Cradle to Gate Life Cycle Assessment of Laminated Veneer Lumber Production from the Southeast

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1 Background

CORRIM, the Consortium for Research on Renewable Industrial Materials, has conducted life cycle inventory (LCI) for major wood products and wood production regions in the United States. The life cycle inventory data cover from forest regeneration through to final product at the mill gate. Research has covered nine major forest products including both structural and nonstructural uses and four major regions. In this report we focus on laminated veneer lumber produced in the US southeast (SE) region. The SE regional data is a representative cross-section of forest growth and manufacturing processes in Georgia, Alabama, Mississippi, and Louisiana. This document updates the current wood product LCI's from a gate to gate to a cradle to gate LCI. Updates include the addition of SE forestry operations, and boiler, resin, and electrical grid data that have been developed since the original mill surveys were conducted in the years 1999 and 2000. The updated LCI data were used to conduct life cycle impact assessments (LCIA) using the North American impact method, TRACI 2 (Simapro version 4.0) (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare et al. 2011). These updates are necessary for the development of environmental product declarations (EPD) which will be based on this document. This document originates from the CORRIM LCI reports by Wilson and Dancer (2004, 2005) and Johnson et al. (2005). Updates in this report from the original Wilson and Dancer (2004) report include: North American resin data (Wilson 2009), plus wood combustion boiler updates, and electricity grid updates (Goemans 2010), with results expressed per unit of final product (1 m^3 laminated veneer lumber), and an LCIA. Updates to veneer production fall under the "Cradle to gate life cycle assessment of softwood plywood from the Pacific Northwest" report (Puettmann et al. 2012). Updates to the forestry operations report (Johnson et al 2005) include electricity grid updates and an LCIA using the TRACI method. This report follows data and reporting requirements as outlined in the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2011) that will provide the guidance for preparation of North American wood product EPD. This report does not include comparative assertions.

2 Introduction

The goal of this work is to determine energy and material inputs and outputs associated with the production of laminated veneer lumber from the manufacturing base located in the SE region of North America. These data are needed for the inclusion of the production process in life-cycle analyses of wood.

The data were obtained through a scientifically sound and consistent process established by the Consortium for Research on Renewable Industrial Materials (CORRIM), following ISO14040 standards (ISO 2006).

The scope of this study includes cradle-to-gate LCIs based on primary data for producing laminated veneer lumber from dry veneer using practices and technology common to the SE region. Veneer production was obtained from the same unit process as developed for softwood plywood (Wilson and Sakimoto 2004, 2005; Puettmann et al. 2012). The logs used for veneer production are obtained from the forest resource base located in Georgia, Alabama, Mississippi, and Louisiana as representative of the SE region and the mill survey covered the states of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Texas. Data for the LCA are based on manufacturing gate to gate LCI's from CORRIM reports (Wilson and Dancer 2004, 2005), the resin LCI's from CORRIM reports (Wilson 2009) and forest resources cradle to gate LCI's specific to the region (Johnson et al. 2005).

3 Description of Product

Laminated veneer lumber (LVL) is a composite wood material made from sheets of veneer generally 2.54 mm or 3.18 mm (1/10 in. or 1/8 in.) thick that are laminated together with their grain orientation in the same direction and then hot-pressed (Figure 1). LVL was first used in WWII to make airplane propellers and since the 1970s it has been used as a construction product (Neuvonen et al. 1998). LVL can vary in thickness and width but is most commonly produced in the dimensions of 4.45 cm (1 3/4-in.) thick and 121.9 cm (4 ft.) wide, into lengths from 2.44 to 18.29 m (8 to 60 ft.). It is used as an alternative to structural lumber for headers and beams and also as the flange component in wood composite I-joists. According to APA - The Engineered Wood Association, in the year 2000 the U.S. produced 1.257 million cubic meters (44.4 million cubic feet) of LVL of which 61% was used in the manufacture of I-joists and another 31% was used as headers or beams (APA 2001). Laminated veneer lumber can be made from any wood species provided its mechanical and physical properties are suitable and it can be properly glued. LVL in the SE region are made with southern pines species, primarily slash pine (*P. elliottii* Engelm.) and loblolly pine (*P. taeda* L.). Laminated veneer lumber is used as an input into the composite I-joist (Wilson and Dancer 2005; Puettmann et al. 2012) but could also be used as a standalone for headers, beams and joists.

Figure 1 Laminated veneer lumber

3.1 Functional and declared unit

In accordance with the PCR (2011), the declared unit for LVL 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 (PCR 2011). For conversion of units from the US industry measure, 1.0 cubic foot is equal to 0.02832 m^3. 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.

3.2 System Boundaries

The system boundary begins with regeneration of forest in the SE (Johnson et al. 2005) and ends with LVL packaged to leave the mill gate (Figure 2). The forest resources system boundary includes: planting the seedlings, forest management which included site preparation, thinning, and fertilization on a subset of hectares, and final harvest. The transportation of logs from the woods to the mill is accounted for with the LVL manufacturing (Figure 2). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. For veneer production logs are transported to plywood manufacturing facilities and after manufacturing is complete dry veneer sheets are transported to LVL plants (Figure 2). The LVL production process was modeled as a single unit process (Figure 2). Outputs to the system boundary include 1 m^3 of LVL ready to be shipped, air and water emissions, solid waste and small volumes of co-products (chips and sawdust). The co-products are no longer tracked once they leave the system boundary.

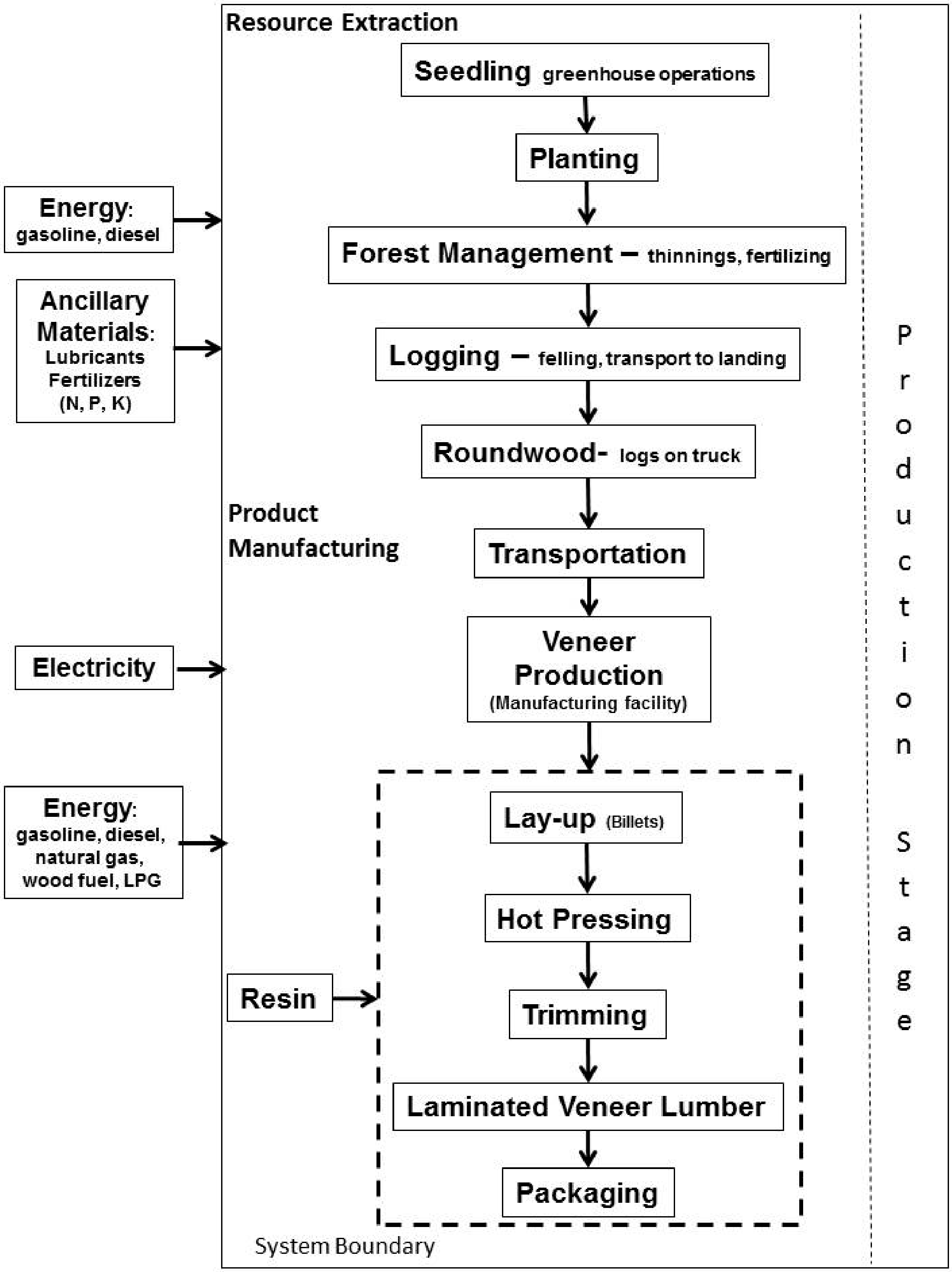

Figure 2 Cradle to gate life cycle stages for Laminated Veneer Lumber, SE.

