 3.28E-09 |
| Isophorone | kg | 2.14E-07 | 6.21E-11 | 2.14E-07 |
| Isoprene | kg | 1.08E-01 | 1.89E-04 | 1.08E-01 |
| Isopropylamine | kg | 2.19E-14 | 0.00E+00 | 2.19E-14 |
| Kerosene | kg | 8.02E-05 | 3.96E-07 | 7.98E-05 |
| Lactic acid | kg | 6.33E-14 | 0.00E+00 | 6.33E-14 |
| Lead | kg | 1.17E-05 | 1.22E-06 | 1.05E-05 |
| Magnesium | kg | 1.64E-04 | 2.35E-06 | 1.61E-04 |
| Manganese | kg | 2.07E-05 | 9.12E-07 | 1.98E-05 |
| Mercaptans, unspecified | kg | 7.99E-05 | 2.19E-08 | 7.99E-05 |
| Mercury | kg | 4.69E-06 | 3.86E-07 | 4.31E-06 |
| Metals, unspecified | kg | 2.08E-04 | 2.14E-14 | 2.08E-04 |
| Methacrylic acid | kg | 5.11E-09 | 0.00E+00 | 5.11E-09 |
| Methane | kg | 5.56E-01 | 3.83E-02 | 5.18E-01 |
| Methane, biogenic | kg | 3.30E-02 | 0.00E+00 | 3.30E-02 |
| Methane, bromo-, Halon 1001 | kg | 5.91E-08 | 1.71E-11 | 5.91E-08 |
| Methane, bromochlorodifluoro-, Halon 1211 | kg | 1.27E-08 | 0.00E+00 | 1.27E-08 |
| Methane, bromotrifluoro-, Halon 1301 | kg | 3.17E-09 | 0.00E+00 | 3.17E-09 |
| Methane, chlorodifluoro-, HCFC-22 | kg | 1.58E-05 | 0.00E+00 | 1.58E-05 |
| Methane, chlorotrifluoro-, CFC-13 | kg | 2.87E-07 | 0.00E+00 | 2.87E-07 |
| Methane, dichloro-, HCC-30 | kg | 1.20E-05 | 4.09E-06 | 7.95E-06 |
| Methane, dichlorodifluoro-, CFC-12 | kg | 3.44E-09 | 1.04E-09 | 2.40E-09 |
| Methane, dichlorofluoro-, HCFC-21 | kg | 3.81E-13 | 0.00E+00 | 3.81E-13 |
| Methane, fossil | kg | 4.25E-01 | 3.11E-03 | 4.22E-01 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Methane, monochloro-, R-40 | kg | 1.95E-07 | 5.68E-11 | 1.95E-07 |
| Methane, tetrachloro-, CFC-10 | kg | 2.91E-06 | 1.04E-10 | 2.91E-06 |
| Methane, tetrafluoro-, CFC-14 | kg | 2.16E-07 | 0.00E+00 | 2.16E-07 |
| Methane, trichlorofluoro-, CFC-11 | kg | 6.19E-13 | 0.00E+00 | 6.19E-13 |
| Methane, trifluoro-, HFC-23 | kg | 1.21E-10 | 0.00E+00 | 1.21E-10 |
| Methanesulfonic acid | kg | 5.78E-14 | 0.00E+00 | 5.78E-14 |
| Methanol | kg | 7.34E-02 | 0.00E+00 | 7.34E-02 |
| Methyl acetate | kg | 2.52E-15 | 0.00E+00 | 2.52E-15 |
| Methyl acrylate | kg | 1.39E-09 | 0.00E+00 | 1.39E-09 |
| Methyl amine | kg | 2.69E-12 | 0.00E+00 | 2.69E-12 |
| Methyl borate | kg | 1.44E-14 | 0.00E+00 | 1.44E-14 |
| Methyl ethyl ketone | kg | 2.35E-06 | 4.18E-11 | 2.35E-06 |
| Methyl formate | kg | 5.42E-12 | 0.00E+00 | 5.42E-12 |
| Methyl lactate | kg | 6.95E-14 | 0.00E+00 | 6.95E-14 |
| Methyl methacrylate | kg | 2.27E-09 | 2.14E-12 | 2.27E-09 |
| Methylene diisocyanate | kg | 4.12E-03 | 0.00E+00 | 4.12E-03 |
| Metolachlor | kg | 1.44E-08 | 0.00E+00 | 1.44E-08 |
| Metribuzin | kg | 6.65E-11 | 0.00E+00 | 6.65E-11 |
| Molybdenum | kg | 1.26E-08 | 0.00E+00 | 1.26E-08 |
| Monoethanolamine | kg | 5.69E-08 | 0.00E+00 | 5.69E-08 |
| m-Xylene | kg | 3.58E-09 | 0.00E+00 | 3.58E-09 |
| Naphthalene | kg | 2.55E-06 | 3.77E-08 | 2.51E-06 |
| Nickel | kg | 4.74E-05 | 2.65E-06 | 4.47E-05 |
| Nickel compounds | kg | 1.57E-05 | 0.00E+00 | 1.57E-05 |
| Nitrate | kg | 1.86E-08 | 0.00E+00 | 1.86E-08 |
| Nitrobenzene | kg | 3.97E-13 | 0.00E+00 | 3.97E-13 |
| Nitrogen oxides | kg | 1.18E+00 | 1.30E-01 | 1.05E+00 |
| Nitrogen, total | kg | 1.76E-09 | 0.00E+00 | 1.76E-09 |
| Nitrous oxide | kg | 1.55E-05 | 0.00E+00 | 1.55E-05 |
