Cradle to Gate Life Cycle Assessment of North American Cellulosic Fiberboard Production

Prepared for:
AWC – The American Wood Council

By:
Maureen Puettmann, WoodLife Environmental Consultants, LLC
Richard Bergman, Forest Products Laboratory, USDA Forest Service
Elaine Oneil, CORRIM, University of Washington

Version 1 December 2015

Version 2 January 2016

WoodLife Environmental Consultants, LLC

CORRIM
Consortium for Research on Renewable Industrial Materials

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

Table of Contents

List of Tables

List of figures

1 Introduction

All consumer products have an environmental footprint. Quantifying that footprint has become more common with the advent of Environmental Preferential Purchasing (EPP), an emergent world-wide phenomenon. The forest products industry in particular has been challenged regarding its environmental sustainability. The greatest challenges with respect to practices center on the extraction of forest resources with questions about product environmental performance focused on uses, longevity and final disposal. In addition forest land owners and product manufacturers are facing increased environmental regulations and competition in the marketplace. The forest sector as a whole is challenged with re-thinking how they grow, manage, and manufacture products to efficiently meet expectations set forth by environmental regulations, government policies, and the public.

To meet the challenges of the EPP framework, the American Wood Council (AWC) commissioned the Consortium for Research on Renewable Industrial Materials (CORRIM) to produce a cradle to gate (CtG) life-cycle assessment of North American cellulosic fiberboard and an Environmental Product Declaration (EPD) based on the LCA. CORRIM (www.corrim.org) has derived life-cycle inventory (LCI) data for major wood products and wood production regions in the United States (US). The LCI data covers 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 US regions including the Pacific Northwest (PNW), Southeast (SE), Inland West, and Northeast/North Central (NE-NC). Comparable data for Canadian wood products and regions has been produced by the ATHENA Sustainable Materials Institute (www.athenasmi.org) and FPInnovations (www.fpinnovations.ca).

This report focuses on the average North American production of cellulosic fiberboard and utilizes underlying data from both CORRIM and ATHENA. This document is based on the life cycle inventory (LCI) report for cellulosic fiberboard by Bergman (2015). It uses the Bergman (2015) LCI data as the basis for conducting a life-cycle impact assessment (LCIA) using the TRACI method (Bare et al. 2011). This report follows data and reporting requirements as outlined in the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015) that will provide the guidance for preparation of North American Environmental Product Declarations (EPD) for cellulosic fiberboard. This report does not include comparative assertions. Some processes have been updated since the publication the original LCI report (Bergman 2015) and they are noted by date in Table 9 of this report. This reports LCIA results for both mass and economic allocation for the production of 1 cubic of meter of uncoated cellulosic fiberboard.

2 Description of Product

North American cellulosic fiberboard used in residential and commercial construction is classified by the following standards: 1) ASTM C208 (2012), Standard Specification for Cellulosic Fiber Insulating Board and 2) CAN/ULC-S706 (2009), Standard for Wood Fiber Insulating Boards for Building. Various uses and applications for fiberboard include: 1) Sound-deadening board, 2) Structural sheathing, and 3) Roofing substrate (i.e., roof fiberboard). Cellulosic fiberboard can be coated with asphalt. Coating of cellulosic fiberboard is not part of this LCA study.

Cellulosic fiberboard is a panel product developed to utilize industrial wood residue (Figure 1 and Figure 2). Woody biomass residues not utilized for fuel were sent to landfills to disposal. Over the last several decades, the product has evolved into a highly engineered product designed to meet specific end-use requirements. The production of cellulosic fiberboard falls into the Standard Industrial Classification (SIC) Code 321219, reconstituted wood products, which include other wood composite products such as hardboard, medium density fiberboard, particleboard, and oriented strandboard (USCB 2012). Cellulosic fiberboard panels are either 0.5 inch (12.7 mm) or 0.781 in (19.8 mm) thick, 4.0 feet (1.22 m) wide, and 8.0 (2.44 m), 9 (2.74 m), or 10 feet (3.05 m) long (Table 1).

Figure 1 Uncoated cellulosic fiberboard (top view).

Figure 2 Uncoated cellulosic fiberboard (side view).

Table 1 Typical production dimensions of cellulosic fiberboard (www.fiberboard.org).

		Sound-Deadening/ Insulation Board	**Sheathing**	**Roofing**
	Units	**English**		
Widths	feet	4	4	Custom
Lengths	feet	8	8, 9, 10	
Thickness	inch	0.50	0.50, 0.78	
		SI		
Widths	meter	1.219	1.219	
Lengths	meter	2.438	2.438, 2.743, 3.048	
Thickness	millimeter	12.70	12.70, 19.837	

Cellulosic fiberboard is produced from industrial wood residues such as shavings, sawdust, and chips that come from primary log breakdown or chipping whole-trees (roundwood), from mixed paper, and from construction waste. Manufacturing cellulosic fiberboard uses a wet process that produces a low-density wood composition panel which is often referred to as insulation board (Figure 3). Density for the final products ranges from 12 to 24 lb/ft3 (190 to 380 kg/m3) (Suchsland and Woodson 1986; US EPA 2002; Stark et al. 2010; ASTM International 2012). A thermo-mechanical process reduces the wood raw material to fibers and binds the fibers with a starch to form cellulosic fiberboard. Other additives may include alum, clay, and wax. Asphalt can be added in the mix as a binder to improve strength properties and as an external coating. Adding water to the fiber creates a slurry (similar to the paper-making process) that is then transformed into a fiber mat. Presses and large dryers are used to remove water. Historically, water usage has been of particular concern. Production plants without any water conservation in place can use 170 gal/ft^3 (22,700 L/m^3) of cellulosic fiberboard (Suchsland and Woodson 1986).

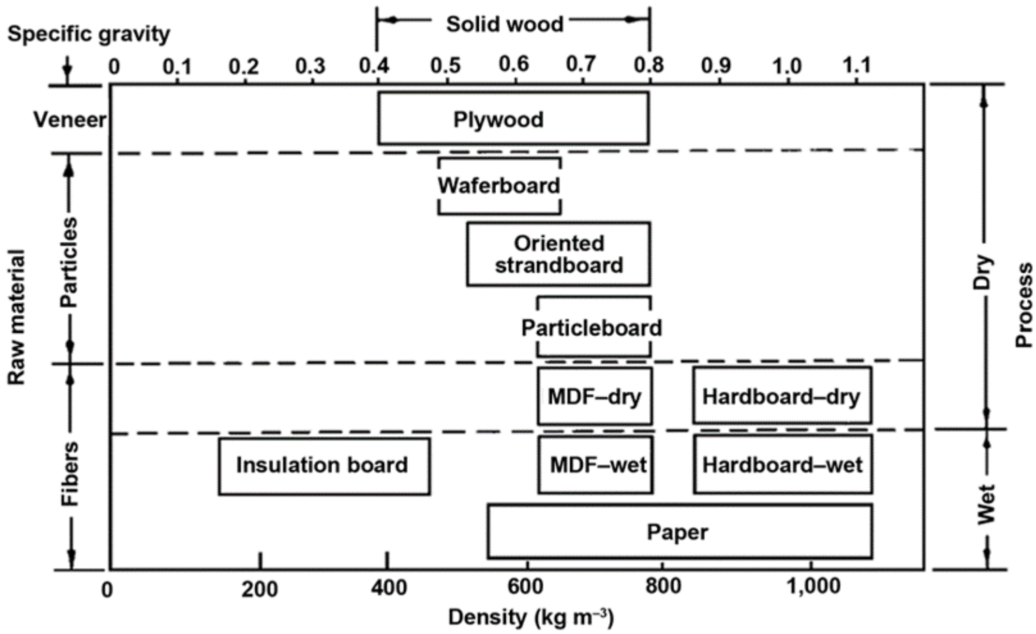

Figure 3 Classification of wood composite panels by particle size, density, and process (Suchsland and Woodson 1986).

2.1 Study goals and scope

The goal of this study was to determine energy and material inputs and outputs associated with the production of cellulosic fiberboard in North America (U.S. and Canada). The data were obtained by surveying manufacturers in the U.S. and Canada. Surveys were consistent with CORRIM protocols for performing LCI's of wood products, follow ISO14040/140444 standards for conducting LCA (ISO 2006b, ISO 2006c), and meet the requirements of the PCR for North American Structural and Architectural Wood Products (FPInnovations 2015).

The scope of this study was to develop a cradle-to-gate LCA for the production of cellulosic fiberboard common to practices and technology common to North America for cellulosic fiberboard feedstock and manufacturing sectors. It covers the impact in terms of material flow, energy type and use, emissions to air and water, solid waste production, and water impacts for the cellulosic fiberboard manufacturing process on a per unit volume basis of 1.0 cubic meter (m^3). Data for the LCA are based on gate to gate inputs and outputs obtained directly from the survey of cellulosic fiberboard mills, previously published data for gate to gate wood residue production (Milota 2015) and cradle to gate forest resources LCI's (Johnson et al. 2005, Oneil et al. 2010).

2.2 Intended audience

The primary audience for the LCA report includes the American Wood Council, Canadian Wood Council, North American cellulosic fiberboard manufacturers, and other LCA practitioners.

2.3 Comparative assertions

The report does not include product use and end of life phases which are required for comparative assertions relative to substitute products. If future comparative studies are intended and disclosed to the public, the LCA boundary would need to be expanded to include the use and end of life phases consistent with the ISO 14040/44:2006 (ISO 2006a) guidelines and principles and compliance with the Wood Products PCR (FPInnovations 2015).[1]

2.4 Functional and declared unit

In accordance with the PCR, the declared unit for cellulosic fiberboard 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 (FPInnovations 2015). For conversion of units from the U.S. industry measure, 1.0 MSF (1,000 square feet) at 0.5-in basis is equal to 1.18 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 standards for conducting LCA's (ISO 2006b, ISO2006c). As the analysis does not take the declared unit to the stage of being an installed building product, no service life is assigned.

2.5 System boundaries

The system boundary begins with regeneration in the forest and ends with cellulosic fiberboard product (Figure 4). The system boundary includes forest operations (A_1), which may include site preparation and planting seedlings, fertilization and thinning, final harvest with the transportation of logs (A_2) to the primary breakdown facility, wood residue production during lumber manufacturing processes, transportation of residues (A_2) to the cellulosic fiberboard mills, and onsite production of cellulosic fiberboard (A_3) (Figure 4). Seedlings and the fertilizer and electricity it took to grow trees were considered as inputs to the system boundary. The cellulosic fiberboard production complex was modeled as a single unit process. The study recognized ten steps (A_3) necessary to make cellulosic fiberboard with energy generation considered as an auxiliary process. On-site energy generation can come from a boiler or direct fire. A single unit process was used to model the cellulosic fiberboard process since the percentage of co-product was small (3.9%) and the approach does not affect the accuracy of assigning the burdens.

[1] If the LCA is used to develop an Environmental Product Declaration (EPD), internal and/or external critical review would be required.

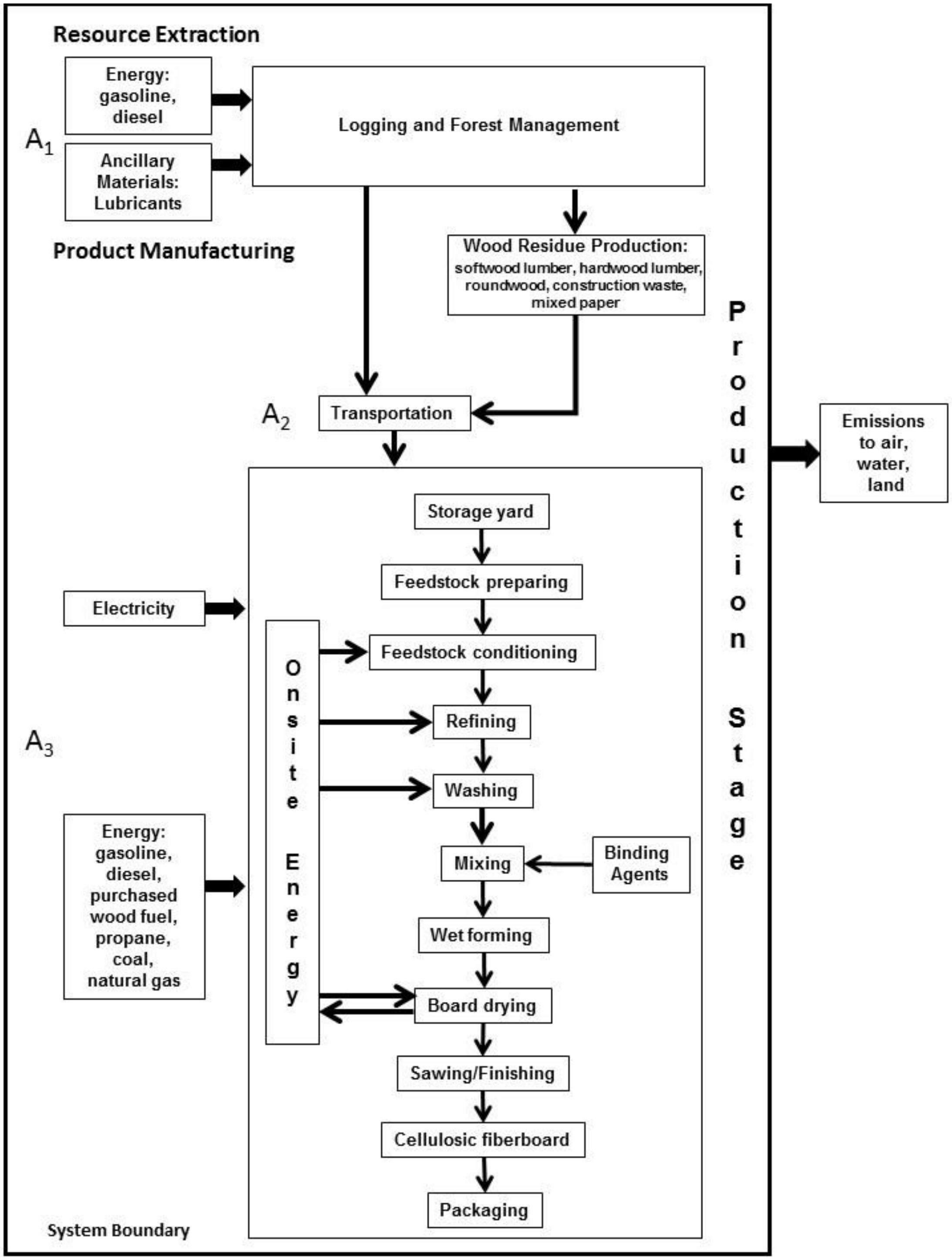

Figure 4 Cradle to gate system boundary for production of cellulosic fiberboard, North America.

2.6 Description of data/Process descriptions

2.6.1 Feedstock resources

Forest operations modeled were based on hardwood forest resource LCI data from the SE (Johnson et al. 2005) and NE-NC U.S. (Oneil et al. 2010) and U.S. and Canadian softwood forests (ASMI 2012). Forestry operations vary regionally (Johnson et al. 2005; Oneil et al. 2010; ASMI 2012) but typically include some combination of growing seedlings, natural regeneration, site preparation, planting, thinning, fertilization (where applicable), and final harvest. For NE-NC U.S. hardwood forests, reforestation was assumed to occur using natural regeneration that did not require seedlings, site preparation, planting and pre-commercial thinning data inputs (Table 2), whereas these steps were included for regeneration of softwood forests in the Canadian and SE U.S. regions. The specific processes involved are reforestation; which includes seedling production, site preparation and planting, pre-commercial thinning, and fertilization, and harvesting. Final harvest 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 seedlings and 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 sawn lumber. The co-product, non-merchantable (logging) slash, is generally left at a landing. Slash disposal was not modeled as it was assumed to decay in-situ. Details of all forestry operations 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 cellulosic fiberboard production are provided in Table 2.

Table 2 Fuel consumption for regional forest resource management processes (regeneration, thinning, and harvest).

Processes	Unit	Fuel consumption per m^3			
		SE	NE-NC hardwoods	Canadian[2]	Weighted average
Seedling, site prep, plant, pre-commercial thinning					
Diesel and gasoline	L	0.515	0	0.088	0.340
Lubricants	L	0.009	0	0.002	0.0061
Electricity	kWh	0.455	0	0.107	0.308
Commercial thinning and final harvest					
Diesel	L	2.93	4.27	4.83	3.604
Lubricants	L	0.05	0.077	0.132	0.076
Electricity	kWh	0	0	0.264	0.073
Total forest extraction process					
Gasoline and diesel	L	3.45	4.27	4.92	3.94
Lubricants	L	0.059	0.077	0.134	0.082
Electricity	kWh	0.455	0	0.371	0.381

[2] Canadian forest resource data is a weighted average of PNW data found in Table 4, Cradle to gate life cycle assessment of softwood lumber production from the Pacific Northwest, April 2013, http://www.corrim.org/pubs/reports/2013/phase1_updates/PNW%20Lumber%20final%20May%202013.pdf

2.6.2 Woody Feedstock Inputs

The feedstocks used for cellulosic fiberboard production vary widely across North America. All residues (except roundwood) are assumed to come from sawmill operations were dimension lumber is the primary product. Wood residues came from both hardwood mills and softwood mills depending on the regions (Table 3). Due to lack of available primary data for residue production in Canada, US western data (Milota 2015; ASMI 2012) was modified to represent Canadian energy types and is therefore referred to as Canadian from hereafter. Roundwood is used as a feedstock for fiberboard and reported from production facilities in the SE and NE-NC regions of the US (Johnson et al 2005, Oneil et al. 2010). The Canadian region used the most planar shavings whereas the SE used the most pulp chips. Pulp chips represent the largest feedstock input at 47 percent (114 kg, oven dry) followed by roundwood, construction waste, and dry planer shavings at 26, 13, and 12 percent, respectively (Table 3). The remaining 3 percent of the total wood input for cellulosic fiberboard comes from mixed paper, dry sawdust, and back to pulper recycled pulp fibers.

The wood residue is comprised of many species, both softwood and hardwood. Softwoods include Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), longleaf pine (*Pinus palustris*), shortleaf pine (*P. echinata*), loblolly pine (*P. taeda* L.), slash pine (*P. elliottii*), lodgepole pine (*P. contorta*), jack pine (*P. banksiana*), balsam fir (*Abies balsamea*), alpine Fir (*A. lasiocarpa*), white spruce (*Picea glauca*), Engelmann pine (*P. engelmannii*), and black spruce (*P. mariana*). Hardwood species include yellow poplar (*Liriodendron tulipfera*), American gum *(Liquidamber styraciflua)*, quaking aspen (*Populus tremuloides*), and bigtooth aspen (*P. grandidentata*). All flow analyses of wood and bark in the process were based on a weighted average oven-dry weight with a green specific gravity of 0.55.

Table 3 Wood feedstock types and source for input for cellulosic fiberboard production, North American average.

Wood residue type by Region	kg/m^3	Percent (%)
Canada[3]		
Pulp chips, softwood, dry	26.48	46
Sawdust, softwood, dry	0.59	1
Planer shavings, softwood, dry	29.99	53
TOTAL	57.06	100
Southeast region (US SE)		
Pulp chips, hardwood, green	5.98	5
Pulp chips, softwood, green	81.08	64
Roundwood chips, softwood, green	39.59	31
TOTAL	126.65	100
Northeast-North central regions (US NE-NC)		
Roundwood, hardwood, green	23.17	100
TOTAL	23.17	100
Recycled waste		
Construction Waste	31.22	85
Mixed Office Paper	4.97	13
Backed to pulper, Fiberboard production coproduct	0.79	2
TOTAL	36.98	100
Canada – Region	57.06	23
Southeast, US – Region	126.65	52
Northeast–North central, US – Region	23.17	10
Recycled waste, North America	36.98	15
TOTAL North American average	243.85	100

[3] Modified from Cradle to gate life cycle assessment of softwood lumber production from the Pacific Northwest, April 2013, http://www.corrim.org/pubs/reports/2013/phase1_updates/PNW%20Lumber%20final%20May%202013.pdf

2.6.3 Cellulosic fiberboard manufacturing

The manufacturing of cellulosic fiberboard can be outlined using ten production processes (Bergman 2015) (Figure 5). These included:

1. Resource transport,
2. Storage yard,
3. Feedstock preparation,
4. Refining,
5. Washing,
6. Mixing,
7. Wet forming,
8. Board drying,
9. Finishing, and
10. Packaging,

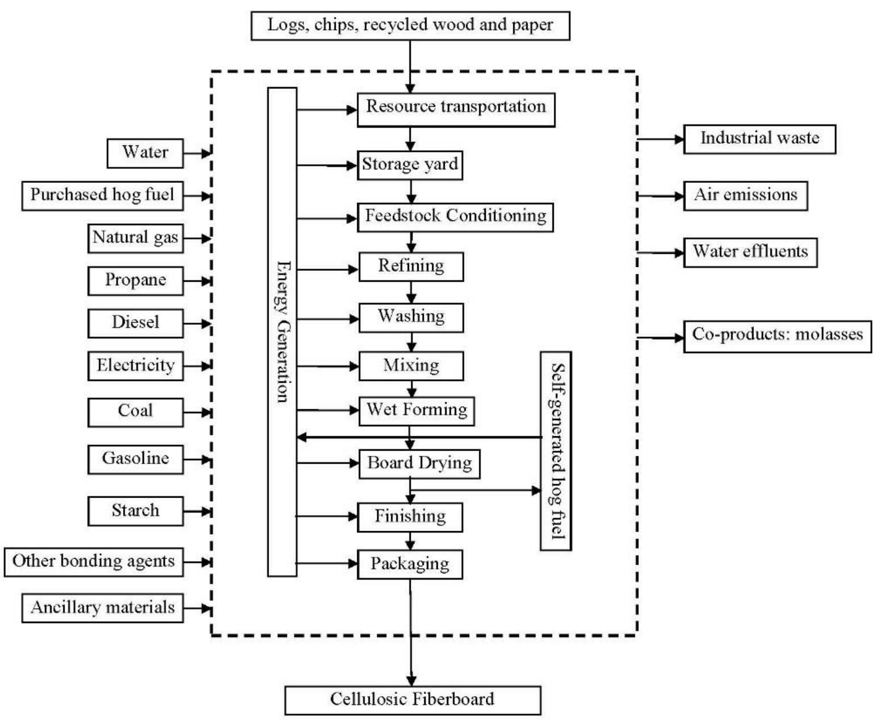

Figure 5 Process flow for the production of cellulosic fiberboard

2.6.3.1 Resource and material transport

Woody feedstocks are delivered to the mill by truck. Cellulosic fiberboard feedstock can consists of whole logs, dry shavings and sawdust, wood chips, construction waste, and/or mixed paper, depending on regional sources. The moisture content of the residues can range from 10 to 100% on an oven-dry weight-basis. Based on mill surveys, the average haul distance for feedstock along with other materials used in the manufacturing process are shown in Table 4. Inputs to the transportation process include diesel fuel and outputs include emission to air and water and solid waste generated from the production and combustion of the fuel.

