Cradle to Gate Life Cycle Assessment of U.S. Medium Density Fiberboard Production

Maureen Puettmann, WoodLife Environmental Consultants, LLC
Elaine Oneil, CORRIM
Jim Wilson, Oregon State University

August 2013

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 (U.S.) 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 the average U.S. production of medium density fiberboard (MDF). Wood residue inputs for the U.S. average MDF production are sourced from the Pacific Northwest (PNW), Southeast (SE), and Northeast-North central (NE-NC) regions and include co-products from various wood manufacturing processes. This document updates the current MDF LCI from a gate to gate to a cradle to gate LCI. Updates include the addition of forestry operations, and boiler and electrical grid data that have been revised since the original mill surveys were conducted in 2004. 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 Wilson (2008, 2010a), Johnson et al. (2005), and Oneil et al. (2010). Updates in this report from the original Wilson (2008, 2010a) MDF report include: wood combustion boiler updates, electricity grid updates (Goemans 2010), and a LCIA. Updates to the forestry operations reports include electricity grid updates and a 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's. 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 medium density fiberboard (MDF) representing average manufacturing practices in the U.S. 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 MDF from a variety of wood residues using practices and technology common to the U.S. forestry and manufacturing sectors. It covers the impacts in terms of input materials, fuels, and electricity through to the outputs of product, co-products, and emissions (Wilson 2008, 2010a). Wood residues used in MDF production are obtained from softwood plywood and lumber manufacturers in the PNW and SE regions and hardwood lumber residues from the NE-NC. These manufacturers obtain logs from forest resource bases located in western Washington, Oregon, Georgia, Alabama, Mississippi, Louisiana, Indiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin as representative of the PNW and SE softwood and NE-NC hardwood regions. Data for the life cycle assessment (LCA) are based on manufacturing gate to gate LCI's from wood product manufacturing reports (Wilson and Sakimoto 2004, Milota et al. 2005, Bergman and Bowe 2008, Wilson 2008 and 2010a) and forest resources cradle to gate LCI's (Johnson et al. 2005, 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

MDF is a non-structural panel product developed in the 1970s to utilize industrial wood residue from the production of primary wood products such as softwood lumber and plywood. These wood residues were previously burned for energy or sent to landfill to dispose of them as waste material. Over the years the product has evolved into a highly engineered product designed to meet specific end-use requirements. MDF is an industrial type panel used for making furniture, cabinets, tables, countertops, and millwork (Figure 1). The production of MDF falls into the Standard Industrial Classification (SIC) Code 2493—reconstituted wood products—which includes other wood composite products such as hardboard, insulation board, particleboard, and oriented strand board (U.S. Census Bureau 2007).

MDF is produced from industrial wood residues such as shavings, sawdust, panel trim, and chips, and can be produced from chips, from logs, or from trees. The residues are refined to fibers or fiber bundles that are dried, blended with resin and wax, and then formed into a mat that is consolidated and cured under pressure and heat. MDF is produced in densities ranging from 31-50 lb/ft^3 (497-801 kg/m^3) (Figure 2) consistent with the material standards listed in the American National Standard ANSI A208.2-2002 (ANSI 2002).

Production is measured on a thousand square foot (MSF) ¾-inch basis (19.05 mm). The panels are produced in thicknesses ranging from 3/8 inch (9.525 mm) to 1-1/4 inch (31.75 mm) and in widths from 4 to 5 feet (1.22 to 1.52 m) and lengths from 8 to 24 feet (2.44 to 7.32 m). Thin MDF, a subgroup of MDF products, which is approximately 1/8-inch thickness (3 mm) was not included in this study.

Figure 1 Medium density fiberboard (MDF).

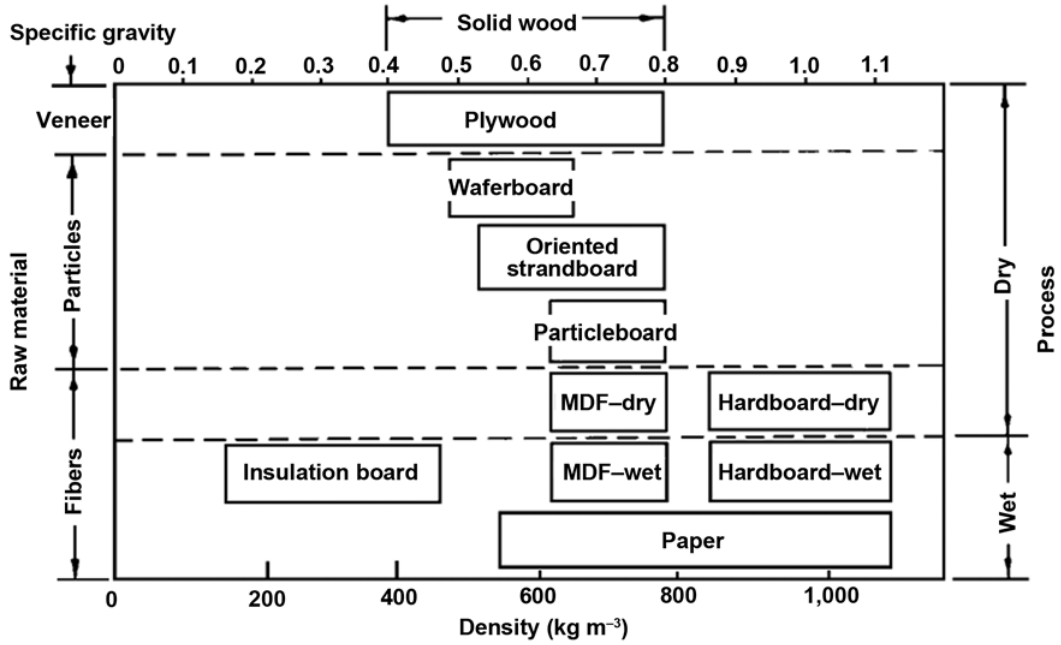

Figure 2 Classification of wood composite panels by particle size, density, and process (Suchsland and Woodson 1986).

3.1 Functional and declared unit

In accordance with the PCR (2011), the declared unit for MDF is one cubic meter (1.0 m^3). A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building product cannot be stated (PCR 2011). For conversion of units from the US industry measure, 1.0 MSF (1000 square feet) is equal to 1.7698 m^3. All input and output data were allocated to the declared unit of product based on the mass of products and co-products in accordance with International Organization for Standardization (ISO) protocol (ISO 2006). As the analysis does not take the declared unit to the stage of being an installed building product no service life is assigned.

3.2 System Boundaries

The system boundary begins with regeneration in the forest and ends with MDF (Wilson 2008, 2010a) (Figure 3). The forest resources system boundary includes: site preparation and planting seedlings, forest management which included fertilization and thinning on a subset of hectares, final harvest with the transportation of logs to the primary breakdown facility, wood residue production during lumber and plywood manufacturing processes, transportation to the MDF facility, and MDF production (Figure 3). Seedlings and the fertilizer and electricity it took to grow them were considered as inputs to the system boundary. The MDF production complex was modeled as a single process representing all the steps necessary to make MDF: sorting of wood residue, digesting, refining, blending, drying, forming, hot pressing, conditioning, sanding and sawing (Figure 4). A single unit approach was used to model the MDF process since the percentage of co-product was very small (0.3%) and the approach does not impact the accuracy of assigning the burdens.

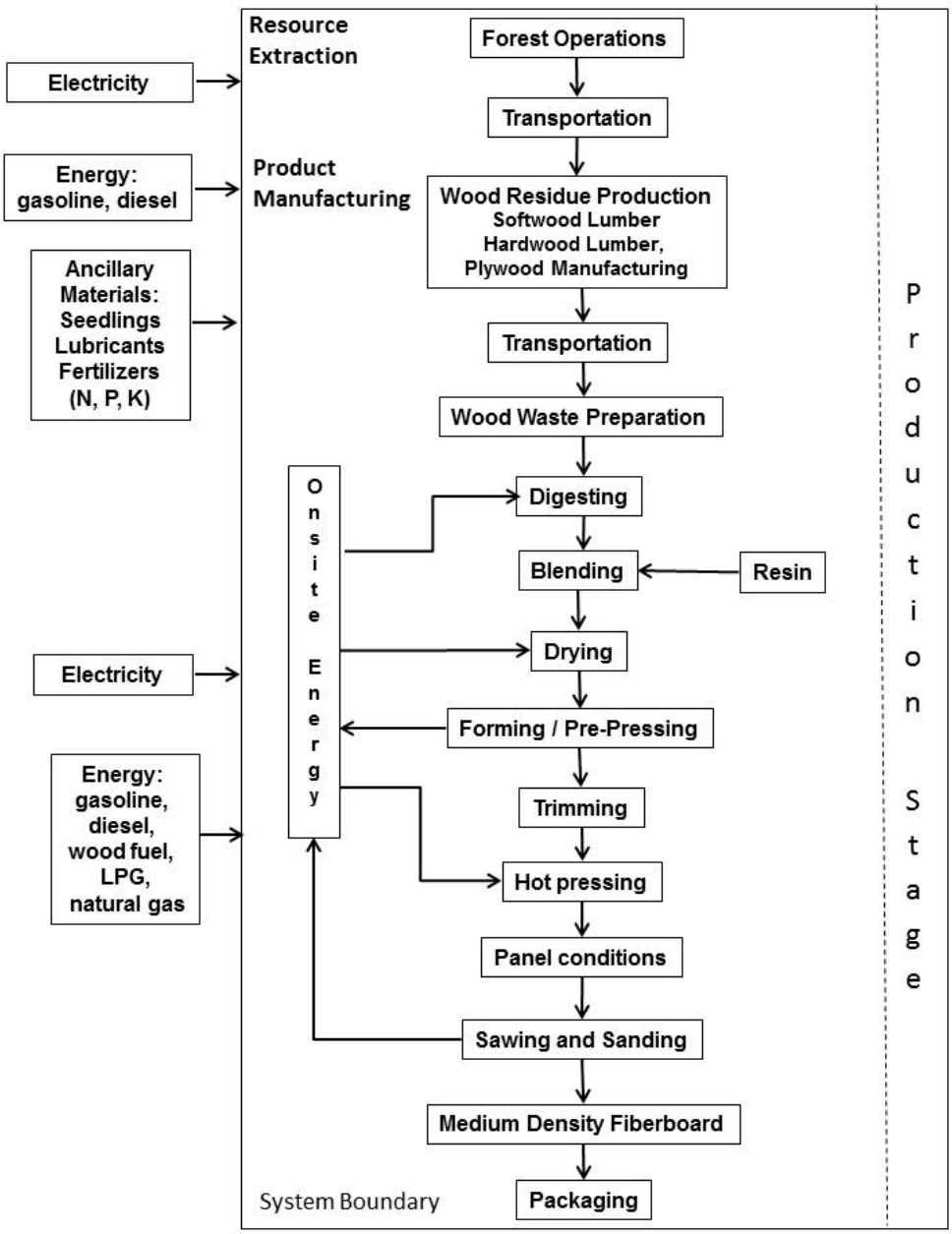

Figure 3 Cradle to gate life cycle stages for medium density fiberboard.

3.3 Description of data/Process Description

3.3.1 Forestry Operations

Forest operations modeled through wood residue production as inputs to MDF production were based on forest resource LCI data inputs from the PNW (38%) and SE (41%) softwood forests (Johnson et al 2005) and NE-NC (21%) hardwood forests (Oneil et al 2010). Forestry operations vary regionally (Johnson et al. 2005 and Oneil et al. 2010) but typically include some combination of growing seedlings, site preparation, planting, thinning, fertilization (where applicable) and final harvest. For NE-NC hardwood forests, reforestation was assumed to occur using natural regeneration that did not require inputs from the technosphere for seedlings, site preparation, planting and pre-commercial thinning (Table 1), whereas these steps were included for regeneration of softwood forests in the PNW and SE regions. The specific processes involved are reforestation: which includes seedling production, site preparation and planting, pre-commercial thinning, 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 thinning, and harvest operations. The primary output product is a log destined for the lumber or plywood mill. The co-product, non-merchantable slash, is generally left at a landing. Slash disposal was not modeled as it was assumed to decay in-situ. Details of the processes are provided in Johnson et al. 2005 and Oneil et al. 2010. A summary of the energy use and fuel consumption for the forest operations by region, along with the weighted average values used in MDF production are provided in Table 1.

Table 1 Fuel consumption for regional forest resource management processes (regeneration, thinning, and harvest).

	Unit	Fuel Consumption per m^3			
		PNW softwoods	SE softwoods	NE-NC hardwoods	Weighted Average
Seedling, Site Prep, Plant, Pre-commercial Thinning					
Diesel and gasoline	L	0.088	0.515	0.000	0.245
Lubricants	L	0.002	0.009	0.000	0.004
Electricity	kWh	0.107	0.455	0.000	0.227
Commercial Thinning and Final Harvest					
Diesel	L	2.850	2.930	4.268	3.181
Lubricants	L	0.051	0.050	0.077	0.056
Total Forest Extraction Process					
Gasoline and Diesel	L	2.938	3.440	4.268	3.423
Lubricants	L	0.053	0.059	0.077	0.061
Electricity	kWh	0.107	0.455	0.000	0.227

3.3.2 Wood Product Manufacturing

The MDF manufacturing process is highly automated, process-controlled and fairly linear. The complete process is shown in Figure 4.