3.3 Description of data/ Processes Description

3.3.1 Forestry Operations

Forestry operations include growing seedlings, site preparation, planting, fertilization (where applicable) and final harvest. The specific processes involved are reforestation: which includes seedling production, site preparation, planting, and fertilization, and harvesting: which includes felling, skidding, processing, and loading for both commercial thinning and final harvest operations. Weighted average allocation to different processes takes into account inherent differences in site productivity and energy usage by different kinds of logging equipment. Inputs to the forest resources management LCI include seed, electricity used during greenhouse operations, fertilizer used during seedling production and stand growth, and the fuel and lubricants needed to power and maintain equipment for site preparation, fertilization, and harvest operations. The primary output product for this analysis is a log destined for the plywood mill where the first step of LVL manufacturing occurs. The co-product, non-merchantable slash, is generally left at a landing and disposed of through mechanical activities or prescribed fire.

Logs used in the production of LVL in the SE include in their life cycle the upstream activities associated with establishment, growth, and harvest of trees (Figure 2). This group of activities is collectively referred to as forest resource management. The forest resource management life cycle stages includes the efforts required to establish a forest stand, to treat that stand through to maturity, and to harvest the merchantable logs from the stand. Stand establishment involves preparation of the site for planting and planting of seedlings on the prepared site. Intermediate stand treatments enhance growth and productivity while the stand is growing and can involve thinning, fertilization, or both. In the SE, 68% of stands have some level of fertilizer applied, with the area treated determined by management intensity.

In the SE most harvested volume comes from forest operations on private lands where investment in timber is the precursor to harvest. Harvested lands are reforested for the next crop cycle with the sequence of treatments from planting to harvest averaging 27 years. Forestry operations and their associated impacts are not stationary and will change based on both past and prospective technologies, evolving forest management procedures, and market demands. Given that the nature of productivity gains is not confirmed or well developed, this assessment was based on data representing the current state of the art in forest operations: it does not discount future operations or estimate potential productivity gains from future technologies. Outputs representing quantities of product, measures of consumed resources, and the emissions associated with those consumed resources were developed as a weighted average across the hectares managed for timber production. These quantities of product are used as inputs to the LVL manufacturing LCI and the consumed resources and emissions are tracked for inclusion in the cradle to gate LCI.

The forest resource management LCI was structured from three general combinations of management intensity and site productivity (Table 1). Scenarios developed for the Southeast represent a composite of stands from the extensive database managed by the Forest Nutrition Cooperative at North Carolina State University (Hafley et al 1982; Buford 1991). Management intensities ranged from little intervention on low site productivity lands that are often managed by Non-industrial Private Forest Landowners with a focus on other forest values, to higher management intensities involving combinations of fertilization and thinning on high productivity lands owned by industrial interests. Associated with each combination of management intensity and site productivity is an estimated yield of biomass based on forest growth and yield models. For the SE, growth and yield was based on models by Hafley et al. (1982) and Buford (1991).

3.3.1.1 Regeneration (seedling production and planting process)

Environmental burdens associated with the production of seedlings including fertilizer used in greenhouses or fields, and the electrical energy required to operate forest nursery pumps and to keep seedlings cool for planting were included as inputs to the regeneration process (Table1). Greenhouse operations data for the SE were based on data from South and Zwolinski 1996. All seedlings in the SE were planted by hand. The only energy factors associated with planting were related to travel to and from the planting site.

Stand treatment options for the Southeast were developed by Lee Allen of the North Carolina Tree Nutrition Cooperative (Allen 2001). Based on that input, fertilization regimes were developed for the mid-intensity and high-intensity scenarios but not for the low-intensity option. Fertilization differences between the mid-and high-intensity options were primarily associated with the frequency of application. The high intensity option involved fertilization every four years over the 25-year life of the stand. The mid-intensity option involved fertilization at years two and sixteen. The fertilizer mixture included nitrogen, potassium, and phosphorus.

Table 1 Inputs to the regeneration phase and mid-rotation fertilization per hectare (ha) of forest.

		Low intensity	Medium intensity	High intensity	Weighted Average
		Reforesting 1 ha			
Diesel and Gasoline	L	38.55	132.27	272.21	104.59
Seedlings, at greenhouse	p[1]	1,794	1,794	1,794	1,794
Nitrogen in fertilizer					
In Seedlings	kg	0.14	0.14	0.14	0.14
On Site	kg	-	264.52	712.86	189.06
Phosphorous in fertilizer		-	-	-	-
In Seedlings	kg	0.01	0.01	0.01	0.01
On Site	kg	-	72.86	128.90	48.70
Potassium in fertilizer		-	-	-	-
In Seedlings	kg	0.08	0.08	0.08	.08
On Site	kg	-	-	-	-

[1] p = individual seedling

3.3.1.2 Equipment

Timber harvesting activities include four components: felling (severing the standing tree from the stump); processing (bucking, limbing and/or topping) which involves removal of non-merchantable limbs and tops and cutting of the tree into merchantable and transportable log lengths; secondary transportation (called skidding on gentle slopes and yarding on steep slopes),which is a transportation step that moves trees or logs from the point of felling to a loading point near a haul road; and loading (moving logs from the ground to haul vehicles). Although all functions are required to remove logs from the woods, the specific order and location of the operations will vary by harvesting system as cable yarding systems used in steep terrain have the processing step occur prior to the secondary transport step. A fifth step, primary transportation, includes hauling logs from the woods to a manufacturing location and it is included in the LCI for the primary manufacturing facility.

This analysis is based on data for the most common mechanized harvesting system in use in the SE region. Mechanized felling utilizes a cutting device mounted on a woods tractor (feller-buncher) that travels through the stand to cut and bunch trees, transportation of those harvested trees to a landing (skidding), and the use of another machine that can delimb and process trees into logs at the landing. Two general systems were used. A smaller feller-buncher and grapple skidder and a larger, more capitalintensive system. The processing operation for this type of system generally takes place at the landing. Thus, whole trees are moved to the landing through the secondary transportation operation and are then processed into logs. Since whole trees are moved to the landing, the removed carbon from the site includes both the stem and the crown.

Variations in harvest equipment size affect machine productivity and therefore emissions per m^3 of logs produced. Harvest equipment operational efficiencies vary between thinning and final harvest (clearcut) which affects machine productivity and therefore emissions per m^3 of logs produced. To account for this, equipment usage was allocated between thinning operations and final harvest for those management regimes that use thinning (Table 2).

Table 2 Equipment allocation by treatment and management intensity

Management Intensity	Thinning	Final Harvest (usage per final volume harvested)
Low intensity site		
Medium Feller Buncher	NA	100%
Small Skidder	NA	100%
Slide Boom De-limber	NA	100%
Large Loader	NA	100%
Medium intensity		
Large Feller Buncher	26%	74%
Medium Crawler	26%	74%
Slide Boom De-limber	26%	74%
Large Loader	26%	74%
High intensity		
Large Feller Buncher	36%	64%
Medium Crawler	36%	64%
Slide Boom De-limber	36%	64%
Large Loader	36%	64%

3.3.1.3 Thinning and Final Harvest Process

A single estimate of the average volume harvested per unit area was developed by weighting three combinations of site productivity and management intensity based on the relative percentage of the land base they occupy which is given as percent area in management class in Table 3. Site productivity as measured by site index, the height of dominant trees at a base year, usually 25 or 50 years, and ownership class was obtained from the U.S. Forest Service Resource Planning Assessment database (USDA 2000, Mills 2001). A combination of these data and expert opinion was used to categorize the number of private forest hectares into management intensity classes. The first class reflects non-industrial private forests (NIPF) with low-intensity management that might be implemented by the small private landowner. The second reflects high-intensity management on NIPF lands and/or low intensity management on industrial lands. The third scenario reflects high intensity management on industrial tree farms. Specific assumptions associated with these three scenarios are outlined in Table 3. In the Southeast, 37% of industrial and non-industrial private forestlands were classified in the lowest productivity class, 58% in the middle productivity class, and 5% in the highest class. The allocation of forested area to management intensity/site productivity class produces the expected log volume recovered from the forest resource as shown in Table 3. Allocating per ha values from Table 1 to the total yield of 236 m^3/ha is used to carry forward the environmental burdens of the reforestation effort on a per m^3 basis.

