CRADLE-TO-GATE LIFE-CYCLE INVENTORY OF HARDBOARD AND ENGINEERED WOOD SIDING AND TRIM PRODUCED IN NORTH AMERICA

CORRIM FINAL REPORT

Prepared for:

CPA – The Composite Panel 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 hardboard and engineered wood siding and trim (EWST) production in North America. In this study, hardboard and EWST are considered the same composite wood product category and in the remaining paper will be referred to as just hardboard for simplicity. 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 hardboard plants. This survey tracked raw material inputs (including energy), product and byproduct 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, 1 m^3. 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. All allocation was based on the mass of the products and coproducts.

Life-cycle Inventory

LCI results for hardboard are presented by three life stages: 1) forestry operations, 2) wood residue production, and 3) hardboard production. The majority of the raw material energy consumption occurs during hardboard production, followed by the production of the wood residue with only a very small portion arising from forestry operations. Wood residue production occurs at softwood and hardwood mills spread across North America and is not dried prior to arrival at hardboard plant facilities. Hardboard production occurs through a dry and wet process and was modeled as a single system because the same final product was generated through both wet and dry processes.

Key Findings

Amount and type of energy has a substantial role during production of building materials such as hardboard. Total cumulative energy consumption for the cradle-to-gate production of hardboard was 25.4 GJ/m^3. Use of renewable energy in manufacturing hardboard was substantial. Renewable energy made up of just less than 50% of the total cumulative energy consumption profile for hardboard production at 45.2% of the 25.4 GJ/m^3 (11.5 GJ/m^3). Renewable biomass, by far the largest renewable energy source, represented 44.5% of the total cumulative energy consumption for all stages of production. As for the other two life-cycle stages, forestry operations consumed relatively little energy and was exclusively fossil fuels, which came out to be 2.2% of the total cumulative energy consumption. In addition, the wood residue production stage consumed 3.7% of the non-renewable fossil fuel leaving the production of hardboard itself with about 94.1% or 4.10 GJ/m^3 of the non-renewable fossil fuel use. Energy consumed during phenol-formaldehyde resin production along with additives was included in the fossil fuel use for hardboard as an upstream process. In summary, to produce 1 m^3 of hardboard from cradle-to-gate, 44.5% of the cumulative energy was from biomass (wood fuel) and 46.2% from non-renewable fossil fuels leaving a small portion of energy needs coming from nuclear (8.6%), hydro (0.6%), and the remaining 0.1% from wind, solar, and geothermal.

Interpretation

Emissions from the forest resources LCI are small relative to manufacturing emissions (wood residue and hardboard). At the hardboard production facility, emissions originate at the boiler, during drying, refining, forming, pressing, tempering, and humidifying. Boiler emissions released are a function of fuel burned, whereas other emissions are a function of the unit process and associated emission control device.

Cradle-to-gate LCI results showed 518-kg fossil CO_2 were released in the production of 1 m^3 of hardboard. However, hardboard stores carbon. Carbon content for wood products is assumed to be 50% by mass of oven-dried (OD) wood. Excluding the resin system, the carbon stored in the wood portion of 1 m^3 (768 × 94.8% = 728 OD kg) of hardboard is equivalent to 1.33 Mg CO_2 emissions if left to decay.

Data quality was high. A mass balance was performed to verify data quality. Inputs and outputs were consistent for the four surveyed mills on cubic meter basis. In addition, total wood mass in and total wood mass out was calculated. Percentage difference for overall wood mass was 1.4%. A percentage difference less than 10% would be good. Therefore, tracking of wood mass is excellent for the present study.

Sensitivity Analysis

A sensitivity analysis was completed per International Organization for Standardization (ISO) 14040 standards to model the effects of onsite fuel switching for thermal energy generation. For hardboard manufacturing, thermal energy (i.e., heat) is used in several unit processes, consuming a combination of wood fuel, natural gas, and residual fuel oil as fuel to generate. Wood fuel consumed was made of self-generated and purchased fuel stocks. Changing fuel sources, also referred to as fuel switching, can have a significant effect on the type and quantity of emissions. Two alternative fuel sources were selected to compare with the baseline fuel source developed from the mill survey data. The two alternative fuel sources were 100% natural gas and 100% purchased wood fuel. The three scenarios were natural gas to baseline, purchased wood fuel to baseline, and natural gas to purchased wood fuel. For all three scenarios, the amount of acetaldehyde, acrolein, methanol, unspecified particulate, and phenol emitted was similar regardless of the fuel used because most of these abovementioned emissions originated in the onsite production of hardboard. 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 hardboard with the following three issues highlighted. One issue is the high use of water in the hardboard production life-cycle stage. However, recycling efforts have substantially reduced overall water consumption. Second, wood fuel consumption in hardboard production greatly lowers fossil carbon dioxide emissions, the major source of greenhouse gases contributing to global warming. Therefore, every effort to maintain or increase wood fuel consumption where practicable should be considered to help mitigate global warming. Last, using green instead of dry wood residue lowers the energy consumed in the preparation of feedstock in the hardboard production stage. Therefore, green wood residue should continue to be used as a feedstock over dry wood residues.

ACKNOWLEDGMENT

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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. The LCI data cover 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: this report focuses on the average North American production of hardboard and engineered wood siding and trim (EWST). In this study, hardboard and EWST are considered the same composite wood product category and in the remaining paper will be referred to as just hardboard for simplicity. No prior North American hardboard LCI has been documented. Wood residue inputs for North American average hardboard production are sourced from several forms of woody biomass including roundwood in forest regions of the United States and co-products from various wood manufacturing processes. This document develops the cradle-to-gate hardboard LCI. LCI data are used to produce life-cycle impact assessments (LCIA). The LCI data developed for the manufacturing life-cycle stage will be incorporated into the US 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 completed LCI can be used internally by the Composite Panel Association (CPA) and its members to explore potential process and parameter improvements and new conversion technologies along with the identification of environmental ‘hotspots’. Intended audiences include life-cycle assessment (LCA) practitioners along with building specifiers looking for green building products with documentation. The LCI was in conformance with the Product Category Rules (PCR) for North American Structural and Architectural Wood Products (FPInnovations 2013) and ISO 14040/14044 standards (ISO 2006a; b). This report follows data and reporting requirements as outlined in the PCR and contains the LCI components for producing a North American EPD (ISO 2006c).

INTRODUCTION

Developing wood product LCI data helps construct product LCAs that are then incorporated into developing whole building LCAs in environmental footprint software such as the Athena Impact Estimator for Buildings (ASMI 2015). Conducting whole building LCAs provide for points that go toward green building certification in rating systems such as LEED v4, Green Globes, and the ICC-700 National Green Building Standard 2012.

Life-cycle assessment

Life-cycle assessment (LCA) has evolved as an internationally accepted method to analyze complex impacts and outputs of a product or process and the corresponding effects they might have on the environment. LCA is an objective process to evaluate a product’s life cycle by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements. LCA studies can evaluate full product life cycles, often referred to as “cradle to grave,” or incorporate only a portion of the products life cycle, referred to as “cradle to gate,” or “gate to gate.” This study can be categorized as a cradle to gate LCA and includes forestry operations though the manufacturing of hardboard ready to be shipped at the mill gate.

As defined by the International Organization for Standardization (ISO 2006a), LCA is a multiphase process consisting of a 1) Goal and Scope Definition, 2) Life Cycle Inventory (LCI), 3) Life Cycle Impact Assessment (LCIA), and 4) Interpretation (Figure 1). These steps are interconnected and their outcomes are based on goals and purposes of a particular study.

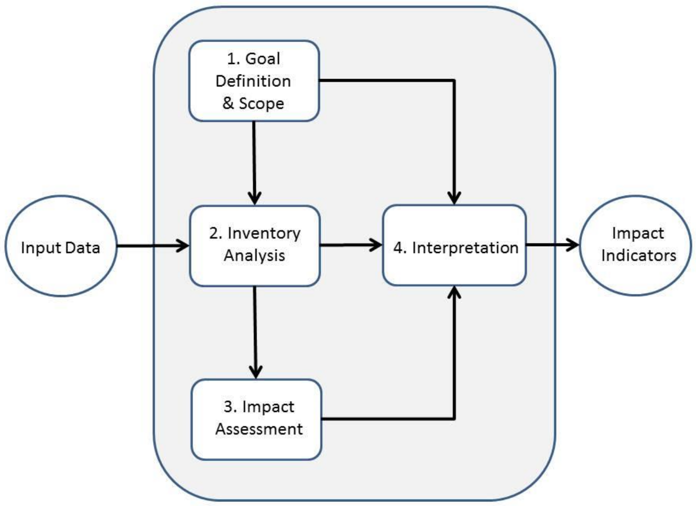

Figure 1. Steps involved in a life-cycle assessment.

An LCA begins with a project goal, scope, functional unit, system boundaries, any assumptions and study limitations, method of allocation, and the impact categories that will be used.

The key component is the LCI that is an objective, data-based process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases occurring within the system boundaries. It is this information that provides a quantitative basis for comparing wood products, their manufacturing processes, and most importantly from the forest industry point of view, wood products performance against competitors who use other resources to create alternative products.

The LCIA process characterizes and assesses the effects of environmental releases identified in the LCI into impact categories such as global warming, acidification, carcinogenics, respiratory effects, eutrophication, ozone depletion, ecotoxicity, and smog. For assessing the environmental impacts of the hardboard production, the TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) impact method will be used. TRACI is a midpoint oriented LCIA methodology developed by the U.S. Environmental Protection Agency specifically for the United States using input parameters consistent with U.S. locations (Bare 2011). TRACI is available through the LCA software used for modeling the hardboard process (PRé Consultants 2015).