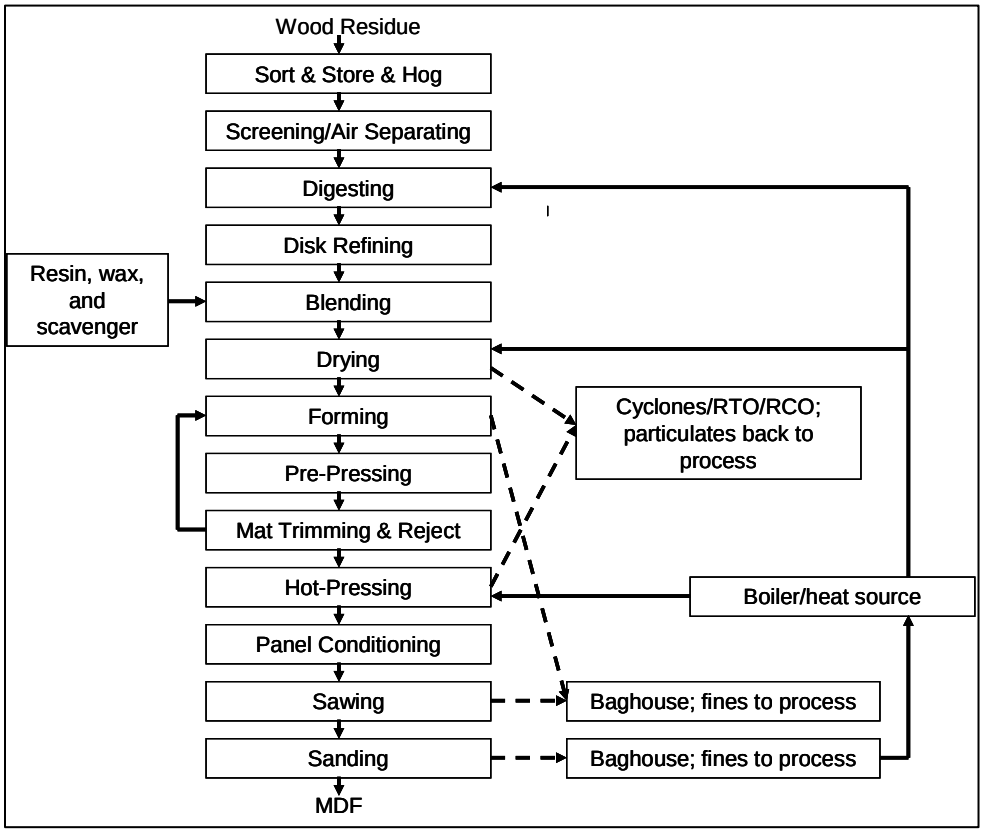

Figure 4 Process flow for the production of MDF

3.3.2.1 Transportation Process

Delivery of wood residues and materials to the mills is by truck. Some resin is delivered by pipeline from adjacent resin plants and is not considered in the transport in this study. Based on mill surveys the average haul distance for wood residues was 161km, bark used for energy generation was 84 km, and resin, wax and scavenger[1] 134 km.

Table 2 Average delivery distance (one-way) for materials to MDF mill, U.S. average.

Material delivered to mill	Delivery Distance (km)	
	km	miles
Wood residue	161	100
Bark for fuel	84	52
Urea-formaldehyde resin	134	83
Wax	134	83
Urea scavenger	134	83

[1] Scavenger is used to "capture" excess formaldehyde to reduce its emission from the panel.

3.3.2.2 Energy use and generation

Energy for the production of MDF comes from electricity, wood sources, natural gas, and oil. Other fuels such as diesel, liquid propane gas (LPG), and gasoline are used to operate transport equipment within the mill. The electricity is used to operate equipment within the plant, including conveyors, refiners, fan motors, hydraulic press motors, sanders, and emission control systems. Electricity is used throughout the process. The fuels for equipment are used for loaders and forklifts, and the natural gas and wood fuels are used to operate flash tube dryers and heat presses.

Emission control devices such as baghouses, cyclones, biofilters (BFs), regenerative thermal oxidizers (RTOs) and regenerative catalytic oxidizers (RCOs) are used throughout the mill. The emission control devices are used to reduce particulate and chemical emissions with a trade-off in that there is a large quantity of natural gas and electricity used to operate the RTO and RCO devices, and similarly large quantities of electricity to operate BF systems.

Wood fuel is the primary fuel used in the MDF process; it is used for providing process heat for digesting, drying wood residue and heating steam or oil for hot pressing. Wood fuel is mainly in the form of sander dust that is generated when the panel is sanded to its desired thickness and smoothness; a small amount of additional wood fuel is generated during other processing steps. The second largest fuel source is natural gas which is used for dryers and for powering emissions control devices (RTO/RCO). A small amount of fuel oil is used for process heat and a small amount of fuel is used to operate fork lift trucks and handlers within the mill. The total fuel use for process heat is 9,223 MJ/m^3 of which 82% is generated through the combustion of wood fuel (Table 3) and the other 18% is from natural gas.

The wood boiler used self-generated wood waste (Table 3 and 4). One kg of wood material based on an oven dry basis for moisture content contained 20.9 MJ of energy. The wood-based fuel mix was 65% bark (purchased), 20% sander dust, and 15% fuel wood from waste.

Table 3 Heat inputs per 1 m^3 MDF, U.S. average.

Fuel	Unit	Value (Unit/m^3)	HHV (MJ/kg)	MJ/m^3 of product
Wood waste- self generated	kg	127	20.9	2,654
Wood waste- purchased	kg	236	20.9	4,932
Natural gas	m^3	43	54.4 [1/]	1,637
TOTAL Heat Energy – at MDF	MJ	-	-	9,223

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

Total energy, which includes fuel for process heat and equipment and electricity, comes from wood fuel (70%), natural gas (15%), and electricity (14%). The non-wood energy component represents an opportunity for improving sustainability by substituting for it with sustainably grown wood fuel.

Table 4 Wood Boiler Process

Product	Value	Unit/m^3
Wood biomass, combusted in industrial boiler-oven dry	1.00	kg
Avoided products		
Electricity, at Grid	0.0048	kWh
Materials/fuels		
Fuel wood	0.15	kg
Sander dust	0.20	kg
Bark, purchased	0.65	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 Wood Residue Sort and Store

Wood residue is delivered to the mill by truck; the residue, referred to in the industry as furnish, consists of shavings, sawdust, panel trim, and chips of various moisture contents; the residue is stored under cover; the moisture content of the residue can range from 10 to 100% on an oven-dry weight-basis. Sometimes a hog[2] is used to reduce residue size.

3.3.2.4 Digesting

The wood residue is placed in a pressurized vessel called a digester to cook the wood in preparation for refining into fibers. The wood is cooked with steam at pressure to soften the lignin binder material between its fibers.

3.3.2.5 Refining

The heated wood residue is then refined, a process of mechanically reducing it into fibers by shearing the wood between two rotating metal disks which separate the fibers at the lignin binder. This process is usually accomplished with the use of pressurized disk refiners—a method for mechanically reducing wood into its individual fibers.

3.3.2.6 Blending

This process distributes the resin, wax, catalyst, and scavenger onto the fibers. Friction and contact between fibers is used to distribute the resin. Urea-formaldehyde (UF) is the most commonly used resin except for those products where moisture resistance is desired which are made with either melamine-urea-formaldehyde or polymeric isocyanate resins. The resin and other additives are either applied to the fibers in the refiner, coming out of the refiner in the blow line, or in the dryer flash tube prior to forming.

3.3.2.7 Drying

The fibers are sent through dryers, most commonly through flash tube dryers consisting of long tubes. Heated air is used to both dry and transport the fibers the length of the tube. The fibers enter the dryer at somewhat higher moisture contents than the 39% (oven dry basis) average residue entering the mill because of steam treating in the digester. The fibers are dried to a targeted moisture content of about 7-9% with resin applied. The dryers are normally direct-fired with natural gas, although some dryers use sander dust generated during finishing the MDF. Heat sources based on wood fuel can also be used for drying. As wood dries at elevated air temperatures of up to 500°F (260°C) in the dryers, particulates and air emissions of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) are released.

3.3.2.8 Forming

The blended fibers are distributed into a flat mat usually in multiple layers of three or five consisting of face and core layers. The distribution of fibers, their moisture, and resin content can be controlled for the face and core layers to obtain desire panel properties and efficiency.

3.3.2.9 Hot pressing

The formed mats are pre-pressed to reduce their thickness and provide mat integrity and are then conveyed into large stack presses with multiple openings. Presses operate at a sufficient temperature of approximately 340°F (170°C) and duration to cure the resin, and sufficient pressure of approximately 750 psi (5.17 MPa) to consolidate the mat to a desired density of 31-50 lb/ft3 (497- 801 kg/m3). As a result of the elevated temperature and resin curing, particulates and air emissions of VOCs, HAPs, and resin related emissions are generated. Hot presses are heated with steam or hot oil.

[2] Hog is a machine used to grind wood into chips for the use as fuel or for other purposes. The wood used is usually waste wood unfit for other uses.

3.3.2.10 Conditioning

The hot panels are placed on a cooling wheel to enable the temperature of the panels to drop below a value where the UF resin will start to break down with time and emit formaldehyde gas. Limited amounts of air emissions occur at this point.

3.3.2.11 Sanding

The panels are sanded on both major surfaces to targeted thickness and smoothness. Sander dust coming off this process can either be put back into residue prior to the blending process or used as fuel for the dryers.

3.3.2.12 Sawing

Sanded, conditioned panels are sawn to their final dimensions during this step in the manufacturing. Typical dimensions are panel widths of 4 or 5 feet and lengths of 8 or 9 feet and sometimes longer lengths. Panel trim is hammermilled[3] into particles and sent back into the process prior to the former. The panels are then stacked and prepared for shipping. Final MDF product has an average dry density of 741 kg/m^3.

Table 5 Unit process inputs/outputs to produce 1 m^3 of MDF, U.S. average.

Products	**Value**	**Unit/m^3**	**Allocation**
Medium density fiberboard (MDF)	1.00	m^3	84.4%
Wood fuel, sander dust	70.00	kg	7.97%
Wood fuel	54.00	kg	6.15%
Bark	12.90	kg	1.47%
Wood waste, sold	0.063	kg	0.01%
Resources	**Value**	**Unit/m^3**	
Water, unspecified natural origin/m^3	935.00	L	
Water, well, in ground	452.00	L	
Materials/fuels	**Value**	**Unit/m^3**	
Wood residue, average US	793.46	kg	
Urea-formaldehyde (UF) resin, 100% solids	83.30	kg	
Urea	1.28	kg	
Slack wax	5.21	kg	
Electricity, at Grid	415.00	kWh	
Diesel	0.71	L	
Gasoline	0.13	L	
LPG	0.76	L	
Natural gas	43.00	m^3	
Wood waste, combusted in boiler, self-generated fuel	127.00	kg	
Wood waste, combusted in boiler, purchased fuel	236.00	kg	
Transport, combination truck, diesel power, wood residue	177.47	tkm	

[3] Hammermill is a machine for producing fibers from solid wood pieces by hammering or flailing them.

Transport, combination truck, diesel powered, UF Resin	17.83	tkm	
Transport, combination truck, diesel powered, Wax and Urea	1.62	tkm	
Transport, train, diesel powered, UF Resin	0.18	tkm	
Wrapping material - Packaging	0.46	kg	
Strap Protectors - Packaging	0.20	kg	
Strapping - Packaging	0.08	kg	
Spacers - Packaging	4.67		
Emissions to air	**Value**	**Unit/m^3**	
VOC, volatile organic compounds	0.840	kg	
Particulates	0.363	kg	
Particulates, < 10 um	0.290	kg	
Formaldehyde	0.159	kg	
Methanol	0.219	kg	
Emissions to water	**Value**	**Unit/m^3**	
Suspended solids, unspecified	0.010	kg	
Ammonia	0.007	kg	
BOD5, Biological Oxygen Demand	0.002	kg	
Waste to treatment			
Disposal, wood waste, to unspecified treatment	2.21	kg	
Disposal, solid waste, unspecified, to unspecified treatment	1.94	kg	

3.3.2.13 Wood residue

The wood residue comes from co-products that are generated during lumber and plywood production. Wood residue attributes vary across the major production centers of the U.S. Residue includes softwoods from the SE and PNW regions, and hardwoods for the NE-NC regions (Table 6)(Wilson and Sakimoto 2004, Milota et al. 2005, Bergman and Bowe 2008). Green chips, a co-product from sawmill operations, represent the largest wood residue input at 54 percent (428 kg, oven dry) followed by green sawdust, dry planer shaving, and green planer shavings at 19, 16, and 8 percent, respectively. Panel trim from plywood manufacturing makes up the remaining 4 percent of the total wood residue input for MDF. All flow analyses of wood and bark in the process were determined on an oven-dry weight basis with a green specific gravity of 0.45.

Table 6 Wood residue type and source for input for MDF production, U.S. average.

Wood Residue Type	kg/m^3	Percent contribution
Pacific Northwest Region (PNW)		
Planer shavings, softwood, kiln dried, at planer, PNW	30.05	10%
Sawdust, softwood, green, at sawmill, PNW	140.62	47%
Planer shavings, softwood, green, at planer, PNW	61.60	21%
Panel trim, from trim and saw at plywood plant, PNW	27.90	9%
Pulp chips, softwood, green, at sawmill, PNW	38.49	13%
TOTAL	298.66	100%
Southwest Region (SE)		
Planar shavings, at planer mill, SE	95.20	29%
Pulp chips, at sawmill, US SE	231.00	71%
TOTAL	326.20	100%
Northeast-North central regions (NE-NC)		
Sawdust, hardwood, green, at sawmill, NE-NC	10.60	6%
Wood chips, hardwood, green, at sawmill, NE-NC	158.00	94%
TOTAL	168.60	
PNW –Region	**298.66**	**38%**
SE - Region	**326.20**	**41%**
NE-NC -Region	**168.60**	**21%**
TOTAL US Average	**793.46**	**100%**

3.3.2.14 Packaging

Table 7 Materials used in packaging and shipping per m^3 MDF, U.S. average.

