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

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1 Background

CORRIM, the Consortium for Research on Renewable Industrial Materials, has derived life cycle inventory (LCI) data for major wood products and wood production regions in the United States. 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 planed dry softwood 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, 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 2.0 (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 reports by Milota et al. (2004, 2005) and Johnson et al. (2005). Updates in this report from the original Milota report include: wood combustion boiler updates, electricity grid updates, results expressed per unit of final product (1 m^3 planed dry softwood lumber), and an LCIA. Updates to the forestry operations report include electricity grid updates (Goemans 2010) and an LCIA using the TRACI v4.0 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 planed dry 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 was to develop an LCI and LCIA for the production of planed dry dimension (framing or construction) lumber from logs using practices and technology common to the SE region. It covers the impacts in terms of input materials, fuels, and electricity through the outputs of product, co-products, and emissions (Milota et al. 2004). The logs are obtained from the forest resource base located in Georgia, Alabama, Mississippi, and Louisiana as representative of the region. Data for the life cycle assessment (LCA) are based on manufacturing gate to gate LCI's from CORRIM reports (Milota et al. 2004) and forest resources cradle to gate LCI's specific to the region (Johnson et al 2005). The report does not consider how the wood was used which requires a comparison to the impact of substitute products.

3 Description of Product

Softwood lumber is used in construction for both structural and non-structural purposes. Softwood lumber has been produced into a wide variety of products from many different species. However, almost all softwood lumber is produced as dimension lumber which is nominally 38 mm to 89 mm thick (2 to 4 inches) and 89 mm to 305 mm wide (4 to 12 inches) (Figure 1). Dimension lumber and boards of some species may be green or dry but most lumber produced in the USA is dried. By definition, dry boards and dimension lumber has been seasoned or dried to a maximum moisture content of 19%. Lumber can also be produced either rough or surfaced (planed). Rough lumber serves as a raw material for further manufacture and also for some decorative purposes. For example, a roughsawn surface is common in post and timber products. Surfaced or planed lumber has been surfaced by a machine on one side or two sides, one edge or two edges or combinations of sides and edges. Lumber is surfaced to attain smoothness of surface and uniformity of size. This LCA report is for planed (surfaced), dry, dimension lumber produced from logs.

Figure 1 Dimension lumber.

3.1 Functional and declared unit

In accordance with the PCR (2011), the declared unit for lumber 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 MBF (1000 board feet[1]) is equal to 1.624 m^3 (actual[2]). All input and output data were allocated to the

[1] Board feet – the basic unit of measure of lumber (US). One board foot is equal to a 1-inch board, 12 inches in width and 1 foot in length.
[2] Actual size – the finished size, as opposed to the nominal size, of a piece of lumber.

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 Southeast (Johnson et al. 2005) and ends with planed dry lumber (Milota et al. 2004, 2005) (Figure 2). 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, final harvest. The transportation of logs from the woods to the mill is accounted for with the plywood manufacturing (Figure 2). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. The sawmill complex was divided into four process units: sawing, drying, energy generation, and planing (Figure 2). Separating the LCI into these unit processes is necessary to ensure accurate allocation of burdens among co-products as some of them leave the mill prior to drying which is the unit process that has the most significant environmental load.