The life-cycle interpretation is a phase of LCA in which the findings of either the LCI or the LCIA, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations. This final step in an LCA involves an investigation of significant environmental aspects (e.g., energy use, greenhouse gases), their contributions to the indicators under consideration, and determination of which unit processes in the system they emanate from. For example, if the results of a life-cycle impact assessment indicate a particularly high value for the global warming potential indicator, the analyst could refer back to the inventory to determine which environmental flows are contributing to the high value, and which unit processes those outputs are coming from. This is also used as a form of *quality control*, and the results can be used to refine the scope definition to focus on the more important unit processes. This step also supports arriving at more certain conclusions and supportable recommendations.

Description of Product

Hardboard is a panel product developed to utilize industrial wood residue (Figures 2 and 3). These woody biomass residues were historically burned for energy or sent to landfill 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 hardboard falls into the North American Industry Classification System (NAICS) Code 321219—reconstituted wood products, which include other wood composite products such as cellulosic fiberboard, medium density fiberboard, particleboard, and oriented strandboard (USCB 2012). EWST are composite panels designed and manufactured to perform in applications with the appearance of traditional wood. In addition, all hardboard plants follow the ”Eco-certified composite sustainability standard” (CPA 2012e).

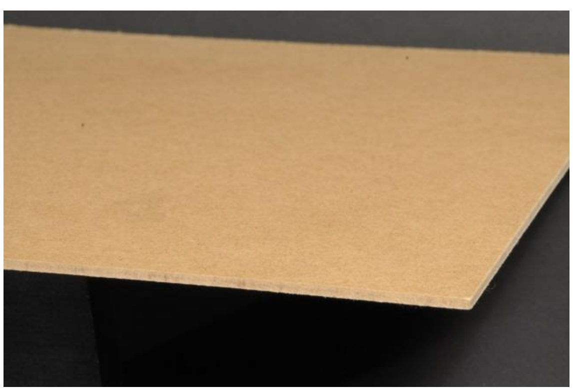

Figure 2. Hardboard/EWST (top view).

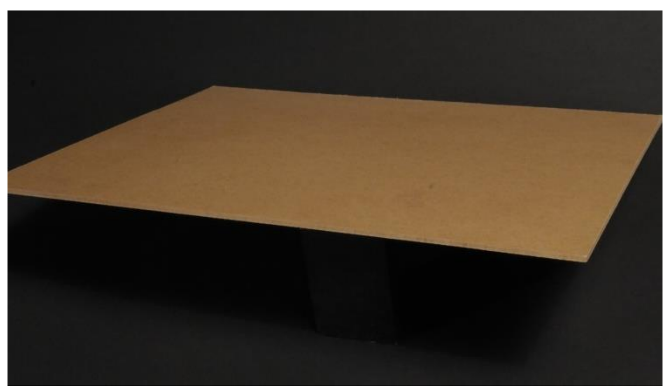

Figure 3. Hardboard/EWST (side view).

Manufacturing hardboard in North America currently uses either a wet or dry production processes to create high-density wood composition panels (CPA 2012a, b). Previously, a semidry process was explored as a hybrid process to lower resin and water usage while maintaining more of the properties found in wet-process hardboard (Myers 1986). However, the semidry process did not offer any manufacturing advantages or panel performance advantages so the industry discontinued its production (Heroux 2015a). The wet and dry processes use a thermomechanical processes to reduce the wood chips or raw material to individual fibers. Resin and additives are added to the fibers before or during mat forming and then the (dry or wet) mats are pressed to create the hardboard panel. Hardboard may be ‘tempered’ with oil and heat after pressing to improve water-resistance properties (Baird and Schwartz 1952; Lewis 1965; Suchsland and Woodson 1986). In this study, oil tempering was included within the system boundaries but no specialty coatings. Final products made from hardboard commonly called “dealer board” include case-goods, paneling and pegboard (Figure 4). Density for the final products ranges from 800 to 1,100 kg/m^3 (USEPA 2002; Gonzalez-Garcia et al. 2009; Stark et al. 2010).

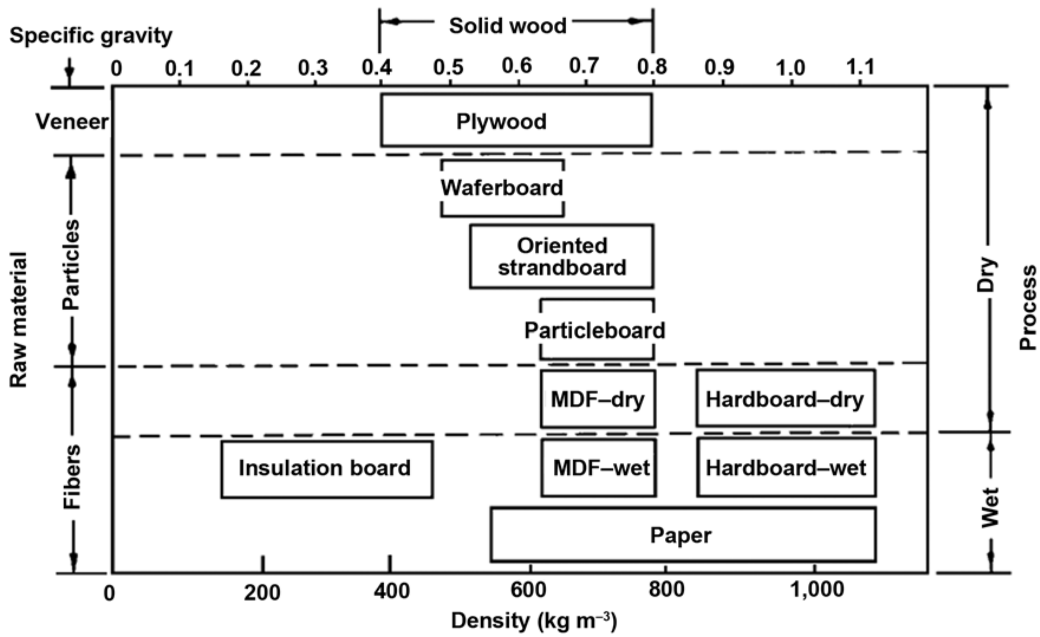

Figure 4. Classification of wood composite panels by particle size, density, and process (Suchsland and Woodson 1986).

The present study does not make a distinction between hardboard and EWST except for the standards used to produce these products. North American hardboard is classified by the following standards: 1) ANSI A135.4-2012 (CPA 2012a), Basic Hardboard and 2) ANSI A135.5-2012 (CPA 2012b), Prefinished Hardboard Paneling. North American EWST is classified by the following standards: 1) ANSI A135.6-2012 (CPA 2012c), Engineered Wood Siding and 2) ANSI A135.7-2012 (CPA 2012d), Engineered Wood Trim. Various uses and applications for hardboard and EWST include 1) furniture components, 2) wall paneling, 3) moulded door skins, 4) underlayment, and 5) perforated boards.

The goal of the present study was to track and determine energy and material inputs and outputs associated with the production of hardboard representing average manufacturing practices in North America. The wet- and dry-process hardboard was analyzed as a single system. The paper documents material flow, energy type and use, emissions to air and water, solid waste production, and water impacts for the hardboard manufacturing process on a per unit volume basis of 1 m^3. Primary mill data were collected through a survey questionnaire mailed to hardboard plants (Appendix B). This survey tracked raw material inputs (including energy), product and byproduct 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). These data were modeled using the software package SimaPro 8+ (Pré Consultants 2015). The scope of this study was to develop an LCI for the production of hardboard including 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 (FPInnovations 2013), the declared unit for hardboard is 1 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, 1,000 square feet (MSF) 1 MSF at 0.125-in basis is equal to 0.295 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 ISO 14044 (ISO 2006b). 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 and ends with hardboard (Figure 5). The forest resources system boundary may include site preparation and planting seedlings, forest management that 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 hardboard facility, and hardboard production (Figure 5). Seedlings and the fertilizer and electricity it took to grow trees were considered as inputs to the system boundary. The hardboard production complex was modeled as a single process representing all the steps necessary to make hardboard from both the wet and dry processes. Eleven main unit processes were identified in manufacturing hardboard for both the wet and dry process. To show the differences between the wet and dry processes, ‘a’ was added to the nomenclature for the wet process’s unit processes and ‘b’ was added to the nomenclature for the dry process. For the wet process, these included 1) resource transportation, 2) yard storage, 3) feedstock preparation, 4) refining, 5a) washing, 6a) mixing, 7a) wet forming, 8a) hot pressing, 9) tempering, 10) humidifying, and 11) finishing with energy generation considered an auxiliary process. For the dry process, these included 1) resource transportation, 2) yard storage, 3) feedstock preparation, 4) refining, 5b) drying, 6b) fiber storage, 7b) dry forming, 8b) hot pressing, 9) tempering, 10) humidifying, and 11) finishing with energy generation considered an auxiliary process. A single unit approach was used to model the hardboard process because no co-products left the system.