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

Packing materials represent only 0.73% 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 hazardous air pollutants (HAPS) specific to their wood products manufacturing process: these include formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde. If applicable to the wood product, HAPS are reported in Table 9 and would be included in the impact assessment. Table 9 shows all air emissions to 10^{-4} to simplify and report on the dominant releases by mass. There were no cut-offs used in the impact assessment. A complete list of all air emissions is located in Section 13 Appendix of this report.

5 Data quality requirements

This study collected data from representative MDF manufacturers in the U.S. that use average technology for their regions. The wood residue to produce MDF comes from a variety of co-products produced in both sawmills and plywood mills the PNW, SE, and NE-NC regions of the U.S in the form of wet and dry shavings, green chips, green sawdust, and panel trim. The wood residue is comprised of softwood species representing a mix of *Pseudotsuga menziesii*, *Tsuga heterophylla*, *Pinus palustris* Mill, *P. echinata*. Mill, *P. taeda* L., *P. elliottii* Engelm., and a large mix of hardwood species representing *Quercus spp., Liriodendron tulipfera., Acer spp., Prunus serotina, Fraxinus spp., Betula spp., Tilia spp., Juglans spp., and Carya spp.* In 2004 the MDF production in the U.S. was approximately 3,091,848 m^3 and Canada produced an additional 1,554,249 m^3 (CPA 2005). For this study of MDF production mills responding to surveys produced 833,221 m^3 in 2004, representing 27% of total production in the U.S or 15% of the total North American production.

An internal critical review of the survey procedures, data, analysis, and report was completed to assess conformance with CORRIM and ISO 14040 standards (Puettmann 2009, Wilson 2009). The review provided assurances that the study methodology, data collection, and analyses were scientifically sound, and in conformance with ISO 14040 and CORRIM research protocol (ISO 2006). Complete details of this study for MDF production and the overall CORRIM project can be found in Wilson (2008, 2010a) and Lippke et al. (2004, 2010), 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 MDF producers in the U.S., with some secondary data on electrical grid inputs from the US LCI database (Goemans 2010). The survey data represents MDF production in terms of input materials, electricity, and fuel use, and emissions for the 2004 production year. The four mills surveyed were selected to be representative of U.S. production practices.

6.2 Calculation rules

MDF is most commonly reported in a thousand square foot (MSF) ¾ inch basis, which in SI units is equivalent to 1.7698 m^3. The survey results were converted to a unit production basis, 1 MSF (3/4 inch basis) and a weighted average of input data was calculated based on production. This approach resulted in a MDF complex that represents a composite of the mills surveyed, but may not represent any mill in particular. The USLCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 7+ (Pré Consultants 2012) was used as the accounting program to track all of the materials.

Missing data is defined as data not reported in surveys by the MDF facilities. Whenever missing data occurred for survey items, they were checked with plant personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros. Any outliers were resolved by contacting mill personnel. Unaccounted wood mass between input and output material flows in the production of MDF based on survey data were found to be 0.3%. Final MDF product has an average dry density of 741 kg/m^3 representing 89.1 percent wood residue and 10.1, 0.6, and 0.2 percent UF resin, wax, and urea scavenger, respectively. Due to the high pressure applied to the wood residue, together with resin and wax, the density of MDF is 61percent higher than the average wood residue density input (491 kg/m^3).

6.3 Allocation rules

All allocation was based on the mass of the products and co-products.

6.4 LCI Results

Life cycle inventory results for MDF are presented by three life stages, 1) forestry operations, 2) wood residue production, and 3) MDF production (Tables 8-11). The majority of the raw material energy consumption occurs during MDF production, followed by the production of the wood residue with only a very small portion arising from forestry operations. Raw material energy requirements are presented in Table 8 for 1 m^3 of MDF. Air emissions are reported in Table 9, water emissions are reported in Table 10 and solid waste emissions are reported in Table 11.

Table 8 Raw material energy consumption per 1 m^3 of MDF, U.S. average.

Fuel	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Coal, in ground	127.1293	0.1926	12.5580	114.3787
Gas, natural, in ground	114.6602	0.4645	4.5208	109.6749
Oil, crude, in ground	28.4910	3.0750	5.6261	19.7899
Uranium oxide, in ore	0.0033	0.0000	0.0003	0.0029

Wood waste	385.6948	0.0000	26.5208	359.1741

MDF manufacturers reported particulate and particulate PM_{10} (less than 10 µm in size) that are emitted during refining, drying, sawing, and sanding. Other air emissions include VOCs from drying, pressing, and panel cooling. Recorded emissions of formaldehyde and methanol are used as a measure of the amount of Hazardous Air Pollutants (HAPs). Mills reported VOC's formaldehyde and methanol as a measure of HAPs released. HAPs not reported in surveys include acetaldehyde, acrolein, and phenol.

Only one of the four mills used a combination of cyclones and RCO/RTO devices to reduce particulates, VOC and HAP emission levels. Both systems have an efficiency of 90% or better for reducing HAPs. In terms of environmental trade-offs, had all four mills used RTOs and/or RCOs the natural gas and electricity use would have been greater. Even if BFs were installed the electricity use would still have been greater.

Table 9 Air emissions released per 1 m^3 of MDF, U.S. average.

Air Emissions	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Carbon dioxide, biogenic	6.95E+02	8.25E-03	6.06E+01	6.35E+02
Carbon dioxide, fossil	5.77E+02	1.01E+01	5.38E+01	5.13E+02
Sulfur dioxide	3.67E+00	1.53E-02	2.79E-01	3.37E+00
Carbon dioxide	3.65E+00	2.49E-01	5.27E-03	3.40E+00
Nitrogen oxides	2.58E+00	1.81E-01	3.16E-01	2.08E+00
Carbon monoxide	2.17E+00	1.83E-05	1.85E-01	1.99E+00
Particulates, > 2.5 um, and < 10um	1.84E+00	5.52E-03	1.67E-01	1.66E+00
Particulates, < 2.5 um	1.58E+00	0.00E+00	1.33E-01	1.44E+00
Methane	1.50E+00	1.74E-02	1.26E-01	1.36E+00
VOC, volatile organic compounds	1.05E+00	5.16E-03	1.39E-01	9.11E-01
Carbon monoxide, fossil	7.41E-01	9.46E-02	1.37E-01	5.09E-01
Particulates, unspecified	7.20E-01	1.13E-03	5.47E-01	1.71E-01
Methane, fossil	4.61E-01	1.64E-03	1.02E-02	4.49E-01
Particulates	3.58E-01	0.00E+00	1.25E-06	3.58E-01
Particulates, < 10 um	3.27E-01	0.00E+00	4.11E-02	2.86E-01
Methanol	2.22E-01	0.00E+00	4.82E-03	2.17E-01
NMVOC, non-methane volatile organic compounds, unspecified origin	2.15E-01	6.06E-03	1.27E-02	1.96E-01
Sulfur oxides	2.02E-01	1.01E-02	2.76E-02	1.64E-01
Formaldehyde	1.74E-01	6.45E-05	2.18E-03	1.72E-01
Metals, unspecified	1.52E-01	2.34E-14	1.32E-02	1.38E-01
Ammonia	1.41E-01	2.52E-04	1.34E-04	1.41E-01
Hydrogen chloride	1.33E-01	1.07E-04	1.24E-02	1.21E-01
Isoprene	5.48E-02	2.07E-04	8.37E-03	4.63E-02

Air Emissions	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Particulates, > 10 um	4.55E-02	0.00E+00	0.00E+00	4.55E-02
Acrolein	2.99E-02	5.03E-06	1.69E-02	1.29E-02
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	2.67E-02	1.63E-04	1.59E-03	2.50E-02
Benzene	1.60E-02	5.08E-05	1.56E-03	1.44E-02
TOC, Total Organic Carbon	1.45E-02	0.00E+00	1.26E-03	1.32E-02
Hydrogen fluoride	8.23E-03	1.26E-05	8.14E-04	7.40E-03
Ethane	7.88E-03	0.00E+00	0.00E+00	7.88E-03
Manganese	5.70E-03	6.98E-08	4.96E-04	5.20E-03
Dinitrogen monoxide	5.50E-03	1.47E-03	4.77E-04	3.55E-03
Hydrocarbons (other than methane)	5.26E-03	0.00E+00	5.26E-03	0.00E+00
Radionuclides (Including Radon)	4.50E-03	6.33E-06	4.60E-04	4.03E-03
Particulates, SPM	3.99E-03	0.00E+00	3.99E-03	0.00E+00
Acetaldehyde	3.62E-03	4.15E-05	8.23E-04	2.76E-03
Propane	3.29E-03	0.00E+00	0.00E+00	3.29E-03
Chlorine	2.81E-03	0.00E+00	2.44E-04	2.57E-03
Pentane	2.68E-03	0.00E+00	0.00E+00	2.68E-03
alpha-Pinene	2.57E-03	0.00E+00	2.57E-03	0.00E+00
N-Nitrodimethylamine	2.49E-03	0.00E+00	0.00E+00	2.49E-03
Butane	2.14E-03	0.00E+00	0.00E+00	2.14E-03
Dimethyl ether	1.79E-03	0.00E+00	2.56E-06	1.79E-03
Water	1.49E-03	0.00E+00	0.00E+00	1.49E-03
Hydrogen sulfide	1.15E-03	2.04E-13	8.25E-12	1.15E-03
Aluminium	1.07E-03	0.00E+00	0.00E+00	1.07E-03
Vanadium	1.06E-03	0.00E+00	0.00E+00	1.06E-03
Methane, dichloro-, HCC-30	1.04E-03	7.09E-08	9.13E-05	9.53E-04
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	9.98E-04	0.00E+00	9.98E-04	0.00E+00
Hydrocarbons, unspecified	9.70E-04	1.36E-06	9.91E-05	8.69E-04
Aldehydes, unspecified	8.18E-04	1.25E-04	2.34E-04	4.60E-04
Hydrocarbons, aliphatic, alkanes, unspecified	8.09E-04	0.00E+00	0.00E+00	8.09E-04
Carbon dioxide, land transformation	7.85E-04	0.00E+00	0.00E+00	7.85E-04
Magnesium	6.23E-04	9.27E-07	5.97E-05	5.62E-04
Methane, biogenic	5.20E-04	0.00E+00	0.00E+00	5.20E-04
Acetic acid	4.81E-04	0.00E+00	0.00E+00	4.81E-04
Toluene	4.56E-04	2.21E-05	8.91E-06	4.25E-04
Nickel	4.42E-04	7.88E-07	1.40E-05	4.27E-04
Propene	3.90E-04	1.40E-04	1.87E-04	6.37E-05
Cumene	3.56E-04	1.03E-11	3.54E-04	2.41E-06

Air Emissions	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Naphthalene	3.45E-04	1.32E-08	3.01E-05	3.15E-04
Hexane	3.45E-04	1.30E-10	2.18E-10	3.45E-04
Organic substances, unspecified	3.40E-04	5.23E-07	3.34E-05	3.06E-04
Hydrocarbons, aromatic	3.24E-04	0.00E+00	0.00E+00	3.24E-04
Sodium	3.19E-04	0.00E+00	0.00E+00	3.19E-04
Carbon disulfide	3.03E-04	2.52E-10	4.24E-10	3.03E-04
D-limonene	2.89E-04	0.00E+00	2.89E-04	0.00E+00
Acetone	2.47E-04	0.00E+00	1.71E-04	7.60E-05
Lead	2.45E-04	5.79E-08	1.72E-05	2.28E-04
Sulfate	1.85E-04	0.00E+00	0.00E+00	1.85E-04
Phenols, unspecified	1.83E-04	3.64E-08	1.61E-05	1.67E-04
Ammonium chloride	1.68E-04	2.36E-07	1.72E-05	1.51E-04
Iron	1.67E-04	0.00E+00	0.00E+00	1.67E-04
Chromium	1.65E-04	3.42E-08	8.06E-06	1.57E-04
Heptane	1.53E-04	0.00E+00	0.00E+00	1.53E-04
Phenol	1.39E-04	3.10E-11	1.36E-04	3.39E-06
Xylene	1.28E-04	1.54E-05	6.21E-06	1.06E-04
Ethanol	1.23E-04	0.00E+00	0.00E+00	1.23E-04
Arsenic	1.14E-04	4.73E-08	9.08E-06	1.05E-04
Hydrogen	1.03E-04	0.00E+00	1.84E-07	1.02E-04

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

Waterborne emissions reported by MDF manufactures and produced all off-site are in shown in Table 10.

Table 10 Emissions to water released per 1 m^3 of MDF, U.S. average.

