Cradle to Gate Life Cycle Assessment of Softwood Plywood 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 product manufacturing. Research has covered nine major forest products including both structural and nonstructural uses and four major regions: in this report we focus on softwood plywood produced in the US Southeast (SE) region. The SE regional data is a representative cross-section of forest growth and manufacturing processes representative from Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas. This document updates the current plywood LCI's from a gate to gate to a cradle to gate LCI. Updates include the addition of SE forestry operations, boiler, resin, and electrical grid data that have been developed since the original mill surveys were conducted in the 1999 and 2000 time period. The updated LCI data were used to conduct life cycle impact assessments (LCIA) using the North American impact method, TRACI 2.0 (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 report by Wilson and Sakimota (2004 and 2005) and Johnson et al. (2005). Data updates in this report from the original Wilson and Sakimoto LCI report include: wood combustion boiler updates, electricity grid updates (Goemans 2010), and resins data to reflect average US resin production (Wilson 2009) and a cradle to grave, LCIA. The functional unit is 1 m^3 (1000 square feet, 3/8-inch basis) of softwood plywood. Updates to the forestry operations report 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 softwood plywood from the manufacturing base located in the Southeast 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 softwood plywood from logs using practices and technology common to the SE region. The logs are obtained from the forest resource base located in Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas as representative of the region. Data for the LCA are based on manufacturing gate to gate LCI's from CORRIM reports (Wilson and Sakimoto 2004) and forest resources cradle to gate LCI's specific to the region (Johnson et al. 2005)

3 Description of Product

Softwood plywood has had a long tradition as a structural building material for both commercial and residential construction. Plywood is used as structural sheathing for roof, wall and flooring, and for sub-flooring applications in home construction, furniture, and cabinet panels. Plywood is also used as a component in other engineered wood products and systems in applications such as prefabricated I-joists, box beams, stressed-skin panels, and panelized roofs, Plywood is a panel product built up wholly or primarily of sheets of veneer called plies (Figure 1). Softwood plywood in the US is produced by peeling logs into veneer sheets, drying the veneer, applying resin (phenol-formaldehyde) to the veneer sheets, and sheets are typically stacked with alternating grain orientation. The veneer stacks are put into a hot press where pressure and heat are used to provide contact and curing, and the cured panel is then removed and sawn to standard sizes, with 1.22 × 2.44 meters (4 × 8 feet) sheets being the most common. Plywood is made from various species: in the SE, it is made primarily from southern pine, which are mainly comprised of loblolly pine (*P. taeda* L.) and slash pine (*P. elliottii* Engelm.). The total softwood plywood production in 2000 for the US was 15,464,000 m^3 (17,475,000 thousand square feet (MSF) 3/8-inch equivalence) (APA 2001). This production represents 59% of structural panel production in the U.S., with the remainder being oriented strandboard (OSB).

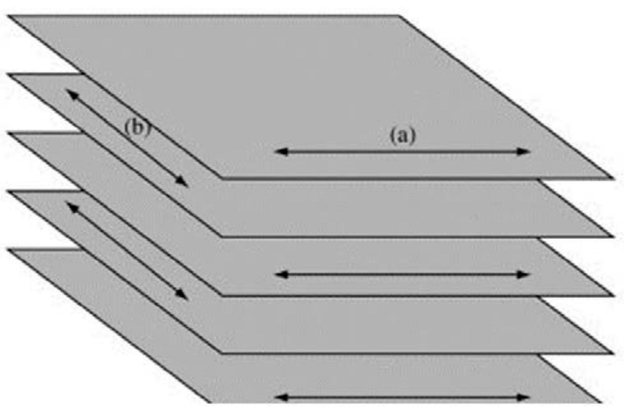

Figure 1 Position of layers in plywood

3.1 Functional and declared unit

In accordance with the PCR (2011), the declared unit for plywood 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 MSF (1000 square feet) is equal to 0.8849 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 softwood plywood. The forest resources system boundary includes: planting the seedlings, forest management which included site preparation on all hectares, fertilization and thinning on a subset of hectares, and final harvest with the transportation of logs, and plywood manufacturing (Figure 2). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. The plywood manufacturing complex was divided into seven process units: debarking and bucking, log conditioning, log peeling, veneer drying, panel pressing, trimming, and energy generation, and planing (Figure 2). Separating the LCI into these unit processes is necessary to ensure accurate allocation of burdens to some co-products that leave the mill prior to drying, as that unit process has the most significant environmental load.

