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CRADLE-TO-GATE LIFE-CYCLE INVENTORY OF CELLULOSIC FIBERBOARD PRODUCED IN NORTH AMERICA

CORRIM FINAL REPORT

Prepared for:

NAFA – The North American Fiberboard Association

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EXECUTIVE SUMMARY

Study Goals

The goal of this study was to gain an understanding of the environmental inputs and outputs through a cradle-to-gate life-cycle inventory (LCI) analysis of cellulosic fiberboard production in North America. Primary mill data were collected per Consortium on Research for Renewable Industrial Materials (CORRIM) Research Guidelines. Life-cycle impact assessment was beyond the scope of the study.

Method

Primary mill data were collected through a survey questionnaire mailed to cellulosic fiberboard plants. This survey tracked raw material inputs (including energy), product and by-product outputs, and pertinent emissions to water and air as well as solid waste generation. An industry standard production unit (i.e., declared unit) was incorporated and translated to a metric production unit, one cubic meter. Secondary data, such as pre-mill gate processes (e.g., wood and electricity production), were from peer-reviewed literature per CORRIM guidelines. Material and energy balances were calculated from primary and secondary data. Using these material and energy data, the LCI was constructed to conform with internationally accepted standards, whereas the LCI flows were modeled using life-cycle assessment (LCA) modeling software populated by the U.S. LCI Database.

Life-cycle Inventory

LCI results for cellulosic fiberboard are presented by three life stages: 1) forestry operations, 2) wood residue production, and 3) cellulosic fiberboard production. The majority of the raw material energy consumption occurs during cellulosic fiber production, followed by the production of the wood residue with only a very small portion arising from forestry operations.

Key Findings

Renewable biomass represented 15.5 percent of the total energy consumption for all stages of production, with 54.5 percent of the woody biomass energy consumed during cellulosic fiberboard production. The use of non-renewable fossil fuels dominated the total energy consumption profile for cellulosic fiberboard production at 72.4 percent of the 5.99 GJ/m^3 (4.34 GJ/m^3). Forestry operations consumed exclusively (0.8%) fossil fuels. The production of the wood residue used in cellulosic fiberboard represented 4.8 percent of the non-renewable fossil fuel consumption leaving the production of cellulosic fiberboard itself with about 94.4 percent or 4.10 GJ/m^3 of the non-renewable fossil fuel use. Energy consumed during starch production is included in the fossil fuel use for cellulosic fiberboard as an upstream process. In summary, to produce 1 cubic meter of cellulosic fiberboard from cradle-to-gate, 15.5 percent of the cumulative energy was from biomass (wood fuel) and 72.4 percent from non-renewable fossil fuels leaving a small portion of energy needs coming from nuclear (7.3%), hydro (4.6%), and wind, solar, and geothermal (0.2%).

Interpretation

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

Cradle-to-gate LCI results showed 270 kg fossil CO_2 were released in the production of 1 m^3 of cellulosic fiberboard. However, cellulosic fiberboard stores carbon. Carbon content for wood products is assumed to be 50% by mass of oven-dried (OD) wood. The carbon stored in the wood portion of 1.0 m^3 (244 OD kg) of cellulosic fiberboard is equivalent to 447 kg CO_2 if left to decay.

Sensitivity Analysis

A sensitivity analysis was completed per International Organization for Standardization 14040 standards to model the effects of on-site fuel switching for thermal energy generation. For cellulosic fiberboard manufacturing, thermal energy (i.e., heat) is used in several unit processes, consuming a combination of wood fuel, natural gas, and coal as fuel to generate. Changing fuel sources, also referred to as fuel switching, can have a significant effect on the type and quantity of emissions. Two alternative scenarios were developed to compare with the baseline scenario developed from the mill survey data. The two alternative scenarios were 100% natural gas and 100% purchased wood fuel. For all three scenarios, the amount of methanol, PM10, and phenol emitted was similar regardless of the fuel used because most methanol, PM10, and phenol originated in the drying of the cellulosic fiberboard. In addition, although expected, there is a stark contrast between biogenic and fossil carbon dioxide emissions for the three scenarios.

Recommendations

Several issues have been found as the result of conducting the cradle-to-gate LCI of cellulosic fiberboard with the following two issues highlighted. One issue is the use of dry feedstock (i.e., wood residue) in the cellulosic fiberboard production stage. Dry wood feedstock results in approximately twice the quantity of woody biomass energy consumed overall because these dry wood residues as a co-product of primary manufacturing are allocated environmental inputs and outputs by mass. Therefore, the energy used for drying the primary product, about 50 percent by mass is partially assigned to the co-products such as dry shavings. Purchasing undried wood feedstock would help in this endeavor. Secondly, increasing wood fuel consumption on-site would reduce fossil carbon dioxide emissions. Wood energy systems exist that are direct-fired and could replace the current natural gas direct-fired systems for the drying process thus lowering fossil GHG emissions.

ACKNOWLEDGEMENT

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BACKGROUND

CORRIM, the Consortium for Research on Renewable Industrial Materials, has derived life-cycle inventory (LCI) data for major wood products and wood production regions in the United States (U.S.) The 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 regions: 1) Pacific Northwest (PNW), 2) Southeast (SE), 3) Inland West, and 4) Northeast North Central (NE-NC). This report focuses on the average North American production of cellulosic fiberboard. No prior cellulosic fiberboard LCIs have been documented. Wood residue inputs for North American average cellulosic fiberboard production are sourced from several forms of woody biomass including roundwood in forest regions of the United States and Canada and co-products from various wood manufacturing processes along with mixed paper and construction waste. This document develops the cradle-to-gate cellulosic fiberboard LCI. LCI data are used to produce life-cycle impact assessments (LCIA). This document will serve as the basis for a LCIA necessary for the development of a North American environmental product declaration (EPD). In addition, the LCI data developed for the manufacturing life-cycle stage will be incorporated into the U.S. LCI Database (NREL 2012). Treatment of biogenic carbon was taken from the Norwegian Solid Wood Product PCR (Aasestad 2008) and the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (PCR 2013) to ensure comparability and consistency. This report does not include any LCIAs or comparative assertions. The intended audiences include life-cycle assessment (LCA) practitioners who use LCI data along with building specifiers looking for green building products with documentation.

INTRODUCTION

Documenting the environmental performance of building products is becoming widespread because of many green marketing claims made without scientific merit (i.e., green-washing). Developing environmental product declarations (EPDs) for building products is one way to accomplish this objective for scientific documentation and to counter green-washing (ISO 2006a; Bergman and Taylor 2011). LCI data are the underlying data for subsequent development of LCIAs and EPDs. EPDs are similar to nutritional labels for food. At present, there are many EPDs for North American structural wood products (AWC 2014 and CWC 2014).

To develop EPDs, the underlying LCI data must be developed from the product of interest. Using an attributional life-cycle analysis approach, LCI measures all raw material and energy inputs and outputs associated with the manufacture of a product on a per-unit basis within carefully defined system boundaries. These boundaries can be limited to only one stage within the product life cycle (e.g., gate-to-gate) although multiple LCIs can be linked together as is performed in the present study (e.g., cradle-to-gate). Additionally, multiple sequential LCI stages are usually included in a LCA. LCAs describe the total environmental impact for a particular product, referred to either as cradle-to-gate (raw material extraction to mill gate output) or as cradle-to-grave (raw material extraction to waste disposal) analysis. LCAs may also be referred to as cradle-to-gate and cradle-to-grave LCAs depending on the goal and scope of the study. The present study covered a cradle-to-gate LCI of uncoated cellulosic fiberboard produced in North America.

Description

Description of industry. For the year 2012 when the study was initiated, eight cellulosic fiberboard facilities operated in North America. These eight facilities produced 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. Board production is measured on a thousand ft^2 (92.9 m^2) at 12.7-mm basis. The panels are typically produced in 12.7 mm but are also produced at 0.781 in (19.8 mm) thicknesses as well and in widths of 4.0 feet (1.22 m) and lengths of 8.0 (2.44 m), 9 (2.74 m), and 10 feet (3.05 m). Some cellulosic fiberboard is coated with asphalt but the coating process was not included in this study. 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% 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.

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 Fibre 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 is a panel product developed to utilize industrial wood residue (Figures 1 and 2). These woody biomass residues were historically burned for energy or sent to landfills to dispose of them as waste material. 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 North American Industry Classification System (NAICS) Code 321219, reconstituted wood products, which include other wood composite products such as hardboard, medium density fiberboard, particleboard, and oriented strandboard (USCB 2012).

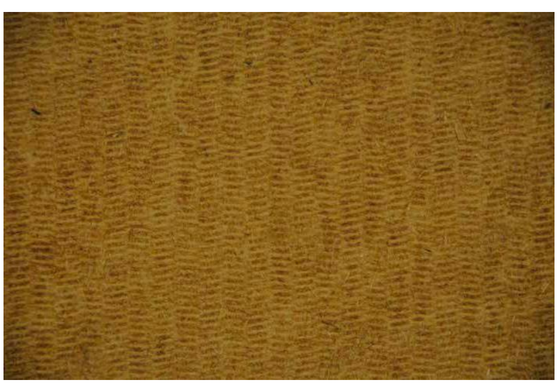

Figure 1 Uncoated cellulosic fiberboard (top view).

Figure 2 Uncoated cellulosic fiberboard (side view).

Cellulosic fiberboard is produced from industrial wood residues such as shavings, sawdust, and chips produced from primary log breakdown, from whole-tree (roundwood) chips directly and from mixed paper and construction waste. Manufacturing cellulosic fiberboard uses a wet process that produces a low-density wood composition panel and is often referred to as insulation board (Figure 3). Density for the final products ranges from 12 to 24 lb/ft^3 (190 to 380 kg/m^3) (Suchsland and Woodson 1986; USEPA 2002; Stark et al. 2010; ASTM International 2012). A thermo-mechanical process reduces the wood raw material and binds the fibers with a starch for recombination into cellulosic fiberboard. Other additives may include alum, clay, and wax. Asphalt is added in the mix to improve strength properties. In addition, cellulosic fiberboard may be coated with asphalt for exterior uses. 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; this process also releases volatile organic compounds. Water usage is of particular concern because plants without any water conservation can use 100 tons of water per ton (22,700 L/m^3) of cellulosic fiberboard (Suchsland and Woodson 1986).

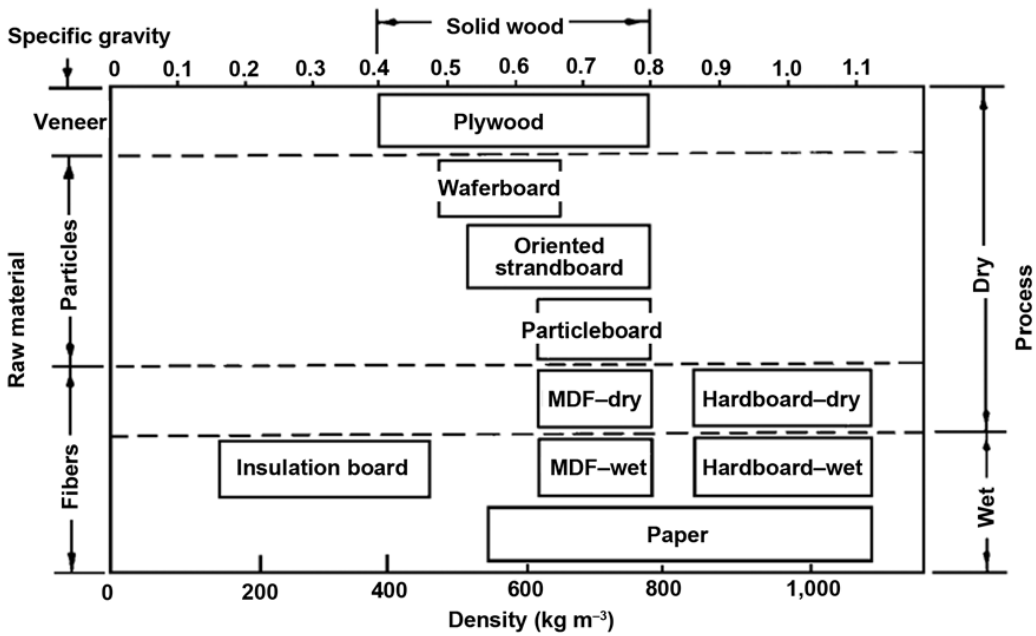

Figure 3 Classification of wood composite panels by particle size, density, and process (Suchsland and Woodson 1986).

The goal of the present study was to track and determine energy and material inputs and outputs associated with the cradle-to-gate production of uncoated cellulosic fiberboard representing average manufacturing practices in North America. The paper documents 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). Primary mill data were collected through a survey questionnaire mailed to cellulosic fiberboard plants (Appendix A). This survey tracked raw material inputs (including energy), product and by-product outputs, and pertinent emissions to water and air as well as solid waste generation. An industry standard production unit (i.e., declared unit) was incorporated that can be translated to a metric production unit. Secondary data, such as pre-mill gate processes (e.g., forestry operations and wood residue production), were from peer-reviewed literature per CORRIM guidelines (CORRIM 2014). Material and energy balances were calculated from primary and secondary data (NREL 2012). Using these material and energy data, raw material consumption and environmental outputs for a functional unit of fiberboard production, 1.0 m^3 (e.g., LCI) were modeled using the software package SimaPro 8 (Pré Consultants 2014). The scope of this study was to develop an LCI for the production of uncoated cellulosic fiberboard from a variety of wood residues using practices and technology common to North American forestry and manufacturing sectors. It covers the impacts in terms of input materials, fuels, and electricity through to the outputs of product, co-products, and emissions.

METHOD

Functional and declared unit

In accordance with the product category rule developed (PCR 2013), 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 (PCR 2013). 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 International Organization for Standardization (ISO) protocol (ISO 2006a). As the analysis does not take the declared unit to the stage of being an installed building product, no service life is assigned.

System boundaries

The system boundary begins with regeneration in the forest (i.e., cradle) and ends with cellulosic fiberboard (i.e., product gate (Figure 4)). The forest resources system boundary may include site preparation and planting seedlings; forest management, which included fertilization and thinning on a subset of hectares; final harvest with the transportation of logs to the primary breakdown facility; wood residue production during lumber manufacturing processes; transportation to the cellulosic fiberboard facility; and production of cellulosic fiberboard (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 main process representing all the steps necessary to make cellulosic fiberboard: 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, with energy generation considered as an auxiliary process. On-site energy generation can come from a boiler or direct fire. Auxiliary processes support the main processes involved in manufacturing final products. A single system approach 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.