Table 4 Weighted average delivery distance (one-way) for materials to cellulosic fiberboard mill, North American average.

Material delivered to mill	Mode of Transport	Delivery Distance	
		kilometer	mile
Roundwood	Truck	6.8	4.2
Chips, green	Truck	62.8	39.0
Chip, dry	Truck	62.8	39.0
Sawdust, dry	Truck	2.7	1.7
Mixed paper	Truck	9.7	6.0
Construction waste	Truck	29.0	18.0
Shavings, dry	Truck	33.8	21.0
Additive: Starch	Truck	675.9	420.0
Additive: Asphalt flake	Truck	273.6	170.0
Additive: Alum	Truck	133.6	83.0
Additive: Wax	Truck	354.1	220.0
Additive: Clay	Truck	1,303.6	810.0
Purchased wood fuel	Truck	0.8	0.5
Coal	Rail	17.4	10.8

2.6.3.2 Storage yard

Upon arrival at the storage yard (Figure 5) all feedstock were weight-scaled and moisture contents were determined. Log stackers or front-end loaders are used to transport logs and chips from the storage yard to the mill for chipping. Additional mobile equipment is used to move all feedstock for further processing. Inputs included woody feedstocks, electricity, fuel, and lubricants. Outputs are feedstock and emissions from fuel use.

2.6.3.3 Feedstock conditioning

The feedstock arrives in various forms that require further processing before refining in order to produce homogeneous residues. Logs and construction waste are chipped and combined with incoming chips. Chips are screened to remove over-sized chips, re-chipped, and then washed to remove dirt and other foreign substances. Steam digesters and steaming screws are typically used for conditioning chip and other wood raw material. Inputs include prepared feedstock, water, steam, and electricity and outputs include chips and emissions.

2.6.3.4 Refining

The purpose of this process is to pulp the prepared residues. The prepared residue is refined by mechanically reducing and thermally softening the material into fibers (pulp fiber) by shearing the wood between two rotating metal disks that separate the fibers at the lignin binder. This process is referred to as mechanical pulping because no chemicals are added. Refining is an energy-intensive process with an average specific energy ranging from 20 to 30 hp-d/ton residue output (250 to 380 kWh/tonne) (Suchsland and Woodson 1986). Inputs include chips, dry wood residues, mixed paper, electricity, and heat (Figure 5). Outputs include pulp fiber and water vapor.

2.6.3.5 Washing

The pulp fibers are washed to remove natural wood sugars (i.e., molasses) that can reduce board quality (Figure 5). In addition, washing removes dirt and other foreign material that might still remain in the pulp fibers. Inputs are pulp fibers and water. Outputs are clean pulp fibers, water, molasses, and solid waste.

2.6.3.6 Mixing

During this step water is added to the pulp fibers along with additives (alum, asphalt, starch, and wax) for bonding the pulp fibers in stock chests to create a slurry to await further processing (Figure 5). No resins are added to produce cellulosic fiberboards. Lignin, a natural component of wood, aids the additives in bonding the pulp fibers. Inputs include water and additives (Figure 5) and output include a pulp/water low-consistency slurry along with additives.

2.6.3.7 Wet forming

The slurry with approximately 2% pulp fiber is sent to forming machines (Fourdrinier machines) where it is metered unto a wire screen. Two percent consistency provides for the highest bonding strength of the final board (Lampert 1967). Gravity and a vacuum applied gradually to the bottom of the wire removes the water from the slurry mix to produce a fiber mat. Once the slurry reaches about 25% solid fiber, the mat is cut to length and trimmed by high-pressure water jets (Figure 5). Then the mat is wet-pressed using continuous rollers at room temperature to remove additional water until it forms the board at its final thickness while allowing for a shrinkage allowance when dried. Most of the collected water is recycled. Inputs include pulp, water, and electricity and outputs include a fiber mat, trim residue, water, and steam.

2.6.3.8 Board drying

Board drying is a continuous energy-intensive process (Figure 5). The fiber mats which are around 65-75 percent moisture content (dry basis) move along a conveyor into a heated enclosure where their moisture content is reduced to approximately 4 percent. In total, approximately two tonnes of water are removed per tonne of dry board. Roller dryers operate with inlet temperatures of approximately 230°C (450°F) and outlet temperatures of approximately 160°C (320°F). Inputs include wet boards, electricity, and combustion gases from burning natural gas and outputs include dry boards, steam, and air emissions.

2.6.3.9 Finishing

Trimming reduces the dry board to final standard dimensions (Figure 5). Input includes untrimmed dry board and electricity and output includes final product, culled boards, and wood dust. Finished fiberboard density ranges from 190 to 380 kg/m^3 (12 to 24 lb/ft^3). Coating of the finished boards is not included in the LCA.

2.6.3.10 Packaging

Finished uncoated cellulosic fiberboard is packaged for transport. Inputs include final product (uncoated cellulosic fiberboard), electricity, and packaging material. Outputs include packaged uncoated cellulosic fiberboard.

2.6.3.11 Energy generation

Energy for the production of cellulosic fiberboard comes from electricity, coal, natural gas, and wood fuel. Natural gas, coal, and wood fuels are used to heat refiners and dryers. Electricity is used throughout the process. It is used to operate equipment within the plant, including conveyors, refiners, fan motors, hydraulic press motors, high-pressure water jets, rollers, and emission control systems. Emission control devices such as baghouses, cyclones, electrostatic precipitators, and wet scrubbers are used throughout the mills. Electricity was produced off-site. Emission resulting from the production of electricity were based on the weighted average allocation of the electrical grid composition for regions that produce North American cellulosic fiberboard (Table 5). Coal (35.3%) and hydro (34.3%) power comprise most of the energy source inputs to the grid used for manufacturing cellulosic fiberboard.

Other fuels such as diesel, liquid propane gas (LPG), and gasoline are used to operate transport equipment within the mill.

Table 5 Percentage of energy source for electricity for producing North American cellulosic fiberboard.

Energy source	Canada-Alberta (%)	Canada-Quebec[1] (%)	MRO[2] (%)	SERC[3] (%)	North American composite grid (%)
Natural gas	43.5	0.0	3.3	19.1	11.7
Coal	42.0	0.0	65.8	50.7	35.4
Oil	0.1	0.0	0.4	0.6	0.4
Nuclear	0.0	1.9	14.4	24.7	15.6
Hydro	8.1	97.1	5.5	2.8	34.3
Wind	2.1	0.8	8.8	0.1	1.3
Biomass	4.2	0.2	1.5	1.7	1.2
Miscellaneous	0.0	0.0	0.3	0.3	0.2
Total	100	100	100	100	100

[1] Grid composition was developed from Ecoinvent high-voltage grid for Quebec.
[2] MRO is the electrical grid comprised of Manitoba, Minnesota, Nebraska, North Dakota, Saskatchewan and parts of Illinois, Michigan, South Dakota and Wisconsin.
[3] SERC is the electric grid comprised of Alabama, Georgia, Mississippi, North Carolina, South Carolina and parts of Arkansas, Florida, Illinois, Iowa, Kentucky, Louisiana, Missouri, Tennessee, Texas and Virginia.

Process heat requirements are 3.80 million Btu/MSF (3,400 GJ/m^3) of which 74.7 percent is generated through the combustion of natural gas, 15.3 percent from wood fuel, and 10.0 percent from coal (Table 6). Natural gas is the primary fuel used for providing direct heat for digesting, refining, drying wood residues and heating steam or oil for hot rolling. Steam is produced by burning wood fuel along with coal in a boiler to generate thermal energy. Wood fuel is primarily purchased bark (96%) as very little on-site wood residue (4% from culled boards) is available for use as fuel.

Table 6 On-site heat inputs per 1 m^3 cellulosic fiberboard, North American average (unallocated).

Fuel	Unit	Value (Unit/m^3)	HHV (MJ/kg)	MJ/m^3 of product	Percent of total energy (%)
Natural gas[1]	m^3	46.7	54.45	1,637	74.7
Wood fuel – purchased	kg	23.7	20.93	495	14.6
Coal	kg	13.0	26.19	342	10.0
Wood fuel – self-generated	kg	1.1	20.93	24	0.7
TOTAL	MJ	–	–	3,400	100

1/ Density of natural gas 0.70 kg/m^3.

CORRIM recently gathered U.S. boiler data from major wood producing facilities for on-site energy generation (Table 7) (Puettmann and Milota 2015). Regional differences in the United States were minor and therefore did not warrant developing separate boilers based on geographical regions. The CORRIM wood boiler process was used to model steam production from wood fuel. Both self-generated wood fuel (culled boards) and purchased wood fuel were used as inputs into the boiler for cellulosic fiberboard manufacturing.

Table 7 CORRIM Wood Boiler used in the production of cellulosic fiberboard (Puettmann and Milota 2015).

INPUTS/OUTPUTS			
Inputs – Materials and Fuels		**Value**	**Unit/m^3**
Culled boards, wood fuel, at cellulosic fiberboard plant, North America		4.00E-02	kg
Wood fuel, unspecified/RNA		9.60E-01	kg
Transport, combination truck, diesel powered/US, Athena		1.38E-03	tkm
Diesel, combusted in industrial equipment/US		8.05E-04	L
Gasoline, combusted in equipment/US		3.96E-05	L
Liquefied petroleum gas, combusted in industrial boiler/US		1.21E-05	L
Lubricants		1.91E-05	L
Engine oil		2.22E-05	L
Hydraulic oil		0.00E+00	L
Antifreeze		4.81E-07	L
Ethylene glycol, at plant/RNA		1.07E-06	kg
Solvents[4]		7.17E-07	kg
Water Treatment		1.23E-04	kg
Boiler streamline treatment		3.67E-06	kg
Urea, as N, at regional storehouse/RER U AWC		3.15E-03	kg
Disposal, ash, to unspecified landfill/kg/RNA		7.59E-03	kg
Disposal, solid waste, unspecified, to unspecified landfill/kg/RNA		7.26E-06	kg
Disposal, metal, to recycling/kg/RNA		3.96E-08	kg
Composite grid, North American cellulosic fiberboard		8.20E-02	kWh
Natural gas, combusted in industrial boiler/US		1.38E-03	m^3
Inputs - Water		**Value**	**Unit/m^3**
Water, process, surface		3.10E-01	kg
Water, process, well		2.40E-01	kg
Water, municipal, process, surface		7.90E-01	kg
Water, municipal, process, well		2.40E-01	kg
Outputs – Products and Co-Products		**Value**	**Unit/m^3**
CORRIM Wood Combusted, at boiler, at mill, kg, RNA		1.00E+00	kg
CORRIM Wood ash, at boiler, at mill, kg, RNA		2.00E-02	kg
Outputs - Emissions to air		**Value**	**Unit/m^3**
Acetaldehyde		1.05E-06	kg
Acrolein		8.07E-07	kg

[4] Solvents may contain substances listed on the US Environmental Agency (EPA) Toxics Release Inventory. US Environmental Protection Agency, Toxics Release Inventory. http://www.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals. Accessed January 2016

Benzene		1.69E-07	kg
Carbon monoxide, biogenic		3.23E-03	kg
Carbon dioxide, biogenic		1.76E+00	kg
Wood (dust)		5.62E-04	kg
Formaldehyde		1.26E-05	kg
HAPs		6.27E-06	kg
Hydrogen chloride		1.17E-06	kg
Lead		1.75E-07	kg
Mercury		1.83E-09	kg
Methane, biogenic		2.23E-05	kg
Methanol		7.95E-06	kg
Nitrogen oxides		1.10E-03	kg
Particulates, < 10 um		4.71E-04	kg
Particulates, < 2.5 um		1.39E-04	kg
Phenol		6.21E-07	kg
Propanal		5.14E-08	kg
Sulfur dioxide		7.71E-05	kg
VOC, volatile organic compounds		8.76E-04	kg
Dinitrogen monoxide		2.93E-06	kg
Naphthalene		5.77E-08	kg
Other Organic		2.11E-07	kg
Outputs - Emissions to water		**Value**	**Unit/m^3**
Suspended solids, unspecified		8.35E-07	kg
BOD5, Biological Oxygen Demand		2.10E-06	kg

2.6.3.12 Packaging

Packing materials represent less than 1.0 percent of the cumulative mass of the model flow. The material list was from mill survey data. The wooden spacers make up the bulk of this mass, representing 88.9 percent of the total packaging material (Table 8). The wrapping material, plastic strapping, strap protectors, and steel strapping made up, 5.2, 4.8, 0.7, and 0.3 percent of the packaging by mass, respectively.

Table 8 Materials used in packaging and shipping per m3 cellulosic fiberboard, North American average (unallocated).

Material	**Value kg/m^3**
Wrapping material – HDPE and LDPE laminated paper	0.0824
PET Strapping	0.0763
Cardboard strap protectors	0.0118
Steel strapping	0.0043
Wooden spacers	1.3942
Total	1.5690

3 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. Under Title III of the Clean Air Act Amendments of 1990, the EPA has designated HAPs that wood products facilities are required to report as surrogates for all HAPs. These are methanol, acetaldehyde, formaldehyde, propionaldehyde (propanal), acrolein, and phenol. All HAPS are included in the LCI, no cut off rules apply. If applicable to the wood product, HAPS are reported in Table 13 and would be included in the impact assessment. Table 13 shows all air emission to the 10^{-4} to simplify and report on the dominant releases by mass. There were no cut-offs used in the impact assessment therefore a complete list of all air emissions (smaller than 10^{-4}) is located in Appendix B of this report.

4 Data sourcing and averaging

The LCA for cellulosic fiberboard contains three life cycle stages: 1) Forest management and harvesting, 2) Wood residue production, and 3) Cellulosic fiberboard production. Primary and secondary data were used in all life cycle stages. This section provides a brief description of the primary and secondary data sources used to complete the LCA.

4.1 Primary and secondary data sources

Forest management and harvesting LCI data used in this study were derived from earlier studies on forest operations in the PNW, SE, and NE-NC U.S. regions and Canada (Johnson et al. 2005, Oneil et al. 2010, ASMI 2012). The data included a weighted average of various harvesting and forest management methods used in each forest types. The forestry systems from each of these regions were a weighted to represent a common forestry system for cellulosic fiberboard production (Table 9).

Wood residue production data used in this study were derived from CORRIM data using SE softwood lumber (Milota 2015), PNW softwood lumber production modified for Canadian electricity (Milota 2015), NE-NC hardwood lumber (Bergman and Bowe 2008a, 2008b) and SE hardwood lumber (Bergman and Bowe 2010, 2011) (Table 9).

Feedstock transportation for cellulosic fiberboard mills was by primary by road with some transportation by rail. The LCA incorporated an appropriate diesel tractor-trailer and diesel locomotive LCI from the US LCI database (https://www.lcacommons.gov/nrel/) based on transportation distances and mass of logs for each mill location. Table 9 list the secondary LCI data sources used in this LCA study.

Primary data on cellulosic fiberboard manufacturing was collected from mills in North America. The mills provided data for the 2012 production year. The participating facilities also provided information and data on the use of fuels, additives, energy consumption, electricity use, and ancillary inputs (e.g. lubricants, oils, greases, packaging, paints, etc.).

Table 9 Secondary LCI data sources used.

Process	LCI data Source	Publication date
Diesel truck	USLCI data for "Transport, combination truck, diesel powered/US"	2008
Diesel locomotive	USLCI data for "Transport, train, diesel powered/US"	2008
Electricity	USLCI data for "Electricity, at Grid, NPCC, 2008/RNA U"	2008
Forestry and Harvesting	CORRIM data for NE-NC hardwood forestry operation; CORRIM data for PNW softwood forestry operation; CORRIM data for SE softwood forestry operations	2005, 2010, updated 2013
Wood residue production	CORRIM data for PNW softwood lumber production modified for Canada electricity; CORRIM data for SE softwood lumber CORRIM data for NE-NC hardwood lumber CORRIM data for SE hardwood lumber	2015 2015 2010 2008
Hydraulic fluid, Lubricants, motor oil, thermal fluid	USLCI data for "Gasoline, at refinery/l/US" without combustion emissions.	2008
Propane	USLCI data for "Liquefied petroleum gas, combusted in industrial boiler/US". Combustion emission removed if mill reported emissions	2008
Gasoline	USLCI data for "Gasoline, combusted in equipment/US". Combustion emission removed if mill reported emissions	2008
Diesel	USLCI data for "Diesel, combusted in industrial equipment/US." Combustion emission removed if mill reported emissions	2008
Natural gas	USLCI data for "Natural gas, processed, at plant/US." Combustion emission removed if mill reported emissions	2008
Starch	Eco-Invent data for "potato starch, at plant/kg/DE"	2007
Slack Wax	CORRIM data for Slack wax obtained from the USLCI	2004
Plastic strapping/wrapping material	USLCI data for "Low density polyethylene resin, at plant/RNA"	2008
Metal strapping	USLCI data for "Hot rolled sheet, steel, at plant/RNA"	2008

4.2 Data quality requirements

This study collected data from representative cellulosic fiberboard manufacturers in North America that use average technology for their regions. Primary data for the LCI were collected through surveys in accordance with CORRIM and ISO 14040 standards. The production facilities surveyed were selected to be representative of North American production practices. In 2012 the cellulosic fiberboard production in North American was 702,386,273 ft^2 (65,253,820 m^2) at 0.50 in (12.7 mm) basis equaling 29,266,000 ft^3 (828,725 m^3) of uncoated cellulosic fiberboard. The mills that responded to the surveys produced 792,865 m^3 in 2012, representing 96 percent of total production in North American (NAFA 2013).

4.3 Assumptions and limitations

For recycled waste used as feedstock, including construction waste and mixed paper, no embodied energy from the first life was included in the analysis because if the material was not used it would have been landfilled. However transportation of the waste from its production site to the cellulosic fiberboard facility was included to reflect the additional energy footprint that belongs to fiberboard production.

5 Life-cycle inventory analysis

5.1 Data collection and calculations methods

A statistically significant sampling frame is required to attain valid results that can be generalized to the cellulosic fiberboard industry. CORRIM (2014) protocol targets a minimum of 20 to 50 percent of total production. Because there are only a few cellulosic fiberboard manufacturers, this study could realistically attain these levels by requesting participation and cooperation from the eight plants operated by North American Fiberboard Association (NAFA) members. In 2012, three of the eight North American mills are located in Canada and the other five in the United States. There were no operating cellulosic fiberboard plants in Mexico at the time of data collection, 2012–2013.

Cellulosic fiberboard is most commonly reported in a thousand square foot (MSF) of 0.5-inch basis, which is equivalent to 1.18 m^3. The survey results were converted to a unit production basis, 1 MSF (0.5-inch basis) and a weighted average of input data was calculated based on production of the seven surveyed production plants. This approach resulted in a cellulosic fiberboard complex that represents a composite of the North American mills surveyed, but may not represent any mill in particular. The U.S. LCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 8.0.4.30 (Pré Consultants 2014) was used as the accounting program to track all of the materials and fuels.

Questionnaires were used to collect primary data on cellulosic fiberboard manufacturing (Bergman 2015). The primary data obtained from the surveys were weight-averaged using the formula shown below (Milota 2015):

$$\bar{P}_{w} = \frac{\sum_{i=1}^{n} P_i x_i}{\sum_{i=1}^{n} x_i}$$

Where $\bar{P}_w$ the weighted average of the values reported by the mills, P_i is the reported mill value, and x_i is the fraction of the mill's value to total production of the surveyed mills for that specific value.

Because the surveyed mill data varied between facilities, a statistical analysis was conducted. In the present study, the coefficient of variation (CoV) was calculated (NIST ITL 1996). The coefficient of variation (CoV) is the standard deviation (*sd*) divided by the weighted mean ($\bar{P}_w$):

$$sd = \sqrt{\frac{\sum_{i=1}^{N}(P_i - \bar{P})^2}{N-1}}$$

$$CoV = \frac{sd}{\bar{P}_w}$$

Where N is the number of non-zero weights, P_i is the value of the individual observation, and P_w is the weighted mean of the observations.

Missing data is defined as data not reported in surveys by the cellulosic fiberboard facilities. Whenever missing data occurred for survey items, they were checked with facility 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.

The mass balance for cellulosic fiberboard is shown in Table 10. The final product, uncoated cellulosic fiberboard, has an average oven-dry density of 254 kg/m^3 representing 96.1 percent wood fiber and 3.9 percent additives. On a mass basis, green pulp chips are the dominant inputs at 87 OD kg, (32.9 %) followed by roundwood chips at 40 OD kg (15.0%). Unaccounted wood mass between input and output material flows were found to be 0.6 percent (Table 10). Coefficient of variance (CoV) provides a statistical analysis of primary data collected from manufacturers. For cellulosic fiberboard, the feedstock and additives have the most variance given that the individual production plants use many different feedstock types and additives to produce the final product. Some feedstock types are only used by a single facility which is noted by '-' for CoV. One important note is that total inputs and outputs have low CoV values of 13.7% and 12.9%, respectively. These two values point to high-quality data representation from the seven surveyed mills as the inputs and outputs converge well.