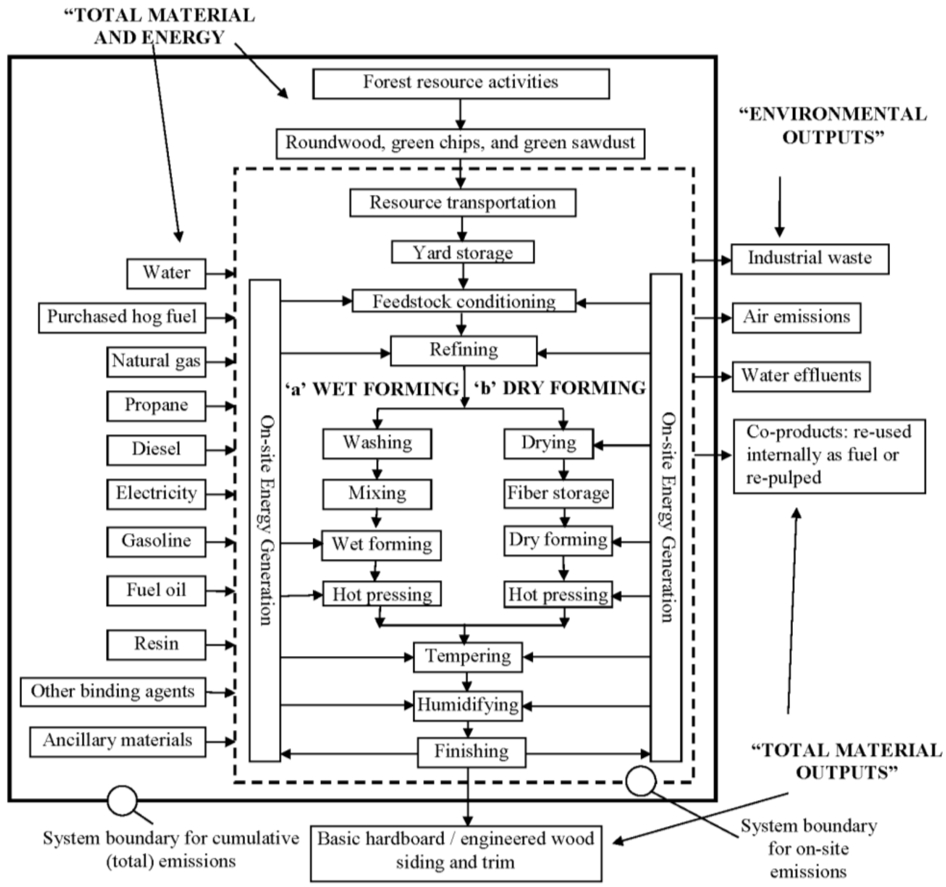

Figure 5. System boundary and process flow for cradle-to-gate production of hardboard detailed description of data and processes ('a' WET FORMING: 'b' DRY FORMING).

Forestry Operations. Forest operations modeled through wood residue production as inputs to hardboard production were based on forest resource LCI data inputs from the Southeast (SE) (30.7%) softwood and hardwood and Pacific Northwest (PNW) softwood (16.9%) (Johnson et al 2005) and Northeast North-Central hardwood and softwood (NE-NC) (32.4%); Oneil et al. 2010) U.S. forests, and Canadian hardwood (19.9%) 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. Harvesting included felling, skidding, processing, and loading for both commercial thinning and final harvest operations. For Canadian and NE-NC forests, reforestation occurs using natural regeneration that did not require inputs from human-related activities (i.e., the technosphere) for seedlings, site preparation, planting and pre-commercial thinning (Figure 5), whereas these steps were included for regeneration of softwood forests in the SE, PNW, and Canadian regions. 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 for the U.S. and ASMI 2012 for Canada. A summary of the energy use and fuel consumption for the forest operations by region, along with the weighted average values used in hardboard production are provided in Table 1.

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

		Fuel Consumption per m³				
	Unit	**Canadian hardwoods**	**PNW softwoods**	**NE-NC hardwoods and softwoods**	**SE softwoods and hardwoods**	**Weighted Average**
Seedling, Site Prep, Plant, Pre-commercial Thinning						
Diesel and gasoline	L	0	0.088	0	0.515	0.191
Lubricants	L	0	0.002	0	0.009	0.004
Electricity	kWh	0	0.107	0	0.455	0.179
Commercial Thinning and Final Harvest						
Diesel	L	4.83	2.85	4.27	2.93	3.73
Lubricants	L	0.132	0.051	0.077	0.05	0.075
Electricity	kWh	0.264	0.264	0	0	0.097
Total Forest Extraction Process						
Gasoline and Diesel	L	4.83	2.94	4.27	3.45	3.92
Lubricants	L	0.132	0.053	0.077	0.059	0.079
Electricity	kWh	0.264	0.371	0	0.455	0.277

[1] PNW: Pacific Northwestern United States.
[2] NE-NC: Northeastern/North Central United States.
[3] SE: Southeastern United States.

Wood residue. Most wood residues are co-products generated during lumber production. Wood residues' attributes vary across the major production centers of North America. Residues include softwoods from the PNW and SE, hardwoods from Canada, and softwoods and hardwoods from the SE and NE-NC (Table 2); (Milota et al. 2005; Bergman and Bowe 2008; Bergman and Bowe 2010; Bergman and Bowe 2012; ASMI 2012). Chips, a co-product from sawmill operations, represent the largest wood residue input at 7% (624 kg, oven dry) followed by roundwood and green sawdust at 20 and 6%, respectively. The highest quantity of wood residues consumed during the hardboard manufacturing process was from the NE-NC region at 274 OD kg followed by residues from the SE region at 259 OD kg. Canada provided about 20% of the wood residues consumed. All feedstock produced in a particular region were utilized within the same region.

Table 2. Wood residue type and source for input for hardboard production, North American average

All inputs (%)	Wood residue type	kg/m^3	Percentage contribution
	Canada (CN)		
19.9	Roundwood, hardwood, green, at mill, Canada	168.20	100
19.9	TOTAL	168.20	100
	Pacific Northwest (PNW)		
10.8	Sawdust, softwood, green, at sawmill, PNW	91.27	65
6.1	Chips, softwood, green, at sawmill, PNW	51.30	36
16.9	TOTAL	142.57	100
	Northeast-North central regions (NE-NC)		
30.2	Chips, hardwood, green, at sawmill, U.S. NE-NC	254.41	93
2.3	Chips, softwood, green, at sawmill, U.S. NE-NC	19.15	7
32.4	TOTAL	273.56	100
	Southeast Region (SE)		
25.5	Chips, hardwood, green, at mill, SE/m3/RNA	214.96	83
5.2	Chips, softwood, green, at mill, SE/m3/RNA	44.03	17
30.7	TOTAL	258.99	100
19.9	**Canada –Region**	168.20	19.9
16.9	**Pacific Northwest, U.S.-Region**	142.57	16.9
32.4	**Northeast-North central, U.S. -Region**	273.56	32.4
30.7	**Southeast, U.S. - Region**	258.99	30.7
100	**TOTAL North American Average**	843.32	100

Wood Product Manufacturing. Eleven main unit processes were identified in manufacturing wet- and dry-process hardboard, which have a few differences (Suchsland and Woodson 1986; Bergman 2014). The main difference involved the conveying medium. The wet process is similar to producing cellulosic fiberboard (Suchsland and Woodson 1986), which has water as the conveying medium. Contrarily, for dry-process hardboard, air is the conveying medium. In addition, both processes require additions of phenol-formaldehyde (PF) resins and additives (ie resin system) for bonding. The terms wood and pulp fibers are used interchangeably in the present study (Lampert 1967; Suchsland and Woodson 1986; USEPA 2002; Stark et al. 2010; ASTM International 2012). All differences were included in the analysis to show the overall impact. For example, dry-process hardboard consumed more PF resin per production unit but still consumed less additives than two other wet-process plants. Water and process energy consumption were similar between three plants with one wet-process plant notably consuming more on a per production unit basis. The main difference concerned the conveying medium. The dry- and wet-processes were merged into a single system based on weighted average plant production to develop the LCI. All environmental outputs (emissions) and energy consumed were assigned on a mass basis and reported based on a single hardboard production system.

Hardboard manufacture involves breaking down wood into its basic fibers then placing the wood back together with the fibers repositioned along with a resin system to form hard panels that have their own set of separate and distinct properties.

Resource transport

Wood raw materials are delivered to the mill by truck; the wood raw material consists of roundwood, green chips and green sawdust of various moisture contents; the moisture content of the residue can range from 35 to 100% on an oven-dry weight-basis. Based on mill surveys, the average haul distance for feedstock along with the components of the resin system is shown in Table 3.

Table 3. Weighted average delivery distance (one-way) by truck for materials to hardboard mill, North American average

Material delivered to mill	Delivery (km)	Distance (miles)
Roundwood	77	48
Chips, green	70	44
Sawdust, green	0.2	0.1
Phenol-formaldehyde resin	376	234
Alum	236	146
Paraffin emulsion (Wax)	591	367
Linseed oil	306	190
Slack wax	1,304	810
Zinc borate	161	100
Wood fuel, purchased	70	44

Storage yard

Upon arrival at the storage yard, all wood raw materials were weight-scaled and moisture levels determined. Log stackers or front-end loaders were used to transport roundwood and chips from the storage yard to the mill. Inputs included roundwood with bark, green chips, green sawdust, fuel, and lubricants. Outputs included roundwood with bark, green chips, green sawdust, 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 (roundwood, chips, and sawdust) and thus requires preparation before refining to generate a homogeneous form. Two facilities chip roundwood onsite. In this process, green 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. Outputs from this process include chips.

Refining

The purpose of this process is to pulp chips and sawdust. 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. Steam is used to soften the material. This process is usually accomplished with the use of 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) for wet-process hardboard and 10 to 20 hp-d/ton (125 to 250 kWh/tonne) for dry-process hardboard stock produced (Suchsland and Woodson 1986). Heating conditions of the wood raw material depend on wood species with hardwoods requiring less time than softwoods (Suchsland and Woodson 1986). Inputs include chips, sawdust, electricity, and heat. Outputs include pulp fiber and water vapor. In addition, for dry-process hardboard, wax may be added at this stage (USEPA 2002).