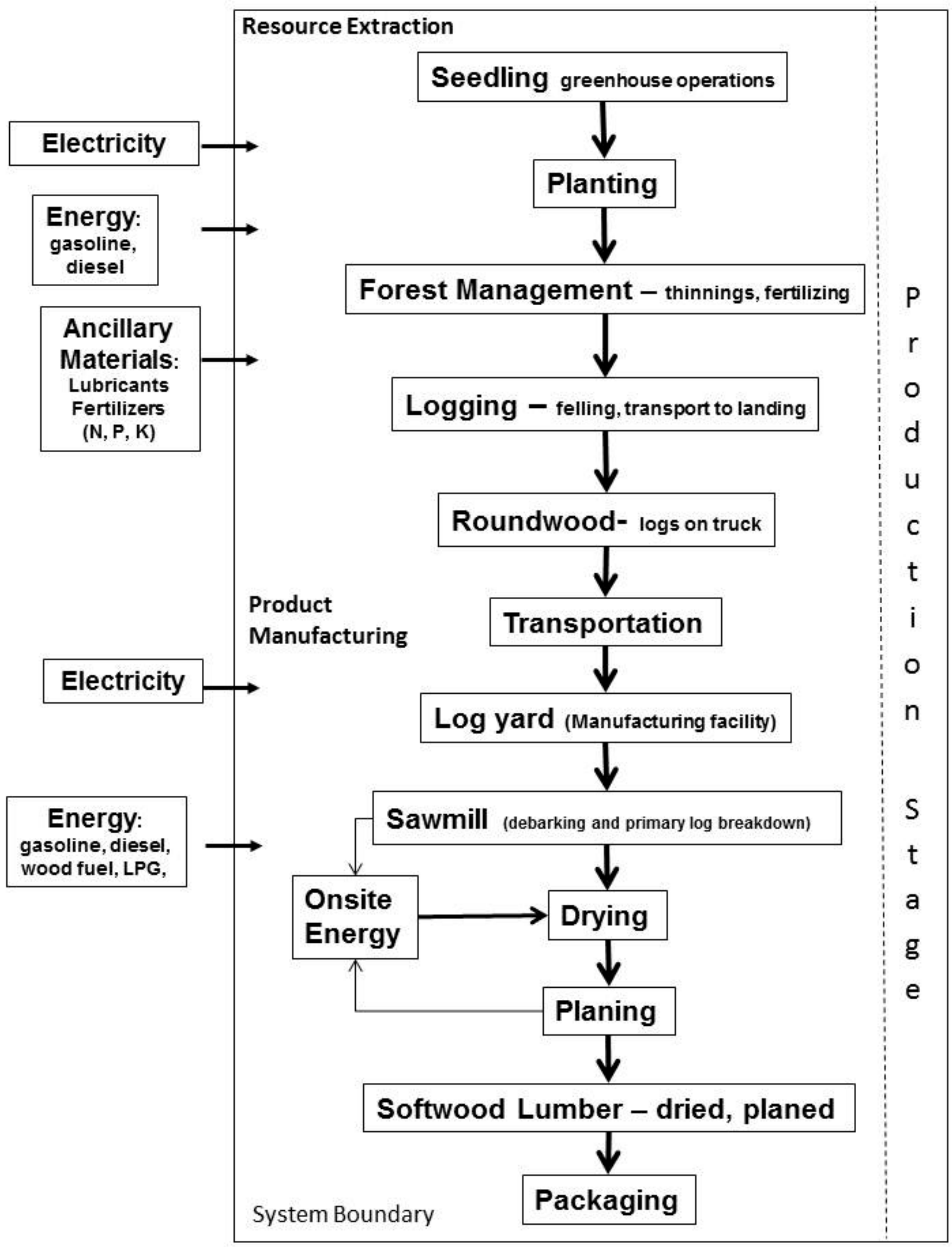

Figure 2 Cradle to gate life cycle stages for softwood lumber production, SE.

3.3 Description of data/Process 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 lumber 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 lumber 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 wood product 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 (Table 1). 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 inputs 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	0.08
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 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

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 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		
Diesel and gasoline	L	3.440
Lubricants	L	0.054
Electricity	kWh	0.455

3.3.2 Wood 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. Based on mill surveys the average haul distance from the forestry operations (landing) to sawmills in the SE region was 92 km with a roundwood moisture content of 100% oven dry basis[3]. Transportation is incorporated into the primary log breakdown process (3.3.2.3 Sawing).

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

Material delivered to mill	Delivery Distance (km)	
	km	**miles**
Logs with bark	92	57

3.3.2.2 Energy use and generation

Steam in southern mills was produced using only wood-based materials. For wood-based fuels, this data was collected by surveys and the combustion emissions were used from the USLCI database. The USLCI database was used for boiler combustion of wood fuel (NREL 2012). The boiler process was based on the US Environmental Protection Agency (EPA) AP-42, Compilation of Air Pollutant Emission Factors (EPA 2006). The AP-42 emission factors assume no emission controls and therefore likely over-estimates the impact factors for wood emissions.

The wood boiler used self-generated wood waste (Table 6 and 7). One kg of dry wood material oven dry basis moisture content contained 20.9 MJ. In the SE, the fuel mix was 38% sawdust and 32% bark. For each gigajoule (GJ) of steam produced, 4.89 kWh of electricity was consumed.

Table 6 Boiler inputs for drying per 1 m3 of dry planed softwood lumber, SE

Fuel	Unit	Value (Unit/m^3)	HHV (MJ/kg)	MJ/m^3 of product
Wood waste	kg	110.99	20.90	2,329.69

[3] MC dry basis = 100 x (Wet Wt. - Dry Wt.) / Dry Wt.; MC wet basis = 100 x (Wet Wt .- Dry Wt.) / Wet Wt.

Table 7 Wood Boiler Process.

Product	Value	Unit/m^3
Wood biomass, combusted in industrial boiler	1.00	kg
Avoided products		
Electricity, at Grid	0.0002	kWh
Materials/fuels		
Bark, green	0.32	kg
Sawdust, green	0.68	kg
Emissions to air		
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-	7.74E-14	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

Based on the survey data received, electrical use in southern sawmills could not be divided among the unit processes; however data show that on average 93 kWh were used to produce 1 m^3 of planed dry lumber. The electrical use was therefore allocated among the process units using percentages from the PNW survey, with a slightly greater amount allocated to drying and energy generation because there is more water to be removed from southern pine than from PNW species. The final electricity allocation used for this study was 45% to sawing, 25% to drying, 15% to the boiler, and 15% to planing. This allocation was similar to the allocation of Puettmann and Bowyer (2000) that found 28% of a southern mill's electrical use is at the kilns.

3.3.2.3 Log Yard

The log yard process included unloading log trucks, scaling logs (measuring logs for volume), storing logs in decks, water spraying logs to prevent dry-out and blue stain, and transporting logs to the sawmill. Inputs may include gasoline, diesel, and electricity. Outputs include logs with bark. Inputs into this process are incorporated into the primary log breakdown stage (3.4.2.3 Sawing). All flow analyses of wood and bark in the process were determined on an oven-dry weight basis and a green specific gravity[4] of 0.51.

3.3.2.4 Sawing

The sawmill process included debarking logs, sawing logs into rough-green lumber, chipping portions of logs that did not make lumber, sorting rough-green lumber into size classes, and stacking rough-green lumber for drying. Inputs include logs with bark and electricity. Outputs include green lumber, green sawdust, green chips, bark, and green fuel wood. Table 8 lists the inputs and outputs for the sawing processes which produce 1m^3 of rough sawn green lumber. The actual sizes are 43.1 mm thick with a width of 150 mm. This is a larger size than the finished lumber to allow for shrinkage and planing. Rough cut lumber has mass of 510 kg/m^3, which represents 48.9% of the mass of the products and co-products. Approximately 70% of the sawdust and bark are sent to the boiler with the rest being sold off-site.

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

Table 8 Unit process inputs/outputs for sawing for the production of 1 m^3 of rough green lumber (includes log yard activities), SE.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Sawn lumber, rough, green	1.00	m^3	49.63
Sawdust, green	60.50	kg	5.89
Pulp chips, green	323.91	kg	31.52
Bark, green	133.10	kg	12.95
Resources		**Unit/m^3**	
Water, cooling, surface	304.65	L	
Materials/fuels		**Unit/m^3**	
Electricity, at Grid	33.42	kWh	
Diesel	0.5248	L	
LPG	0.0002	L	
Gasoline	0.0885	L	
Roundwood w/ bark	1.9288	m^3	
Transport	176.84	tkm	
Emissions to air		**Unit/m^3**	
Particulates, unspecified	0.8483	kg	
Emissions to soil		**Unit/m^3**	
Bark	13.71	kg	
Wood waste to landfill	0.3728	kg	

Water is mainly used in the process for wetting logs when they are stored prior to sawing. Water usage varied from zero to 822 kg. The high variability arises because not all mills sprinkle logs.