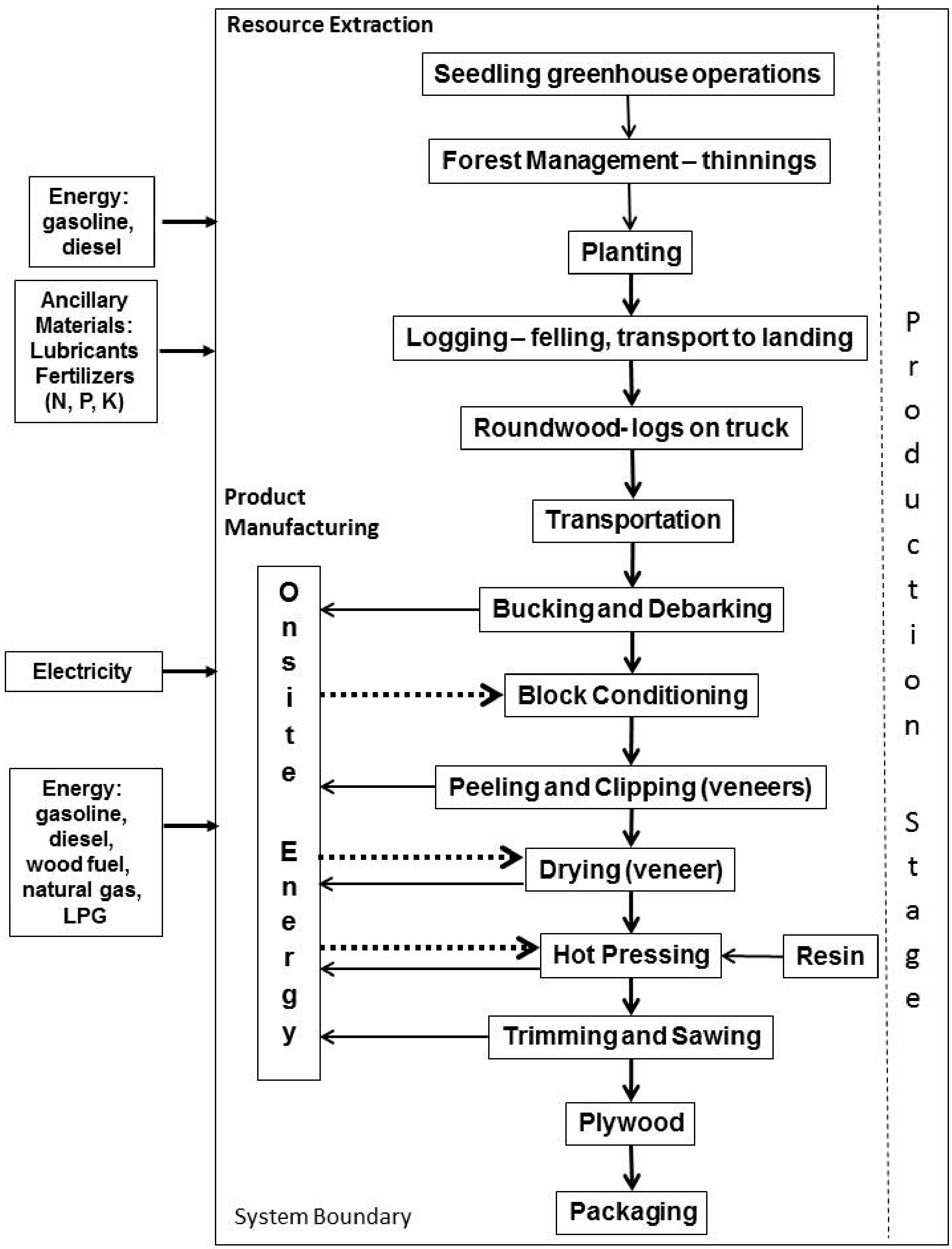

Figure 2 Processes included in the cradle to gate LCA for SE softwood Plywood.

3.3 Description of data/Process Description

3.3.1 Forestry Operations

Forestry operations include growing seedlings, 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, thinning, fertilization, and harvest operations. The primary output product for this analysis is a log destined for the plywood mill or plywood mill. 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 softwood plywood 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 and thinning activity, 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 the potential productivity gains from future technologies. Outputs representing quantities of product, measures of consumed resources, and the emission factors associated with those resources were developed as a weighted average across the hectares managed for timber production. These quantities of product are used as inputs to the wood product manufacturing LCI and the consumed resources and emission factors 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). 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).

Inputs to the forest resources system include site preparation activities required to prepare a site for planting, seedlings, electrical energy required to operate forest nursery pumps and to keep seedlings cool for planting, the human effort required to hand plant seedlings, fertilizer used during seedling production and stand growth, and the fuel and lubricants needed to power and maintain the harvesting system(s) equipment. The primary output product for this analysis is a log destined for the plywood mill. The co-product, non-merchantable slash, is generally left at a landing and disposed of through mechanical activities or prescribed fire.

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, 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. Primary transportation is 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 capital-intensive 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

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).

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 the 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 m3/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	*0.054*
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 typically arrive at the mill by truck. For the SE the average haul distance is 156 km (Table 5) from forest landing to plywood production. Dry veneer and resin were delivered to the plywood mill requiring an additional 246 km and 158 km, respectively.

Table 5 Average delivery distance (one-way) for materials to plywood mill, SE.

Material delivered to mill	Delivery Distance (km)	
	km	**miles**
Logs with bark	156	97
Purchased veneer	246	153
Purchased wood fuel	103	64
Phenol-formaldehyde resin	158	98

3.3.2.2 Energy use and generation

To produce plywood, heat and steam are used for conditioning logs, drying veneer, and pressing panels. The boiler processes (energy generation) encompass fuel storage, the boiler, and steam distribution system. Both wood-fired and natural gas boilers are used by SE softwood plywood mills (Table 6). For the wood boiler, wood waste from various plywood operations is used for fuel. Inputs include green and dry wood waste and bark. Outputs include wood fuel on an oven dry basis.

Table 6 Boiler energy requirements for conditioning, drying, and pressing processes used in plywood production for the SE.

Fuel Inputs	Conditioning	Drying	Pressing
	MJ/m^3		
Wood fuel	344.80	2241.92	448.25
Natural gas	0.00	315.20	0.00
Total	344.80	2557.12	448.25
Percent %	10.3%	76.3%	13.4%

Wood fuel used represented 91% of the total energy requirement for producing plywood with the remainder from natural gas. To produce plywood, heat and steam are used for conditioning logs, drying veneer, and pressing panels. SE softwood plywood mills reported using both natural gas and wood waste fuels as boiler inputs (Table 6). Wood fuel used represented 91% of the total energy wood waste with the remainder from natural gas. Veneer drying used the dominant amount of energy for heating (76%), followed by hot pressing (13%) and conditioning (10%) (Table 6). The USLCI database was used for boiler processes inputting natural gas or wood fuel (NREL 2012). These boiler processes are based on the US Environmental Protection Agency (EPA) AP-42, Compilation of Air Pollutant Emission Factors (EPA 1998, 2006). The AP-42 emission factors assume no emission controls and therefore likely over-estimate the impact factors for wood emissions (Table 7).

Table 7 Wood Boiler Process

Product	Value	Unit/m^3
Wood biomass, combusted in industrial boiler	1.00	kg
Materials/fuels	**Value**	**Unit/m^3**
Bark, green	0.7237	kg
Trim waste	0.1237	kg
Wood waste, purchased	0.1526	kg
Emissions to air	**Value**	**Unit/m^3**
Acetaldehyde	7.47E-06	kg
Acrolein	3.60E-05	kg
Antimony	7.11E-08	kg
Arsenic	1.98E-07	kg
Benzene	3.78E-05	kg
Beryllium	9.90E-09	kg
Cadmium	3.69E-08	kg
Carbon dioxide, biogenic	1.76E+00	kg
Carbon monoxide	5.40E-03	kg
Chlorine	7.11E-06	kg
Chromium	1.89E-07	kg
Cobalt	5.85E-08	kg
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	1.50E-08	kg
Formaldehyde	3.96E-05	kg

Hydrogen chloride	1.71E-04	kg
Lead	4.32E-07	kg
Manganese	1.44E-05	kg
Mercury	3.15E-08	kg
Metals, unspecified	3.85E-04	kg
Methane	1.89E-04	kg
Methane, dichloro-, HCC-30	2.61E-06	kg
Naphthalene	8.73E-07	kg
Nickel	2.97E-07	kg
Nitrogen oxides	1.17E-04	kg
Nitrogen oxides	1.98E-03	kg
Particulates, > 2.5 um, and < 10um	4.50E-03	kg
Phenols, unspecified	4.59E-07	kg
Selenium	2.52E-08	kg
Sulfur oxides	2.25E-04	kg
TOC, Total Organic Carbon	3.68E-05	kg

Electricity was used in all processes. Electricity was consumed by the debarker, bucker, lathe, pneumatic and mechanical conveying equipment, fans, hydraulic pumps, saws, and a radio-frequency re-dryer (Tables 8-13). Diesel fuel use is attributed solely to log loaders in the "Debarking" sub-unit process (Table 8). As such, all of the diesel use was assigned to this process. Forklift trucks used small amounts of LPG in one or more of the remaining five sub-unit processes (Tables 8 - 13). This fuel use was assigned evenly over the five sub-unit processes from "Conditioning" to "Trimming and Sawing". That meant 20% of the LPG use and emissions were assigned to each of these operations.

3.3.2.3 Debarking and Bucking

The debarking and bucking process includes mechanically removing the bark from the logs and cutting them to the proper length to make peeler "blocks[1]" (Table 8). Co-products generated include bark and some wood waste. Inputs include electricity to operate equipment and diesel fuel for the log haulers.

[1] A block is a log to be used in veneer production that has been cut to a designated length, usually 4 x 8 feet.

