Cradle to Gate Life Cycle Assessment of Softwood Lumber Production from the Northeast-North Central

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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 Northeast-North central (NE-NC) region. The NE-NC regional data is a representative cross-section of forest growth and manufacturing processes in 20 states. Due to little or no production 6 states have been omitted: Connecticut, Delaware, Illinois, Iowa, New Jersey, and Ohio. 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 NE-NC forestry operations, boiler, and electrical grid 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 Bergman and Bowe (2009, 2010) and Oneil et al. (2010). Updates in this report from the original Bergman report include: wood combustion boiler updates, electricity grid updates (Goemans 2010), and an LCIA. 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 planed dry lumber from the manufacturing base located in the NE-NC region of North America. These data are needed for the inclusion of the production process in life-cycle analyses of wood. The data were obtained through a scientifically sound and consistent process established by the Consortium for Research on Renewable Industrial Materials (CORRIM), following ISO14040 standards (ISO 2006).

The scope of this study includes cradle-to-gate LCIs based on primary data for producing planed, dry dimension (framing or construction) lumber from logs using practices and technology common to the NE-NC region. The logs are obtained from the forest resource base located Indiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin. Data for the LCA are based on manufacturing gate to gate LCI's from CORRIM reports (Bergman and Bowe 2009, 2010) and forest resources cradle to gate LCI's specific to the region (Oneil et al. 2010). 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 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 NE-NC (Oneil et al. 2010) and ends with planed dry lumber (Bergman et al. 2009, 2010) (Figure 2). The forest resources system boundary includes: planting the seedlings, forest management which includes site preparation, thinning and fertilization and final harvest with the transportation of logs, and lumber manufacturing allocated to the manufacturing process. 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 five process units: logyard, sawing, drying, 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.

[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

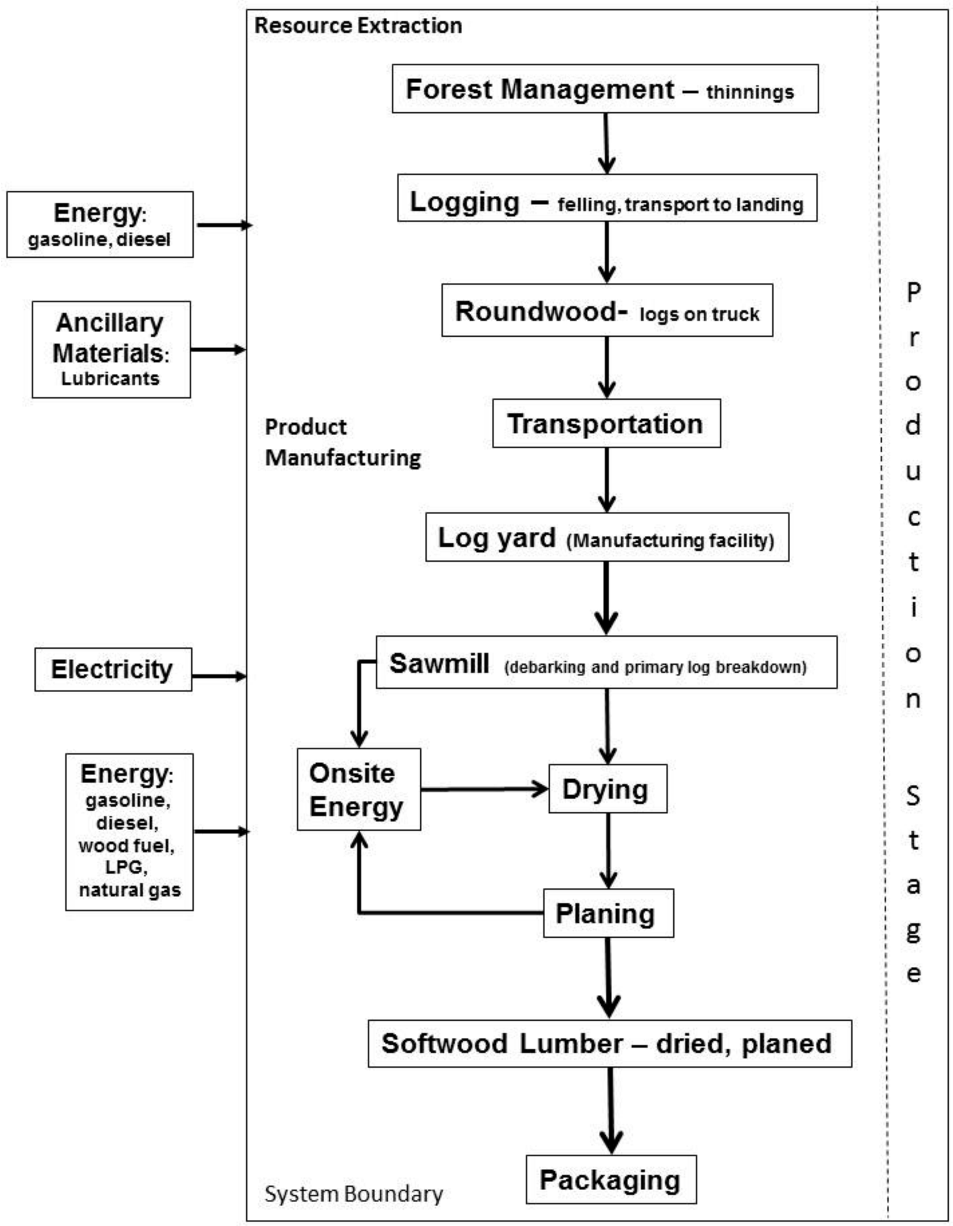

Figure 2 Cradle to gate life cycle stages for softwood lumber production, NE-NC

3.3 Description of data/Process Description

3.3.1 Forestry Operations

Forestry operations can include growing seedlings, planting, thinning, and fertilization and will include final harvest. The specific processes involved are reforestation: which can include 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, 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.

Forest growth and harvesting scenarios for the Northeast/North Central (NE-NC) region were developed using FIA data for the region. Data from Connecticut, Delaware, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin were assessed. A distance analysis was used to select a representative plot from the pool of candidate plots in the appropriate forest type and age range from each state database. The objective of the distance analysis was to select a single plot that was as similar as possible to the average species composition, basal area, quadratic mean diameter, and biomass volume of all the plots available. Using this method, four major forest types were identified covering the dominant hardwood and softwood managed forest types in the region. For the softwood LCI, the spruce/fir forest type from the Maine FIA inventory was chosen as representative of NE/NC softwood species.

3.3.1.1 Regeneration (seedling production and planting process)

For the NE-NC natural regeneration was assumed across all forest type and management intensities. Therefore no planting is modeled for the NE-NC as natural regeneration is assumed to be sufficient on all sites. For the NE-NC no slash reduction activities are mandated for fire risk reduction and the analysis did not include slash disposal as it is assumed to decay in situ. Neither are on-site fertilization or pre-commercial thinning commonly used in the region so these processes were not included in the forest resources modeling. This low input model is unique to the region and is in marked contrast to other regional forest resource analyses.