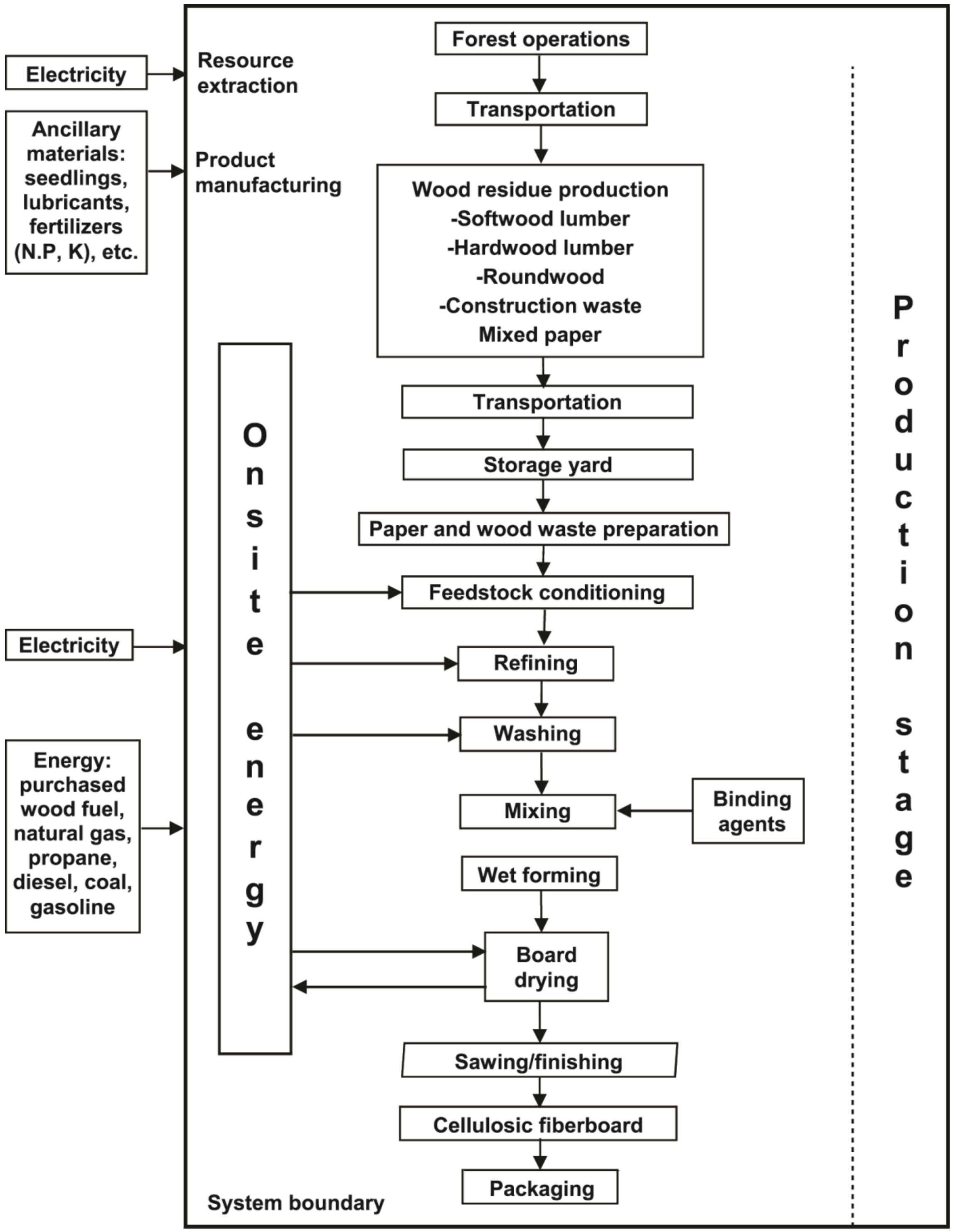

Figure 4 System boundary for cradle-to-gate production of cellulosic fiberboard.

Detailed description of data and processes

Forestry Operations. Forest operations modeled through wood residue production as inputs to cellulosic fiberboard production were based on forest resource LCI data inputs from the SE

(61%) (Johnson et al. 2005) and NE-NC (11%) hardwood (Oneil et al. 2010) U.S. forest and Canadian (28%) hardwood 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 hardwood forests, reforestation was assumed to occur using natural regeneration that did not require inputs from the technosphere for seedlings, site preparation, planting and pre-commercial thinning (Table 1), whereas these steps were included for regeneration of softwood forests in the Canadian and SE regions. The specific processes involved are reforestation; which includes seedling production, site preparation and planting, pre-commercial thinning, and fertilization and harvesting; which includes felling, skidding, processing, and loading for both commercial thinning and final harvest operations. Weighted average allocation to different processes takes into account inherent differences in site productivity and energy usage by different kinds of logging equipment. Inputs to the forest resources management LCI include seed, electricity used during greenhouse operations, fertilizer used during seedling production and stand growth, and the fuel and lubricants needed to power and maintain equipment for thinning and harvest operations. The primary output product is a log destined for 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 1.

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

		Fuel consumption per m^3			
Processes	Unit	SE	NE-NC hardwoods	Canadian	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	0.050	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

Wood Product Manufacturing. Ten main unit processes were identified in manufacturing cellulosic fiberboard ((Bergman 2014) 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, with energy generation considered an auxiliary process. All emissions (environmental outputs) and energy consumed were assigned to the cellulosic fiberboard along with the co-products (molasses, culled boards, and fines) on mass. The terms, wood and pulp fibers are used interchangeably in the present study (Suchsland and Woodson 1986; USEPA 2002; Stark et al. 2010; ASTM International 2012).

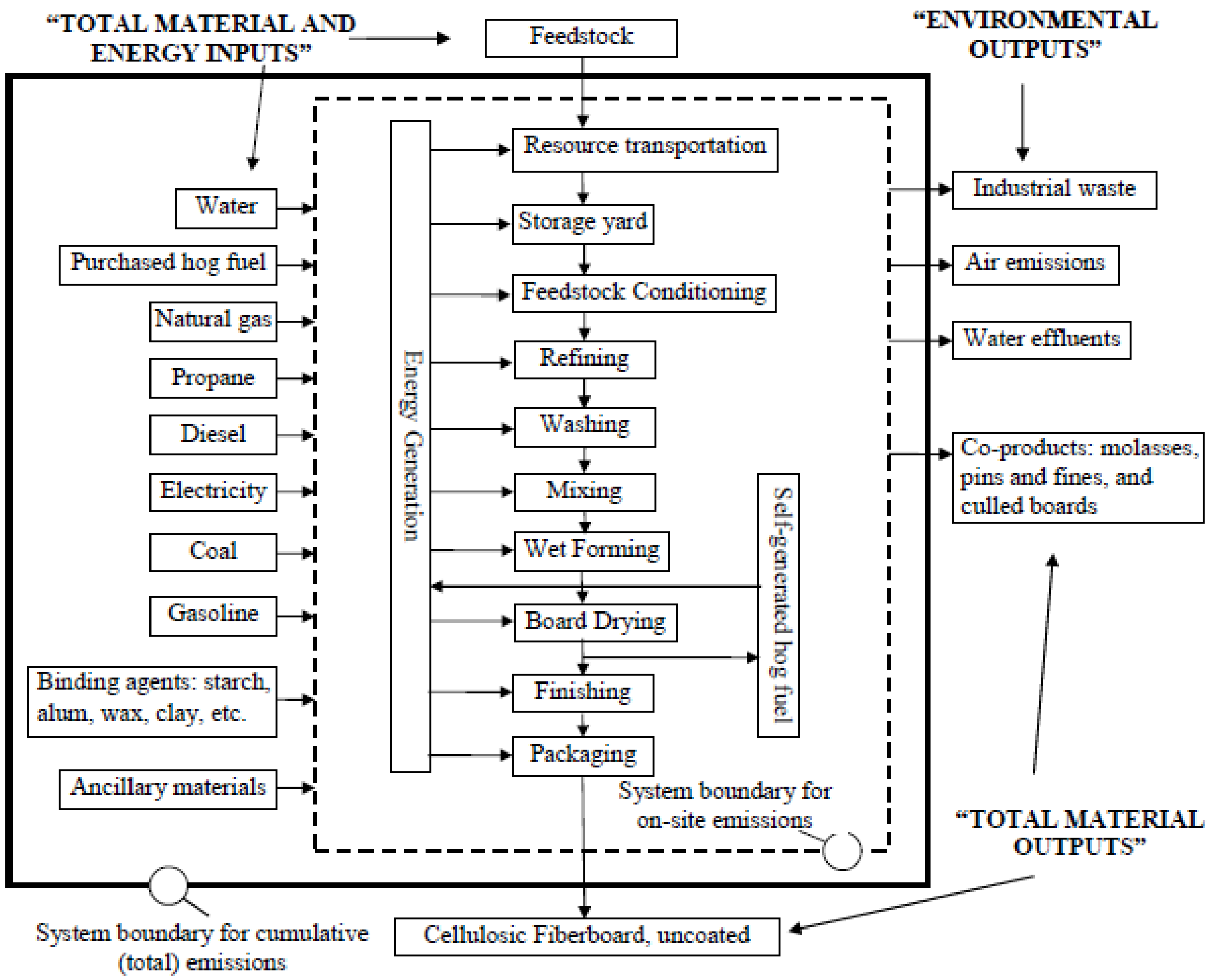

Figure 5 Process flow for the production of cellulosic fiberboard.

Resource transport

Wood raw materials are delivered to the mill by truck; the wood raw materials consists of logs, dry shavings and sawdust, and chips of various moisture contents along with construction waste and mixed paper; the moisture content of the residue can range from 10 to 100% on an oven-dry weight-basis. Based on mill surveys, the average haul distance for feedstock along with additives is shown in Table 2. Inputs include diesel fuel and outputs include fossil CO_2.

Table 2 Weighted average delivery distance (one-way) for materials to cellulosic fiberboard mill, North American average.

Material delivered to mill	Delivery distance (km)	Delivery distance (mile)
Roundwood	6.7	4.2
Chips, green	63	39
Chip, dry	63	39
Sawdust, dry	2.8	1.7
Mixed paper	10	6.0
Construction waste	29	18
Shavings, dry	33	21
Starch	670	420
Asphalt flake	270	170
Alum	130	83
Wax	360	220
Clay	1,300	810
Purchased wood fuel	0.8	0.5
Coal	17.3	10.8

Storage yard

Upon arrival at the storage yard, all wood raw materials including logs and recycled materials, construction waste, and mixed office paper were weight-scaled and moisture levels were determined. Log stackers or front-end loaders were used to transport logs and chips from the storage yard to the mill for chipping. Inputs included logs with bark, chips, recycled materials, electricity, fuel, and lubricants. Outputs included logs with bark, chips, recycled materials, and emissions from burning fossil fuels used by the storage yard machines.

Feedstock conditioning

The wood raw material arrives at the facilities in various forms and thus requires preparation before refining to generate a homogeneous form. One facility chips the incoming logs with bark attached while another facility chips clean construction waste. Chips are screened to remove over-sized chips so they may be 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 wood raw material, water, steam, and electricity and outputs include chips.

Refining

The purpose of this process is to pulp the raw wood material and the recycled materials. The process is often referred to as mechanical pulping because no chemicals are added. The raw wood material is refined through mechanically reducing the thermally softened material into fibers by shearing the wood between two rotating metal disks that separate the fibers at the lignin binder. This process is usually accomplished with pressurized disk refiners—a method for mechanically reducing wood into its individual fibers. Refining is an energy-intensive process with an average specific energy ranging from 20 to 30 hp-d/ton (250 to 380 kWh/tonne) stock produced (Suchsland and Woodson 1986). Inputs include chips, dry wood residues, mixed paper, electricity, and heat and outputs include pulp fiber and water vapor.

Washing

The pulp fibers are washed to remove wood sugars (i.e., molasses) that could reduce board quality. In addition, washing removed dirt and other foreign material. Inputs are pulp and water and outputs are pulp and water along with wood sugar and solid waste.

Mixing

During mixing, water is added to the pulp fibers along with additives for bonding the pulp fibers in stock chests. As a result, a slurry is created. 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 and output includes a low-consistency slurry along with additives.

Wet forming

The low-consistency slurry, about 2% fiber is pumped to the Fourdrinier board-forming machines where the slurry is metered unto a wire screen. Two percent consistency provides for the highest bonding strength of the final board (Lampert 1967). Gravity and vacuum applied gradually to the bottom of the wire removes the water from the mat being produced. After leaving the wire at about 25% solid fiber, the fiber mat is cut to length and trimmed by high-pressure water jets. Then the board is usually wet-pressed using continuous rollers at room temperature to remove additional water while pressing the board to its final thickness plus a shrinkage allowance for drying. Most of the collected water is recycled. Inputs include pulp, water, and electricity and outputs include a fiber mat, trim residue, water, and steam.

Board drying

Board drying is a continuous energy-intensive process. The boards of about 65 to 75% moisture are conveyed on chain-driven rollers into a heated enclosure broken into zones where the drying medium, heated air typically from direct-fired natural gas removes most of the remaining water in vapor form (i.e., steam). The zones are at different temperatures and air flows. In total, about two tonnes of water are removed per tonne of dry board. Roller dryers are 50 to 75% percent energy efficient (Jessen 1952; Suchsland and Woodson 1986). Inputs include wet boards, electricity, and combustion gases from burning natural gas and outputs include dry boards, steam, fossil carbon dioxide, and volatile organic compounds. Combustion emissions from burning natural gas were provided by the U.S. LCI Database (NREL 2012).

Finishing

Trimming reduces the dry board to final standard dimensions, typically 4.0 by 8.0 ft (1.22 by 2.44 m). Input includes untrimmed dry board and electricity and output includes final product, culled boards, and wood dust. The finished boards were not coated.