At this point in the production process, the wood fibers may enter a wet process or a dry process to form boards from the wood fibers leaving the refining process (Figure 5). Over 90% of hardboard production occurs through the wet process. Once hot pressing is complete, the boards from the wet and dry process continue on a similar process starting at the cooling and tempering step.

Wet-process board forming stages

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 mechanical mixing, water is added to the pulp fibers along with phenol-formaldehyde (PF) resin (Wilson 2010a) and additives for bonding the pulp fibers in stock chests. Adding the additional water creates a slurry. Lignin, a natural component of wood aids the resin system in bonding the pulp fibers. Inputs include pulp, water, and the resin system and the output is a slurry.

Wet forming

The low-consistency slurry, about 2% fiber, is pumped to board-forming (e.g., Fourdrinier) 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.

Hot pressing

Board drying is a continuous energy-intensive process to help set and cure the resin. The boards of about 65 to 75% moisture are conveyed on chain-driven rollers into a heated-enclosure broken into zones where the steam-heated presses remove 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% energy efficient (Jessen 1952; Suchsland and Woodson 1986). The press cycles are dependent upon press temperatures, board thickness, board density, and wood species thus vary from mill to mill. The board leaves the press as what industry calls S1S (smooth one side and a screen pattern on the back) hardboard (Granum and Eustis 1999). All wet process hardboards are surfaced on one side and are called S1S boards. Inputs include wet boards, combustion air, electricity, and combustion gases from burning wood fuel and outputs include dry boards, steam, fossil and biogenic carbon dioxide, and volatile organic compounds (VOCs). Combustion emissions from burning natural gas, residual fuel oil and wood fuel were provided by the US LCI Database (NREL 2012).

Dry-process board forming stages

Drying

Before drying, slack wax is added in the refining stages while the other additives of the resin system are added commonly through a blowline. This injection of additives produces wet resinated fibers. The wet resinated fibers are dried to approximately from 50 to 20% MC via tube dryers and the dried resinated fibers are conveyed to dry storage. There may be secondary tube dryers along the primary tube dryers to dry the boards to roughly 5% MC. The tube dryers are typically direct-heated from burning wood fuel and other fuels. Drying emissions are sent to regenerative thermal oxidizers to destroy volatile organic compounds emitted during the drying process. Inputs include wet fibers, resins, additives, combustion exhaust, fuel, and electricity while outputs include dry resinated fibers, volatile air emissions, and wet cool air.

Storage

During storage, the dry resinated fibers are prepared and staged for dry forming. Enough dry resinated fibers are stored to ensure the next stage, dry forming can be done at full speed.

Dry forming

Dry forming is a batch process. The dry resinated fibers are conveyed to the forming machine where they are pre-pressed into a mat and trimmed. The inputs include dry resinated fibers and electricity and the outputs include a dry fiber mat and trim residue.

Hot pressing

Board drying is a batch process. The mat enters a hot multi-opening press that activated the PF resin and bonds the fibers in the mat into the board. The presses are indirectly heated from boiler steam. The board leaves the press as S2S (smooth on both sides) hardboard. Inputs include dry fiber mat, indirect steam, and electricity while outputs include dry hot boards, steam, and volatile organic compounds.

The next steps are included for both the wet and dry processes.

Cooling/tempering

Before tempering, the dry hot boards are cooled and linseed oil added sometimes. In the wet-process, the cooled boards are dried further to aid in dimensional stability and physical properties (USEPA 2002). Once again, the tempering process can be performed with direct or indirect heating. Regardless of the process, all boards are humidified to the expected equilibrium moisture content to complete the tempering process. Inputs include the dry hot boards, heat, linseed oil, and moisture and outputs include the unfinished hardboard.

Finishing

Trimming reduces the unfinished hardboard to final standard dimensions, typically 4.0 by 8.0 ft (1.22 by 2.44 m). Input includes unfinished hardboard and output includes the final hardboard product, culled boards, and wood dust. Culled boards are boards that fail to pass a quality control inspection and are ground up for wood fuel. For this study, the hardboard was not coated.

Packaging

Finished hardboard is packaged for transport using wooden runners. Inputs include final product (hardboard) and packaging material like plastic wrapping and outputs including packaged hardboard. Packing materials represent less than 1% of the cumulative mass of the model flow. The material list was developed from mill survey data. The wooden runners make up the bulk of this mass, representing 75.6% of the total packaging material (Table 4). The cardboard strap protectors, wrapping material, plastic strapping, and steel strapping made up 15.4, 5.4, 3.4, and 0.2% of the packaging by mass, respectively.

Table 4. Materials used in packaging and shipping per m^3 hardboard, North American average

Material	Value	Unit	Percent (%)
Wrapping Material – HDPE and LDPE laminated	0.494	kg	5.4
PET Strapping	0.312	kg	3.4
Cardboard strap protectors	1.421	kg	15.4
Steel strapping	0.018	kg	0.2
Wooden runners	6.974	kg	75.6
Total	9.219	kg	100

Energy sources

Energy sources consumed onsite were derived from onsite and off-site sources. Onsite sources, process (thermal) energy used at the plant was provided by burning a mix of natural gas, residual oil, and purchased and self-generated wood fuel. Thermal energy was commonly produced in the form of steam and then used in the conditioning, refining, and drying unit processes. Outputs from generating thermal energy included steam from the boilers, combustion gases from the drying process, solid waste (wood ash), and CO_2 (biomass and fossil). Off-site source, the main source was from (grid) electricity, which released its emissions off-site. These production emissions were captured as part of the LCI. Table 5 shows the electrical grid composition for the North American production of hardboard. Coal (51.8%) and nuclear (27.0%) power comprises most of the grid when manufacturing hardboard. Outputs included electricity and emissions primarily of fossil CO_2.

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

Energy source	Canada-Nova Scotia[a] (%)	NWPP[b] (%)	MRO[c] (%)	SRVC[d] (%)	North American composite grid (%)
Natural gas	4.2	14.3	3.3	11.7	10.2
Coal	84.0	31.3	65.8	45.7	51.8
Oil	4.9	0.3	0.4	0.5	1.2
Nuclear	0.0	3.4	14.4	38.2	27.0
Hydro	3.7	43.6	5.5	1.5	6.4
Wind	0.6	4.8	8.8	0.0	1.1
Biomass	2.7	1.2	1.5	2.0	2.0
Miscellaneous	0.0	1.0	0.3	0.3	0.3
Total	100	100	100	100	100

[a] Grid composition was developed from Ecoinvent high-voltage grid for Quebec.
[b] NWPP is the electrical grid comprised of Washington, Oregon, Idaho, Utah, most of Montana (less NROW), Wyoming (less RMPA), Nevada (less AZNM) and northern parts of California, Arizona, and New Mexico.
[c] MRO is the electrical grid comprised of Manitoba, Minnesota, Nebraska, North Dakota, Saskatchewan and parts of Illinois, Michigan, South Dakota and Wisconsin.
[d] SRVC is the electric grid comprised of North and South Carolina and most of Virginia (less southwest Virginia).

Air Emissions

Hardboard production air emission data were collected from surveyed mill data and augmented by secondary resources (USEPA 2002; Santos et al. 2007). The main emission sources outside of boilers are digesters/refiners, mat formers, hot presses, dryers, tempering ovens, humidification kilns, and sanding/finishing operations. Baghouses are the primary collectors of particulate matter with all four surveyed mills using the emission control device (ECD). To reduce VOC emissions from dryers and refiners, mills reported the use of regenerative thermal oxidizer (RTO), wet scrubbers, or biofiltration systems. RTO are designed to destroy VOCs and other emissions including PM and soot (USEPA 2003a). The biofiltration system, similar to a wet scrubber, also captures nitrous oxides, carbon monoxide, and other organic compounds such as formaldehyde (USEPA 2002).

Resource and Material Inputs

The feedstock mass between input and output material flows in the production of hardboard were found to be within 1.7% (Table 6). The final product hardboard has an average oven-dry density of 768 kg/m^3 representing 94.8% wood fiber and 5.2% resin system. Table 6 shows feedstock used in the production of the hardboard. Green pulp chips have the highest feedstock input at 624 OD kg per cubic meter of hardboard with roundwood at second with 168 OD kg. PF resin at 1.7% of total incoming raw material has the highest resin system portion at 15.3 OD kg/m^3 with paraffin wax contributing 13.6 OD kg. All of the co-products generated during hardboard production are used internally either as wood fuel or re-pulped. Most of the co-products came from the wood dust collection systems either as bag house or sander dust.

Table 6. Mass balance of hardboard[a] manufacturing per m^3, North America

	Inputs (OD kg)	Mass (%)	CoV[b] (%)		Outputs (OD kg)	Mass (%)	CoV[b] (%)
Feedstocks				Products			
Roundwood	168	18.9	120	Hardboard	768	86.3	12.0
Chips, green	624	70.1	86.7	Co-Products			
Sawdust, green	51	5.8	-	Bag house dust, wood fuel	46.7	5.3	171
TOTAL, FEEDSTOCK	843	94.8	13.8	Culled boards, wood fuel	33.8	3.8	-
Resin system				Sander dust, wood fuel	18.7	2.1	116
Phenol-formaldehyde resin	15.3	1.7	45.9	Dry sawdust, wood fuel	5.9	0.7	143
Paraffin/wax emulsion	13.6	1.5	81.3	Bag house dust, re-pulped	1.4	0.2	-
Zinc borate	6.9	0.8	-	Other, not specified	15	1.7	-
Alum	5.1	0.6	76.4	TOTAL, CO-PRODUCTS	121	13.7	84.2
Compregnite	4.2	0.5	-	TOTAL, OUT	889	100	15.3
Release agent	0.5	0.1	-				
Slack wax	0.3	0.0	-				
Linseed oil	0.1	0.0	-				
TOTAL, RESIN SYSTEM	46	5.2	15.9				
TOTAL, IN	889	100	13.1				

[a] Hardboard includes engineered wood siding and trim.
[b] Weighted coefficient of variation.