Table 10 Mass balance of cellulosic fiberboard manufacturing per m^3, North America (unallocated).

	Inputs		
Feedstock	**Oven dry mass (kg)**	**Mass (%)**	**CoV[1] (%)**
Pulp chips, green	87	32.9	134
Roundwood chips	40	15	–
Construction waste	31	11.8	204
Shavings, dry	30	11.3	–
Pulp chips, dry	26	10	–
Roundwood	23	8.8	–
Mixed paper	5	1.9	153
Sawdust, dry	1	0.2	–
Back to pulper	1	0.3	–
TOTAL, FEEDSTOCK	**244**	**92.1**	**14.7**
Additives			
Asphalt flake	10.0	3.9	97.7
Starch	4.0	1.5	148
Wax	2.9	1.1	94.1
Clay	1.6	0.6	204
Alum	1.5	0.6	122
Carbon black	0.4	0.2	216
Sodium aluminate	0.15	0.1	–
Other	0.02	0	–
TOTAL, ADDITIVES	**21**	**7.9**	**49.7**
TOTAL, INPUTs	**265**	**100**	**13.7**
	Outputs		
Products	**Oven dry mass (kg)**	**Mass (%)**	**CoV[1] (%)**
Cellulosic fiberboard	254	96.1	11.6

Co-products			
Culled boards, wood fuel	1.1	0.4	–
Molasses	5.8	2.2	–
Pins and fines	1.9	0.7	–
Other, not specified	1.5	0.6	–
TOTAL, CO-PRODUCTS	**11**	**3.9**	**205**
TOTAL, OUTPUTS	**265**	**100**	**12.9**

[1] Coefficient of variation.

5.2 Allocation rules

If one or more co-products are generated during the production process, it is necessary to allocate the inputs and outputs using a standardized approach. The LCA on cellulosic fiberboard follows the allocation rules in the PCR (FPInnovations 2015) which states that when the total revenues between the main product and co-products is more than 10%, allocation shall be based on the revenue [economic] allocation. The 10% rule is applied based on a per unit basis, in this case per m^3 of cellulosic fiberboard. To ensure comparability with previous CORRIM wood product LCAs (http://www.corrim.org/pubs/reports.asp), this report also presents results based on mass allocation. Mass allocation results can be found in the subsequent sections of this report, while economic allocation results are located in Appendix A- Section 12 of this report.

5.3 Gate-to-gate LCI of cellulosic fiberboard manufacturing system

Table 11 summarizes the gate to gate LCI flows associated with North American cellulosic fiberboard production. These flows are linked to the upstream processes for forestry operations, feedstock production, transportation, fuels, and electricity to calculate a CtG profile for cellulosic fiberboard. Under materials, wood feedstock include wood material arriving at the production facilities either in roundwood form or fully or partially broken down into wood residues. Incoming roundwood makes up 9.5 percent of the total feedstock. Electricity consumed onsite was calculated to be 205 kWh/m^3. Cellulosic fiberboard manufacturing intakes 2,526 L of water on-site to produce 1 m^3 of uncoated cellulosic fiberboard but recycles 63% for a total consumption of 931 L/m^3.

Table 11 Unit process inputs/outputs to produce 1 m^3 of cellulosic fiberboard, North American average (unallocated).

Inputs/Outputs			
Inputs – Materials and Fuels	**Value**	**Unit/m^3**	
Wood feedstock, average North America	183.70	kg	
Wood feedstock, average North America, roundwood	23.17	kg	
Recycled waste, average North America	36.98	kg	
Starch, 100% solids	3.99	kg	
Asphalt flake	10.21	kg	
Wax	2.94	kg	
Clay	1.57	kg	
Alum	1.48	kg	
Carbon black	0.44	kg	
Sodium aluminate	0.15	kg	
Other	0.02	kg	
Electricity, at grid	205.00	kWh	
Diesel, combusted in industrial equipment	0.53	L	
Gasoline, combusted in equipment	0.34	L	
Hydraulic fluid	0.03	kg	
Oils and grease	0.0033	kg	

Lubricant and oil	0.03	kg	
Marking paint and ink	0.03	kg	
LPG, combusted in industrial equipment	1.09	L	
Natural gas, combusted in industrial boiler, direct-fired	46.66	m^3	
CORRIM Wood Boiler	24.84	kg	
Anthracite coal, combusted in industrial boiler	13.04	kg	
Transport, combination truck, diesel power, wood feedstock	16.66	tkm	
Transport, combination truck, diesel powered, starch	2.66	tkm	
Transport, combination truck, diesel powered, asphalt flake	2.76	tkm	
Transport, combination truck, diesel powered, wax	1.05	tkm	
Transport, combination truck, diesel powered, clay	2.04	tkm	
Transport, combination truck, diesel powered, alum	0.20	tkm	
Transport, train, diesel powered, coal	0.23	tkm	
Wrapping material – packaging	0.46	kg	
Strap protectors – packaging	0.20	kg	
Strapping – packaging	0.08	kg	
Spacers – packaging	1.39	kg	
Inputs - Water	**Value**	**Unit/m^3**	
Water, well, in ground	1,230.00	L	
Water, cooling, surface	943.00	L	
Water, process, surface	353.00	L	
Outputs – Products and Co-Products	**Value**	**Unit/m^3**	**Mass Allocation %**
Cellulosic fiberboard	1.00	m^3	96.1
Culled boards, wood fuel	1.10	kg	0.4
Molasses	5.80	kg	2.2
Pins and fines	1.90	kg	0.7
Other, not specified	1.50	kg	0.6
Outputs - Emissions to air	**Value**	**Unit/m^3**	
VOC, volatile organic compounds	0.21000	kg	
Acetaldehyde	0.01990	kg	
Acetone	0.00964	kg	
Acrolein	0.00705	kg	
Alpha-Pinene	0.11000	kg	
Benzene	0.00088	kg	
Carbon monoxide	0.04090	kg	
Cumene	0.00519	kg	
Formaldehyde	0.01640	kg	
Lead	0.00003	kg	
Limonene	0.00763	kg	
Methanol	0.06240	kg	
Methyl ethyl ketone	0.00202	kg	
Dinitrogen monoxide (N2O)	0.04870	kg	
Particulates, < 2.5 um	0.04460	kg	
Particulates, > 2.5 um, and < 10um	0.12800	kg	
Particulates, < 10 um	0.17200	kg	
Particulates, unspecified	0.15100	kg	
Phenol	0.00393	kg	
Propanal	0.01400	kg	
Sulfur dioxide	0.00028	kg	
Toluene	0.00111	kg	

Outputs - Emissions to water	Value	Unit/m³	
BOD5, Biological Oxygen Demand	0.2712	kg	
COD, Chemical Oxygen Demand	0.2029	kg	
Oils, unspecified	0.0152	kg	
Solved solids	1.1130	kg	
Suspended solids, unspecified	0.223	kg	
Outputs - Waste to treatment	**Value**	**Unit/m³**	
Waste to inert landfill	5.63	kg	
Waste to recycling	8.83	kg	

5.4 Cradle-to-gate LCI results

Life-cycle inventory results for cellulosic fiberboard are presented by three life cycle stages, 1) forestry operations, 2) wood residue production, and 3) cellulosic fiberboard production (Table 12 - Table 15). The majority of the raw material consumption used for energy production occurs during cellulosic fiber manufacturing, followed by the production of the wood residue with only a very small portion arising from forestry operations. Table 12 shows the raw material consumption of energy inputs per m^3 of cellulosic fiberboard. Highest consumption rates are for coal with all processes consuming a total of 62.2 kg/m^3. Coal is used for on-site thermal energy and off-site electricity production. Natural gas at 41.6 kg/m^3 was used onsite primarily for drying of mats during cellulosic fiberboard production, and off site for electricity generation. Wood fuel usage represented 32 percent of primary energy mass and was used in wood residue production (14.93%) and cellulosic fiberboard production (85.07%). Sixty one percent of the residues used in cellulosic fiberboard were obtained from green residues generated during lumber manufacturing. Drying the feedstock was not necessary for making cellulosic fiberboard but fell within the system boundary and thus needed to be taken into account.

Table 12 Raw material consumption for energy production per 1 m^3 of cellulosic fiberboard, North American average (mass allocation).

Fuel	Total	Forestry operations	Wood residue production	Cellulosic fiberboard Production
	(kg/m³)			
Coal, in ground	62.1588	0.0552	3.9855	58.1180
Gas, natural, in ground	41.5525	0.1534	1.2650	40.1340
Oil, crude, in ground	10.5371	0.8715	2.7564	6.9091
Uranium oxide, in ore	0.0012	0.0000	0.0001	0.0011
Wood fuel	54.5994	0.0000	8.1522	46.4472

Table 13 lists the CtG air emissions generated as a result of cellulosic fiberboard production. Cellulosic fiberboard manufacturing generates air emissions including particulate and particulate PM_{10} (less than 10 µm in size) during refining, drying, and trimming. Other air emissions include VOCs from drying and pressing. Recorded emissions of formaldehyde and methanol are used as a measure of the amount of Hazardous Air Pollutants (HAPs). Mills reported acetaldehyde, acrolein, formaldehyde, methanol, phenol, propionaldehyde (or propanal), and VOCs as a measure of HAPs released.

Table 13 Air emissions released per 1 m^3 of cellulosic fiberboard, North American average (mass allocation).

Air Emissions[1]	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
Acetaldehyde	0.0207	0.0000	0.0015	0.0192
Acetone	0.0093	0.0000	0.0000	0.0093
Acrolein	0.0069	0.0000	0.0001	0.0068
Aldehydes, unspecified	0.0003	0.0000	0.0001	0.0001
alpha-Pinene	0.1064	0.0000	0.0003	0.1061
Ammonia	0.0064	0.0001	0.0002	0.0060
Benzene	0.0024	0.0000	0.0000	0.0023
Biphenyl	0.0002	0.0000	0.0000	0.0002
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0146	0.0001	0.0004	0.0141
Carbon dioxide	2.1979	0.0866	0.0664	2.0449
Carbon dioxide, biogenic	58.3915	0.0024	14.4408	43.9483
Carbon dioxide, fossil	257.6714	2.8573	19.7007	235.1134
Carbon monoxide	0.0489	0.0000	0.0042	0.0447
Carbon monoxide, biogenic	0.1025	0.0000	0.0258	0.0767
Carbon monoxide, fossil	0.3062	0.0260	0.0611	0.2190
Chlorothalonil	0.0006	0.0000	0.0000	0.0006
Chromium	0.0001	0.0000	0.0000	0.0001
Cumene	0.0050	0.0000	0.0000	0.0050
Dinitrogen monoxide	0.0523	0.0005	0.0007	0.0511
Dipropylthiocarbamic acid S-ethyl ester	0.0002	0.0000	0.0000	0.0002
Formaldehyde	0.0166	0.0000	0.0002	0.0163
HAPs	0.0002	0.0000	0.0001	0.0001
Hydrocarbons, unspecified	0.0124	0.0000	0.0001	0.0123
Hydrogen chloride	0.0218	0.0000	0.0020	0.0197
Hydrogen fluoride	0.0103	0.0000	0.0003	0.0100
Isoprene	0.0593	0.0001	0.0066	0.0526
Limonene	0.0074	0.0000	0.0000	0.0074
Magnesium	0.0002	0.0000	0.0000	0.0002
Mancozeb	0.0005	0.0000	0.0000	0.0005
Metam-sodium dihydrate	0.0028	0.0000	0.0000	0.0028
Methane	0.7157	0.0052	0.0390	0.6716
Methane, biogenic	0.0007	0.0000	0.0002	0.0005
Methane, fossil	0.0846	0.0005	0.0030	0.0811
Methanol	0.0617	0.0000	0.0013	0.0604
Methyl ethyl ketone	0.0020	0.0000	0.0000	0.0019
Naphthalene	0.0010	0.0000	0.0000	0.0010
Nickel	0.0001	0.0000	0.0000	0.0001
Nitrogen oxides	0.7561	0.0513	0.1242	0.5806
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0181	0.0017	0.0064	0.0100
N-Nitrodimethylamine	0.0014	0.0000	0.0000	0.0014
Organic substances, unspecified	0.0006	0.0000	0.0004	0.0002
Particulates, < 10 um	0.1817	0.0000	0.0046	0.1771
Particulates, < 2.5 um	0.0496	0.0000	0.0028	0.0468
Particulates, > 10 um	0.0050	0.0000	0.0049	0.0001
Particulates, > 2.5 um, and < 10um	0.1473	0.0016	0.0031	0.1426
Particulates, unspecified	0.2916	0.0003	0.0071	0.2842
Phenol	0.0038	0.0000	0.0000	0.0038
Phorate	0.0001	0.0000	0.0000	0.0001
Propanal	0.0136	0.0000	0.0001	0.0135
Propene	0.0001	0.0000	0.0000	0.0000

Air Emissions[1]	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
Propene, 1,3-dichloro-	0.0014	0.0000	0.0000	0.0014
Radionuclides (Including Radon)	0.0017	0.0000	0.0001	0.0015
Sulfur dioxide	2.3130	0.0050	0.0867	2.2214
Sulfur monoxide	0.0231	0.0029	0.0066	0.0136
Sulfur oxides	0.0035	0.0000	0.0031	0.0004
Toluene	0.0011	0.0000	0.0000	0.0011
VOC, volatile organic compounds	0.2924	0.0015	0.0241	0.2668
Wood (dust)	0.0208	0.0000	0.0074	0.0134

[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 Appendix B of this report
[2] Non-methane volatile organic compounds, unspecified origin.

Most of the waterborne emissions reported by cellulosic fiberboard manufacturers are produced on-site as shown in Table 14. For unspecified suspended solids to water, a value of 13.7 kg/m^3 of cellulosic fiberboard was estimated. Most of unspecified suspended solids emissions were from the process of extracting natural gas from the ground and thus did not occur at the production facilities.

Table 14 Emissions to water released per 1 m^3 of cellulosic fiberboard, North American average (mass allocation).

Water emissions	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
Aluminium	0.0063	0.0003	0.0010	0.0050
Ammonia	0.0028	0.0001	0.0003	0.0025
Barium	0.0852	0.0040	0.0134	0.0677
Benzene	0.0004	0.0000	0.0000	0.0003
Benzoic acid	0.0002	0.0000	0.0000	0.0002
BOD5, Biological Oxygen Demand	0.3012	0.0007	0.0042	0.2962
Boron	0.0007	0.0000	0.0000	0.0006
Bromide	0.0458	0.0008	0.0033	0.0417
Calcium	0.6824	0.0122	0.0452	0.6250
Calcium, ion	0.0041	0.0000	0.0041	0.0000
Chloride	7.7158	0.1370	0.5541	7.0248
COD, Chemical Oxygen Demand	0.2615	0.0013	0.0060	0.2542
Detergent, oil	0.0002	0.0000	0.0000	0.0002
Fluoride	0.0044	0.0025	0.0016	0.0002
Iron	0.0169	0.0006	0.0021	0.0142
Lithium	0.2003	0.0007	0.0049	0.1947
Lithium, ion	0.0013	0.0000	0.0013	0.0000
Magnesium	0.1342	0.0024	0.0096	0.1222
Manganese	0.0008	0.0000	0.0000	0.0007
Metam-sodium dihydrate	0.0002	0.0000	0.0000	0.0002
Nitrogen, total	0.0112	0.0000	0.0000	0.0111
Oils, unspecified	0.0191	0.0001	0.0004	0.0186
Phosphate	0.0031	0.0019	0.0012	0.0000
Phosphorus compounds, unspecified	0.0004	0.0000	0.0000	0.0004
Silver	0.0004	0.0000	0.0000	0.0004
Sodium	2.1630	0.0386	0.1432	1.9812
Sodium, ion	0.0131	0.0000	0.0131	0.0000
Solved solids	0.0574	0.0000	0.0574	0.0000
Strontium	0.0116	0.0002	0.0008	0.0106

Water emissions	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
Sulfate	0.0426	0.0003	0.0033	0.0390
Sulfur	0.0006	0.0000	0.0000	0.0005
Suspended solids, unspecified	13.7123	0.1779	0.6704	12.8640
Toluene	0.0003	0.0000	0.0000	0.0003
Waste water/m3	0.0008	0.0000	0.0001	0.0007
Xylene	0.0002	0.0000	0.0000	0.0002
Zinc	0.0002	0.0000	0.0000	0.0001

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 Appendix B of this report.

Solid emissions generated onsite during cellulosic fiberboard manufacturing includes ash generated at the boiler. Other waste generated is a result of upstream processes, primarily fuels and resins, used in cellulosic fiberboard production (Table 15). A total of 13.93 kg/m^3 waste was generated onsite with 55 percent going to the landfill and the remaining portion being recycled (Bergman 2015). A total of 55.90 kg of solid waste was generated from cradle-to-gate for the production of 1 m^3 cellulosic fiberboard, includes all upstream and secondary LCI processes, of that 97 percent was generated during the cellulosic fiberboard production or generated by an upstream processes used during the production process.

Table 15 Waste to treatment per 1 m^3 of cellulosic fiberboard, North American average (mass allocation).

Waste to treatment	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
Waste generated onsite	13.93	0.00	0.00	13.93
Waste disposal	41.97	0.05	1.57	40.35
Total waste	55.90	0.05	1.57	54.28

6 Life-cycle impact assessment results

The life cycle impact assessment (LCIA) phase establishes links between the life cycle inventory results and potential environmental impacts. The LCIA calculates impact indicators, such as global warming potential and smog. These impact indicators provide general, but quantifiable, indications of potential environmental impacts. The target impact indicator, the impact category, and means of characterizing the impacts are summarized in Table 16. Environmental impacts are determined using the TRACI method (Bare et al. 2011). These five impact categories are reported consistent with the requirement of the wood products PCR (FPInnovations 2015).

Table 16 Selected impact indicators, characterization models, and impact categories.

Impact Indicator	Characterization Model	Impact Category
Greenhouse gas (GHG) emissions	Calculate total emissions in the reference unit of CO_2 equivalents for CO_2, methane, and nitrous oxide.	Global warming
Releases to air decreasing or thinning of ozone layer	Calculate the total ozone forming chemicals in the stratosphere including CFC's HCFC's, chlorine, and bromine. Ozone depletion values are measured in the reference units of CFC equivalents.	Ozone depletion
Releases to air potentially resulting in acid rain (acidification)	Calculate total hydrogen ion (SO_2) equivalent for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of SO_2 mole-eq. is used as a reference unit.	Acidification
Releases to air potentially resulting in smog	Calculate total substances that can be photo-chemically oxidized. Smog forming potential of O_3 is used as a reference unit.	Photochemical smog
Releases to air potentially resulting in eutrophication of water bodies	Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq. is used as a reference unit.	Eutrophication

Each impact indicator is a measure of an aspect of a potential impact. This LCIA does not make value judgments about the impact indicators, meaning that no single indicator is given more or less value than any of the others. All are presented as equals. Additionally, each impact indicator value is stated in units that are not comparable to others. For the same reasons, indicators should not be combined or added.

Table 17 provides the environmental impact by category for cellulosic fiberboard. In addition, energy and material resource consumption values and the waste generated are also provided.

Table 17 Environmental performance of 1 m^3 cellulosic fiberboard, North American average (mass allocation).

Impact category	Unit	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
Global warming potential (GWP)	kg CO_2 eq	295.49	3.24	21.03	271.22
Acidification Potential	kg SO_2 eq	2.92	0.04	0.19	2.69
Eutrophication Potential	kg N eq	0.08	0.01	0.01	0.06
Ozone depletion Potential	kg CFC-11 eq	0.000	0.0000	0.0000	0.0000
Smog Potential	kg O_3 eq	21.44	1.28	3.25	16.91
Total Primary Energy	MJ	6,273.84	50.08	534.2	5,689.56
Non-renewable fossil	*MJ*	*4,398.52*	49.53	312.13	4,036.86
Non-renewable nuclear	*MJ*	*445.65*	0.49	36.11	409.05
Renewable (solar, wind, hydroelectric, and geothermal)	*MJ*	*286.64*	0.06	15.28	271.30
Renewable, biomass	*MJ*	*1143.03*	0.00	170.68	972.35
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Non-renewable materials	kg	0.3165	0.0000	0.0114	0.3051
Renewable materials	kg	343.46	186.19	155.90	1.37
Fresh water	L	3707.33	0.63	53.04	3653.66
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Solid waste	kg	55.9	0.05	1.57	54.28

Environmental performance results for global warming potential (GWP), acidification, eutrophication, ozone depletion and smog, energy consumption from non-renewables, renewables, wind, hydro, solar, and nuclear fuels, renewable and nonrenewable resources, and solid waste are shown in Table 17. For GWP, 92 percent of the CO_2 eq. emissions come from producing cellulosic fiberboard. Similar results are presented for acidification, eutrophication, and smog, representing 92, 78, and 79 percent contributed from cellulosic fiberboard production, respectively.

Non-renewable fuels represented the greatest proportion of energy consumed (77%) for total CtG primary energy use. Renewable biomass fuels and non-renewable nuclear represented 18 and 7 percent of the total primary energy, respectively. Of the three life cycle stages considered in this study, cellulosic fiberboard production consumes 91 percent of the total primary energy consumption. Overall, the manufacture of cellulosic fiberboard in North America is 18 percent energy self-sufficient with its use of renewable biomass. By the nature of the production process, self-producing wood fuel would be difficult to obtain onsite; therefore, to increase the use of renewable biomass onsite would be limited to purchasing wood fuel from other wood production industries or utilization of whole logs not suitable for lumber or plywood production.