Packaging

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

Auxiliary process

The auxiliary energy process provided process (thermal) energy. Thermal energy used at the plant was provided by burning a mix of natural gas, purchased and self-generated wood fuel and coal. Natural gas used in drying boards was direct-fired. Thermal energy was also produced in the form of steam and then used in the conditioning, refining, and drying unit processes. Another major source of energy was derived from off-site (grid) electricity which released emissions off-site. These grid emissions were captured as part of the LCI. Table 3 shows the electrical grid composition for the North American production of cellulosic fiberboard. Coal (35.3%) and hydro (34.3%) power comprises most of the grid when manufacturing cellulosic fiberboard. Outputs from this upstream process included steam from the boilers, combustion gases from the drying process, solid waste (wood ash), and air emissions (e.g., CO_2, CO) from combustion.

Table 3 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.

Resource and Material Inputs

Unaccounted wood mass between input and output material flows in the production of cellulosic fiberboard based on survey data were found to be 0.6% (Table 4). The final product, uncoated cellulosic fiberboard, has an average oven-dry density of 254 kg/m^3 representing 92.1 percent wood fiber and 7.9 percent additives. Table 4 shows feedstock used in the production of the cellulosic fiberboard. Green pulp chips have the highest portion at 87 OD kg, 32.9% followed by roundwood chips at 40 OD kg, 15.0%. 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 4 Mass balance of cellulosic fiberboard manufacturing per m^3, North America.

Feedstocks	Inputs (OD kg)	Mass (%)	CoV[1] (%)	Products	Outputs (OD kg)	Mass (%)	CoV[1] (%)
Roundwood	23	8.8	–	Cellulosic fiberboard	254	96.1	11.6
Roundwood chips	40	15.0	–	Co-products			
Pulp chips, green	87	32.9	134	Culled boards, wood fuel	1.1	0.4	–
Pulp chips, dry	26	10.0	–	Molasses	5.8	2.2	–
Sawdust, dry	1	0.2	–	Pins and fines	1.9	0.7	–
Mixed paper	5	1.9	153	Other, not specified	1.5	0.6	–
Construction waste	31	11.8	204	TOTAL,CO-PRODUCTS	11	3.9	205
Back to pulper	1	0.3	–	TOTAL, OUT	265	100	12.9
Shavings, dry	30	11.3	–				
TOTAL, FEEDSTOCK	244	92.1	14.7				
Additives							
Starch	4.0	1.5	148				
Asphalt flake	10	3.9	97.7				
Alum	1.5	0.6	122				
Wax	2.9	1.1	94.1				
Carbon black	0.4	0.2	216				
Clay	1.6	0.6	204				
Sodium aluminate	0.15	0.1	–				
Other	0.02	0.0	–				
TOTAL, ADDITIVES	21	7.9	49.7				
TOTAL, IN	265	100	13.7				

[1] Weighted coefficient of variation.

Energy Inputs

Energy for the production of cellulosic fiberboard comes from electricity, woody biomass, natural gas, and coal. Woody biomass source include on-site generated and purchased wood fuels. Other fuels such as diesel, liquid propane gas (LPG), and gasoline are used to operate transport equipment within the mill. The electricity is used to operate equipment within the plant, including conveyors, refiners, fan motors, hydraulic press motors, high-pressure water jets, rollers, and emission control systems. Electricity is used throughout the process. The fuels for equipment are used for loaders and forklifts, and natural gas, coal, and wood fuels are used to heat refiners and dryers.

Emission control devices such as baghouses, cyclones, electrostatic precipitators, and wet scrubbers are used throughout the mills. Two mills have no emission control devices and no facility reported using regenerative thermal oxidizers and regenerative catalytic oxidizers.

Natural gas is the primary fuel used in the cellulosic fiberboard manufacturing process; it is used for providing process heat for digesting, refining, drying wood residues and heating steam or oil for hot rolling. Natural gas is mostly used for drying boards through direct-firing. The second largest fuel source used on-site is purchased wood fuel as very little on-site residue is available for use as wood fuel. Steam is produced by burning wood fuel along with coal in a boiler to generate thermal energy. The total fuel use for process heat is 3.80 million Btu/Msf (3,400 GJ/m^3) of which 74.7% is generated through the combustion of natural gas (Table 5), 15.3% from wood fuel, and the other 10.0% from coal. The non-wood energy component represents an opportunity for improving sustainability by substituting for it with sustainably grown wood fuel.

Boilers provide thermal energy for use on-site for the production of cellulosic fiberboard. The boilers can burn wood or fossil fuels as a fuel source. The composite cellulosic fiberboard wood boiler primarily burned purchased instead of on-site generated wood fuel (Table 6). One kg of wood material based on an oven dry basis for moisture content contained 20.9 MJ of energy. The wood-based fuel mix was 96% bark (purchased) and 4% reground culled boards (self-generated).

Table 5 Heat inputs per 1 m^3 cellulosic fiberboard, North American average.

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	54.4	1,637	74.7
Wood fuel – purchased	kg	23.7	20.9	495	14.6
Coal	kg	13.0	26.2	342	10.0
Wood fuel – self-generated	kg	1.1	20.9	24	0.7
TOTAL	MJ	–	–	3,400	100

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

Table 6 Cellulosic fiberboard wood boiler inputs and outputs, North American average.

Product	Value	Unit/m^3
Wood biomass, combusted in industrial boiler-oven dry	1.00	Kg
Avoided products		
Electricity, at grid, North America	0.0048	kWh
Materials/fuels		
Bark, purchased wood fuel	0.96	Kg
Culled boards, wood fuel	0.04	kg
Emissions to air		
Acetaldehyde	7.47E-06	kg
Acrolein	3.60E-05	kg
Antimony	7.11E-08	kg
Arsenic	1.98E-07	kg
Benzene	3.78E-05	kg
Beryllium	9.90E-09	kg
Cadmium	3.69E-08	kg
Carbon dioxide, biogenic	1.76E+00	kg
Carbon monoxide	5.40E-03	kg
Chlorine	7.11E-06	kg
Chromium	1.89E-07	kg
Cobalt	5.85E-08	kg
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	7.74E-14	kg
Formaldehyde	3.96E-05	kg
Hydrogen chloride	1.71E-04	kg
Lead	4.32E-07	kg
Manganese	1.44E-05	kg
Mercury	3.15E-08	kg

Metals, unspecified	3.85E-04	kg
Methane	1.89E-04	kg
Methane, dichloro-, HCC-30	2.61E-06	kg
Naphthalene	8.73E-07	kg
Nickel	2.97E-07	kg
Nitrogen oxides	1.17E-04	kg
Nitrogen oxides	1.98E-03	kg
Particulates, > 2.5 um, and < 10um	4.50E-03	kg
Phenols, unspecified	4.59E-07	kg
Selenium	2.52E-08	kg
Sulfur oxides	2.25E-04	kg
TOC, total organic carbon	3.68E-05	kg

Table 7 shows the detailed description of the material and energy inputs and outputs crossing the system boundary of cellulosic fiberboard. Under materials, wood feedstocks include wood material arriving at the production facilities either in roundwood form or already either fully or partially broken down into wood residues. Incoming roundwood makes up 9.5% of the total feedstock. Electricity consumed onsite was calculated to be 205 kWh/m^3.

Table 7 Unit process inputs/outputs to produce 1 m^3 of cellulosic fiberboard, North American average.

Products	**Value**	**Unit/m^3**	**Allocation (%)**
Cellulosic fiberboard	1.00	m^3	96.1
Culled boards, wood fuel	1.1	kg	0.4
Molasses	5.8	kg	2.2
Pins and fines	1.9	kg	0.7
Other, not specified	1.5	kg	0.6
Resources	**Value**	**Unit/m^3**	
Water, well, in ground	1,230.00	L	
Water, cooling, surface	943.00	L	
Water, process, surface	353.00	L	
Materials/fuels	**Value**	**Unit/m^3**	**Percentage**
Wood feedstock, average North America	183.70	kg	75.3
Wood feedstock, average North America, roundwood	23.17	kg	9.5
Recycled waste, average North America	36.98	kg	15.2
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	0.14	L	
LPG, combusted in industrial equipment	0.43	L	
Natural gas, combusted in industrial boiler, direct-fired	46.66	m^3	
Wood waste, combusted in boiler, self-generated fuel	1.14	kg	
Wood waste, combusted in boiler, purchased fuel	23.70	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	
Emissions to air	**Value**	**Unit/m^3**	
VOC, volatile organic compounds	0.21	kg	
Acetaldehyde	0.0199	kg	
Acetone	0.00964	kg	
Acrolein	0.00705	kg	
Alpha-Pinene	0.11	kg	
Benzene	0.000882	kg	
Carbon monoxide	0.0409	kg	
Cumene	0.00519	kg	
Formaldehyde	0.0164	kg	
Lead	2.64E-05	kg	
Limonene	0.00763	kg	
Mercury	0	kg	
Methanol	0.0624	kg	
Methyl ethyl ketone	0.00202	kg	
Dinitrogen monoxide (N2O)	0.0487	kg	
Particulates, < 2.5 um	0.0446	kg	
Particulates, > 2.5 um, and < 10um	0.128	kg	
Particulates, < 10 um	0.172	kg	
Particulates, unspecified	0.151	kg	
Phenol	0.00393	kg	
Propanal	0.014	kg	
Sulfur dioxide	0.000276	kg	
Toluene	0.00111	kg	
Emissions to water	**Value**	**Unit/m^3**	
BOD5, Biological Oxygen Demand	0.2712	kg	
COD, Chemical Oxygen Demand	0.2029	kg	
Oils, unspecified	0.01515	kg	
Solved solids	1.113	kg	
Suspended solids, unspecified	0.223	kg	
Waste to treatment	**Value**	**Unit/m^3**	
Waste to inert landfill	5.63	kg	
Waste to recycling	8.83	kg	

Wood residue

Wood residues come from co-products that are generated during lumber production. The attributes of wood residues vary across the major production centers of North America. Residues include softwoods from the SE and hardwoods from the SE, NE-NC, and Canada (Table 8 (Milota 2004; Bergman and Bowe 2008; Bergman and Bowe 2010; ASMI 2012)). Only the NE-NC region provides roundwood to the production of cellulosic fiberboard. The Canadian region produces the most planar shavings whereas the SE produces the most pulp chips. As shown in Table 4, pulp chips, a co-product from sawmill operations, represent the largest wood residue input at 47 percent (114 kg, oven dry) followed by roundwood chips (includes incoming roundwood), construction waste, and dry planer shavings at 26, 13, and 12 percent, respectively. The remaining 3 percent of the total wood input for cellulosic fiberboard comes from mixed paper, dry sawdust, and back to pulper. All flow analyses of wood and bark in the process were determined on an oven-dry weight basis with a green specific gravity of 0.55.

Table 8 Wood residue type and source for input for cellulosic fiberboard production, North American average.

Wood residue type	**kg/m^3**	**Percent contribution (%)**
Canada (CN)		
Pulp chips, softwood, dry, at sawmill, Canada	26.48	46
Sawdust, softwood, dry, at sawmill, PNW	0.59	1
Planer shavings, softwood, kiln dried, at planer, Canada	29.99	53
TOTAL	57.06	100
Southeast region (U.S. SE)		
Pulp chips, hardwood, green, at sawmill, U.S. SE	5.98	5
Pulp chips, softwood, green, at sawmill, U.S. SE	81.08	64
Roundwood chips, softwood, green, at mill, U.S. SE	39.59	31
TOTAL	126.65	100
Northeast-North central regions (U.S. NE-NC)		
Roundwood, hardwood, green, at mill, U.S. NE-NC	23.17	100
TOTAL	23.17	100
Recycled waste		
Construction Waste	31.22	85
Mixed Office Paper	4.97	13
Backed to pulper	0.79	2
TOTAL	36.98	100
Canada–Region	57.06	23
Southeast, U.S. – Region	126.65	52
Northeast–North central, U.S. – Region	23.17	10
Recycled waste, North America	36.98	15
TOTAL North American average	243.85	100

Packaging

Packing materials represent less than 1.0% 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 9). 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 9 Materials used in packaging and shipping per m^3 cellulosic fiberboard, North American average.

Material	Value	Unit
Wrapping material – HDPE and LDPE laminated	0.0824	kg
PET Strapping	0.0763	kg
Cardboard strap protectors	0.0118	kg
Steel strapping	0.0043	kg
Wooden spacers	1.3942	kg
Total	1.5690	kg

Cut Off Rules

According to the PCR, if the mass/energy of a flow is less 1% of the cumulative mass/energy of the model flow it may be excluded, provided its environmental relevance is minor. This analysis included all energy and mass flows for primary data.

In the primary surveys, manufacturers were asked to report total hazardous air pollutants (HAPS) specific to their wood products manufacturing process: these include formaldehyde, methanol, acrolein, acetaldehyde, phenol, and propionaldehyde (propanal). If applicable to the wood product, HAPS are reported in the LCI data results.

Data Quality Requirements

This study collected data from representative cellulosic fiberboard manufacturers in North America that use average technology for their regions. The raw wood material to produce cellulosic fiberboard comes from a variety of co-products produced in product manufacturing facilities mills in Canada and the SE and NE-NC regions of the U.S in the form of wet and dry shavings, green chips, green sawdust, and panel trim. The wood residue is comprised of many softwood species representing a mix of 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*), black spruce (*P. mariana*), and a small mix of hardwood species of yellow poplar (*Liriodendron tulipfera*), American gum *(Liquidamber styraciflua)*, quaking aspen (*Populus tremuloides*), and bigtooth aspen (*P. grandidentata*). In 2012, the cellulosic fiberboard production in North America was approximately 828,737 m^3 (NAFA 2013). For this study of cellulosic fiberboard production mills responding to surveys produced 792,865 m^3 in 2012, representing 96% of total production in North American.

Critical Review

An internal critical review of the survey procedures, data, analysis, and report was completed to assess conformance with CORRIM and ISO 14040 standards by Dr. Maureen Puettmann, WoodLife Environmental Consultants, Corvallis, Oregon.

The review provided assurances that the study methodology, data collection, and analyses were scientifically sound, and in conformance with internally accepted standards and CORRIM research protocol (ISO 2006b; ILCD 2010; CORRIM 2014).

Assumptions and Limitations

For recycled waste used as feedstock, no embodied energy from their first life was included in the analysis because if the material was not used it would have been landfilled thus only the transportation of the waste from its production site to the cellulosic fiberboard facility was included.