Table 1 Inputs to the regeneration phase including site preparation and planting per hectare (ha) of forest.

		Low intensity	Medium intensity	High intensity	Weighted Average
		Reforesting 1 ha			
Diesel and Gasoline	L	-	-	-	-
Seedlings, at greenhouse	p[1]	-	-	-	-
Nitrogen in fertilizer					
In Seedlings	kg	-	-	-	-
On Site	kg	-	-	-	-
Phosphorous in fertilizer					
In Seedlings	kg	-	-	-	-
On Site	kg	-	-	-	-
Potassium in fertilizer					
In Seedlings	kg	-	-	-	-
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 flatter terrain 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. For the NE-NC all harvest and thinning operations were assumed to use ground based systems and occur on slopes less than 35% (Wang and McNeel, 2006). 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.

Ground based 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). The use of another machine that can delimb and process trees into logs at the landing is common, but some systems use a chainsaw at the landing to delimb and process the logs.

Variations in harvest equipment and size affect machine productivity and therefore emissions per m^3 of logs produced. Harvest equipment operational efficiencies also 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, and weighted for the relative number of acres that can be expected to use either type of system (Table 2).

Table 2 Equipment allocation by treatment and forest type/owner group.

Management Intensity	Commercial Thinning	Final Harvest (usage per final volume harvested)
Low intensity site		
Large Feller Buncher	NA	100%
Large Grapple Skidder	NA	100%
Chainsaw Delimbing	NA	100%
Large Loader		
Medium intensity		
Large Feller Buncher	0.1%	99.9%
Large Grapple Skidder	0.1%	99.9%
Chainsaw Delimbing	0.1%	99.9%
Large Loader	0.1%	99.9%
High intensity		
Large Feller Buncher	1.4%	98.6%
Large Grapple Skidder	1.4%	98.6%
Chainsaw Delimbing	1.4%	98.6%
Large Loader	1.4%	98.6%

3.3.1.3 Thinning and Final Harvest Process

Scenarios developed for the NE-NC used a subset of the United States Forest Service (USFS) Forest Inventory and Analysis (FIA) data for Maine spruce fir forests. The median FIA stand was grown forward to the final simulation year to generate harvest volume estimates and % production of sawlogs and pulpwood logs. Specific assumptions used for the growth and yield modeling associated with these three management intensities are outlined in Table 3.

The three management intensity categories were aggregated to generate a weighted average representing the composite input value for the region. In calculating output variables, results were weighted by the number of acres in each management intensity. Weighted average harvest volume was forwarded to the manufacturing modules for incorporation in their life cycle analysis. In the NE-NC Region, the rotation age for softwoods ranged from 55 to 75 years with 65 years selected as the reference year for comparison. Allocating per ha values from Table 1 to the total yield of 263 m^3/ha from the reference year with 52% of the harvested volume going into sawlogs 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 forest management intensity in the NE-NC region.

Ownership / Forest Type / Prescription Scenarios				
Management Intensity	**Low**	**Medium**	**High**	**Weighted Average**
Site Index	50	60	70	57
Rotation Age	75	65	55	-
Planting Density - Trees/ha	0	0	0	0
Fertilization	None	None	None	-
Pre-commercial Thin	0	0	0	0
Number of Trees/ha	0	125	125	66
Commercial Thin-m^3/ha	0	0	3	1
at Year	0	40	35	20
Final Harvest - m^3/Ha	302	282	191	275
at Year	75	65	55	68
Total Harvest - m^3/ha	302	282	194	275
Total Harvest at 65 years (reference year) - m^3/ha	262	282	229	263
Sawlog - %	54.30%	52.90%	45.90%	52%
Sawlog - m^3/ha	164	149	89	145
Pulpwood - %	45.70%	47.10%	54.10%	48%
Pulpwood - m^3/ha	138	133	105	130
Percent Thinned	0.00%	0.10%	1.40%	0.3%
Percent Land in Category	47.40%	34.00%	18.70%	

The primary output product for this analysis is a log destined for a sawmill. Pulpwood logs are only removed from the woods where markets are sufficiently strong to pay for their removal. In the Inland Northwest, most of the feedstock for pulp and paper mills comes from the residual material from the manufacturing plants for the primary wood products (lumber, plywood, and OSB) and allocation is done at that stage of the LCI. A primary co-product, non-merchantable slash, is generally left in the woods or at a landing. This material is disposed of through mechanical activities and/or prescribed fire.

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 NE-NC region by major process (Table 4).

Table 4 Fuel consumption for NE-NC forest resource management processes (regeneration and harvest).

	Unit	Fuel Consumption per m^3
Seedling, Site Prep, Plant, Pre-commercial Thinning		
Diesel and gasoline	L	-
Lubricants	L	-
Electricity	kWh	-
Commercial Thinning and Final Harvest		
Diesel	L	4.268
Lubricants	L	0.077
Total Forest Extraction Process		
Diesel and gasoline	L	4.268
Lubricants	L	0.077
Electricity	kWh	-

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. For the NE-NC the average haul distance is 109 km from the forest landing to the mill with a roundwood moisture content of 96.5% oven dry basis[3].

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

Material delivered to mill	Delivery Distance (km)	
	km	miles
Logs with bark	109	80

3.3.2.2 Energy use and generation

Steam in NE-NC mills was produced using self-generated wood waste (Table 6). Boiler input data was collected by surveys and the combustion emissions were used from the USLCI database. The USLCI database was used for the wood boiler process (EPA 2006). The boiler process is based on the US Environmental Protection Agency (EPA) AP-42, Compilation of Air Pollutant Emission Factors (EPA 1998). 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 (60%) and purchased (40%) wood waste (Table 6 and 7). One kg of dry wood material with an oven dry basis moisture content contained 20.9 MJ of energy. Most of the wood fuel was generated during the sawing process (68%) with the remainder coming from the planer. The total wood fuel burned was 116 kg/m^3 of oven-dry weight wood fuel. Total heat energy requirement for NE-NC softwood lumber was 2,564 MJ/m^3. Cumulative process energy for electric power allocated to one cubic meter (360 kg) of planed-dried softwood lumber was 83.2 kWh/m^3. Total electricity consumed during the entire lumber production process per cubic meter of planed-dried softwood lumber, was allocated to the log yard (6%), sawing (47%), kiln drying (24%), and planing (23%) processes respectively.

Table 6 Boiler inputs for producing per 1 m^3 of dry planed softwood lumber, NE-NC.