Energy Inputs

Onsite energy for the production of hardboard comes from electricity, woody biomass, natural gas, and residual fuel oil. Woody biomass sources include onsite 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, forklifts, and natural gas, residual fuel oil, and wood fuels are used to heat refiners, presses, and dryers.

Self-generated wood fuel at 318 OD kg per cubic meter of hardboard is the primary fuel used in the hardboard manufacturing process; it is used for providing process heat for digesting, refining, drying boards, and heating steam or oil for hot rolling (Table 7). The second largest fuel source used onsite is purchased wood fuel. Natural gas is mostly used for drying boards through direct firing. Steam is produced by burning wood fuel along with residual fuel oil in a boiler to generate thermal energy. The total fuel use for process heat is 13.6 GJ/m^3 (3.82 million Btu/MSF) of which 93.1% is generated through the combustion of wood fuel (Table 7), 3.7% from residual fuel oil, and the other 3.2% from natural gas. The high wood energy component demonstrated the environmental performance of sustainably grown wood fuel.

Table 7. Heat inputs per 1 m^3 hardboard[a], North American average

Fuel	Unit	Value (Unit/m^3)	HHV (MJ/kg)	MJ/m^3 of product	Percentage of total energy
Wood fuel – self-generated	kg	318	20.9	6,655	48.8
Wood fuel – purchased	kg	290	20.9	6,051	44.3
Residual fuel oil	kg	11.8	43.41	511	3.7
Natural gas[b]	m^3	7.9	54.41	431	3.2
TOTAL Heat	MJ	-	-	13,647	100

[a] Hardboard includes engineered wood siding and trim.

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

The wood boiler primarily used both self-generated and purchased wood fuel Table 7 and Table 8). 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 52.4% bark, bag house dust, culled boards, sander dust, and dry sawdust (self-generated) and 47.6% green chips and sawdust (purchased).

Table 8 lists the wood boiler process inputs and outputs for manufacturing North American hardboard. The wood boiler profile is a composite process from the wood products industry (FAL 2008).

Table 8. Wood boiler process for manufacturing North American hardboard[a]

Product	Value
Wood biomass, combusted in industrial boiler-oven dry	1.00
Wood ash, at boiler, at mill,	0.0191
Materials/fuels	
Self-generated wood fuel	0.524
Purchased wood fuel	0.476
Emissions to air	
Acetaldehyde	1.05E-06
Acrolein	8.07E-07
Benzene	1.69E-07
Carbon monoxide, biogenic	0.003228
Carbon dioxide, biogenic	1.76
Wood (dust)	0.000562
Formaldehyde	1.26E-05
HAPs	6.27E-06
Hydrogen chloride	1.17E-06
Lead	1.75E-07
Mercury	1.83E-09
Methane, biogenic	2.23E-05
Methanol	7.95E-06
Nitrogen oxides	0.001096
Particulates, < 10 um	0.000471
Particulates, < 2.5 um	0.000139
Phenol	6.21E-07
Propanal (Propionaldehyde)	5.14E-08
Sulfur dioxide	7.71E-05
VOC, volatile organic compounds	0.000876
Dinitrogen monoxide (nitrous oxide)	2.93E-06
Naphthalene	5.77E-08
Other Organic	2.11E-07
Particulates, > 2.5 um, and < 10um	0.000332
Emissions to water	
Suspended solids, unspecified	8.35E-07
BOD5, Biological Oxygen Demand	2.10E-06

[a] Hardboard includes engineered wood siding and trim; Boiler data from FAL (2008).

Table 9 shows the detailed description of the material and energy inputs and outputs crossing the system boundary of hardboard. 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. Roundwood in log form makes up 18.9% of the total feedstock on average for North America. Electricity consumed onsite was calculated to be 654 kWh/m^3.

Water usage is broken down into two sources: 1) ground (well) water and 2) cooling (surface) water. By far, cooling water used was the highest at 11,323 L/m^3. Air emissions were derived from the surveyed mills along with pertinent emissions data categorized by the U.S. Environmental Protection Agency (USEPA 2002; USEPA 2003a; USEPA 2003b; USEPA 2003c; USEPA 2003d; DEQ 2006a; 2006b; Santos et al. 2007). When available, surveyed air emission data as primary data were selected over secondary data.

Table 9. Unit process inputs/outputs to produce 1 m^3 of hardboard[a], North American average

Products	Value	Unit/m^3	Allocation (%)
Hardboard/Engineered wood siding and trim	1	m^3	86.3
Bag house dust, wood fuel	46.7	kg	5.2
Culled boards, wood fuel	33.8	kg	3.8
Sander dust, wood fuel	18.7	kg	2.1
Dry sawdust, wood fuel	5.9	kg	0.7
Bag house dust, re-pulped	1.4	kg	0.2
Other, not specified	15.0	kg	1.7
Resources	**Value**	**Unit/m3**	
Water, well, in ground	303	L	
Water, cooling, surface	11,323	L	
Materials/fuels	**Value**	**Unit/m3**	
Wood feedstock, average North America, oven-dried	843	kg	
Phenol-formaldehyde (PF) resin	15.3	kg	
Paraffin Emulsion (Wax)	13.6	kg	
Zinc Borate	6.92	kg	
Alum	5.09	kg	
Compregnite	4.18	kg	
Release agent	0.456	kg	
Slack Wax	0.306	kg	
Linseed oil	0.086	kg	
Electricity, at Grid	654	kWh	
Diesel, combusted in industrial equipment	3.56	L	
Gasoline, combusted in equipment	0.15	L	
LPG, combusted in industrial equipment	7.96	L	
Natural gas, combusted in industrial boiler	7.9	m3	
Wood fuel, combusted in boiler, self-generated	318	kg	
Wood fuel, combusted in boiler, purchased	290	kg	
Residual fuel oil, combusted in industrial boiler	12	L	
Transport, combination truck, diesel power, purchased wood fuel	3.2	tkm	
Transport, combination truck, diesel power, wood feedstock	56.6	tkm	
Transport, combination truck, diesel powered, PF resin	5.76	tkm	
Transport, combination truck, diesel powered, paraffin wax	8.05	tkm	
Transport, combination truck, diesel powered, zinc borate	0.75	tkm	
Transport, combination truck, diesel powered, alum	1.20	tkm	
Transport, combination truck, diesel powered, Compregnite	0.45	tkm	
Transport, combination truck, diesel powered, release agent	0.05	tkm	
Transport, combination truck, diesel powered, slack wax	0.02	tkm	
Transport, combination truck, diesel powered, landfill waste	2.13	tkm	
Transport, combination truck, diesel powered, linseed oil	0.00	tkm	
Hydraulic fluid	0.38	kg	
Greases	0.04	kg	
Motor oil	0.02	kg	

Table 9. cont.

Potable water	10.3	L	
Paint	8.99	L	
Ink	0.006	kg	
Boiler chemicals	0.056	Kg	
Wrapping material - Packaging	0.494	kg	
Strap Protectors - Packaging	1.42	kg	
Strapping - Packaging	0.330	kg	
Runners - Packaging	6.97	kg	
Emissions to air	**Value**	**Unit/m3**	**Data**
Acetaldehyde	5.30E-02	kg	Primary
Acetone	1.74E-02	kg	
Acrolein	2.30E-02	kg	Primary
Alpha-pinene	8.08E-06	kg	
Benzene	3.57E-05	kg	Primary
Beta-pinene	1.31E-05	kg	
Carbon monoxide	2.06E-01	kg	
Chloroethane (Ethane, chloro-)	1.81E-05	kg	
Chloromethane (Methane, monochloro-,R-40)	1.71E-04	kg	
Cresols	7.71E-04	kg	
Cumene	0.00E+00	kg	
Ethylbenzene (Benzene, ethyl)	4.57E-05	kg	
Formaldehyde	6.93E-02	kg	Primary
Formic acid	7.85E-02	kg	Primary
Hexaldehyde (hexanal)	1.69E-02	kg	
Lead	0.00E+00	kg	
Limonene	7.24E-04	kg	
Mercury	0.00E+00	kg	
Methanol	3.08E-01	kg	Primary
Methyl ethyl ketone	3.41E-03	kg	
Methyl isobutyl ketone	7.85E-03	kg	
Nitroux oxide	4.00E-03	kg	
NMVOC, unspecified origin[b]	0.00E+00	kg	
PM2.5	0.00E+00	kg	
PM10	8.91E-02	kg	
Particulates, > 2.5 um, and < 10um	8.91E-02	kg	
Particulates, unspecified	1.47E-01	kg	
Phenol	9.42E-02	kg	Primary
Propionaldehyde (propanal)	1.79E-01	kg	Primary
Styrene	0.00E+00	kg	
Sulfur dioxide	3.07E-01	kg	Primary
Toluene	1.85E-03	kg	
Total hydrocarbons	1.99E+00	kg	
VOC, volatile organic compounds	1.40E+00	kg	Primary
Xylenes	7.66E-05	kg	
Emissions to water	**Value**	**Unit/m3**	**Data**
BOD5, Biological Oxygen Demand	2.0	kg	Primary
COD, Chemical Oxygen Demand	7.7	kg	Primary
Suspended solids, unspecified	3.8	kg	Primary
Waste to treatment	**Value**	**Unit/m3**	**Data**
Waste to inert landfill	42.6	kg	Primary
Waste to recycling	26.5	kg	Primary

[a] Hardboard includes engineered wood siding and trim.