Water intake is high for the cradle-to-gate production of cellulosic fiberboard at 3,707 L/m^3 but much more lower than a previous reported value, 22,700 L/m^3 (Suchsland and Woodson 1986). In addition, the water intake value did not consider the water recycling efforts that now are at 63% at the cellulosic fiberboard facilities. It is clear, based on previous published water use, that water conservation measures currently in place in North American cellulosic fiberboard facilities have made a dramatic impact in the reduction of water consumption.

7 Carbon

Treatment of biogenic carbon is consistent with the Intergovernmental Panel for Climate Change (IPCC 2006) inventory reporting framework. 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, 296 kg CO_2e were released in the production of 1 m^3 of cellulosic fiberboard. That same 1 m^3 of cellulosic fiberboard stores 122 kg of carbon[5] or 447 kg CO_2 eq.[6], resulting in more carbon storage in the product then released during manufacturing (cradle to gate) (Table 18)

Table 18 Carbon per 1 m^3 cellulosic fiberboard, North American average (mass allocation).

	kg CO_2 equivalent
released forestry operations	3.24
released cellulosic fiberboard and residue manufacturing	292.25
CO_2 eq. stored in product[7]	447.33

8 Life Cycle Interpretation

As defined by ISO (2006), the term life cycle interpretation is the phase of the LCA that the findings of either the LCI or the LCIA, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations. This phase in the LCA reports the significant issues based on the results of the presented in LCI and the LCIA of this report. Additional components report an evaluation that considers completeness, sensitivity and consistency checks of the LCI and LCIA results, and conclusions, limitations, and recommendations.

8.1 Identification of the significant issues

The objective of this element is to structure the results from the LCI or the LCIA phases in order to help determine the significant issues found in the results and presented in previous sections of this report. A contribution analysis was applied for the interpretation phase of this LCA study. Contribution analysis

[5] Assuming a 50% carbon content

[6] 244 OD kg of wood in cellulosic fiberboard × (0.5 kg carbon/1.0 OD kg wood) × (44 kg CO_2/kmole/12 kg carbon/kmole) = 477.33 kg CO_2 eq.

[7] Assuming 44/12 molecular weight ratio of CO_2/C

examines the contribution of life cycles stages, unit process contributions in a multi-unit manufacturing process, or specific substances which contribute particular impact categories.

8.2 Life cycle phase contribution analysis

Three life cycle stages were used in the overall CtG assessment of cellulosic fiberboard. Their contribution to impact categories varied depending on whether mass or economic allocation was applied. Table 19 shows the contribution difference to several impact measures for both mass and economic allocation. Economic allocation resulted in a slight increase in the cellulosic fiberboard life cycle stage due to all burdens shifted towards the production of cellulosic fiberboard and zero percent to coproducts. Production of the wood residues had the most significant influence on impact measures depending on the allocation methods applied. Applying an economic allocation resulted in nearly 50 percent decrease in all impact categories and energy consumption for residue production. With the slight increase in cellulosic fiberboard and decrease in residue, the overall CtG production resulted in less than a 5% difference between economic and mass allocation methods overall impact measurements.

Table 19 Life cycle stages contribution analysis of 1 cubic meter (m3) of cellulosic fiberboard (mass and economic allocation)

		Mass Allocation			Economic Allocation		
Impact category	**Unit**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Ozone depletion	kg CFC-11 eq	3.5%	14.1%	82.3%	3.7%	6.5%	89.8%
Global warming	kg CO2 eq	1.1%	7.1%	91.8%	1.1%	3.6%	95.3%
Smog	kg O3 eq	6.0%	15.2%	78.9%	6.2%	8.8%	85.0%
Acidification	kg SO2 eq	1.5%	6.4%	92.1%	1.5%	3.1%	95.4%
Eutrophication	kg N eq	9.6%	12.7%	77.7%	9.7%	8.8%	81.5%
Primary Energy	**Unit**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Total	MJ	0.8%	8.5%	90.7%	0.8%	3.2%	96.0%
Non-renewable fossil	*MJ*	1.1%	7.1%	91.8%	1.1%	3.7%	95.2%
Non-renewable nuclear	*MJ*	0.1%	8.1%	91.8%	0.1%	4.1%	95.8%
Renewable (solar, wind, hydroelectric, and geothermal)	*MJ*	0.0%	5.3%	94.7%	0.0%	1.0%	99.0%
Renewable, biomass	*MJ*	0.0%	14.9%	85.1%	0.0%	3.0%	97.0%
Material resources consumption (Non-fuel resources)	**Unit**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Non-renewable materials	kg	0.0%	3.6%	96.4%	0.0%	0.4%	99.6%
Renewable materials	kg	54.2%	45.4%	0.4%	55.9%	43.7%	0.4%
Fresh water	L	0.0%	1.4%	98.6%	0.0%	0.2%	99.8%
Waste generated	**Unit**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Solid waste	kg	0.1%	2.8%	97.1%	0.1%	1.1%	98.8%

8.3 Substance contribution analysis

The impact indicators presented in the LCIA results (Table 17) in this report do not show how each of the substance releases (Table 13) within each of the life cycle stages contributes to individual impact indicators. Highlighting particular substances can result in a more focused approach to making process improvements therefore saving time and money. Table 20 lists the level of contribution of the 3 main GHG emissions (fossil CO_2, CH_3, and N_2O) to global warming potential (GWP) of the three life cycle stages for cellulosic fiberboard manufacturing. To produce cellulosic fiberboard production, no minor GHG emissions contributed to GWP. Both mass and economic allocation results are presented.

Table 20. Substance contribution[1/] analysis to Global Warming Potential (kg CO_2 eq.) by life cycle stage total percent basis and values are displayed per 1.0 m^3.

		Mass Allocation				Economic Allocation			
GWP substances	Compartment type	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production
Total of all compartments		**100.00%**	3.24	21.03	271.22	**100.00%**	3.24	10.63	281.23
Carbon dioxide, fossil (CO_2)	Air	**87.94%**	2.94	19.77	237.16	**87.73%**	2.94	10.04	245.91
Methane (CH_4)	Air	**6.78%**	0.14	1.05	18.83	**6.82%**	0.14	0.47	19.52
Dinitrogen monoxide (N_2O)	Air	**5.28%**	0.15	0.21	15.23	**5.45%**	0.15	0.12	15.80
Remaining substances	Air	**0.00%**	0.00	0.00	0.00	**0.00%**	0.00	0.00	0.00

1/ additional substance contributions for other impact categories can be found in Appendix C of this report

8.4 Completeness, sensitivity and consistency checks

Evaluating the LCA's completeness, sensitivity, and consistency offers confidence in and the reliability of the LCA results. The ***completeness check*** process verifies whether information from the life cycle phases of a LCA are sufficient for reaching the goals and scope and conclusions of the study and making sound interpretations of the results. Three life cycle stages (forestry operations, wood residue production, and cellulosic fiberboard production) were checked for data completeness including all input elements such as raw and ancillary materials input, energy input, transportation scenarios, water consumption, and outputs such as products and coproducts, emissions to air, water, land, and final waste disposals. All input and output data were found to be complete and no data gaps were identified.

Consistency check process verifies that the assumptions, methods and data are consistently applied throughout the study and are in accordance with the goal and scope of the LCA. A comprehensive review process was completed to this LCA to make certain consistency was applied to the assumptions made, methods used, models, data quality including data sources, and data accuracy, age, time-related coverage, technology, and geographical coverage.

Sensitivity analysis can be applied to the LCA to determine changes in results due to variations in assumptions, methods, and data. A sensitivity check was performed on this LCA contrasting the mass and economic allocation methods. This LCA used mass allocation method, similar to previous LCA's on wood products. To stay within conformance with the updated PCR (2015), an economic allocation was required on the data. Cellulosic fiberboard is primarily a single-output product (96.1% by mass) with approximately 3.2% coproduct leaving the system, and the remaining 0.6% re-entering the system as a fuel source. For the economic allocation methods, no allocation was applied to the cellulosic fiberboard production process. Most of the wood residue inputs to cellulosic fiberboard production, however, are the coproducts of hardwood and softwood lumber manufacturing. Lumber production results in multiple valuable products, such as green rough lumber, planed green and dry lumber and several variety of co-products (i.e. pulp chips, sawdust, shavings). When either mass or economic allocation is applied, the total environmental burden is "shared" between the primary product (lumber) and the co-products (chips, etc.) based on total mass or total value (sales) respectively. In this LCA, wood residue values were based on prices published in Random Lengths (2012) for the year data were collected from cellulosic fiberboard manufacturers. Figures 6 and 7 graphically display the two allocation methods side by side across impact indicators for cellulosic fiberboard and wood residue production, respectively. It is apparent that the allocation method does have an influence on certain impact indicators and is highly dependent on the life cycle stage. Overall differences in indicator totals had little influence on final results (Figure 6), while economic allocation significantly decreased the contribution of wood residue production over mass allocation for 5 of the 9 impact indicators (Figure 7). This decrease in contribution from wood residue production occurred because when economic allocation was assigned lumber contributed far more of the environmental impacts than the coproducts did versus mass allocation. Table 25 (Appendix A, Section

12) summarizes the LCIA results for the cradle-to-gate cellulosic fiberboard with no allocation applied to cellulosic fiberboard and an economic allocation applied to the wood residue cradle-to-gate product system.

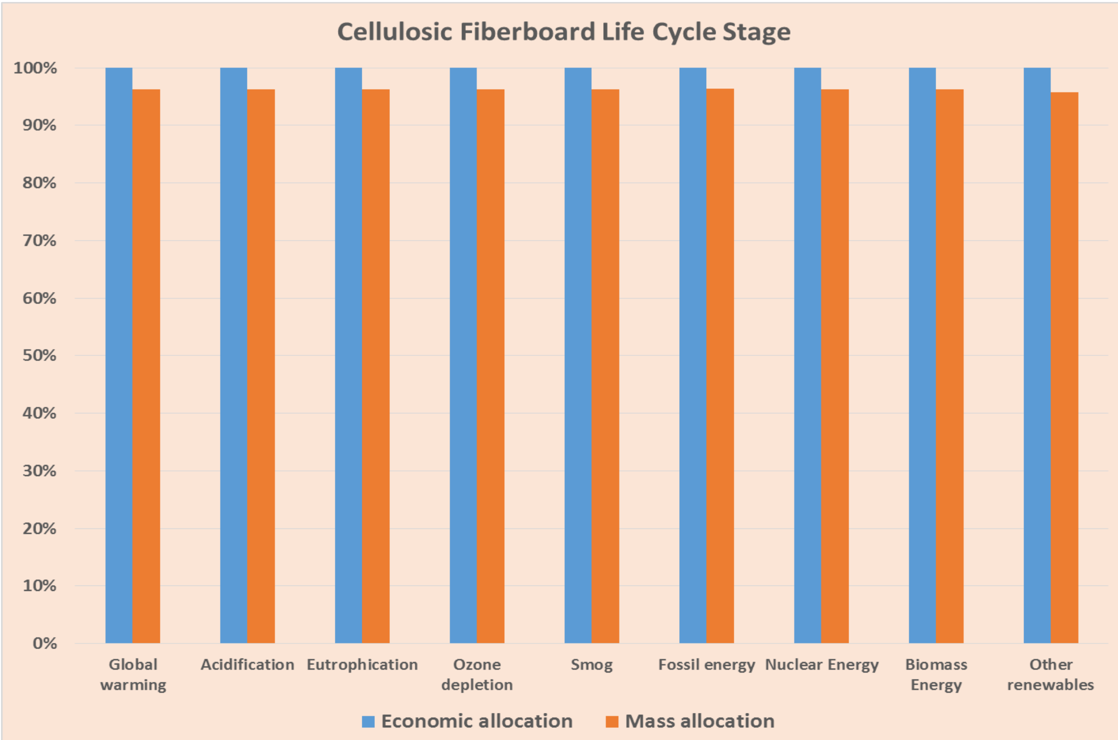

Figure 6 Sensitivity analysis for the gate-to-gate cellulosic fiberboard life cycle stage comparison between mass and economic allocation methods.

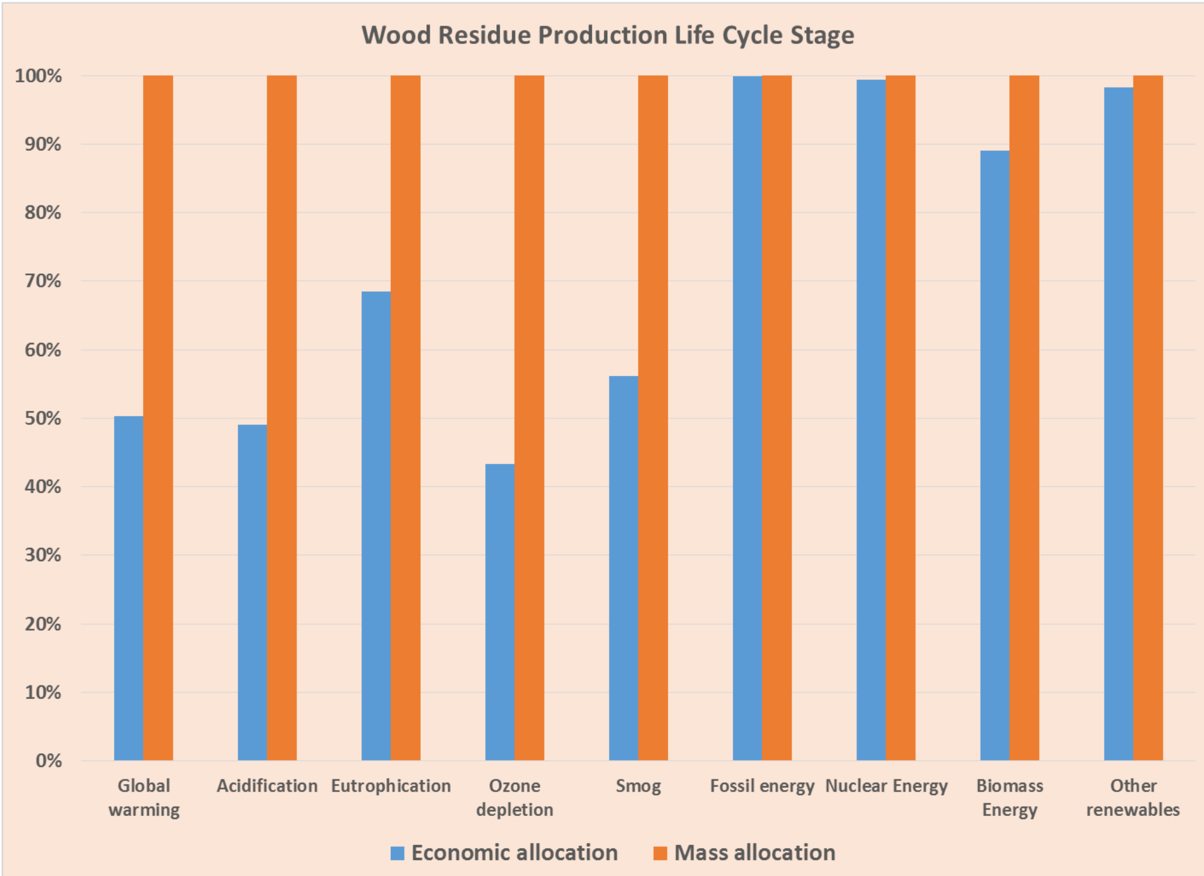

Figure 7 Sensitivity analysis for the gate-to-gate wood residue life cycle stage comparison between mass and economic allocation methods

9 Conclusions, limitations, and recommendations

This study provides a comprehensive cradle-to-gate LCA of North American cellulosic fiberboard production. The goal of this study was to develop a LCIA from a previous published LCI report (Bergman 2015) on cellulosic fiberboard that could be used to develop an EPD in accordance with the Wood PCR standards (FPInnovations 2015). In additions to the previous published LCI (Bergman 2015), this report used updated data for residue production originating from the PNW (modified for Canadian electricity) and SE. This LCA incorporates the necessary scope to develop a "business-to-business" EPD in accordance with the Wood PCR (FPInnovations 2015).

This report is all inclusive in that it reports both the CtG LCI and the LCIA cellulosic fiberboard. Three life cycle stages were considered in the LCA: 1) forestry operations, 2) wood residue production and, 3) cellulosic fiberboard. The CtG LCA for cellulosic fiberboard is representative of North American average for all wood and energy inputs. Both mass and economic (product value) allocation methods were applied.

The cellulosic fiberboard manufacturing stage clearly drives the environmental profile from cradle to gate. The wood residue production environmental profile changes based on allocation method applied. Applying an economic allocation method to wood residue production resulting in significantly lower environmental burdens as compared to mass allocation. When no allocation was applied to cellulosic fiberboard production there was only a slight increase compared to mass allocation methods, over all impact indicators. Cradle to Gate results are similar between mass and economic allocation.

The life cycle impact categories are driven by the type of fuel used. The majority of the biomass fuel is used during cellulosic fiberboard production, but fossil fuels remain the main energy source. By the nature of the production process, very little wood waste is generated during cellulosic fiberboard production therefore there is little wood waste available for use as a fuel source. The cellulosic fiberboard production life cycle stage represents the greatest contribution to any individual impact category. Direct fossil fuels consumption and upstream processes used during manufacturing are the main contributors to each category.

Carbon is released as CO_2 during all life cycle stages. The majority of the emission are released during the production of cellulosic fiberboard. This is consistent with most wood product manufacturing life cycles. In summary, cellulosic fiberboard attains a positive carbon balance in its production – a finding worthy of communicating to users of this product.

Recommendations for continuing LCA coverage of cellulosic fiber include, but not limited to, 1) modeling use and end-of-life life cycle phases, 2) evaluate coated cellulosic fiberboard, 3) investigate the influence of substituting the use of renewable biomass fuel on fossil fuels and how this may effect coproduct supply to other wood products (e.g. particleboard, medium density fiberboard).

10 Critical review

10.1 Internal review

An internal review of the LCA product was provided by the other two authors, Dr. Bergman and Dr. Oneil; both of which are knowledgeable and experienced LCA and wood products reviewers. The LCI report (Bergman 2015) also had undergone a peer-review process before publishing. The purpose of the LCA report internal review is to check for errors and conformance with the PCR prior to submittal for external review. The technical and editorial comments of the reviewers were carefully considered and in most instances incorporated into the final document.

10.2 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 2006a) and the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015). Following CORRIM's internal review, documents were submitted to UL Environment (ULE) for independent external review. The independent external review performed by ULE was conducted by:

Wade Stout EPD Project Manager
UL Environment
UL LLC
2211 Newmarket Parkway, Suite 106
Marietta, GA 30067 USA
Mobile: 678.469.3598; Office: 678.444.4046

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 2006a) and the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2015).

11 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.

ASMI. 2012. A cradle-to-gate life cycle assessment of Canadian oriented strand board: An update. Athena Sustainable Materials Institute. 43 pp.

ASTM International. 2012. Standard specification for cellulosic fiber insulating board. American Society for Testing and Materials. ASTM C208-12. West Conshohocken, PA. 58-61.

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. 2015. Cradle-to-gate life-cycle inventory of cellulosic fiberboard produced in North America. CORRIM Final Report. University of Washington. Seattle, WA. Revised May 2015. 57 pp.

Bergman R.D and Bowe S.A. 2011. Life-Cycle Inventory of Manufacturing Hardwood Lumber in Southeastern US. Wood and Fiber Science, 44(1), 2012, pp. 71-84.

Bergman R.D and Bowe S.A. 2010. Life-Cycle Inventory of Hardwood Lumber Manufacturing in the Southeastern United States. CORRIM Phase II Report Module L. Seattle, WA. 50 pp. http://www.corrim.org/pubs/reports/2010/phase2/Module_L.pdf. Accessed Nov. 2015.

Bergman R.D and Bowe S.A. (2008a) Environmental impact of producing hardwood lumber using life-cycle inventory. Wood Fiber Sci 40(3):448-458.

Bergman RD and Bowe S.A. (2008b) Life-cycle inventory of hardwood lumber manufacturing in the Northeast and North central United States, CORRIM Phase II Report Module C. Environmental performance measures for renewable building materials with alternatives for improved performance. Seattle, WA. 48 pp. http://www.corrim.org/pubs/reports/2010/phase2/Module_C.pdf. Accessed Nov. 2015.

CAN/ULC-S706. 2009. Standard for Wood Fibre Insulating Boards for Building. Second Edition. Underwriters Laboratories of Canada.

FPInnovations. 2015. Product Category Rules (PCR) for preparing and environmental Product Declaration (EPD) for North American Structural and Architectural Wood Products. https://fpinnovations.ca/ResearchProgram/environment-sustainability/epd-program/Documents/pcr-v2.pdf. Accessed September 2015.

ISO. 2006a. Environmental labels and declarations—Type III environmental declarations—Principles and procedures. ISO 14025. International Organization for Standardization, Geneva, Switzerland. 25 pp.

ISO. 2006b. Environmental management—life-cycle assessment—requirements and guidelines. ISO 14044. International Organization for Standardization, Geneva, Switzerland. 46 pp.

ISO. 2006c. Environmental management—life-cycle assessment—principles and framework. ISO 14040. International Organization for Standardization, Geneva, Switzerland. 20 pp.

Jessen H.C. 1952. Drying of insulating board. TAPPI 35(10):455-467.

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.

Lampert H. 1967. Fibre-boards: raw materials, manufacturing processes, properties. Faserplatten: Rohstoffe, Herstellungsverfahren, Eigenschaften (German). Leipzig, Germany. 453 pp.

Milota, M.R. 2015. CORRIM REPORT: Life Cycle assessment for the production of Pacific Northwest softwood lumber. In review. November 2015. 58 pp.

Milota, M.R. 2015. CORRIM REPORT: Life Cycle assessment for the production of southeastern softwood lumber. In review. November 2015. 57 pp.

NAFA (2013) Fiberboard total shipments through 2012. North American Fiberboard Association. Rolling Meadows, IL. 1 pp.