Fuel	Unit	Value (Unit/m^3)	HHV (MJ/kg)	MJ/m^3 of product
Wood waste	kg	116	20.90	2,426.26

[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
Materials/fuels		
Wood fuel, green	1.00	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

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 include gasoline, diesel, and electricity (Table 8). Water is mainly used in the process for wetting logs when they are stored prior to sawing. Outputs include logs with bark. 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 0.36.

Table 8 Unit process inputs/outputs for log yard activities to produce 1 m^3 of green logs, NE-NC.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Roundwood	1.00	m^3	88
Bark	49.2	kg	12
Resources	**Value**	**Unit/m^3**	
Water, cooling, surface	165	L	
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	4.730	kWh	
Diesel	0.780	L	
Gasoline	0.146	L	
Roundwood + Bark	1.137	m^3	
Transport (roundwood w/ bark)	87.800	tkm	
Emissions to air	**Value**	**Unit/m^3**	
	-		

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 9 lists the sawing processes which produce 1m^3 of rough sawn green lumber in the NE-NC. The actual sizes are 38 mm thick with a width of 140 mm. Rough cut lumber has mass of 360 kg/m^3, which represents 46.89% of the mass of the products and co-products.

Outputs of this unit process are sawn rough green lumber and wood residues from the sawing process; bark, sawdust, slabs, edgings, and chips (hog fuel is a mixture of the wood residues produced). Most wood residues are sold as a co-product; others, especially sawdust, are combusted as fuel, mostly to dry lumber. The remaining wood residues produce salable goods such as mulch (bark), pulp chips, and feedstock for particle board plants.

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

Table 9 Unit process inputs/outputs for sawing for the production of 1 m^3 of rough green lumber, NE-NC.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Sawn lumber, rough, green	1.00	m^3	46.89
Pulp chips, green	252.58	kg	32.9
Sawdust, green	30.19	kg	3.93
Bark, green	92.16	kg	12.00
Wood fuel, green	32.88	kg	4.28
Resources			
Water, process and cooling, surface	590.4	L	
Materials/fuels	**Value**	**Unit/m^3**	
Roundwood w/bark	2.128	m^3	
Electricity, at Grid	39.096	kWh	
Diesel	0.8856	L	
Gasoline	0.0166	L	
Solid waste	**Value**	**Unit/m^3**	
Solid waste, recycling	0.0305	kg	
Solid waste, landfill	0.3816	kg	

3.3.2.5 Kiln Drying

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 (Table 10). Northeast-North central softwood lumber is typically dried to a moisture content of 16%. Wood-fuel cogeneration provided 13.58% of the total electricity produced. The drying process begins with rough green lumber and includes loading lumber into drying kilns, and drying, equalizing, and conditioning of lumber within the kiln, maintenance of all kiln equipment and related yard transportation vehicles, treatment of process air, liquids, and solids, and unloading and transportation of kiln-dried lumber to the planer mill.

Table 10 Unit process inputs/outputs for kiln drying to produce 1 m^3 of rough dry softwood lumber, NE-NC.

Products	**Value**	**Unit/m^3**
Sawn Lumber, rough, kiln dried	1.00	m^3
Materials/fuels		
Electricity, at Grid	19.85	kWh
Diesel	0.32	L
Gasoline	0.01	L
Wood waste, combusted in industrial boiler	116.00	kg
Sawn lumber, rough, green	392.00	kg
Emissions to air		
VOC, volatile organic compounds	0.624	kg

3.3.2.6 Planing

The planer process includes un-stacking rough dry lumber, planing (surfacing) of lumber, trimming, grading, and sorting of lumber, stacking, strapping, and packaging of lumber, transportation of lumber within the planer mill and loading for shipping, maintenance of all planer equipment and associated yard transportation vehicles, and treatment of process air, liquids, and solids (Table 11). Inputs include dry lumber, electricity, and diesel. The output of this unit process is surfaced and packaged lumber, sorted by type, size, and grade as well as planer shavings, sawdust, and/or lumber trim ends. This process is the final stage of manufacturing. Some dry wood residue is burned on-site in the boilers for energy, whereas most is sold as co-products. The planed dry lumber had a dry mass of 360 kg, which represents 79.1% of the co-product mass from this unit process. Shavings and wood waste (wood fuel) represented 20.9% of the input volume. Lumber is bundled and banded and some is wrapped for shipping.

Table 11 Unit process inputs/outputs for planing process to produce 1 m^3 of planed dry softwood lumber, NE-NC.

Products	Value	Unit/m^3	Allocation
Sawn Lumber, softwood, planed, kiln dried	1	m^3	79.1%
Shavings	80.6	kg	4.6%
Wood fuel	22.9	kg	16.3%
Materials/fuels	**Value**	**Unit/m^3**	
Electricity, at Grid	19.56	kWh	
Diesel	0.4080	L	
Gasoline	0.0076	L	
Sawn Lumber, kiln dried	1.27	m^3	
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**	
	-		

3.3.2.7 Packaging

Materials used for packaging lumber for shipping are shown in Table 12.

Table 12 Materials used in packaging and shipping per m^3, NE-NC lumber.

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 1.50% 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 14 and would be included in the impact assessment. Table 14 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

In the 20 state NE-NC region Maine, Michigan, New Hampshire, Minnesota, and Wisconsin are the major softwood-lumber-producing states. Connecticut, Delaware, Illinois, Iowa, New Jersey, and Ohio were omitted from the survey because their total annual production was very small. The remaining fourteen state softwood lumber producing states' total annual production for the 2006/2007, was 4.37 million m^3 (2.1 billion board feet) (USCB 2008). Weight-average annual production for the softwood sawmills that provided data was 110 thousand m^3 (52.9 million board feet). Annual production for the six sawmills surveyed during 2006 and 2007 was 365,000 thousand m^3 (256 million board feet (bf)) of rough green lumber, roughly 12% of the total softwood lumber production of this region for this two-year period. A mill questionnaire was used to survey six softwood sawmills across the region with an emphasis on the highest volume producing states of Maine and Michigan. Softwood lumber species in the region include were eastern white pine (Pinus strobus), red pine (Pinus resinosa ait.), jack pine (Pinus banksiana), eastern spruce (Picea rubens, Picea marina, and Picea glauca), and balsam fir (Abies balsamea).

An internal critical review of the survey procedures, data, analysis, and report was done for conformance with CORRIM and ISO 14040 standards (Wilson 2009 and Puettmann 2009). The review provided assurances that the study methodology, data collection, and analyses were scientifically sound. It also ensured they were 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 Bergman and Bowe (2009) and Lippke et al. (2004), respectively.