[b] Non-methane volatile organic compound

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 later in the LCI Data section.

Data Quality Requirements

This study collected data from representative hardboard manufacturers in North America that use average technology for their regions. The raw wood material to produce hardboard comes from a variety of coproducts produced in product manufacturing facilities mills in Canada and the PNW, SE, and NE-NC regions of the United States in the form of green chips and green sawdust. The wood residue is comprised of many softwood species representing a mix of Douglas-fir (*Pseudotsuga menziesii*), red pine (*Pinus resinosa*), jack pine (*P. banksiana*), Virginia pine (*P. virginiana*), eastern white pine (*P. strobus*), and loblolly pine (*P. taeda* L.) and a mix of hardwood species representing a mix of of quaking aspen (*Populus tremuloides*), basswood (*Tilia americana*), silver maple (*Acer saccharinum*), red maple (*A. rubrum*), sugar maple (*A. saccharum*), paper birch (*Betula papyrifera*), yellow birch (*B. alleghaniensis*), northern red oak (*Quercus rubra*), white oak (*Q. alba*), post oak (*Q. stellata*), chestnut oak (*Q. prinus*), swamp chestnut oak (*Q. michauxii*), laurel oak (*Q. laurifolia*), southern red oak (*Q. falcata*), southern live oak (*Q. virginiana*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), blackjack oak (*Q. marilandica*), pin oak (*Q. palustris*), water oak (*Q. nigra*), willow oak (*Q. phellos*), yellow poplar (*Liriodendron tulipfera*), American gum *(Liquidamber styraciflua)*.

For the year 2012 when the study was initiated, seven hardboard facilities operated in North America. These seven facilities produced 2.20 billion ft^2 (205 million m^2) at 0.125-in (3.2-mm) basis equaling 22.9 million ft^3 (650 thousand m^3) of hardboard. Board production is measured on a thousand ft^2 (92.9 m^2) at 3.2-mm basis. The panels are typically produced in 0.125 up to 0.75 in (3.2–19.5 mm) thicknesses and in widths of 4.0 feet (1.22 m) and lengths of 8.0 (2.44 m). In 2012, hardboard production in North America was approximately 828,737 m^3 (NAFA 2013). For this study of hardboard production mills responding to surveys produced 792,865 m^3 in 2012, representing 42% of total production in North American. At the time of the survey, seven mills were operating in in Canada and the United States. There were no operating hardboard plants in Mexico at the time of data collection.

Critical Review

An internal critical review of the survey procedures, data, analysis, and report will be 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

All flow analyses of wood and bark in the process were determined on an oven-dry weight basis with a weighted average green specific gravity of 0.55.

Wood dust collected from various hardboard processes including sanding is collected by bag houses and used as wood fuel.

As shown in Table 2, although roundwood brought to the hardboard facilities was considered a ‘wood residue’ as shown, the electricity required breaking down the material that could not be separated out at the hardboard plants. Therefore, the electricity used for grinding the roundwood into chips was accounted for under “hardboard production.”

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 hardboard producers in North America, with some secondary data on electrical grid inputs and resource forest activities from the US LCI database (Goemans 2010; NREL 2012). The survey data represent hardboard production in terms of input materials, electricity, and fuel use, and emissions for the 2012 production year. The four production facilities surveyed were selected to be representative of North American production practices.

Questionnaires were used to survey the hardboard dry- and wet-process operations to collect primary data on hardboard manufacturing (Appendix B). The primary data obtained from the surveys were weight-averaged using the formula shown below (Milota 2004).

Calculation Rules

Hardboard is most commonly reported in a thousand square foot (MSF) 0.125-inch basis, which in SI units is equivalent to 0.295 m^3. The survey results were converted to a unit production basis, 1 m^3 (3.2-mm basis) and a weighted average of input data was calculated based on production. This approach resulted in a hardboard complex that represents a composite of the North American mills surveyed, but may not represent any mill in particular. The US LCI database was used to assess off-site impacts associated with the materials and energy used. SimaPro, version 8+ (Pré Consultants 2015) was used as the accounting program to track all of the materials.

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

Where $\bar{P}_{weighted}$ is the weighted average of the values is reported by 'n' 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 ith observation, 'N' is the number of non-zero weights, and $\bar{x}_w$ is the weighted mean of the observations.

Missing data are defined as data not reported in surveys by the hardboard 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

Cradle-to-gate life-cycle inventory results for hardboard are presented by three life stages, 1) forestry operations, 2) wood residue production, and 3) hardboard production (Tables 10-14). The majority of the raw material energy consumption occurs during hardboard 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 for 1 m^3 of hardboard. By mass, wood fuel at 539 kg/m^3 was consumed the most. Wood fuel was burned onsite to generate onsite thermal energy and off-site at a sawmill facility to produce wooden runners for the final product. Coal at 177 kg/m^3 was used primarily to generate electricity. Wood fuel was consumed entirely during hardboard production as no drying of feedstock during wood residue production was performed before arriving at the hardboard plants.

Table 10. Raw material energy consumption per 1 m^3 of cradle-to-gate hardboard[a], North American average, mass allocation

Fuel	Total	Forestry operations	Wood residue production	Hardboard production
			kg/m^3	
Coal, in ground	177	0.34	8.63	168.23
Gas, natural, in ground	57.4	0.29	1.01	56.10
Oil, crude, in ground	86.7	5.17	3.24	78.29
Uranium oxide, in ore	0.00573	0.00001	0.00023	0.00550
Wood fuel	539	0.0	0.0	539

[a] Hardboard includes engineered wood siding and trim.

Table 11 shows the cumulative energy consumption for the cradle-to-gate production of hardboard. By far, hardboard life-cycle stage consumed the most primary energy at 24,556 MJ/m^3 (96.9%). Most of the primary energy was derived from wood fuel at 11,277 MJ/m^3 and coal at 4,637 MJ/m^3 with cumulative energy consumption for all three life-cycle stages at 25,351 MJ/m^3. Crude oil consumption was third at 3,945 MJ/m^3 (15.5%) and came primarily from the production of alum, PF resin, slack wax, and burned onsite for thermal energy. Including other renewable energy sources of hydro and wind along with wood fuel, they comprise 45.2% of cumulative energy consumption.

Table 11. Cumulative energy consumption per 1 m^3 of cradle-to-gate hardboard[a], North American average (mass allocation)

Fuel	Percent	Total	Forestry operations	Wood residue production	Hardboard production
				MJ/m3	
Wood fuel	44.5	11,277	0.0	0.0	11,277
Coal, in ground	18.3	4,637	8.9	225.8	4,403
Oil, crude, in ground	15.%	3,945	235.0	147.3	3,562
Gas, natural, in ground	12.3	3,122	15.6	54.9	3,052
Uranium oxide, in ore	8.6	2,185	2.5	85.8	2,097
Hydro	0.6	154	0.0	13.2	141
Wind	0.1	30	0.0	5.8	25
Total	100.0	25,351	262.0	532.8	24,556
Total, by percent		100	1.0	2.1	96.9

[a] Hardboard includes engineered wood siding and trim.

Hardboard manufacturers reported onsite air emissions (Table 9) 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. Table 12 lists the most pertinent emissions along with the ones reported by the mills themselves. Fossil and biogenic CO_2 released in the production of 1 m^3 of hardboard were 518 and 959 kg, respectively. A complete list of all air emissions for the cradle-to-gate production of hardboard can be found in Appendix C. Boiler emissions are tracked separately and are not included in Table 12.

Table 12. Air emissions released per 1 m^3 of hardboard[a], cradle to gate, North American average (mass allocation)[b]