3.3.2.5 Kiln Drying Process

The kiln drying process included loading rough-green stacked lumber into kilns, drying rough-green lumber, and unloading rough-dry stacked lumber from the kilns. The boiler processes included steam production for the dry kilns. Inputs include green lumber, electricity, diesel, and wood fuel. Outputs include dry lumber. The major non-lumber inputs to drying are steam and electricity (Table 9). Electrical use in the dryer represents approximately 25% of that used by the mill complex. Steam comes from wood boilers for the SE softwood lumber processes. Diesel in equipment is used for machinery, such as forklifts. Some air emissions are attributed to drying, including VOCs that are emitted by the wood.

Table 9 Unit process inputs/outputs for kiln drying to produce 1 m3 of rough dry softwood lumber, SE.

Products	**Value**	**Unit/m^3**
Sawn Lumber, rough, kiln dried	1	m^3
Materials/fuels		
Electricity, at Grid	18.55	kWh
Diesel, combusted in industrial boiler	0.10	L
Wood waste, combusted in industrial boiler	111.18	kg
Sawn lumber, rough, green	510.00	kg
Emissions to air		
VOC, volatile organic compounds	0.4911	kg

3.3.2.6 Planing

The planer process included un-stacking rough-dry lumber, planing rough-dry lumber, grading planed lumber, sorting graded lumber, packaging graded lumber, and loading graded lumber for shipment. Inputs include dry lumber, electricity, diesel, and LPG. In the SE region (Table 10), the planing process produced 1 m^3 of planed, dry lumber from rough dry lumber. Electricity is used to operate the planer, saws, conveyers, and other equipment and the other fuels that are used in lumber handling equipment, such as forklifts. No packaging material was reported to be used in the SE lumber production regions. Surveys indicated that all other materials, such as paints for end-sealing, used in the process were minor. The dry sawdust is sold offsite.

In the SE region, the planed dry lumber had a dry mass of 452 kg, which represents 86.1% of the co-product mass from this unit process. Approximately 4% more lineal feet of lumber enters the planer than leaves due to end trimming to improve grade.

Table 10 Unit process inputs/outputs for planing to produce 1 m^3 of planed dry softwood lumber, SE.

Products	**Value**	**Unit/m^3**	**Allocation**
Sawn Lumber, softwood, planed, kiln dried	1	m^3	85%
Sawdust, dry	90.58	kg	15%
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	13.08	kWh	
Diesel	0.2683	L	
LPG	0.0001	L	
Sawn Lumber, kiln dried	599.76	kg	
Wrapping material - Packaging	0.460	kg	
Strap Protectors - Packaging	0.200	kg	
Strapping - Packaging	0.083	kg	
Spacers - Packaging	4.672	kg	

3.3.2.7 Packaging

Materials used for packaging lumber for shipping are shown in Table 11.

Table 11 Materials used in packaging and shipping per m^3, 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 0.90% 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 13 and would be included in the impact assessment. Table 13 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 mills in the SE region. The survey was for dimension lumber produced in the states Georgia, Alabama, Mississippi, and Louisiana which produces 51% of lumber in the SE region. For southern production, the survey was for dimension lumber produced in the southern pine region. A large production sawmill was defined as having at least 121,674 m^3 of production per year. The main wood species consider were Southern pine is used to describe a collection of several pine species (Panshin and de Zeeuw 1980),) and typically includes longleaf pine (*Pinus palustris* Mill.), shortleaf pine (*P. echinata*. Mill.), loblolly pine (*P. taeda* L.), and slash pine (*P. elliottii* Engelm.). Regional softwood lumber production is approximately 36 million cubic meters. The total production of the SE mills was 1.23 million m^3 or 6.3% of the SE regional production.

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 wre scientifically sound, and in conformance with ISO 14040 and CORRIM research protocol (ISO 2006). Complete details of this study for lumber production and the overall CORRIM project can be found in Milota et al. (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 lumber producers from the SE, with some secondary data on electrical grid inputs from the US LCI database (Goemans 2010). Nine sawmills were identified with the assistance of the Southern Forest Products Association as typical large production pine mills in the southeast. Surveys were sent to each of the nine mills. Four mills returned surveys, two from bandmill operations and one each from curve saw and chip and saw operations. These mills provided detailed responses for the material and energy inputs and outputs for each process unit in the sawmill for either calendar year 1999 or 2000. 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

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 m^3 of production.

Three southern mills purchased logs based on mass and the other mills use U.S. South Scribner board foot measurement to calculate log volume. The U.S. South Scribner value was converted to a mass using an average value of 7.25 tons/MBF[5] (thousand board feet). The mass for each mill was then converted to a volume using a wood specific gravity of 0.51 and a moisture content of 100%. The production-weighted average log volume was 3.92 m^3. The resulting log volumes sawn per unit of production calculated for each mill varied by 7.6% around the mean. As a second check, log mass in (dry measure) was within 4.5% of the sum of the co-products mass from the sawing unit process

[5] One thousand cubic feet (MCF) is equivalent to 0.02832 thousand cubic meters (1,000 m^3)

Southern pine lumber ranges from 38-184 mm thick. Most planed dry lumber reported in the surveys was 38 mm in thickness with widths from 63 to 286 mm. The weighted average width was 172 mm. For this analysis the volume of planed, dry lumber produced was assumed to be all 38 by 140 mm, corresponding to U.S. nominal 2 x 6-inch lumber.

The survey results for each unit process were converted to a production basis (e.g., logs used per m^3 of lumber produced) and production-weighted averages were calculated for each material. This approach resulted in a sawmill 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 7.3.3 (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 lumber 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 lumber are presented by two life stages, 1) forestry operations, 2) lumber production (Tables 13-15). 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 12 for 1 m^3 of softwood lumber. Air emissions are reported in Table 13, water emissions are reported in Table 14 and solid waste emissions are reported in Table 15.