6 Life cycle inventory results

6.1 Data collection

The logs are obtained from the forest resource base located in Indiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin. The forest resources cradle to gate LCI (Oneil et al. 2010) is based on secondary data. The secondary data were derived using the USFS Forest Inventory and Analysis (FIA) census data for the NE-NC region. A distance analysis was used to select a representative plot from the pool of candidate FIA plots in the appropriate forest type and age range from each state database. The objective of the distance analysis was to select a single plot that was as similar as possible to the average species composition, basal area, quadratic mean diameter, and biomass volume of all the plots available. The spruce/fir forest type from the Maine FIA inventory was chosen as representative of NE/NC softwood species. Simulations of growth, yield and harvest were developed from these data to represent the wood basket that would service manufacturing facilities for the region surveyed during the mill survey.

Primary softwood lumber production data was collected by written surveys and covered operations of the mills throughout one full calendar year, including summer and winter operations. A copy of the mill surveys can be found in the full report of this study (Bergman and Bowe 2009). A mill questionnaire was used to survey six softwood sawmills across the NE-NC region. The wood species examined were eastern white pine (roughly half), red and jack pine, spruce, and balsam fir. This study relied almost exclusively on production and emissions data provided by lumber producers from the NE-NC, with some secondary data on electrical grid inputs from the US LCI database (Goemans 2010). Six lumber manufacturing plants from within the region provided data for this study. Data for packaging was obtained from field sampling and personal communications with manufacturers.

6.2 Calculation rules

For converting log volumes to mass, the international ¼ rule is typically used (Cassens 2001). For NE-NC softwood logs a mill weight-averaged overrun of 26 percent was estimated from scaling the incoming logs and the resultant rough green lumber tally. An average log conversion of 4.73 m^3/MBF was calculated based on a weight-averaged reported log diameter of 9.4 inches, with a range from 6.7 to 14 inches, (Fonseca 2005). A green log volume of 2.58 m^3 was calculated based on 931 OD kg (oven dry kg) of incoming wood volume on a per unit basis and a green specific gravity of 0.361.

Green and dry wood density and specific gravity values found in the Wood Handbook (Bergman et al. 2010) for the five major wood species were used to determine the mass basis conversion from board feet. Weighted densities of 543 kg/m^3 (33.9 lb/ft^3) and 454 kg/m^3 (28.3 lb/ft^3) were used for green and kiln dry lumber, respectively. Higher heating value (HHV) is used to convert volume or mass basis of a fuel to its energy value. HHV represents the energy content of a fuel with the combustion products such as water vapor brought to 25ºC (77ºF).

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.

As part of the CORRIM protocol for ensuring data quality, an overall “wood balance” is required to fall within 5% from material input to material output. Log mass was calculated based on the previous assumption of 4.73 m^3/MBF and an average green density of 543 kg/m^3. In this study, a 1% difference was calculated for the overall wood mass balance, falling within the CORRIM protocol. Additionally, a 2.3% difference was calculated before and after sawing and a 3.9% difference before and after planing.

6.3 Allocation rules

All allocation was based on the mass of the products and co-products. NENC 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 13-16). 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 13 for 1 m^3 of softwood lumber. Air emissions are reported in Table 14, water emissions are reported in Table 15 and solid waste emissions are reported in Table 16.

Table 13 Raw material energy consumption per 1 m^3 of dry planed softwood lumber, NE-NC.

Fuel	Total	Forestry Operations	Wood Production
	kg/m^3		
Coal, in ground	16.1582	0.2313	15.9269
Gas, natural, in ground	2.7429	0.1670	2.5759
Oil, crude, in ground	16.9003	4.3388	12.5615
Uranium oxide, in ore	0.0005	0.0000	0.0005
Wood waste	121.8553	0.0000	121.8553

Table 14 Air emissions released per 1 m^3 of dry planed softwood lumber, NE-NC.

Air Emission[1/]	Total	Forestry Operations	Wood Production
	kg/m^3		
Carbon dioxide, biogenic	141.4294	0.0103	141.4191
Carbon dioxide, fossil	88.4413	14.0272	74.4140
Nitrogen oxides	0.7672	0.2558	0.5114
VOC, volatile organic compounds	0.6742	0.0068	0.6674
Carbon monoxide	0.4411	0.0000	0.4411
Particulates, > 2.5 um, and < 10um	0.3760	0.0079	0.3682
Carbon monoxide, fossil	0.3645	0.1253	0.2392
Particulates, < 2.5 um	0.3096	0.0000	0.3096
Sulfur dioxide	0.2769	0.0071	0.2698
Methane	0.1592	0.0182	0.1410
Sulfur oxides	0.0784	0.0142	0.0642
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0335	0.0085	0.0250
Metals, unspecified	0.0308	0.0000	0.0308
Particulates, unspecified	0.0279	0.0013	0.0266
Hydrogen chloride	0.0228	0.0001	0.0227
Isoprene	0.0107	0.0003	0.0104

Air Emission[1/]	Total	Forestry Operations	Wood Production
	kg/m^3		
Methane, fossil	0.0088	0.0013	0.0075
Formaldehyde	0.0033	0.0001	0.0032
Benzene	0.0031	0.0001	0.0031
TOC, Total Organic Carbon	0.0029	0.0000	0.0029
Acrolein	0.0029	0.0000	0.0029
Manganese	0.0012	0.0000	0.0012
Hydrogen fluoride	0.0011	0.0000	0.0010
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0009	0.0001	0.0009
Dinitrogen monoxide	0.0008	0.0000	0.0008
Acetaldehyde	0.0007	0.0001	0.0006
Radionuclides (Including Radon)	0.0007	0.0000	0.0007
Aldehydes, unspecified	0.0007	0.0002	0.0005
Chlorine	0.0006	0.0000	0.0006
Ammonia	0.0004	0.0001	0.0003
Carbon dioxide	0.0003	0.0000	0.0003
Propene	0.0003	0.0002	0.0001
Methane, dichloro-, HCC-30	0.0002	0.0000	0.0002
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 13.

Waterborne emissions are all off-site (Table 15). 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 13) of this report.

Table 15 Emissions to water released per 1 m^3 of dry planed softwood lumber, NE-NC.

Water emission	Total	Forestry Operations	Wood Production
	kg/m^3		
Solved solids	3.1235	0.7207	2.4028
Chloride	2.5323	0.5843	1.9480
Sodium, ion	0.7141	0.1648	0.5493
Calcium, ion	0.2253	0.0520	0.1733
Suspended solids, unspecified	0.1712	0.0430	0.1282
Barium	0.0749	0.0191	0.0557
Magnesium	0.0440	0.0102	0.0339
COD, Chemical Oxygen Demand	0.0272	0.0056	0.0216
Sulfate	0.0161	0.0013	0.0148
Bromide	0.0150	0.0035	0.0116
BOD5, Biological Oxygen Demand	0.0138	0.0030	0.0109
Lithium, ion	0.0128	0.0008	0.0120
Iron	0.0115	0.0028	0.0087
Aluminum	0.0056	0.0014	0.0042
Strontium	0.0038	0.0009	0.0029
Oils, unspecified	0.0016	0.0004	0.0013
Ammonia	0.0013	0.0003	0.0010
Boron	0.0002	0.0001	0.0002
Manganese	0.0002	0.0000	0.0002
Sulfur	0.0002	0.0000	0.0001
Silver	0.0001	0.0000	0.0001
Chromium	0.0001	0.0000	0.0001
Zinc	0.0001	0.0000	0.0001
Benzene	0.0001	0.0000	0.0001
Toluene	0.0001	0.0000	0.0001

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

Surveys reported some solid waste that is collected from the log-yard and cannot be sent to the boiler because it is mixed with dirt and rock as well as upstream waste flows generated from fuel production (Table 16). There was also a small portion of ash reported from the boilers. The total solid waste generated at the mills was 4% of the total waste.