Air Emissions	Total	Forestry operations	Wood residue production	Hardboard production[b]
			kg/m^3	
Acetaldehyde	4.76E-02	6.99E-05	8.23E-05	4.74E-02
Acetone	1.54E-02	0.00E+00	0.00E+00	1.54E-02
Acrolein	2.08E-02	8.47E-06	2.04E-06	2.08E-02
Aldehydes, unspecified	2.95E-03	2.10E-04	1.35E-04	2.60E-03
Alpha-Pinene	7.14E-06	0.00E+00	0.00E+00	7.14E-06
Benzene	3.91E-04	8.52E-05	1.36E-05	2.92E-04
Beta-Pinene	1.16E-05	0.00E+00	0.00E+00	1.16E-05
Carbon dioxide, fossil	6.27E+02	1.68E+01	2.90E+01	5.81E+02
Carbon dioxide, biogenic	9.60E+02	1.57E-02	4.50E-01	9.59E+02
Carbon monoxide, fossil	2.13E+00	1.45E-01	7.38E-02	1.91E+00
Carbon monoxide, biogenic	3.00E+00	1.45E-01	7.38E-02	2.78E+00
Chloride	8.31E-09	1.20E-11	3.45E-10	7.95E-09
Chloroethane (Ethane, chloro-)	1.60E-05	2.96E-12	7.72E-11	1.60E-05
Chloromethane (Methane, monochloro-)	1.51E-04	3.74E-11	9.74E-10	1.51E-04
Cresol	6.81E-04	0.00E+00	0.00E+00	6.81E-04
Cumene	1.07E-09	3.74E-13	9.74E-12	1.06E-09
Ethylbenzene (Benzene, ethyl-)	4.04E-05	6.62E-12	1.79E-10	4.04E-05
Formaldehyde	9.10E-02	1.08E-04	1.34E-05	9.09E-02
Formic acid	6.93E-02	0.00E+00	0.00E+00	6.93E-02
Hexanal	1.40E-02	0.00E+00	0.00E+00	1.40E-02
Lead	1.35E-04	8.99E-08	1.65E-06	1.33E-04
HAPs	3.37E-03	0.00E+00	0.00E+00	3.37E-03
Limonene	6.39E-04	0.00E+00	0.00E+00	6.39E-04
Mercury	1.20E-02	0.00E+00	0.00E+00	1.20E-02
Methane, fossil	1.50E+00	2.34E-02	5.20E-02	1.43E+00
Methane, biogenic	1.20E-02	0.00E+00	0.00E+00	1.20E-02
Methanol	2.76E-01	0.00E+00	1.29E-04	2.76E-01
Methyl ethyl ketone	3.01E-03	2.75E-11	7.17E-10	3.01E-03
Nitrous oxide (dinitrogen monoxide)	1.09E-02	1.33E-05	2.28E-04	1.06E-02
Naphthalene	3.79E-05	2.18E-08	7.68E-08	3.78E-05
Non-methane VOC	1.58E-01	1.02E-02	7.23E-03	1.40E-01
Particulates, < 10 um	3.32E-01	0.00E+00	0.00E+00	3.32E-01
Particulates, < 2.5 um	7.46E-02	0.00E+00	0.00E+00	7.46E-02
Particulates, > 2.5 um, and < 10um	5.37E-02	9.39E-03	2.80E-03	4.15E-02
Particulates, unspecified	2.60E+00	1.69E-03	3.68E-01	2.23E+00
Phenol	1.06E-01	1.13E-12	1.33E-05	1.06E-01
Propionaldehyde (propanal)	4.68E-02	2.68E-11	6.99E-10	4.68E-02
Styrene	5.04E-09	1.76E-12	4.60E-11	4.99E-09
Sulfur dioxide	3.67E+00	9.42E-03	1.32E-01	3.53E+00
Toluene	1.70E-03	3.73E-05	3.74E-06	1.66E-03
TOC, Total Organic Carbon	9.88E-03	0.00E+00	0.00E+00	9.88E-03
Toluene	1.70E-03	3.73E-05	3.74E-06	1.66E-03
VOC, volatile organic compounds	1.78E+00	7.99E-03	9.27E-03	1.77E+00
Wood (dust)	3.02E-01	0.00E+00	0.00E+00	3.02E-01
Xylene	4.01E-04	1.64E-05	1.24E-05	3.72E-04

[a] Hardboard includes engineered wood siding and trim.
[b] Due to large amount of water emissions, emissions greater than of 10-4 and HAPs generated from hardboard production are shown. A complete list of all air emissions can be found in APPENDIX C.

Waterborne emissions produced are shown in Table 13. For suspended solids, unspecified to water, a value of 24.0 kg/m^3 hardboard was estimated followed by chloride at 16.0 kg/m^3. For suspended solids, unspecified, most of the emissions came from crude oil production and natural gas extraction followed by hardboard production itself. Most of chloride emission was from the process of producing PF resin and alum used to form the panels and thus did not occur at the production facilities.

Table 13. Emissions to water released per 1 m^3 of hardboard[a], North American average (mass allocation)[b]

Water emissions	Total	Forestry operations	Wood residue production	Hardboard production
			kg/m^3	
BOD5, Biological Oxygen Demand	1.86E+00	3.52E-03	2.67E-03	1.85E+00
Chloride	1.72E+01	6.96E-01	5.31E-01	1.60E+01
COD, Chemical Oxygen Demand	6.94E+00	6.69E-03	4.95E-03	6.92E+00
DOC, Dissolved Organic Carbon	1.97E-04	7.77E-13	2.22E-11	1.97E-04
Lead	2.40E-04	1.11E-05	8.12E-06	2.21E-04
Oils, unspecified	1.07E-02	4.45E-04	3.45E-04	9.92E-03
Phenol	1.33E-04	8.18E-06	5.13E-06	1.20E-04
Solids, inorganic	1.35E-08	1.96E-11	5.60E-10	1.29E-08
Solved solids	2.60E-04	0.00E+00	0.00E+00	2.60E-04
Suspended solids, unspecified	2.56E+01	9.09E-01	6.90E-01	2.40E+01

[a] Hardboard includes engineered wood siding and trim.
[b] Due to large amount of water emissions, emissions greater than of 10-4 and HAPs generated from hardboard production 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 hardboard production (Table 14). A total of 61.1 kg/m^3 solid waste was generated with 61.7% going to the landfill and the remaining portion being recycled.

Table 14. Waste to treatment per 1 m^3 of hardboard[a], cradle-to-gate, North American average (mass allocation)

Waste to treatment	Total	Forestry operations	Wood residue production	Hardboard production
			kg/m^3	
Waste in inert landfill	38.5	0.0	0.8	37.7
Waste to recycling	23.4	0.0	0.0	23.4

[a] Hardboard includes engineered wood siding and trim.

CARBON

As a wood product, hardboard stores carbon as part of its composition. Carbon content for wood products is assumed to be 50% by mass of OD wood. Therefore, excluding the resin system, the carbon stored in the wood portion of 1 m^3 (768 × 94.8% = 728 OD kg) of hardboard is equivalent to 1.33 Mg CO_2[1].

INTERPRETATION

Emissions from the forest resources LCI are small relative to manufacturing emissions (wood residue and hardboard). At the hardboard production facility, emissions originate at the boiler, during drying, refining, forming, pressing, tempering, and humidifying. Boiler emissions released are a function of the fuel burned while other emissions are a function of the unit process and associated emission control device.

Cradle-to-gate LCI results showed 518-kg fossil CO_2 were released in the production of 1 m^3 of hardboard. However, hardboard stores carbon. Carbon content for wood products is assumed to be 50% by mass of oven-dried (OD) wood. Excluding the resin system, the carbon stored in the wood portion of 1 m^3 (768 × 94.8% = 728 OD kg) of hardboard is equivalent to 1.33 Mg CO_2 emissions if left to decay.

Data quality was high. A wood mass balance was performed to verify data quality. As shown in Table 6, inputs and outputs were consistent for the four surveyed mills on cubic meter basis. In addition, total wood mass in and total wood mass out was calculated. Percentage difference for overall wood mass was 1.4%. A percentage difference less than 10% would be good. Therefore, tracking of wood mass is excellent for the present study. In addition, an energy comparison was conducted between competing products.

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 medium-density fiberboard (MDF) in the United States, cumulative allocated energy consumption for 1 m^3 of MDF is 19.7 GJ/m^3, with 41% from wood fuel (Wilson 2010b; Puettmann et al 2013a). For making oriented strandboard (OSB) in the southeastern (SE) United States, cumulative allocated energy consumption for 1 m^3 of OSB is 11.0 GJ/m^3, with 38% from wood fuel (Kline 2005). The values listed in the previous studies use mass allocation. From a European perspective, Gonzales and others (2009) did not report a cumulative energy demand value for conventional hardboard but Gonzales and others (2011) did report a CED value of 6.23 GJ/m^3 based on lower-heating values (LLVs) for the energy consumed for a 'green' hardboard using a laccase-activated system. The CED value of 6.23 GJ/m^3 was about 70% of conventional European hardboard shown in Gonzales and others (2011). Therefore, it still would be expected to be less than the cumulative energy value found in the present study because of the use of LLVs. This study also allocates primary energy to hardboard and co-products on mass. Primary energy is energy embodied in the original resources such as crude oil and coal before conversion. Softwood lumber from spruce, pine, redwood and cedar are alternative materials but likely would require additional processing than what has been reported from primary production (Bergman and Bowe 2010; Bergman et al 2014; Heroux 2015b).

[1] 728 OD kg wood × (0.5 kg carbon/1.0 OD kg wood) × (44 kg CO_2/kmole/12 kg carbon/kmole) = 1,330 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 2006a; b) to model the effects of fuel switching onsite thermal energy generation. Sensitivity analysis can be useful to understand how various process parameters contribute to environmental output factors. For instance, in hardboard manufacturing, thermal energy (i.e., heat) is used in several unit processes, consuming a combination of wood fuel, natural gas, and residual fuel oil 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 mixes were selected to compare with the baseline fuel mix developed from the mill survey data. This sensitivity analysis compared the air emission profile of the "baseline" fuel mix to (1) burning 100% natural gas and (2) burning 100% purchased wood fuel as a fuel input. Purchased instead of self-generated wood fuel was chosen because most of the wood residue generated during the board-making process was already burned as wood fuel. Natural gas was chosen because it burns cleaner than residual fuel oil and is abundantly available in North America.

Fuel Switching Analysis

In the present study, the "baseline" fuel mix included four fuel sources, with self-generated and purchased wood fuel supplying the most thermal energy with a small portion from fossil fuels. Based on survey data, the original model showed 48.8% of the fuel used was self-generated wood fuel, 43.3% purchased wood fuel, 3.7% residual fuel oil and the remaining natural gas, 3.2% (Table 7). 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 four production plants. In this sensitivity analysis, two alternative fuel-use schemes were created for comparison to the "composite plant" or "baseline" fuel mix. One alternative, "100% natural gas" case had natural gas consumption increase from the base value of 7.9 to 251 m^3 to generate 13.6 GJ/m^3 hardboard. 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 318 to 653 OD kg for purchased wood fuel to provide all necessary heat for the production facility.

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" hardboard fuel mix that used self-generated and purchased wood fuel, natural gas, and residual fuel oil, (2) comparing 100% purchased wood fuel to the "baseline" hardboard fuel mix that again had no fuel changes, and (3) comparing 100% natural gas to 100% self-generated wood fuel cases.