Water Emissions	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Solved solids	1.83E+01	5.81E-01	1.80E+00	1.59E+01
Chloride	1.52E+01	4.71E-01	1.46E+00	1.33E+01
Sodium, ion	4.48E+00	1.33E-01	4.12E-01	3.93E+00
Calcium, ion	1.54E+00	4.19E-02	1.30E-01	1.37E+00
Sulfate	8.57E-01	1.05E-03	1.04E-02	8.46E-01
Suspended solids, unspecified	4.95E-01	3.15E-02	6.94E-02	3.94E-01
Lithium, ion	3.69E-01	2.27E-03	2.20E-02	3.45E-01
Magnesium	3.65E-01	8.19E-03	2.54E-02	3.31E-01
COD, Chemical Oxygen Demand	3.11E-01	4.43E-03	1.83E-02	2.88E-01
BOD5, Biological Oxygen Demand	2.99E-01	2.37E-03	1.27E-02	2.84E-01

Water Emissions	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Silicon	2.59E-01	0.00E+00	0.00E+00	2.59E-01
Barium	1.81E-01	1.40E-02	3.03E-02	1.37E-01
Bromide	8.80E-02	2.79E-03	8.66E-03	7.66E-02
Potassium, ion	6.27E-02	0.00E+00	0.00E+00	6.27E-02
Oils, unspecified	5.90E-02	2.95E-04	8.81E-04	5.78E-02
TOC, Total Organic Carbon	5.77E-02	0.00E+00	1.57E-03	5.61E-02
DOC, Dissolved Organic Carbon	5.76E-02	4.08E-13	1.57E-03	5.61E-02
Iron	3.48E-02	2.07E-03	5.04E-03	2.77E-02
Phosphate	3.41E-02	5.37E-03	3.39E-05	2.86E-02
Iron, ion	3.38E-02	0.00E+00	0.00E+00	3.38E-02
Strontium	2.63E-02	7.11E-04	2.20E-03	2.34E-02
Solids, inorganic	2.61E-02	1.03E-11	4.14E-10	2.61E-02
Aluminium	2.46E-02	8.61E-06	5.64E-05	2.46E-02
Fluoride	1.67E-02	7.13E-03	1.05E-04	9.49E-03
Ammonium, ion	1.47E-02	5.05E-08	3.67E-06	1.47E-02
Ammonia	1.25E-02	2.34E-04	6.39E-04	1.16E-02
Manganese	1.11E-02	1.45E-05	1.43E-04	1.10E-02
Waste, solid	1.08E-02	0.00E+00	0.00E+00	1.08E-02
Ammonia, as N	9.95E-03	6.67E-11	2.69E-09	9.95E-03
Barite	9.71E-03	0.00E+00	0.00E+00	9.71E-03
Aluminum	7.18E-03	1.01E-03	2.25E-03	3.92E-03
Nitrate	6.35E-03	4.47E-14	1.81E-12	6.35E-03
Formaldehyde	5.99E-03	0.00E+00	0.00E+00	5.99E-03
Nitrogen	5.02E-03	0.00E+00	0.00E+00	5.02E-03
Zinc, ion	3.63E-03	0.00E+00	0.00E+00	3.63E-03
Boron	3.45E-03	4.09E-05	1.27E-04	3.28E-03
Carboxylic acids, unspecified	3.27E-03	0.00E+00	0.00E+00	3.27E-03
Benzene	1.33E-03	2.19E-05	6.48E-04	6.57E-04
Sulfur	1.23E-03	3.45E-05	1.07E-04	1.09E-03
Nickel, ion	9.81E-04	0.00E+00	0.00E+00	9.81E-04
Titanium, ion	8.72E-04	9.77E-06	2.07E-05	8.42E-04
Silver	8.61E-04	2.74E-05	8.48E-05	7.49E-04
Cumene	8.56E-04	0.00E+00	8.51E-04	5.80E-06
Waste water/m3	8.19E-04	0.00E+00	6.13E-05	7.58E-04
Toluene	7.42E-04	2.07E-05	6.41E-05	6.57E-04
Copper, ion	6.03E-04	5.18E-06	1.21E-05	5.86E-04
Bromine	5.47E-04	0.00E+00	0.00E+00	5.47E-04
Benzoic acid	4.17E-04	1.32E-05	4.10E-05	3.62E-04

Water Emissions	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Xylene	4.15E-04	1.10E-05	3.39E-05	3.70E-04
Hydrocarbons, aromatic	4.03E-04	0.00E+00	0.00E+00	4.03E-04
Detergent, oil	3.98E-04	1.12E-05	3.70E-05	3.50E-04
Zinc	3.64E-04	2.37E-05	5.71E-05	2.83E-04
Cobalt	3.45E-04	2.89E-07	8.96E-07	3.44E-04
Propene	3.18E-04	0.00E+00	3.13E-04	4.88E-06
Nitrogen, organic bound	2.61E-04	0.00E+00	0.00E+00	2.61E-04
VOC, volatile organic compounds, unspecified origin	2.58E-04	0.00E+00	0.00E+00	2.58E-04
Lead	2.18E-04	8.31E-06	1.87E-05	1.91E-04
Arsenic, ion	2.02E-04	5.89E-06	1.02E-05	1.86E-04
Hydrocarbons, unspecified	1.88E-04	5.10E-13	2.06E-11	1.88E-04
Chromium, ion	1.87E-04	2.76E-06	1.35E-05	1.71E-04
Chromium VI	1.80E-04	1.10E-07	2.01E-07	1.80E-04
Chromium	1.64E-04	2.98E-05	4.78E-05	8.62E-05
Phenols, unspecified	1.58E-04	1.62E-06	1.04E-05	1.46E-04
Acid as H+	1.29E-04	0.00E+00	0.00E+00	1.29E-04
Vanadium, ion	1.02E-04	0.00E+00	0.00E+00	1.02E-04
Phenol	1.02E-04	4.87E-06	8.90E-06	8.82E-05

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

Solid emissions include ash generated at the boiler and in the upstream processes, primarily fuels and resins, used in MDF production (Table 11). Onsite waste for producing MDF represented only 4.15 kg/m^3, or 4.9 percent of the total waste generated from cradle-to-gate.

Table 11 Waste to treatment per 1 m^3 of MDF, U.S. average.

Waste to treatment	Total	Forestry Operations	Wood Residue Production	MDF Production
	kg/m^3			
Solid waste[4]	85.06	0.22	8.79	76.06

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

7 Life cycle impact assessment

The life cycle impact assessment (LCIA) phase establishes links between the life cycle inventory results and potential environmental impacts. The LCIA calculates impact indicators, such as global warming potential and smog. These impact indicators provide general, but quantifiable, indications of potential environmental impacts. The target impact indicator, the impact category, and means of characterizing the impacts are summarized in Table 12. Environmental impacts are determined using the TRACI method (Bare et al. 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (PCR 2011).

Table 12 Selected impact indicators, characterization models, and impact categories.

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

Each impact indicator is a measure of an aspect of a potential impact. This LCIA does not make value judgments about the impact indicators, meaning that no single indicator is given more or less value than any of the others. 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 13 provides the environmental impact by category for MDF. In addition, energy and material resource consumption values and the waste generated are also provided.

Environmental performance results for global warming potential (GWP), acidification, eutrophication, ozone depletion and smog, energy consumption from non-renewables, renewables, wind, hydro, solar, and nuclear fuels, renewable and nonrenewable resources, and solid waste are shown in Table 13. For GWP, 89 percent of the CO_2 equivalent emissions come from producing MDF, with 9 and 2 percent assigned to wood residue production and forestry operations, respectively. Similar results are presented for acidification, where wood residue production contributed 12 percent to the smog impact and forestry operations contributed 8 percent to the impact category eutrophication.

Non-renewable resources represented the greatest proportion of energy consumption (53%) with the MDF production life cycle dominating the use at 90 percent. Renewable biomass consumption for energy was 40 percent with 93 percent consumed during MDF production and 7 percent used during wood residue production. Biomass energy is the primarily used in drying, conditioning, and pressing process for both wood residue and MDF production.

Table 13 Environmental performance of 1 m^3 MDF, U.S. average.

Impact category	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Global warming potential (GWP)	kg CO_2 equiv	568.82	14.40	52.54	501.88
Acidification Potential	H+ moles equiv	342.46	11.05	26.36	305.05
Eutrophication Potential	kg N equiv	0.1908	0.0242	0.0137	0.1528
Ozone depletion Potential	kg CFC-11 equiv	0.0000	0.0000	0.0000	0.0000
Smog Potential	kg O_3 equiv	69.36	5.90	7.42	56.05
Total Primary Energy Consumption	**Unit**	**Total**	**Forestry Operations**	**Wood Residue Production**	**MDF Production**
Non-renewable fossil	MJ	10,188.78	217.00	762.41	9,162.27
Non-renewable nuclear	MJ	1231.30	2.16	119.23	1109.91
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	158.80	0.28	32.64	125.89
Renewable, biomass	MJ	8,076.07	0.02	556.24	7,520.13
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Wood Residue Production**	**MDF Production**
Non-renewable materials[5]	kg	0.77	0.00	0.08	0.66
Renewable materials[6]	kg	757.13	0.00	728.75	5.79
Fresh water	L	1,623.53	5.28	177.75	1,440.50
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Wood Production**	**MDF Production**
Solid waste	kg	85.06	0.22	8.79	76.06

[5] 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.

[6] Density for: NE-NC hardwoods = 526 kg/m^3 , SE softwoods 509 kg/m^3 = , and PNW softwoods = 452 kg/m^3.

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, 632 kg CO_2e were released in the production of 1 m^3 of MDF. That same 1 m^3 of MDF stores 388 kg of carbon[7] or 1,364 kg CO_2e resulting in more carbon storage in the product then released during manufacturing (cradle to gate) (Table 14).

Table 14 Carbon per 1 m^3 MDF, U.S. average.

	kg CO_2 equivalent
released forestry operations	11.22
released wood residue production	57.35
released MDF manufacturing	563.10
CO_2 eq. stored in product	1,364.15

[7] Using 52.4% carbon content of MDF (Wilson 2010)

9 Conclusions

The cradle to gate LCA for medium density fiberboard (MDF) includes: 1) the LCI of forest resources that relies on secondary and tertiary data, 2) the LCI of lumber and plywood manufacturing that generate the wood residue co-product that is used as an input into MDF and which relies on primary survey data and secondary data for process inputs such as natural gas, diesel, and electricity, and 3) the MDF LCI that relies on primary survey data and secondary data for process inputs such as natural gas, diesel, and electricity. The survey results for MDF were representative of the U.S. average with wood inputs representing the PNW, SE, and NE-NC regions of the U.S. The survey data are representative of the MDF sizes and production volumes consistent with trade association production data.

Emissions from the forest resources LCI are small relative to manufacturing emissions (MDF and wood residue). At the MDF production facility emissions originate at the boiler, and during drying and pressing. They are a function of the fuel burned and resin use.

Renewable biomass represented 40 percent of the total energy consumption for all stages of production, with 93 percent of the biomass energy consumed during MDF production. The use of non-renewable fossil fuels dominated the total energy consumption profile for MDF production at 10,874 of the 20,366 MJ/m^3 (54%). Forestry operations consumed exclusively (99%) fossil fuels. The production of the wood residue used in MDF represented 7 percent of the fossil consumption leaving the production of MDF with about 90 percent or 9,821 MJ/m^3 of the fossil fuel use. Energy consumed during urea formaldehyde (UF) resin production is included in the fossil fuel use for MDF as an upstream process. Wilson (2010b) reported that UF resin total production energy was 29.35 MJ/kg or 2,635 MJ. Although not specifically assessed in this LCA, this would represent approximately 26 percent of the fossil consumption in the MDF production process. In summary, to produce 1 cubic meter of MDF consumed 40 percent of the total energy from biomass (wood fuel) and 54 percent from nonrenewable fossil fuels leaving a small portion of energy needs coming from nuclear (6%) and solar, wind, hydroelectric, and geothermal (<1%).

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, 632 kg CO_2e were released in the production of 1 m^3 of MDF. That same 1 m^3 of MDF stores 1,364 kg CO_2e.

10 Acknowledgments

The original research project would not have been possible without the financial and technical assistance provided by the USDA Forest Service, Forest Products Laboratory (USFS (JV11111137-084&094)), by DOE's support for developing the research plan (DE-FC07-961D13437), CORRIM's University membership, and the contributions of many companies. The data updates provided in this document were made possible with the financial assistance of the American Wood Council. Our special thanks are extended to those companies and their employees that participated in the surveys to obtain production data. Any opinions, findings, conclusions, or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the contributing entities.

11 Critical Review

11.1 Internal Review

An internal review of the LCA product was provided by:

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:

TBD – this will be finalized when we know the verifier's name

12 References

Aasestad, K. 2008. The Norwegian Emission Inventory 2008. Documentation of methodologies for estimating emissions of greenhouse gases and long-range trans-boundary air pollutants. Statistisk sentralbyrå. Reports 2008/48 252 pp.

ANSI. 2002. American National Standard. ANSI A208.2-2002. Medium Density Fiberboard (MDF) for Interior Applications. Composite Panel Association, Gaithersburg, MD. pp 11.

Bare, J. C. 2011. TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Techn. Environ Policy. 21 January 2011.

Bergman R.D., and S.A. Bowe. 2008. Life-cycle inventory of hardwood lumber manufacturing in the Northeast and North central United States. Module C. CORRIM Phase II Final Report 54 pp. http://www.corrim.org/pubs/reports/2010/phase2/Module_C.pdf. Accessed July 2013.

Composite Panel Association (CPA). 2005. 2004 North American Shipments Report – Particleboard, Medium Density Fiberboard, and Hardboard. CPA, 18922 Premiere Court, Gaithersburg, MD 20879.

Goemans, C. 2010. Athena Institute, NREL US LCI Database – N.A. Electricity Generation by Fuel Type Update & Template Methodology. http://www.nrel.gov/lci/database/.

IPCC 2006. Task Force on National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/faq/faq.html. Accessed October 2, 2012.

ISO 2006. Environmental management - Life cycle assessment–Requirements and guidelines. International Organization for Standardization. (ISO 14044:2006[E]). 54pp.

Johnson, L.R. B. Lippke, J.D. Marshall, and J. Comnick. 2005. Life-cycle impacts of forest resource activities in the Pacific Northwest and southeast United States. Wood and Fiber Sci. 37 CORRIM Special Issue. pp. 30-46.

Lippke, B. and J.B. Wilson. 2010. Extending the findings on the environmental performance of wood building materials. Wood and Fiber Sci. 37 CORRIM Special Issue. Pp. 1-4

Lippke, B, J. Wilson, J. Perez-Garcia, J. Bowyer, and J. Meil. 2004. CORRIM: Life cycle environmental performance of renewable building materials. Forest Products J. 54(6)8-99.

Milota, M.R, C.D. West, and I.D. Hartley. 2005. Gate-to-gate life cycle inventory of softwood lumber production. Wood and Fiber Sci. 37 CORRIM Special Issue. Pp. 47-57.