NIST ITL. 1996. Weighted standard deviation. National Institute of Standards and Technology Information Technology Laboratory.
www.itl.nist.gov/div898/software/dataplot/refman2/ch2/weightsd.pdf. Accessed July 2015.

NREL. 2012. Life-cycle inventory database project. National Renewable Energy Laboratory. www.lcacommons.gov/nrel/search. Accessed July 2015.

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. 2014. Simapro 8.0.4.30 Life-Cycle Assessment Software Package. Plotter 12, 3821 BB Amersfoort, the Netherlands. Http://www.pre.nl/. Accessed July 2015.

Puettmann, M.E., and M. Milota. 2015. Development of wood boiler data for use in life cycle assessment modeling. CORRIM report. Draft.

Puettmann, M.E., A. Taylor, and E. Oneil. 2014. CORRIM Research guidelines for life-cycle inventories (working document). Consortium for Research on Renewable Industrial Materials (CORRIM), Inc., University of Washington, Seattle, WA. 40 pp.

Stark N.M., Z. Cai, and C. Carll. 2010. Wood-based composite materials: Panel products, glued-laminated timber, structural composite lumber, and wood–nonwood composite materials. In: Wood handbook—wood as an engineering material. Gen Tech Rep FPL–GTR–113. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Madison, WI pp. 11-1–11-28.

Suchsland O. and G.E. Woodson. 1986. Fiberboard manufacturing practices in the United States. Agriculture Handbook No. 640. Washington, DC: U.S. Department of Agriculture, Forest Service. 263 pp.

USCB. 2012. 2012 North American Industry Classification System Definitions. 321219 Reconstituted Wood Product Manufacturing. United States Census Bureau. www.census.gov/eos/www/naics/ accessed July 2015.

US EPA. 2002. AP 42 Section 10.6.4 Hardboard and fiberboard manufacturing. United States Environmental Protection Agency. pp. 10.6.4-1-38. www.epa.gov/ttn/chief/ap42/ch10/final/c10s0604.pdf accessed July 2015.

Appendix A – Economic allocation

12 Economic Allocation

12.1 Cradle-to-gate LCI results – Economic Allocation

Life-cycle inventory results for cellulosic fiberboard are presented by three life cycle stages, 1) forestry operations, 2) wood residue production, and 3) cellulosic fiberboard production (Table 21 – Table 23).

The majority of the raw material consumption used for energy production occurs during cellulosic fiber manufacturing, followed by the production of the wood residue with only a very small portion arising from forestry operations. Table 21 lists the raw material consumption of energy inputs per m^3 of cellulosic fiberboard. Highest consumption rates are for coal with all processes consuming a total of 62 kg/m^3. Coal is used for on-site thermal energy and off-site electricity production. Natural gas at 42 kg/m^3 was used onsite primarily for drying of mats during cellulosic fiberboard production and off site for electricity generation. Wood fuel usage represented 34 percent of primary energy mass and was used in wood residue production (17%) and cellulosic fiberboard production (83%). Most of the residues used in cellulosic fiberboard were obtained from green residues generated during lumber manufacturing. Drying the feedstock was not necessary for making cellulosic fiberboard but fell within the system boundary and thus needed to be taken into account.

Table 21 Raw material consumption for energy production per 1 m^3 of cellulosic fiberboard, North American average (economic allocation).

Fuel	Total	Forestry operations	Wood residue production	Cellulosic fiberboard Production
	(kg/m^3)			
Coal, in ground	62.1042	0.0552	1.7865	60.2625
Gas, natural, in ground	42.1534	0.1534	0.3850	41.6150
Oil, crude, in ground	9.7971	0.8715	1.7616	7.1640
Uranium oxide, in ore	0.0011	0.0000	0.0000	0.0011
Wood fuel	48.642	0.0000	0.4809	48.1611

Table 22 lists the CtG air emissions generated as a result of cellulosic fiberboard production. Cellulosic fiberboard manufacturing generates air emissions including particulate and particulate PM_{10} (less than 10 µm in size) during refining, drying, and trimming. Other air emissions include VOCs from drying and pressing. Recorded emissions of formaldehyde and methanol are used as a measure of the amount of Hazardous Air Pollutants (HAPs). Mills reported acetaldehyde, acrolein, formaldehyde, methanol, phenol, propionaldehyde (or propanal), and VOCs as a measure of HAPs released.

Table 22 Air emissions released per 1 m^3 of cellulosic fiberboard, North American average (economic allocation).

Air Emissions[1]	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
Acetaldehyde	0.0200	0.0000	0.0001	0.0199
Acetone	0.0096	0.0000	0.0000	0.0096
Acrolein	0.0071	0.0000	0.0000	0.0071
Aldehydes, unspecified	0.0002	0.0000	0.0001	0.0001

Air Emissions[1]	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
alpha-Pinene	0.1100	0.0000	0.0000	0.1100
Ammonia	0.0064	0.0001	0.0001	0.0063
Benzene	0.0024	0.0000	0.0000	0.0024
Biphenyl	0.0002	0.0000	0.0000	0.0002
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	0.0148	0.0001	0.0001	0.0146
Carbon dioxide	2.2607	0.0866	0.0537	2.1204
Carbon dioxide, biogenic	46.5789	0.0024	1.0065	45.5699
Carbon dioxide, fossil	256.5977	2.8573	9.9515	243.7889
Carbon monoxide	0.0478	0.0000	0.0015	0.0463
Carbon monoxide, biogenic	0.0810	0.0000	0.0015	0.0795
Carbon monoxide, fossil	0.2925	0.0260	0.0394	0.2271
Chlorothalonil	0.0006	0.0000	0.0000	0.0006
Chromium	0.0001	0.0000	0.0000	0.0001
Cumene	0.0052	0.0000	0.0000	0.0052
Dinitrogen monoxide	0.0539	0.0005	0.0004	0.0530
Dipropylthiocarbamic acid S-ethyl ester	0.0002	0.0000	0.0000	0.0002
Formaldehyde	0.0170	0.0000	0.0000	0.0169
HAPs	0.0002	0.0000	0.0000	0.0002
Heat, waste	25.2888	0.0000	0.0017	25.2871
Hydrocarbons, unspecified	0.0128	0.0000	0.0000	0.0128
Hydrogen chloride	0.0214	0.0000	0.0009	0.0204
Hydrogen fluoride	0.0105	0.0000	0.0001	0.0103
Isoprene	0.0570	0.0001	0.0024	0.0545
Limonene	0.0076	0.0000	0.0000	0.0076
Magnesium	0.0002	0.0000	0.0000	0.0002
Mancozeb	0.0005	0.0000	0.0000	0.0005
Metam-sodium dihydrate	0.0029	0.0000	0.0000	0.0029
Methane	0.7187	0.0052	0.0171	0.6964
Methane, biogenic	0.0006	0.0000	0.0000	0.0005
Methane, fossil	0.0857	0.0005	0.0011	0.0841
Methanol	0.0627	0.0000	0.0001	0.0626
Methyl ethyl ketone	0.0020	0.0000	0.0000	0.0020
Naphthalene	0.0010	0.0000	0.0000	0.0010
Nickel	0.0001	0.0000	0.0000	0.0001
Nitrogen oxides	0.7253	0.0513	0.0719	0.6020
NMVOC, non-methane volatile organic compounds, unspecified origin	0.0159	0.0017	0.0038	0.0104
N-Nitrodimethylamine	0.0014	0.0000	0.0000	0.0014
Organic substances, unspecified	0.0002	0.0000	0.0000	0.0002
Particulates, < 10 um	0.1839	0.0000	0.0003	0.1836
Particulates, < 2.5 um	0.0490	0.0000	0.0005	0.0485
Particulates, > 10 um	0.0010	0.0000	0.0009	0.0001
Particulates, > 2.5 um, and < 10um	0.1512	0.0016	0.0017	0.1479
Particulates, unspecified	0.2980	0.0003	0.0030	0.2946
Phenol	0.0039	0.0000	0.0000	0.0039
Phorate	0.0001	0.0000	0.0000	0.0001
Propanal	0.0140	0.0000	0.0000	0.0140
Propene	0.0001	0.0000	0.0000	0.0000
Propene, 1,3-dichloro-	0.0014	0.0000	0.0000	0.0014
Radionuclides (Including Radon)	0.0017	0.0000	0.0001	0.0016
Sulfur dioxide	2.3419	0.0050	0.0335	2.3034
Sulfur monoxide	0.0229	0.0029	0.0060	0.0141
Sulfur oxides	0.0006	0.0000	0.0001	0.0004
Toluene	0.0011	0.0000	0.0000	0.0011

Air Emissions[1]	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
VOC, volatile organic compounds	0.2825	0.0015	0.0043	0.2767
Wood (dust)	0.0144	0.0000	0.0005	0.0139

[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 Appendix B in this report
[2] Non-methane volatile organic compounds, unspecified origin.

Most of the waterborne emissions reported by cellulosic fiberboard manufacturers are produced on-site as shown in Table 23. For unspecified suspended solids to water, a value of 13.9 kg/m^3 of cellulosic fiberboard is listed. Most of unspecified suspended solids emissions was from the process of extracting natural gas from the ground and thus did not occur at the production facilities.

Table 23 Emissions to water released per 1 m3 of cellulosic fiberboard, North American average (economic allocation).

Water emissions	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
Aluminium	0.0061	0.0003	0.0006	0.0052
Ammonia	0.0028	0.0001	0.0001	0.0026
Barium	0.0824	0.0040	0.0082	0.0702
Benzene	0.0004	0.0000	0.0000	0.0003
Benzoic acid	0.0002	0.0000	0.0000	0.0002
BOD5, Biological Oxygen Demand	0.3093	0.0007	0.0015	0.3071
Boron	0.0007	0.0000	0.0000	0.0006
Bromide	0.0457	0.0008	0.0017	0.0432
Calcium	0.6859	0.0122	0.0257	0.6481
Chloride	7.7093	0.1370	0.2884	7.2840
COD, Chemical Oxygen Demand	0.2676	0.0013	0.0027	0.2636
Detergent, oil	0.0002	0.0000	0.0000	0.0002
Fluoride	0.0043	0.0025	0.0015	0.0002
Iron	0.0166	0.0006	0.0013	0.0147
Lithium	0.2045	0.0007	0.0019	0.2018
Magnesium	0.1341	0.0024	0.0050	0.1267
Manganese	0.0008	0.0000	0.0000	0.0008
Metam-sodium dihydrate	0.0002	0.0000	0.0000	0.0002
Nitrogen, total	0.0115	0.0000	0.0000	0.0115
Oils, unspecified	0.0195	0.0001	0.0002	0.0192
Phosphate	0.0031	0.0019	0.0012	0.0000
Phosphorus compounds, unspecified	0.0004	0.0000	0.0000	0.0004
Silver	0.0004	0.0000	0.0000	0.0004
Sodium	2.1743	0.0386	0.0813	2.0543
Strontium	0.0116	0.0002	0.0004	0.0110
Sulfate	0.0424	0.0003	0.0017	0.0404
Sulfur	0.0006	0.0000	0.0000	0.0005
Suspended solids, unspecified	13.8908	0.1779	0.3742	13.3387
Toluene	0.0003	0.0000	0.0000	0.0003
Xylene	0.0002	0.0000	0.0000	0.0002
Zinc	0.0002	0.0000	0.0000	0.0001
Aluminium	0.0061	0.0003	0.0006	0.0052

Water emissions	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
Ammonia	0.0028	0.0001	0.0001	0.0026
Barium	0.0824	0.0040	0.0082	0.0702
Benzene	0.0004	0.0000	0.0000	0.0003
Benzoic acid	0.0002	0.0000	0.0000	0.0002
BOD5, Biological Oxygen Demand	0.3093	0.0007	0.0015	0.3071
Boron	0.0007	0.0000	0.0000	0.0006
Bromide	0.0457	0.0008	0.0017	0.0432
Calcium	0.6859	0.0122	0.0257	0.6481
Chloride	7.7093	0.1370	0.2884	7.2840
COD, Chemical Oxygen Demand	0.2676	0.0013	0.0027	0.2636
Detergent, oil	0.0002	0.0000	0.0000	0.0002
Fluoride	0.0043	0.0025	0.0015	0.0002
Iron	0.0166	0.0006	0.0013	0.0147
Lithium	0.2045	0.0007	0.0019	0.2018
Magnesium	0.1341	0.0024	0.0050	0.1267
Manganese	0.0008	0.0000	0.0000	0.0008
Metam-sodium dihydrate	0.0002	0.0000	0.0000	0.0002
Nitrogen, total	0.0115	0.0000	0.0000	0.0115
Oils, unspecified	0.0195	0.0001	0.0002	0.0192
Phosphate	0.0031	0.0019	0.0012	0.0000
Phosphorus compounds, unspecified	0.0004	0.0000	0.0000	0.0004
Silver	0.0004	0.0000	0.0000	0.0004
Sodium	2.1743	0.0386	0.0813	2.0543
Strontium	0.0116	0.0002	0.0004	0.0110
Sulfate	0.0424	0.0003	0.0017	0.0404
Sulfur	0.0006	0.0000	0.0000	0.0005
Suspended solids, unspecified	13.8908	0.1779	0.3742	13.3387
Toluene	0.0003	0.0000	0.0000	0.0003
Xylene	0.0002	0.0000	0.0000	0.0002
Zinc	0.0002	0.0000	0.0000	0.0001

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 Appendix B of this report.

Solid emissions generated onsite during cellulosic fiberboard manufacturing includes ash generated at the boiler. Other waste generated is a result of upstream processes, primarily fuels and additives, used in cellulosic fiberboard production (Table 15). A total of 14.47 kg/m^3 solid waste was generated onsite with 55 percent going to the landfill and the remaining portion being recycled (6.46 kg) (Bergman 2015). A total of 56.98 kg of solid waste was generated from cradle-to-gate for the production of 1 m^3 cellulosic fiberboard, of that 99 percent was generated during the cellulosic fiberboard production or generated by processes used during the production process.

Table 24 Waste to treatment per 1 m3 of cellulosic fiberboard, North American average (economic allocation).

Waste to treatment	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	kg/m^3			
Waste generated onsite	14.47	0.00	0.00	14.47
Waste disposal	42.51	0.05	0.65	41.82
Total waste	56.98	0.05	0.65	56.29

12.2 Life-cycle impact assessment

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 25 provides the environmental impact by category for cellulosic fiberboard. 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 25. For GWP, 95 percent of the CO_2 eq. emissions come from producing cellulosic fiberboard. Similar results are presented for acidification, eutrophication, and smog, representing 95, 82, and 85 percent contributed from cellulosic fiberboard production, respectively.

Non-renewable fuels represented the greatest proportion of energy consumed (71%) for total CtG primary energy use. Renewable biomass fuels and non-renewable nuclear represented 17 and 7 percent of the total primary energy, respectively. Of the three life cycle stages considered in this study, cellulosic fiberboard production consumes 96 percent of the total primary energy consumption. Overall, the manufacture of cellulosic fiberboard in North America is 17 percent energy self-sufficient with its use of renewable biomass. By the nature of the production process, self-producing wood fuel would be difficult to obtain onsite; therefore, to increase the use of renewable biomass onsite would be limited to purchasing wood fuel from other wood production industries or utilization of whole logs not suitable for lumber or plywood production.

Water intake is high for the cradle-to-gate production of cellulosic fiberboard at 3,796 L/m^3 but much more lower than a previous reported value, 22,700 L/m^3 (Suchsland and Woodson 1986). In addition, the water intake value did not consider the water recycling efforts that now are at 63% at the cellulosic fiberboard facilities. It is clear, based on previous published water use, that water conservation measures currently in place in North American cellulosic fiberboard facilities have made a dramatic impact in the reduction of water consumption.

Table 25 Environmental performance of 1 m3 cellulosic fiberboard, North American average (economic allocation).

Impact category	Unit	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
Global warming potential (GWP)	kg CO_2 eq	295.0548	3.2387	10.5869	281.2292
Acidification Potential	kg SO_2 eq	2.9207	0.0439	0.0912	2.7856
Eutrophication Potential	kg N eq	0.0712	0.0069	0.0063	0.0580
Ozone depletion Potential	kg CFC-11 eq	0.0	0.0000	0.0000	0.0000
Smog Potential	kg O_3 eq	20.6424	1.2793	1.8262	17.5369
Total Primary Energy	MJ	6,148.23	50.04	198.75	5,899.44
Non-renewable fossil	*MJ*	4,395.48	49.49	161.71	4,184.28
Non-renewable nuclear	*MJ*	442.95	0.49	18.32	424.14
Renewable (solar, wind, hydroelectric, and geothermal)	*MJ*	291.51	0.06	8.65	282.80

Renewable, biomass	*MJ*	1,018.29	0.00	10.07	1,008.22
Material resources consumption (Non-fuel resources)	**Unit**	**Total**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Non-renewable materials	kg	0.3173	0.0000	0.0013	0.3160
Renewable materials	kg	333.208	186.194	145.590	1.424
Fresh water	L	3,795.78	0.63	6.68	3,788.47
Waste generated	**Unit**	**Total**	**Forestry Operations**	**Wood residue production**	**Cellulosic fiberboard production**
Solid waste	kg	56.98	0.05	0.65	56.28

12.3 Carbon

Using the same method applied for mass allocation, 292 kg CO_2e were released in the production of 1 m^3 of cellulosic fiberboard. That same 1 m^3 of cellulosic fiberboard stores 122 kg of carbon[8] or 447 kg CO_2 eq.[9], resulting in more carbon storage in the product then released during manufacturing (cradle to gate) (Table 26). There was only a 3 kilogram difference between mass and economic allocation methods.

Table 26 Carbon per 1 m^3 cellulosic fiberboard, North American average (economic allocation).

	kg CO_2 equivalent
released forestry operations	3.24
released cellulosic fiberboard and residue manufacturing	291.82
CO_2 eq. stored in product[10]	447.33

[8] Assuming a 50% carbon content
[9] 244 OD kg of wood in cellulosic fiberboard × (0.5 kg carbon/1.0 OD kg wood) × (44 kg CO_2/kmole/12 kg carbon/kmole) = 477.33 kg CO_2 eq.
[10] Assuming 44/12 molecular weight ratio of CO_2/C

Appendix B - Life cycle inventory, Full Results

Air Emissions – Mass Allocation

Table 27 Air emissions released per 1 m3 of uncoated cellulosic fiberboard, North American average (mass allocation).

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
2-Chloroacetophenone	kg	4.71E-12	1.83E-11	1.87E-10	2.10E-10
2-Methyl-4-chlorophenoxyacetic acid	kg	x	5.74E-14	1.11E-11	1.12E-11
2,4-D	kg	x	3.10E-11	9.09E-09	9.12E-09
5-methyl Chrysene	kg	5.32E-13	3.72E-11	3.60E-10	3.98E-10
Acenaphthene	kg	1.23E-11	8.63E-10	8.34E-09	9.22E-09
Acenaphthylene	kg	6.04E-12	4.23E-10	4.09E-09	4.52E-09
Acetaldehyde	kg	1.18E-05	1.49E-03	1.92E-02	2.07E-02
Acetochlor	kg	x	4.27E-11	8.26E-09	8.30E-09
Acetone	kg	x	3.06E-05	9.30E-03	9.33E-03
Acetophenone	kg	1.01E-11	3.93E-11	4.01E-10	4.51E-10
Acrolein	kg	1.43E-06	8.92E-05	6.82E-03	6.92E-03
Alachlor	kg	x	4.20E-12	8.13E-10	8.17E-10
Aldehydes, unspecified	kg	3.54E-05	1.31E-04	1.35E-04	3.02E-04
Aldicarb	kg	x	9.47E-08	2.88E-05	2.89E-05
alpha-Pinene	kg	x	3.49E-04	1.06E-01	1.06E-01
Ammonia	kg	8.39E-05	2.48E-04	6.03E-03	6.36E-03
Ammonium chloride	kg	6.77E-08	5.03E-06	5.69E-05	6.20E-05
Anthracene	kg	5.08E-12	3.55E-10	3.43E-09	3.79E-09
Antimony	kg	4.35E-10	3.07E-08	2.94E-07	3.26E-07
Arsenic	kg	1.35E-08	7.25E-07	8.58E-06	9.32E-06
Ash	kg	x	8.62E-08	2.62E-05	2.63E-05
Atrazine	kg	x	8.32E-11	1.61E-08	1.62E-08
Azinphos-methyl	kg	x	2.21E-08	6.73E-06	6.75E-06
Barium	kg	x	2.05E-07	x	2.05E-07
Bentazone	kg	x	3.39E-13	6.57E-11	6.60E-11
Benzene	kg	1.44E-05	2.40E-05	2.33E-03	2.37E-03
Benzene, chloro-	kg	1.48E-11	5.76E-11	5.89E-10	6.61E-10
Benzene, ethyl-	kg	6.32E-11	1.58E-08	3.34E-09	1.92E-08
Benzo(a)anthracene	kg	1.93E-12	1.35E-10	1.31E-09	1.45E-09
Benzo(a)pyrene	kg	9.18E-13	6.43E-11	6.22E-10	6.87E-10
Benzo(b,j,k)fluoranthene	kg	2.66E-12	1.86E-10	1.80E-09	1.99E-09
Benzo(g,h,i)perylene	kg	6.53E-13	2.50E-11	4.42E-10	4.67E-10
Benzo(ghi)perylene	kg	x	2.06E-11	x	2.06E-11