Table 8 Unit process inputs/outputs for debarking and bucking to produce 1 m^3 of debarked-bucked log for softwood plywood, SE.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Peeler Blocks	1.00	m^3	88.86
Bark, green	63.33	kg	11.14
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	8.10	kWh	
Diesel	0.55	L	
Transport	168.46	tkm	
Logs	1.11	m^3	
Waste to Treatment	**Value**	**Unit/m^3**	
Solid waste, to landfill	11.17	kg	

3.3.2.4 Conditioning

The peeler blocks are conditioned with steam which makes them easier to peel, reduces veneer breakage, and results in smoother, higher quality veneer. The unit process inputs and outputs for this production step are provided in Table 9. Conditioning of the block involves heating the wood blocks with either hot water or direct steam to improve the quality of peeled veneer. There are no co-products and the inputs include steam and electricity. No solid waste to landfill was reported for SE plywood production. Conditioning consumed 10% of the total heat energy requirements for producing SE plywood.

Table 9 Unit process inputs/outputs for conditioning block to produce 1 m^3 of Conditioned block for softwood plywood, SE.

Products	**Value**	**Unit/m^3**
Conditioned Blocks	1.00	m^3
Materials/fuels	**Value**	**Unit/m^3**
Electricity, at Grid	4.51	kWh
LPG	0.16	L
Wood waste, combusted in industrial boiler	15.41	kg
Peeler Block	1.00	m^3
Waste to Treatment		
Solid waste, to landfill	-	-

3.3.2.5 Log Peeling

The heated blocks are then conveyed to a veneer lathe. Each block is gripped on the ends at the block's geometric center and rotated at high speed. The rotating block is fed against a stationary knife parallel to its length. Veneer is peeled from the block in a continuous, uniformly thin sheet, at a speed of up to 4.1 m/s (13.3 linear ft/s). Veneer thickness can range from 1.6 to 4.8 mm (1/16 to 3/16 in) depending on use. he long sheets of veneer are then transported by conveyor to a clipper where they are clipped into usable widths and defects removed. Co-products represent about 44 percent by mass of the outputs from the peeling process (Table 10). A small amount (7.4%) of green, trimmed veneer is sold off site. The trimmed wet veneer is then transported to the dryers.

Table 10 Unit process inputs/outputs for peeling to produce 1 m^3 of green veneer for softwood plywood, SE.

Products	Value	Unit/m^3	Allocation (%)
Veneer, green	1.00	m^3	56.16
Veneer, green, sold	66.74	kg	7.42
Pulp chips	279.03	kg	31.03
Peeler core[2], green	48.03	kg	5.39
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	20.48	kWh	
LPG	0.29	L	
Conditioned Block	1.781	m^3	
Emissions to air			
Particulates, > 2.5 um, and < 10um	-	-	
Particulates, unspecified	-	-	

3.3.2.6 Veneer Drying

Dryers are used to take the moisture content of green veneer from approximately 25-60% to 3-6% (oven-dry basis). Dryer temperatures are normally in the 149 º- 185 ºC (300 to 365ºF) range; however, the wood veneer does not experience this higher temperature until much of its moisture is evaporated near the output end of the dryer. Several emissions are generated at dryer (Table 11). Veneers are dried in continuous dryers. This is the most energy intensive unit process and uses various heat sources. Co-products include veneer downfall and other wood waste. Air emissions occur as the wood elevates in temperature and the wood dries. Inputs include steam and electricity.

[2] A peeler core is that portion of the block that remains after the veneer has been taken.

Table 11 Unit process inputs/outputs for drying to produce 1 m^3 of dry softwood veneer, SE.

Products	Value	Unit/m^3	Allocation (%)
Veneer, dry	1	m^3	100.00
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	42.70	kWh	
Natural gas, combusted in industrial boiler	7.73	m^3	
LPG	0.29	L	
Wood waste, combusted in industrial boiler	100.14	kg	
Veneer, green	505.00	kg	
Emissions to air	**Value**	**Unit/m^3**	
Acetaldehyde	0.0001	kg	
Formaldehyde	0.0001	kg	
Methanol	0.0003	kg	
Particulates, unspecified	0.0318	kg	
Phenol	0.0001	kg	

3.3.2.7 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 its manufacture 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 was 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 resin at 47.4% non-volatile solids content. The inputs to produce 1.0 kg of neat phenol-formaldehyde (PF) resin at 47.4% non-volatile solids content consist of the two primary chemicals of phenol at 0.244 kg and methanol at 0.209 kg, a lesser amount of sodium hydroxide of 0.061, and 0.349 kg of water. Electricity is used for processing such as fans and pumps, and for operating emissions control equipment, while the natural gas is used for boiler fuel and emission control equipment, and propane is used for fuel in forklifts.

3.3.2.8 Lay-up and Pressing

In the lay-up and pressing process the veneers are coated with phenol-formaldehyde resin and stacked into panels for hot-pressing (Table 12). After drying the veneers are taken to the lay-up area. Adhesive (PF resin) resin is applied to the veneers. After coating with the resin on both sides, the veneers are placed in alternating directions either by hand or machine. Once assembled to the desired amount of veneers, panels are conveyed from the lay-up area to the press. Planes are first subjected to cold pressing to flatten the veneers and transfer the resin to uncoated areas. The panels are then hot pressed. Hot pressing is done in the plywood process to provide intimate contact between veneers while the PF resin cures as a result of temperature in the 163-171^{o}C (325-340^{o}F) range. Emissions are generated from the wood as a result of the high temperatures and the curing of the PF resin. Pressing consumed 13% of the total heat requirements for producing softwood plywood in the SE.

Table 12 Unit process inputs/outputs for pressing veneers to produce 1 m^3 of softwood plywood, SE.

Products	**Value**	**Unit/m^3**
Plywood, pressed	1.00	m^3
Materials/fuels	**Value**	**Unit/m^3**
Electricity, at Grid	14.47	kWh
Wood waste, combusted in industrial boiler	22.61	kg
LPG	0.33	L
Phenol-formaldehyde resin	10.68	kg
Veneer, dry	505.00	kg
Emissions to air	**Value**	**Unit/m^3**
Acetaldehyde	0.0021	kg
Acetone	0.0032	kg
alpha-Pinene	0.0479	kg
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	0.0186	kg
D-limonene	0.0054	kg
Formaldehyde	0.0009	kg
Methanol	0.0685	kg
Methyl ethyl ketone	0.0003	kg
Particulates, unspecified	0.087	kg
Phenol	0.0007	kg
VOC, volatile organic compounds	0.1222	kg

3.3.2.9 Panel Trimming

Panels that require further processing are sent to a finishing area for trimming and sanding depending on their final use (Table 13). The trimming and sawing process the plywood panels coming out of the press are sawn to dimension, usually 1.22 × 2.44 meters (m) (4 × 8 feet). Co-products include plywood trim and sawdust. Emissions include a small amount of particulate.