Table 16 Waste to treatment per 1 m^3 of dry planed softwood lumber, NE-NC.

Waste to treatment	Total	Forestry Operations	Wood Production
	kg/m^3		
Solid waste	13.22	0.22	13.00

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 17. 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 17 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 18 provides the environmental impact by category for softwood lumber produced in the NE-NC 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 18. For GWP, 92 percent of the CO^2 equivalent emissions come from producing lumber production, with remainder assigned to forestry operations.

Table 18 Environmental performance of 1 m^3 planed dry softwood lumber, NE-NC.

Impact category	Unit	Total	Forestry Operations	Wood Production
Global warming potential (GWP)	kg CO_2 equiv	92.89	14.52	78.38
Acidification Potential	H+ moles equiv	49.90	11.34	38.56
Eutrophication Potential	kg N equiv	0.0371	0.0120	0.0251
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000
Smog Potential	kg O3 equiv	21.66	6.37	15.29
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable fossil	MJ	1342.09	212.57	1130.54
Non-renewable nuclear	MJ	182.35	2.10	180.25
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	25.31	0.23	25.08
Renewable, biomass	MJ	2586.16	0.00	2586.16
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Non-renewable materials[5]	kg	0.0853	0.00	0.0853
Renewable materials	kg	403.17	0.00	403.17
Fresh water	L	179.38	0.00	179.38
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Wood Production**
Solid waste	kg	13.22	0.22	13.00

[5] Limestone, in ground has been removed from a pre-combustion 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, 93 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 678 kg CO_2e (Table 19).

Table 19 Carbon per 1 m^3 planed dry softwood lumber, NE-NC.

	kg CO_2 equivalent
released forestry operations	14.52
released manufacturing	78.38
CO_2 eq. stored in product	678.32

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 on process inputs such as natural gas, diesel, and electricity. The survey results were representative of the forest operations in the region that produce eastern white pine, red pine, jack pine, eastern spruce, black spruce, and balsam fir. The survey data are representative of the lumber sizes and production volumes consistent with trade association production data. Softwood lumber production from the NE-NC region required 1.23 m^3 or 454 kg of roundwood (wood and bark) harvested from NE-NC forest per cubic meter of lumber.

Lowering energy consumption would be of great benefit to the mills both in terms of financial benefits (cost reduction) and environmental burden benefits, especially in sawing and drying. There are several approaches to lowering energy consumption, and mills that incorporate these methods would ultimately have significantly lower energy use and thus less environmental burdens. Drying consumes the highest proportion of fuel. Lowering overall energy consumption in drying is necessary and has a large influence on reducing the environmental impact on softwood lumber manufacturing. The majority of the cradle to gate energy consumption comes from renewable fuels (63%) and non-renewable fossil fuels (32%). Sawing consumes the highest proportion of electricity in the manufacturing of softwood lumber. Thus, installing optimization equipment would lower electrical consumption by reducing sawing errors. Thinner kerf saws reduce electrical consumption and also reduce the volume of green wood residue produced. The region selected for production affects the environmental impact of this product because coal is the off-site material used most for electrical power generation in the NE-NC region.

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, 93 kg CO_2e were released in the production of 1 m^3 of lumber. That same 1 m^3 of lumber stores 678 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, NE-NC.

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
2,4-D	kg	1.12E-09	0.00E+00	1.12E-09
2-Chloroacetophenone	kg	2.18E-10	3.42E-13	2.18E-10
5-methyl Chrysene	kg	1.55E-10	2.23E-12	1.52E-10
Acenaphthene	kg	3.59E-09	5.17E-11	3.53E-09
Acenaphthylene	kg	1.76E-09	2.53E-11	1.73E-09
Acetaldehyde	kg	6.85E-04	5.87E-05	6.27E-04
Acetochlor	kg	1.56E-08	0.00E+00	1.56E-08
Acetophenone	kg	4.68E-10	7.32E-13	4.67E-10
Acrolein	kg	2.90E-03	7.11E-06	2.89E-03
Alachlor	kg	1.53E-09	0.00E+00	1.53E-09
Aldehydes, unspecified	kg	6.73E-04	1.76E-04	4.97E-04
Ammonia	kg	3.68E-04	8.86E-05	2.79E-04
Ammonium chloride	kg	2.53E-05	2.92E-07	2.50E-05
Anthracene	kg	1.48E-09	2.13E-11	1.45E-09
Antimony	kg	5.82E-06	1.82E-09	5.82E-06
Arsenic	kg	1.94E-05	5.93E-08	1.94E-05
Atrazine	kg	3.04E-08	0.00E+00	3.04E-08
Barium	kg	1.76E-07	0.00E+00	1.76E-07
Bentazone	kg	1.24E-10	0.00E+00	1.24E-10
Benzene	kg	3.14E-03	7.16E-05	3.07E-03
Benzene, chloro-	kg	6.86E-10	1.07E-12	6.85E-10
Benzene, ethyl-	kg	2.93E-09	4.59E-12	2.93E-09
Benzo(a)anthracene	kg	5.62E-10	8.10E-12	5.54E-10
Benzo(a)pyrene	kg	2.67E-10	3.85E-12	2.63E-10
Benzo(b,j,k)fluoranthene	kg	7.73E-10	1.11E-11	7.62E-10
Benzo(ghi)perylene	kg	1.90E-10	2.74E-12	1.87E-10
Benzyl chloride	kg	2.18E-08	3.42E-11	2.18E-08
Beryllium	kg	1.29E-06	2.90E-09	1.28E-06
Biphenyl	kg	1.20E-08	1.72E-10	1.18E-08
Bromoform	kg	1.22E-09	1.90E-12	1.21E-09
Bromoxynil	kg	2.72E-10	0.00E+00	2.72E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	9.25E-04	5.88E-05	8.66E-04
Butadiene	kg	4.44E-06	2.99E-06	1.44E-06
Cadmium	kg	3.78E-06	1.46E-08	3.77E-06