LIFE-CYCLE INVENTORY ANALYSIS

Data Collection

Primary data for the LCI were collected through surveys in accordance with CORRIM and ISO 14040 standards. The present study relied almost exclusively on production and emissions data provided by cellulosic fiberboard producers in North America, with some secondary data on electrical grid inputs and resource forest activities from the U.S. LCI database (Goemans 2010; NREL 2012). The survey data represents cellulosic fiberboard production in terms of input materials, electricity, fuel use, and emissions for the 2012 production year. The seven production facilities surveyed were selected to be representative of North American production practices.

Calculation Rules

Cellulosic fiberboard is most commonly reported in a thousand square foot (Msf) of 0.5-inch basis, which in SI units 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+ (Pré Consultants 2014) was used as the accounting program to track all of the materials.

Questionnaires were used to survey the cellulosic fiberboard operations to collect primary data on cellulosic fiberboard manufacturing (APPENDIX B). The primary data obtained from the surveys were weight-averaged using the formula shown below (Milota 2004):

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

Where $\bar{P}_{\text{weighted}}$ is 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 weighted coefficient of variation was calculated (NIST ITL 1996). The weighted coefficient of variation is the weighted standard deviation divided by the weighted mean:

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

$$sd_w = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x}_w)^2}{\frac{(N'-1)\sum_{i=1}^{N} w_i}{N'}}}$$

Where w_i is the weight of the i^{th} observation, N' is the number of non-zero weights, x_i is the value of the individual observation, and $\bar{x}_w$ 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 plant personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros. Any outliers were resolved by contacting mill personnel.

Allocation rules

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

LIFE-CYCLE INVENTORY DATA

Life-cycle inventory results for cellulosic fiberboard are presented by three life stages, 1) forestry operations, 2) wood residue production, and 3) cellulosic fiberboard production (Tables 10–14). The majority of the raw material energy consumption occurs during cellulosic fiber production, followed by the production of the wood residue with only a very small portion arising from forestry operations. Raw material energy requirements are presented in Table 10. Table 10 shows the raw material consumption per m^3 of cellulosic fiberboard. By mass, coal at 61.5 kg/m^3 was consumed the most. Coal was burned on-site to generate on-site thermal energy and off-site for power production. Natural gas at 43.1 kg/m^3 was used similarly to coal. Wood fuel consumption was split roughly between wood residue (45.5%) and cellulosic fiberboard production (54.5%). Most wood fuel used for wood residue production was to dry the feedstock. Drying the feedstock was not necessary for making cellulosic fiberboard but fell within the system boundary and thus needed to be accounted for.

Table 10 Raw material energy consumption per 1 m^3 of cellulosic fiberboard, North American average.

Fuel	Total	Forestry operations	Wood residue production	Cellulosic fiberboard Production
	(kg/m^3)			
Coal, in ground	61.5	0.06	3.87	57.54
Gas, natural, in ground	43.1	0.15	2.79	40.19
Oil, crude, in ground	8.4	0.87	0.80	6.77
Uranium oxide, in ore	0.00116	0.00000	0.00010	0.00106
Wood fuel	44.3	0.0	20.2	24.1

Table 11 shows the cumulative energy consumption for the cradle-to-gate production of cellulosic fiberboard. By far, cellulosic fiberboard life-cycle stage consumed the most primary energy at 5,175 MJ/m^3 (86.4%). Most of the primary energy was derived from natural gas at 2,346 MJ/m^3 and coal at 1,608 MJ/m^3 with cumulative energy consumption for all three life-cycle stages at 5,992 MJ/m^3. Wood fuel consumption was a distant third at 927 MJ/m^3 (15.5%) with 54.5% consumed on-site. Including other renewable energy sources of hydro and wind along with wood fuel, they comprise 20.3% of cumulative energy consumption.

Table 11 Cumulative energy consumption per 1 m^3 of cellulosic fiberboard, North American average (mass allocation).

Fuel	Percent (%)	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
		(kg/m^3)			
Gas, natural, in ground	39.2	2,346	8.3	151.7	2,186.3
Coal, in ground	26.8	1,608	1.4	101.3	1,505.8
Wood fuel	15.5	927	0.0	421.8	505.2
Uranium oxide, in ore	7.3	440	0.5	36.2	403.7
Oil, crude, in ground	6.4	384	39.7	36.4	308.3
Hydro	4.6	275	0.0	19.0	256.1
Wind	0.2	10	0.0	0.5	9.9
Total	100.0	5,992	49.9	766.9	5,175.2
Total (%)		100	0.8	12.8	86.4

Cellulosic fiberboard manufacturers reported many air emissions including particulate and particulate PM_{10} (less than 10 µm in size) that are emitted 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 the VOCs formaldehyde and methanol as a measure of HAPs released.

In addition, HAPs reported in surveys include acetaldehyde, acrolein, phenol, and propionaldehyde (or propanal). Table 12 lists the most pertinent along with emissions generated as a result of cellulosic fiberboard production to simplify and report on the dominant releases by mass. A complete list of all air emissions is located in Appendix C: Life-cycle inventory flows of this report.

Table 12 Air emissions released per 1 m^3 of cellulosic fiberboard, North American average.

Air Emissions	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	(kg/m^3)			
Acetaldehyde	0.0194	0.0000	0.0000	0.0193
Acetone	0.0093	0.0000	0.0000	0.0093
Acrolein	0.0076	0.0000	0.0000	0.0076
Aldehydes, unspecified	0.0002	0.0000	0.0000	0.0001
Alpha-Pinene	0.1057	0.0000	0.0000	0.1057
Benzene	0.0032	0.0000	0.0000	0.0032
Carbon dioxide, biogenic	81.7387	0.0024	37.1825	44.5538
Carbon dioxide, fossil	254.9571	2.9439	17.6520	234.3612
Carbon monoxide	0.5790	0.0260	0.0222	0.5307
Chloride	0.0000	0.0000	0.0000	0.0000
Cumene	0.0050	0.0000	0.0000	0.0050
Dinitrogen monoxide, N_20	0.0515	0.0005	0.0001	0.0509
Formaldehyde	0.0169	0.0000	0.0000	0.0169
Lead	0.0001	0.0000	0.0000	0.0001
Limonene	0.0073	0.0000	0.0000	0.0073
Mercury	0.0000	0.0000	0.0000	0.0000
Methane	0.8293	0.0057	0.0568	0.7667
Methanol	0.0600	0.0000	0.0001	0.0600
Methyl Ethyl Ketone	0.0019	0.0000	0.0000	0.0019
Nitrogen oxides	8.2166	0.0513	0.0433	8.1220
NMVOC[2]	0.0136	0.0017	0.0020	0.0099
Particulates, < 10 um	0.1653	0.0000	0.0000	0.1653
Particulates, < 2.5 um	0.0432	0.0000	0.0000	0.0432
Particulates, > 2.5 um and < 10 um	0.2472	0.0016	0.0011	0.2445
Particulates, unspecified	0.7889	0.0003	0.0909	0.6977
Phenol	0.0038	0.0000	0.0000	0.0038
Propionaldehyde (Propanal)	0.0135	0.0000	0.0000	0.0135
Sulfur dioxide	2.3095	0.0050	0.1207	2.1839
Sulfur oxides	0.0014	0.0000	0.0000	0.0014
Toluene	0.0011	0.0000	0.0000	0.0011
VOC[3]	0.2601	0.0015	0.0134	0.2453
Xylene	0.0000	0.0000	0.0000	0.0000

[1] Because of large amount of air emissions, the most pertinent along with emissions generated as a result of fiberboard production are shown. A complete list of all air emissions can be found in APPENDIX C.
[2] Non-methane volatile organic compounds, unspecified origin.
[3] Volatile organic compounds.

Most of the waterborne emissions reported by cellulosic fiberboard manufacturers are produced on-site are in shown in Table 13. For unspecified suspended solids to water, a value of 13.1

kg/m^3 cellulosic fiberboard was estimated. Most of unspecified suspended solids emission was from the process of exacting natural gas from the ground and thus did not occur at the production facilities.

Table 13 Emissions to water released per 1 m^3 of cellulosic fiberboard, North American average[1].

Water emissions	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	(kg/m^3)			
BOD5, biological oxygen demand	0.6990	0.00069	0.00272	0.69556
Chloride	8.0829	0.13697	0.55864	7.38731
COD, chemical oxygen demand	0.2623	0.00128	0.00463	0.25637
DOC, dissolved organic carbon	0.0000	0.00000	0.00000	0.00004
Lead	0.0001	0.00000	0.00001	0.00007
Oils, unspecified	0.0190	0.00009	0.00032	0.01863
Phenol	0.0000	0.00000	0.00000	0.00001
Solids, inorganic	0.0000	0.00000	0.00000	0.00000
Solved solids	1.0696	0.00000	0.00000	1.06959
Suspended solids, unspecified	13.1443	0.17792	0.70539	12.26098

[1]Because of a large amount of water emissions, the most pertinent along with emissions generated on-site are shown. A complete list of all water emissions can be found in APPENDIX C.

Solid emissions include ash generated at the boiler and in the upstream processes, primarily fuels and resins, used in cellulosic fiberboard production (Table 14). A total of 13.8 kg/m^3 solid waste was generated with 39.2% going to the landfill and the remaining portion being recycled.

Table 14 Waste to treatment per 1 m^3 of cellulosic fiberboard, North American average.

Waste to treatment	Total	Forestry operations	Wood residue production	Cellulosic fiberboard production
	(kg/m^3)			
Waste in inert landfill	5.4104	0.0000	0.0000	5.4104
Waste to recycling	8.4856	0.0000	0.0000	8.4856

CARBON

Cellulosic fiberboard stores carbon. Carbon content for wood products is assumed to be 50% by mass of OD wood. Therefore, the carbon stored in the wood portion of 1.0 m^3 (244 OD kg) of cellulosic fiberboard is equivalent to 447 kg CO_2[1] .

[1] 244 OD kg wood × (0.5 kg carbon/1.0 OD kg wood) × (44 kg CO_2/kmole/12 kg carbon/kmole) = 477 kg CO_2 eq.

SENSITIVITY ANALYSIS

Sensitivity analysis is a systematic approach for estimating the effects of the choices made concerning methods and data on the outcome of a study. Sensitivity analysis is a key component of data quality analysis and can be applied to quantify the impact of changes in assumptions or input data on study results. A sensitivity analysis was completed per ISO 14040 standards (ISO 2006b; 2006c) to model the effects of fuel switching on-site thermal energy generation. Sensitivity analysis can be useful to understand how various process parameters contribute to environmental output factors. For instance, in cellulosic fiberboard manufacturing, thermal energy (i.e., heat) is used in several unit processes, consuming a combination of wood fuel, natural gas, and coal as fuel to generate heat. Changing fuel sources, also referred to as fuel switching, can have a significant effect on the type and quantity of emissions. Two alternative fuel schemes were developed to compare to each other and with the baseline scenario developed from the mill survey data on their air emission profiles.

Fuel Switching

In the present study, the “baseline” fuel mix included four fuel sources, with natural gas, purchased wood fuel and coal supplying the majority of the thermal energy. On-site generated wood fuel contributed only 0.7%. Based on survey data, the original model showed 74.7% of the fuel used was natural gas and 15.3% in the form of wood fuel (95.4% purchased and the remainder generated on-site) (Table 5). Most mills use only one or two types of fuel, whereas the original study resulted in a weighted-average composite plant incorporating different fuel sources taken from primary mill data for the seven production plants. In this sensitivity analysis, two alternative fuel-use schemes were created for comparison to the “composite plant” or “baseline” scenario. One alternative, “100% natural gas” case had natural gas consumption increase from the base value of 43.1 to 62.5 m^3 to generate 3.40 GJ/m^3 uncoated cellulosic fiberboard. Natural gas is chosen because it burns cleaner than coal and is abundantly available domestically. The second alternative fuel-use scheme, “100% purchased wood fuel” case assumed consumption of only purchased wood fuel used for all thermal energy which increased the initial base value of 23.7 to 163 OD kg for purchased wood fuel to provide all necessary heat for the facility.

Three Fuel Source Scenarios

This sensitivity analysis examined three scenarios for heat generation using the baseline fuel mix, 100% natural gas, and 100% purchased wood fuel cases. The following three scenarios were modeled using SimaPro to find the differences in emissions: (1) comparing 100% natural gas case to the “baseline” cellulosic fiberboard fuel mix that used natural gas, purchased wood fuel, and coal; (2) comparing 100% purchased wood fuel to the “baseline” cellulosic fiberboard fuel mix that again had no fuel changes; and (3) comparing 100% natural gas to 100% purchased wood fuel cases.

Sensitivity Analysis Results

Table 15 presents the summary of the three fuel use scenarios, with a partial list of air emissions. In scenarios 1 and 2, a negative percentage difference number indicated that the alternative fuel source released fewer emissions than did the base model. A positive percentage difference means that the base or original model released fewer emissions. Scenario 1 indicated that less benzene, biogenic CO_2, carbon monoxide, unspecified particulate, and sulfur oxides, but more methane and VOCs were emitted when burning 100% natural gas than in the base fuel mix (original). Scenario 2 showed more acrolein, benzene, biogenic CO_2, carbon monoxide, formaldehyde and sulfur oxides, but less fossil CO_2, methane, non-methane VOC, unspecified particulate, and VOCs were emitted when burning 100% purchased wood fuel than in the base fuel mix (original). In scenario 3, a negative number indicates that the 100% natural gas case released fewer emissions than the 100% purchased wood fuel case and a positive percentage number means that 100% purchased wood fuel model released fewer emissions. Scenario 3 highlighted the increase of fossil CO_2, methane, non-methane VOC, and VOCs emitted along with less acrolein, benzene, biogenic CO_2, carbon monoxide, and sulfur oxides emitted compared with scenario 1. For all three scenarios, the amount of methanol, PM10, and phenol emitted was similar regardless of the fuel used because most methanol, PM10, and phenol originated in the drying of the cellulosic fiberboard as shown in Table 12. In addition, although expected, there is a stark contrast between biogenic and fossil carbon dioxide emissions for the three scenarios.

Table 15 Sensitivity analysis for manufacturing 1 m^3 cellulosic fiberboard in North America.