Table 13 Unit process inputs/outputs for final trimming to produce 1 m^3 softwood plywood , SE.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Plywood, final product	1	m^3	90.11
Panel trim, dry	32.78	kg	5.17
Sawdust, dry	2.27	kg	0.36
Wood fuel, dry	27.55	kg	4.36
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	22.42	kWh	
LPG	0.37	L	
Plywood, pressed	633.60	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	**Value**	**Unit/m^3**	
Particulates, unspecified	0.19	kg	

3.3.2.10 Packaging

Materials used for packaging plywood for shipping are shown in Table 14.

Table 14 Materials used in packaging and shipping per m3, PNW plywood

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 1.00% 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.

In the primary surveys, manufacturers were asked to report total hazard air pollutants (HAPS) specific to their wood products manufacturing process: formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde. If applicable to the wood product, HAPS are reported in Table 16 and would be included in the impact assessment. Table 16 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 plants that would be considered in the upper production for a plywood mill. Five mills provided data for 2000 including plywood and co-product production, raw material inputs, electricity and fuel use, and emissions. In 2000 the total annual softwood plywood production for the SE region was 8,705,646 m^3 (9,838,000 MSF) with the mills providing data representing 14 percent of production (APA 2001).

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 OSB production and the overall CORRIM project can be found in Kline (2004) and Lippke et al. (2004), respectively.

6 Life cycle inventory analysis

6.1 Data collection

Primary data for the LCI was collected through surveys in accordance with CORRIM and ISO 14040 protocols. This study relied almost exclusively on production and emissions data provided by plywood producers from the SE, with some secondary data on electrical grid inputs from the US LCI database (Goemans 2010). Five mills provided data for 2000 in terms of plywood and co-product production, raw materials, electricity and fuel use, and on-site emissions released. The states covered in the SE region included Alabama, Georgia, Louisiana, Mississippi, Florida, Arkansas, and Texas. 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. Milling technology has not changed substantially in the past 10 years so the data likely continue to reflect processes as they are now with one caveat. With the collapse of the US housing market, a lot of smaller inefficient mills were closed during 2006-2010 therefore any future mill surveys are likely to show even better environmental performance than is represented here.

6.2 Calculation rules

Site preparation and planting input data for the SE Forestry Operations were developed from published studies on forest nursery operations (South and Zwolinski 1996) and site preparation production and fuel consumption rates (Frazier et al. 1981). 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 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 m3 of production.

The plywood production survey results for each unit process were converted to a production basis (e.g., logs used per m^3 of plywood produced) and production-weighted averages were calculated for each material. This approach resulted in a plywood production complex that represents a composite of the mills surveyed, but may not represent any mill in particular. The USLCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 7+ (Pré Consultants 2012) was used as the accounting program to track all of the materials.

Missing data is defined as data not reported in surveys by the softwood lumber 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.

6.3 Allocation rules

All allocation was based on the mass of the products and co-products. SE plywood does not have a value differential 10 times greater than the value of the main co-product that is sold outside the mill at today's prices.

6.4 LCI results

Life cycle inventory results for plywood are presented by two life stages, 1) forestry operations, 2) plywood production (Tables 15-18). The majority of the raw material energy consumption occurs during wood production with only a small portion arising from forestry operations. Raw material energy requirements are presented in Table 14 for 1 m^3 of softwood plywood. The majority of the raw material energy consumption occurs during wood production with only a small portion arising from forestry operations. Air emission and emissions to water are reported for forestry operations and plywood production (Table 16 and 17). Plywood production encompasses resin production.

Table 15 Cradle to gate raw material energy consumption per 1 m^3 of softwood plywood, SE.

Fuel	Total	Forestry Operations	Plywood Production
	kg/m^3		
Coal, in ground	34.1810	0.2131	33.9679
Gas, natural, in ground	15.5977	0.7721	14.8256
Oil, crude, in ground	13.6391	3.2116	10.4275
Uranium oxide, in ore	0.0010	0.0000	0.0010
Wood waste	174.3350	0.0000	174.3350

Air emission and emissions to water are reported for forestry operations and plywood production (Table 16). Plywood production encompasses resin production.

Table 16 Cradle to gate air emissions released per 1 m^3 of softwood plywood, SE.

Air Emission[1/]	Total	Forestry Operations	Plywood Production
	kg/m^3		
Carbon dioxide, biogenic	266.5818	0.0091	266.5727
Carbon dioxide, fossil	133.8114	10.5899	123.2216
Nitrogen oxides	0.8991	0.1894	0.7097
Sulfur dioxide	0.8395	0.0243	0.8153
Carbon monoxide	0.8230	0.0000	0.8230
Particulates, > 2.5 um, and < 10um	0.6939	0.0058	0.6881
Particulates, < 2.5 um	0.5843	0.0000	0.5843
Carbon dioxide	0.5421	0.4700	0.0721
Methane	0.3861	0.0219	0.3641
Particulates, unspecified	0.3385	0.0013	0.3372
Carbon monoxide, fossil	0.2910	0.0945	0.1965
VOC, volatile organic compounds	0.1466	0.0056	0.1410
Sulfur oxides	0.0816	0.0105	0.0711
Methanol	0.0675	0.0000	0.0675
Metals, unspecified	0.0582	0.0000	0.0582
alpha-Pinene	0.0470	0.0000	0.0470
Hydrogen chloride	0.0436	0.0001	0.0435
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0401	0.0063	0.0338
Methane, fossil	0.0331	0.0022	0.0308
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	0.0182	0.0000	0.0182
Isoprene	0.0145	0.0002	0.0142
Benzene	0.0105	0.0001	0.0104
Formaldehyde	0.0072	0.0001	0.0071
Cumene	0.0068	0.0000	0.0068
TOC, Total Organic Carbon	0.0056	0.0000	0.0056
Acrolein	0.0054	0.0000	0.0054
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0054	0.0003	0.0051
D-limonene	0.0053	0.0000	0.0053
Dinitrogen monoxide	0.0042	0.0028	0.0014
Acetaldehyde	0.0034	0.0000	0.0033
Acetone	0.0031	0.0000	0.0031
Propene	0.0027	0.0001	0.0025
Hydrogen fluoride	0.0022	0.0000	0.0022
Manganese	0.0022	0.0000	0.0022
Radionuclides (Including Radon)	0.0014	0.0000	0.0014

Air Emission[1/]	Total	Forestry Operations	Plywood Production
	kg/m^3		
Chlorine	0.0011	0.0000	0.0011
Phenol	0.0008	0.0000	0.0008
Particulates, < 10 um	0.0008	0.0000	0.0008
Ammonia	0.0007	0.0004	0.0003
Aldehydes, unspecified	0.0006	0.0001	0.0004
Methane, dichloro-, HCC-30	0.0004	0.0000	0.0004
Methyl ethyl ketone	0.0003	0.0000	0.0003
Hydrocarbons, unspecified	0.0003	0.0000	0.0003
Magnesium	0.0002	0.0000	0.0002
Naphthalene	0.0001	0.0000	0.0001

[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 are all off-site (Table 17). 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 17 Emissions to water released per 1 m^3 of softwood plywood, SE.