Table 12 Raw material energy consumption per 1 m^3 of dry planed softwood lumber, SE.

Fuel	Total	Forestry Operations	Wood Production
	kg/m^3		
Coal, in ground	15.3760	0.1931	15.1829
Gas, natural, in ground	2.5536	0.6997	1.8539
Oil, crude, in ground	6.6782	2.9105	3.7677
Uranium oxide, in ore	0.0004	0.0000	0.0004
Wood waste	112.3031	0.0000	112.3031

Table 13 Air emissions released per 1 m^3 of dry planed softwood lumber, SE.

Air Emission[1/]	Total	Forestry Operations	Wood Production
	kg/m^3		
Carbon dioxide, biogenic	197.6739	0.0082	197.6657
Carbon dioxide, fossil	55.8085	9.5971	46.2114
Carbon monoxide	0.6072	0.0000	0.6072
Nitrogen oxides	0.5837	0.1716	0.4121
Particulates, unspecified	0.5411	0.0012	0.5399
Particulates, > 2.5 um, and < 10um	0.5133	0.0053	0.5080
VOC, volatile organic compounds	0.5056	0.0050	0.5005
Particulates, < 2.5 um	0.4335	0.0000	0.4335
Carbon dioxide	0.4263	0.4259	0.0004
Sulfur dioxide	0.2699	0.0220	0.2479
Carbon monoxide, fossil	0.1691	0.0857	0.0834
Methane	0.1295	0.0199	0.1096
Sulfur oxides	0.0497	0.0095	0.0402
Metals, unspecified	0.0432	0.0000	0.0432
Hydrogen chloride	0.0272	0.0001	0.0271
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0144	0.0057	0.0086
Isoprene	0.0066	0.0002	0.0064
Methane, fossil	0.0066	0.0020	0.0046
Formaldehyde	0.0045	0.0001	0.0045
Benzene	0.0043	0.0000	0.0043
TOC, Total Organic Carbon	0.0041	0.0000	0.0041
Acrolein	0.0040	0.0000	0.0040
Dinitrogen monoxide	0.0034	0.0025	0.0009
Manganese	0.0016	0.0000	0.0016
Hydrogen fluoride	0.0010	0.0000	0.0010
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0009	0.0002	0.0007
Acetaldehyde	0.0009	0.0000	0.0008
Chlorine	0.0008	0.0000	0.0008
Radionuclides (Including Radon)	0.0006	0.0000	0.0006
Ammonia	0.0005	0.0004	0.0001
Methane, dichloro-, HCC-30	0.0003	0.0000	0.0003
Aldehydes, unspecified	0.0003	0.0001	0.0002
Propene	0.0001	0.0001	0.0000
Hydrocarbons, unspecified	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 12.

Waterborne emissions are all off-site (Table 14). No mill in the survey discharged any process water. Most sawmills operate with this restriction. 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 12) of this report.

Table 14 Emissions to water released per 1 m^3 of dry planed softwood lumber, SE.

Water emission[1/]	Total	Forestry Operations	Wood Production
	kg/m^3		
Solved solids	1.5720	0.6020	0.9700
Chloride	1.2744	0.4881	0.7863
Waste water	0.7677	0.0000	0.7677
Sodium, ion	0.3594	0.1376	0.2217
Calcium, ion	0.1134	0.0434	0.0699
Suspended solids, unspecified	0.0762	0.0305	0.0457
Barium	0.0324	0.0136	0.0188
Magnesium	0.0222	0.0085	0.0137
COD, Chemical Oxygen Demand	0.0158	0.0045	0.0113
Sulfate	0.0126	0.0011	0.0115
Lithium, ion	0.0124	0.0034	0.0090
Fluoride	0.0123	0.0122	0.0001
Phosphate	0.0092	0.0092	0.0000
BOD5, Biological Oxygen Demand	0.0077	0.0024	0.0052
Bromide	0.0076	0.0029	0.0047
Iron	0.0053	0.0020	0.0033
Aluminum	0.0025	0.0010	0.0015
Strontium	0.0019	0.0007	0.0012
Oils, unspecified	0.0008	0.0003	0.0005
Ammonia	0.0006	0.0002	0.0004
Manganese	0.0002	0.0000	0.0002
Boron	0.0001	0.0000	0.0001

[1/] Due to large amount of water emissions, total emissions less than 10^{-4} are not shown.

Solid emissions include some waste that is collected from the log-yard and cannot be sent to the boiler because it is mixed with dirt as well as upstream waste flows generated from fuel production (Table 15). Of the total solid waste generated, 35 percent originated on-site from at the logyard and primary log breakdown. The solid waste generated represented less than 5 percent per kg of lumber produced.

Table 15 Waste to treatment per 1 m3 of dry planed softwood lumber, SE produced.

Waste to treatment	Total	Forestry Operations	Wood Production
	kg/m^3		
Solid waste	23.5802	0.1742	23.4060

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 16. 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 16 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 17 provides the environmental impact by category for softwood lumber 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 17. For GWP, 90 percent of the CO_2 equivalent emissions come from producing lumber, with remainder assigned to forestry operations.

Table 17 Environmental performance of 1 m^3 planed dry softwood lumber, SE.

Impact category	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Global warming potential (GWP)	kg CO_2 equiv	60.65	11.32	49.34
Acidification Potential	H+ moles equiv	40.95	8.51	32.43
Eutrophication Potential	kg N equiv	0.0495	0.0301	0.0195
Ozone depletion Potential	kg CFC-11 equiv	0.00000	0.00000	0.00000
Smog Potential	kg O3 equiv	16.49	4.28	12.22
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable fossil	MJ	846.11	175.56	670.55
Non-renewable nuclear	MJ	165.47	1.68	163.79
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	4.28	0.19	4.10
Renewable, biomass	MJ	2347.13	0.00	2347.13
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable materials[6]	kg	0.1036	0.0000	0.1036
Renewable materials	kg	479.30	0.00	479.30
Fresh water	L	185.60	0.04	185.56
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Solid waste	kg	23.58	0.17	23.41

[6] Limestone, in ground has been removed from a precombustion wood fuel extraction process (NREL 2012). This process was used for "purchased wood fuel" as reported by some wood product manufacturers. As noted in the process documentation the data was collected from pulp and paper mills using fluidized bed boilers. Fluidized bed boilers are not used in the solid wood products industry.