| NMVOC, non-methane volatile organic compounds, unspecified origin | kg | 1.11E-01 | 1.77E-02 | 9.32E-02 |
| N-Nitrodimethylamine | kg | 1.33E-03 | 0.00E+00 | 1.33E-03 |
| Organic acids | kg | 6.15E-07 | 3.04E-09 | 6.12E-07 |
| Organic substances, unspecified | kg | 7.09E-03 | 1.31E-06 | 7.09E-03 |
| Ozone | kg | 1.09E-06 | 0.00E+00 | 1.09E-06 |
| PAH, polycyclic aromatic hydrocarbons | kg | 1.07E-05 | 1.64E-06 | 9.04E-06 |
| Paraquat | kg | 2.91E-10 | 0.00E+00 | 2.91E-10 |
| Parathion, methyl | kg | 2.19E-10 | 0.00E+00 | 2.19E-10 |
| Particulates, < 10 um | kg | 2.04E-01 | 0.00E+00 | 2.04E-01 |
| Particulates, < 2.5 um | kg | 1.40E-01 | 0.00E+00 | 1.40E-01 |
| Particulates, > 10 um | kg | 2.95E-04 | 0.00E+00 | 2.95E-04 |
| Particulates, > 2.5 um, and < 10um | kg | 2.81E-02 | 2.83E-03 | 2.53E-02 |
| Particulates, unspecified | kg | 6.09E-02 | 2.80E-03 | 5.81E-02 |
| Pendimethalin | kg | 1.49E-09 | 0.00E+00 | 1.49E-09 |
| Pentane | kg | 1.49E-05 | 0.00E+00 | 1.49E-05 |
| Permethrin | kg | 1.34E-10 | 0.00E+00 | 1.34E-10 |
| PFC (perfluorocarbons) | kg | 1.57E-04 | 0.00E+00 | 1.57E-04 |
| Phenanthrene | kg | 3.88E-08 | 5.76E-10 | 3.82E-08 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Phenol | kg | 3.18E-03 | 1.71E-12 | 3.18E-03 |
| Phenol, 2,4-dichloro- | kg | 3.38E-14 | 0.00E+00 | 3.38E-14 |
| Phenol, pentachloro- | kg | 5.78E-10 | 0.00E+00 | 5.78E-10 |
| Phenols, unspecified | kg | 5.35E-06 | 3.04E-06 | 2.31E-06 |
| Phorate | kg | 6.88E-11 | 0.00E+00 | 6.88E-11 |
| Phosphine | kg | 1.06E-12 | 0.00E+00 | 1.06E-12 |
| Phosphorus | kg | 1.03E-07 | 0.00E+00 | 1.03E-07 |
| Phthalate, diisooctyl- | kg | 1.86E-08 | 0.00E+00 | 1.86E-08 |
| Phthalate, dioctyl- | kg | 8.29E-09 | 7.82E-12 | 8.28E-09 |
| Platinum | kg | 4.30E-14 | 0.00E+00 | 4.30E-14 |
| Polychlorinated biphenyls | kg | 1.79E-10 | 0.00E+00 | 1.79E-10 |
| Polycyclic organic matter, unspecified | kg | 7.30E-07 | 0.00E+00 | 7.30E-07 |
| Potassium | kg | 2.81E-04 | 0.00E+00 | 2.81E-04 |
| Propanal | kg | 2.59E-03 | 4.07E-11 | 2.59E-03 |
| Propane | kg | 1.99E-05 | 0.00E+00 | 1.99E-05 |
| Propene | kg | 2.27E-04 | 8.57E-05 | 1.41E-04 |
| Propionic acid | kg | 1.24E-07 | 0.00E+00 | 1.24E-07 |
| Propylamine | kg | 2.04E-14 | 0.00E+00 | 2.04E-14 |
| Propylene oxide | kg | 1.34E-08 | 0.00E+00 | 1.34E-08 |
| Pyrene | kg | 4.74E-09 | 7.05E-11 | 4.67E-09 |
| Radionuclides (Including Radon) | kg | 4.49E-03 | 2.22E-05 | 4.46E-03 |
| Scandium | kg | 7.22E-09 | 0.00E+00 | 7.22E-09 |
| Selenium | kg | 2.10E-05 | 2.11E-06 | 1.89E-05 |
| Silicon | kg | 2.29E-05 | 0.00E+00 | 2.29E-05 |
| Silicon tetrafluoride | kg | 7.23E-10 | 0.00E+00 | 7.23E-10 |
| Silver | kg | 2.40E-10 | 0.00E+00 | 2.40E-10 |
| Simazine | kg | 9.43E-10 | 0.00E+00 | 9.43E-10 |
| Sodium | kg | 7.56E-06 | 0.00E+00 | 7.56E-06 |
| Sodium chlorate | kg | 7.89E-09 | 0.00E+00 | 7.89E-09 |
| Sodium dichromate | kg | 4.91E-10 | 0.00E+00 | 4.91E-10 |
| Sodium formate | kg | 5.66E-11 | 0.00E+00 | 5.66E-11 |
| Sodium hydroxide | kg | 1.23E-08 | 0.00E+00 | 1.23E-08 |
| Strontium | kg | 2.85E-07 | 0.00E+00 | 2.85E-07 |
| Styrene | kg | 1.23E-08 | 2.68E-12 | 1.23E-08 |
| Sulfate | kg | 1.63E-05 | 0.00E+00 | 1.63E-05 |
| Sulfur | kg | 4.41E-06 | 0.00E+00 | 4.41E-06 |
| Sulfur dioxide | kg | 1.26E+00 | 1.63E-02 | 1.24E+00 |