Table 3 Input assumptions for three levels of management intensity in the SE.

Management intensity class prescription	Low Intensity	Medium Intensity	High Intensity	Weighted Average
	per hectare			
Rotation Age - Years	30	25	25	27
Planting Density-Trees/hectare	1,794	1,794	1,794	1,794
Fertilization	None	Years 2,16	Years 2,5,9,13,17,21	
Commercial Thin 1st - m^3	0	63	59	39
at year		17	13	
Commercial Thin 2nd - m^3	0	0	58	3
at year			19	
Final Harvest - m^3	220	175	205	193
at year	30	25	25	
Total yield/hectare - m^3	220	238	323	236
Percent Thinned	0%	26%	36%	17%
Percent Sawlogs	38%	31%	52%	35%
Percent area in Class	37%	58%	5%	

Fuel consumption and energy use for forest resource management processes were averaged by the percent area in each class to develop weighted average values for the SE region by major process (Table 4).

Table 4 Fuel consumption for SE forest resource management processes (regeneration, thinning, and harvest).

	Unit	Fuel Consumption per m^3
Seedling, Site Prep, Plant, Pre-commercial Thinning		
Diesel and gasoline	L	0.515
Lubricants	L	0.009
Electricity	kWh	0.455
Commercial Thinning and Final Harvest		
Diesel	L	2.930
Lubricants	L	0.050
Total Forest Extraction Process		
Gasoline and Diesel	L	3.440
Lubricants	L	0.059
Electricity	kWh	0.455

3.3.2 Product Manufacturing

3.3.2.1 Transportation Process

Transportation is the first process of product manufacturing (Figure 2). Logs are transported by truck to plywood or veneer production facilities for veneer production (Table 5). Average haul distance in the SE was 156 km from forest landing to veneer production. Dry veneer and resin were delivered to the LVL mill requiring an additional 84 km and 79 km, respectively. All flow analyses of wood processes were determined on an oven-dry weight specific gravity[1] of 0.55.

Table 5 Average delivery distance (one-way) for materials to produce Laminated Veneer Lumber, SE.

Material delivered to mill	Delivery Distance	
Material	**km**	**miles**
Logs with bark to veneer production	156	97
Dry veneer to LVL	84	52
Phenol-formaldehyde resin	79	49

3.3.2.2 Parallel Laminated Veneer Production (PLV)

No PLV was reported to be used for LVL production in the SE region.

3.3.2.3 Veneer Production

Veneers are usually produced during plywood production. Veneers are dried to a moisture content of 3-6% (oven-dry basis). For detailed description of veneer production for LVL see Wilson and Sakimoto (2004, 2005).

3.3.2.4 Phenol-formaldehyde resin

The life cycle inventory for the production of phenol-formaldehyde (PF) resin covers its cycle from in-ground resources through the production and delivery of input chemicals and fuels, through to the manufacturing of a resin as shipped to the customer (Wilson 2009). It examines the use of all resources, fuels and electricity and all emissions to air, water and land; it also includes feedstock of natural gas and crude oil used to produce the chemicals. The PF resin survey data were from 13 plants in U.S. that represented 62% of total production for the year 2005 (Wilson 2009). Total annual production was 779,063,000 kg (1,717,500,000 lb) of neat phenol-formaldehyde (PF) resin at 47.4% non-volatile solids content. The inputs to produce 1.0 kg of neat (PF) resin consist of the two primary chemicals: 0.244 kg of phenol and 0.209 kg of methanol, a lesser amount of sodium hydroxide (0.061 kg), and 0.349 kg of water. Electricity is used for running fans and pumps, and for operating emissions control equipment. Natural gas is used for boiler fuel and emission control equipment, and propane fuel is used in forklifts.

3.3.2.5 Phenol resorcinol formaldehyde resin

No phenol resorcinol formaldehyde resin was reported to be used for LVL production in the SE region.

3.3.2.6 Energy generation

Energy production for the manufacturing of LVL comes from electricity, natural gas, diesel, and liquid petroleum gas (LPG). Electricity is used to operate the lay-up and hot-pressing equipment, as well as pneumatic and mechanical conveying equipment, fans, and other equipment in the plant. Natural gas is used for the purpose of generating heat for the presses in the LVL plants. The diesel is used for equipment, which transports materials outside of the plant, and the LPG is used in forklift trucks, which

[1] Specific gravity uses oven dry mass and oven dry volume of the wood resource.

are operated inside the plant. Other types of fuels are used to generate energy during veneer production. These energy sources are not analyzed in this report, but the burdens that are created are carried over into the LVL final product. For information on the energy consumption for producing dry veneer see Wilson and Sakimoto (2004, 2005).

3.3.2.7 Laminated Veneer Production

The steps for producing LVL include the lay-up of billets, pressing, and trimming. A billet is produced by aligning the dry veneers so their grain direction is parallel. They are then coated with resin and ready for pressing. Outputs from this process include billets and waste veneer. During pressing the billets are heated under pressure (320-350^{o}F and approximately 250 lb/in^{2}) which cures the resin thereby bonding the veneers into LVL. The LVL is sawn and trimmed to the proper width and length. Outputs include LVL, panel trim, and sawdust. A single unit process approach was used to model LVL production because the steps for producing LVL are relatively simple and there are a low number of sub-unit processes.

Dry veneers and resin are the primary raw materials consumed for the production of SE LVL (Table 6). The weight of the input wood to produce a functional unit of LVL was calculated using the oven-dry density of veneer at 551 kg/m^{3} (34.38 lb/ft^{3}). The density of the LVL is 606 kg/m^{3} (37.8 lb/ft^{3}) wood only.

Table 6 Unit process inputs/outputs for Laminated Veneer Production (1 m^{3}), SE

Products	**Value**	**Unit/m^{3}**	**Allocation (%)**
Laminated Veneer Lumber	1.00	m^{3}	91.30
Co-Products (waste, scrap, trim, sawdust)	57.51	kg	8.70
Resources			
Water, cooling, surface	93.97	L	
Materials/fuels			
Electricity, at Grid	69.55	kWh	
Diesel	0.37	L	
LPG	0.48	L	
Natural gas	10.93	m^{3}	
Phenol-formaldehyde resin	10.75	kg	
Veneer, dry	603.28	kg	
Wrapping material - Packaging	0.460	kg	
Strap Protectors - Packaging	0.200	kg	
Strapping - Packaging	0.083	kg	
Spacers - Packaging	4.672	kg	
Emissions to air			
Acetone	0.0147	kg	
Formaldehyde	0.0015	kg	
Methanol	0.0541	kg	
Particulates, unspecified	0.5421	kg	
Emissions to water			
	-	-	

3.3.2.8 Packaging

Materials used for packaging LVL for shipping are shown in Table 7.

Table 7 Materials used in packaging and shipping per m^3, Laminated Veneer Production, SE.

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

Packing materials for represent just less than 1 percent of the cumulative mass of the model flow. 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.

4 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 and with the exception of packaging noted above, raw materials/energy from upstream processes that were used in small quantities that comprise less than 1% of the product mass/energy were not included in the LCA.

In the primary surveys, manufacturers were asked to report total hazardous air pollutants (HAPS) specific to their wood products manufacturing process: these included formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde. If applicable to the wood product, HAPS are reported in Table 9 and are included in the impact assessment. Table 9 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. A complete list of all air emissions is located in Section 13: Appendix of this report.

5 Data quality requirements

This study collected data from representative LVL production facilities in the SE region of the US. Total annual production in the SE region was 0.425 million cubic meters (15.0 million cubic feet) (APA 2001). This represents the equivalent of approximately 34 percent of the total LVL produced in the U.S. in the year 2001. Data gathered from the industry survey accounted for 0.221 million cubic meters (7.8 million cubic feet) of production, which is slightly over 52% of the total volume produced in the region.

An external critical review of the survey procedures, data, analysis, and report was done for conformance with CORRIM and ISO 14040 standards (Werner 2004). The review provided assurances that the study methodology, data collection, and analyses were scientifically sound, and in conformance with ISO 14040 and CORRIM research protocol (ISO 2006). Complete details of this study for LVL production and the overall CORRIM project can be found in Wilson and Dancer (2004) and Lippke et al. (2004), respectively.

6 Life cycle inventory analysis

6.1 Data collection

Primary data for the LCI was collected through mill surveys administered in accordance with CORRIM and ISO 14040 protocols. This study relied almost exclusively on production and emissions data provided by LVL producers from the SE for the 2000 production year, with some secondary data on electrical grid inputs from the US LCI database. The data were gathered through primary surveys that were sent out to LVL production facilities. Two mills participated in the surveys. The surveys were extensive and included questions about annual production, energy and fuel uses, emissions, and co-product volumes. The states covered in the SE region included Georgia, Alabama, Mississippi, and Louisiana for both manufacturing data and forest resources data. Data for packaging was obtained from field sampling and personal communications with manufacturers.