	Fuel distribution (kg/m^3 cellulosic fiberboard)				Difference (%)		
Substance	100% natural gas	100% wood fuel[1]	Original (base)		Scenario 1 100% natural gas to original	Scenario 2 100% wood fuel to original	Scenario 3 100% natural gas to 100% wood fuel
Acetaldehyde	1.94E-02	2.04E-02	1.94E-02		0.0	5.0	–5.0
Acrolein	6.78E-03	1.24E-02	7.60E-03		–11.4	48.1	–58.7
Benzene	9.07E-04	6.83E-03	3.19E-03		–111.5	72.5	–153.1
CO_2 (biogenic)	3.98E+01	3.15E+02	8.17E+01		–68.9	117.5	–155.1
CO_2 (fossil)	2.43E+02	1.15E+02	2.55E+02		–4.9	–75.7	71.4
CO	5.79E-01	1.22E+00	5.79E-01		0.0	71.1	–71.1
Formaldehyde	1.59E-02	2.20E-02	1.69E-02		–6.0	26.4	–32.3
Methane	9.65E-01	3.25E-01	8.29E-01		15.1	–87.3	99.2
Methanol	6.00E-02	6.00E-02	6.00E-02		0.0	0.0	0.0
NOx	8.05E+00	8.48E+00	8.22E+00		–2.1	3.2	–5.3
Non-methane, VOC	1.31E-02	1.20E-02	1.36E-02		–3.8	–12.3	8.5
Particulate (PM10)	1.65E-01	1.65E-01	1.65E-01		0.0	0.0	0.0
Particulate (unspecified)	7.09E-01	7.09E-01	7.89E-01		–10.7	–10.7	–0.1
Phenol	3.78E-03	3.78E-03	3.78E-03		0.0	0.0	0.0
Sox	2.62E-04	7.78E-03	1.36E-03		–135.2	140.7	–187.0
VOC	2.69E-01	2.27E-01	2.60E-01		3.3	–13.6	16.9

[1] Wood fuel burned was purchased off-site.

CONCLUSION

The cradle to gate LCI for uncoated cellulosic fiberboard includes 1) the LCI of forest resources that relies on secondary data, 2) the LCI of wood residue production that generate the wood residue co-product that is used as an input into cellulosic fiberboard and relies on primary survey data and secondary data for process inputs such as natural gas, diesel, and electricity, and

3) the cellulosic fiberboard manufacturing LCI that relies on primary survey data and secondary data for process inputs such as natural gas, coal, diesel, and electricity. The survey results for cellulosic fiberboard were representative of the North American average with wood inputs representing the Canadian, SE, and NE-NC regions of North America. The survey data were representative of the cellulosic fiberboard sizes and production volumes consistent with trade association production data.

Renewable biomass represented 15.5 percent of the total energy consumption for all stages of production, with 54.5 percent of the woody biomass energy consumed during cellulosic fiberboard production. The use of non-renewable fossil fuels dominated the total energy consumption profile for cellulosic fiberboard production at 72.4 percent of the 5.99 GJ/m^3 (4.34 GJ/m^3). Forestry operations consumed exclusively (0.8%) fossil fuels. The production of the wood residue used in cellulosic fiberboard represented 4.8 percent of the non-renewable fossil fuel consumption leaving the production of cellulosic fiberboard itself with about 94.4 percent or 4.10 GJ/m^3 of the non-renewable fossil fuel use. Energy consumed during starch production is included in the fossil fuel use for cellulosic fiberboard as an upstream process. In summary, to produce 1 cubic meter of cellulosic fiberboard from cradle-to-gate, 15.5 percent of the cumulative energy was from biomass (wood fuel) and 72.4 percent from non-renewable fossil fuels leaving a small portion of energy needs coming from nuclear (7.3%), hydro (4.6%), and wind, solar, and geothermal (0.2%).

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

Wood products typically consume more energy during the manufacturing stage than any other stage (Puettmann and Wilson 2005; Winistorfer et al. 2005; Puettmann et al. 2010). For making oriented strandboard (OSB) in the southeastern (SE) United States, cumulative allocated energy consumption for 1.0 m^3 of OSB is 11.0 GJ/m^3, with 38% from wood fuel (Kline 2005). For making softwood plywood in the SE United States, cumulative allocated energy consumption for 1.0 m^3 of plywood is 5.43 GJ/m^3, with 38% from wood fuel (Wilson and Sakimoto 2005; Puettmann and Wilson 2005). The values listed in Kline (2005) and Wilson and Sakimoto (2005) use mass allocation. This study also allocates primary energy to cellulosic fiberboard and co-products on mass. Primary energy is energy embodied in the original resources such as crude oil and coal before conversion. Cumulative energy consumption for cellulosic fiberboard of 5.99 GL/m^3 is slightly higher than softwood plywood made in the SE United States at 5.44 MJ/m^3.

Using LCI analysis, 255 kg fossil CO_2 were released in the production of 1 m^3 of uncoated cellulosic fiberboard. However, cellulosic fiberboard stores carbon. Carbon content for wood products is assumed to be 50% by mass of OD wood. Therefore, the carbon stored in the wood portion of 1.0 m^3 (244 OD kg) of cellulosic fiberboard is equivalent to 447 kg CO_2

RECOMMENDATIONS

Several issues have been found as the result of conducting the cradle-to-gate LCI of cellulosic fiberboard with the following two issues highlighted. One issue is the use of dry feedstock (i.e., wood residue) in the cellulosic fiberboard production stage. Dry wood feedstock results in an approximately twice the quantity of woody biomass energy consumed overall because these dry wood residues as a co-product of primary manufacturing are allocated environmental inputs and outputs by mass. Therefore, the energy used for drying the primary product, about 50% by mass is partially assigned to the co-products such as dry shavings. Purchasing undried wood feedstock would help in this endeavor. Secondly, increasing wood fuel consumption on-site would reduce fossil carbon dioxide emissions. Wood energy systems exist that are direct-fired and could replace the current natural gas direct-fired systems for the drying process thus lowering fossil GHG emissions.

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APPENDIX A: CONVERSION FACTORS

Table 16 Common conversions from English units to SI.

To convert from	to	multiply by
Cubic feet (ft^3)	Cubic meter (m^3)	0.02831685
Pounds (avdp) (lb)	Kilograms (kg)	0.4535924
Cubic inches (in^3)	cubic centimeters (cm^3)	16.393
Btu's	joules	1054
Cubic yards (yd^3)	m^3	0.7645549
Feet	meters	0.305
Gallons (U. S.)	liters	3.785
Kilowatt - hours (kWh)	Mega joules	3.6
Miles	kilometers	1.609
Ounces (avdp)	kilograms	0.028
Square feet	square meters	0.093
Tons (short)	kilograms	907.185
Tons (short)	metric ton	0.9071847
Pounds	metric ton	0.0004
Watts	joules / sec	1
Yards	meters	0.914
Acres	hectares	0.405

Sources: Starr C (1971) *Energy & Power*. Scientific American; Handbook of Industrial Energy Analysis.

Table 17 Electricity grids and dataset name by region.

Region	North American grid
Canadian - Alberta	Electricity, at grid, WECC, 2008/RNA U
U.S. Average	Electricity, at grid, U.S., 2008 2008/RNA
NE-NC	Electricity, at grid, MRO, 2008/RNA U
SE	Electricity, at grid, SERC, 2008/RNA U.
Canadian - Quebec	Electricity, high voltage {Quebec}| market for | Alloc Def, U

Table 18 Non-wood material densities.

Material	kg/m^3
Cement	1,483
Concrete	2,373
Dry packed gravel	1,600–1,920
Wet gravel	2,020
Calcined gypsum	880–960
Pebble lime	850–1,025

For wood and bark densities, use Miles and Smith (2009) Res. Note NRS-38. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 35 p.

Table 19 Energy contents and densities of various fuels (SI Units).

Fuel	Unit	HHV[1] MJ/Unit	HHV [2] MJ/Unit	HHV MJ/kg	Density	Density units
Coal	kg	26.19	24.76	26.19		
DFO	L	38.74		45.54	0.85	kg/L
LPG	L	26.62		54.05	0.49	kg/L
Natural gas	m^3	38.38	38.74	54.45	0.70	kg/m^3
RFO	L	41.81		43.45	0.96	kg/L
Wood	kg	20.93	23.6	20.93		
Uranium	kg			381,000.00		
Gasoline	L	34.84			0.72	kg/L
Diesel	L	38.74			0.88	kg/L
Kerosene	L	37.88				
Coke						
Spent pulping liquor						
Coke oven gas						
Petroleum coke	L					

[1] Salazar and Meil (2009) Franklin Database. http://www.fal.com/lifecycle-services.html.
[2] Todreas NE, Kazimi MS (1993) Thermal Hydraulics Fundamentals, Taylor & Francis, Page 2, Table 1-1 Nuclear System I – .

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APPENDIX B: PRODUCTION FACILITY SURVEY QUESTIONNAIRE

USDA FS Forest Products Laboratory/North American Fiberboard Association Survey

Cellulosic Fiberboard Plants
2013

This survey was sent to you as part of a larger collaboration between the USDA FS Forest Products Laboratory, North American Fiberboard Association, American Wood Council (AWC), FPInnovations, and Consortium for Research on Renewable Industrial Materials (CORRIM).

Questions will be concentrated on annual production, electricity production and usage, fuel use, material flows, and environmental emissions (i.e., emission data). We realize that you may not have all the information requested, especially when it comes to specific equipment/processing groups or what we call 'machine centers'. The data you are able to provide will be appreciated.

Your data will be confidential; only weight-averaged values for the whole industry will be reported.

Our objective is to use the life-cycle information developed from this project to help develop Business-to-Business Environmental Product Declaration for US building materials. To complete this objective, we are developing a generic cellulosic fiberboard product that ignores special additives, high densities, etc.

Company: ______________________________

Facility Site (city, state): ______________________________

Should we have a follow-up question about the data, please provide the name and the following information for the contact in your company.

Name: ______________ Title: ______________

Telephone: ______________ Email: ______________

<u>Please send the completed survey to the following email or address by May 31</u>. In addition, if you have questions about the survey, contact Rick Bergman at the listed phone/email. Email is preferred.

Rick Bergman
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Economics, Statistics, and Life Cycle Analysis Unit
USDA Forest Service Forest Products Laboratory
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General Plant Information

1. **Reporting Year: ________ Starting Month: ________ Ending Month: ________**

Yes	No	Equipment in mill
O	O	**Log storage**
		log yard size _____million bf
O	O	wet (spray or pond)
O	O	settling tank
O	O	log pond
O	O	sprinkler
O	O	dry deck
		Log handlers
O	O	log sorter
O	O	debarker
O	O	**Chipping**
		chipper(s) #________
		chip storage______tons or yds
		Feedstock conditioning
O	O	steam digester
O	O	steaming screw
O	O	**Refiner(s) #______**
O	O	atmospheric
O	O	pressurized
O	O	**Washer(s) #______**
O	O	**Stock chest(s) #________**
		additives
O	O	starch
O	O	alum
O	O	wax
O	O	**Forming machine(s) #______**
		width: 4’, 8’, 12’ (circle one)

Yes	No	Equipment in mill
O	O	**Fiberboard board dryer**
O	O	direct-fired
O	O	indirect-fired
O	O	conventional steam
O	O	high pressure steam
O	O	oil
O	O	natural gas
O	O	propane
O	O	**Boiler**
O	O	wood-fired boiler(s) #____
		#1 size _______mmbtu/hr
		#2 size _______mmbtu/hr
O	O	gas-fired boiler
		size __________mmbtu/hr
O	O	oil-fired boiler
		size __________mmbtu/hr
		Finishing
O	O	trimmer(s) #______
O	O	asphalt coater
O	O	painted (white coat)
O	O	rolled
O	O	flooded on and rolled off
O	O	top side coating only
		Packaging
O	O	plastic wrapping (bags)
O	O	metal strapping
O	O	plasitc strapping

2. **Log storage – wet or dry (circle one)**
   Average log diameter ________________ inches
   Average log length ________________inches

3. **What type of log scaling is used? _________________________**

4. **Volume of incoming logs __________________ bf**

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Cellulosic Fiberboard Plant Annual Wood Production Data

Please complete the following table showing the breakdown of the individual tree species and approximate sizes processed by your plant by species or the average log diameter. If less than 2% of total, use category labeled "Other".

Tree species	% of total log input into plant	Log Diameter* (in)
Total	100%	

5. Other feedstock sources (non-log)

Other feedstock sources	Species, if applicable	Annual consumption (tons)	Percent of total (%)	% moisture content
Sawmill trim				
Sawdust				
Planer shavings				
Chips				
Construction waste				
Post-consumer kraft paper				
Newsprint				
Office paper				
Other				
Other				
Total non-log feedstock sources			100%	

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Cellulosic Fiberboard Annual Production			
(Please provide units of measurement if different than stated)			Total Production
	Annual Cellulosic Fiberboard production, 2012	ft^3	
	Annual Cellulosic Fiberboard production, 2012	ft^2 @ ½" basis	
	Annual Cellulosic Fiberboard production, 2012	tons	

SEE LIST ON PREVIOUS PAGE

Transportation method(s) and average delivery distance for logs				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for other feedstocks: type?_______________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for other feedstocks: type?_______________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for other feedstocks: type?_______________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for other feedstocks: type?_______________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		

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Cellulosic Fiberboard Plant Annual Energy Consumption

If you have completed a 2012 Annual Fuel and Energy Survey for AF&PA, you may want to attach the survey and skip to the next section entitled "Other Annual Production." The first section refers to energy generation (non-transport fuel). (Please provide units of measurement if different)

Fuel	Unit	Quantity
Total electricity for fiberboard plant	kWh	
Purchased steam	lbs (°F)	
Wood Fuel *Self-generated*	Tons / (%MC)	/
Wood Fuel *Purchased*	Tons / (%MC)	/
Natural Gas	1,000 ft^3	
Kerosene (fuel oil #1)	Gallons	
Fuel oil #2	Gallons	
Residual fuel oil #6 (Bunker C)	Gallons	
Diesel	Gallons	
Gasoline	Gallons	
Liquid Propane Gas	Gallons	

If your facility has a boiler, please provide the following. Otherwise, enter N/A as applicable.