Water emission[1/]	Total	Forestry Operations	Plywood Production
	kg/m^3		
Solved solids	5.2387	0.6643	4.5745
Chloride	4.2270	0.5385	3.6885
Sodium, ion	1.1921	0.1519	1.0402
Calcium, ion	0.3760	0.0479	0.3281
Suspended solids, unspecified	0.1804	0.0337	0.1467
COD, Chemical Oxygen Demand	0.1461	0.0050	0.1411
BOD5, Biological Oxygen Demand	0.1271	0.0027	0.1244
Barium	0.0779	0.0150	0.0629
Lithium, ion	0.0749	0.0038	0.0711
Magnesium	0.0735	0.0094	0.0641
Sulfate	0.0308	0.0012	0.0296
TOC, Total Organic Carbon	0.0303	0.0000	0.0303
DOC, Dissolved Organic Carbon	0.0303	0.0000	0.0303
Bromide	0.0251	0.0032	0.0219
Cumene	0.0164	0.0000	0.0164
Fluoride	0.0137	0.0135	0.0002
Iron	0.0134	0.0022	0.0111
Benzene	0.0114	0.0000	0.0114
Phosphate	0.0102	0.0101	0.0000

Water emission[1/]	Total	Forestry Operations	Plywood Production
	kg/m³		
Strontium	0.0064	0.0008	0.0056
Propene	0.0061	0.0000	0.0061
Aluminum	0.0032	0.0011	0.0021
Aluminium	0.0028	0.0000	0.0028
Oils, unspecified	0.0026	0.0003	0.0022
Ammonia	0.0018	0.0003	0.0015
Manganese	0.0004	0.0000	0.0004
Boron	0.0004	0.0000	0.0003
Sulfur	0.0003	0.0000	0.0003
Silver	0.0002	0.0000	0.0002
Toluene	0.0002	0.0000	0.0002
Zinc	0.0001	0.0000	0.0001
Chromium	0.0001	0.0000	0.0001
Benzoic acid	0.0001	0.0000	0.0001
Detergent, oil	0.0001	0.0000	0.0001

[1/]Due to large amount of air emissions, total 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 18).

Table 18 Waste to treatment per 1 m3 of dry softwood plywood, SE.

Waste to treatment	Total	Forestry Operations	Plywood Production
	kg/m³		
Solid waste	38.28	0.19	38.09

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 18. 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 19 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. 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 20 provides the environmental impact by category for softwood plywood produced in the SE region. It 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 20. For GWP, 91 percent of the CO_2 equivalent emissions come from producing plywood, with remainder assigned to forestry operations.

Table 20 Environmental performance of 1 m^3 softwood plywood, SE.

Impact category	Unit	Total	Forestry Operations	Plywood Production
Global warming potential (GWP)	kg CO_2 equiv	146.07	12.49	133.59
Acidification Potential	H+ moles equiv	84.98	9.40	75.59
Eutrophication Potential	kg N equiv	0.07920	0.03318	0.04602
Ozone depletion Potential	kg CFC-11 equiv	0.00000	0.00000	0.00000
Smog Potential	kg O3 equiv	23.58	4.72	18.86
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Plywood Production**
Non-renewable fossil	MJ	2363.79	193.71	2169.99
Non-renewable nuclear	MJ	367.89	1.86	366.03
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	0.27	0.00	0.27
Renewable, biomass	MJ	3647.09	0.00	3647.09
Material resources consumption (Non-fuel resouces)	**Unit**	**Total**	**Forestry Operations**	**Plywood Production**
Non-renewable materials	kg	3.36	0.00	3.36
Renewable materials	kg	472.07	0	472.07
Fresh water	L	497.10	0.05	497.05
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Plywood Production**
Solid waste	kg	38.28	0.19	38.09

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 CO2 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, 146 kg CO_2e were released in the production of 1 m^3 of plywood. That same 1 m^3 of plywood stores 936 kg CO_2e (Table 21).

Table 21 Carbon balance per 1 m^3 softwood plywood, SE.

	kg CO_2 equivalent
released forestry operations	12.49
released manufacturing	133.59
CO_2 eq. stored in product	935.92

9 Conclusions

The cradle to gate LCA for softwood plywood includes the LCI of forest resources that rely on secondary and tertiary data and the LCI of manufacturing and resin production that relies on primary survey data and secondary data on process inputs such as natural gas, diesel, and electricity. The survey results were representative of the forest operations in the region that would produce southern pine plywood that are reported as outputs for the region. The survey data are representative of the plywood processes and production volumes consistent with trade association production data.

Emissions from the forest resources LCI and LCIA are small relative to manufacturing emissions. The plywood manufacturing process has some onsite emissions from drying veneers and pressing the panels with the resins. These emissions were reported by the mills in the surveys. Of the total CO_2 emissions, both biogenic and fossil, 67 percent were biogenic based emitted from the combustion of wood fuel.

Energy use for manufacturing plywood is dominated by the combustion of wood fuel (biomass), which is comprised of wood and bark waste generated during the manufacture of plywood. Wood fuel represented 77% of the mill site use of heat energy. Energy generated by renewable fuels, such as woody biomass, represents about 57 percent of the total energy from cradle to gate. Of the renewable biomass fuels, 99 percent were wood fuel from the plywood production (85%) and purchased wood waste (15%). 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. Forestry operations consumed exclusively (99%) fossil fuels. Plywood production alone consumed 59 percent of the total energy from biomass (wood fuel) and 35 percent from nonrenewable fossil fuels.

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. Under the TRACI method, combustion of fossil fuels generates CO_2 and other air emissions that contribute to the global warming impact. Using the TRACI method 146 kg CO_2e were released in the production of 1 m^3 of plywood. That same 1 m^3 of plywood stores 936 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 per1 m^3 of softwood plywood, SE.

Air Emissions	Unit	Total	Forestry Operations	Plywood Production
2,4-D	kg	1.37E-09		1.37E-09
2-Chloroacetophenone	kg	3.90E-10	2.54E-11	3.65E-10
5-methyl Chrysene	kg	3.25E-10	2.05E-12	3.23E-10
Acenaphthene	kg	7.53E-09	4.76E-11	7.48E-09
Acenaphthylene	kg	3.69E-09	2.33E-11	3.67E-09
Acetaldehyde	kg	3.35E-03	4.33E-05	3.31E-03
Acetochlor	kg	1.90E-08		1.90E-08
Acetone	kg	3.11E-03	0.00E+00	3.11E-03
Acetophenone	kg	8.36E-10	5.44E-11	7.82E-10
Acrolein	kg	5.45E-03	5.25E-06	5.44E-03
Alachlor	kg	1.87E-09		1.87E-09
Aldehydes, unspecified	kg	5.56E-04	1.31E-04	4.26E-04
alpha-Pinene	kg	4.70E-02	0.00E+00	4.70E-02
Ammonia	kg	6.80E-04	4.24E-04	2.56E-04
Ammonium chloride	kg	5.12E-05	2.59E-07	5.09E-05
Anthracene	kg	3.10E-09	1.96E-11	3.08E-09
Antimony	kg	1.10E-05	1.68E-09	1.10E-05
Arsenic	kg	3.62E-05	5.16E-08	3.61E-05
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	1.05E-02	5.31E-05	1.04E-02
Benzene, chloro-	kg	1.23E-09	7.98E-11	1.15E-09
Benzene, ethyl-	kg	8.15E-08	3.41E-10	8.11E-08
Benzo(a)anthracene	kg	1.18E-09	7.46E-12	1.17E-09
Benzo(a)pyrene	kg	5.61E-10	3.55E-12	5.57E-10
Benzo(b,j,k)fluoranthene	kg	1.62E-09	1.03E-11	1.61E-09
Benzo(ghi)perylene	kg	3.99E-10	2.52E-12	3.96E-10
Benzyl chloride	kg	3.90E-08	2.54E-09	3.65E-08
Beryllium	kg	1.86E-06	2.59E-09	1.86E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	kg	1.82E-02	0.00E+00	1.82E-02
Biphenyl	kg	2.51E-08	1.59E-10	2.49E-08
Bromoform	kg	2.17E-09	1.42E-10	2.03E-09
Bromoxynil	kg	3.31E-10		3.31E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	5.42E-03	2.72E-04	5.15E-03