| Sulfur hexafluoride | kg | 1.27E-08 | 0.00E+00 | 1.27E-08 |
| Sulfur monoxide | kg | 3.16E-02 | 1.94E-03 | 2.96E-02 |
| Sulfur oxides | kg | 1.30E-01 | 2.72E-02 | 1.03E-01 |
| Sulfur trioxide | kg | 3.23E-12 | 0.00E+00 | 3.23E-12 |
| Sulfur, total reduced | kg | 1.98E-05 | 0.00E+00 | 1.98E-05 |
| Sulfuric acid | kg | 1.60E-07 | 0.00E+00 | 1.60E-07 |
| Sulfuric acid, dimethyl ester | kg | 1.77E-08 | 5.14E-12 | 1.77E-08 |
| Tar | kg | 3.71E-09 | 6.50E-12 | 3.71E-09 |
| t-Butyl methyl ether | kg | 1.36E-08 | 3.75E-12 | 1.36E-08 |
| t-Butylamine | kg | 6.05E-14 | 0.00E+00 | 6.05E-14 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Terbufos | kg | 2.35E-09 | 0.00E+00 | 2.35E-09 |
| Terpenes | kg | 1.94E-10 | 0.00E+00 | 1.94E-10 |
| Thallium | kg | 2.36E-09 | 0.00E+00 | 2.36E-09 |
| Thorium | kg | 2.69E-09 | 0.00E+00 | 2.69E-09 |
| Tin | kg | 5.74E-08 | 0.00E+00 | 5.74E-08 |
| Titanium | kg | 6.37E-07 | 0.00E+00 | 6.37E-07 |
| TOC, Total Organic Carbon | kg | 2.42E-02 | 0.00E+00 | 2.42E-02 |
| Toluene | kg | 3.61E-03 | 1.36E-05 | 3.59E-03 |
| Toluene, 2,4-dinitro- | kg | 1.03E-10 | 3.00E-14 | 1.03E-10 |
| Toluene, 2-chloro- | kg | 1.30E-13 | 0.00E+00 | 1.30E-13 |
| Trimethylamine | kg | 4.53E-15 | 0.00E+00 | 4.53E-15 |
| Tungsten | kg | 6.13E-10 | 0.00E+00 | 6.13E-10 |
| Uranium | kg | 3.57E-09 | 0.00E+00 | 3.57E-09 |
| Vanadium | kg | 3.15E-07 | 0.00E+00 | 3.15E-07 |
| Vinyl acetate | kg | 2.80E-09 | 8.14E-13 | 2.80E-09 |
| VOC, volatile organic compounds | kg | 3.94E-01 | 6.53E-03 | 3.88E-01 |
| Water | kg | 4.04E-05 | 0.00E+00 | 4.04E-05 |
| Wood (dust) | kg | 3.15E-01 | 0.00E+00 | 3.15E-01 |
| Xylene | kg | 2.10E-03 | 9.47E-06 | 2.09E-03 |
| Zinc | kg | 5.45E-06 | 4.84E-07 | 4.96E-06 |
| Zirconium | kg | 1.91E-10 | 0.00E+00 | 1.91E-10 |

## 13.2 Water Emissions

**Table 25 Emissions to water released per 1 $m^3$ of LSL North American average (Mass allocation).**

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| 1-Butanol | kg | 7.99E-09 | 1.60E-08 | 7.99E-09 |
| 1-Pentanol | kg | 8.47E-14 | 1.69E-13 | 8.47E-14 |
| 1-Pentene | kg | 6.40E-14 | 1.28E-13 | 6.40E-14 |
| 1-Propanol | kg | 1.82E-13 | 3.64E-13 | 1.82E-13 |
| 1,4-Butanediol | kg | 1.02E-11 | 2.03E-11 | 1.02E-11 |
| 2-Aminopropanol | kg | 1.53E-14 | 3.05E-14 | 1.53E-14 |
| 2-Hexanone | kg | 1.52E-06 | 2.82E-06 | 1.30E-06 |
| 2-Methyl-1-propanol | kg | 1.73E-13 | 3.46E-13 | 1.73E-13 |
| 2-Methyl-2-butene | kg | 1.42E-17 | 2.84E-17 | 1.42E-17 |
| 2-Methyl-4-chlorophenoxyacetic acid | kg | 1.05E-12 | 2.10E-12 | 1.05E-12 |
| 2-Propanol | kg | 1.90E-08 | 3.80E-08 | 1.90E-08 |
| 2,4-D | kg | 5.62E-11 | 1.12E-10 | 5.62E-11 |
| 4-Methyl-2-pentanone | kg | 9.60E-07 | 1.78E-06 | 8.18E-07 |
| Acenaphthene | kg | 3.14E-11 | 6.28E-11 | 3.14E-11 |
| Acenaphthylene | kg | 1.96E-12 | 3.92E-12 | 1.96E-12 |
| Acetaldehyde | kg | 1.46E-08 | 2.92E-08 | 1.46E-08 |
| Acetic acid | kg | 3.74E-08 | 7.47E-08 | 3.74E-08 |
| Acetochlor | kg | 7.78E-10 | 1.56E-09 | 7.78E-10 |
| Acetone | kg | 2.28E-06 | 4.23E-06 | 1.95E-06 |
| Acetonitrile | kg | 4.79E-14 | 9.58E-14 | 4.79E-14 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Acetyl chloride | kg | 6.65E-14 | 1.33E-13 | 6.65E-14 |
| Acid as H+ | kg | 6.89E-05 | 1.38E-04 | 6.89E-05 |
| Acidity, unspecified | kg | 6.54E-09 | 1.31E-08 | 6.54E-09 |