The primary mill survey data are more than 10 years old and were updated using current electricity grid and boiler data to complete this LCA. Boilers are the most energy intensive process for the cradle to production gate and therefore generate the dominant share of the environmental footprint. LVL production technology has not changed substantially in the past 10 years so the data likely continue to reflect processes as they are now.

6.2 Calculation rules

Fuel consumption was calculated per seedling and then multiplied by the number of planted seedlings per unit area specified for each of the three management scenarios to determine fuel consumption rates per unit area. Total fuel consumption per unit area was divided by the final harvested volume per unit area to establish the contribution of fuel consumption for site preparation, seedlings, and planting per unit of harvested volume.

To determine the environmental burdens of equipment used for the forest extraction part of the forest management life cycle stage (Figure 2) the applicable fuel and oil consumption rates were developed for each equipment component within the harvesting system (Table 2). These data were derived from existing studies for the types of harvesting equipment used in the region and included both published information and personal interviews with timber harvesting contractors (Biltonen 2002; Keegan et al. 1995; Kellogg and Bettinger. 1995; Kellogg et al. 1996; Lawson 2002; Reynolds 2002). Production and consumption factors of the harvesting system were calculated by adding the emissions for each piece of equipment used per m^3 of production.

The survey results for each unit process were converted to a production basis (e.g., logs used per m^3 of LVL produced) and production-weighted averages were calculated for each material. This approach resulted in a mill complex that represents a composite of the mills surveyed, but may not represent any mill in particular. Survey data was converted from cubic feet to cubic meters. One thousand cubic feet (MCF) is equivalent to 0.02832 thousand cubic meters (1,000 m^3). Veneer and inputs were given in MSF (1,000 ft^2 3/8-in. basis) volumes and converted to cubic meters or mass. The USLCI database (NREL 2012) was used to assess off-site impacts associated with the materials and energy consumed. SimaPro, version 7.3.3 (Pré Consultants 2012) was used as the accounting program to track all of the materials.

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.

6.3 Allocation rules

Allocation was based on mass. SE LVL production generates low value co-products (8.7% by mass of input. By-products are sold as dry wood residues with a price differential approximately 28 times[2] lower than LVL based on equivalent mass. The differential on a mass versus economic allocation is 5.3 percent.

6.4 LCI Results

Life cycle inventory results for laminated veneer lumber are presented by three life stages, 1) forestry operations, 2) veneer production, and 3) LVL production (Table 8-11). The majority of the raw material energy consumption occurs during wood production with only a small portion arising from forestry operations. LVL and PLV production (wrapped up) encompasses resin production. Raw material energy requirements are presented in Table 8 for 1 cubic meter (m^3) of laminated veneer lumber. Air emissions are reported in Table 9, water emissions are reported in Table 10, and solid waste emissions are reported in Table 11.

Table 8 Raw material energy consumption per 1 m^3 of Laminated Veneer Lumber, SE

Fuel	Total	Forestry Operations	Veneer Production	LVL Production
	kg/m^3			
Coal, in ground	46.0323	0.2347	25.3938	20.4038
Gas, natural, in ground	24.8845	0.8505	10.3182	13.7157
Oil, crude, in ground	17.3881	3.5377	7.6128	6.2375
Uranium oxide, in ore	0.0013	0.0000	0.0007	0.0006
Wood waste	166.665	0.0000	165.452	1.214

Table 9 Air emissions released per 1 m^3 of Laminated Veneer Lumber, SE.

Air Emission[1/]	Total	Forestry Operations	Veneer Production	LVL Production
	kg/m^3			
Carbon dioxide, biogenic	255.2848	0.0100	252.8628	2.4120
Carbon dioxide, fossil	194.8811	11.6654	100.2839	82.9318
Sulfur dioxide	1.2321	0.0267	0.5930	0.6124
Nitrogen oxides	1.0664	0.2086	0.6291	0.2287
Carbon monoxide	0.7875	0.0000	0.7793	0.0081
Particulates, > 2.5 um, and < 10um	0.6691	0.0064	0.6522	0.0106
Particulates, unspecified	0.6184	0.0014	0.0858	0.5312
Carbon dioxide	0.5876	0.5177	0.0023	0.0677
Particulates, < 2.5 um	0.5591	0.0000	0.5551	0.0040
Methane	0.5573	0.0242	0.2688	0.2643

[2] Based on http://www.wbpionline.com/features/euphoria-will-subside-but-recovery-will-continue/image/euphoria-will-subside-but-recovery-will-continue-1.html for LVL prices and Timber-Mart South Market News quarterly 2nd Q 2013 vol 18 no. 2 for wood residues.

Air Emission[1/]	Total	Forestry Operations	Veneer Production	LVL Production
	kg/m^3			
Carbon monoxide, fossil	0.3837	0.1041	0.1538	0.1258
Sulfur oxides	0.0936	0.0116	0.0585	0.0236
Metals, unspecified	0.0557	0.0000	0.0552	0.0004
Methane, fossil	0.0525	0.0025	0.0218	0.0282
Methanol	0.0519	0.0000	0.0025	0.0494
Hydrogen chloride	0.0487	0.0001	0.0378	0.0108
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0481	0.0070	0.0166	0.0245
VOC, volatile organic compounds	0.0471	0.0061	0.0202	0.0207
Isoprene	0.0195	0.0003	0.0106	0.0087
Acetone	0.0136	0.0000	0.0001	0.0135
Benzene	0.0101	0.0001	0.0056	0.0045
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0087	0.0003	0.0036	0.0048
Formaldehyde	0.0074	0.0001	0.0059	0.0015
Cumene	0.0066	0.0000	0.0002	0.0064
TOC, Total Organic Carbon	0.0053	0.0000	0.0053	0.0000
Acrolein	0.0052	0.0000	0.0052	0.0000
Dinitrogen monoxide	0.0047	0.0030	0.0007	0.0010
Hydrogen fluoride	0.0030	0.0000	0.0016	0.0013
Propene	0.0026	0.0002	0.0001	0.0024
Manganese	0.0021	0.0000	0.0021	0.0000
Radionuclides (Including Radon)	0.0019	0.0000	0.0010	0.0008
alpha-Pinene	0.0015	0.0000	0.0015	0.0000
Acetaldehyde	0.0014	0.0000	0.0013	0.0000
Chlorine	0.0010	0.0000	0.0010	0.0000
Ammonia	0.0008	0.0005	0.0002	0.0002
Aldehydes, unspecified	0.0007	0.0001	0.0003	0.0003
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	0.0006	0.0000	0.0006	0.0000
Hydrocarbons, unspecified	0.0004	0.0000	0.0002	0.0002
Methane, dichloro-, HCC-30	0.0004	0.0000	0.0004	0.0000
Magnesium	0.0002	0.0000	0.0001	0.0001
Phenol	0.0002	0.0000	0.0002	0.0000
D-limonene	0.0002	0.0000	0.0002	0.0000
Organic substances, unspecified	0.0001	0.0000	0.0001	0.0001
Naphthalene	0.0001	0.0000	0.0001	0.0000

Air Emission[1/]	Total	Forestry Operations	Veneer Production	LVL Production
	kg/m^3			
Nitrogen, total	0.0001	0.0001	0.0000	0.0000

1/ Due to the extensive list of emissions, those emissions less than 10^{-4} are not shown. A complete list of all air emissions can be found in Section 13.

Most waterborne emissions are all off-site (Table 10). No mill in the survey discharged any process water. The water sprayed on logs is collected and recycled or soaks into the ground. Water used at the boiler and kilns is evaporated. A complete list of all emissions to water is located in the Appendix (Section 13) of this report.

Table 10 Emissions to water released per 1 m^3 Laminated Veneer Lumber, SE.