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, 112 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 829 kg CO_2e (Table 18).

Table 18 Carbon per 1 m^3 softwood lumber, SE.

	kg CO_2 equivalent
released forestry operations	11.32
released manufacturing	60.65
CO_2 eq. stored in product	933.17

9 Conclusions

The cradle to gate LCA for softwood 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 and secondary data for process inputs such as natural gas, diesel, and electricity. The survey results were representative of the forest operations in the region that produce southern pine. The survey data are representative of the lumber sizes and production volumes consistent with trade association production data. Softwood lumber production from the SE region required 1.16 m^3 or 592 kg of roundwood (wood and bark) harvested from SE forest per cubic meter of lumber.

Emissions from the forest resources LCI are small relative to manufacturing emissions. The lumber manufacturing process has few on-site emissions from sawing and planing. The dryer emits small amounts of VOCs from wood and the boiler has emissions associated with burning wood. Total energy use in lumber manufacturing is driven by the drying process which consumes over 85 percent of all energy; however, the mills generated this internally from wood residue and were independent of fossil fuels usage for energy generation. This makes the SE lumber life cycle inventory very favorable with respect to energy use.

Wood fuel represented 74 percent of the mill site use of heat energy for drying. From the total cradle to gate energy consumption, 70 percent of the energy consumption comes from renewable biomass, 25 percent from non-renewable fossil fuels, and 5 percent solar, wind and hydro combined. The forestry operations life cycle stage energy use is 99 percent from fossil fuels. All biomass energy used during lumber production is generated during lumber production.

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 this method, 72 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 933 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 dry planed softwood lumber, SE.

Air emission		Total	Forestry Operations	Wood Production
2,4-D	kg	1.37E-09		1.37E-09
2-Chloroacetophenone	kg	2.82E-10	2.30E-11	2.59E-10
5-methyl Chrysene	kg	1.46E-10	1.86E-12	1.44E-10
Acenaphthene	kg	3.39E-09	4.31E-11	3.34E-09
Acenaphthylene	kg	1.66E-09	2.11E-11	1.64E-09
Acetaldehyde	kg	8.81E-04	3.92E-05	8.41E-04
Acetochlor	kg	1.90E-08		1.90E-08
Acetophenone	kg	6.03E-10	4.93E-11	5.54E-10
Acrolein	kg	4.04E-03	4.76E-06	4.04E-03
Alachlor	kg	1.87E-09		1.87E-09
Aldehydes, unspecified	kg	2.79E-04	1.18E-04	1.61E-04
Ammonia	kg	4.91E-04	3.84E-04	1.06E-04
Ammonium chloride	kg	2.31E-05	2.34E-07	2.28E-05
Anthracene	kg	1.39E-09	1.78E-11	1.38E-09
Antimony	kg	8.09E-06	1.52E-09	8.09E-06
Arsenic	kg	2.50E-05	4.67E-08	2.50E-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	4.30E-03	4.81E-05	4.25E-03
Benzene, chloro-	kg	8.85E-10	7.24E-11	8.13E-10
Benzene, ethyl-	kg	3.78E-09	3.09E-10	3.47E-09
Benzo(a)anthracene	kg	5.31E-10	6.76E-12	5.24E-10
Benzo(a)pyrene	kg	2.52E-10	3.21E-12	2.49E-10
Benzo(b,j,k)fluoranthene	kg	7.30E-10	9.30E-12	7.21E-10
Benzo(ghi)perylene	kg	1.79E-10	2.28E-12	1.77E-10
Benzyl chloride	kg	2.82E-08	2.30E-09	2.59E-08
Beryllium	kg	1.28E-06	2.35E-09	1.28E-06
Biphenyl	kg	1.13E-08	1.44E-10	1.11E-08
Bromoform	kg	1.57E-09	1.28E-10	1.44E-09
Bromoxynil	kg	3.31E-10		3.31E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	8.99E-04	2.46E-04	6.52E-04
Butadiene	kg	2.19E-06	2.00E-06	1.90E-07
Cadmium	kg	4.56E-06	1.19E-08	4.55E-06
Carbofuran	kg	2.83E-10		2.83E-10