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Benzyl chloride	kg	4.71E-10	1.83E-09	1.87E-08	2.10E-08
Beryllium	kg	6.74E-10	4.19E-08	1.59E-06	1.63E-06
Biphenyl	kg	4.11E-11	6.26E-07	1.89E-04	1.90E-04
Bromoform	kg	2.62E-11	1.02E-10	1.04E-09	1.17E-09
Bromoxynil	kg	x	7.44E-13	1.44E-10	1.45E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	5.40E-05	4.44E-04	1.41E-02	1.46E-02
Butadiene	kg	6.00E-07	4.96E-07	7.02E-07	1.80E-06
Cadmium	kg	3.40E-09	1.24E-07	2.63E-06	2.75E-06
Carbaryl	kg	x	2.59E-08	7.87E-06	7.89E-06
Carbofuran	kg	x	6.35E-08	1.93E-05	1.94E-05
Carbon dioxide	kg	8.66E-02	6.64E-02	2.04E+00	2.20E+00
Carbon dioxide, biogenic	kg	2.40E-03	1.44E+01	4.39E+01	5.84E+01
Carbon dioxide, fossil	kg	2.86E+00	1.97E+01	2.35E+02	2.58E+02
Carbon disulfide	kg	8.74E-11	3.40E-10	3.48E-09	3.91E-09
Carbon monoxide	kg	6.27E-06	4.20E-03	4.47E-02	4.89E-02
Carbon monoxide, biogenic	kg	x	2.58E-02	7.67E-02	1.03E-01
Carbon monoxide, fossil	kg	2.60E-02	6.11E-02	2.19E-01	3.06E-01
Chloride	kg	1.84E-12	2.03E-10	1.60E-09	1.81E-09
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	x	2.91E-09	9.85E-09	1.28E-08
Chlorine	kg	x	3.73E-07	6.51E-09	3.80E-07
Chloroform	kg	3.97E-11	1.55E-10	1.58E-09	1.77E-09
Chlorothalonil	kg	x	2.04E-06	6.22E-04	6.24E-04
Chlorpyrifos	kg	x	4.89E-12	9.47E-10	9.52E-10
Chromium	kg	9.80E-09	8.40E-07	1.12E-04	1.13E-04
Chromium VI	kg	1.91E-09	1.34E-07	1.29E-06	1.43E-06
Chrysene	kg	2.42E-12	1.69E-10	1.64E-09	1.81E-09
Cobalt	kg	1.78E-08	2.39E-07	2.00E-06	2.26E-06
Copper	kg	1.75E-10	3.54E-09	4.08E-08	4.45E-08
Cumene	kg	3.56E-12	1.73E-05	5.01E-03	5.02E-03
Cyanazine	kg	x	7.33E-13	1.42E-10	1.43E-10
Cyanide	kg	1.68E-09	6.55E-09	6.69E-08	7.51E-08
Diazinon	kg	x	1.21E-09	3.66E-07	3.68E-07
Dicamba	kg	x	4.32E-12	8.36E-10	8.41E-10
Dimethenamid	kg	x	1.02E-11	1.98E-09	1.99E-09
Dimethyl ether	kg	x	6.25E-09	x	6.25E-09
Dinitrogen monoxide	kg	5.09E-04	7.18E-04	5.11E-02	5.23E-02
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	5.79E-14	2.73E-12	1.42E-11	1.70E-11

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	x	1.80E-16	x	1.80E-16
Dipropylthiocarbamic acid S-ethyl ester	kg	x	6.30E-07	1.91E-04	1.92E-04
Disulfoton	kg	x	1.02E-07	3.11E-05	3.12E-05
Endosulfan	kg	x	4.89E-08	1.49E-05	1.49E-05
Ethane, 1,1,1-trichloro-, HCFC-140	kg	9.52E-11	3.06E-10	8.10E-10	1.21E-09
Ethane, 1,2-dibromo-	kg	8.07E-13	3.27E-12	3.21E-11	3.62E-11
Ethane, 1,2-dichloro-	kg	2.69E-11	1.05E-10	1.07E-09	1.20E-09
Ethane, chloro-	kg	2.82E-11	1.10E-10	1.12E-09	1.26E-09
Ethene, tetrachloro-	kg	1.24E-09	7.39E-08	7.11E-07	7.86E-07
Ethene, trichloro-	kg	x	3.41E-11	1.66E-11	5.06E-11
Ethoprop	kg	x	2.36E-07	7.18E-05	7.21E-05
Ethylene oxide	kg	x	8.56E-09	1.91E-09	1.05E-08
Fluoranthene	kg	1.72E-11	1.20E-09	1.16E-08	1.28E-08
Fluorene	kg	2.20E-11	1.54E-09	1.49E-08	1.64E-08
Fluoride	kg	1.01E-06	8.71E-07	2.50E-06	4.38E-06
Formaldehyde	kg	1.83E-05	2.37E-04	1.63E-02	1.66E-02
Furan	kg	1.07E-13	8.33E-12	8.10E-11	8.94E-11
Glyphosate	kg	x	1.49E-08	4.53E-06	4.54E-06
HAPs	kg	x	5.02E-05	1.49E-04	1.99E-04
HAPS, unspecified	kg	x	1.40E-05	x	1.40E-05
Heat, waste	MJ	x	1.10E-01	2.44E+01	2.45E+01
Hexane	kg	4.50E-11	1.75E-10	1.79E-09	2.01E-09
Hydrazine, methyl-	kg	1.14E-10	4.45E-10	4.55E-09	5.11E-09
Hydrocarbons, unspecified	kg	3.91E-07	6.84E-05	1.23E-02	1.24E-02
Hydrogen	kg	x	1.53E-08	4.87E-08	6.40E-08
Hydrogen chloride	kg	3.05E-05	2.05E-03	1.97E-02	2.18E-02
Hydrogen fluoride	kg	3.59E-06	2.78E-04	9.98E-03	1.03E-02
Hydrogen sulfide	kg	5.95E-14	6.55E-12	5.18E-11	5.84E-11
Indeno(1,2,3-cd)pyrene	kg	1.47E-12	1.03E-10	9.98E-10	1.10E-09
Iron	kg	x	2.05E-07	x	2.05E-07
Isophorone	kg	3.90E-10	1.52E-09	1.55E-08	1.74E-08
Isoprene	kg	6.04E-05	6.64E-03	5.26E-02	5.93E-02
Kerosene	kg	3.24E-08	2.41E-06	2.73E-05	2.97E-05
Lead	kg	1.69E-08	2.44E-06	8.09E-05	8.33E-05
Limonene	kg	x	2.42E-05	7.36E-03	7.38E-03
Linuron	kg	x	2.75E-08	8.35E-06	8.38E-06
Magnesium	kg	2.66E-07	1.86E-05	1.80E-04	1.99E-04
Mancozeb	kg	x	1.58E-06	4.80E-04	4.82E-04

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Manganese	kg	1.99E-08	1.34E-06	2.30E-05	2.44E-05
Mercaptans, unspecified	kg	1.46E-07	5.67E-07	5.80E-06	6.51E-06
Mercury	kg	3.45E-09	2.02E-07	1.18E-05	1.20E-05
Metals, unspecified	kg	6.83E-15	4.25E-08	3.09E-10	4.28E-08
Metam-sodium dihydrate	kg	x	9.33E-06	2.84E-03	2.85E-03
Methane	kg	5.22E-03	3.90E-02	6.72E-01	7.16E-01
Methane, biogenic	kg	x	1.78E-04	5.29E-04	7.07E-04
Methane, bromo-, Halon 1001	kg	1.08E-10	4.19E-10	4.28E-09	4.81E-09
Methane, chlorodifluoro-, HCFC-22	kg	x	7.12E-14	1.59E-14	8.71E-14
Methane, chlorotrifluoro-, CFC-13	kg	x	6.76E-13	1.51E-13	8.26E-13
Methane, dichloro-, HCC-30	kg	2.02E-08	5.64E-07	5.20E-06	5.78E-06
Methane, dichlorodifluoro-, CFC-12	kg	1.01E-10	3.14E-10	3.40E-10	7.55E-10
Methane, fossil	kg	5.02E-04	3.03E-03	8.11E-02	8.46E-02
Methane, monochloro-, R-40	kg	3.56E-10	1.39E-09	1.42E-08	1.59E-08
Methane, tetrachloro-, CFC-10	kg	1.01E-11	1.89E-10	3.44E-10	5.43E-10
Methanol	kg	x	1.35E-03	6.04E-02	6.17E-02
Methyl ethyl ketone	kg	2.62E-10	6.41E-06	1.95E-03	1.95E-03
Methyl methacrylate	kg	1.34E-11	5.24E-11	5.35E-10	6.01E-10
Metolachlor	kg	x	9.27E-08	2.82E-05	2.83E-05
Metribuzin	kg	x	1.11E-07	3.38E-05	3.39E-05
N-Nitrodimethylamine	kg	x	4.51E-06	1.37E-03	1.38E-03
Naphthalene	kg	3.77E-09	3.86E-06	9.87E-04	9.91E-04
Nickel	kg	2.24E-07	1.84E-06	1.11E-04	1.13E-04
Nitrogen oxides	kg	5.13E-02	1.24E-01	5.81E-01	7.56E-01
Nitrogen, total	kg	1.96E-05	1.28E-05	1.11E-05	4.35E-05
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.72E-03	6.39E-03	1.00E-02	1.81E-02
Organic acids	kg	2.49E-10	1.85E-08	2.09E-07	2.28E-07
Organic substances, unspecified	kg	1.50E-07	4.19E-04	1.95E-04	6.13E-04
Other Organic	kg	x	1.69E-06	5.02E-06	6.71E-06
Oxamyl	kg	x	2.60E-08	7.90E-06	7.92E-06
PAH, polycyclic aromatic hydrocarbons	kg	2.58E-06	2.13E-06	3.44E-06	8.15E-06
Paraquat	kg	x	1.05E-08	3.18E-06	3.19E-06
Parathion, methyl	kg	x	6.78E-09	2.06E-06	2.07E-06
Particulates	kg	x	3.05E-09	x	3.05E-09
Particulates, < 10 um	kg	x	4.61E-03	1.77E-01	1.82E-01
Particulates, < 2.5 um	kg	x	2.84E-03	4.68E-02	4.96E-02
Particulates, > 10 um	kg	x	4.95E-03	6.05E-05	5.01E-03
Particulates, > 2.5 um, and < 10um	kg	1.57E-03	3.08E-03	1.43E-01	1.47E-01

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Particulates, unspecified	kg	3.29E-04	7.09E-03	2.84E-01	2.92E-01
Pendimethalin	kg	x	6.68E-08	2.03E-05	2.04E-05
Permethrin	kg	x	5.39E-09	1.64E-06	1.64E-06
Phenanthrene	kg	6.53E-11	1.74E-07	5.16E-05	5.17E-05
Phenol	kg	1.08E-11	1.96E-05	3.80E-03	3.82E-03
Phenols, unspecified	kg	1.04E-08	8.20E-08	6.03E-07	6.96E-07
Phorate	kg	x	3.52E-07	1.07E-04	1.07E-04
Phosphate	kg	4.47E-07	2.92E-07	4.76E-09	7.44E-07
Phthalate, dioctyl-	kg	4.91E-11	1.91E-10	1.95E-09	2.19E-09
Polycyclic organic matter, unspecified	kg	x	1.72E-12	3.83E-13	2.10E-12
Potassium	kg	x	3.64E-05	x	3.64E-05
Propanal	kg	2.55E-10	5.52E-05	1.35E-02	1.36E-02
Propene	kg	3.96E-05	3.31E-05	4.63E-05	1.19E-04
Propene, 1,3-dichloro-	kg	x	4.47E-06	1.36E-03	1.36E-03
Propylene oxide	kg	x	1.30E-08	4.99E-10	1.35E-08
Pyrene	kg	7.98E-12	5.58E-10	5.40E-09	5.96E-09
Radioactive species, unspecified	Bq	1.33E+03	9.56E+04	9.24E+05	1.02E+06
Radionuclides (Including Radon)	kg	1.81E-06	1.35E-04	1.52E-03	1.66E-03
Selenium	kg	3.36E-08	2.25E-06	3.13E-05	3.36E-05
Simazine	kg	x	2.21E-12	4.29E-10	4.31E-10
Sodium	kg	x	8.39E-07	x	8.39E-07
Styrene	kg	1.68E-11	6.55E-11	6.69E-10	7.51E-10
Sulfur	kg	x	7.96E-09	1.28E-06	1.28E-06
Sulfur dioxide	kg	4.95E-03	8.67E-02	2.22E+00	2.31E+00
Sulfur monoxide	kg	2.85E-03	6.65E-03	1.36E-02	2.31E-02
Sulfur oxides	kg	x	3.13E-03	4.11E-04	3.54E-03
Sulfur, total reduced	kg	x	3.00E-07	x	3.00E-07
Sulfuric acid, dimethyl ester	kg	3.23E-11	1.26E-10	1.28E-09	1.44E-09
t-Butyl methyl ether	kg	2.35E-11	9.17E-11	9.36E-10	1.05E-09
Tar	kg	2.07E-12	2.28E-10	1.80E-09	2.03E-09
Terbufos	kg	x	5.51E-12	1.07E-09	1.07E-09
TOC, Total Organic Carbon	kg	x	2.92E-09	x	2.92E-09
Toluene	kg	6.27E-06	8.79E-06	1.08E-03	1.09E-03
Toluene, 2,4-dinitro-	kg	1.88E-13	7.33E-13	7.49E-12	8.41E-12
Trifluralin	kg	x	1.45E-08	4.40E-06	4.42E-06
Vinyl acetate	kg	5.11E-12	1.99E-11	2.03E-10	2.28E-10
VOC, volatile organic compounds	kg	1.47E-03	2.41E-02	2.67E-01	2.92E-01
Wood (dust)	kg	x	7.44E-03	1.34E-02	2.08E-02

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Xylene	kg	4.37E-06	3.65E-06	5.12E-06	1.31E-05
Zinc	kg	3.61E-07	4.44E-07	2.86E-07	1.09E-06

Water Emissions – Mass Allocation

Table 28 Water emissions released per 1 m3 of uncoated cellulosic fiberboard, North American average (mass allocation).

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	Total
2-Hexanone	kg	2.48E-08	1.00E-07	1.27E-06	1.39E-06
2-Methyl-4-chlorophenoxyacetic acid	kg	x	2.46E-15	4.76E-13	4.79E-13
2-Propanol	kg	x	2.85E-10	9.54E-10	1.24E-09
2,4-D	kg	x	1.81E-12	5.35E-10	5.37E-10
4-Methyl-2-pentanone	kg	1.59E-08	6.45E-08	8.17E-07	8.98E-07
Acetaldehyde	kg	x	9.01E-09	2.01E-09	1.10E-08
Acetochlor	kg	x	1.83E-12	3.54E-10	3.56E-10
Acetone	kg	3.79E-08	1.53E-07	1.94E-06	2.14E-06
Acid as H+	kg	x	2.33E-07	7.09E-05	7.11E-05
Acidity, unspecified	kg	x	3.94E-11	2.98E-13	3.97E-11
Acids, unspecified	kg	3.87E-11	1.41E-07	5.90E-07	7.31E-07
Alachlor	kg	x	1.80E-13	3.48E-11	3.50E-11
Aldicarb	kg	x	5.68E-09	1.73E-06	1.73E-06
Aluminium	kg	2.91E-04	1.01E-03	4.97E-03	6.27E-03
Aluminum	kg	x	1.14E-06	x	1.14E-06
Ammonia	kg	6.76E-05	2.59E-04	2.51E-03	2.84E-03
Ammonia, as N	kg	1.94E-11	2.14E-09	1.69E-08	1.91E-08
Ammonium, ion	kg	1.45E-08	3.42E-06	-1.11E-05	-7.65E-06
Antimony	kg	1.81E-07	6.04E-07	2.77E-06	3.56E-06
Arsenic	kg	1.85E-06	4.22E-06	4.41E-05	5.02E-05
Arsenic, ion	kg	x	2.90E-07	x	2.90E-07
Atrazine	kg	x	3.56E-12	6.90E-10	6.93E-10
Azinphos-methyl	kg	x	1.33E-09	4.04E-07	4.05E-07
Barium	kg	4.00E-03	1.34E-02	6.77E-02	8.52E-02
Bentazone	kg	x	1.45E-14	2.81E-12	2.83E-12
Benzene	kg	6.36E-06	2.71E-05	3.26E-04	3.59E-04
Benzene, 1-methyl-4-(1-methylethyl)-	kg	3.79E-10	1.53E-09	1.94E-08	2.13E-08
Benzene, ethyl-	kg	3.58E-07	1.45E-06	1.84E-05	2.02E-05
Benzene, pentamethyl-	kg	2.84E-10	1.15E-09	1.46E-08	1.60E-08

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	Total
Benzenes, alkylated, unspecified	kg	1.59E-07	5.30E-07	2.43E-06	3.12E-06
Benzo(a)pyrene	kg	x	3.10E-09	2.30E-08	2.61E-08
Benzoic acid	kg	3.85E-06	1.56E-05	1.97E-04	2.17E-04
Beryllium	kg	5.50E-08	2.07E-07	2.02E-06	2.28E-06
Biphenyl	kg	1.03E-08	3.43E-08	1.57E-07	2.02E-07
BOD5, Biological Oxygen Demand	kg	6.89E-04	4.25E-03	2.96E-01	3.01E-01
Boron	kg	1.19E-05	4.84E-05	6.10E-04	6.71E-04
Bromide	kg	8.13E-04	3.29E-03	4.17E-02	4.58E-02
Bromoxynil	kg	x	1.92E-14	3.72E-12	3.74E-12
Cadmium	kg	4.28E-07	7.34E-07	6.56E-06	7.73E-06
Cadmium, ion	kg	x	4.99E-08	x	4.99E-08
Calcium	kg	1.22E-02	4.52E-02	6.25E-01	6.82E-01
Calcium, ion	kg	x	4.12E-03	x	4.12E-03
Carbaryl	kg	x	1.55E-09	4.72E-07	4.73E-07
Carbofuran	kg	x	3.81E-09	1.16E-06	1.16E-06
CFCs, unspecified	kg	x	2.85E-10	9.54E-10	1.24E-09
Chloride	kg	1.37E-01	5.54E-01	7.02E+00	7.72E+00
Chlorothalonil	kg	x	7.30E-08	2.22E-05	2.23E-05
Chlorpyrifos	kg	x	2.10E-13	4.06E-11	4.08E-11
Chromate	kg	x	7.46E-10	1.53E-11	7.61E-10
Chromium	kg	8.67E-06	2.48E-05	3.15E-05	6.49E-05
Chromium III	kg	8.32E-07	2.86E-06	9.34E-05	9.71E-05
Chromium VI	kg	3.12E-08	9.69E-08	1.05E-07	2.33E-07
Chromium, ion	kg	x	6.12E-07	x	6.12E-07
Cobalt	kg	8.40E-08	3.40E-07	4.31E-06	4.73E-06
COD, Chemical Oxygen Demand	kg	1.28E-03	5.96E-03	2.54E-01	2.61E-01
Copper	kg	1.59E-06	4.76E-06	4.24E-05	4.87E-05
Copper, ion	kg	x	2.04E-07	x	2.04E-07
Cumene	kg	x	2.08E-06	x	2.08E-06
Cyanazine	kg	x	3.14E-14	6.08E-12	6.11E-12
Cyanide	kg	2.74E-10	3.56E-07	2.64E-06	2.99E-06
Decane	kg	1.11E-07	4.47E-07	5.67E-06	6.23E-06
Detergent, oil	kg	3.27E-06	1.37E-05	1.92E-04	2.09E-04
Diazinon	kg	x	7.23E-11	2.20E-08	2.21E-08
Dibenzofuran	kg	7.21E-10	2.92E-09	3.70E-08	4.06E-08
Dibenzothiophene	kg	6.16E-10	2.47E-09	3.04E-08	3.35E-08
Dicamba	kg	x	1.85E-13	3.58E-11	3.60E-11

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	Total
Dimethenamid	kg	x	4.37E-13	8.46E-11	8.51E-11
Dipropylthiocarbamic acid S-ethyl ester	kg	x	2.25E-08	6.84E-06	6.86E-06
Dissolved organics	kg	x	1.49E-07	4.54E-05	4.55E-05
Disulfoton	kg	x	3.65E-09	1.11E-06	1.11E-06
Diuron	kg	x	3.03E-15	5.87E-13	5.90E-13
DOC, Dissolved Organic Carbon	kg	1.19E-13	3.83E-06	1.03E-10	3.83E-06
Docosane	kg	4.06E-09	1.64E-08	2.08E-07	2.29E-07
Dodecane	kg	2.10E-07	8.48E-07	1.08E-05	1.18E-05
Eicosane	kg	5.77E-08	2.34E-07	2.96E-06	3.25E-06
Endosulfan	kg	x	2.94E-09	8.93E-07	8.96E-07
Ethoprop	kg	x	8.44E-09	2.57E-06	2.57E-06
Fluorene	kg	x	1.68E-13	3.75E-14	2.06E-13
Fluorene, 1-methyl-	kg	4.32E-10	1.75E-09	2.21E-08	2.43E-08
Fluorenes, alkylated, unspecified	kg	9.22E-09	3.07E-08	1.41E-07	1.81E-07
Fluoride	kg	2.48E-03	1.64E-03	2.25E-04	4.35E-03
Fluorine	kg	4.59E-09	1.55E-08	8.18E-08	1.02E-07
Furan	kg	x	1.04E-11	3.50E-11	4.54E-11
Glyphosate	kg	x	8.93E-10	2.71E-07	2.72E-07
Hexadecane	kg	2.29E-07	9.26E-07	1.17E-05	1.29E-05
Hexanoic acid	kg	7.97E-07	3.22E-06	4.09E-05	4.49E-05
Hydrocarbons, unspecified	kg	1.49E-13	1.05E-08	3.51E-08	4.56E-08
Iron	kg	5.92E-04	2.14E-03	1.42E-02	1.69E-02
Lead	kg	2.46E-06	7.97E-06	6.75E-05	7.79E-05
Lead-210/kg	kg	3.94E-16	1.59E-15	2.02E-14	2.22E-14
Linuron	kg	x	1.65E-09	5.01E-07	5.03E-07
Lithium	kg	7.49E-04	4.88E-03	1.95E-01	2.00E-01
Lithium, ion	kg	x	1.26E-03	x	1.26E-03
m-Xylene	kg	1.15E-07	4.65E-07	5.89E-06	6.47E-06
Magnesium	kg	2.38E-03	9.64E-03	1.22E-01	1.34E-01
Mancozeb	kg	x	5.64E-08	1.72E-05	1.72E-05
Manganese	kg	4.22E-06	4.77E-05	7.46E-04	7.98E-04
Mercury	kg	1.58E-08	2.02E-08	6.44E-08	1.00E-07
Metallic ions, unspecified	kg	1.81E-12	8.44E-07	8.23E-09	8.52E-07
Metam-sodium dihydrate	kg	x	5.60E-07	1.70E-04	1.71E-04
Methane, monochloro-, R-40	kg	1.53E-10	6.17E-10	7.83E-09	8.60E-09
Methyl ethyl ketone	kg	3.05E-10	1.23E-09	1.57E-08	1.72E-08
Metolachlor	kg	x	5.56E-09	1.69E-06	1.70E-06