Air Emissions	Unit	Total	Forestry Operations	Plywood Production
Butadiene	kg	2.24E-06	2.21E-06	3.22E-08
Cadmium	kg	6.69E-06	1.32E-08	6.68E-06
Carbofuran	kg	2.83E-10		2.83E-10
Carbon dioxide	kg	5.42E-01	4.70E-01	7.21E-02
Carbon dioxide, biogenic	kg	2.67E+02	9.09E-03	2.67E+02
Carbon dioxide, fossil	kg	1.34E+02	1.06E+01	1.23E+02
Carbon disulfide	kg	7.25E-09	4.72E-10	6.77E-09
Carbon monoxide	kg	8.23E-01	3.31E-05	8.23E-01
Carbon monoxide, fossil	kg	2.91E-01	9.45E-02	1.96E-01
Chloride	kg	4.41E-10	6.97E-12	4.34E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	1.24E-07		1.24E-07
Chlorine	kg	1.08E-03	0.00E+00	1.08E-03
Chloroform	kg	3.29E-09	2.14E-10	3.07E-09
Chlorpyrifos	kg	2.17E-09		2.17E-09
Chromium	kg	3.29E-05	3.76E-08	3.28E-05
Chromium VI	kg	1.17E-06	7.37E-09	1.16E-06
Chrysene	kg	1.48E-09	9.33E-12	1.47E-09
Cobalt	kg	1.07E-05	6.65E-08	1.07E-05
Copper	kg	9.58E-08	6.84E-10	9.51E-08
Cumene	kg	6.84E-03	1.92E-11	6.84E-03
Cyanazine	kg	3.26E-10		3.26E-10
Cyanide	kg	1.39E-07	9.07E-09	1.30E-07
Dicamba	kg	1.92E-09		1.92E-09
Dimethenamid	kg	4.54E-09		4.54E-09
Dimethyl ether	kg	4.95E-05		4.95E-05
Dinitrogen monoxide	kg	4.15E-03	2.76E-03	1.40E-03
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	2.25E-06		2.25E-06
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.32E-11	2.17E-13	1.30E-11
Dipropylthiocarbamic acid S-ethyl ester	kg	3.11E-09		3.11E-09
D-limonene	kg	5.27E-03	0.00E+00	5.27E-03
Ethane, 1,1,1-trichloro-, HCFC-140	kg	2.36E-09	3.74E-10	1.99E-09
Ethane, 1,2-dibromo-	kg	6.69E-11	4.35E-12	6.25E-11
Ethane, 1,2-dichloro-	kg	2.23E-09	1.45E-10	2.08E-09
Ethane, chloro-	kg	2.34E-09	1.52E-10	2.19E-09
Ethene, tetrachloro-	kg	6.48E-07	4.74E-09	6.44E-07
Ethene, trichloro-	kg	6.15E-14		6.15E-14
Fluoranthene	kg	1.05E-08	6.62E-11	1.04E-08
Fluorene	kg	1.34E-08	8.49E-11	1.33E-08
Fluoride	kg	8.94E-06	5.47E-06	3.47E-06
Formaldehyde	kg	7.19E-03	6.72E-05	7.12E-03
Furan	kg	7.23E-11	4.08E-13	7.19E-11
Glyphosate	kg	4.08E-09		4.08E-09

Air Emissions	Unit	Total	Forestry Operations	Plywood Production
Heat, waste	MJ	7.17E+00		7.17E+00
Hexane	kg	3.73E-09	2.43E-10	3.49E-09
Hydrazine, methyl-	kg	9.47E-09	6.17E-10	8.86E-09
Hydrocarbons, unspecified	kg	2.96E-04	1.49E-06	2.94E-04
Hydrogen	kg	3.69E-06		3.69E-06
Hydrogen chloride	kg	4.36E-02	1.17E-04	4.35E-02
Hydrogen fluoride	kg	2.21E-03	1.38E-05	2.20E-03
Hydrogen sulfide	kg	1.43E-11	2.25E-13	1.40E-11
Indeno(1,2,3-cd)pyrene	kg	9.01E-10	5.69E-12	8.95E-10
Iron	kg	2.14E-07		2.14E-07
Isophorone	kg	3.23E-08	2.10E-09	3.02E-08
Isoprene	kg	1.45E-02	2.28E-04	1.42E-02
Kerosene	kg	2.45E-05	1.24E-07	2.44E-05
Lead	kg	7.21E-05	6.82E-08	7.20E-05
Magnesium	kg	1.62E-04	1.03E-06	1.61E-04
Manganese	kg	2.18E-03	7.57E-08	2.18E-03
MCPA	kg	2.55E-11		2.55E-11
Mercaptans, unspecified	kg	1.21E-05	7.87E-07	1.13E-05
Mercury	kg	6.37E-06	1.46E-08	6.35E-06
Metals, unspecified	kg	5.82E-02	2.58E-14	5.82E-02
Methacrylic acid, methyl ester	kg	1.11E-09	7.26E-11	1.04E-09
Methane	kg	3.86E-01	2.19E-02	3.64E-01
Methane, bromo-, Halon 1001	kg	8.92E-09	5.81E-10	8.34E-09
Methane, dichloro-, HCC-30	kg	3.99E-04	7.63E-08	3.99E-04
Methane, dichlorodifluoro-, CFC-12	kg	1.54E-09	3.73E-10	1.17E-09
Methane, fossil	kg	3.31E-02	2.24E-03	3.08E-02
Methane, monochloro-, R-40	kg	2.95E-08	1.92E-09	2.76E-08
Methane, tetrachloro-, CFC-10	kg	1.03E-07	3.73E-11	1.03E-07
Methanol	kg	6.75E-02	0.00E+00	6.75E-02
Methyl ethyl ketone	kg	3.40E-04	1.42E-09	3.40E-04
Methyl methacrylate	kg	2.05E-12		2.05E-12
Metolachlor	kg	1.50E-08		1.50E-08
Metribuzin	kg	6.95E-11		6.95E-11
Naphthalene	kg	1.32E-04	1.42E-08	1.32E-04
Nickel	kg	5.52E-05	8.33E-07	5.44E-05
Nitrogen oxides	kg	8.99E-01	1.89E-01	7.10E-01
Nitrogen, total	kg	1.06E-04	1.06E-04	1.83E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	4.01E-02	6.34E-03	3.38E-02
N-Nitrodimethylamine	kg	1.38E-14		1.38E-14
Organic acids	kg	1.88E-07	9.50E-10	1.87E-07
Organic substances, unspecified	kg	1.03E-04	5.79E-07	1.02E-04
PAH, polycyclic aromatic hydrocarbons	kg	9.60E-06	9.48E-06	1.14E-07