| Acids, unspecified | kg | 1.12E-05 | 2.24E-05 | 1.12E-05 |
| Acrylate, ion | kg | 2.91E-09 | 5.81E-09 | 2.91E-09 |
| Actinides, radioactive, unspecified | Bq | 4.42E-03 | 8.84E-03 | 4.42E-03 |
| Alachlor | kg | 7.66E-11 | 1.53E-10 | 7.66E-11 |
| Aluminium | kg | 1.39E-02 | 2.49E-02 | 1.10E-02 |
| Aluminum | kg | 7.53E-05 | 1.51E-04 | 7.53E-05 |
| Ammonia | kg | 4.52E-03 | 8.42E-03 | 3.89E-03 |
| Ammonia, as N | kg | 3.48E-08 | 6.96E-08 | 3.48E-08 |
| Ammonium, ion | kg | 4.03E-05 | 8.04E-05 | 4.01E-05 |
| Aniline | kg | 7.01E-13 | 1.40E-12 | 7.01E-13 |
| Antimony | kg | 9.06E-06 | 1.63E-05 | 7.25E-06 |
| Antimony-122 | Bq | 1.38E-05 | 2.75E-05 | 1.38E-05 |
| Antimony-124 | Bq | 1.20E-03 | 2.39E-03 | 1.20E-03 |
| Antimony-125 | Bq | 1.16E-03 | 2.32E-03 | 1.16E-03 |
| AOX, Adsorbable Organic Halogen as Cl | kg | 7.00E-08 | 1.40E-07 | 7.00E-08 |
| Arsenic | kg | 3.39E-05 | 6.72E-05 | 3.33E-05 |
| Arsenic, ion | kg | 2.71E-05 | 4.56E-05 | 1.85E-05 |
| Atrazine | kg | 1.52E-09 | 3.03E-09 | 1.52E-09 |
| Barite | kg | 5.38E-05 | 1.08E-04 | 5.38E-05 |
| Barium | kg | 1.69E-01 | 2.98E-01 | 1.29E-01 |
| Barium-140 | Bq | 6.03E-05 | 1.21E-04 | 6.03E-05 |
| Bentazone | kg | 6.19E-12 | 1.24E-11 | 6.19E-12 |
| Benzene | kg | 3.85E-04 | 7.14E-04 | 3.29E-04 |
| Benzene, 1-methyl-4-(1-methylethyl)- | kg | 2.28E-08 | 4.23E-08 | 1.94E-08 |
| Benzene, 1,2-dichloro- | kg | 3.41E-09 | 6.82E-09 | 3.41E-09 |
| Benzene, chloro- | kg | 7.04E-08 | 1.41E-07 | 7.04E-08 |
| Benzene, ethyl- | kg | 2.18E-05 | 4.04E-05 | 1.86E-05 |
| Benzene, pentamethyl- | kg | 1.71E-08 | 3.17E-08 | 1.46E-08 |
| Benzenes, alkylated, unspecified | kg | 7.81E-06 | 1.40E-05 | 6.22E-06 |
| Benzoic acid | kg | 2.36E-04 | 4.38E-04 | 2.02E-04 |
| Beryllium | kg | 3.39E-06 | 6.27E-06 | 2.88E-06 |
| Biphenyl | kg | 5.06E-07 | 9.09E-07 | 4.03E-07 |
| BOD5, Biological Oxygen Demand | kg | 5.47E-02 | 1.03E-01 | 4.86E-02 |
| Borate | kg | 7.04E-12 | 1.41E-11 | 7.04E-12 |
| Boron | kg | 7.98E-04 | 1.49E-03 | 6.92E-04 |
| Bromate | kg | 2.02E-07 | 4.04E-07 | 2.02E-07 |
| Bromide | kg | 4.90E-02 | 9.08E-02 | 4.18E-02 |
| Bromine | kg | 4.89E-06 | 9.78E-06 | 4.89E-06 |
| Bromoxynil | kg | 8.19E-12 | 1.64E-11 | 8.19E-12 |
| Butene | kg | 1.90E-09 | 3.79E-09 | 1.90E-09 |
| Butyl acetate | kg | 1.04E-08 | 2.08E-08 | 1.04E-08 |
| Butyrolactone | kg | 1.76E-11 | 3.52E-11 | 1.76E-11 |
| Cadmium | kg | 5.32E-06 | 1.05E-05 | 5.22E-06 |
| Cadmium, ion | kg | 5.18E-06 | 9.09E-06 | 3.91E-06 |
| Calcium | kg | 4.60E-01 | 9.12E-01 | 4.52E-01 |
| Calcium, ion | kg | 2.86E-01 | 4.71E-01 | 1.85E-01 |
| Carbofuran | kg | 1.16E-11 | 2.32E-11 | 1.16E-11 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Carbon disulfide | kg | 3.86E-12 | 7.72E-12 | 3.86E-12 |
| Carbonate | kg | 6.20E-07 | 1.24E-06 | 6.20E-07 |
| Carboxylic acids, unspecified | kg | 2.20E-05 | 4.39E-05 | 2.20E-05 |
| Cerium-141 | Bq | 2.41E-05 | 4.82E-05 | 2.41E-05 |
| Cerium-144 | Bq | 7.34E-06 | 1.47E-05 | 7.34E-06 |
| Cesium | kg | 5.04E-09 | 1.01E-08 | 5.04E-09 |
| Cesium-134 | Bq | 6.45E-04 | 1.29E-03 | 6.45E-04 |
| Cesium-136 | Bq | 4.28E-06 | 8.56E-06 | 4.28E-06 |
| Cesium-137 | Bq | 5.15E-01 | 1.03E+00 | 5.15E-01 |
| CFCs, unspecified | kg | 1.90E-08 | 3.80E-08 | 1.90E-08 |