National Renewable Energy Laboratory (NREL). 2012. US LCI database for Simapro. Updated February 2012.

Oneil, E.E., L.R. Johnson, B.R. Lippke, J.B. McCarter, M.E. McDill, P.A. Roth, and J.C. Finley. 2010. Life-cycle impacts of inland northwest and northeast/north central forest resources. Wood and Fiber Sci., 42(CORRIM Special Issue) pp. 15-28.

Pré Consultants, B.V. 2012. Simapro7 Life-Cycle Assessment Software Package, Version 36. Plotter 12, 3821 BB Amersfoort, The Netherlands. Http://www.pre.nl/.

Product Category Rules (PCR). 2011. North American Structural and Architectural Wood Products. FP Innovations. November 8, 2011.

Puettmann, M.E. 2009. Review of SimaPro process models for conformity to ISO standards and review of final CORRIM reports. Internal review.

Suchsland, O. and G.E. Woodson. 1986. Fiberboard manufacturing practices in the United States. USDA Forest Service Agricultural Handbook No. 640. Pp 270. http://naldc.nal.usda.gov/download/CAT87881030/PDF. Accessed July 2013.

U.S. Census Bureau. 2007. 2002 NAICS Definitions. http://www.naics.com/censusfiles/ND321219.HTM

Wilson, J.B. 2010a. Life-cycle inventory of medium density fiberboard in terms of resources, emissions, energy and carbon. Wood and Fiber Sci., 42(CORRIM Special Issue) pp. 107-124.

Wilson, J.B. 2010b. Life-cycle inventory of formaldehyde-based resins used in wood composites in terms of resources, emissions, energy and carbon. Wood and Fiber Sci., 42(CORRIM Special Issue) pp. 125-143.

Wilson, J.B. 2009. Review of process models for energy and mass balances and review of final CORRIM reports. Internal review.

Wilson, J.B. 2008. Medium density fiberboard (MDF): A life cycle inventory of manufacturing panels from resource through product. Module G. CORRIM Phase II Final Report70 pp. http://www.corrim.org/pubs/reports/2010/phase2/Module_G.pdf. Accessed July 2013.

Wilson, J.B. and E. T. Sakimoto. 2004. Softwood plywood manufacturing. In CORRIM Phase I Final Report Module D. June 2004 95 pp. http://www.corrim.org/pubs/reports/2005/Phase1/Module_D_Final.pdf

13 Appendix

13.1 Air Emissions

Table A.1 Air emissions released per 1 m^3 of dry MDF, U.S. average.

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
1,4-Butanediol	kg	6.21E-10	0.00E+00	0.00E+00	6.21E-10
1-Butanol	kg	2.78E-12	0.00E+00	0.00E+00	2.78E-12
1-Pentanol	kg	1.21E-12	0.00E+00	0.00E+00	1.21E-12
1-Pentene	kg	9.11E-13	0.00E+00	0.00E+00	9.11E-13
1-Propanol	kg	1.80E-10	0.00E+00	0.00E+00	1.80E-10
2,4-D	kg	1.35E-09	0.00E+00	0.00E+00	1.35E-09
2-Aminopropanol	kg	2.44E-13	0.00E+00	0.00E+00	2.44E-13
2-Butanone, 3,3-dimethyl-	kg	1.78E-05	0.00E+00	1.78E-05	0.00E+00
2-Butene, 2-methyl-	kg	2.02E-16	0.00E+00	0.00E+00	2.02E-16
2-Chloroacetophenone	kg	4.38E-10	1.36E-11	2.28E-11	4.02E-10
2-Methyl-1-propanol	kg	2.82E-12	0.00E+00	0.00E+00	2.82E-12
2-Nitrobenzoic acid	kg	4.34E-13	0.00E+00	0.00E+00	4.34E-13
2-Propanol	kg	1.15E-05	0.00E+00	0.00E+00	1.15E-05
5-methyl Chrysene	kg	1.18E-09	1.85E-12	1.19E-10	1.06E-09
Acenaphthene	kg	2.74E-08	4.30E-11	2.77E-09	2.46E-08
Acenaphthylene	kg	1.34E-08	2.11E-11	1.36E-09	1.21E-08
Acetaldehyde	kg	3.62E-03	4.15E-05	8.23E-04	2.76E-03
Acetic acid	kg	4.81E-04	0.00E+00	0.00E+00	4.81E-04
Acetochlor	kg	1.87E-08	0.00E+00	0.00E+00	1.87E-08
Acetone	kg	2.47E-04	0.00E+00	1.71E-04	7.60E-05
Acetonitrile	kg	2.25E-08	0.00E+00	0.00E+00	2.25E-08
Acetophenone	kg	9.39E-10	2.91E-11	4.89E-11	8.61E-10
Acrolein	kg	2.99E-02	5.03E-06	1.69E-02	1.29E-02
Acrylic acid	kg	2.99E-08	0.00E+00	0.00E+00	2.99E-08
Alachlor	kg	1.84E-09	0.00E+00	0.00E+00	1.84E-09
Aldehydes, unspecified	kg	8.18E-04	1.25E-04	2.34E-04	4.60E-04
alpha-Pinene	kg	2.57E-03	0.00E+00	2.57E-03	0.00E+00
Aluminium	kg	1.07E-03	0.00E+00	0.00E+00	1.07E-03
Ammonia	kg	1.41E-01	2.52E-04	1.34E-04	1.41E-01
Ammonium carbonate	kg	4.02E-09	0.00E+00	0.00E+00	4.02E-09
Ammonium chloride	kg	1.68E-04	2.36E-07	1.72E-05	1.51E-04
Aniline	kg	1.90E-11	0.00E+00	0.00E+00	1.90E-11
Anthracene	kg	1.13E-08	1.77E-11	1.14E-09	1.01E-08

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Anthranilic acid	kg	3.18E-13	0.00E+00	0.00E+00	3.18E-13
Antimony	kg	3.00E-05	1.52E-09	2.53E-06	2.75E-05
Arsenic	kg	1.14E-04	4.73E-08	9.08E-06	1.05E-04
Arsine	kg	3.48E-13	0.00E+00	0.00E+00	3.48E-13
Ash	kg	4.75E-05	0.00E+00	0.00E+00	4.75E-05
Atrazine	kg	3.65E-08	0.00E+00	0.00E+00	3.65E-08
Barium	kg	1.65E-06	0.00E+00	0.00E+00	1.65E-06
Bentazone	kg	1.49E-10	0.00E+00	0.00E+00	1.49E-10
Benzal chloride	kg	1.66E-15	0.00E+00	0.00E+00	1.66E-15
Benzaldehyde	kg	1.01E-09	0.00E+00	0.00E+00	1.01E-09
Benzene	kg	1.60E-02	5.08E-05	1.56E-03	1.44E-02
Benzene, 1,2-dichloro-	kg	9.25E-12	0.00E+00	0.00E+00	9.25E-12
Benzene, 1-methyl-2-nitro-	kg	3.75E-13	0.00E+00	0.00E+00	3.75E-13
Benzene, chloro-	kg	1.38E-09	4.26E-11	7.17E-11	1.26E-09
Benzene, ethyl-	kg	1.54E-05	1.82E-10	4.26E-09	1.54E-05
Benzene, hexachloro-	kg	6.17E-09	0.00E+00	0.00E+00	6.17E-09
Benzene, pentachloro-	kg	3.33E-10	0.00E+00	0.00E+00	3.33E-10
Benzo(a)anthracene	kg	4.30E-09	6.74E-12	4.34E-10	3.86E-09
Benzo(a)pyrene	kg	2.04E-07	3.20E-12	2.06E-10	2.04E-07
Benzo(b,j,k)fluoranthene	kg	5.92E-09	9.27E-12	5.97E-10	5.31E-09
Benzo(ghi)perylene	kg	1.45E-09	2.28E-12	1.47E-10	1.30E-09
Benzyl chloride	kg	4.38E-08	1.36E-09	2.28E-09	4.02E-08
Beryllium	kg	5.15E-06	2.35E-09	4.74E-07	4.67E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	kg	9.98E-04	0.00E+00	9.98E-04	0.00E+00
Biphenyl	kg	9.14E-08	1.43E-10	9.23E-09	8.20E-08
Boron	kg	5.39E-05	0.00E+00	0.00E+00	5.39E-05
Boron trifluoride	kg	4.76E-15	0.00E+00	0.00E+00	4.76E-15
Bromine	kg	5.98E-06	0.00E+00	0.00E+00	5.98E-06
Bromoform	kg	2.44E-09	7.55E-11	1.27E-10	2.24E-09
Bromoxynil	kg	3.26E-10	0.00E+00	0.00E+00	3.26E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	2.67E-02	1.63E-04	1.59E-03	2.50E-02
Butadiene	kg	3.40E-06	2.12E-06	8.50E-07	4.37E-07
Butane	kg	2.14E-03	0.00E+00	0.00E+00	2.14E-03
Butene	kg	1.55E-05	0.00E+00	0.00E+00	1.55E-05
Butyrolactone	kg	1.78E-10	0.00E+00	0.00E+00	1.78E-10
Cadmium	kg	3.49E-05	1.18E-08	1.68E-06	3.32E-05
Calcium	kg	8.72E-05	0.00E+00	0.00E+00	8.72E-05

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Carbofuran	kg	2.79E-10	0.00E+00	0.00E+00	2.79E-10
Carbon dioxide	kg	3.65E+00	2.49E-01	5.27E-03	3.40E+00
Carbon dioxide, biogenic	kg	6.95E+02	8.25E-03	6.06E+01	6.35E+02
Carbon dioxide, fossil	kg	5.77E+02	1.01E+01	5.38E+01	5.13E+02
Carbon dioxide, land transformation	kg	7.85E-04	0.00E+00	0.00E+00	7.85E-04
Carbon disulfide	kg	3.03E-04	2.52E-10	4.24E-10	3.03E-04
Carbon monoxide	kg	2.17E+00	1.83E-05	1.85E-01	1.99E+00
Carbon monoxide, biogenic	kg	8.52E-05	0.00E+00	0.00E+00	8.52E-05
Carbon monoxide, fossil	kg	7.41E-01	9.46E-02	1.37E-01	5.09E-01
Chloramine	kg	4.73E-12	0.00E+00	0.00E+00	4.73E-12
Chloride	kg	1.67E-09	6.32E-12	2.55E-10	1.41E-09
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	3.60E-08	0.00E+00	5.06E-09	3.10E-08
Chlorine	kg	2.81E-03	0.00E+00	2.44E-04	2.57E-03
Chloroacetic acid	kg	2.38E-09	0.00E+00	0.00E+00	2.38E-09
Chloroform	kg	3.09E-08	1.14E-10	1.92E-10	3.06E-08
Chlorosilane, trimethyl-	kg	4.10E-09	0.00E+00	0.00E+00	4.10E-09
Chlorosulfonic acid	kg	2.86E-12	0.00E+00	0.00E+00	2.86E-12
Chlorpyrifos	kg	2.15E-09	0.00E+00	0.00E+00	2.15E-09
Chromium	kg	1.65E-04	3.42E-08	8.06E-06	1.57E-04
Chromium VI	kg	6.06E-06	6.66E-09	4.29E-07	5.62E-06
Chrysene	kg	5.38E-09	8.43E-12	5.43E-10	4.83E-09
Cobalt	kg	6.37E-05	6.27E-08	2.71E-06	6.09E-05
Copper	kg	5.81E-05	6.06E-10	3.89E-08	5.81E-05
Cumene	kg	3.56E-04	1.03E-11	3.54E-04	2.41E-06
Cyanazine	kg	3.22E-10	0.00E+00	0.00E+00	3.22E-10
Cyanide	kg	1.55E-06	4.84E-09	8.15E-09	1.54E-06
Cyanoacetic acid	kg	2.34E-12	0.00E+00	0.00E+00	2.34E-12
Dicamba	kg	1.89E-09	0.00E+00	0.00E+00	1.89E-09
Diethylamine	kg	8.56E-12	0.00E+00	0.00E+00	8.56E-12
Dimethenamid	kg	4.48E-09	0.00E+00	0.00E+00	4.48E-09
Dimethyl ether	kg	1.79E-03	0.00E+00	2.56E-06	1.79E-03
Dimethyl malonate	kg	2.94E-12	0.00E+00	0.00E+00	2.94E-12
Dinitrogen monoxide	kg	5.50E-03	1.47E-03	4.77E-04	3.55E-03
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	1.17E-07	1.65E-15	1.16E-07	1.48E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	4.21E-11	2.02E-13	5.15E-12	3.68E-11