Water Emission[1/]	Total	Forestry Operations	Veneer Production	LVL Production
	kg/m^3			
Solved solids	7.7365	0.7317	3.2282	3.7766
Chloride	6.2525	0.5932	2.6164	3.0428
Sodium, ion	1.7633	0.1673	0.7379	0.8581
Calcium, ion	0.5562	0.0528	0.2328	0.2707
Suspended solids, unspecified	0.2456	0.0371	0.1037	0.1047
COD, Chemical Oxygen Demand	0.1598	0.0055	0.0258	0.1285
BOD5, Biological Oxygen Demand	0.1338	0.0030	0.0162	0.1146
Lithium, ion	0.1207	0.0041	0.0499	0.0667
Magnesium	0.1087	0.0103	0.0455	0.0529
Barium	0.1065	0.0165	0.0451	0.0449
Sulfate	0.0426	0.0013	0.0219	0.0194
Bromide	0.0371	0.0035	0.0155	0.0181
TOC, Total Organic Carbon	0.0294	0.0000	0.0010	0.0284
DOC, Dissolved Organic Carbon	0.0294	0.0000	0.0010	0.0284
Iron	0.0185	0.0025	0.0080	0.0081
Cumene	0.0159	0.0000	0.0005	0.0154
Fluoride	0.0151	0.0149	0.0001	0.0001
Phosphate	0.0112	0.0112	0.0000	0.0000
Benzene	0.0112	0.0000	0.0005	0.0107
Strontium	0.0094	0.0009	0.0039	0.0046
Propene	0.0059	0.0000	0.0002	0.0057
Aluminum	0.0052	0.0012	0.0017	0.0024
Oils, unspecified	0.0037	0.0004	0.0015	0.0018
Aluminium	0.0029	0.0000	0.0018	0.0010
Ammonia	0.0026	0.0003	0.0011	0.0012
Manganese	0.0006	0.0000	0.0003	0.0003
Boron	0.0005	0.0001	0.0002	0.0003
Sulfur	0.0005	0.0000	0.0002	0.0002
Silver	0.0004	0.0000	0.0002	0.0002
Toluene	0.0003	0.0000	0.0001	0.0001

Water Emission[1/]	Total	Forestry Operations	Veneer Production	LVL Production
	kg/m^3			
Zinc	0.0002	0.0000	0.0001	0.0001
Benzoic acid	0.0002	0.0000	0.0001	0.0001
Detergent, oil	0.0002	0.0000	0.0001	0.0001
Chromium	0.0002	0.0000	0.0001	0.0001
Xylene	0.0001	0.0000	0.0001	0.0001

[1/] Due to the extensive list of emissions, those emissions less than 10^{-4} are not shown.

Solid emissions include ash generated at the boiler and the extraction of natural gas. Some waste is collected from the log-yard and debarking and cannot be sent to the boiler is sent the landfill (Table 11).

Table 11 Waste to treatment per 1 m^3 of Laminated Veneer Lumber production, SE.

Waste to treatment	Total	Forestry Operations	Veneer Production	LVL Production
	kg/m^3			
Solid Waste	43.07	0.21	35.58	7.28

7 Life cycle impact assessment

The life cycle impact assessment (LCIA) phase establishes links between the life cycle inventory results and potential environmental impacts. The LCIA calculates impact indicators, such as global warming potential and smog. These impact indicators provide general, but quantifiable, indications of potential environmental impacts. The target impact indicator, the impact category, and means of characterizing the impacts are summarized in Table 12. 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 (PCR 2011).

Table 12 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 hydrogen ion (H+) equivalent for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of H^+ mole-eq. 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. 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 12 provides the environmental impact by category for LVL produced in the SE region. It addition, energy and material resource consumption values and the waste generated are also provided.

Table 13 provides the environmental impact by category for one cubic meter of LVL produced in the SE region. 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 13. For GWP, 43 percent of the CO_2 equivalent emissions come from producing the dry veneer and 51 percent from LVL production with remainder (6%) assigned to forestry operations. Values in Table 13 are the cumulative impact of all upstream processes required for LVL production including those from forestry, veneer, plywood, resin, and packaging production and transportation energy required to move these materials to the LVL facility. For example, differences between LVL Production data in table 7 with results in table 13 are a result of the resources and fuels used in the upstream processes, i.e. fresh water use.

Table 13 Environmental performance of 1 m^3 Laminated Veneer Lumber, SE.

Impact category	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Global warming potential (GWP)	kg CO_2 equiv	212.13	13.75	107.76	90.61
Acidification Potential	H+ moles equiv	112.53	10.35	60.12	42.06
Eutrophication Potential	kg N equiv	0.0907	0.0365	0.0308	0.0233
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000	0.0000
Smog Potential	kg O3 equiv	27.11	5.20	15.97	5.94
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Veneer Production**	**LVL Production**
Non-renewable fossil	MJ	3,352.34	213.40	1,573.79	1,565.15
Non-renewable nuclear	MJ	496.44	2.04	275.61	218.79
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	13.73	0.23	7.07	6.43
Renewable, biomass	MJ	3,495.03	0.00	3,464.68	30.35
Material resources consumption (non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Veneer Production**	**LVL Production**
Non-renewable materials	kg	0.66	0.00	0.02	0.64
Renewable materials	kg	687.80	0.00	682.04	5.76
Fresh water	L	608.7	0.05	316.05	292.60
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Veneer Production**	**LVL Production**
Solid waste	kg	43.07	0.21	35.58	7.28

8 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, 212 kg CO_2e were released in the production of 1 m^3 of LVL. That same 1 m^3 of LVL stores 1093 kg CO_2e (Table 14).

Table 14 Carbon balance per 1 m^3 softwood LVL, SE.

	kg CO_2 equivalent
released forestry operations	13.75
released manufacturing	198.37
CO_2 eq. stored in product	1,092.99

9 Conclusions

The cradle to gate LCA for laminated veneer lumber includes the LCI of forest resources that relies on secondary and tertiary data and the LCI of manufacturing that relies on primary survey data for wood product inputs and secondary data on process inputs such as natural gas, diesel, and electricity. The survey results were representative of the forest operations in the SE region. The survey data are representative of the processes and production volumes consistent with trade association data.

Veneer was produced during plywood production and required 788 kg of roundwood for LVL production in the SE. To produce one cubic meter of LVL finished product including resin (606 kg) required 603.28 kg of dry veneer. The LVL production process produced 57.51 kg of co-product (chips, trimming, veneer waste). Any wood fuel would have been consumed during veneer production. See SE plywood for information of self-generated wood fuel.

Emissions from the forest resources LCI are small relative to manufacturing emissions. The LVL manufacturing process has some onsite emissions from pressing of the billets with the resin. Energy use for manufacturing LVL is dominated by the combustion of wood fuel (biomass), which is comprised of wood and bark waste generated during veneer production. Wood fuel represented 71 percent of the heat energy during veneer production and 54 percent of the total cradle to gate energy to produce LVL. Total nonrenewable fossil fuel use was 37 percent of the total energy from cradle to gate. Resins used to bond the veneers also almost exclusively dependent upon fossil fuels for both energy and feedstock. The production of the veneer dominated the total energy (76%). Forestry operations consumed exclusively (98%) fossil fuels, but only represent less than 2 percent of the total energy. Laminated veneer lumber production consumed 85 percent of the total energy from nonrenewable fossil fuels and contributed only 22 percent to the total cradle to gate energy consumption.

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 rules on wood emissions from stationary sources which counts the CO_2 taken up by the forest ecosystem when the tree grew as balancing any CO_2 emissions when it is burned. Under the TRACI method, combustion of fossil fuels generates CO_2 and other air emissions that contribute to the global warming impact as do methane and nitrous oxides that are emitted during biomass burning. Using this method, 212 kg CO_2e were released in the production of 1 m^3 of LVL. That same 1 m^3 of LVL stores 1093 kg CO_2e.

10 Acknowledgments

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11 Critical Review

11.1 Internal Review

An internal review of the LCA product was provided using two knowledgeable and experienced LCA and wood products reviewers. They are:

- Wayne B. Trusty, President, Wayne B. Trusty and Associates Limited,
- Bruce Lippke, Professor Emeritus, University of Washington

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

11.2 External Review

The external review process is intended to ensure consistency between the completed LCA and the principals and requirements of the International Standards on LCA (ISO 2006) and the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2011). 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:

- Thomas Gloria, Ph.D., Industrial Ecology Consultants

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13 Appendix

13.1 Air Emissions

Table A.1 Air emissions released per 1 m^3 of laminated veneer lumber, SE.