| Chloramine | kg | 1.22E-12 | 2.45E-12 | 1.22E-12 |
| Chlorate | kg | 1.93E-06 | 3.87E-06 | 1.93E-06 |
| Chloride | kg | 9.70E+00 | 1.82E+01 | 8.48E+00 |
| Chlorinated solvents, unspecified | kg | 1.31E-09 | 2.61E-09 | 1.31E-09 |
| Chlorine | kg | 7.16E-09 | 1.43E-08 | 7.16E-09 |
| Chloroacetic acid | kg | 1.02E-09 | 2.04E-09 | 1.02E-09 |
| Chloroacetyl chloride | kg | 2.04E-14 | 4.07E-14 | 2.04E-14 |
| Chloroform | kg | 3.29E-08 | 6.58E-08 | 3.29E-08 |
| Chlorosulfonic acid | kg | 1.74E-13 | 3.48E-13 | 1.74E-13 |
| Chlorpyrifos | kg | 8.93E-11 | 1.79E-10 | 8.93E-11 |
| Chromate | kg | 2.48E-12 | 4.97E-12 | 2.48E-12 |
| Chromium | kg | 2.60E-04 | 4.44E-04 | 1.84E-04 |
| Chromium-51 | Bq | 4.70E-03 | 9.40E-03 | 4.70E-03 |
| Chromium III | kg | 6.42E-05 | 1.28E-04 | 6.38E-05 |
| Chromium VI | kg | 4.90E-06 | 9.48E-06 | 4.58E-06 |
| Chromium, ion | kg | 1.41E-05 | 2.27E-05 | 8.66E-06 |
| Cobalt | kg | 1.42E-05 | 2.77E-05 | 1.35E-05 |
| Cobalt-57 | Bq | 1.36E-04 | 2.72E-04 | 1.36E-04 |
| Cobalt-58 | Bq | 2.17E-02 | 4.34E-02 | 2.17E-02 |
| Cobalt-60 | Bq | 1.90E-02 | 3.79E-02 | 1.90E-02 |
| COD, Chemical Oxygen Demand | kg | 1.00E-01 | 1.89E-01 | 8.84E-02 |
| Copper | kg | 5.62E-05 | 1.12E-04 | 5.55E-05 |
| Copper, ion | kg | 4.14E-05 | 7.36E-05 | 3.22E-05 |
| Cumene | kg | 1.25E-07 | 2.49E-07 | 1.25E-07 |
| Cyanazine | kg | 1.34E-11 | 2.68E-11 | 1.34E-11 |
| Cyanide | kg | 6.31E-07 | 1.26E-06 | 6.28E-07 |
| Decane | kg | 6.78E-06 | 1.26E-05 | 5.79E-06 |
| Detergent, oil | kg | 2.06E-04 | 3.85E-04 | 1.78E-04 |
| Dibenzofuran | kg | 4.34E-08 | 8.04E-08 | 3.70E-08 |
| Dibenzothiophene | kg | 3.66E-08 | 6.77E-08 | 3.11E-08 |
| Dicamba | kg | 7.88E-11 | 1.58E-10 | 7.88E-11 |
| Dichromate | kg | 1.69E-09 | 3.37E-09 | 1.69E-09 |
| Diethylamine | kg | 3.17E-13 | 6.34E-13 | 3.17E-13 |
| Dimethenamid | kg | 1.86E-10 | 3.72E-10 | 1.86E-10 |
| Dimethylamine | kg | 5.85E-13 | 1.17E-12 | 5.85E-13 |
| Dipropylamine | kg | 1.94E-13 | 3.88E-13 | 1.94E-13 |
| Dipropylthiocarbamic acid S-ethyl ester | kg | 7.69E-11 | 1.54E-10 | 7.69E-11 |
| Dissolved organics | kg | 4.41E-05 | 8.82E-05 | 4.41E-05 |
| Dissolved solids | kg | 1.15E+00 | 2.30E+00 | 1.15E+00 |
| Disulfoton | kg | 4.59E-12 | 9.19E-12 | 4.59E-12 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Diuron | kg | 1.29E-12 | 2.58E-12 | 1.29E-12 |
| DOC, Dissolved Organic Carbon | kg | 5.14E-04 | 1.03E-03 | 5.14E-04 |
| Docosane | kg | 2.44E-07 | 4.53E-07 | 2.08E-07 |
| Dodecane | kg | 1.29E-05 | 2.39E-05 | 1.10E-05 |
| Eicosane | kg | 3.54E-06 | 6.57E-06 | 3.03E-06 |
| Ethane, 1,2-dichloro- | kg | 4.59E-09 | 9.17E-09 | 4.59E-09 |
| Ethanol | kg | 1.84E-08 | 3.68E-08 | 1.84E-08 |
| Ethene | kg | 2.95E-08 | 5.89E-08 | 2.95E-08 |
| Ethene, chloro- | kg | 2.44E-10 | 4.88E-10 | 2.44E-10 |
| Ethyl acetate | kg | 1.60E-12 | 3.19E-12 | 1.60E-12 |
| Ethylamine | kg | 2.13E-13 | 4.26E-13 | 2.13E-13 |
| Ethylene diamine | kg | 2.08E-12 | 4.17E-12 | 2.08E-12 |
| Ethylene oxide | kg | 1.37E-09 | 2.74E-09 | 1.37E-09 |
| Fluorene | kg | 4.62E-08 | 9.23E-08 | 4.62E-08 |
| Fluorene, 1-methyl- | kg | 2.60E-08 | 4.81E-08 | 2.21E-08 |
| Fluorenes, alkylated, unspecified | kg | 4.53E-07 | 8.14E-07 | 3.61E-07 |
| Fluoride | kg | 9.18E-04 | 1.83E-03 | 9.15E-04 |
| Fluorine | kg | 1.83E-07 | 3.20E-07 | 1.37E-07 |