Boiler	Boiler size (million BTU/hr)	Boiler Fuel	Boiler Fuel Unit	Quantity	Electricity to operate boiler (kWh)
#1					
#2					
#3					
#4					

Fiberboard Plant Annual On-site Transportation Fuel Use (includes all fuels for yard equipment, forklifts, and carriers:

Type	Total Quantity	Percent of total by unit process (percentage or volume) estimates and ranges are ok					Units
		Feedstock prep	Boiler	Finishing	Support vehicles	Other	
Off-road diesel							Gallons
On-road diesel							Gallons
Propane							Gallons
Gasoline							Gallons
Electricity							Gallons
Other							kWh

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Other Cellulosic Fiberboard Plant Annual Use Data

Formulation and usage of starch, asphalt, binders, and other components			
Component Type	Percent of component type by weight in board (range is ok)	Total annual use (lbs.)	Percent liquid (%) if applicable
Corn starch			
Potato starch			
Wheat starch			
Asphalt coating			
Alum			
Wax			
Carbon black			
Clay			
Other binder: __________			
Other: ___________			

Transportation method and distance for starch			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation method and distance for asphalt coating			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation method and distance for alum			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation method and distance for wax			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Transportation method and distance for carbon black ______________________			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		
Transportation method and distance for clay ______________________			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		
Transportation method and distance for other ______________________			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Source of heat for board dryer: direct or in-direct heating (circle one)		
Natural Gas	1000 ft^3	
Electricity	kWh	
Propane	gallon	
Wood fuel	tons / %MC	
Steam	lbs	
Other	?	

Fiberboard properties

1. Moisture content of fiber mats into board dryer ______________ %MC (dry basis)
2. Moisture content of fiberboard out of board dryer ______________ %MC (dry basis)
3. Fiberboard produced per hour out of the board dryer ______________ Msf/hr
4. Density of fiberboard leaving board dryer ________ lb/ft^3 ____________ lb/Msf
5. Density of fiberboard before packaging ________ lb/ft^3 4 may equal 5

____________________percent coated product

Cellulosic Fiberboard Plant <u>Annual</u> Wood Residue Production

Wood residues are any wood material produced in conjunction with making cellulosic fiberboard and are called co-products in this survey. For each of the co-products produced at your plant, please indicate the weight (tons) of **<u>annual</u>** wood residue production for the reporting period that are shipped to other users, used internally as fuel or for the production of another co-product at your facility, stockpiled for future use or land filled (estimates are acceptable). If zero, enter a dash (-). Please state units if other than tons like cubic yards. The final column (Total Quantity) should equal the sum of the individual rows.

Estimate amount of wood residue produced ___________tons/Msf cellulosic fiberboard

Wood residue	Moisture Content (wet basis)	Sold (Shipped)	Used Internally (as fuel)	Used Internally (re-pulped)	Landfill	Total Quantity
	(%)	tons	tons	tons	tons	Tons
Board trim (sawdust)						
Molasses						
Culled boards						
Other						

Cellulosic Fiberboard Plant Ancillary Material Inputs

Ancillary Material	Used		Amount	How amount was found? Circle one[1]		Where the ancillary material is used as a percent Estimation is ok. If not able to estimate, please leave blank								
	Yes	No		M	E	Feedstock prep	Steam digester	Boiler	Refiner	Washer	Stock chest	Wet former	Board dryer	Finishing
Hydraulic fluids	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Greases	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Motor Oil	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Plastic wrapping	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Cardboard packaging	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Steel strapping	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Potable water	O	O	gal/yr	O	O	%	%	%	%	%	%	%	%	%
Paints	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Ink	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Plastic strapping	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Runners	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%
Boiler chemicals	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%

[1] Estimated (E) / Measured (M)

Cellulosic Fiberboard Plant Air Emissions

If air emission inventories are available, please provide as an alternative to the following table. Check here if inventory is attached □

	Tracked			How amount was found? Mark one[1]			Where the air emission is emitted as a percent of unit processes listed below. Estimation is ok. If not able to estimate, please leave blank								
Air emission	**Yes**	**No**	**Amount (lb/yr)**	**M**	**E**	**Sampling method or source[1]**	**Feedstock prep**	**Steam digester**	**Boiler**	**Refiner**	**Washer**	**Stock chest**	**Wet former**	**Board dryer**	**Finishing**
Dust	O	O		O	O		%	%	%	%	%	%	%	%	%
Particulate, PM10	O	O		O	O		%	%	%	%	%	%	%	%	%
Particulate, PM2.5	O	O		O	O		%	%	%	%	%	%	%	%	%
VOC	O	O		O	O		%	%	%	%	%	%	%	%	%
Sulfur dioxide	O	O		O	O		%	%	%	%	%	%	%	%	%
HAP: Total	O	O		O	O		%	%	%	%	%	%	%	%	%
Methanol	O	O		O	O		%	%	%	%	%	%	%	%	%
Formaldehyde	O	O		O	O		%	%	%	%	%	%	%	%	%
Acetaldehyde	O	O		O	O		%	%	%	%	%	%	%	%	%
Propionaldehyde	O	O		O	O		%	%	%	%	%	%	%	%	%
Acrolein	O	O		O	O		%	%	%	%	%	%	%	%	%
Phenol	O	O		O	O		%	%	%	%	%	%	%	%	%
Acetone	O	O		O	O		%	%	%	%	%	%	%	%	%
HAP: _________	O	O		O	O		%	%	%	%	%	%	%	%	%
HAP: _________	O	O		O	O		%	%	%	%	%	%	%	%	%
Organic[2]: ______	O	O		O	O		%	%	%	%	%	%	%	%	%
Inorganic[3]: _____	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: _________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: _________	O	O		O	O		%	%	%	%	%	%	%	%	%

[1] Sampling methods might be Method 25A, Method 5, NCASI 105. Estimates might be based on AP42, Standard Air Contaminate Discharge Permit or other source.
[2] Non-HAP organics that are not included in VOC value.
[3] Estimated (E) / Measured (M)

[4] Inorganics such as chlorine, mercury sulfur.

Cellulosic Fiberboard Plant Water Emissions

If water emission inventories are available, please provide as an alternative to the following table

Check here if inventory is attached □

Water emission	Tracked		Amount (lb/yr)	How amount was found? Mark one[1]		Sampling method or source[1]	Where the water emission is emitted as a percent of unit processes listed below. Estimation is ok. If not able to estimate, please leave blank.								
	Yes	No		M	E		Feedstock prep	Steam digester	Boiler	Refiner	Washer	Stock chest	Wet former	Board dryer	Finishing
Suspended solids	O	O		O	O		%	%	%	%	%	%	%	%	%
BOD	O	O		O	O		%	%	%	%	%	%	%	%	%
COD	O	O		O	O		%	%	%	%	%	%	%	%	%
Oil and grease	O	O		O	O		%	%	%	%	%	%	%	%	%
HAPs	O	O		O	O		%	%	%	%	%	%	%	%	%
Chemicals in boiler blowdown (if not included above)	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%

[1] Sampling methods is type of water test or how estimate was obtained.

[2] Report the mass of material, not the mass of material and water.

[3] Estimated (E) / Measured (M).

Confidential

Cellulosic Fiberboard Plant Solid Waste

If annual solid waste summary is available, please provide as an alternative to the following table.

Check here if summary is attached □

Material	Landfilled (L) or Recycled (R)	Amount[2] (lb/yr)	How amount was found? Circle one[1]			Where the solid waste is emitted as a percent of unit processes listed below. Estimation is ok. If not able to estimate, please leave blank								
			M	E	PV	Feedstock prep	Steam digester	Boiler	Refiner	Washer	Stock chest	Wet former	Board dryer	Finishing
Discarded Wood	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Discarded Bark	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Dirt and rocks	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Ash	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Plastic packaging	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Strapping	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Other metals	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Other organics	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Other non-organics	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.

[2] Report the mass of material, for example, report wood separately from dirt and rocks.

Confidential

Cellulosic Fiberboard Plant Annual Water Use

Recycling rate of water helps reduce the water footprint.

Type	Total Quantity	Units
Input		
Surface water		Gallons
Groundwater		Gallons
Municipal water		Gallons
Output		
Water discharged		Gallons
Water recycled		Gallons

Was water measured or estimated? ________________

Does your facility collect steam as condensate to return to boiler? (Y/N) __________________

Does your facility have a water balance? ________________ If yes, please provide as an alternative to the following table.

Process	Water (tons)	Percent of water (%)
Input		
Green chips/feedstock		
Steam digester		
Pits		
In-process use[1]		
Total input		100%
Output		
To fields		
From board drying		
Other		
Total output		100%
DIFFERENCE		

[1] Used in levalley (washer) spray bars, seals, emulsion plant, high pressure water mat saw

Confidential

Cellulosic Fiberboard Plant Emission Control Device (ECD)

The following is a chart of emission control devices. Please fill in all information related to the control devices. **Estimates are ok.**

Emission Control Device (ECD)- Type, Electricity, Fuel Usage					
	ECD 1	ECD 2	ECD 3	ECD 4	ECD 5
Equipment controlled (i.e., boiler, steam digester, board dryer, etc.)					
Type (name)					
Model					
Year Installed					
Electricity used to operate ECD; either kWh or % of total plant use					
Natural Gas used to operate ECD; either $ft.^3$ or % of total plant use					

Machine Center Breakdown for Electricity and Fuel Use

Fill in all that apply and for which you have data. If you **do not** have given machines center such as a coating system, **write N/A**. **Estimates are ok.**

Machine Center	Model/Type	Annual electricity	Fuel Usage
	Year Installed (plus or minus 5 years)	kWh or % of the total use for plant	% of total use for plant
Boiler(s) #1			
Boiler(s) #2			
Co-generator			
Chipper			
Evaporator			
Refiner			
Washer			
Stock chest			
Wet former			
Board dryer			
High-pressure water jets			
Trim saws			
Coating system			

APPENDIX C: LIFE-CYCLE INVENTORY FLOWS

SimaPro 8.0.3.14	Inventory	Date:	12/16/2014	Time:	2:56:00 PM	
Project	EWP					
Calculation:	Compare					
Results:	Inventory					
Product 1:	0.376 m3 Forest harvest, cellulosic fiberboard, at forest road, NA (of project EWP)					
Product 2:	244 kg Wood residue, at mill, cellulosic fiberboard, NA (of project EWP)					
Product 3:	254 kg Cellulosic fiberboard, uncoated, at cellulosic fiberboard plant, North America (of project EWP)					
Method:	TRACI 2.1 V1.01 / US-Canadian 2008					
Indicator:	Inventory					
Compartment:	All compartments					
Per sub-compartment:	No					
Default units:	Yes					
Exclude infrastructure processes:	Yes					
Exclude long-term emissions:	No					
Sorted on item:	Main category					
Sort order:	Ascending					
No	Substance	Compartment	Unit	Forest operations	Wood residue production	Cellulosic fiberboard production
1	Carbon dioxide, in air	Raw	kg	3.59E+02	3.72E+01	6.93E+01
2	Carbon, organic, in soil or biomass stock	Raw	kg	0.00E+00	0.00E+00	4.66E+02
3	Coal, 26.4 MJ per kg	Raw	kg	5.52E-02	3.87E+00	3.75E+01
4	Coal, 29.3 MJ per kg	Raw	kg	0.00E+00	0.00E+00	2.01E+01
5	Energy, from hydro power	Raw	MJ	0.00E+00	1.90E+01	2.56E+02
6	Energy, geothermal	Raw	MJ	0.00E+00	7.46E-01	0.00E+00
7	Energy, kinetic (in wind), converted	Raw	MJ	0.00E+00	5.35E-01	9.91E+00
8	Energy, solar, converted	Raw	MJ	0.00E+00	3.67E-02	0.00E+00
9	Gas, natural/kg	Raw	kg	0.00E+00	0.00E+00	7.20E-02
10	Gas, natural/m3	Raw	m3	2.19E-01	3.98E+00	5.73E+01
11	Limestone	Raw	kg	0.00E+00	0.00E+00	2.92E+00
12	Occupation, arable, conservation tillage	Raw	m2a	0.00E+00	0.00E+00	1.68E-04
13	Occupation, arable, conventional tillage	Raw	m2a	0.00E+00	0.00E+00	1.84E-04
14	Occupation, arable, reduced tillage	Raw	m2a	0.00E+00	0.00E+00	1.13E-04
15	Oil, crude	Raw	kg	8.72E-01	8.01E-01	6.77E+00
16	Scrap, external	Raw	kg	0.00E+00	0.00E+00	2.17E-02
17	Sodium carbonate	Raw	kg	0.00E+00	0.00E+00	1.87E-05
18	Sodium chloride	Raw	kg	0.00E+00	0.00E+00	1.62E-03
19	Sodium sulfate	Raw	kg	0.00E+00	0.00E+00	3.47E-04
20	Sulfur	Raw	kg	0.00E+00	0.00E+00	2.03E-05
21	Uranium	Raw	kg	0.00E+00	0.00E+00	1.09E-06
22	Uranium oxide, 332 GJ per kg, in ore	Raw	kg	1.28E-06	9.51E-05	1.06E-03
23	Water, cooling, surface	Raw	kg	0.00E+00	0.00E+00	9.06E+02
24	Water, process, surface	Raw	kg	0.00E+00	0.00E+00	3.39E+02
25	Water, river	Raw	m3	0.00E+00	0.00E+00	7.31E-01