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
2,4-D	kg	1.37E-09			1.37E-09
2-Chloroacetophenone	kg	4.08E-10	2.80E-11	4.08E-11	3.39E-10
5-methyl Chrysene	kg	4.37E-10	2.26E-12	2.41E-10	1.94E-10
Acenaphthene	kg	1.01E-08	5.24E-11	5.59E-09	4.50E-09
Acenaphthylene	kg	4.97E-09	2.57E-11	2.74E-09	2.20E-09
Acetaldehyde	kg	1.37E-03	4.77E-05	1.32E-03	8.97E-06
Acetochlor	kg	1.90E-08			1.90E-08
Acetone	kg	1.36E-02	0.00E+00	9.90E-05	1.35E-02
Acetophenone	kg	8.75E-10	6.00E-11	8.74E-11	7.27E-10
Acrolein	kg	5.22E-03	5.78E-06	5.17E-03	4.28E-05
Alachlor	kg	1.87E-09			1.87E-09
Aldehydes, unspecified	kg	7.14E-04	1.44E-04	3.07E-04	2.63E-04
alpha-Pinene	kg	1.49E-03	0.00E+00	1.49E-03	0.00E+00
Ammonia	kg	8.06E-04	4.67E-04	1.77E-04	1.62E-04
Ammonium chloride	kg	6.91E-05	2.85E-07	3.83E-05	3.05E-05
Anthracene	kg	4.17E-09	2.16E-11	2.30E-09	1.85E-09
Antimony	kg	1.06E-05	1.85E-09	1.04E-05	2.38E-07
Arsenic	kg	3.71E-05	5.68E-08	3.30E-05	3.97E-06
Atrazine	kg	3.70E-08			3.70E-08
Barium	kg	2.14E-07			2.14E-07
Bentazone	kg	1.51E-10			1.51E-10
Benzene	kg	1.01E-02	5.85E-05	5.59E-03	4.45E-03
Benzene, chloro-	kg	1.28E-09	8.80E-11	1.28E-10	1.07E-09
Benzene, ethyl-	kg	7.94E-08	3.76E-10	2.97E-09	7.60E-08
Benzo(a)anthracene	kg	1.59E-09	8.22E-12	8.77E-10	7.05E-10
Benzo(a)pyrene	kg	7.55E-10	3.91E-12	4.17E-10	3.35E-10
Benzo(b,j,k)fluoranthene	kg	2.19E-09	1.13E-11	1.21E-09	9.70E-10
Benzo(ghi)perylene	kg	5.37E-10	2.77E-12	2.96E-10	2.38E-10
Benzyl chloride	kg	4.08E-08	2.80E-09	4.08E-09	3.39E-08
Beryllium	kg	1.93E-06	2.85E-09	1.70E-06	2.27E-07
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	kg	5.79E-04	0.00E+00	5.79E-04	0.00E+00
Biphenyl	kg	3.38E-08	1.75E-10	1.86E-08	1.50E-08

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Bromoform	kg	2.27E-09	1.56E-10	2.27E-10	1.89E-09
Bromoxynil	kg	3.31E-10			3.31E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	8.74E-03	2.99E-04	3.61E-03	4.83E-03
Butadiene	kg	2.47E-06	2.43E-06	1.84E-08	2.01E-08
Cadmium	kg	6.97E-06	1.45E-08	6.16E-06	8.00E-07
Carbofuran	kg	2.83E-10			2.83E-10
Carbon dioxide	kg	5.88E-01	5.18E-01	2.28E-03	6.77E-02
Carbon dioxide, biogenic	kg	2.55E+02	1.00E-02	2.53E+02	2.41E+00
Carbon dioxide, fossil	kg	1.95E+02	1.17E+01	1.00E+02	8.29E+01
Carbon disulfide	kg	7.58E-09	5.20E-10	7.57E-10	6.30E-09
Carbon monoxide	kg	7.87E-01	3.64E-05	7.79E-01	8.14E-03
Carbon monoxide, fossil	kg	3.84E-01	1.04E-01	1.54E-01	1.26E-01
Chloride	kg	5.96E-10	7.67E-12	3.22E-10	2.66E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	1.21E-07		3.11E-09	1.18E-07
Chlorine	kg	1.03E-03	0.00E+00	1.02E-03	9.42E-06
Chloroform	kg	3.44E-09	2.36E-10	3.44E-10	2.86E-09
Chlorpyrifos	kg	2.17E-09			2.17E-09
Chromium	kg	3.33E-05	4.15E-08	3.04E-05	2.90E-06
Chromium VI	kg	1.57E-06	8.12E-09	8.66E-07	6.96E-07
Chrysene	kg	1.99E-09	1.03E-11	1.10E-09	8.82E-10
Cobalt	kg	1.10E-05	7.33E-08	9.71E-06	1.20E-06
Copper	kg	1.46E-07	7.53E-10	9.18E-08	5.36E-08
Cumene	kg	6.63E-03	2.12E-11	2.18E-04	6.42E-03
Cyanazine	kg	3.26E-10			3.26E-10
Cyanide	kg	1.46E-07	9.99E-09	1.46E-08	1.21E-07
Dicamba	kg	1.92E-09			1.92E-09
Dimethenamid	kg	4.54E-09			4.54E-09
Dimethyl ether	kg	4.80E-05		1.57E-06	4.64E-05
Dinitrogen monoxide	kg	4.73E-03	3.04E-03	6.95E-04	9.95E-04
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	2.15E-06		2.15E-06	1.46E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.83E-11	2.39E-13	1.01E-11	7.88E-12
Dipropylthiocarbamic acid S-ethyl ester	kg	3.11E-09			3.11E-09
D-limonene	kg	1.68E-04	0.00E+00	1.68E-04	0.00E+00
Ethane, 1,1,1-trichloro-, HCFC-140	kg	2.77E-09	4.12E-10	8.01E-10	1.55E-09
Ethane, 1,2-dibromo-	kg	7.00E-11	4.80E-12	6.99E-12	5.82E-11
Ethane, 1,2-dichloro-	kg	2.33E-09	1.60E-10	2.33E-10	1.94E-09
Ethane, chloro-	kg	2.45E-09	1.68E-10	2.45E-10	2.04E-09

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Ethene, tetrachloro-	kg	8.74E-07	5.23E-09	4.82E-07	3.87E-07
Ethene, trichloro-	kg	6.15E-14			6.15E-14
Fluoranthene	kg	1.41E-08	7.30E-11	7.78E-09	6.26E-09
Fluorene	kg	1.81E-08	9.35E-11	9.98E-09	8.02E-09
Fluoride	kg	1.00E-05	6.02E-06	1.12E-06	2.85E-06
Formaldehyde	kg	7.45E-03	7.41E-05	5.88E-03	1.50E-03
Furan	kg	9.75E-11	4.50E-13	5.40E-11	4.31E-11
Glyphosate	kg	4.08E-09			4.08E-09
Heat, waste	MJ	6.95E+00		2.28E-01	6.72E+00
Hexane	kg	3.91E-09	2.68E-10	3.90E-10	3.25E-09
Hydrazine, methyl-	kg	9.91E-09	6.80E-10	9.90E-10	8.24E-09
Hydrocarbons, unspecified	kg	3.99E-04	1.64E-06	2.21E-04	1.76E-04
Hydrogen	kg	3.58E-06		1.13E-07	3.47E-06
Hydrogen chloride	kg	4.87E-02	1.29E-04	3.78E-02	1.08E-02
Hydrogen fluoride	kg	2.98E-03	1.52E-05	1.64E-03	1.32E-03
Hydrogen sulfide	kg	1.93E-11	2.48E-13	1.04E-11	8.60E-12
Indeno(1,2,3-cd)pyrene	kg	1.21E-09	6.27E-12	6.69E-10	5.38E-10
Iron	kg	2.14E-07			2.14E-07
Isophorone	kg	3.38E-08	2.32E-09	3.38E-09	2.81E-08
Isoprene	kg	1.95E-02	2.51E-04	1.06E-02	8.72E-03
Kerosene	kg	3.31E-05	1.36E-07	1.84E-05	1.46E-05
Lead	kg	7.16E-05	7.51E-08	6.69E-05	4.66E-06
Magnesium	kg	2.19E-04	1.13E-06	1.21E-04	9.70E-05
Manganese	kg	2.09E-03	8.34E-08	2.07E-03	2.11E-05
MCPA	kg	2.55E-11			2.55E-11
Mercaptans, unspecified	kg	1.26E-05	8.67E-07	1.26E-06	1.05E-05
Mercury	kg	6.67E-06	1.61E-08	5.55E-06	1.10E-06
Metals, unspecified	kg	5.57E-02	2.85E-14	5.52E-02	4.29E-04
Methacrylic acid, methyl ester	kg	1.16E-09	8.00E-11	1.15E-10	9.69E-10
Methane	kg	5.57E-01	2.42E-02	2.69E-01	2.64E-01
Methane, bromo-, Halon 1001	kg	9.33E-09	6.40E-10	9.32E-10	7.76E-09
Methane, dichloro-, HCC-30	kg	3.84E-04	8.40E-08	3.78E-04	5.94E-06
Methane, dichlorodifluoro-, CFC-12	kg	1.98E-09	4.11E-10	8.47E-10	7.23E-10
Methane, fossil	kg	5.25E-02	2.47E-03	2.18E-02	2.82E-02
Methane, monochloro-, R-40	kg	3.09E-08	2.12E-09	3.09E-09	2.57E-08
Methane, tetrachloro-, CFC-10	kg	9.95E-08	4.11E-11	3.33E-09	9.61E-08
Methanol	kg	5.19E-02	0.00E+00	2.52E-03	4.94E-02
Methyl ethyl ketone	kg	1.08E-05	1.56E-09	1.08E-05	1.89E-08
Methyl methacrylate	kg	2.11E-12		1.21E-12	9.06E-13