| Fluosilicic acid | kg | 5.04E-08 | 1.01E-07 | 5.04E-08 |
| Formaldehyde | kg | 7.48E-09 | 1.50E-08 | 7.48E-09 |
| Formamide | kg | 1.55E-13 | 3.10E-13 | 1.55E-13 |
| Formate | kg | 1.87E-11 | 3.73E-11 | 1.87E-11 |
| Formic acid | kg | 4.50E-14 | 8.99E-14 | 4.50E-14 |
| Furan | kg | 6.84E-10 | 1.37E-09 | 6.84E-10 |
| Glutaraldehyde | kg | 6.64E-09 | 1.33E-08 | 6.64E-09 |
| Glyphosate | kg | 1.67E-10 | 3.35E-10 | 1.67E-10 |
| Heat, waste | MJ | 1.84E-01 | 3.67E-01 | 1.84E-01 |
| Hexadecane | kg | 1.40E-05 | 2.60E-05 | 1.20E-05 |
| Hexanoic acid | kg | 4.89E-05 | 9.06E-05 | 4.18E-05 |
| Hydrocarbons, aliphatic, alkanes, unspecified | kg | 6.56E-07 | 1.31E-06 | 6.56E-07 |
| Hydrocarbons, aliphatic, unsaturated | kg | 6.05E-08 | 1.21E-07 | 6.05E-08 |
| Hydrocarbons, aromatic | kg | 2.74E-06 | 5.49E-06 | 2.74E-06 |
| Hydrocarbons, unspecified | kg | 1.81E-06 | 3.62E-06 | 1.81E-06 |
| Hydrogen-3, Tritium | Bq | 1.17E+03 | 2.35E+03 | 1.17E+03 |
| Hydrogen peroxide | kg | 2.75E-08 | 5.50E-08 | 2.75E-08 |
| Hydrogen sulfide | kg | 3.40E-07 | 6.81E-07 | 3.40E-07 |
| Hydroxide | kg | 9.13E-08 | 1.83E-07 | 9.13E-08 |
| Hypochlorite | kg | 5.19E-08 | 1.04E-07 | 5.19E-08 |
| Iodide | kg | 5.26E-07 | 1.05E-06 | 5.26E-07 |
| Iodine-131 | Bq | 2.78E-04 | 5.55E-04 | 2.78E-04 |
| Iodine-133 | Bq | 3.79E-05 | 7.57E-05 | 3.79E-05 |
| Iron | kg | 2.89E-02 | 5.19E-02 | 2.31E-02 |
| Iron-59 | Bq | 1.04E-05 | 2.08E-05 | 1.04E-05 |
| Iron, ion | kg | 9.07E-04 | 1.81E-03 | 9.07E-04 |
| Isopropylamine | kg | 5.26E-14 | 1.05E-13 | 5.26E-14 |
| Lactic acid | kg | 1.52E-13 | 3.04E-13 | 1.52E-13 |
| Lanthanum-140 | Bq | 6.43E-05 | 1.29E-04 | 6.43E-05 |
| Lead | kg | 1.09E-04 | 1.98E-04 | 8.95E-05 |
| Lead-210 | Bq | 2.77E-01 | 5.54E-01 | 2.77E-01 |
| Lead-210/kg | kg | 2.42E-14 | 4.48E-14 | 2.07E-14 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Lithium | kg | 1.29E-01 | 2.57E-01 | 1.28E-01 |
| Lithium, ion | kg | 8.43E-03 | 1.52E-02 | 6.73E-03 |
| m-Xylene | kg | 7.04E-06 | 1.31E-05 | 6.01E-06 |
| Magnesium | kg | 1.68E-01 | 3.14E-01 | 1.46E-01 |
| Manganese | kg | 1.07E-03 | 2.09E-03 | 1.03E-03 |
| Manganese-54 | Bq | 1.32E-03 | 2.63E-03 | 1.32E-03 |
| Mercury | kg | 2.27E-07 | 4.22E-07 | 1.95E-07 |
| Metallic ions, unspecified | kg | 9.86E-09 | 1.97E-08 | 9.85E-09 |
| Methane, dichloro-, HCC-30 | kg | 8.45E-08 | 1.69E-07 | 8.45E-08 |
| Methane, monochloro-, R-40 | kg | 9.19E-09 | 1.70E-08 | 7.83E-09 |
| Methanol | kg | 2.23E-07 | 4.47E-07 | 2.23E-07 |
| Methyl acetate | kg | 6.04E-15 | 1.21E-14 | 6.04E-15 |
| Methyl acrylate | kg | 2.72E-08 | 5.44E-08 | 2.72E-08 |
| Methyl amine | kg | 6.45E-12 | 1.29E-11 | 6.45E-12 |
| Methyl ethyl ketone | kg | 1.84E-08 | 3.40E-08 | 1.57E-08 |
| Methyl formate | kg | 2.16E-12 | 4.33E-12 | 2.16E-12 |
| Metolachlor | kg | 6.15E-10 | 1.23E-09 | 6.15E-10 |
| Metribuzin | kg | 2.85E-12 | 5.70E-12 | 2.85E-12 |
| Molybdenum | kg | 7.52E-06 | 1.43E-05 | 6.74E-06 |
| Molybdenum-99 | Bq | 2.22E-05 | 4.43E-05 | 2.22E-05 |
| n-Hexacosane | kg | 1.52E-07 | 2.82E-07 | 1.30E-07 |
| Naphthalene | kg | 4.23E-06 | 7.84E-06 | 3.61E-06 |
| Naphthalene, 2-methyl- | kg | 3.68E-06 | 6.82E-06 | 3.14E-06 |
| Naphthalenes, alkylated, unspecified | kg | 1.28E-07 | 2.30E-07 | 1.02E-07 |