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Dipropylamine	kg	5.33E-12	0.00E+00	0.00E+00	5.33E-12
Dipropylthiocarbamic acid S-ethyl ester	kg	3.06E-09	0.00E+00	0.00E+00	3.06E-09
D-limonene	kg	2.89E-04	0.00E+00	2.89E-04	0.00E+00
Ethane	kg	7.88E-03	0.00E+00	0.00E+00	7.88E-03
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	2.59E-06	0.00E+00	0.00E+00	2.59E-06
Ethane, 1,1,1-trichloro-, HCFC-140	kg	3.04E-09	3.27E-10	5.92E-10	2.12E-09
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	1.42E-09	0.00E+00	0.00E+00	1.42E-09
Ethane, 1,1-difluoro-, HFC-152a	kg	4.54E-09	0.00E+00	0.00E+00	4.54E-09
Ethane, 1,2-dibromo-	kg	7.51E-11	2.32E-12	3.91E-12	6.89E-11
Ethane, 1,2-dichloro-	kg	1.35E-06	7.75E-11	1.30E-10	1.35E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	6.41E-08	0.00E+00	0.00E+00	6.41E-08
Ethane, chloro-	kg	2.63E-09	8.13E-11	1.37E-10	2.41E-09
Ethane, hexafluoro-, HFC-116	kg	7.48E-07	0.00E+00	0.00E+00	7.48E-07
Ethanol	kg	1.23E-04	0.00E+00	0.00E+00	1.23E-04
Ethene	kg	4.91E-05	0.00E+00	0.00E+00	4.91E-05
Ethene, chloro-	kg	7.84E-07	0.00E+00	0.00E+00	7.84E-07
Ethene, tetrachloro-	kg	2.34E-06	4.32E-09	2.39E-07	2.10E-06
Ethene, trichloro-	kg	6.06E-14	0.00E+00	0.00E+00	6.06E-14
Ethyl acetate	kg	5.35E-05	0.00E+00	0.00E+00	5.35E-05
Ethyl cellulose	kg	1.08E-07	0.00E+00	0.00E+00	1.08E-07
Ethylamine	kg	2.81E-12	0.00E+00	0.00E+00	2.81E-12
Ethylene diamine	kg	3.07E-11	0.00E+00	0.00E+00	3.07E-11
Ethylene oxide	kg	6.73E-08	0.00E+00	0.00E+00	6.73E-08
Ethyne	kg	1.35E-06	0.00E+00	0.00E+00	1.35E-06
Fluoranthene	kg	3.82E-08	5.99E-11	3.86E-09	3.43E-08
Fluorene	kg	4.89E-08	7.67E-11	4.94E-09	4.39E-08
Fluoride	kg	9.35E-06	2.90E-06	5.50E-07	5.91E-06
Fluorine	kg	5.41E-06	0.00E+00	0.00E+00	5.41E-06
Fluosilicic acid	kg	7.60E-07	0.00E+00	0.00E+00	7.60E-07
Formaldehyde	kg	1.74E-01	6.45E-05	2.18E-03	1.72E-01
Formamide	kg	2.20E-12	0.00E+00	0.00E+00	2.20E-12
Formic acid	kg	2.17E-07	0.00E+00	0.00E+00	2.17E-07
Furan	kg	4.29E-08	3.76E-13	2.65E-11	4.29E-08
Glyphosate	kg	4.02E-09	0.00E+00	0.00E+00	4.02E-09
Helium	kg	3.00E-05	0.00E+00	0.00E+00	3.00E-05
Heptane	kg	1.53E-04	0.00E+00	0.00E+00	1.53E-04
Hexane	kg	3.45E-04	1.30E-10	2.18E-10	3.45E-04

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Hydrazine, methyl-	kg	1.06E-08	3.29E-10	5.54E-10	9.76E-09
Hydrocarbons (other than methane)	kg	5.26E-03	0.00E+00	5.26E-03	0.00E+00
Hydrocarbons, aliphatic, alkanes, cyclic	kg	4.77E-08	0.00E+00	0.00E+00	4.77E-08
Hydrocarbons, aliphatic, alkanes, unspecified	kg	8.09E-04	0.00E+00	0.00E+00	8.09E-04
Hydrocarbons, aliphatic, unsaturated	kg	2.67E-05	0.00E+00	0.00E+00	2.67E-05
Hydrocarbons, aromatic	kg	3.24E-04	0.00E+00	0.00E+00	3.24E-04
Hydrocarbons, chlorinated	kg	1.20E-06	0.00E+00	0.00E+00	1.20E-06
Hydrocarbons, unspecified	kg	9.70E-04	1.36E-06	9.91E-05	8.69E-04
Hydrogen	kg	1.03E-04	0.00E+00	1.84E-07	1.02E-04
Hydrogen chloride	kg	1.33E-01	1.07E-04	1.24E-02	1.21E-01
Hydrogen fluoride	kg	8.23E-03	1.26E-05	8.14E-04	7.40E-03
Hydrogen peroxide	kg	8.03E-08	0.00E+00	0.00E+00	8.03E-08
Hydrogen sulfide	kg	1.15E-03	2.04E-13	8.25E-12	1.15E-03
Indeno(1,2,3-cd)pyrene	kg	3.28E-09	5.14E-12	3.31E-10	2.94E-09
Iodine	kg	3.13E-06	0.00E+00	0.00E+00	3.13E-06
Iron	kg	1.67E-04	0.00E+00	0.00E+00	1.67E-04
Isocyanic acid	kg	2.53E-07	0.00E+00	0.00E+00	2.53E-07
Isophorone	kg	3.63E-08	1.12E-09	1.89E-09	3.33E-08
Isoprene	kg	5.48E-02	2.07E-04	8.37E-03	4.63E-02
Isopropylamine	kg	7.02E-13	0.00E+00	0.00E+00	7.02E-13
Kerosene	kg	8.05E-05	1.13E-07	8.22E-06	7.21E-05
Lactic acid	kg	4.17E-12	0.00E+00	0.00E+00	4.17E-12
Lead	kg	2.45E-04	5.79E-08	1.72E-05	2.28E-04
Magnesium	kg	6.23E-04	9.27E-07	5.97E-05	5.62E-04
Manganese	kg	5.70E-03	6.98E-08	4.96E-04	5.20E-03
MCPA	kg	2.52E-11	0.00E+00	0.00E+00	2.52E-11
Mercaptans, unspecified	kg	1.33E-05	4.20E-07	6.99E-07	1.22E-05
Mercury	kg	1.87E-05	1.15E-08	1.59E-06	1.71E-05
Metals, unspecified	kg	1.52E-01	2.34E-14	1.32E-02	1.38E-01
Methacrylic acid, methyl ester	kg	1.22E-09	3.87E-11	6.51E-11	1.12E-09
Methane	kg	1.50E+00	1.74E-02	1.26E-01	1.36E+00
Methane, biogenic	kg	5.20E-04	0.00E+00	0.00E+00	5.20E-04
Methane, bromo-, Halon 1001	kg	1.00E-08	3.10E-10	5.21E-10	9.18E-09
Methane, bromochlorodifluoro-, Halon 1211	kg	2.38E-06	0.00E+00	0.00E+00	2.38E-06
Methane, bromotrifluoro-, Halon 1301	kg	4.02E-07	0.00E+00	0.00E+00	4.02E-07
Methane, chlorodifluoro-, HCFC-22	kg	8.25E-06	0.00E+00	0.00E+00	8.25E-06
Methane, dichloro-, HCC-30	kg	1.04E-03	7.09E-08	9.13E-05	9.53E-04

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Methane, dichlorodifluoro-, CFC-12	kg	3.54E-08	3.57E-10	6.52E-10	3.44E-08
Methane, dichlorofluoro-, HCFC-21	kg	9.30E-12	0.00E+00	0.00E+00	9.30E-12
Methane, fossil	kg	4.61E-01	1.64E-03	1.02E-02	4.49E-01
Methane, monochloro-, R-40	kg	3.38E-08	1.03E-09	1.73E-09	3.11E-08
Methane, tetrachloro-, CFC-10	kg	3.50E-08	3.57E-11	5.35E-09	2.96E-08
Methane, tetrafluoro-, CFC-14	kg	5.86E-06	0.00E+00	0.00E+00	5.86E-06
Methane, trichlorofluoro-, CFC-11	kg	1.51E-11	0.00E+00	0.00E+00	1.51E-11
Methane, trifluoro-, HFC-23	kg	2.96E-09	0.00E+00	0.00E+00	2.96E-09
Methanesulfonic acid	kg	2.37E-12	0.00E+00	0.00E+00	2.37E-12
Methanol	kg	2.22E-01	0.00E+00	4.82E-03	2.17E-01
Methyl acetate	kg	1.01E-13	0.00E+00	0.00E+00	1.01E-13
Methyl acrylate	kg	3.39E-08	0.00E+00	0.00E+00	3.39E-08
Methyl amine	kg	6.73E-11	0.00E+00	0.00E+00	6.73E-11
Methyl borate	kg	4.85E-13	0.00E+00	0.00E+00	4.85E-13
Methyl ethyl ketone	kg	9.50E-05	7.55E-10	4.15E-05	5.36E-05
Methyl formate	kg	7.10E-05	0.00E+00	0.00E+00	7.10E-05
Methyl lactate	kg	4.58E-12	0.00E+00	0.00E+00	4.58E-12
Methyl methacrylate	kg	3.26E-11	5.73E-15	4.03E-14	3.25E-11
Metolachlor	kg	1.48E-08	0.00E+00	0.00E+00	1.48E-08
Metribuzin	kg	6.85E-11	0.00E+00	0.00E+00	6.85E-11
Molybdenum	kg	6.83E-06	0.00E+00	0.00E+00	6.83E-06
Monoethanolamine	kg	1.39E-06	0.00E+00	0.00E+00	1.39E-06
m-Xylene	kg	1.99E-07	0.00E+00	0.00E+00	1.99E-07
Naphthalene	kg	3.45E-04	1.32E-08	3.01E-05	3.15E-04
Nickel	kg	4.42E-04	7.88E-07	1.40E-05	4.27E-04
Nitrate	kg	8.68E-07	0.00E+00	0.00E+00	8.68E-07
Nitrobenzene	kg	2.58E-11	0.00E+00	0.00E+00	2.58E-11
Nitrogen oxides	kg	2.58E+00	1.81E-01	3.16E-01	2.08E+00
Nitrogen, total	kg	5.65E-05	5.62E-05	3.52E-07	1.81E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	2.15E-01	6.06E-03	1.27E-02	1.96E-01
N-Nitrodimethylamine	kg	2.49E-03	0.00E+00	0.00E+00	2.49E-03
Organic acids	kg	6.17E-07	8.69E-10	6.31E-08	5.53E-07
Organic substances, unspecified	kg	3.40E-04	5.23E-07	3.34E-05	3.06E-04
Ozone	kg	5.61E-05	0.00E+00	0.00E+00	5.61E-05
PAH, polycyclic aromatic hydrocarbons	kg	3.27E-05	9.02E-06	3.65E-06	2.00E-05
Paraquat	kg	2.99E-10	0.00E+00	0.00E+00	2.99E-10
Parathion, methyl	kg	2.26E-10	0.00E+00	0.00E+00	2.26E-10

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Particulates	kg	3.58E-01	0.00E+00	1.25E-06	3.58E-01
Particulates, < 10 um	kg	3.27E-01	0.00E+00	4.11E-02	2.86E-01
Particulates, < 2.5 um	kg	1.58E+00	0.00E+00	1.33E-01	1.44E+00
Particulates, > 10 um	kg	4.55E-02	0.00E+00	0.00E+00	4.55E-02
Particulates, > 2.5 um, and < 10um	kg	1.84E+00	5.52E-03	1.67E-01	1.66E+00
Particulates, SPM	kg	3.99E-03	0.00E+00	3.99E-03	0.00E+00
Particulates, unspecified	kg	7.20E-01	1.13E-03	5.47E-01	1.71E-01
Pendimethalin	kg	1.54E-09	0.00E+00	0.00E+00	1.54E-09
Pentane	kg	2.68E-03	0.00E+00	0.00E+00	2.68E-03
Permethrin	kg	1.38E-10	0.00E+00	0.00E+00	1.38E-10
Phenanthrene	kg	1.45E-07	2.28E-10	1.47E-08	1.30E-07
Phenol	kg	1.39E-04	3.10E-11	1.36E-04	3.39E-06
Phenol, 2,4-dichloro-	kg	2.60E-12	0.00E+00	0.00E+00	2.60E-12
Phenol, pentachloro-	kg	4.05E-08	0.00E+00	0.00E+00	4.05E-08
Phenols, unspecified	kg	1.83E-04	3.64E-08	1.61E-05	1.67E-04
Phorate	kg	7.09E-11	0.00E+00	0.00E+00	7.09E-11
Phosphate	kg	1.29E-06	#VALUE!	8.09E-09	x
Phosphine	kg	2.58E-11	0.00E+00	0.00E+00	2.58E-11
Phosphorus	kg	8.07E-07	0.00E+00	0.00E+00	8.07E-07
Phthalate, dioctyl-	kg	4.57E-09	1.41E-10	2.38E-10	4.19E-09
Platinum	kg	2.21E-12	0.00E+00	0.00E+00	2.21E-12
Polychlorinated biphenyls	kg	1.03E-08	0.00E+00	0.00E+00	1.03E-08
Potassium	kg	9.13E-05	0.00E+00	0.00E+00	9.13E-05
Propanal	kg	2.49E-08	7.36E-10	1.24E-09	2.29E-08
Propane	kg	3.29E-03	0.00E+00	0.00E+00	3.29E-03
Propene	kg	3.90E-04	1.40E-04	1.87E-04	6.37E-05
Propionic acid	kg	3.03E-05	0.00E+00	0.00E+00	3.03E-05
Propylamine	kg	6.98E-13	0.00E+00	0.00E+00	6.98E-13
Propylene oxide	kg	4.60E-07	0.00E+00	3.58E-09	4.57E-07
Pyrene	kg	1.77E-08	2.78E-11	1.79E-09	1.59E-08
Radionuclides (Including Radon)	kg	4.50E-03	6.33E-06	4.60E-04	4.03E-03
Scandium	kg	2.60E-07	0.00E+00	0.00E+00	2.60E-07
Selenium	kg	8.67E-05	1.17E-07	8.04E-06	7.85E-05
Silicon	kg	5.51E-05	0.00E+00	0.00E+00	5.51E-05
Silicon tetrafluoride	kg	3.80E-09	0.00E+00	0.00E+00	3.80E-09
Silver	kg	1.36E-08	0.00E+00	0.00E+00	1.36E-08
Simazine	kg	9.71E-10	0.00E+00	0.00E+00	9.71E-10