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Carbofuran	kg	2.32E-10	0.00E+00	2.32E-10
Carbon dioxide	kg	3.30E-04	0.00E+00	3.30E-04
Carbon dioxide, biogenic	kg	1.41E+02	1.03E-02	1.41E+02
Carbon dioxide, fossil	kg	8.84E+01	1.40E+01	7.44E+01
Carbon disulfide	kg	4.05E-09	6.35E-12	4.05E-09
Carbon monoxide	kg	4.41E-01	2.64E-06	4.41E-01
Carbon monoxide, fossil	kg	3.65E-01	1.25E-01	2.39E-01
Chloride	kg	3.25E-10	7.87E-12	3.17E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	2.12E-08	0.00E+00	2.12E-08
Chlorine	kg	5.70E-04	0.00E+00	5.70E-04
Chloroform	kg	1.84E-09	2.88E-12	1.84E-09
Chlorpyrifos	kg	1.79E-09	0.00E+00	1.79E-09
Chromium	kg	1.75E-05	4.25E-08	1.75E-05
Chromium VI	kg	5.55E-07	8.00E-09	5.47E-07
Chrysene	kg	7.03E-10	1.01E-11	6.93E-10
Cobalt	kg	6.38E-06	8.58E-08	6.30E-06
Copper	kg	6.82E-07	7.55E-10	6.81E-07
Cumene	kg	1.65E-10	2.59E-13	1.65E-10
Cyanazine	kg	2.68E-10	0.00E+00	2.68E-10
Cyanide	kg	7.79E-08	1.22E-10	7.78E-08
Dicamba	kg	1.58E-09	0.00E+00	1.58E-09
Dimethenamid	kg	3.73E-09	0.00E+00	3.73E-09
Dinitrogen monoxide	kg	8.42E-04	1.26E-05	8.30E-04
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	1.21E-09	0.00E+00	1.21E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	1.75E-11	2.72E-13	1.72E-11
Dipropylthiocarbamic acid S-ethyl ester	kg	2.55E-09	0.00E+00	2.55E-09
Ethane, 1,1,1-trichloro-, HCFC-140	kg	2.16E-09	4.08E-10	1.75E-09
Ethane, 1,2-dibromo-	kg	3.74E-11	5.86E-14	3.73E-11
Ethane, 1,2-dichloro-	kg	1.25E-09	1.95E-12	1.24E-09
Ethane, chloro-	kg	1.31E-09	2.05E-12	1.31E-09
Ethene, tetrachloro-	kg	3.77E-07	5.31E-09	3.72E-07
Ethene, trichloro-	kg	5.05E-14	0.00E+00	5.05E-14
Fluoranthene	kg	4.99E-09	7.19E-11	4.92E-09
Fluorene	kg	6.40E-09	9.22E-11	6.30E-09
Fluoride	kg	1.96E-06	8.69E-09	1.95E-06
Formaldehyde	kg	3.32E-03	9.11E-05	3.23E-03
Furan	kg	3.30E-11	4.61E-13	3.25E-11
Glyphosate	kg	3.35E-09	0.00E+00	3.35E-09
Hexane	kg	2.09E-09	3.27E-12	2.08E-09
Hydrazine, methyl-	kg	5.30E-09	8.30E-12	5.29E-09
Hydrocarbons, unspecified	kg	1.46E-04	1.69E-06	1.45E-04

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Hydrogen	kg	1.07E-07	0.00E+00	1.07E-07
Hydrogen chloride	kg	2.28E-02	1.31E-04	2.27E-02
Hydrogen fluoride	kg	1.05E-03	1.52E-05	1.04E-03
Hydrogen sulfide	kg	1.05E-11	2.54E-13	1.03E-11
Indeno(1,2,3-cd)pyrene	kg	4.29E-10	6.18E-12	4.23E-10
Iron	kg	1.76E-07	0.00E+00	1.76E-07
Isophorone	kg	1.81E-08	2.83E-11	1.80E-08
Isoprene	kg	1.07E-02	2.58E-04	1.04E-02
Kerosene	kg	1.21E-05	1.40E-07	1.20E-05
Lead	kg	3.90E-05	6.50E-08	3.89E-05
Magnesium	kg	7.73E-05	1.11E-06	7.62E-05
Manganese	kg	1.16E-03	8.93E-08	1.16E-03
MCPA	kg	2.10E-11	0.00E+00	2.10E-11
Mercaptans, unspecified	kg	6.73E-06	9.91E-09	6.72E-06
Mercury	kg	3.53E-06	1.12E-08	3.52E-06
Metals, unspecified	kg	3.08E-02	2.92E-14	3.08E-02
Methacrylic acid, methyl ester	kg	6.23E-10	9.76E-13	6.22E-10
Methane	kg	1.59E-01	1.82E-02	1.41E-01
Methane, bromo-, Halon 1001	kg	4.99E-09	7.81E-12	4.98E-09
Methane, dichloro-, HCC-30	kg	2.15E-04	9.38E-08	2.15E-04
Methane, dichlorodifluoro-, CFC-12	kg	1.90E-09	5.04E-10	1.40E-09
Methane, fossil	kg	8.82E-03	1.32E-03	7.50E-03
Methane, monochloro-, R-40	kg	1.65E-08	2.59E-11	1.65E-08
Methane, tetrachloro-, CFC-10	kg	4.53E-10	5.04E-11	4.03E-10
Methyl ethyl ketone	kg	1.22E-08	1.90E-11	1.21E-08
Methyl methacrylate	kg	1.45E-13	0.00E+00	1.45E-13
Metolachlor	kg	1.23E-08	0.00E+00	1.23E-08
Metribuzin	kg	5.71E-11	0.00E+00	5.71E-11
Naphthalene	kg	7.03E-05	1.77E-08	7.03E-05
Nickel	kg	4.02E-05	1.09E-06	3.91E-05
Nitrogen oxides	kg	7.67E-01	2.56E-01	5.11E-01
Nitrogen, total	kg	1.51E-09	0.00E+00	1.51E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	3.35E-02	8.54E-03	2.50E-02
N-Nitrodimethylamine	kg	1.13E-14	0.00E+00	1.13E-14
Organic acids	kg	9.30E-08	1.07E-09	9.19E-08
Organic substances, unspecified	kg	5.18E-05	6.29E-07	5.11E-05
PAH, polycyclic aromatic hydrocarbons	kg	1.91E-05	1.29E-05	6.20E-06
Paraquat	kg	2.49E-10	0.00E+00	2.49E-10
Parathion, methyl	kg	1.88E-10	0.00E+00	1.88E-10
Particulates, < 10 um	kg	6.80E-06	0.00E+00	6.80E-06
Particulates, < 2.5 um	kg	3.10E-01	0.00E+00	3.10E-01