26	Water, unspecified natural origin/m3	Raw	m3	6.30E-04	0.00E+00	7.76E-04
27	Water, well, in ground	Raw	m3	0.00E+00	0.00E+00	1.61E+00
28	Wood and wood waste, 20.9 MJ per kg, ovendry basis	Raw	kg	0.00E+00	2.02E+01	2.41E+01
29	Wood, feedstock	Raw	kg	0.00E+00	0.00E+00	9.10E-02
30	Wood, hard, NE-NC, standing	Raw	m3	4.21E-02	0.00E+00	0.00E+00
31	Wood, soft, US PNW, standing/m3	Raw	m3	1.04E-01	0.00E+00	0.00E+00
32	Wood, soft, US SE, standing/m3	Raw	m3	2.30E-01	0.00E+00	2.50E-03
33	2-Chloroacetophenone	Air	kg	4.71E-12	5.73E-12	1.86E-10
34	2-Methyl-4-chlorophenoxyacetic acid	Air	kg	0.00E+00	0.00E+00	1.11E-11
35	2,4-D	Air	kg	0.00E+00	0.00E+00	9.08E-09
36	5-methyl Chrysene	Air	kg	5.32E-13	3.68E-11	3.56E-10
37	Acenaphthene	Air	kg	1.23E-11	8.53E-10	8.24E-09
38	Acenaphthylene	Air	kg	6.04E-12	4.18E-10	4.04E-09
39	Acetaldehyde	Air	kg	1.18E-05	3.67E-05	1.93E-02
40	Acetochlor	Air	kg	0.00E+00	0.00E+00	8.23E-09
41	Acetone	Air	kg	0.00E+00	0.00E+00	9.26E-03
42	Acetophenone	Air	kg	1.01E-11	1.23E-11	3.99E-10
43	Acrolein	Air	kg	1.43E-06	5.69E-07	7.60E-03
44	Alachlor	Air	kg	0.00E+00	0.00E+00	8.10E-10
45	Aldehydes, unspecified	Air	kg	3.54E-05	3.42E-05	1.34E-04
46	Aldicarb	Air	kg	0.00E+00	0.00E+00	2.88E-05
47	alpha-Pinene	Air	kg	0.00E+00	0.00E+00	1.06E-01
48	Ammonia	Air	kg	8.39E-05	2.68E-05	5.67E-03
49	Ammonium chloride	Air	kg	6.77E-08	5.05E-06	5.62E-05
50	Anthracene	Air	kg	5.08E-12	3.51E-10	3.39E-09
51	Antimony	Air	kg	4.35E-10	3.01E-08	1.91E-06
52	Arsenic	Air	kg	1.35E-08	7.23E-07	1.30E-05
53	Atrazine	Air	kg	0.00E+00	0.00E+00	1.60E-08
54	Azinphos-methyl	Air	kg	0.00E+00	0.00E+00	6.72E-06
55	Bentazone	Air	kg	0.00E+00	0.00E+00	6.54E-11
56	Benzene	Air	kg	1.44E-05	2.67E-06	3.18E-03
57	Benzene, chloro-	Air	kg	1.48E-11	1.80E-11	5.86E-10
58	Benzene, ethyl-	Air	kg	6.32E-11	7.69E-11	3.05E-09
59	Benzo(a)anthracene	Air	kg	1.93E-12	1.34E-10	1.29E-09
60	Benzo(a)pyrene	Air	kg	9.18E-13	6.36E-11	6.14E-10
61	Benzo(b,j,k)fluoranthene	Air	kg	2.66E-12	1.84E-10	1.78E-09
62	Benzo(g,h,i)perylene	Air	kg	6.53E-13	4.52E-11	4.36E-10
63	Benzyl chloride	Air	kg	4.71E-10	5.73E-10	1.86E-08
64	Beryllium	Air	kg	6.74E-10	4.59E-08	1.81E-06
65	Biphenyl	Air	kg	4.11E-11	2.84E-09	1.88E-04
66	Bromoform	Air	kg	2.62E-11	3.19E-11	1.04E-09
67	Bromoxynil	Air	kg	0.00E+00	0.00E+00	1.43E-10
68	BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	Air	kg	5.40E-05	9.81E-04	1.41E-02
69	Butadiene	Air	kg	6.00E-07	1.19E-08	6.88E-07
70	Cadmium	Air	kg	3.40E-09	1.67E-07	3.43E-06
71	Carbaryl	Air	kg	0.00E+00	0.00E+00	7.86E-06
72	Carbofuran	Air	kg	0.00E+00	0.00E+00	1.93E-05
73	Carbon dioxide	Air	kg	8.66E-02	0.00E+00	1.62E-01
74	Carbon dioxide, biogenic	Air	kg	2.40E-03	3.72E+01	4.46E+01
75	Carbon dioxide, fossil	Air	kg	2.86E+00	1.77E+01	2.34E+02
76	Carbon disulfide	Air	kg	8.74E-11	1.06E-10	3.46E-09
77	Carbon monoxide	Air	kg	6.27E-06	1.91E-05	3.13E-01

78	Carbon monoxide, fossil	Air	kg	2.60E-02	2.22E-02	2.18E-01
79	Chloride	Air	kg	1.84E-12	1.68E-10	1.58E-09
80	Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	Air	kg	0.00E+00	0.00E+00	9.81E-09
81	Chlorine	Air	kg	0.00E+00	0.00E+00	1.62E-04
82	Chloroform	Air	kg	3.97E-11	4.83E-11	1.57E-09
83	Chlorothalonil	Air	kg	0.00E+00	0.00E+00	6.21E-04
84	Chlorpyrifos	Air	kg	0.00E+00	0.00E+00	9.44E-10
85	Chromium	Air	kg	9.80E-09	5.39E-07	1.16E-04
86	Chromium VI	Air	kg	1.91E-09	1.32E-07	1.28E-06
87	Chrysene	Air	kg	2.42E-12	1.67E-10	1.62E-09
88	Cobalt	Air	kg	1.78E-08	2.27E-07	3.32E-06
89	Copper	Air	kg	1.75E-10	1.96E-08	4.97E-08
90	Cumene	Air	kg	3.56E-12	4.34E-12	4.99E-03
91	Cyanazine	Air	kg	0.00E+00	0.00E+00	1.41E-10
92	Cyanide	Air	kg	1.68E-09	2.05E-09	6.66E-08
93	Diazinon	Air	kg	0.00E+00	0.00E+00	3.66E-07
94	Dicamba	Air	kg	0.00E+00	0.00E+00	8.33E-10
95	Dimethenamid	Air	kg	0.00E+00	0.00E+00	1.97E-09
96	Dinitrogen monoxide	Air	kg	5.09E-04	8.59E-05	5.09E-02
97	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	kg	5.79E-14	1.76E-12	3.42E-07
98	Dipropylthiocarbamic acid S-ethyl ester	Air	kg	0.00E+00	0.00E+00	1.91E-04
99	Disulfoton	Air	kg	0.00E+00	0.00E+00	3.10E-05
100	Endosulfan	Air	kg	0.00E+00	0.00E+00	1.49E-05
101	Ethane, 1,1,1-trichloro-, HCFC-140	Air	kg	9.52E-11	9.15E-11	8.06E-10
102	Ethane, 1,2-dibromo-	Air	kg	8.07E-13	9.82E-13	3.19E-11
103	Ethane, 1,2-dichloro-	Air	kg	2.69E-11	3.27E-11	1.06E-09
104	Ethane, chloro-	Air	kg	2.82E-11	3.44E-11	1.12E-09
105	Ethene, tetrachloro-	Air	kg	1.24E-09	7.44E-08	7.03E-07
106	Ethoprop	Air	kg	0.00E+00	0.00E+00	7.18E-05
107	Fluoranthene	Air	kg	1.72E-11	1.19E-09	1.15E-08
108	Fluorene	Air	kg	2.20E-11	1.52E-09	1.47E-08
109	Fluoride	Air	kg	1.01E-06	1.52E-07	2.48E-06
110	Formaldehyde	Air	kg	1.83E-05	5.73E-06	1.69E-02
111	Furan	Air	kg	1.07E-13	8.20E-12	8.00E-11
112	Glyphosate	Air	kg	0.00E+00	0.00E+00	4.52E-06
113	Heat, waste	Air	MJ	0.00E+00	0.00E+00	2.22E+01
114	Hexane	Air	kg	4.50E-11	5.48E-11	1.78E-09
115	Hydrazine, methyl-	Air	kg	1.14E-10	1.39E-10	4.53E-09
116	Hydrocarbons, unspecified	Air	kg	3.91E-07	2.91E-05	1.23E-02
117	Hydrogen	Air	kg	0.00E+00	0.00E+00	4.85E-08
118	Hydrogen chloride	Air	kg	3.05E-05	2.03E-03	2.34E-02
119	Hydrogen fluoride	Air	kg	3.59E-06	2.51E-04	9.90E-03
120	Hydrogen sulfide	Air	kg	5.95E-14	5.43E-12	5.12E-11
121	Indeno(1,2,3-cd)pyrene	Air	kg	1.47E-12	1.02E-10	9.86E-10
122	Isophorone	Air	kg	3.90E-10	4.75E-10	1.54E-08
123	Isoprene	Air	kg	6.04E-05	5.50E-03	5.19E-02
124	Kerosene	Air	kg	3.24E-08	2.42E-06	2.69E-05
125	Lead	Air	kg	1.69E-08	7.81E-07	8.58E-05
126	Limonene	Air	kg	0.00E+00	0.00E+00	7.33E-03
127	Linuron	Air	kg	0.00E+00	0.00E+00	8.35E-06
128	Magnesium	Air	kg	2.66E-07	1.84E-05	1.78E-04
129	Mancozeb	Air	kg	0.00E+00	0.00E+00	4.80E-04

130	Manganese	Air	kg	1.99E-08	8.90E-07	3.51E-04
131	Mercaptans, unspecified	Air	kg	1.46E-07	1.76E-07	5.77E-06
132	Mercury	Air	kg	3.45E-09	1.67E-07	1.24E-05
133	Metals, unspecified	Air	kg	6.83E-15	6.22E-13	8.77E-03
134	Metam-sodium dihydrate	Air	kg	0.00E+00	0.00E+00	2.83E-03
135	Methane	Air	kg	5.22E-03	5.11E-02	6.86E-01
136	Methane, bromo-, Halon 1001	Air	kg	1.08E-10	1.31E-10	4.26E-09
137	Methane, dichloro-, HCC-30	Air	kg	2.02E-08	6.34E-07	6.46E-05
138	Methane, dichlorodifluoro-, CFC-12	Air	kg	1.01E-10	9.29E-11	3.38E-10
139	Methane, fossil	Air	kg	5.02E-04	5.74E-03	8.11E-02
140	Methane, monochloro-, R-40	Air	kg	3.56E-10	4.34E-10	1.41E-08
141	Methane, tetrachloro-, CFC-10	Air	kg	1.01E-11	9.29E-12	9.22E-06
142	Methanol	Air	kg	0.00E+00	6.23E-05	6.00E-02
143	Methyl ethyl ketone	Air	kg	2.62E-10	3.19E-10	1.94E-03
144	Methyl methacrylate	Air	kg	1.34E-11	1.64E-11	5.32E-10
145	Metolachlor	Air	kg	0.00E+00	0.00E+00	2.81E-05
146	Metribuzin	Air	kg	0.00E+00	0.00E+00	3.38E-05
147	Naphthalene	Air	kg	3.77E-09	6.99E-08	9.99E-04
148	Nickel	Air	kg	2.24E-07	1.38E-06	1.17E-04
149	Nitrogen oxides	Air	kg	5.13E-02	4.33E-02	8.12E+00
150	Nitrogen, total	Air	kg	1.96E-05	0.00E+00	1.11E-05
151	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	kg	1.72E-03	1.98E-03	9.93E-03
152	Organic acids	Air	kg	2.49E-10	1.85E-08	2.07E-07
153	Organic substances, unspecified	Air	kg	1.50E-07	1.04E-05	1.01E-04
154	Oxamyl	Air	kg	0.00E+00	0.00E+00	7.89E-06
155	PAH, polycyclic aromatic hydrocarbons	Air	kg	2.58E-06	5.13E-08	3.34E-06
156	Paraquat	Air	kg	0.00E+00	0.00E+00	3.17E-06
157	Parathion, methyl	Air	kg	0.00E+00	0.00E+00	2.06E-06
158	Particulates, < 10 um	Air	kg	0.00E+00	0.00E+00	1.65E-01
159	Particulates, < 2.5 um	Air	kg	0.00E+00	0.00E+00	4.32E-02
160	Particulates, > 2.5 um, and < 10um	Air	kg	1.57E-03	1.10E-03	2.45E-01
161	Particulates, unspecified	Air	kg	3.29E-04	9.09E-02	6.98E-01
162	Pendimethalin	Air	kg	0.00E+00	0.00E+00	2.03E-05
163	Permethrin	Air	kg	0.00E+00	0.00E+00	1.64E-06
164	Phenanthrene	Air	kg	6.53E-11	4.52E-09	5.12E-05
165	Phenol	Air	kg	1.08E-11	6.45E-06	3.78E-03
166	Phenols, unspecified	Air	kg	1.04E-08	1.39E-07	1.11E-05
167	Phorate	Air	kg	0.00E+00	0.00E+00	1.07E-04
168	Phosphate	Air	kg	4.47E-07	0.00E+00	4.74E-09
169	Phthalate, dioctyl-	Air	kg	4.91E-11	5.98E-11	1.94E-09
170	Propanal	Air	kg	2.55E-10	3.11E-10	1.35E-02
171	Propene	Air	kg	3.96E-05	7.87E-07	4.54E-05
172	Propene, 1,3-dichloro-	Air	kg	0.00E+00	0.00E+00	1.36E-03
173	Propylene oxide	Air	kg	0.00E+00	0.00E+00	4.97E-10
174	Pyrene	Air	kg	7.98E-12	5.52E-10	5.33E-09
175	Radioactive species, unspecified	Air	Bq	1.33E+03	9.46E+04	9.13E+05
176	Radionuclides (Including Radon)	Air	kg	1.81E-06	1.35E-04	1.51E-03
177	Selenium	Air	kg	3.36E-08	2.23E-06	3.16E-05
178	Simazine	Air	kg	0.00E+00	0.00E+00	4.27E-10
179	Styrene	Air	kg	1.68E-11	2.05E-11	6.66E-10
180	Sulfur	Air	kg	0.00E+00	0.00E+00	1.27E-06
181	Sulfur dioxide	Air	kg	4.95E-03	1.21E-01	2.18E+00