Air emission		Total	Forestry Operations	Wood Production
Carbon dioxide	kg	4.26E-01	4.26E-01	4.01E-04
Carbon dioxide, biogenic	kg	1.98E+02	8.24E-03	1.98E+02
Carbon dioxide, fossil	kg	5.58E+01	9.60E+00	4.62E+01
Carbon disulfide	kg	5.23E-09	4.28E-10	4.80E-09
Carbon monoxide	kg	6.07E-01	3.00E-05	6.07E-01
Carbon monoxide, fossil	kg	1.69E-01	8.57E-02	8.34E-02
Chloride	kg	2.02E-10	6.31E-12	1.96E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	2.58E-08		2.58E-08
Chlorine	kg	7.97E-04		7.97E-04
Chloroform	kg	2.37E-09	1.94E-10	2.18E-09
Chlorpyrifos	kg	2.17E-09		2.17E-09
Chromium	kg	2.30E-05	3.41E-08	2.30E-05
Chromium VI	kg	5.25E-07	6.68E-09	5.18E-07
Chrysene	kg	6.64E-10	8.45E-12	6.56E-10
Cobalt	kg	7.39E-06	6.03E-08	7.33E-06
Copper	kg	5.50E-08	6.20E-10	5.44E-08
Cumene	kg	2.13E-10	1.74E-11	1.96E-10
Cyanazine	kg	3.26E-10		3.26E-10
Cyanide	kg	1.01E-07	8.22E-09	9.23E-08
Dicamba	kg	1.92E-09		1.92E-09
Dimethenamid	kg	4.54E-09		4.54E-09
Dinitrogen monoxide	kg	3.40E-03	2.50E-03	9.00E-04
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	1.47E-09		1.47E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	6.39E-12	1.97E-13	6.19E-12
Dipropylthiocarbamic acid S-ethyl ester	kg	3.11E-09		3.11E-09
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1.43E-09	3.39E-10	1.09E-09
Ethane, 1,2-dibromo-	kg	4.83E-11	3.95E-12	4.43E-11
Ethane, 1,2-dichloro-	kg	1.61E-09	1.32E-10	1.48E-09
Ethane, chloro-	kg	1.69E-09	1.38E-10	1.55E-09
Ethene, tetrachloro-	kg	2.93E-07	4.30E-09	2.88E-07
Ethene, trichloro-	kg	6.15E-14		6.15E-14
Fluoranthene	kg	4.71E-09	6.00E-11	4.65E-09
Fluorene	kg	6.04E-09	7.69E-11	5.97E-09
Fluoride	kg	7.12E-06	4.96E-06	2.16E-06
Formaldehyde	kg	4.51E-03	6.09E-05	4.45E-03
Furan	kg	3.25E-11	3.70E-13	3.21E-11
Glyphosate	kg	4.08E-09		4.08E-09
Hexane	kg	2.70E-09	2.20E-10	2.47E-09
Hydrazine, methyl-	kg	6.84E-09	5.59E-10	6.28E-09
Hydrocarbons, unspecified	kg	1.33E-04	1.35E-06	1.32E-04
Hydrogen	kg	1.30E-07		1.30E-07

Air emission		Total	Forestry Operations	Wood Production
Hydrogen chloride	kg	2.72E-02	1.06E-04	2.71E-02
Hydrogen fluoride	kg	9.94E-04	1.25E-05	9.82E-04
Hydrogen sulfide	kg	6.53E-12	2.04E-13	6.33E-12
Indeno(1,2,3-cd)pyrene	kg	4.05E-10	5.16E-12	4.00E-10
Iron	kg	2.14E-07		2.14E-07
Isophorone	kg	2.33E-08	1.91E-09	2.14E-08
Isoprene	kg	6.63E-03	2.07E-04	6.42E-03
Kerosene	kg	1.10E-05	1.12E-07	1.09E-05
Lead	kg	5.16E-05	6.18E-08	5.15E-05
Magnesium	kg	7.30E-05	9.30E-07	7.21E-05
Manganese	kg	1.62E-03	6.86E-08	1.62E-03
MCPA	kg	2.55E-11		2.55E-11
Mercaptans, unspecified	kg	8.72E-06	7.13E-07	8.01E-06
Mercury	kg	4.19E-06	1.32E-08	4.17E-06
Metals, unspecified	kg	4.32E-02	2.34E-14	4.32E-02
Methacrylic acid, methyl ester	kg	8.04E-10	6.58E-11	7.39E-10
Methane	kg	1.29E-01	1.99E-02	1.10E-01
Methane, bromo-, Halon 1001	kg	6.44E-09	5.26E-10	5.91E-09
Methane, dichloro-, HCC-30	kg	2.95E-04	6.91E-08	2.95E-04
Methane, dichlorodifluoro-, CFC-12	kg	7.75E-10	3.38E-10	4.37E-10
Methane, fossil	kg	6.62E-03	2.03E-03	4.59E-03
Methane, monochloro-, R-40	kg	2.13E-08	1.74E-09	1.96E-08
Methane, tetrachloro-, CFC-10	kg	3.98E-10	3.38E-11	3.64E-10
Methyl ethyl ketone	kg	1.57E-08	1.28E-09	1.44E-08
Methyl methacrylate	kg	1.77E-13		1.77E-13
Metolachlor	kg	1.50E-08		1.50E-08
Metribuzin	kg	6.95E-11		6.95E-11
Naphthalene	kg	9.81E-05	1.29E-08	9.81E-05
Nickel	kg	3.76E-05	7.55E-07	3.68E-05
Nitrogen oxides	kg	5.84E-01	1.72E-01	4.12E-01
Nitrogen, total	kg	9.62E-05	9.62E-05	1.83E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.44E-02	5.75E-03	8.63E-03
N-Nitrodimethylamine	kg	1.38E-14		1.38E-14
Organic acids	kg	8.47E-08	8.61E-10	8.38E-08
Organic substances, unspecified	kg	5.09E-05	5.25E-07	5.04E-05
PAH, polycyclic aromatic hydrocarbons	kg	9.41E-06	8.59E-06	8.16E-07
Paraquat	kg	3.03E-10		3.03E-10
Parathion, methyl	kg	2.29E-10		2.29E-10
Particulates, < 10 um	kg	8.28E-06		8.28E-06
Particulates, < 2.5 um	kg	4.33E-01		4.33E-01
Particulates, > 2.5 um, and < 10um	kg	5.13E-01	5.27E-03	5.08E-01