Air Emissions	Unit	Total	Forestry Operations	Lumber Production
Particulates, > 2.5 um, and < 10um	kg	3.76E-01	7.86E-03	3.68E-01
Particulates, unspecified	kg	2.79E-02	1.34E-03	2.66E-02
Pendimethalin	kg	1.28E-09	0.00E+00	1.28E-09
Permethrin	kg	1.15E-10	0.00E+00	1.15E-10
Phenanthrene	kg	1.90E-08	2.74E-10	1.87E-08
Phenol	kg	1.60E-06	7.81E-13	1.60E-06
Phenols, unspecified	kg	4.02E-05	5.01E-08	4.01E-05
Phorate	kg	5.90E-11	0.00E+00	5.90E-11
Phthalate, dioctyl-	kg	2.28E-09	3.56E-12	2.27E-09
Potassium	kg	3.11E-05	0.00E+00	3.11E-05
Propanal	kg	1.18E-08	1.86E-11	1.18E-08
Propene	kg	2.93E-04	1.98E-04	9.53E-05
Pyrene	kg	2.32E-09	3.34E-11	2.29E-09
Radioactive species, unspecified	Bq	3.97E+05	5.74E+03	3.91E+05
Radionuclides (Including Radon)	kg	6.78E-04	7.82E-06	6.70E-04
Selenium	kg	1.30E-05	1.42E-07	1.28E-05
Simazine	kg	8.09E-10	0.00E+00	8.09E-10
Sodium	kg	7.18E-07	0.00E+00	7.18E-07
Styrene	kg	7.79E-10	1.22E-12	7.78E-10
Sulfur	kg	3.78E-06	0.00E+00	3.78E-06
Sulfur dioxide	kg	2.77E-01	7.15E-03	2.70E-01
Sulfur oxides	kg	7.84E-02	1.42E-02	6.42E-02
Sulfur, total reduced	kg	2.22E-06	0.00E+00	2.22E-06
Sulfuric acid, dimethyl ester	kg	1.50E-09	2.34E-12	1.49E-09
Tar	kg	3.66E-10	8.85E-12	3.57E-10
t-Butyl methyl ether	kg	1.09E-09	1.71E-12	1.09E-09
Terbufos	kg	2.01E-09	0.00E+00	2.01E-09
TOC, Total Organic Carbon	kg	2.95E-03	0.00E+00	2.95E-03
Toluene	kg	4.64E-05	3.13E-05	1.51E-05
Toluene, 2,4-dinitro-	kg	8.73E-12	1.37E-14	8.71E-12
Vinyl acetate	kg	2.37E-10	3.71E-13	2.37E-10
VOC, volatile organic compounds	kg	6.74E-01	6.76E-03	6.67E-01
Xylene	kg	3.23E-05	2.18E-05	1.05E-05
Zinc	kg	6.30E-07	5.03E-10	6.30E-07

13.2 Water Emissions

Table 20 Emissions to water released per 1 m^3 of dry planed softwood lumber, NE-NC.

Water Emission	Unit	Total	Forestry Operations	Lumber Production
2,4-D	kg	4.82E-11	0	4.82E-11
2-Hexanone	kg	4.58E-07	1.06E-07	3.52E-07
2-Propanol	kg	2.09E-09	0	2.09E-09
4-Methyl-2-pentanone	kg	2.95E-07	6.8E-08	2.27E-07
Acetochlor	kg	6.68E-10	0	6.68E-10
Acetone	kg	7.01E-07	1.62E-07	5.39E-07
Acidity, unspecified	kg	4.66E-15	0	4.66E-15
Acids, unspecified	kg	2.97E-06	1.65E-10	2.97E-06
Alachlor	kg	6.58E-11	0	6.58E-11
Aluminium	kg	2.01E-05	0	2.01E-05
Aluminum	kg	5.64E-03	0.001399	4.24E-03
Ammonia	kg	1.27E-03	0.000303	9.66E-04
Ammonia, as N	kg	3.43E-09	8.3E-11	3.35E-09
Ammonium, ion	kg	5.41E-06	6.24E-08	5.35E-06
Antimony	kg	3.40E-06	8.73E-07	2.52E-06
Arsenic, ion	kg	1.89E-05	4.44E-06	1.45E-05
Atrazine	kg	1.30E-09	0	1.30E-09
Barium	kg	7.49E-02	0.019149	5.57E-02
Bentazone	kg	5.31E-12	0	5.31E-12
Benzene	kg	1.18E-04	2.71E-05	9.05E-05
Benzene, 1-methyl-4-(1-methylethyl)-	kg	7.01E-09	1.62E-09	5.39E-09
Benzene, ethyl-	kg	6.62E-06	1.53E-06	5.09E-06
Benzene, pentamethyl-	kg	5.25E-09	1.21E-09	4.04E-09
Benzenes, alkylated, unspecified	kg	2.98E-06	7.66E-07	2.21E-06
Benzoic acid	kg	7.11E-05	1.64E-05	5.47E-05
Beryllium	kg	1.02E-06	2.47E-07	7.76E-07
Biphenyl	kg	1.93E-07	4.96E-08	1.43E-07
BOD5, Biological Oxygen Demand	kg	1.38E-02	0.00296	1.09E-02
Boron	kg	2.20E-04	5.08E-05	1.69E-04
Bromide	kg	1.50E-02	0.003466	1.16E-02
Bromoxynil	kg	7.02E-12	0	7.02E-12
Cadmium, ion	kg	2.84E-06	6.55E-07	2.19E-06
Calcium, ion	kg	2.25E-01	0.051974	1.73E-01
Carbofuran	kg	9.95E-12	0	9.95E-12
CFCs, unspecified	kg	2.09E-09	0	2.09E-09
Chloride	kg	2.53E+00	0.58432	1.95E+00
Chlorpyrifos	kg	7.66E-11	0	7.66E-11
Chromate	kg	2.78E-13	0	2.78E-13
Chromium	kg	1.39E-04	3.69E-05	1.02E-04