Air Emissions	Unit	Total	Forestry Operations	Plywood Production
Paraquat	kg	3.03E-10		3.03E-10
Parathion, methyl	kg	2.29E-10		2.29E-10
Particulates	kg	2.42E-05		2.42E-05
Particulates, < 10 um	kg	8.40E-04	0.00E+00	8.40E-04
Particulates, < 2.5 um	kg	5.84E-01	0.00E+00	5.84E-01
Particulates, > 2.5 um, and < 10um	kg	6.94E-01	5.81E-03	6.88E-01
Particulates, SPM	kg	8.07E-05		8.07E-05
Particulates, unspecified	kg	3.38E-01	1.31E-03	3.37E-01
Pendimethalin	kg	1.56E-09		1.56E-09
Permethrin	kg	1.40E-10		1.40E-10
Phenanthrene	kg	3.99E-08	2.52E-10	3.96E-08
Phenol	kg	8.46E-04	5.81E-11	8.46E-04
Phenols, unspecified	kg	7.02E-05	3.86E-08	7.02E-05
Phorate	kg	7.18E-11		7.18E-11
Phosphate	kg	2.42E-06	2.42E-06	
Phthalate, dioctyl-	kg	4.07E-09	2.65E-10	3.80E-09
Potassium	kg	3.79E-05		3.79E-05
Propanal	kg	2.12E-08	1.38E-09	1.98E-08
Propene	kg	2.67E-03	1.46E-04	2.52E-03
Propylene oxide	kg	6.91E-08		6.91E-08
Pyrene	kg	4.87E-09	3.08E-11	4.84E-09
Radioactive species, unspecified	Bq	8.32E+05	5.08E+03	8.27E+05
Radionuclides (Including Radon)	kg	1.37E-03	6.92E-06	1.36E-03
Selenium	kg	2.33E-05	1.30E-07	2.32E-05
Simazine	kg	9.84E-10		9.84E-10
Sodium	kg	8.74E-07		8.74E-07
Styrene	kg	1.39E-09	9.07E-11	1.30E-09
Sulfur	kg	4.61E-06		4.61E-06
Sulfur dioxide	kg	8.40E-01	2.43E-02	8.15E-01
Sulfur oxides	kg	8.16E-02	1.05E-02	7.11E-02
Sulfur, total reduced	kg	2.70E-06		2.70E-06
Sulfuric acid, dimethyl ester	kg	2.68E-09	1.74E-10	2.50E-09
Tar	kg	4.96E-10	7.83E-12	4.88E-10
t-Butyl methyl ether	kg	1.95E-09	1.27E-10	1.82E-09
Terbufos	kg	2.45E-09		2.45E-09
TOC, Total Organic Carbon	kg	5.56E-03	0.00E+00	5.56E-03
Toluene	kg	2.37E-05	2.31E-05	6.49E-07
Toluene, 2,4-dinitro-	kg	1.56E-11	1.02E-12	1.46E-11
Vinyl acetate	kg	4.24E-10	2.76E-11	3.96E-10
VOC, volatile organic compounds	kg	1.47E-01	5.57E-03	1.41E-01
Xylene	kg	1.65E-05	1.61E-05	3.82E-07
Zinc	kg	2.23E-06	1.96E-06	2.77E-07

13.2 Water Emissions

Table 22 Emissions to water released per 1 m^3 of softwood plywood, SE.

Water Emissions	Unit	Total	Forestry Operations	Plywood Production
2,4-D	kg	5.86E-11		5.86E-11
2-Hexanone	kg	7.64E-07	9.74E-08	6.67E-07
2-Propanol	kg	2.54E-09		2.54E-09
4-Methyl-2-pentanone	kg	4.92E-07	6.27E-08	4.29E-07
Acetochlor	kg	8.13E-10		8.13E-10
Acetone	kg	1.17E-06	1.49E-07	1.02E-06
Acidity, unspecified	kg	5.67E-15		5.67E-15
Acids, unspecified	kg	3.61E-06	1.46E-10	3.61E-06
Alachlor	kg	8.00E-11		8.00E-11
Aluminium	kg	2.77E-03	0.00E+00	2.77E-03
Aluminum	kg	3.19E-03	1.09E-03	2.10E-03
Ammonia	kg	1.78E-03	2.61E-04	1.52E-03
Ammonia, as N	kg	4.65E-09	7.35E-11	4.58E-09
Ammonium, ion	kg	1.09E-05	5.53E-08	1.09E-05
Antimony	kg	3.43E-06	6.79E-07	2.76E-06
Arsenic, ion	kg	3.34E-05	8.48E-06	2.49E-05
Atrazine	kg	1.58E-09		1.58E-09
Barium	kg	7.79E-02	1.50E-02	6.29E-02
Bentazone	kg	6.46E-12		6.46E-12
Benzene	kg	1.14E-02	2.50E-05	1.14E-02
Benzene, 1-methyl-4-(1-methylethyl)-	kg	1.17E-08	1.49E-09	1.02E-08
Benzene, ethyl-	kg	1.10E-05	1.41E-06	9.64E-06
Benzene, pentamethyl-	kg	8.77E-09	1.12E-09	7.65E-09
Benzenes, alkylated, unspecified	kg	3.01E-06	5.96E-07	2.42E-06
Benzoic acid	kg	1.19E-04	1.51E-05	1.04E-04
Beryllium	kg	1.43E-06	2.12E-07	1.22E-06
Biphenyl	kg	1.95E-07	3.86E-08	1.56E-07
BOD5, Biological Oxygen Demand	kg	1.27E-01	2.70E-03	1.24E-01
Boron	kg	3.67E-04	4.68E-05	3.20E-04
Bromide	kg	2.51E-02	3.19E-03	2.19E-02
Bromoxynil	kg	8.55E-12		8.55E-12
Cadmium, ion	kg	5.86E-06	2.09E-06	3.76E-06
Calcium, ion	kg	3.76E-01	4.79E-02	3.28E-01
Carbofuran	kg	1.21E-11		1.21E-11
CFCs, unspecified	kg	2.54E-09		2.54E-09
Chloride	kg	4.23E+00	5.39E-01	3.69E+00
Chlorpyrifos	kg	9.32E-11		9.32E-11
Chromate	kg	3.38E-13		3.38E-13
Chromium	kg	1.20E-04	3.41E-05	8.59E-05