| Nickel | kg | 5.15E-05 | 9.39E-05 | 4.24E-05 |
| Nickel, ion | kg | 2.36E-05 | 4.72E-05 | 2.36E-05 |
| Niobium-95 | Bq | 1.22E-04 | 2.44E-04 | 1.22E-04 |
| Nitrate | kg | 1.61E-04 | 3.22E-04 | 1.61E-04 |
| Nitrate compounds | kg | 1.27E-09 | 2.53E-09 | 1.27E-09 |
| Nitric acid | kg | 2.11E-06 | 4.21E-06 | 2.10E-06 |
| Nitrite | kg | 2.31E-07 | 4.62E-07 | 2.31E-07 |
| Nitrobenzene | kg | 1.59E-12 | 3.18E-12 | 1.59E-12 |
| Nitrogen | kg | 1.30E-06 | 2.60E-06 | 1.30E-06 |
| Nitrogen, organic bound | kg | 2.05E-06 | 4.11E-06 | 2.05E-06 |
| Nitrogen, total | kg | 1.13E-04 | 2.26E-04 | 1.13E-04 |
| o-Cresol | kg | 6.69E-06 | 1.24E-05 | 5.72E-06 |
| o-Xylene | kg | 9.72E-08 | 1.94E-07 | 9.72E-08 |
| Octadecane | kg | 3.47E-06 | 6.43E-06 | 2.97E-06 |
| Oils, unspecified | kg | 6.20E-03 | 1.16E-02 | 5.42E-03 |
| Organic substances, unspecified | kg | 1.36E-08 | 2.73E-08 | 1.36E-08 |
| p-Cresol | kg | 7.22E-06 | 1.34E-05 | 6.17E-06 |
| p-Xylene | kg | 9.72E-08 | 1.94E-07 | 9.72E-08 |
| PAH, polycyclic aromatic hydrocarbons | kg | 3.27E-08 | 6.55E-08 | 3.27E-08 |
| Paraquat | kg | 1.25E-11 | 2.49E-11 | 1.25E-11 |
| Parathion, methyl | kg | 9.41E-12 | 1.88E-11 | 9.41E-12 |
| Pendimethalin | kg | 6.40E-11 | 1.28E-10 | 6.40E-11 |
| Permethrin | kg | 5.75E-12 | 1.15E-11 | 5.75E-12 |
| Phenanthrene | kg | 5.15E-08 | 9.37E-08 | 4.22E-08 |
| Phenanthrenes, alkylated, unspecified | kg | 5.31E-08 | 9.54E-08 | 4.23E-08 |
| Phenol | kg | 5.43E-05 | 9.43E-05 | 4.01E-05 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| Phenol, 2,4-dimethyl- | kg | 6.51E-06 | 1.21E-05 | 5.57E-06 |
| Phenols, unspecified | kg | 6.69E-05 | 1.31E-04 | 6.41E-05 |
| Phorate | kg | 1.78E-12 | 3.56E-12 | 1.78E-12 |
| Phosphate | kg | 1.04E-03 | 2.09E-03 | 1.04E-03 |
| Phosphorus | kg | 5.07E-06 | 1.01E-05 | 5.07E-06 |
| Phosphorus compounds, unspecified | kg | 3.30E-08 | 6.59E-08 | 3.30E-08 |
| Phosphorus, total | kg | 2.26E-05 | 4.52E-05 | 2.26E-05 |
| Polonium-210 | Bq | 4.20E-01 | 8.40E-01 | 4.20E-01 |
| Potassium-40 | Bq | 3.97E-02 | 7.94E-02 | 3.97E-02 |
| Potassium, ion | kg | 3.34E-02 | 6.69E-02 | 3.34E-02 |
| Process solvents, unspecified | kg | 6.84E-08 | 1.37E-07 | 6.84E-08 |
| Propanal | kg | 1.23E-13 | 2.45E-13 | 1.23E-13 |
| Propene | kg | 9.35E-08 | 1.87E-07 | 9.35E-08 |
| Propionic acid | kg | 1.16E-13 | 2.32E-13 | 1.16E-13 |
| Propylamine | kg | 4.90E-14 | 9.81E-14 | 4.90E-14 |
| Propylene oxide | kg | 3.21E-08 | 6.43E-08 | 3.21E-08 |
| Protactinium-234 | Bq | 8.27E-03 | 1.65E-02 | 8.27E-03 |
| Radioactive species, alpha emitters | Bq | 8.16E-04 | 1.63E-03 | 8.16E-04 |
| Radioactive species, Nuclides, unspecified | Bq | 5.20E+03 | 1.04E+04 | 5.18E+03 |
| Radium-224 | Bq | 2.52E-01 | 5.04E-01 | 2.52E-01 |
| Radium-226 | Bq | 5.86E+00 | 1.17E+01 | 5.86E+00 |
| Radium-226/kg | kg | 8.41E-12 | 1.56E-11 | 7.19E-12 |
| Radium-228 | Bq | 5.05E-01 | 1.01E+00 | 5.05E-01 |
| Radium-228/kg | kg | 4.30E-14 | 7.98E-14 | 3.68E-14 |
| Rubidium | kg | 5.04E-08 | 1.01E-07 | 5.04E-08 |
| Ruthenium-103 | Bq | 4.67E-06 | 9.35E-06 | 4.67E-06 |
| Scandium | kg | 8.99E-07 | 1.80E-06 | 8.99E-07 |
| Selenium | kg | 1.56E-05 | 3.07E-05 | 1.52E-05 |
| Silicon | kg | 7.70E-03 | 1.54E-02 | 7.70E-03 |
| Silver | kg | 4.80E-04 | 8.90E-04 | 4.09E-04 |