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Metolachlor	kg	1.50E-08			1.50E-08
Metribuzin	kg	6.95E-11			6.95E-11
Naphthalene	kg	1.27E-04	1.56E-08	1.26E-04	1.40E-06
Nickel	kg	5.66E-05	9.17E-07	4.91E-05	6.64E-06
Nitrogen oxides	kg	1.07E+00	2.09E-01	6.29E-01	2.29E-01
Nitrogen, total	kg	1.17E-04	1.17E-04	0.00E+00	1.83E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	4.81E-02	6.98E-03	1.66E-02	2.45E-02
N-Nitrodimethylamine	kg	1.38E-14			1.38E-14
Organic acids	kg	2.54E-07	1.05E-09	1.41E-07	1.12E-07
Organic substances, unspecified	kg	1.34E-04	6.38E-07	6.70E-05	6.62E-05
PAH, polycyclic aromatic hydrocarbons	kg	1.06E-05	1.04E-05	6.82E-08	7.30E-08
Paraquat	kg	3.03E-10			3.03E-10
Parathion, methyl	kg	2.29E-10			2.29E-10
Particulates	kg	2.34E-05		7.69E-07	2.27E-05
Particulates, < 10 um	kg	8.28E-06			8.28E-06
Particulates, < 2.5 um	kg	5.59E-01	0.00E+00	5.55E-01	3.97E-03
Particulates, > 2.5 um, and < 10um	kg	6.69E-01	6.40E-03	6.52E-01	1.06E-02
Particulates, unspecified	kg	6.18E-01	1.44E-03	8.58E-02	5.31E-01
Pendimethalin	kg	1.56E-09			1.56E-09
Permethrin	kg	1.40E-10			1.40E-10
Phenanthrene	kg	5.37E-08	2.77E-10	2.96E-08	2.38E-08
Phenol	kg	2.12E-04	6.40E-11	1.90E-04	2.20E-05
Phenols, unspecified	kg	6.76E-05	4.25E-08	6.65E-05	1.01E-06
Phorate	kg	7.18E-11			7.18E-11
Phosphate	kg	2.67E-06	2.67E-06		
Phthalate, dioctyl-	kg	4.26E-09	2.92E-10	4.25E-10	3.54E-09
Potassium	kg	3.79E-05			3.79E-05
Propanal	kg	2.22E-08	1.52E-09	2.21E-09	1.84E-08
Propene	kg	2.61E-03	1.60E-04	8.14E-05	2.37E-03
Propylene oxide	kg	6.70E-08		2.20E-09	6.48E-08
Pyrene	kg	6.56E-09	3.39E-11	3.62E-09	2.91E-09
Radioactive species, unspecified	Bq	1.12E+06	5.60E+03	6.20E+05	4.96E+05
Radionuclides (Including Radon)	kg	1.85E-03	7.63E-06	1.03E-03	8.16E-04
Selenium	kg	2.99E-05	1.43E-07	1.81E-05	1.17E-05
Simazine	kg	9.84E-10			9.84E-10
Sodium	kg	8.74E-07			8.74E-07
Styrene	kg	1.46E-09	9.99E-11	1.46E-10	1.21E-09
Sulfur	kg	4.61E-06			4.61E-06

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Sulfur dioxide	kg	1.23E+00	2.67E-02	5.93E-01	6.12E-01
Sulfur oxides	kg	9.36E-02	1.16E-02	5.85E-02	2.36E-02
Sulfur, total reduced	kg	2.70E-06			2.70E-06
Sulfuric acid, dimethyl ester	kg	2.80E-09	1.92E-10	2.80E-10	2.33E-09
Tar	kg	6.71E-10	8.63E-12	3.63E-10	2.99E-10
t-Butyl methyl ether	kg	2.04E-09	1.40E-10	2.04E-10	1.70E-09
Terbufos	kg	2.45E-09			2.45E-09
TOC, Total Organic Carbon	kg	5.32E-03	0.00E+00	5.28E-03	4.11E-05
Toluene	kg	2.61E-05	2.54E-05	2.04E-07	5.03E-07
Toluene, 2,4-dinitro-	kg	1.63E-11	1.12E-12	1.63E-12	1.36E-11
Vinyl acetate	kg	4.43E-10	3.04E-11	4.43E-11	3.68E-10
VOC, volatile organic compounds	kg	4.71E-02	6.14E-03	2.02E-02	2.07E-02
Xylene	kg	1.81E-05	1.77E-05	1.39E-07	2.85E-07
Zinc	kg	2.47E-06	2.16E-06	6.12E-08	2.49E-07

13.1 Water Emissions

Table 15 Emissions to water released per 1 m^3 of laminated veneer lumber, SE.

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
2,4-D	kg	5.86E-11			5.86E-11
2-Hexanone	kg	1.13E-06	1.07E-07	4.73E-07	5.50E-07
2-Propanol	kg	2.54E-09			2.54E-09
4-Methyl-2-pentanone	kg	7.27E-07	6.90E-08	3.04E-07	3.54E-07
Acetochlor	kg	8.13E-10			8.13E-10
Acetone	kg	1.73E-06	1.64E-07	7.24E-07	8.42E-07
Acidity, unspecified	kg	5.67E-15			5.67E-15
Acids, unspecified	kg	3.62E-06	1.61E-10	6.77E-09	3.61E-06
Alachlor	kg	8.00E-11			8.00E-11
Aluminium	kg	2.86E-03		1.82E-03	1.04E-03
Aluminum	kg	5.22E-03	1.20E-03	1.66E-03	2.35E-03
Ammonia	kg	2.57E-03	2.87E-04	1.08E-03	1.20E-03
Ammonia, as N	kg	6.29E-09	8.09E-11	3.40E-09	2.81E-09
Ammonium, ion	kg	1.48E-05	6.09E-08	8.20E-06	6.52E-06
Antimony	kg	4.66E-06	7.48E-07	1.98E-06	1.94E-06
Arsenic, ion	kg	4.71E-05	9.34E-06	1.77E-05	2.01E-05
Atrazine	kg	1.58E-09			1.58E-09
Barium	kg	1.06E-01	1.65E-02	4.51E-02	4.49E-02
Bentazone	kg	6.46E-12			6.46E-12
Benzene	kg	1.12E-02	2.76E-05	4.78E-04	1.07E-02
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.73E-08	1.64E-09	7.24E-09	8.42E-09
Benzene, ethyl-	kg	1.63E-05	1.55E-06	6.84E-06	7.95E-06
Benzene, pentamethyl-	kg	1.30E-08	1.23E-09	5.43E-09	6.31E-09
Benzenes, alkylated, unspecified	kg	4.09E-06	6.56E-07	1.73E-06	1.70E-06
Benzoic acid	kg	1.76E-04	1.67E-05	7.35E-05	8.55E-05
Beryllium	kg	2.07E-06	2.34E-07	8.68E-07	9.66E-07
Biphenyl	kg	2.65E-07	4.25E-08	1.12E-07	1.10E-07
BOD5, Biological Oxygen Demand	kg	1.34E-01	2.98E-03	1.62E-02	1.15E-01
Boron	kg	5.43E-04	5.16E-05	2.27E-04	2.64E-04
Bromide	kg	3.71E-02	3.52E-03	1.55E-02	1.81E-02
Bromoxynil	kg	8.55E-12			8.55E-12
Cadmium, ion	kg	7.99E-06	2.31E-06	2.68E-06	3.00E-06
Calcium, ion	kg	5.56E-01	5.28E-02	2.33E-01	2.71E-01
Carbofuran	kg	1.21E-11			1.21E-11
CFCs, unspecified	kg	2.54E-09			2.54E-09