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Chromium VI	kg	5.86E-07	1.55E-07	4.31E-07
Chromium, ion	kg	1.51E-05	2.77E-06	1.23E-05
Cobalt	kg	1.55E-06	3.58E-07	1.19E-06
COD, Chemical Oxygen Demand	kg	2.72E-02	0.005619	2.16E-02
Copper, ion	kg	2.37E-05	4.61E-06	1.91E-05
Cyanazine	kg	1.15E-11	0	1.15E-11
Cyanide	kg	5.10E-09	1.17E-09	3.93E-09
Decane	kg	2.04E-06	4.72E-07	1.57E-06
Detergent, oil	kg	6.03E-05	1.36E-05	4.67E-05
Dibenzofuran	kg	1.33E-08	3.08E-09	1.03E-08
Dibenzothiophene	kg	1.14E-08	2.65E-09	8.75E-09
Dicamba	kg	6.76E-11	0	6.76E-11
Dimethenamid	kg	1.60E-10	0	1.60E-10
Dipropylthiocarbamic acid S-ethyl ester	kg	6.60E-11	0	6.60E-11
Disulfoton	kg	3.94E-12	0	3.94E-12
Diuron	kg	1.11E-12	0	1.11E-12
DOC, Dissolved Organic Carbon	kg	2.10E-11	5.07E-13	2.05E-11
Docosane	kg	7.50E-08	1.73E-08	5.77E-08
Dodecane	kg	3.88E-06	8.95E-07	2.98E-06
Eicosane	kg	1.07E-06	2.46E-07	8.21E-07
Fluorene, 1-methyl-	kg	7.98E-09	1.84E-09	6.14E-09
Fluorenes, alkylated, unspecified	kg	1.73E-07	4.44E-08	1.28E-07
Fluoride	kg	8.80E-05	1.02E-06	8.70E-05
Fluorine	kg	8.58E-08	2.19E-08	6.39E-08
Furan	kg	7.65E-11	0	7.65E-11
Glyphosate	kg	1.44E-10	0	1.44E-10
Hexadecane	kg	4.23E-06	9.77E-07	3.26E-06
Hexanoic acid	kg	1.47E-05	3.4E-06	1.13E-05
Hydrocarbons, unspecified	kg	7.66E-08	6.35E-13	7.66E-08
Iron	kg	1.15E-02	0.002788	8.70E-03
Lead	kg	3.87E-05	9.32E-06	2.94E-05
Lead-210/kg	kg	7.28E-15	1.68E-15	5.60E-15
Lithium, ion	kg	1.28E-02	0.000828	1.20E-02
Magnesium	kg	4.40E-02	0.01016	3.39E-02
Manganese	kg	2.08E-04	1.8E-05	1.90E-04
MCPA	kg	8.99E-13	0	8.99E-13
Mercury	kg	6.65E-08	1.54E-08	5.12E-08
Metallic ions, unspecified	kg	2.00E-09	7.75E-12	2.00E-09
Methane, monochloro-, R-40	kg	2.82E-09	6.51E-10	2.17E-09
Methyl ethyl ketone	kg	5.64E-09	1.3E-09	4.34E-09
Metolachlor	kg	5.28E-10	0	5.28E-10

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Metribuzin	kg	2.45E-12	0	2.45E-12
Molybdenum	kg	1.61E-06	3.72E-07	1.24E-06
m-Xylene	kg	2.12E-06	4.9E-07	1.63E-06
Naphthalene	kg	1.28E-06	2.95E-07	9.82E-07
Naphthalene, 2-methyl-	kg	1.11E-06	2.56E-07	8.54E-07
Naphthalenes, alkylated, unspecified	kg	4.88E-08	1.25E-08	3.63E-08
n-Hexacosane	kg	4.68E-08	1.08E-08	3.60E-08
Nickel	kg	1.81E-05	4.37E-06	1.37E-05
Nickel, ion	kg	2.42E-13	0	2.42E-13
Nitrate	kg	2.48E-07	5.56E-14	2.48E-07
Nitrate compounds	kg	9.26E-11	2.24E-12	9.04E-11
Nitric acid	kg	2.08E-07	5.02E-09	2.03E-07
Nitrogen, total	kg	2.21E-05	1.55E-07	2.19E-05
o-Cresol	kg	2.02E-06	4.65E-07	1.55E-06
Octadecane	kg	1.05E-06	2.41E-07	8.04E-07
Oils, unspecified	kg	1.64E-03	0.000373	1.26E-03
Organic substances, unspecified	kg	1.53E-09	0	1.53E-09
Paraquat	kg	1.07E-11	0	1.07E-11
Parathion, methyl	kg	8.07E-12	0	8.07E-12
p-Cresol	kg	2.18E-06	5.02E-07	1.67E-06
Pendimethalin	kg	5.49E-11	0	5.49E-11
Permethrin	kg	4.93E-12	0	4.93E-12
Phenanthrene	kg	1.81E-08	4.5E-09	1.36E-08
Phenanthrenes, alkylated, unspecified	kg	2.02E-08	5.2E-09	1.50E-08
Phenol	kg	2.62E-05	6.87E-06	1.94E-05
Phenol, 2,4-dimethyl-	kg	1.96E-06	4.53E-07	1.51E-06
Phenols, unspecified	kg	8.97E-06	1.3E-06	7.67E-06
Phorate	kg	1.53E-12	0	1.53E-12
Phosphate	kg	1.87E-05	0	1.87E-05
Phosphorus	kg	4.28E-06	0	4.28E-06
Phosphorus compounds, unspecified	kg	2.83E-08	0	2.83E-08
Phosphorus, total	kg	2.53E-06	0	2.53E-06
Process solvents, unspecified	kg	7.65E-09	0	7.65E-09
Radioactive species, Nuclides, unspecified	Bq	7.86E+02	9.067028	7.77E+02
Radium-226/kg	kg	2.53E-12	5.85E-13	1.95E-12
Radium-228/kg	kg	1.30E-14	2.99E-15	9.97E-15
Selenium	kg	2.55E-06	1.91E-07	2.36E-06
Silver	kg	1.47E-04	3.4E-05	1.13E-04
Simazine	kg	3.47E-11	0	3.47E-11
Sodium, ion	kg	7.14E-01	0.164761	5.49E-01
Solids, inorganic	kg	5.28E-10	1.28E-11	5.15E-10

Water Emission	Unit	Total	Forestry Operations	Lumber Production
Solved solids	kg	3.12E+00	0.72069	2.40E+00
Strontium	kg	3.82E-03	0.000882	2.94E-03
Styrene	kg	9.68E-12	0	9.68E-12
Sulfate	kg	1.61E-02	0.001303	1.48E-02
Sulfide	kg	2.70E-05	7.97E-07	2.62E-05
Sulfur	kg	1.86E-04	4.29E-05	1.43E-04
Sulfuric acid	kg	6.70E-11	0	6.70E-11
Suspended solids, unspecified	kg	1.71E-01	0.042996	1.28E-01
Tar	kg	5.23E-12	1.27E-13	5.11E-12
Terbufos	kg	5.21E-11	0	5.21E-11
Tetradecane	kg	1.70E-06	3.92E-07	1.31E-06
Thallium	kg	7.16E-07	1.84E-07	5.32E-07
Tin	kg	1.44E-05	3.55E-06	1.08E-05
Titanium, ion	kg	5.22E-05	1.34E-05	3.87E-05
TOC, Total Organic Carbon	kg	9.68E-08	0	9.68E-08
Toluene	kg	1.11E-04	2.56E-05	8.55E-05
Vanadium	kg	1.90E-06	4.39E-07	1.46E-06
Waste water/m^3	m^3	6.31E-04	0	6.31E-04
Xylene	kg	5.94E-05	1.38E-05	4.56E-05
Yttrium	kg	4.73E-07	1.09E-07	3.63E-07
Zinc	kg	1.35E-04	3.23E-05	1.02E-04
Zinc, ion	kg	3.38E-07	0	3.38E-07