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Sodium	kg	3.19E-04	0.00E+00	0.00E+00	3.19E-04
Sodium chlorate	kg	4.20E-08	0.00E+00	0.00E+00	4.20E-08
Sodium dichromate	kg	2.10E-08	0.00E+00	0.00E+00	2.10E-08
Sodium formate	kg	1.66E-09	0.00E+00	0.00E+00	1.66E-09
Sodium hydroxide	kg	2.99E-07	0.00E+00	0.00E+00	2.99E-07
Strontium	kg	1.39E-06	0.00E+00	0.00E+00	1.39E-06
Styrene	kg	8.53E-08	4.84E-11	8.15E-11	8.52E-08
Sulfate	kg	1.85E-04	0.00E+00	0.00E+00	1.85E-04
Sulfur	kg	4.54E-06	0.00E+00	0.00E+00	4.54E-06
Sulfur dioxide	kg	3.67E+00	1.53E-02	2.79E-01	3.37E+00
Sulfur hexafluoride	kg	7.38E-07	0.00E+00	0.00E+00	7.38E-07
Sulfur oxides	kg	2.02E-01	1.01E-02	2.76E-02	1.64E-01
Sulfur trioxide	kg	2.09E-10	0.00E+00	0.00E+00	2.09E-10
Sulfur, total reduced	kg	2.67E-06	0.00E+00	0.00E+00	2.67E-06
Sulfuric acid	kg	6.27E-08	0.00E+00	0.00E+00	6.27E-08
Sulfuric acid, dimethyl ester	kg	3.00E-09	9.30E-11	1.56E-10	2.75E-09
Tar	kg	1.88E-09	7.11E-12	2.87E-10	1.59E-09
t-Butyl methyl ether	kg	1.94E-08	6.78E-11	1.14E-10	1.92E-08
t-Butylamine	kg	2.26E-12	0.00E+00	0.00E+00	2.26E-12
Terbufos	kg	2.42E-09	0.00E+00	0.00E+00	2.42E-09
Terpenes	kg	1.87E-08	0.00E+00	0.00E+00	1.87E-08
Thallium	kg	8.50E-09	0.00E+00	0.00E+00	8.50E-09
Thorium	kg	4.40E-09	0.00E+00	0.00E+00	4.40E-09
Tin	kg	1.57E-06	0.00E+00	0.00E+00	1.57E-06
Titanium	kg	5.58E-06	0.00E+00	0.00E+00	5.58E-06
TOC, Total Organic Carbon	kg	1.45E-02	0.00E+00	1.26E-03	1.32E-02
Toluene	kg	4.56E-04	2.21E-05	8.91E-06	4.25E-04
Toluene, 2,4-dinitro-	kg	1.75E-11	5.42E-13	9.13E-13	1.61E-11
Toluene, 2-chloro-	kg	8.10E-12	0.00E+00	0.00E+00	8.10E-12
Trimethylamine	kg	1.80E-13	0.00E+00	0.00E+00	1.80E-13
Tungsten	kg	2.90E-08	0.00E+00	0.00E+00	2.90E-08
Uranium	kg	5.11E-09	0.00E+00	0.00E+00	5.11E-09
Vanadium	kg	1.06E-03	0.00E+00	0.00E+00	1.06E-03
Vinyl acetate	kg	4.76E-10	1.47E-11	2.48E-11	4.36E-10
VOC, volatile organic compounds	kg	1.05E+00	5.16E-03	1.39E-01	9.11E-01
Water	kg	1.49E-03	0.00E+00	0.00E+00	1.49E-03
Xylene	kg	1.28E-04	1.54E-05	6.21E-06	1.06E-04

Air Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Zinc	kg	7.10E-05	1.04E-06	3.24E-08	6.99E-05
Zirconium	kg	1.12E-08	0.00E+00	0.00E+00	1.12E-08

13.2 Water Emissions

Table 15 Emissions to water released per 1 m^3 of MDF, average U.S.

Water Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
1,4-Butanediol	kg	2.49E-10	0.00E+00	0.00E+00	2.49E-10
1-Butanol	kg	7.72E-06	0.00E+00	0.00E+00	7.72E-06
1-Pentanol	kg	2.89E-12	0.00E+00	0.00E+00	2.89E-12
1-Pentene	kg	2.19E-12	0.00E+00	0.00E+00	2.19E-12
1-Propanol	kg	6.68E-12	0.00E+00	0.00E+00	6.68E-12
2,4-D	kg	5.79E-11	0.00E+00	0.00E+00	5.79E-11
2-Aminopropanol	kg	6.12E-13	0.00E+00	0.00E+00	6.12E-13
2-Hexanone	kg	2.68E-06	8.51E-08	2.64E-07	2.33E-06
2-Methyl-1-propanol	kg	6.77E-12	0.00E+00	0.00E+00	6.77E-12
2-Methyl-2-butene	kg	4.85E-16	0.00E+00	0.00E+00	4.85E-16
2-Propanol	kg	2.51E-09	0.00E+00	0.00E+00	2.51E-09
4-Methyl-2-pentanone	kg	1.73E-06	5.48E-08	1.70E-07	1.50E-06
Acenaphthene	kg	4.57E-09	0.00E+00	0.00E+00	4.57E-09
Acenaphthylene	kg	2.86E-10	0.00E+00	0.00E+00	2.86E-10
Acetaldehyde	kg	1.24E-05	0.00E+00	0.00E+00	1.24E-05
Acetic acid	kg	1.17E-06	0.00E+00	0.00E+00	1.17E-06
Acetochlor	kg	8.02E-10	0.00E+00	0.00E+00	8.02E-10
Acetone	kg	4.11E-06	1.30E-07	4.04E-07	3.57E-06
Acetonitrile	kg	1.96E-12	0.00E+00	0.00E+00	1.96E-12
Acetyl chloride	kg	2.27E-12	0.00E+00	0.00E+00	2.27E-12
Acid as H+	kg	1.29E-04	0.00E+00	0.00E+00	1.29E-04
Acidity, unspecified	kg	4.81E-07	0.00E+00	0.00E+00	4.81E-07
Acids, unspecified	kg	3.59E-06	1.33E-10	5.36E-09	3.59E-06
Acrylate, ion	kg	7.07E-08	0.00E+00	0.00E+00	7.07E-08
Alachlor	kg	7.90E-11	0.00E+00	0.00E+00	7.90E-11
Aluminium	kg	2.46E-02	8.61E-06	5.64E-05	2.46E-02
Aluminum	kg	7.18E-03	1.01E-03	2.25E-03	3.92E-03
Ammonia	kg	1.25E-02	2.34E-04	6.39E-04	1.16E-02
Ammonia, as N	kg	9.95E-03	6.67E-11	2.69E-09	9.95E-03
Ammonium, ion	kg	1.47E-02	5.05E-08	3.67E-06	1.47E-02
Aniline	kg	4.58E-11	0.00E+00	0.00E+00	4.58E-11
Antimony	kg	5.24E-05	6.36E-07	1.35E-06	5.05E-05
AOX, Adsorbable Organic Halogen as Cl	kg	7.48E-07	0.00E+00	0.00E+00	7.48E-07
Arsenic, ion	kg	2.02E-04	5.89E-06	1.02E-05	1.86E-04

Water Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Atrazine	kg	1.56E-09	0.00E+00	0.00E+00	1.56E-09
Barite	kg	9.71E-03	0.00E+00	0.00E+00	9.71E-03
Barium	kg	1.81E-01	1.40E-02	3.03E-02	1.37E-01
Bentazone	kg	6.38E-12	0.00E+00	0.00E+00	6.38E-12
Benzene	kg	1.33E-03	2.19E-05	6.48E-04	6.57E-04
Benzene, 1,2-dichloro-	kg	8.30E-08	0.00E+00	0.00E+00	8.30E-08
Benzene, 1-methyl-4-(1-methylethyl)-	kg	4.10E-08	1.30E-09	4.04E-09	3.57E-08
Benzene, chloro-	kg	1.71E-06	0.00E+00	0.00E+00	1.71E-06
Benzene, ethyl-	kg	5.64E-05	1.23E-06	3.82E-06	5.14E-05
Benzene, pentamethyl-	kg	3.08E-08	9.77E-10	3.03E-09	2.68E-08
Benzenes, alkylated, unspecified	kg	6.67E-06	5.58E-07	1.18E-06	4.93E-06
Benzoic acid	kg	4.17E-04	1.32E-05	4.10E-05	3.62E-04
Beryllium	kg	2.17E-05	1.91E-07	5.15E-07	2.10E-05
Biphenyl	kg	4.32E-07	3.61E-08	7.66E-08	3.19E-07
BOD5, Biological Oxygen Demand	kg	2.99E-01	2.37E-03	1.27E-02	2.84E-01
Borate	kg	2.44E-10	0.00E+00	0.00E+00	2.44E-10
Boron	kg	3.45E-03	4.09E-05	1.27E-04	3.28E-03
Bromate	kg	2.80E-06	0.00E+00	0.00E+00	2.80E-06
Bromide	kg	8.80E-02	2.79E-03	8.66E-03	7.66E-02
Bromine	kg	5.47E-04	0.00E+00	0.00E+00	5.47E-04
Bromoxynil	kg	8.43E-12	0.00E+00	0.00E+00	8.43E-12
Butene	kg	4.34E-07	0.00E+00	0.00E+00	4.34E-07
Butyl acetate	kg	1.00E-05	0.00E+00	0.00E+00	1.00E-05
Butyrolactone	kg	4.28E-10	0.00E+00	0.00E+00	4.28E-10
Cadmium, ion	kg	6.64E-05	1.32E-06	1.54E-06	6.36E-05
Calcium, ion	kg	1.54E+00	4.19E-02	1.30E-01	1.37E+00
Carbofuran	kg	1.19E-11	0.00E+00	0.00E+00	1.19E-11
Carbon disulfide	kg	1.28E-10	0.00E+00	0.00E+00	1.28E-10
Carbonate	kg	1.73E-05	0.00E+00	0.00E+00	1.73E-05
Carboxylic acids, unspecified	kg	3.27E-03	0.00E+00	0.00E+00	3.27E-03
Cesium	kg	7.35E-07	0.00E+00	0.00E+00	7.35E-07
CFCs, unspecified	kg	2.51E-09	0.00E+00	0.00E+00	2.51E-09
Chloramine	kg	4.25E-11	0.00E+00	0.00E+00	4.25E-11
Chlorate	kg	2.37E-05	0.00E+00	0.00E+00	2.37E-05
Chloride	kg	1.52E+01	4.71E-01	1.46E+00	1.33E+01
Chlorinated solvents, unspecified	kg	4.22E-08	0.00E+00	0.00E+00	4.22E-08
Chlorine	kg	1.90E-07	0.00E+00	0.00E+00	1.90E-07
Chloroacetic acid	kg	4.49E-08	0.00E+00	0.00E+00	4.49E-08
Chloroacetyl chloride	kg	8.16E-13	0.00E+00	0.00E+00	8.16E-13

Water Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Chloroform	kg	3.95E-09	0.00E+00	0.00E+00	3.95E-09
Chlorosulfonic acid	kg	7.13E-12	0.00E+00	0.00E+00	7.13E-12
Chlorpyrifos	kg	9.20E-11	0.00E+00	0.00E+00	9.20E-11
Chromate	kg	3.34E-13	0.00E+00	0.00E+00	3.34E-13
Chromium	kg	1.64E-04	2.98E-05	4.78E-05	8.62E-05
Chromium VI	kg	1.80E-04	1.10E-07	2.01E-07	1.80E-04
Chromium, ion	kg	1.87E-04	2.76E-06	1.35E-05	1.71E-04
Cobalt	kg	3.45E-04	2.89E-07	8.96E-07	3.44E-04
COD, Chemical Oxygen Demand	kg	3.11E-01	4.43E-03	1.83E-02	2.88E-01
Copper, ion	kg	6.03E-04	5.18E-06	1.21E-05	5.86E-04
Cumene	kg	8.56E-04	0.00E+00	8.51E-04	5.80E-06
Cyanazine	kg	1.38E-11	0.00E+00	0.00E+00	1.38E-11
Cyanide	kg	2.14E-05	9.41E-10	2.93E-09	2.14E-05
Decane	kg	1.20E-05	3.80E-07	1.18E-06	1.04E-05
Detergent, oil	kg	3.98E-04	1.12E-05	3.70E-05	3.50E-04
Dibenzofuran	kg	7.81E-08	2.48E-09	7.69E-09	6.79E-08
Dibenzothiophene	kg	6.46E-08	2.12E-09	6.47E-09	5.60E-08
Dicamba	kg	8.12E-11	0.00E+00	0.00E+00	8.12E-11
Dichromate	kg	7.48E-08	0.00E+00	0.00E+00	7.48E-08
Diethylamine	kg	2.05E-11	0.00E+00	0.00E+00	2.05E-11
Dimethenamid	kg	1.92E-10	0.00E+00	0.00E+00	1.92E-10
Dimethylamine	kg	2.69E-11	0.00E+00	0.00E+00	2.69E-11
Dipropylamine	kg	1.28E-11	0.00E+00	0.00E+00	1.28E-11
Dipropylthiocarbamic acid S-ethyl ester	kg	7.93E-11	0.00E+00	0.00E+00	7.93E-11
Dissolved organics	kg	8.23E-05	0.00E+00	0.00E+00	8.23E-05
Disulfoton	kg	4.73E-12	0.00E+00	0.00E+00	4.73E-12
Diuron	kg	1.33E-12	0.00E+00	0.00E+00	1.33E-12
DOC, Dissolved Organic Carbon	kg	5.76E-02	4.08E-13	1.57E-03	5.61E-02
Docosane	kg	4.39E-07	1.39E-08	4.33E-08	3.82E-07
Dodecane	kg	2.27E-05	7.21E-07	2.24E-06	1.98E-05
Eicosane	kg	6.25E-06	1.98E-07	6.16E-07	5.44E-06
Ethane, 1,2-dichloro-	kg	3.46E-08	0.00E+00	0.00E+00	3.46E-08
Ethanol	kg	1.78E-05	0.00E+00	0.00E+00	1.78E-05
Ethene	kg	1.82E-06	0.00E+00	0.00E+00	1.82E-06
Ethene, chloro-	kg	6.39E-09	0.00E+00	0.00E+00	6.39E-09
Ethyl acetate	kg	5.35E-11	0.00E+00	0.00E+00	5.35E-11
Ethylamine	kg	6.74E-12	0.00E+00	0.00E+00	6.74E-12
Ethylene diamine	kg	7.39E-11	0.00E+00	0.00E+00	7.39E-11
Ethylene oxide	kg	3.33E-08	0.00E+00	0.00E+00	3.33E-08