182	Sulfur monoxide	Air	kg	2.85E-03	3.29E-03	1.83E-02
183	Sulfur oxides	Air	kg	0.00E+00	0.00E+00	1.36E-03
184	Sulfuric acid, dimethyl ester	Air	kg	3.23E-11	3.93E-11	1.28E-09
185	t-Butyl methyl ether	Air	kg	2.35E-11	2.86E-11	9.32E-10
186	Tar	Air	kg	2.07E-12	1.89E-10	1.78E-09
187	Terbufos	Air	kg	0.00E+00	0.00E+00	1.06E-09
188	TOC, Total Organic Carbon	Air	kg	0.00E+00	0.00E+00	8.38E-04
189	Toluene	Air	kg	6.27E-06	1.25E-07	1.07E-03
190	Toluene, 2,4-dinitro-	Air	kg	1.88E-13	2.29E-13	7.45E-12
191	Trifluralin	Air	kg	0.00E+00	0.00E+00	4.40E-06
192	Vinyl acetate	Air	kg	5.11E-12	6.22E-12	2.02E-10
193	VOC, volatile organic compounds	Air	kg	1.47E-03	1.34E-02	2.45E-01
194	Xylene	Air	kg	4.37E-06	8.70E-08	5.02E-06
195	Zinc	Air	kg	3.61E-07	1.31E-08	8.25E-08
196	2-Hexanone	Water	kg	2.48E-08	1.01E-07	1.34E-06
197	2-Methyl-4-chlorophenoxyacetic acid	Water	kg	0.00E+00	0.00E+00	4.75E-13
198	2-Propanol	Water	kg	0.00E+00	0.00E+00	9.50E-10
199	2,4-D	Water	kg	0.00E+00	0.00E+00	5.35E-10
200	4-Methyl-2-pentanone	Water	kg	1.59E-08	6.50E-08	8.59E-07
201	Acetochlor	Water	kg	0.00E+00	0.00E+00	3.53E-10
202	Acetone	Water	kg	3.79E-08	1.55E-07	2.04E-06
203	Acids, unspecified	Water	kg	3.87E-11	3.53E-09	7.03E-05
204	Alachlor	Water	kg	0.00E+00	0.00E+00	3.47E-11
205	Aldicarb	Water	kg	0.00E+00	0.00E+00	1.73E-06
206	Aluminium	Water	kg	2.91E-04	5.27E-04	5.85E-03
207	Ammonia	Water	kg	6.76E-05	2.13E-04	2.65E-03
208	Ammonia, as N	Water	kg	1.94E-11	1.77E-09	1.67E-08
209	Ammonium, ion	Water	kg	1.45E-08	1.08E-06	1.20E-05
210	Antimony	Water	kg	1.81E-07	3.01E-07	3.33E-06
211	Arsenic	Water	kg	1.85E-06	3.61E-06	4.69E-05
212	Atrazine	Water	kg	0.00E+00	0.00E+00	6.87E-10
213	Azinphos-methyl	Water	kg	0.00E+00	0.00E+00	4.03E-07
214	Barium	Water	kg	4.00E-03	7.09E-03	7.98E-02
215	Bentazone	Water	kg	0.00E+00	0.00E+00	2.80E-12
216	Benzene	Water	kg	6.36E-06	2.59E-05	3.43E-04
217	Benzene, 1-methyl-4-(1-methylethyl)-	Water	kg	3.79E-10	1.55E-09	2.04E-08
218	Benzene, ethyl-	Water	kg	3.58E-07	1.46E-06	1.93E-05
219	Benzene, pentamethyl-	Water	kg	2.84E-10	1.16E-09	1.53E-08
220	Benzenes, alkylated, unspecified	Water	kg	1.59E-07	2.64E-07	2.91E-06
221	Benzoic acid	Water	kg	3.85E-06	1.57E-05	2.07E-04
222	Beryllium	Water	kg	5.50E-08	1.71E-07	2.17E-06
223	Biphenyl	Water	kg	1.03E-08	1.71E-08	1.89E-07
224	BOD5, Biological Oxygen Demand	Water	kg	6.89E-04	2.72E-03	6.96E-01
225	Boron	Water	kg	1.19E-05	4.85E-05	6.42E-04
226	Bromide	Water	kg	8.13E-04	3.31E-03	4.38E-02
227	Bromoxynil	Water	kg	0.00E+00	0.00E+00	3.71E-12
228	Cadmium	Water	kg	4.28E-07	5.39E-07	6.97E-06
229	Calcium	Water	kg	1.22E-02	4.97E-02	6.57E-01
230	Carbaryl	Water	kg	0.00E+00	0.00E+00	4.71E-07
231	Carbofuran	Water	kg	0.00E+00	0.00E+00	1.16E-06
232	CFCs, unspecified	Water	kg	0.00E+00	0.00E+00	9.50E-10
233	Chloride	Water	kg	1.37E-01	5.59E-01	7.39E+00
234	Chlorothalonil	Water	kg	0.00E+00	0.00E+00	2.22E-05
235	Chlorpyrifos	Water	kg	0.00E+00	0.00E+00	4.04E-11

236	Chromium	Water	kg	8.67E-06	6.81E-06	5.49E-05
237	Chromium III	Water	kg	8.32E-07	6.83E-06	9.36E-05
238	Chromium VI	Water	kg	3.12E-08	2.87E-08	1.04E-07
239	Cobalt	Water	kg	8.40E-08	3.43E-07	4.53E-06
240	COD, Chemical Oxygen Demand	Water	kg	1.28E-03	4.63E-03	2.56E-01
241	Copper	Water	kg	1.59E-06	3.61E-06	4.51E-05
242	Cyanazine	Water	kg	0.00E+00	0.00E+00	6.06E-12
243	Cyanide	Water	kg	2.74E-10	1.13E-09	1.49E-08
244	Decane	Water	kg	1.11E-07	4.51E-07	5.96E-06
245	Detergent, oil	Water	kg	3.27E-06	1.49E-05	2.00E-04
246	Diazinon	Water	kg	0.00E+00	0.00E+00	2.20E-08
247	Dibenzofuran	Water	kg	7.21E-10	2.94E-09	3.89E-08
248	Dibenzothiophene	Water	kg	6.16E-10	2.44E-09	3.21E-08
249	Dicamba	Water	kg	0.00E+00	0.00E+00	3.57E-11
250	Dimethenamid	Water	kg	0.00E+00	0.00E+00	8.43E-11
251	Dipropylthiocarbamic acid S-ethyl ester	Water	kg	0.00E+00	0.00E+00	6.83E-06
252	Disulfoton	Water	kg	0.00E+00	0.00E+00	1.11E-06
253	Diuron	Water	kg	0.00E+00	0.00E+00	5.85E-13
254	DOC, Dissolved Organic Carbon	Water	kg	1.19E-13	1.08E-11	4.46E-05
255	Docosane	Water	kg	4.06E-09	1.65E-08	2.19E-07
256	Dodecane	Water	kg	2.10E-07	8.55E-07	1.13E-05
257	Eicosane	Water	kg	5.77E-08	2.35E-07	3.11E-06
258	Endosulfan	Water	kg	0.00E+00	0.00E+00	8.92E-07
259	Ethoprop	Water	kg	0.00E+00	0.00E+00	2.56E-06
260	Fluorene, 1-methyl-	Water	kg	4.32E-10	1.76E-09	2.33E-08
261	Fluorenes, alkylated, unspecified	Water	kg	9.22E-09	1.53E-08	1.69E-07
262	Fluoride	Water	kg	2.48E-03	1.75E-05	2.22E-04
263	Fluorine	Water	kg	4.59E-09	8.40E-09	9.56E-08
264	Furan	Water	kg	0.00E+00	0.00E+00	3.48E-11
265	Glyphosate	Water	kg	0.00E+00	0.00E+00	2.71E-07
266	Hexadecane	Water	kg	2.29E-07	9.34E-07	1.23E-05
267	Hexanoic acid	Water	kg	7.97E-07	3.25E-06	4.30E-05
268	Hydrocarbons, unspecified	Water	kg	1.49E-13	1.35E-11	3.50E-08
269	Iron	Water	kg	5.92E-04	1.33E-03	1.59E-02
270	Lead	Water	kg	2.46E-06	5.82E-06	7.27E-05
271	Lead-210/kg	Water	kg	3.94E-16	1.61E-15	2.12E-14
272	Linuron	Water	kg	0.00E+00	0.00E+00	5.01E-07
273	Lithium	Water	kg	7.49E-04	1.35E-02	1.95E-01
274	m-Xylene	Water	kg	1.15E-07	4.69E-07	6.20E-06
275	Magnesium	Water	kg	2.38E-03	9.72E-03	1.28E-01
276	Mancozeb	Water	kg	0.00E+00	0.00E+00	1.71E-05
277	Manganese	Water	kg	4.22E-06	4.68E-05	7.51E-04
278	Mercury	Water	kg	1.58E-08	6.67E-09	7.39E-08
279	Metallic ions, unspecified	Water	kg	1.81E-12	1.65E-10	1.86E-09
280	Metam-sodium dihydrate	Water	kg	0.00E+00	0.00E+00	1.70E-04
281	Methane, monochloro-, R-40	Water	kg	1.53E-10	6.22E-10	8.23E-09
282	Methyl ethyl ketone	Water	kg	3.05E-10	1.24E-09	1.65E-08
283	Metolachlor	Water	kg	0.00E+00	0.00E+00	1.69E-06
284	Metribuzin	Water	kg	0.00E+00	0.00E+00	2.03E-06
285	Molybdenum	Water	kg	8.72E-08	3.55E-07	4.70E-06
286	n-Hexacosane	Water	kg	2.53E-09	1.03E-08	1.37E-07
287	Naphthalene	Water	kg	6.91E-08	2.81E-07	3.72E-06
288	Naphthalene, 2-methyl-	Water	kg	6.01E-08	2.45E-07	3.24E-06
289	Naphthalenes, alkylated, unspecified	Water	kg	2.61E-09	4.33E-09	4.77E-08

290	Nickel	Water	kg	1.39E-06	2.99E-06	3.81E-05
291	Nitrate	Water	kg	1.30E-14	1.19E-12	5.26E-08
292	Nitrate compounds	Water	kg	5.24E-13	4.78E-11	4.51E-10
293	Nitric acid	Water	kg	1.18E-09	1.07E-07	1.01E-06
294	Nitrogen, total	Water	kg	3.60E-08	2.69E-06	1.11E-02
295	o-Cresol	Water	kg	1.09E-07	4.45E-07	5.88E-06
296	Octadecane	Water	kg	5.66E-08	2.31E-07	3.05E-06
297	Oils, unspecified	Water	kg	8.54E-05	3.16E-04	1.86E-02
298	Oxamyl	Water	kg	0.00E+00	0.00E+00	2.82E-07
299	p-Cresol	Water	kg	1.18E-07	4.80E-07	6.35E-06
300	Paraquat	Water	kg	0.00E+00	0.00E+00	1.90E-07
301	Parathion, methyl	Water	kg	0.00E+00	0.00E+00	1.24E-07
302	Pendimethalin	Water	kg	0.00E+00	0.00E+00	1.22E-06
303	Permethrin	Water	kg	0.00E+00	0.00E+00	9.82E-08
304	Phenanthrene	Water	kg	9.73E-10	2.43E-09	2.98E-08
305	Phenanthrenes, alkylated, unspecified	Water	kg	1.08E-09	1.79E-09	1.98E-08
306	Phenol	Water	kg	1.38E-06	1.27E-06	1.03E-05
307	Phenol, 2,4-dimethyl-	Water	kg	1.06E-07	4.33E-07	5.73E-06
308	Phenols, unspecified	Water	kg	5.04E-07	5.82E-06	8.19E-05
309	Phorate	Water	kg	0.00E+00	0.00E+00	3.81E-06
310	Phosphate	Water	kg	1.87E-03	0.00E+00	2.35E-05
311	Phosphorus	Water	kg	0.00E+00	0.00E+00	2.95E-07
312	Phosphorus compounds, unspecified	Water	kg	0.00E+00	0.00E+00	4.14E-04
313	Phosphorus, total	Water	kg	0.00E+00	0.00E+00	1.15E-06
314	Process solvents, unspecified	Water	kg	0.00E+00	0.00E+00	3.48E-09
315	Propene, 1,3-dichloro-	Water	kg	0.00E+00	0.00E+00	4.85E-05
316	Radioactive species, Nuclides, unspecified	Water	Bq	2.10E+00	1.57E+02	1.75E+03
317	Radium-226/kg	Water	kg	1.37E-13	5.59E-13	7.39E-12
318	Radium-228/kg	Water	kg	7.01E-16	2.86E-15	3.78E-14
319	Selenium	Water	kg	4.03E-08	4.37E-07	4.86E-06
320	Silver	Water	kg	7.96E-06	3.24E-05	4.29E-04
321	Simazine	Water	kg	0.00E+00	0.00E+00	1.83E-11
322	Sodium	Water	kg	3.86E-02	1.58E-01	2.08E+00
323	Solids, inorganic	Water	kg	2.99E-12	2.72E-10	2.57E-09
324	Solved solids	Water	kg	0.00E+00	0.00E+00	1.07E+00
325	Solved substances, inorganic	Water	kg	0.00E+00	0.00E+00	8.31E-06
326	Strontium	Water	kg	2.07E-04	8.43E-04	1.11E-02
327	Styrene	Water	kg	0.00E+00	0.00E+00	4.41E-12
328	Sulfate	Water	kg	3.06E-04	3.32E-03	3.94E-02
329	Sulfide	Water	kg	1.60E-07	1.47E-07	5.14E-06
330	Sulfur	Water	kg	1.00E-05	4.10E-05	5.42E-04
331	Suspended solids, unspecified	Water	kg	1.78E-01	7.05E-01	1.23E+01
332	Tar	Water	kg	2.96E-14	2.70E-12	2.55E-11
333	Terbufos	Water	kg	0.00E+00	0.00E+00	2.75E-11
334	Tetradecane	Water	kg	9.19E-08	3.75E-07	4.96E-06
335	Thallium	Water	kg	3.82E-08	6.36E-08	7.02E-07
336	Tin	Water	kg	7.73E-07	2.03E-06	2.51E-05
337	Titanium	Water	kg	2.79E-06	4.63E-06	5.11E-05
338	TOC, Total Organic Carbon	Water	kg	0.00E+00	0.00E+00	4.41E-08
339	Toluene	Water	kg	6.01E-06	2.45E-05	3.24E-04
340	Trifluralin	Water	kg	0.00E+00	0.00E+00	1.57E-07
341	Vanadium	Water	kg	1.03E-07	4.20E-07	5.55E-06
342	Waste water/m3	Water	m3	0.00E+00	0.00E+00	6.75E-04

343	Xylene	Water	kg	3.21E-06	1.28E-05	1.69E-04
344	Yttrium	Water	kg	2.56E-08	1.04E-07	1.38E-06
345	Zinc	Water	kg	6.76E-06	1.38E-05	1.56E-04
346	Waste in inert landfill	Waste	kg	0.00E+00	0.00E+00	5.41E+00
347	Waste to recycling	Waste	kg	0.00E+00	0.00E+00	8.49E+00
348	Waste, solid	Waste	kg	0.00E+00	0.00E+00	2.40E-03
349	Bark	Soil	kg	0.00E+00	1.31E+00	1.78E-02