Water Emissions	Unit	Total	Forestry Operations	Plywood Production
Chromium VI	kg	4.76E-07	1.15E-07	3.61E-07
Chromium, ion	kg	4.26E-05	3.54E-06	3.91E-05
Cobalt	kg	2.59E-06	3.30E-07	2.26E-06
COD, Chemical Oxygen Demand	kg	1.46E-01	5.00E-03	1.41E-01
Copper, ion	kg	3.68E-05	7.01E-06	2.98E-05
Cumene	kg	1.64E-02	0.00E+00	1.64E-02
Cyanazine	kg	1.40E-11		1.40E-11
Cyanide	kg	8.50E-09	1.08E-09	7.42E-09
Decane	kg	3.41E-06	4.35E-07	2.98E-06
Detergent, oil	kg	1.09E-04	1.30E-05	9.59E-05
Dibenzofuran	kg	2.23E-08	2.84E-09	1.94E-08
Dibenzothiophene	kg	1.86E-08	2.42E-09	1.62E-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	3.03E-02	4.49E-13	3.03E-02
Docosane	kg	1.25E-07	1.60E-08	1.09E-07
Dodecane	kg	6.47E-06	8.25E-07	5.65E-06
Eicosane	kg	1.78E-06	2.27E-07	1.55E-06
Fluorene, 1-methyl-	kg	1.33E-08	1.70E-09	1.16E-08
Fluorenes, alkylated, unspecified	kg	1.74E-07	3.45E-08	1.40E-07
Fluoride	kg	1.37E-02	1.35E-02	1.77E-04
Fluorine	kg	9.07E-08	1.72E-08	7.35E-08
Furan	kg	9.32E-11		9.32E-11
Glyphosate	kg	1.75E-10		1.75E-10
Hexadecane	kg	7.06E-06	9.00E-07	6.16E-06
Hexanoic acid	kg	2.46E-05	3.13E-06	2.15E-05
Hydrocarbons, unspecified	kg	9.32E-08	5.62E-13	9.32E-08
Iron	kg	1.34E-02	2.23E-03	1.11E-02
Lead	kg	5.37E-05	1.01E-05	4.36E-05
Lead-210/kg	kg	1.22E-14	1.55E-15	1.06E-14
Lithium, ion	kg	7.49E-02	3.76E-03	7.11E-02
Magnesium	kg	7.35E-02	9.37E-03	6.41E-02
Manganese	kg	4.09E-04	1.66E-05	3.93E-04
MCPA	kg	1.09E-12		1.09E-12
Mercury	kg	1.43E-07	8.01E-08	6.29E-08
Metallic ions, unspecified	kg	2.48E-09	6.86E-12	2.48E-09
Methane, monochloro-, R-40	kg	4.71E-09	6.00E-10	4.11E-09
Methyl ethyl ketone	kg	9.42E-09	1.20E-09	8.22E-09
Metolachlor	kg	6.42E-10		6.42E-10

Water Emissions	Unit	Total	Forestry Operations	Plywood Production
Metribuzin	kg	2.98E-12		2.98E-12
Molybdenum	kg	2.69E-06	3.43E-07	2.35E-06
m-Xylene	kg	3.55E-06	4.52E-07	3.09E-06
Naphthalene	kg	2.13E-06	2.72E-07	1.86E-06
Naphthalene, 2-methyl-	kg	1.85E-06	2.36E-07	1.62E-06
Naphthalenes, alkylated, unspecified	kg	4.93E-08	9.76E-09	3.96E-08
n-Hexacosane	kg	7.81E-08	9.95E-09	6.82E-08
Nickel	kg	2.75E-05	6.02E-06	2.15E-05
Nickel, ion	kg	2.94E-13		2.94E-13
Nitrate	kg	3.02E-07	4.92E-14	3.02E-07
Nitrate compounds	kg	1.26E-10	1.98E-12	1.24E-10
Nitric acid	kg	2.82E-07	4.45E-09	2.77E-07
Nitrogen, total	kg	3.77E-05	1.38E-07	3.76E-05
o-Cresol	kg	3.37E-06	4.29E-07	2.94E-06
Octadecane	kg	1.75E-06	2.22E-07	1.52E-06
Oils, unspecified	kg	2.56E-03	3.33E-04	2.22E-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	3.63E-06	4.63E-07	3.17E-06
Pendimethalin	kg	6.68E-11		6.68E-11
Permethrin	kg	6.00E-12		6.00E-12
Phenanthrene	kg	2.24E-08	3.70E-09	1.87E-08
Phenanthrenes, alkylated, unspecified	kg	2.05E-08	4.05E-09	1.64E-08
Phenol	kg	2.14E-05	5.09E-06	1.63E-05
Phenol, 2,4-dimethyl-	kg	3.28E-06	4.18E-07	2.86E-06
Phenols, unspecified	kg	3.44E-05	2.28E-06	3.21E-05
Phorate	kg	1.86E-12		1.86E-12
Phosphate	kg	1.02E-02	1.01E-02	2.27E-05
Phosphorus	kg	5.21E-06		5.21E-06
Phosphorus compounds, unspecified	kg	3.44E-08		3.44E-08
Phosphorus, total	kg	3.07E-06		3.07E-06
Process solvents, unspecified	kg	9.32E-09		9.32E-09
Propene	kg	6.06E-03	0.00E+00	6.06E-03
Radioactive species, Nuclides, unspecified	Bq	1.59E+03	8.03E+00	1.58E+03
Radium-226/kg	kg	4.23E-12	5.39E-13	3.69E-12
Radium-228/kg	kg	2.16E-14	2.76E-15	1.89E-14
Selenium	kg	4.50E-06	1.51E-07	4.35E-06
Silver	kg	2.45E-04	3.13E-05	2.14E-04
Simazine	kg	4.22E-11		4.22E-11
Sodium, ion	kg	1.19E+00	1.52E-01	1.04E+00
Solids, inorganic	kg	7.16E-10	1.13E-11	7.04E-10

Water Emissions	Unit	Total	Forestry Operations	Plywood Production
Solved solids	kg	5.24E+00	6.64E-01	4.57E+00
Strontium	kg	6.38E-03	8.13E-04	5.57E-03
Styrene	kg	2.16E-10		2.16E-10
Sulfate	kg	3.08E-02	1.20E-03	2.96E-02
Sulfide	kg	3.40E-05	5.90E-07	3.34E-05
Sulfur	kg	3.10E-04	3.95E-05	2.71E-04
Sulfuric acid	kg	8.15E-11		8.15E-11
Suspended solids, unspecified	kg	1.80E-01	3.37E-02	1.47E-01
Tar	kg	7.09E-12	1.12E-13	6.98E-12
Terbufos	kg	6.34E-11		6.34E-11
Tetradecane	kg	2.84E-06	3.61E-07	2.48E-06
Thallium	kg	7.24E-07	1.43E-07	5.81E-07
Tin	kg	1.83E-05	2.95E-06	1.54E-05
Titanium, ion	kg	5.28E-05	1.04E-05	4.23E-05
TOC, Total Organic Carbon	kg	3.03E-02	0.00E+00	3.03E-02
Toluene	kg	1.86E-04	2.36E-05	1.62E-04
Vanadium	kg	3.18E-06	4.05E-07	2.77E-06
Waste water/m3	m3	7.68E-04		7.68E-04
Xylene	kg	9.77E-05	1.26E-05	8.50E-05
Yttrium	kg	7.89E-07	1.00E-07	6.88E-07
Zinc	kg	1.49E-04	2.54E-05	1.24E-04
Zinc, ion	kg	4.11E-07		4.11E-07