Water Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Fluorene, 1-methyl-	kg	4.67E-08	1.48E-09	4.60E-09	4.07E-08
Fluorenes, alkylated, unspecified	kg	3.87E-07	3.23E-08	6.86E-08	2.86E-07
Fluoride	kg	1.67E-02	7.13E-03	1.05E-04	9.49E-03
Fluorine	kg	2.14E-07	1.61E-08	3.52E-08	1.63E-07
Fluosilicic acid	kg	1.37E-06	0.00E+00	0.00E+00	1.37E-06
Formaldehyde	kg	5.99E-03	0.00E+00	0.00E+00	5.99E-03
Formamide	kg	5.29E-12	0.00E+00	0.00E+00	5.29E-12
Formate	kg	6.95E-10	0.00E+00	0.00E+00	6.95E-10
Formic acid	kg	1.54E-12	0.00E+00	0.00E+00	1.54E-12
Furan	kg	9.19E-11	0.00E+00	0.00E+00	9.19E-11
Glutaraldehyde	kg	1.20E-06	0.00E+00	0.00E+00	1.20E-06
Glyphosate	kg	1.72E-10	0.00E+00	0.00E+00	1.72E-10
Hexadecane	kg	2.48E-05	7.87E-07	2.44E-06	2.16E-05
Hexanoic acid	kg	8.63E-05	2.74E-06	8.49E-06	7.50E-05
Hydrocarbons, aliphatic, alkanes, unspecified	kg	9.56E-05	0.00E+00	0.00E+00	9.56E-05
Hydrocarbons, aliphatic, unsaturated	kg	8.82E-06	0.00E+00	0.00E+00	8.82E-06
Hydrocarbons, aromatic	kg	4.03E-04	0.00E+00	0.00E+00	4.03E-04
Hydrocarbons, unspecified	kg	1.88E-04	5.10E-13	2.06E-11	1.88E-04
Hydrogen peroxide	kg	6.62E-07	0.00E+00	0.00E+00	6.62E-07
Hydrogen sulfide	kg	1.51E-05	0.00E+00	0.00E+00	1.51E-05
Hydroxide	kg	2.22E-06	0.00E+00	0.00E+00	2.22E-06
Hypochlorite	kg	3.49E-06	0.00E+00	0.00E+00	3.49E-06
Iodide	kg	7.39E-05	0.00E+00	0.00E+00	7.39E-05
Iron	kg	3.48E-02	2.07E-03	5.04E-03	2.77E-02
Iron, ion	kg	3.38E-02	0.00E+00	0.00E+00	3.38E-02
Isopropylamine	kg	1.68E-12	0.00E+00	0.00E+00	1.68E-12
Lactic acid	kg	1.00E-11	0.00E+00	0.00E+00	1.00E-11
Lead	kg	2.18E-04	8.31E-06	1.87E-05	1.91E-04
Lead-210/kg	kg	4.27E-14	1.35E-15	4.20E-15	3.71E-14
Lithium, ion	kg	3.69E-01	2.27E-03	2.20E-02	3.45E-01
Magnesium	kg	3.65E-01	8.19E-03	2.54E-02	3.31E-01
Manganese	kg	1.11E-02	1.45E-05	1.43E-04	1.10E-02
MCPA	kg	1.08E-12	0.00E+00	0.00E+00	1.08E-12
Mercury	kg	2.09E-06	4.73E-08	2.86E-08	2.02E-06
Metallic ions, unspecified	kg	3.67E-09	6.23E-12	2.52E-10	3.41E-09
Methane, dichloro-, HCC-30	kg	1.39E-05	0.00E+00	0.00E+00	1.39E-05
Methane, monochloro-, R-40	kg	1.65E-08	5.25E-10	1.63E-09	1.44E-08
Methanol	kg	4.54E-05	0.00E+00	0.00E+00	4.54E-05

Water Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Methyl acetate	kg	2.41E-13	0.00E+00	0.00E+00	2.41E-13
Methyl acrylate	kg	6.62E-07	0.00E+00	0.00E+00	6.62E-07
Methyl amine	kg	1.62E-10	0.00E+00	0.00E+00	1.62E-10
Methyl ethyl ketone	kg	3.31E-08	1.05E-09	3.25E-09	2.88E-08
Methyl formate	kg	2.83E-05	0.00E+00	0.00E+00	2.83E-05
Metolachlor	kg	6.34E-10	0.00E+00	0.00E+00	6.34E-10
Metribuzin	kg	2.94E-12	0.00E+00	0.00E+00	2.94E-12
Molybdenum	kg	8.43E-05	3.00E-07	9.29E-07	8.31E-05
m-Xylene	kg	1.24E-05	3.95E-07	1.23E-06	1.08E-05
Naphthalene	kg	7.46E-06	2.37E-07	7.36E-07	6.49E-06
Naphthalene, 2-methyl-	kg	6.51E-06	2.06E-07	6.40E-07	5.66E-06
Naphthalenes, alkylated, unspecified	kg	1.09E-07	9.14E-09	1.94E-08	8.08E-08
n-Hexacosane	kg	2.74E-07	8.70E-09	2.70E-08	2.38E-07
Nickel	kg	7.98E-05	4.58E-06	9.08E-06	6.61E-05
Nickel, ion	kg	9.81E-04	0.00E+00	0.00E+00	9.81E-04
Nitrate	kg	6.35E-03	4.47E-14	1.81E-12	6.35E-03
Nitrate compounds	kg	4.76E-10	1.80E-12	7.27E-11	4.02E-10
Nitric acid	kg	1.07E-06	4.04E-09	1.63E-07	9.01E-07
Nitrite	kg	2.08E-06	0.00E+00	0.00E+00	2.08E-06
Nitrobenzene	kg	1.03E-10	0.00E+00	0.00E+00	1.03E-10
Nitrogen	kg	5.02E-03	0.00E+00	0.00E+00	5.02E-03
Nitrogen, organic bound	kg	2.61E-04	0.00E+00	0.00E+00	2.61E-04
Nitrogen, total	kg	9.98E-05	1.26E-07	9.14E-06	9.05E-05
o-Cresol	kg	1.18E-05	3.75E-07	1.16E-06	1.03E-05
Octadecane	kg	6.13E-06	1.94E-07	6.03E-07	5.33E-06
Oils, unspecified	kg	5.90E-02	2.95E-04	8.81E-04	5.78E-02
Organic substances, unspecified	kg	1.83E-09	0.00E+00	0.00E+00	1.83E-09
o-Xylene	kg	5.18E-11	0.00E+00	0.00E+00	5.18E-11
PAH, polycyclic aromatic hydrocarbons	kg	4.41E-06	0.00E+00	0.00E+00	4.41E-06
Paraquat	kg	1.28E-11	0.00E+00	0.00E+00	1.28E-11
Parathion, methyl	kg	9.69E-12	0.00E+00	0.00E+00	9.69E-12
p-Cresol	kg	1.27E-05	4.05E-07	1.25E-06	1.11E-05
Pendimethalin	kg	6.59E-11	0.00E+00	0.00E+00	6.59E-11
Permethrin	kg	5.92E-12	0.00E+00	0.00E+00	5.92E-12
Phenanthrene	kg	6.31E-08	3.39E-09	8.32E-09	5.14E-08
Phenanthrenes, alkylated, unspecified	kg	4.53E-08	3.79E-09	8.04E-09	3.35E-08
Phenol	kg	1.02E-04	4.87E-06	8.90E-06	8.82E-05
Phenol, 2,4-dimethyl-	kg	1.15E-05	3.65E-07	1.13E-06	1.00E-05
Phenols, unspecified	kg	1.58E-04	1.62E-06	1.04E-05	1.46E-04

Water Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Phorate	kg	1.83E-12	0.00E+00	0.00E+00	1.83E-12
Phosphate	kg	3.41E-02	5.37E-03	3.39E-05	2.86E-02
Phosphorus	kg	1.03E-05	0.00E+00	0.00E+00	1.03E-05
Phosphorus compounds, unspecified	kg	3.40E-08	0.00E+00	0.00E+00	3.40E-08
Phosphorus, total	kg	3.03E-06	0.00E+00	0.00E+00	3.03E-06
Potassium, ion	kg	6.27E-02	0.00E+00	0.00E+00	6.27E-02
Process solvents, unspecified	kg	9.19E-09	0.00E+00	0.00E+00	9.19E-09
Propanal	kg	4.19E-12	0.00E+00	0.00E+00	4.19E-12
Propene	kg	3.18E-04	0.00E+00	3.13E-04	4.88E-06
Propionic acid	kg	7.64E-12	0.00E+00	0.00E+00	7.64E-12
Propylamine	kg	1.68E-12	0.00E+00	0.00E+00	1.68E-12
Propylene oxide	kg	1.10E-06	0.00E+00	0.00E+00	1.10E-06
Radium-226/kg	kg	1.48E-11	4.71E-13	1.46E-12	1.29E-11
Radium-228/kg	kg	7.59E-14	2.41E-15	7.48E-15	6.61E-14
Rubidium	kg	7.35E-06	0.00E+00	0.00E+00	7.35E-06
Scandium	kg	2.94E-05	0.00E+00	0.00E+00	2.94E-05
Selenium	kg	6.65E-05	1.41E-07	1.55E-06	6.48E-05
Silicon	kg	2.59E-01	0.00E+00	0.00E+00	2.59E-01
Silver	kg	8.61E-04	2.74E-05	8.48E-05	7.49E-04
Silver, ion	kg	3.40E-06	0.00E+00	0.00E+00	3.40E-06
Simazine	kg	4.16E-11	0.00E+00	0.00E+00	4.16E-11
Sodium formate	kg	3.99E-09	0.00E+00	0.00E+00	3.99E-09
Sodium, ion	kg	4.48E+00	1.33E-01	4.12E-01	3.93E+00
Solids, inorganic	kg	2.61E-02	1.03E-11	4.14E-10	2.61E-02
Solved solids	kg	1.83E+01	5.81E-01	1.80E+00	1.59E+01
Strontium	kg	2.63E-02	7.11E-04	2.20E-03	2.34E-02
Styrene	kg	2.22E-11	0.00E+00	1.06E-11	1.16E-11
Sulfate	kg	8.57E-01	1.05E-03	1.04E-02	8.46E-01
Sulfide	kg	3.34E-05	5.65E-07	1.16E-06	3.17E-05
Sulfite	kg	9.51E-06	0.00E+00	0.00E+00	9.51E-06
Sulfur	kg	1.23E-03	3.45E-05	1.07E-04	1.09E-03
Sulfuric acid	kg	8.05E-11	0.00E+00	0.00E+00	8.05E-11
Suspended solids, unspecified	kg	4.95E-01	3.15E-02	6.94E-02	3.94E-01
Tar	kg	2.69E-11	1.02E-13	4.11E-12	2.27E-11
t-Butyl methyl ether	kg	1.58E-06	0.00E+00	0.00E+00	1.58E-06
t-Butylamine	kg	5.41E-12	0.00E+00	0.00E+00	5.41E-12
Terbufos	kg	6.25E-11	0.00E+00	0.00E+00	6.25E-11
Tetradecane	kg	9.96E-06	3.16E-07	9.80E-07	8.66E-06
Thallium	kg	6.50E-06	1.34E-07	2.84E-07	6.08E-06

Water Emission	Unit	Total	Forestry Operations	Wood Residue Production	MDF Production
Tin	kg	5.29E-05	2.69E-06	6.74E-06	4.35E-05
Tin, ion	kg	4.71E-05	0.00E+00	0.00E+00	4.71E-05
Titanium, ion	kg	8.72E-04	9.77E-06	2.07E-05	8.42E-04
TOC, Total Organic Carbon	kg	5.77E-02	0.00E+00	1.57E-03	5.61E-02
Toluene	kg	7.42E-04	2.07E-05	6.41E-05	6.57E-04
Toluene, 2-chloro-	kg	1.65E-11	0.00E+00	0.00E+00	1.65E-11
Tributyltin compounds	kg	7.88E-07	0.00E+00	0.00E+00	7.88E-07
Triethylene glycol	kg	2.66E-05	0.00E+00	0.00E+00	2.66E-05
Trimethylamine	kg	4.32E-13	0.00E+00	0.00E+00	4.32E-13
Tungsten	kg	6.62E-05	0.00E+00	0.00E+00	6.62E-05
Urea	kg	5.04E-12	0.00E+00	0.00E+00	5.04E-12
Vanadium	kg	1.12E-05	3.54E-07	1.10E-06	9.70E-06
Vanadium, ion	kg	1.02E-04	0.00E+00	0.00E+00	1.02E-04
VOC, volatile organic compounds, unspecified origin	kg	2.58E-04	0.00E+00	0.00E+00	2.58E-04
Waste water/m3	m3	8.19E-04	0.00E+00	6.13E-05	7.58E-04
Waste, solid	kg	1.08E-02	0.00E+00	0.00E+00	1.08E-02
Xylene	kg	4.15E-04	1.10E-05	3.39E-05	3.70E-04
Yttrium	kg	2.77E-06	8.78E-08	2.72E-07	2.41E-06
Zinc	kg	3.64E-04	2.37E-05	5.71E-05	2.83E-04
Zinc, ion	kg	3.63E-03	0.00E+00	0.00E+00	3.63E-03