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	Total
Metribuzin	kg	x	6.67E-09	2.03E-06	2.04E-06
Molybdenum	kg	8.72E-08	3.53E-07	4.47E-06	4.91E-06
n-Hexacosane	kg	2.53E-09	1.02E-08	1.30E-07	1.43E-07
Naphthalene	kg	6.91E-08	2.55E-07	3.36E-06	3.68E-06
Naphthalene, 2-methyl-	kg	6.01E-08	2.43E-07	3.08E-06	3.38E-06
Naphthalenes, alkylated, unspecified	kg	2.61E-09	8.68E-09	3.98E-08	5.11E-08
Nickel	kg	1.39E-06	3.92E-06	3.54E-05	4.07E-05
Nickel, ion	kg	x	6.19E-15	x	6.19E-15
Nitrate	kg	1.30E-14	1.31E-08	5.29E-08	6.60E-08
Nitrate compounds	kg	5.24E-13	5.77E-11	4.57E-10	5.15E-10
Nitric acid	kg	1.18E-09	1.29E-07	1.02E-06	1.15E-06
Nitrogen, total	kg	3.60E-08	3.98E-05	1.11E-02	1.12E-02
o-Cresol	kg	1.09E-07	4.41E-07	5.59E-06	6.14E-06
o-Xylene	kg	x	3.58E-13	7.98E-14	4.38E-13
Octadecane	kg	5.66E-08	2.29E-07	2.90E-06	3.19E-06
Oils, unspecified	kg	8.54E-05	4.10E-04	1.86E-02	1.91E-02
Organic substances, unspecified	kg	x	5.14E-07	5.45E-08	5.68E-07
Oxamyl	kg	x	9.28E-10	2.82E-07	2.83E-07
p-Cresol	kg	1.18E-07	4.76E-07	6.04E-06	6.63E-06
p-Xylene	kg	x	3.58E-13	7.98E-14	4.38E-13
Paraquat	kg	x	6.27E-10	1.91E-07	1.91E-07
Parathion, methyl	kg	x	4.07E-10	1.24E-07	1.24E-07
Pendimethalin	kg	x	4.01E-09	1.22E-06	1.22E-06
Permethrin	kg	x	3.23E-10	9.83E-08	9.86E-08
Phenanthrene	kg	9.73E-10	3.48E-09	2.70E-08	3.14E-08
Phenanthrenes, alkylated, unspecified	kg	1.08E-09	3.60E-09	1.65E-08	2.12E-08
Phenol	kg	1.38E-06	4.31E-06	5.91E-06	1.16E-05
Phenol, 2,4-dimethyl-	kg	1.06E-07	4.30E-07	5.45E-06	5.98E-06
Phenols, unspecified	kg	5.04E-07	3.16E-06	8.18E-05	8.55E-05
Phorate	kg	x	1.26E-08	3.82E-06	3.83E-06
Phosphate	kg	1.87E-03	1.22E-03	2.36E-05	3.12E-03
Phosphorus	kg	x	1.30E-08	3.54E-07	3.67E-07
Phosphorus compounds, unspecified	kg	x	1.36E-06	4.14E-04	4.15E-04
Phosphorus, total	kg	x	3.45E-07	1.15E-06	1.50E-06
Process solvents, unspecified	kg	x	1.04E-09	3.50E-09	4.54E-09
Propene	kg	x	7.64E-07	x	7.64E-07
Propene, 1,3-dichloro-	kg	x	1.60E-07	4.85E-05	4.87E-05
Radioactive species, Nuclides, unspecified	Bq	2.10E+00	1.56E+02	1.77E+03	1.93E+03

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	Total
Radium-226/kg	kg	1.37E-13	5.55E-13	7.03E-12	7.72E-12
Radium-228/kg	kg	7.01E-16	2.84E-15	3.60E-14	3.95E-14
Selenium	kg	4.03E-08	4.94E-07	4.81E-06	5.34E-06
Silver	kg	7.96E-06	3.22E-05	4.08E-04	4.48E-04
Simazine	kg	x	9.49E-14	1.84E-11	1.85E-11
Sodium	kg	3.86E-02	1.43E-01	1.98E+00	2.16E+00
Sodium, ion	kg	x	1.31E-02	x	1.31E-02
Solids, inorganic	kg	2.99E-12	3.29E-10	2.60E-09	2.94E-09
Solved solids	kg	x	5.74E-02	x	5.74E-02
Solved substances, inorganic	kg	x	2.74E-08	8.34E-06	8.37E-06
Strontium	kg	2.07E-04	8.36E-04	1.06E-02	1.16E-02
Styrene	kg	x	1.42E-12	4.44E-12	5.86E-12
Sulfate	kg	3.06E-04	3.31E-03	3.90E-02	4.26E-02
Sulfide	kg	1.60E-07	2.61E-06	1.29E-05	1.57E-05
Sulfur	kg	1.00E-05	4.06E-05	5.15E-04	5.66E-04
Sulfuric acid	kg	x	5.31E-08	1.19E-08	6.50E-08
Surfactants	kg	x	1.66E-11	3.70E-12	2.03E-11
Suspended solids, unspecified	kg	1.78E-01	6.70E-01	1.29E+01	1.37E+01
Tar	kg	2.96E-14	3.26E-12	2.58E-11	2.91E-11
Terbufos	kg	x	1.43E-13	2.76E-11	2.77E-11
Tetradecane	kg	9.19E-08	3.72E-07	4.71E-06	5.18E-06
Thallium	kg	3.82E-08	1.27E-07	5.86E-07	7.51E-07
Tin	kg	7.73E-07	2.79E-06	2.29E-05	2.65E-05
Titanium	kg	2.79E-06	8.98E-06	4.26E-05	5.44E-05
Titanium, ion	kg	x	2.95E-07	x	2.95E-07
TOC, Total Organic Carbon	kg	x	3.84E-06	4.42E-08	3.88E-06
Toluene	kg	6.01E-06	2.43E-05	3.08E-04	3.39E-04
Trifluralin	kg	x	5.17E-10	1.57E-07	1.58E-07
Vanadium	kg	1.03E-07	4.17E-07	5.28E-06	5.80E-06
Waste water/m3	m3	x	8.29E-05	6.77E-04	7.60E-04
Xylene	kg	3.21E-06	1.29E-05	1.60E-04	1.76E-04
Yttrium	kg	2.56E-08	1.03E-07	1.31E-06	1.44E-06
Zinc	kg	6.76E-06	2.44E-05	1.35E-04	1.67E-04
Zinc, ion	kg	x	1.82E-08	x	1.82E-08

Air Emissions – Economic Allocation

Table 29Air emissions released per 1 m3 of uncoated cellulosic fiberboard, North American average (economic allocation).

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
2-Chloroacetophenone	kg	4.71E-12	6.06E-12	1.94E-10	2.05E-10
2-Methyl-4-chlorophenoxyacetic acid	kg	x	1.21E-15	1.15E-11	1.15E-11
2,4-D	kg	x	6.49E-14	9.43E-09	9.43E-09
5-methyl Chrysene	kg	5.32E-13	1.70E-11	3.73E-10	3.91E-10
Acenaphthene	kg	1.23E-11	3.94E-10	8.65E-09	9.06E-09
Acenaphthylene	kg	6.04E-12	1.93E-10	4.24E-09	4.44E-09
Acetaldehyde	kg	1.18E-05	9.01E-05	1.99E-02	2.00E-02
Acetochlor	kg	x	9.00E-13	8.56E-09	8.56E-09
Acetone	kg	x	x	9.64E-03	9.64E-03
Acetophenone	kg	1.01E-11	1.30E-11	4.16E-10	4.39E-10
Acrolein	kg	1.43E-06	5.23E-06	7.08E-03	7.08E-03
Alachlor	kg	x	8.86E-14	8.43E-10	8.43E-10
Aldehydes, unspecified	kg	3.54E-05	7.24E-05	1.40E-04	2.48E-04
Aldicarb	kg	x	x	2.99E-05	2.99E-05
alpha-Pinene	kg	x	x	1.10E-01	1.10E-01
Ammonia	kg	8.39E-05	8.82E-05	6.25E-03	6.42E-03
Ammonium chloride	kg	6.77E-08	2.55E-06	5.90E-05	6.16E-05
Anthracene	kg	5.08E-12	1.62E-10	3.56E-09	3.73E-09
Antimony	kg	4.35E-10	1.40E-08	3.05E-07	3.20E-07
Arsenic	kg	1.35E-08	3.33E-07	8.90E-06	9.25E-06
Ash	kg	x	x	2.72E-05	2.72E-05
Atrazine	kg	x	1.75E-12	1.67E-08	1.67E-08
Azinphos-methyl	kg	x	x	6.98E-06	6.98E-06
Barium	kg	x	1.87E-07	x	1.87E-07
Bentazone	kg	x	7.15E-15	6.81E-11	6.81E-11
Benzene	kg	1.44E-05	1.04E-05	2.42E-03	2.44E-03
Benzene, chloro-	kg	1.48E-11	1.91E-11	6.10E-10	6.44E-10
Benzene, ethyl-	kg	6.32E-11	1.98E-09	3.46E-09	5.51E-09
Benzo(a)anthracene	kg	1.93E-12	6.18E-11	1.36E-09	1.42E-09
Benzo(a)pyrene	kg	9.18E-13	2.93E-11	6.44E-10	6.75E-10
Benzo(b,j,k)fluoranthene	kg	2.66E-12	8.50E-11	1.87E-09	1.95E-09
Benzo(g,h,i)perylene	kg	6.53E-13	2.09E-11	4.58E-10	4.79E-10
Benzo(ghi)perylene	kg	x	7.96E-16	x	7.96E-16

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Benzyl chloride	kg	4.71E-10	6.06E-10	1.94E-08	2.05E-08
Beryllium	kg	6.74E-10	1.74E-08	1.65E-06	1.67E-06
Biphenyl	kg	4.11E-11	1.31E-09	1.96E-04	1.96E-04
Bromoform	kg	2.62E-11	3.38E-11	1.08E-09	1.14E-09
Bromoxynil	kg	x	1.57E-14	1.49E-10	1.49E-10
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	kg	5.40E-05	1.35E-04	1.46E-02	1.48E-02
Butadiene	kg	6.00E-07	3.80E-07	7.28E-07	1.71E-06
Cadmium	kg	3.40E-09	5.13E-08	2.72E-06	2.78E-06
Carbaryl	kg	x	x	8.16E-06	8.16E-06
Carbofuran	kg	x	1.34E-14	2.00E-05	2.00E-05
Carbon dioxide	kg	8.66E-02	5.37E-02	2.12E+00	2.26E+00
Carbon dioxide, biogenic	kg	2.40E-03	1.01E+00	4.56E+01	4.66E+01
Carbon dioxide, fossil	kg	2.86E+00	9.95E+00	2.44E+02	2.57E+02
Carbon disulfide	kg	8.74E-11	1.13E-10	3.61E-09	3.81E-09
Carbon monoxide	kg	6.27E-06	1.50E-03	4.63E-02	4.78E-02
Carbon monoxide, biogenic	kg	x	1.51E-03	7.95E-02	8.10E-02
Carbon monoxide, fossil	kg	2.60E-02	3.94E-02	2.27E-01	2.93E-01
Chloride	kg	1.84E-12	7.32E-11	1.66E-09	1.74E-09
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	kg	x	1.66E-10	1.02E-08	1.04E-08
Chlorine	kg	x	3.32E-07	6.75E-09	3.38E-07
Chloroform	kg	3.97E-11	5.11E-11	1.64E-09	1.73E-09
Chlorothalonil	kg	x	x	6.45E-04	6.45E-04
Chlorpyrifos	kg	x	1.03E-13	9.82E-10	9.82E-10
Chromium	kg	9.80E-09	2.20E-07	1.16E-04	1.17E-04
Chromium VI	kg	1.91E-09	6.10E-08	1.34E-06	1.40E-06
Chrysene	kg	2.42E-12	7.72E-11	1.70E-09	1.78E-09
Cobalt	kg	1.78E-08	1.24E-07	2.08E-06	2.22E-06
Copper	kg	1.75E-10	1.66E-09	4.23E-08	4.41E-08
Cumene	kg	3.56E-12	6.20E-09	5.19E-03	5.19E-03
Cyanazine	kg	x	1.55E-14	1.47E-10	1.47E-10
Cyanide	kg	1.68E-09	2.17E-09	6.93E-08	7.32E-08
Diazinon	kg	x	x	3.80E-07	3.80E-07
Dicamba	kg	x	9.11E-14	8.67E-10	8.67E-10
Dimethenamid	kg	x	2.15E-13	2.05E-09	2.05E-09
Dimethyl ether	kg	x	4.48E-11	x	4.48E-11
Dinitrogen monoxide	kg	5.09E-04	4.23E-04	5.30E-02	5.39E-02
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	5.79E-14	8.06E-13	1.47E-11	1.56E-11

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	x	7.75E-17	x	7.75E-17
Dipropylthiocarbamic acid S-ethyl ester	kg	x	1.47E-13	1.98E-04	1.98E-04
Disulfoton	kg	x	x	3.22E-05	3.22E-05
Endosulfan	kg	x	x	1.54E-05	1.54E-05
Ethane, 1,1,1-trichloro-, HCFC-140	kg	9.52E-11	1.82E-10	8.40E-10	1.12E-09
Ethane, 1,2-dibromo-	kg	8.07E-13	1.05E-12	3.33E-11	3.52E-11
Ethane, 1,2-dichloro-	kg	2.69E-11	3.46E-11	1.11E-09	1.17E-09
Ethane, chloro-	kg	2.82E-11	3.64E-11	1.16E-09	1.23E-09
Ethene, tetrachloro-	kg	1.24E-09	3.39E-08	7.37E-07	7.72E-07
Ethene, trichloro-	kg	x	1.39E-11	1.72E-11	3.11E-11
Ethoprop	kg	x	x	7.45E-05	7.45E-05
Ethylene oxide	kg	x	6.73E-10	1.98E-09	2.65E-09
Fluoranthene	kg	1.72E-11	5.48E-10	1.20E-08	1.26E-08
Fluorene	kg	2.20E-11	7.03E-10	1.54E-08	1.62E-08
Fluoride	kg	1.01E-06	7.01E-07	2.59E-06	4.30E-06
Formaldehyde	kg	1.83E-05	3.43E-05	1.69E-02	1.70E-02
Furan	kg	1.07E-13	3.77E-12	8.40E-11	8.79E-11
Glyphosate	kg	x	1.93E-13	4.69E-06	4.69E-06
HAPs	kg	x	2.93E-06	1.55E-04	1.57E-04
HAPS, unspecified	kg	x	8.14E-07	x	8.14E-07
Heat, waste	MJ	x	1.70E-03	2.53E+01	2.53E+01
Hexane	kg	4.50E-11	5.80E-11	1.86E-09	1.96E-09
Hydrazine, methyl-	kg	1.14E-10	1.47E-10	4.72E-09	4.98E-09
Hydrocarbons, unspecified	kg	3.91E-07	1.47E-05	1.28E-02	1.28E-02
Hydrogen	kg	x	8.59E-10	5.05E-08	5.14E-08
Hydrogen chloride	kg	3.05E-05	9.34E-04	2.04E-02	2.14E-02
Hydrogen fluoride	kg	3.59E-06	1.16E-04	1.03E-02	1.05E-02
Hydrogen sulfide	kg	5.95E-14	2.37E-12	5.38E-11	5.62E-11
Indeno(1,2,3-cd)pyrene	kg	1.47E-12	4.71E-11	1.03E-09	1.08E-09
Iron	kg	x	1.87E-07	x	1.87E-07
Isophorone	kg	3.90E-10	5.02E-10	1.61E-08	1.70E-08
Isoprene	kg	6.04E-05	2.40E-03	5.45E-02	5.70E-02
Kerosene	kg	3.24E-08	1.22E-06	2.83E-05	2.95E-05
Lead	kg	1.69E-08	4.87E-07	8.39E-05	8.44E-05
Limonene	kg	x	x	7.63E-03	7.63E-03
Linuron	kg	x	x	8.66E-06	8.66E-06
Magnesium	kg	2.66E-07	8.50E-06	1.87E-04	1.95E-04
Mancozeb	kg	x	x	4.98E-04	4.98E-04

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Manganese	kg	1.99E-08	7.87E-07	2.39E-05	2.47E-05
Mercaptans, unspecified	kg	1.46E-07	1.87E-07	6.01E-06	6.35E-06
Mercury	kg	3.45E-09	6.96E-08	1.22E-05	1.23E-05
Metals, unspecified	kg	6.83E-15	3.38E-09	3.20E-10	3.70E-09
Metam-sodium dihydrate	kg	x	x	2.94E-03	2.94E-03
Methane	kg	5.22E-03	1.71E-02	6.96E-01	7.19E-01
Methane, biogenic	kg	x	1.04E-05	5.49E-04	5.59E-04
Methane, bromo-, Halon 1001	kg	1.08E-10	1.39E-10	4.44E-09	4.68E-09
Methane, chlorodifluoro-, HCFC-22	kg	x	5.60E-15	1.64E-14	2.21E-14
Methane, chlorotrifluoro-, CFC-13	kg	x	5.32E-14	1.56E-13	2.09E-13
Methane, dichloro-, HCC-30	kg	2.02E-08	2.70E-07	5.39E-06	5.68E-06
Methane, dichlorodifluoro-, CFC-12	kg	1.01E-10	2.04E-10	3.52E-10	6.57E-10
Methane, fossil	kg	5.02E-04	1.10E-03	8.41E-02	8.57E-02
Methane, monochloro-, R-40	kg	3.56E-10	4.59E-10	1.47E-08	1.55E-08
Methane, tetrachloro-, CFC-10	kg	1.01E-11	5.03E-11	3.57E-10	4.17E-10
Methanol	kg	x	7.70E-05	6.26E-02	6.27E-02
Methyl ethyl ketone	kg	2.62E-10	3.38E-10	2.02E-03	2.02E-03
Methyl methacrylate	kg	1.34E-11	1.73E-11	5.55E-10	5.86E-10
Metolachlor	kg	x	7.11E-13	2.92E-05	2.92E-05
Metribuzin	kg	x	3.29E-15	3.51E-05	3.51E-05
N-Nitrodimethylamine	kg	x	3.11E-12	1.42E-03	1.42E-03
Naphthalene	kg	3.77E-09	1.52E-07	1.02E-03	1.02E-03
Nickel	kg	2.24E-07	9.02E-07	1.15E-04	1.16E-04
Nitrogen oxides	kg	5.13E-02	7.19E-02	6.02E-01	7.25E-01
Nitrogen, total	kg	1.96E-05	1.21E-05	1.15E-05	4.32E-05
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.72E-03	3.76E-03	1.04E-02	1.59E-02
Organic acids	kg	2.49E-10	9.38E-09	2.17E-07	2.27E-07
Organic substances, unspecified	kg	1.50E-07	1.39E-05	2.02E-04	2.16E-04
Other Organic	kg	x	9.87E-08	5.21E-06	5.30E-06
Oxamyl	kg	x	x	8.19E-06	8.19E-06
PAH, polycyclic aromatic hydrocarbons	kg	2.58E-06	1.63E-06	3.57E-06	7.78E-06
Paraquat	kg	x	1.44E-14	3.30E-06	3.30E-06
Parathion, methyl	kg	x	1.09E-14	2.14E-06	2.14E-06
Particulates	kg	x	2.19E-11	x	2.19E-11
Particulates, < 10 um	kg	x	2.89E-04	1.84E-01	1.84E-01
Particulates, < 2.5 um	kg	x	4.60E-04	4.85E-02	4.90E-02
Particulates, > 10 um	kg	x	8.98E-04	6.27E-05	9.60E-04
Particulates, > 2.5 um, and < 10um	kg	1.57E-03	1.69E-03	1.48E-01	1.51E-01

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Particulates, unspecified	kg	3.29E-04	3.03E-03	2.95E-01	2.98E-01
Pendimethalin	kg	x	7.40E-14	2.11E-05	2.11E-05
Permethrin	kg	x	6.65E-15	1.70E-06	1.70E-06
Phenanthrene	kg	6.53E-11	2.09E-09	5.35E-05	5.35E-05
Phenol	kg	1.08E-11	1.99E-06	3.95E-03	3.95E-03
Phenols, unspecified	kg	1.04E-08	4.66E-08	6.26E-07	6.83E-07
Phorate	kg	x	3.41E-15	1.11E-04	1.11E-04
Phosphate	kg	4.47E-07	2.76E-07	4.93E-09	7.28E-07
Phthalate, dioctyl-	kg	4.91E-11	6.32E-11	2.02E-09	2.14E-09
Polycyclic organic matter, unspecified	kg	x	1.35E-13	3.97E-13	5.33E-13
Potassium	kg	x	3.31E-05	x	3.31E-05
Propanal	kg	2.55E-10	6.84E-07	1.40E-02	1.40E-02
Propene	kg	3.96E-05	2.51E-05	4.80E-05	1.13E-04
Propene, 1,3-dichloro-	kg	x	x	1.41E-03	1.41E-03
Propylene oxide	kg	x	1.63E-09	5.16E-10	2.15E-09
Pyrene	kg	7.98E-12	2.55E-10	5.60E-09	5.86E-09
Radioactive species, unspecified	Bq	1.33E+03	4.37E+04	9.58E+05	1.00E+06
Radionuclides (Including Radon)	kg	1.81E-06	6.84E-05	1.58E-03	1.65E-03
Selenium	kg	3.36E-08	1.01E-06	3.24E-05	3.35E-05
Simazine	kg	x	4.67E-14	4.44E-10	4.44E-10
Sodium	kg	x	7.63E-07	x	7.63E-07
Styrene	kg	1.68E-11	2.17E-11	6.93E-10	7.32E-10
Sulfur	kg	x	2.18E-10	1.32E-06	1.32E-06
Sulfur dioxide	kg	4.95E-03	3.35E-02	2.30E+00	2.34E+00
Sulfur monoxide	kg	2.85E-03	6.02E-03	1.41E-02	2.29E-02
Sulfur oxides	kg	x	1.37E-04	4.26E-04	5.63E-04
Sulfur, total reduced	kg	x	1.74E-08	x	1.74E-08
Sulfuric acid, dimethyl ester	kg	3.23E-11	4.16E-11	1.33E-09	1.41E-09
t-Butyl methyl ether	kg	2.35E-11	3.03E-11	9.71E-10	1.02E-09
Tar	kg	2.07E-12	8.24E-11	1.87E-09	1.95E-09
Terbufos	kg	x	1.16E-13	1.11E-09	1.11E-09
TOC, Total Organic Carbon	kg	x	1.69E-10	x	1.69E-10
Toluene	kg	6.27E-06	3.99E-06	1.12E-03	1.13E-03
Toluene, 2,4-dinitro-	kg	1.88E-13	2.42E-13	7.77E-12	8.20E-12
Trifluralin	kg	x	x	4.56E-06	4.56E-06
Vinyl acetate	kg	5.11E-12	6.58E-12	2.11E-10	2.22E-10
VOC, volatile organic compounds	kg	1.47E-03	4.32E-03	2.77E-01	2.82E-01
Wood (dust)	kg	x	5.19E-04	1.39E-02	1.44E-02

Substance	Unit	Forestry Operations	Wood residue Production	Cellulosic fiberboard Production	TOTAL
Xylene	kg	4.37E-06	2.78E-06	5.31E-06	1.25E-05
Zinc	kg	3.61E-07	4.11E-07	2.96E-07	1.07E-06

Water Emissions – Economic Allocation

Table 30 Water emissions released per 1 m3 of uncoated cellulosic fiberboard, North American average (economic allocation).