Air emission		Total	Forestry Operations	Wood Production
Particulates, unspecified	kg	5.41E-01	1.18E-03	5.40E-01
Pendimethalin	kg	1.56E-09		1.56E-09
Permethrin	kg	1.40E-10		1.40E-10
Phenanthrene	kg	1.79E-08	2.28E-10	1.77E-08
Phenol	kg	1.94E-06	5.26E-11	1.94E-06
Phenols, unspecified	kg	5.19E-05	3.50E-08	5.18E-05
Phorate	kg	7.18E-11		7.18E-11
Phosphate	kg	2.20E-06	2.20E-06	
Phthalate, dioctyl-	kg	2.94E-09	2.40E-10	2.70E-09
Potassium	kg	3.79E-05		3.79E-05
Propanal	kg	1.53E-08	1.25E-09	1.40E-08
Propene	kg	1.44E-04	1.32E-04	1.25E-05
Propylene oxide	kg	2.50E-14		2.50E-14
Pyrene	kg	2.19E-09	2.79E-11	2.16E-09
Radioactive species, unspecified	Bq	3.74E+05	4.61E+03	3.69E+05
Radionuclides (Including Radon)	kg	6.17E-04	6.27E-06	6.11E-04
Selenium	kg	1.16E-05	1.17E-07	1.15E-05
Simazine	kg	9.84E-10		9.84E-10
Sodium	kg	8.74E-07		8.74E-07
Styrene	kg	1.01E-09	8.22E-11	9.23E-10
Sulfur	kg	4.61E-06		4.61E-06
Sulfur dioxide	kg	2.70E-01	2.20E-02	2.48E-01
Sulfur oxides	kg	4.97E-02	9.53E-03	4.02E-02
Sulfur, total reduced	kg	2.70E-06		2.70E-06
Sulfuric acid, dimethyl ester	kg	1.93E-09	1.58E-10	1.77E-09
Tar	kg	2.27E-10	7.10E-12	2.20E-10
t-Butyl methyl ether	kg	1.41E-09	1.15E-10	1.29E-09
Terbufos	kg	2.45E-09		2.45E-09
TOC, Total Organic Carbon	kg	4.13E-03		4.13E-03
Toluene	kg	2.29E-05	2.09E-05	1.99E-06
Toluene, 2,4-dinitro-	kg	1.13E-11	9.21E-13	1.03E-11
Vinyl acetate	kg	3.06E-10	2.50E-11	2.81E-10
VOC, volatile organic compounds	kg	5.06E-01	5.05E-03	5.01E-01
Xylene	kg	1.60E-05	1.46E-05	1.39E-06
Zinc	kg	2.02E-06	1.77E-06	2.50E-07

13.2 Water Emissions

Table A.2 Emissions to water released per 1 m^3 of dry planed softwood lumber, SE.

Water r emission		Total	Forestry Operations	Wood Production
2-Hexanone	kg	2.30E-07	8.82E-08	1.42E-07
2-Propanol	kg	2.54E-09		2.54E-09
2,4-D	kg	5.86E-11		5.86E-11
4-Methyl-2-pentanone	kg	1.48E-07	5.68E-08	9.15E-08
Acetochlor	kg	8.13E-10		8.13E-10
Acetone	kg	3.53E-07	1.35E-07	2.18E-07
Acidity, unspecified	kg	5.67E-15		5.67E-15
Acids, unspecified	kg	3.61E-06	1.33E-10	3.61E-06
Alachlor	kg	8.00E-11		8.00E-11
Aluminium	kg	2.44E-05		2.44E-05
Aluminum	kg	2.53E-03	9.88E-04	1.54E-03
Ammonia	kg	6.07E-04	2.36E-04	3.71E-04
Ammonia, as N	kg	2.13E-09	6.66E-11	2.07E-09
Ammonium, ion	kg	4.93E-06	5.01E-08	4.88E-06
Antimony	kg	1.46E-06	6.15E-07	8.44E-07
Arsenic, ion	kg	1.34E-05	7.68E-06	5.70E-06
Atrazine	kg	1.58E-09		1.58E-09
Barium	kg	3.24E-02	1.36E-02	1.88E-02
Bentazone	kg	6.46E-12		6.46E-12
Benzene	kg	5.92E-05	2.27E-05	3.65E-05
Benzene, 1-methyl-4-(1-methylethyl)-	kg	3.53E-09	1.35E-09	2.18E-09
Benzene, ethyl-	kg	3.33E-06	1.28E-06	2.06E-06
Benzene, pentamethyl-	kg	2.64E-09	1.01E-09	1.63E-09
Benzenes, alkylated, unspecified	kg	1.28E-06	5.40E-07	7.40E-07
Benzoic acid	kg	3.58E-05	1.37E-05	2.21E-05
Beryllium	kg	4.84E-07	1.92E-07	2.92E-07
Biphenyl	kg	8.29E-08	3.49E-08	4.79E-08
BOD5, Biological Oxygen Demand	kg	7.69E-03	2.45E-03	5.25E-03
Boron	kg	1.11E-04	4.24E-05	6.83E-05
Bromide	kg	7.56E-03	2.90E-03	4.66E-03
Bromoxynil	kg	8.55E-12		8.55E-12
Cadmium, ion	kg	2.79E-06	1.90E-06	8.91E-07
Calcium, ion	kg	1.13E-01	4.34E-02	6.99E-02
Carbofuran	kg	1.21E-11		1.21E-11
CFCs, unspecified	kg	2.54E-09		2.54E-09
Chloride	kg	1.27E+00	4.88E-01	7.86E-01
Chlorpyrifos	kg	9.32E-11		9.32E-11
Chromate	kg	3.38E-13		3.38E-13

Water r emission		Total	Forestry Operations	Wood Production
Chromium	kg	6.29E-05	3.09E-05	3.20E-05
Chromium VI	kg	2.39E-07	1.04E-07	1.35E-07
Chromium, ion	kg	9.53E-06	3.21E-06	6.32E-06
Cobalt	kg	7.82E-07	2.99E-07	4.82E-07
COD, Chemical Oxygen Demand	kg	1.58E-02	4.53E-03	1.13E-02
Copper, ion	kg	1.59E-05	6.36E-06	9.56E-06
Cyanazine	kg	1.40E-11		1.40E-11
Cyanide	kg	2.58E-09	9.76E-10	1.61E-09
Decane	kg	1.03E-06	3.94E-07	6.35E-07
Detergent, oil	kg	3.13E-05	1.18E-05	1.95E-05
Dibenzofuran	kg	6.71E-09	2.57E-09	4.14E-09
Dibenzothiophene	kg	5.69E-09	2.19E-09	3.50E-09
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	1.30E-11	4.07E-13	1.26E-11
Docosane	kg	3.78E-08	1.45E-08	2.33E-08
Dodecane	kg	1.95E-06	7.47E-07	1.20E-06
Eicosane	kg	5.37E-07	2.06E-07	3.31E-07
Fluorene, 1-methyl-	kg	4.02E-09	1.54E-09	2.48E-09
Fluorenes, alkylated, unspecified	kg	7.42E-08	3.13E-08	4.29E-08
Fluoride	kg	1.23E-02	1.22E-02	7.93E-05
Fluorine	kg	3.73E-08	1.56E-08	2.17E-08
Furan	kg	9.32E-11		9.32E-11
Glyphosate	kg	1.75E-10		1.75E-10
Hexadecane	kg	2.13E-06	8.16E-07	1.31E-06
Hexanoic acid	kg	7.41E-06	2.84E-06	4.57E-06
Hydrocarbons, unspecified	kg	9.32E-08	5.09E-13	9.32E-08
Iron	kg	5.32E-03	2.03E-03	3.29E-03
Lead	kg	2.03E-05	9.16E-06	1.12E-05
Lead-210/kg	kg	3.67E-15	1.40E-15	2.26E-15
Lithium, ion	kg	1.24E-02	3.41E-03	9.02E-03
m-Xylene	kg	1.07E-06	4.09E-07	6.60E-07
Magnesium	kg	2.22E-02	8.49E-03	1.37E-02
Manganese	kg	1.67E-04	1.50E-05	1.52E-04
MCPA	kg	1.09E-12		1.09E-12
Mercury	kg	9.37E-08	7.26E-08	2.11E-08
Metallic ions, unspecified	kg	2.25E-09	6.22E-12	2.24E-09
Methane, monochloro-, R-40	kg	1.42E-09	5.44E-10	8.76E-10