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Chloride	kg	6.25E+00	5.93E-01	2.62E+00	3.04E+00
Chlorpyrifos	kg	9.32E-11			9.32E-11
Chromate	kg	3.38E-13			3.38E-13
Chromium	kg	1.53E-04	3.76E-05	6.21E-05	5.30E-05
Chromium VI	kg	6.11E-07	1.27E-07	2.61E-07	2.23E-07
Chromium, ion	kg	6.63E-05	3.90E-06	2.76E-05	3.49E-05
Cobalt	kg	3.83E-06	3.64E-07	1.60E-06	1.87E-06
COD, Chemical Oxygen Demand	kg	1.60E-01	5.51E-03	2.58E-02	1.29E-01
Copper, ion	kg	5.05E-05	7.73E-06	2.16E-05	2.12E-05
Cumene	kg	1.59E-02		5.23E-04	1.54E-02
Cyanazine	kg	1.40E-11			1.40E-11
Cyanide	kg	1.26E-08	1.19E-09	5.25E-09	6.12E-09
Decane	kg	5.05E-06	4.79E-07	2.11E-06	2.46E-06
Detergent, oil	kg	1.63E-04	1.43E-05	6.79E-05	8.03E-05
Dibenzofuran	kg	3.29E-08	3.12E-09	1.38E-08	1.60E-08
Dibenzothiophene	kg	2.75E-08	2.66E-09	1.15E-08	1.33E-08
Dicamba	kg	8.23E-11			8.23E-11
Dimethenamid	kg	1.94E-10			1.94E-10
Dipropylthiocarbamic acid S-ethyl ester	kg	8.03E-11			8.03E-11
Disulfoton	kg	4.80E-12			4.80E-12
Diuron	kg	1.35E-12			1.35E-12
DOC, Dissolved Organic Carbon	kg	2.94E-02	4.95E-13	9.64E-04	2.84E-02
Docosane	kg	1.85E-07	1.76E-08	7.75E-08	9.01E-08
Dodecane	kg	9.57E-06	9.08E-07	4.01E-06	4.66E-06
Eicosane	kg	2.64E-06	2.50E-07	1.10E-06	1.28E-06
Fluorene, 1-methyl-	kg	1.97E-08	1.87E-09	8.24E-09	9.59E-09
Fluorenes, alkylated, unspecified	kg	2.37E-07	3.80E-08	1.00E-07	9.85E-08
Fluoride	kg	1.51E-02	1.49E-02	1.33E-04	1.06E-04
Fluorine	kg	1.24E-07	1.90E-08	5.26E-08	5.28E-08
Furan	kg	9.32E-11			9.32E-11
Glyphosate	kg	1.75E-10			1.75E-10
Hexadecane	kg	1.04E-05	9.92E-07	4.37E-06	5.08E-06
Hexanoic acid	kg	3.64E-05	3.45E-06	1.52E-05	1.77E-05
Hydrocarbons, unspecified	kg	9.32E-08	6.19E-13	2.60E-11	9.32E-08
Iron	kg	1.85E-02	2.46E-03	7.98E-03	8.10E-03
Lead	kg	7.58E-05	1.11E-05	3.11E-05	3.36E-05
Lead-210/kg	kg	1.80E-14	1.71E-15	7.53E-15	8.75E-15
Lithium, ion	kg	1.21E-01	4.15E-03	4.99E-02	6.67E-02

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Magnesium	kg	1.09E-01	1.03E-02	4.55E-02	5.29E-02
Manganese	kg	5.67E-04	1.83E-05	2.90E-04	2.59E-04
MCPA	kg	1.09E-12			1.09E-12
Mercury	kg	1.76E-07	8.83E-08	4.53E-08	4.29E-08
Metallic ions, unspecified	kg	2.64E-09	7.56E-12	3.18E-10	2.31E-09
Methane, monochloro-, R-40	kg	6.97E-09	6.61E-10	2.92E-09	3.39E-09
Methyl ethyl ketone	kg	1.39E-08	1.32E-09	5.83E-09	6.78E-09
Metolachlor	kg	6.42E-10			6.42E-10
Metribuzin	kg	2.98E-12			2.98E-12
Molybdenum	kg	3.98E-06	3.78E-07	1.67E-06	1.94E-06
m-Xylene	kg	5.24E-06	4.98E-07	2.19E-06	2.55E-06
Naphthalene	kg	3.15E-06	2.99E-07	1.32E-06	1.53E-06
Naphthalene, 2-methyl-	kg	2.74E-06	2.60E-07	1.15E-06	1.33E-06
Naphthalenes, alkylated, unspecified	kg	6.70E-08	1.07E-08	2.84E-08	2.78E-08
n-Hexacosane	kg	1.16E-07	1.10E-08	4.84E-08	5.62E-08
Nickel	kg	3.89E-05	6.63E-06	1.53E-05	1.70E-05
Nickel, ion	kg	2.94E-13			2.94E-13
Nitrate	kg	3.02E-07	5.43E-14	2.28E-12	3.02E-07
Nitrate compounds	kg	1.70E-10	2.18E-12	9.18E-11	7.58E-11
Nitric acid	kg	3.81E-07	4.90E-09	2.06E-07	1.70E-07
Nitrogen, total	kg	4.73E-05	1.52E-07	2.04E-05	2.67E-05
o-Cresol	kg	4.98E-06	4.73E-07	2.08E-06	2.42E-06
Octadecane	kg	2.58E-06	2.45E-07	1.08E-06	1.26E-06
Oils, unspecified	kg	3.71E-03	3.67E-04	1.54E-03	1.80E-03
Organic substances, unspecified	kg	1.86E-09			1.86E-09
Paraquat	kg	1.30E-11			1.30E-11
Parathion, methyl	kg	9.82E-12			9.82E-12
p-Cresol	kg	5.37E-06	5.10E-07	2.25E-06	2.61E-06
Pendimethalin	kg	6.68E-11			6.68E-11
Permethrin	kg	6.00E-12			6.00E-12
Phenanthrene	kg	3.17E-08	4.08E-09	1.34E-08	1.43E-08
Phenanthrenes, alkylated, unspecified	kg	2.78E-08	4.46E-09	1.18E-08	1.15E-08
Phenol	kg	2.74E-05	5.60E-06	1.16E-05	1.02E-05
Phenol, 2,4-dimethyl-	kg	4.85E-06	4.60E-07	2.03E-06	2.36E-06
Phenols, unspecified	kg	5.43E-05	2.51E-06	2.24E-05	2.94E-05
Phorate	kg	1.86E-12			1.86E-12
Phosphate	kg	1.12E-02	1.12E-02		2.27E-05
Phosphorus	kg	5.21E-06			5.21E-06
Phosphorus compounds, unspecified	kg	3.44E-08			3.44E-08

Substance	Unit	Total	Forestry Operations	Veneer Production	LVL Production
Phosphorus, total	kg	3.07E-06			3.07E-06
Process solvents, unspecified	kg	9.32E-09			9.32E-09
Propene	kg	5.87E-03		1.93E-04	5.68E-03
Radioactive species, Nuclides, unspecified	Bq	2.15E+03	8.84E+00	1.19E+03	9.47E+02
Radium-226/kg	kg	6.26E-12	5.94E-13	2.62E-12	3.04E-12
Radium-228/kg	kg	3.20E-14	3.04E-15	1.34E-14	1.56E-14
Selenium	kg	6.08E-06	1.66E-07	3.25E-06	2.66E-06
Silver	kg	3.63E-04	3.45E-05	1.52E-04	1.77E-04
Simazine	kg	4.22E-11			4.22E-11
Sodium, ion	kg	1.76E+00	1.67E-01	7.38E-01	8.58E-01
Solids, inorganic	kg	9.68E-10	1.25E-11	5.23E-10	4.32E-10
Solved solids	kg	7.74E+00	7.32E-01	3.23E+00	3.78E+00
Strontium	kg	9.44E-03	8.95E-04	3.95E-03	4.59E-03
Styrene	kg	2.10E-10		6.51E-12	2.04E-10
Sulfate	kg	4.26E-02	1.32E-03	2.19E-02	1.94E-02
Sulfide	kg	3.46E-05	6.50E-07	1.42E-06	3.25E-05
Sulfur	kg	4.59E-04	4.35E-05	1.92E-04	2.23E-04
Sulfuric acid	kg	8.15E-11			8.15E-11
Suspended solids, unspecified	kg	2.46E-01	3.71E-02	1.04E-01	1.05E-01
Tar	kg	9.59E-12	1.23E-13	5.19E-12	4.28E-12
Terbufos	kg	6.34E-11			6.34E-11
Tetradecane	kg	4.20E-06	3.98E-07	1.76E-06	2.04E-06
Thallium	kg	9.84E-07	1.58E-07	4.17E-07	4.09E-07
Tin	kg	2.60E-05	3.25E-06	1.10E-05	1.18E-05
Titanium, ion	kg	7.16E-05	1.15E-05	3.04E-05	2.98E-05
TOC, Total Organic Carbon	kg	2.94E-02		9.64E-04	2.84E-02
Toluene	kg	2.74E-04	2.60E-05	1.15E-04	1.34E-04
Vanadium	kg	4.70E-06	4.46E-07	1.97E-06	2.29E-06
Waste water/m3	m3	7.68E-04			7.68E-04
Xylene	kg	1.44E-04	1.39E-05	6.03E-05	6.99E-05
Yttrium	kg	1.17E-06	1.11E-07	4.88E-07	5.68E-07
Zinc	kg	2.04E-04	2.80E-05	8.93E-05	8.66E-05
Zinc, ion	kg	4.11E-07			4.11E-07