| Silver-110 | Bq | 1.82E-02 | 3.64E-02 | 1.82E-02 |
| Silver, ion | kg | 9.33E-08 | 1.87E-07 | 9.33E-08 |
| Simazine | kg | 4.04E-11 | 8.08E-11 | 4.04E-11 |
| Sodium | kg | 1.46E+00 | 2.89E+00 | 1.43E+00 |
| Sodium-24 | Bq | 1.68E-04 | 3.35E-04 | 1.68E-04 |
| Sodium formate | kg | 1.36E-10 | 2.72E-10 | 1.36E-10 |
| Sodium, ion | kg | 1.66E+00 | 3.00E+00 | 1.34E+00 |
| Solids, inorganic | kg | 1.55E-04 | 3.10E-04 | 1.55E-04 |
| Solved solids | kg | 3.59E+00 | 5.78E+00 | 2.19E+00 |
| Strontium | kg | 1.28E-02 | 2.37E-02 | 1.09E-02 |
| Strontium-89 | Bq | 4.07E-04 | 8.15E-04 | 4.07E-04 |
| Strontium-90 | Bq | 2.96E+00 | 5.92E+00 | 2.96E+00 |
| Styrene | kg | 4.57E-09 | 9.14E-09 | 4.57E-09 |
| Sulfate | kg | 4.89E-01 | 9.76E-01 | 4.86E-01 |
| Sulfide | kg | 1.09E-04 | 2.16E-04 | 1.07E-04 |
| Sulfite | kg | 1.42E-07 | 2.83E-07 | 1.42E-07 |
| Sulfur | kg | 7.53E-03 | 1.50E-02 | 7.44E-03 |
| Sulfuric acid | kg | 5.99E-10 | 1.20E-09 | 5.99E-10 |
| Surfactants | kg | 4.58E-06 | 9.15E-06 | 4.58E-06 |
| Suspended solids, unspecified | kg | 6.83E+00 | 1.35E+01 | 6.63E+00 |

| Substance | Unit | Total | Forestry Operations | LSL Production |
|---|---|---|---|---|
| t-Butyl methyl ether | kg | 9.87E-09 | 1.97E-08 | 9.87E-09 |
| t-Butylamine | kg | 1.45E-13 | 2.91E-13 | 1.45E-13 |
| Tar | kg | 5.31E-11 | 1.06E-10 | 5.30E-11 |
| Technetium-99m | Bq | 5.09E-04 | 1.02E-03 | 5.09E-04 |
| Tellurium-123m | Bq | 8.88E-05 | 1.78E-04 | 8.88E-05 |
| Tellurium-132 | Bq | 1.28E-06 | 2.57E-06 | 1.28E-06 |
| Terbufos | kg | 6.07E-11 | 1.21E-10 | 6.07E-11 |
| Tetradecane | kg | 5.63E-06 | 1.04E-05 | 4.81E-06 |
| Thallium | kg | 1.74E-06 | 3.09E-06 | 1.36E-06 |
| Thorium-228 | Bq | 1.01E+00 | 2.02E+00 | 1.01E+00 |
| Thorium-230 | Bq | 1.13E+00 | 2.26E+00 | 1.13E+00 |
| Thorium-232 | Bq | 1.28E-03 | 2.57E-03 | 1.28E-03 |
| Thorium-234 | Bq | 8.27E-03 | 1.65E-02 | 8.27E-03 |
| Tin | kg | 3.81E-05 | 6.88E-05 | 3.07E-05 |
| Tin, ion | kg | 1.50E-06 | 3.00E-06 | 1.50E-06 |
| Titanium | kg | 4.08E-05 | 7.96E-05 | 3.89E-05 |
| Titanium, ion | kg | 1.07E-04 | 1.88E-04 | 8.08E-05 |
| TOC, Total Organic Carbon | kg | 1.33E-03 | 2.66E-03 | 1.33E-03 |
| Toluene | kg | 3.64E-04 | 6.75E-04 | 3.11E-04 |
| Toluene, 2-chloro- | kg | 2.59E-13 | 5.19E-13 | 2.59E-13 |
| Tributyltin compounds | kg | 8.71E-09 | 1.74E-08 | 8.71E-09 |
| Triethylene glycol | kg | 1.41E-07 | 2.83E-07 | 1.41E-07 |
| Trimethylamine | kg | 1.09E-14 | 2.17E-14 | 1.09E-14 |
| Tungsten | kg | 2.13E-06 | 4.27E-06 | 2.13E-06 |
| Uranium-234 | Bq | 9.92E-03 | 1.98E-02 | 9.92E-03 |
| Uranium-235 | Bq | 1.64E-02 | 3.27E-02 | 1.64E-02 |
| Uranium-238 | Bq | 1.67E-01 | 3.34E-01 | 1.67E-01 |
| Uranium alpha | Bq | 4.76E-01 | 9.53E-01 | 4.76E-01 |
| Urea | kg | 1.47E-13 | 2.93E-13 | 1.47E-13 |
| Vanadium | kg | 7.01E-06 | 1.31E-05 | 6.10E-06 |
| Vanadium, ion | kg | 3.07E-06 | 6.13E-06 | 3.07E-06 |
| VOC, volatile organic compounds, unspecified origin | kg | 1.79E-06 | 3.57E-06 | 1.79E-06 |
| Xylene | kg | 1.92E-04 | 3.54E-04 | 1.63E-04 |
| Yttrium | kg | 1.57E-06 | 2.91E-06 | 1.34E-06 |
| Zinc | kg | 3.42E-04 | 6.16E-04 | 2.74E-04 |
| Zinc-65 | Bq | 2.27E-03 | 4.54E-03 | 2.27E-03 |
| Zinc, ion | kg | 9.95E-05 | 1.99E-04 | 9.95E-05 |
| Zirconium-95 | Bq | 2.63E-05 | 5.26E-05 | 2.63E-05 |