Water r emission		Total	Forestry Operations	Wood Production
Methyl ethyl ketone	kg	2.84E-09	1.09E-09	1.75E-09
Metolachlor	kg	6.42E-10		6.42E-10
Metribuzin	kg	2.98E-12		2.98E-12
Molybdenum	kg	8.11E-07	3.11E-07	5.00E-07
n-Hexacosane	kg	2.36E-08	9.02E-09	1.45E-08
Naphthalene	kg	6.42E-07	2.46E-07	3.96E-07
Naphthalene, 2-methyl-	kg	5.59E-07	2.14E-07	3.45E-07
Naphthalenes, alkylated, unspecified	kg	2.10E-08	8.84E-09	1.21E-08
Nickel	kg	1.06E-05	5.46E-06	5.15E-06
Nickel, ion	kg	2.94E-13		2.94E-13
Nitrate	kg	3.02E-07	4.46E-14	3.02E-07
Nitrate compounds	kg	5.75E-11	1.80E-12	5.57E-11
Nitric acid	kg	1.29E-07	4.03E-09	1.25E-07
Nitrogen, total	kg	2.28E-05	1.25E-07	2.26E-05
o-Cresol	kg	1.01E-06	3.89E-07	6.26E-07
Octadecane	kg	5.26E-07	2.02E-07	3.25E-07
Oils, unspecified	kg	8.30E-04	3.02E-04	5.28E-04
Organic substances, unspecified	kg	1.86E-09		1.86E-09
p-Cresol	kg	1.10E-06	4.19E-07	6.76E-07
Paraquat	kg	1.30E-11		1.30E-11
Parathion, methyl	kg	9.82E-12		9.82E-12
Pendimethalin	kg	6.68E-11		6.68E-11
Permethrin	kg	6.00E-12		6.00E-12
Phenanthrene	kg	8.25E-09	3.36E-09	4.89E-09
Phenanthrenes, alkylated, unspecified	kg	8.70E-09	3.67E-09	5.03E-09
Phenol	kg	1.09E-05	4.61E-06	6.31E-06
Phenol, 2,4-dimethyl-	kg	9.88E-07	3.79E-07	6.10E-07
Phenols, unspecified	kg	6.67E-06	2.06E-06	4.60E-06
Phorate	kg	1.86E-12		1.86E-12
Phosphate	kg	9.22E-03	9.20E-03	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
Radioactive species, Nuclides, unspecified	Bq	7.16E+02	7.28E+00	7.09E+02
Radium-226/kg	kg	1.28E-12	4.88E-13	7.87E-13
Radium-228/kg	kg	6.52E-15	2.50E-15	4.03E-15
Selenium	kg	2.01E-06	1.37E-07	1.87E-06
Silver	kg	7.41E-05	2.84E-05	4.57E-05
Simazine	kg	4.22E-11		4.22E-11
Sodium, ion	kg	3.59E-01	1.38E-01	2.22E-01

Water r emission		Total	Forestry Operations	Wood Production
Solids, inorganic	kg	3.28E-10	1.02E-11	3.18E-10
Solved solids	kg	1.57E+00	6.02E-01	9.70E-01
Strontium	kg	1.92E-03	7.37E-04	1.19E-03
Styrene	kg	1.18E-11		1.18E-11
Sulfate	kg	1.26E-02	1.09E-03	1.15E-02
Sulfide	kg	3.04E-05	5.35E-07	2.98E-05
Sulfur	kg	9.35E-05	3.58E-05	5.77E-05
Sulfuric acid	kg	8.15E-11		8.15E-11
Suspended solids, unspecified	kg	7.62E-02	3.05E-02	4.57E-02
Tar	kg	3.25E-12	1.02E-13	3.15E-12
Terbufos	kg	6.34E-11		6.34E-11
Tetradecane	kg	8.55E-07	3.28E-07	5.28E-07
Thallium	kg	3.08E-07	1.30E-07	1.78E-07
Tin	kg	6.61E-06	2.67E-06	3.93E-06
Titanium, ion	kg	2.24E-05	9.45E-06	1.30E-05
TOC, Total Organic Carbon	kg	1.18E-07		1.18E-07
Toluene	kg	5.59E-05	2.14E-05	3.45E-05
Vanadium	kg	9.58E-07	3.67E-07	5.91E-07
Waste water/m3	m3	7.68E-04		7.68E-04
Xylene	kg	2.97E-05	1.14E-05	1.83E-05
Yttrium	kg	2.38E-07	9.11E-08	1.47E-07
Zinc	kg	6.24E-05	2.30E-05	3.94E-05
Zinc, ion	kg	4.11E-07		4.11E-07