Substance	Unit	Forestry Operations	Wood Residue Production	Cellulosic Fiberboard Production	Total
2-Hexanone	kg	2.48E-08	5.21E-08	1.32E-06	1.39E-06
2-Methyl-4-chlorophenoxyacetic acid	kg	x	5.19E-17	4.94E-13	4.94E-13
2-Propanol	kg	x	1.63E-11	9.89E-10	1.01E-09
2,4-D	kg	x	2.78E-15	5.55E-10	5.55E-10
4-Methyl-2-pentanone	kg	1.59E-08	3.36E-08	8.47E-07	8.97E-07
Acetaldehyde	kg	x	7.09E-10	2.08E-09	2.79E-09
Acetochlor	kg	x	3.86E-14	3.67E-10	3.67E-10
Acetone	kg	3.79E-08	7.98E-08	2.02E-06	2.13E-06
Acid as H+	kg	x	x	7.35E-05	7.35E-05
Acidity, unspecified	kg	x	4.54E-12	3.09E-13	4.84E-12
Acids, unspecified	kg	3.87E-11	9.38E-09	6.12E-07	6.21E-07
Alachlor	kg	x	3.80E-15	3.61E-11	3.61E-11
Aldicarb	kg	x	x	1.79E-06	1.79E-06
Aluminium	kg	2.91E-04	6.12E-04	5.15E-03	6.06E-03
Aluminum	kg	x	6.59E-08	x	6.59E-08
Ammonia	kg	6.76E-05	1.42E-04	2.60E-03	2.81E-03
Ammonia, as N	kg	1.94E-11	7.73E-10	1.75E-08	1.83E-08
Ammonium, ion	kg	1.45E-08	7.62E-07	-1.15E-05	-1.07E-05
Antimony	kg	1.81E-07	3.70E-07	2.88E-06	3.43E-06
Arsenic	kg	1.85E-06	2.65E-06	4.57E-05	5.02E-05
Arsenic, ion	kg	x	1.54E-11	x	1.54E-11
Atrazine	kg	x	7.51E-14	7.15E-10	7.15E-10
Azinphos-methyl	kg	x	x	4.19E-07	4.19E-07
Barium	kg	4.00E-03	8.16E-03	7.02E-02	8.24E-02
Bentazone	kg	x	3.07E-16	2.92E-12	2.92E-12
Benzene	kg	6.36E-06	1.34E-05	3.38E-04	3.58E-04
Benzene, 1-methyl-4-(1-methylethyl)-	kg	3.79E-10	7.98E-10	2.01E-08	2.13E-08
Benzene, ethyl-	kg	3.58E-07	7.54E-07	1.90E-05	2.01E-05

Substance	Unit	Forestry Operations	Wood Residue Production	Cellulosic Fiberboard Production	Total
Benzene, pentamethyl-	kg	2.84E-10	5.98E-10	1.51E-08	1.60E-08
Benzenes, alkylated, unspecified	kg	1.59E-07	3.24E-07	2.52E-06	3.00E-06
Benzo(a)pyrene	kg	x	1.45E-10	2.38E-08	2.39E-08
Benzoic acid	kg	3.85E-06	8.10E-06	2.05E-04	2.16E-04
Beryllium	kg	5.50E-08	1.14E-07	2.09E-06	2.26E-06
Biphenyl	kg	1.03E-08	2.10E-08	1.63E-07	1.94E-07
BOD5, Biological Oxygen Demand	kg	6.89E-04	1.48E-03	3.07E-01	3.09E-01
Boron	kg	1.19E-05	2.52E-05	6.33E-04	6.70E-04
Bromide	kg	8.13E-04	1.71E-03	4.32E-02	4.57E-02
Bromoxynil	kg	x	4.06E-16	3.86E-12	3.86E-12
Cadmium	kg	4.28E-07	4.92E-07	6.81E-06	7.73E-06
Cadmium, ion	kg	x	2.21E-09	x	2.21E-09
Calcium	kg	1.22E-02	2.57E-02	6.48E-01	6.86E-01
Calcium, ion	kg	x	2.11E-07	x	2.11E-07
Carbaryl	kg	x	x	4.89E-07	4.89E-07
Carbofuran	kg	x	5.74E-16	1.20E-06	1.20E-06
CFCs, unspecified	kg	x	1.63E-11	9.89E-10	1.01E-09
Chloride	kg	1.37E-01	2.88E-01	7.28E+00	7.71E+00
Chlorothalonil	kg	x	x	2.30E-05	2.30E-05
Chlorpyrifos	kg	x	4.42E-15	4.21E-11	4.21E-11
Chromate	kg	x	3.44E-10	1.58E-11	3.60E-10
Chromium	kg	8.67E-06	1.58E-05	3.26E-05	5.71E-05
Chromium III	kg	8.32E-07	1.82E-06	9.68E-05	9.95E-05
Chromium VI	kg	3.12E-08	6.29E-08	1.09E-07	2.03E-07
Chromium, ion	kg	x	3.08E-11	x	3.08E-11
Cobalt	kg	8.40E-08	1.77E-07	4.47E-06	4.73E-06
COD, Chemical Oxygen Demand	kg	1.28E-03	2.70E-03	2.64E-01	2.68E-01
Copper	kg	1.59E-06	2.91E-06	4.39E-05	4.84E-05
Copper, ion	kg	x	2.84E-11	x	2.84E-11
Cumene	kg	x	1.49E-08	x	1.49E-08
Cyanazine	kg	x	6.63E-16	6.31E-12	6.31E-12
Cyanide	kg	2.74E-10	1.72E-08	2.74E-06	2.75E-06
Decane	kg	1.11E-07	2.33E-07	5.88E-06	6.22E-06
Detergent, oil	kg	3.27E-06	6.93E-06	1.99E-04	2.09E-04
Diazinon	kg	x	x	2.28E-08	2.28E-08
Dibenzofuran	kg	7.21E-10	1.52E-09	3.83E-08	4.06E-08
Dibenzothiophene	kg	6.16E-10	1.29E-09	3.16E-08	3.35E-08
Dicamba	kg	x	3.90E-15	3.72E-11	3.72E-11

Substance	Unit	Forestry Operations	Wood Residue Production	Cellulosic Fiberboard Production	Total
Dimethenamid	kg	x	9.22E-15	8.78E-11	8.78E-11
Dipropylthiocarbamic acid S-ethyl ester	kg	x	3.81E-15	7.09E-06	7.09E-06
Dissolved organics	kg	x	x	4.70E-05	4.70E-05
Disulfoton	kg	x	2.28E-16	1.15E-06	1.15E-06
Diuron	kg	x	6.39E-17	6.08E-13	6.08E-13
DOC, Dissolved Organic Carbon	kg	1.19E-13	2.74E-08	1.07E-10	2.75E-08
Docosane	kg	4.06E-09	8.54E-09	2.16E-07	2.28E-07
Dodecane	kg	2.10E-07	4.42E-07	1.12E-05	1.18E-05
Eicosane	kg	5.77E-08	1.22E-07	3.07E-06	3.25E-06
Endosulfan	kg	x	x	9.26E-07	9.26E-07
Ethoprop	kg	x	x	2.66E-06	2.66E-06
Fluorene	kg	x	1.33E-14	3.89E-14	5.22E-14
Fluorene, 1-methyl-	kg	4.32E-10	9.09E-10	2.29E-08	2.43E-08
Fluorenes, alkylated, unspecified	kg	9.22E-09	1.88E-08	1.46E-07	1.74E-07
Fluoride	kg	2.48E-03	1.55E-03	2.34E-04	4.26E-03
Fluorine	kg	4.59E-09	9.37E-09	8.48E-08	9.87E-08
Furan	kg	x	5.99E-13	3.63E-11	3.69E-11
Glyphosate	kg	x	8.29E-15	2.81E-07	2.81E-07
Hexadecane	kg	2.29E-07	4.82E-07	1.22E-05	1.29E-05
Hexanoic acid	kg	7.97E-07	1.68E-06	4.24E-05	4.48E-05
Hydrocarbons, unspecified	kg	1.49E-13	6.05E-10	3.64E-08	3.70E-08
Iron	kg	5.92E-04	1.26E-03	1.47E-02	1.66E-02
Lead	kg	2.46E-06	4.56E-06	6.99E-05	7.70E-05
Lead-210/kg	kg	3.94E-16	8.30E-16	2.10E-14	2.22E-14
Linuron	kg	x	x	5.20E-07	5.20E-07
Lithium	kg	7.49E-04	1.87E-03	2.02E-01	2.04E-01
Lithium, ion	kg	x	6.32E-08	x	6.32E-08
m-Xylene	kg	1.15E-07	2.42E-07	6.11E-06	6.47E-06
Magnesium	kg	2.38E-03	5.02E-03	1.27E-01	1.34E-01
Mancozeb	kg	x	x	1.78E-05	1.78E-05
Manganese	kg	4.22E-06	2.29E-05	7.74E-04	8.01E-04
Mercury	kg	1.58E-08	1.50E-08	6.68E-08	9.75E-08
Metallic ions, unspecified	kg	1.81E-12	9.71E-08	8.53E-09	1.06E-07
Metam-sodium dihydrate	kg	x	x	1.76E-04	1.76E-04
Methane, monochloro-, R-40	kg	1.53E-10	3.21E-10	8.12E-09	8.59E-09
Methyl ethyl ketone	kg	3.05E-10	6.43E-10	1.62E-08	1.72E-08
Metolachlor	kg	x	3.05E-14	1.75E-06	1.75E-06
Metribuzin	kg	x	1.41E-16	2.10E-06	2.10E-06

Substance	Unit	Forestry Operations	Wood Residue Production	Cellulosic Fiberboard Production	Total
Molybdenum	kg	8.72E-08	1.84E-07	4.64E-06	4.91E-06
n-Hexacosane	kg	2.53E-09	5.33E-09	1.35E-07	1.42E-07
Naphthalene	kg	6.91E-08	1.44E-07	3.48E-06	3.69E-06
Naphthalene, 2-methyl-	kg	6.01E-08	1.26E-07	3.19E-06	3.38E-06
Naphthalenes, alkylated, unspecified	kg	2.61E-09	5.31E-09	4.13E-08	4.92E-08
Nickel	kg	1.39E-06	2.28E-06	3.67E-05	4.03E-05
Nickel, ion	kg	x	3.59E-16	x	3.59E-16
Nitrate	kg	1.30E-14	9.15E-10	5.49E-08	5.58E-08
Nitrate compounds	kg	5.24E-13	2.08E-11	4.73E-10	4.95E-10
Nitric acid	kg	1.18E-09	4.68E-08	1.06E-06	1.11E-06
Nitrogen, total	kg	3.60E-08	1.39E-06	1.15E-02	1.15E-02
o-Cresol	kg	1.09E-07	2.30E-07	5.80E-06	6.14E-06
o-Xylene	kg	x	2.82E-14	8.28E-14	1.11E-13
Octadecane	kg	5.66E-08	1.19E-07	3.01E-06	3.18E-06
Oils, unspecified	kg	8.54E-05	1.83E-04	1.92E-02	1.95E-02
Organic substances, unspecified	kg	x	1.56E-07	5.65E-08	2.13E-07
Oxamyl	kg	x	x	2.92E-07	2.92E-07
p-Cresol	kg	1.18E-07	2.48E-07	6.26E-06	6.62E-06
p-Xylene	kg	x	2.82E-14	8.28E-14	1.11E-13
Paraquat	kg	x	6.17E-16	1.98E-07	1.98E-07
Parathion, methyl	kg	x	4.66E-16	1.28E-07	1.28E-07
Pendimethalin	kg	x	3.17E-15	1.26E-06	1.26E-06
Permethrin	kg	x	2.85E-16	1.02E-07	1.02E-07
Phenanthrene	kg	9.73E-10	2.00E-09	2.80E-08	3.10E-08
Phenanthrenes, alkylated, unspecified	kg	1.08E-09	2.20E-09	1.71E-08	2.04E-08
Phenol	kg	1.38E-06	2.78E-06	6.13E-06	1.03E-05
Phenol, 2,4-dimethyl-	kg	1.06E-07	2.24E-07	5.65E-06	5.98E-06
Phenols, unspecified	kg	5.04E-07	1.17E-06	8.48E-05	8.65E-05
Phorate	kg	x	8.81E-17	3.96E-06	3.96E-06
Phosphate	kg	1.87E-03	1.16E-03	2.44E-05	3.05E-03
Phosphorus	kg	x	6.12E-10	3.67E-07	3.67E-07
Phosphorus compounds, unspecified	kg	x	1.63E-12	4.29E-04	4.29E-04
Phosphorus, total	kg	x	1.98E-08	1.20E-06	1.22E-06
Process solvents, unspecified	kg	x	5.99E-11	3.63E-09	3.69E-09
Propene	kg	x	5.48E-09	x	5.48E-09
Propene, 1,3-dichloro-	kg	x	x	5.03E-05	5.03E-05
Radioactive species, Nuclides, unspecified	Bq	2.10E+00	7.93E+01	1.83E+03	1.91E+03
Radium-226/kg	kg	1.37E-13	2.89E-13	7.29E-12	7.71E-12

Substance	Unit	Forestry Operations	Wood Residue Production	Cellulosic Fiberboard Production	Total
Radium-228/kg	kg	7.01E-16	1.48E-15	3.73E-14	3.95E-14
Selenium	kg	4.03E-08	2.63E-07	4.98E-06	5.29E-06
Silver	kg	7.96E-06	1.68E-05	4.23E-04	4.47E-04
Simazine	kg	x	2.00E-15	1.90E-11	1.90E-11
Sodium	kg	3.86E-02	8.13E-02	2.05E+00	2.17E+00
Sodium, ion	kg	x	6.68E-07	x	6.68E-07
Solids, inorganic	kg	2.99E-12	1.19E-10	2.70E-09	2.82E-09
Solved solids	kg	x	5.46E-05	x	5.46E-05
Solved substances, inorganic	kg	x	x	8.65E-06	8.65E-06
Strontium	kg	2.07E-04	4.35E-04	1.10E-02	1.16E-02
Styrene	kg	x	8.16E-14	4.60E-12	4.68E-12
Sulfate	kg	3.06E-04	1.69E-03	4.04E-02	4.24E-02
Sulfide	kg	1.60E-07	4.33E-07	1.34E-05	1.40E-05
Sulfur	kg	1.00E-05	2.12E-05	5.34E-04	5.65E-04
Sulfuric acid	kg	x	2.33E-08	1.23E-08	3.56E-08
Surfactants	kg	x	1.30E-12	3.83E-12	5.14E-12
Suspended solids, unspecified	kg	1.78E-01	3.74E-01	1.33E+01	1.39E+01
Tar	kg	2.96E-14	1.18E-12	2.68E-11	2.80E-11
Terbufos	kg	x	3.01E-15	2.86E-11	2.86E-11
Tetradecane	kg	9.19E-08	1.94E-07	4.89E-06	5.17E-06
Thallium	kg	3.82E-08	7.79E-08	6.08E-07	7.24E-07
Tin	kg	7.73E-07	1.60E-06	2.38E-05	2.61E-05
Titanium	kg	2.79E-06	5.68E-06	4.42E-05	5.27E-05
Titanium, ion	kg	x	1.59E-11	x	1.59E-11
TOC, Total Organic Carbon	kg	x	2.82E-08	4.59E-08	7.41E-08
Toluene	kg	6.01E-06	1.27E-05	3.20E-04	3.38E-04
Trifluralin	kg	x	x	1.63E-07	1.63E-07
Vanadium	kg	1.03E-07	2.17E-07	5.48E-06	5.80E-06
Waste water/m3	m3	x	4.67E-06	7.02E-04	7.07E-04
Xylene	kg	3.21E-06	6.75E-06	1.66E-04	1.76E-04
Yttrium	kg	2.56E-08	5.38E-08	1.36E-06	1.44E-06
Zinc	kg	6.76E-06	1.46E-05	1.40E-04	1.62E-04
Zinc, ion	kg	x	1.72E-09	x	1.72E-09

Appendix C – Substance Contribution Analysis

Table 31. Substance contribution analysis to Global Warming Potential (kg CO_2 eq.) by life cycle stage total percent basis and values are displayed.

		Mass Allocation				Economic Allocation			
Substances	Compartment type	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production
Total of all compartments		**100.00%**	3.24	21.03	271.22	**100.00%**	3.24	10.63	281.23
Carbon dioxide, fossil (CO_2)	Air	**87.94%**	2.94	19.77	237.16	**87.73%**	2.94	10.04	245.91
Methane (CH_4)	Air	**6.78%**	0.14	1.05	18.83	**6.82%**	0.14	0.47	19.52
Dinitrogen monoxide (N_2O)	Air	**5.28%**	0.15	0.21	15.23	**5.45%**	0.15	0.12	15.80
Remaining substances	Air	**0.00%**	0.00	0.00	0.00	**0.00%**	0.00	0.00	0.00

Table 32. Substance contribution[1/] analysis to Acidification (kg SO2 eq.) by life cycle stage total percent basis and values are displayed.

		Mass Allocation				Economic Allocation			
Substances	Compartment type	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production
Total of all compartments		**100.00%**	0.0420	0.1782	2.6554	**100.00%**	0.044	0.092	2.786
Sulfur dioxide	Air	79.31%	0.0050	0.0867	2.2214	80.22%	0.005	0.035	2.303
Nitrogen oxides	Air	18.15%	0.0359	0.0869	0.4064	17.35%	0.036	0.049	0.421
Ammonia	Air	0.41%	0.0002	0.0005	0.0113	0.41%	0.000	0.000	0.01
Remaining substances	Air	**2.13%**	0.0010	0.0041	0.0162	2.02%	0.003	0.007	0.05

Table 33. Substance contribution analysis to Eutrophication (kg N eq.) by life cycle stage total percent basis and values are displayed.

		Mass Allocation				Economic Allocation			
Substances	Compartment type	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production	TOTAL	Forestry Operations	Wood residue production	Cellulosic fiberboard production
Total of all compartments		**100.00%**	0.011	0.013	0.086	**100.00%**	0.007	0.006	0.058
Nitrogen oxides	air	46.51%	0.007	0.009	0.056	45.16%	0.002	0.003	0.027
Ammonia	air	1.05%	0.000	0.000	0.001	1.07%	0.000	0.000	0.001
BOD5, Biological Oxygen Demand	water	20.91%	0.000	0.000	0.015	21.78%	0.000	0.000	0.015
COD, Chemical Oxygen Demand	water	18.16%	0.000	0.000	0.013	18.84%	0.000	0.000	0.013
Phosphate	water	10.31%	0.004	0.003	0.000	10.05%	0.004	0.003	0.000
Ammonia	water	3.07%	0.000	0.000	0.002	3.09%	0.000	0.000	0.002
Other substances		0.00%	0.000	0.000	0.000	0.01%	0.000	0.000	0.000

Puettmann M, Bergman R, Oneil E. 2016a. Cradle-to-gate life-cycle assessment of cellulosic fiberboard produced in North America. CORRIM Final Report. University of Washington. Seattle, WA. January 2016. 66 p.