Fuel Switching 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, NOx, PM10, sulfur oxides (SOx), and VOCs, but more fossil CO_2, fossil CO, and fossil methane were emitted when burning 100% natural gas than in the baseline fuel mix (original). Scenario 2 showed more biogenic CO_2, PM10, and SOx but less fossil CO_2, fossil CO, fossil methane, and non-methane 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, fossil CO, and fossil methane emitted along with less benzene, biogenic CO_2, formaldehyde, NOx, PM10, and sulfur oxides emitted compared with scenario 1. For all three scenarios, the amounts of acetaldehyde, acrolein, methanol, particulate (unspecified), and phenol emitted were similar regardless of the fuel used because these emissions mostly originated onsite in the drying and finishing of the hardboard as shown in Table 9. In addition, although expected, there is a stark contrast between biogenic and fossil carbon dioxide emissions for the three scenarios. Furthermore, because purchased wood fuel required transportation by diesel truck, there were more SOx emission released as a result than the original and 100% natural gas fuel mixes. When no purchased wood fuel was consumed, all of the SOx were derived from making the cardboard in packaging.

Table 15. Sensitivity analysis for cradle-to-gate manufacturing 1 m^3 hardboard[a] in North America (mass allocation)

	Fuel distribution (kg/m^3 hardboard)			Difference (%)		
Substance	100% natural gas	100% wood fuel[a]	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	4.70E-02	4.76E-02	4.76E-02	–1.2	0.1	–1.3
Acrolein	2.04E-02	2.08E-02	2.08E-02	–2.1	0.2	–2.3
Benzene	4.04E-05	3.96E-04	3.91E-04	–162.5	1.4	–163.0
CO_2 (biogenic)	1.47E+01	1.03E+03	9.60E+02	–194.0	7.0	–194.4
CO_2 (fossil)	1.04E+03	5.77E+02	6.27E+02	50.0	–8.3	57.7
CO (fossil)	2.32E+00	1.97E+00	2.13E+00	8.6	–6.4	15.0
Formaldehyde	8.45E-02	9.15E-02	9.10E-02	–7.4	0.5	-7.9
Methane (fossil)	3.85E+00	1.38E+00	1.50E+00	87.6	–8.5	94.3
Methanol	2.72E-01	2.77E-01	2.76E-01	–1.6	0.1	–1.7
NOx	9.24E-03	1.09E-02	1.09E-02	–16.1	0.1	–16.2
Non-methane, VOC	1.40E-01	1.38E-01	1.58E-01	–11.8	–13.3	1.5
Particulate (PM10)	7.87E-02	3.50E-01	3.32E-01	–123.3	5.5	–126.6
Particulate (unspecified)	2.60E+00	2.60E+00	2.60E+00	–0.1	0.0	–0.1
Phenol	1.06E-01	1.06E-01	1.06E-01	–0.3	0.0	–0.3
Sox	7.08E-03	7.08E-03	1.94E-02	–92.8	57.0	–132.3
VOC	1.46E+00	1.81E+00	1.78E+00	–19.8	1.6	–21.5

[a] Wood fuel burned was purchased from off-site.

CONCLUSION

Amount and type of energy has a substantial role during production of building materials such as hardboard. Total cumulative energy consumption for the cradle-to-gate production of hardboard was 25.4 GJ/m^3. Use of renewable energy in manufacturing hardboard was substantial. Renewable energy made up just less than 50% of the total cumulative energy consumption profile for hardboard production at 45.2% of the 25.4 GJ/m^3 (11.5 GJ/m3). Renewable biomass, by far the largest renewable energy source represented 44.5% of the total cumulative energy consumption for all stages of production. As for the other two life-cycle stages, forestry operations consumed relatively little energy and was exclusively fossil fuels which came out to be 2.2% of the total cumulative energy consumption. In addition, the wood residue production stage consumed 3.7% of the non-renewable fossil fuel leaving the production of hardboard itself with about 94.1% or 4.10 GJ/m^3 of the non-renewable fossil fuel use. Energy consumed during PF resin production along with the additives was included in the fossil fuel use for hardboard as an upstream process. In summary, to produce 1 m^3 of hardboard from cradle-to-gate, 44.5% of the cumulative energy was from biomass (wood fuel) and 46.2% from non-renewable fossil fuels leaving a small portion of energy needs coming from nuclear (8.6%), hydro (0.6%), and the remaining 0.1% from wind, solar, and geothermal.

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

Emissions vary greatly between the life-cycle stages. Emissions from the forest resources LCI are small relative to manufacturing emissions (hardboard and wood residue). At the hardboard production facility emissions originate primarily at the boilers which are a function of the fuel burned, and during drying, pressing, tempering, and humidifying.

Using LCI analysis, 581 kg fossil CO_2 were released in the production of 1 m^3 of hardboard. However, hardboard 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 (728 OD kg) of hardboard is equivalent to 1.33 Mg CO_2. The carbon stored is twice the fossil CO_2 emissions released from cradle-to-gate.

RECOMMENDATIONS

Several issues have been found as the result of conducting the cradle-to-gate LCI of hardboard with the following two issues highlighted. One issue is the high use of water in the process. However, it is noted that recycling efforts have substantially reduced overall water consumption. Second, wood fuel consumption in hardboard production greatly lowers fossil carbon dioxide emissions, the major source of greenhouse gases contributing to global warming impact. Therefore, every effort to maintain or increase wood fuel consumption where practicable ought to be considered to help mitigate the global warming impact. Last, using green instead of dry wood residue lowers the energy consumed in the preparation of feedstock in the hardboard production stage. Therefore, green wood residue should continue to be used as a feedstock over dry wood residues.

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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 (1971).

Table 17. Electricity grids and dataset name by region and source

Region	North American grid	Source
US Average	Electricity, at grid, US, 2008	NREL (2012)
Canadian – Nova Scotia	Electricity, high voltage {CA-NS}| market for | Alloc Def, U	Ecoinvent LCI Database
Pacific Northwest	Electricity, at grid, NWPP, 2010	USEPA (2014): p. 6
Northeastern/North central (Midwest)	Electricity, at grid, MRO, 2010	USEPA (2014): p. 9
Virginia/Carolina	Electricity, at eGrid, SRVC, 2010	USEPA (2014): p. 6

Table 18. Energy contents and densities of various fuels.

Fuel	HHV[1, 2, 3, 4] MJ/kg	Density	Density Units
Coal	26.19		
Distillate fuel oil[5]	45.54	0.85	kg/L
Liquid propane gas	54.05	0.49	kg/L
Natural gas	54.45	0.70	kg/m^3
Residual fuel oil	43.45	0.96	kg/L
Wood	20.93		
Uranium	381,000.00		
Gasoline	48.36	0.72	kg/L
Diesel	44.00	0.88	kg/L
Kerosene			

[1] Hodgman (1955).
[2] Salazar and Meil (2009).
[3] Todreas and Kazimi (1993).
[4] Used in the present study.
[5] Same as for crude oil.

APPENDIX B: PRODUCTION FACILITY SURVEY QUESTIONNAIRES

USDA FS Forest Products Laboratory/Composite Panel Association Survey

Hardboard/Engineered Wood Siding/Engineered Wood Trim (EWST) Plants – Wet Process

2013

This survey was sent to you as part of a larger collaboration between the USDA FS Forest Products Laboratory, the Composite Panel Association, the University of Tennessee-Knoxville and the American Wood Council (AWC).

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. The completion time for the questionnaire could range from 8 to 16 hours depending if the requested data are easily accessible.

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 hardboard/EWST 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 Friday, August 2nd</u>.
In addition, contact Rick Bergman at the listed phone/email with any questions about the survey.

Rick Bergman
Research Forest Products Technologist,
Economics, Statistics, and Life Cycle Analysis Unit
USDA Forest Service Forest Products Laboratory
One Gifford Pinchot Dr,
Madison, WI 53726-2398
(608) 231-9477 (ph)/(608) 231-9508 (fax)/rbergman@fs.fed.us

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	phenol-formaldehyde resin
O	O	other resins
O	O	catalyst
O	O	alum
O	O	wax
O	O	Forming machine(s) #______
		width: 4', 8', 12' (circle one)
		Hot press(es) #______
O	O	batch
O	O	continuous

Yes	No	Equipment in mill
O	O	Hot press(es) continued
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	Oven(s) # _____________
O	O	Board cooler(s) # __________
O	O	Humidification kiln(s) # _____
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	sander(s) # ______
O	O	coating
		Emission controls
O	O	Dust collection system(s) # ___
O	O	Thermal oxidizer(s) # ______
O	O	Catalytic oxidizer(s) # ______
O	O	Scrubber(s) # ______
O	O	Biofiltration systems(s) # _____
		Packaging
O	O	plastic wrapping (bags)
O	O	metal strapping
O	O	plastic strapping

2. Log storage – wet or dry (circle one)

3. Average log diameter ________________ inches

4. Average log length _______________feet

5. **What type of log scaling is used? Weight, Electronic, Doyle, Scribner Decimal C, International ¼, other (circle one)**

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

Hardboard/EWST Plant Annual Wood Usage/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%	

7. **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%	

Hardboard/EWST Annual Production			
(Please provide units of measurement if different than stated)			Total Production
	Annual Hardboard/EWST production, 2012	ft^3	
	Annual Hardboard/EWST production, 2012	ft^2 @ ½” basis	
	Annual Hardboard/EWST 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? Sawmill trim, sawdust, planar shavings, other _________________ (circle one)			
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? Sawmill trim, sawdust, planar shavings, other _________________ (circle one)			
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? Sawmill trim, sawdust, planar shavings, other _________________ (circle one)			
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? Sawmill trim, sawdust, planar shavings, other _________________ (circle one)			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Hardboard/EWST 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) and the second section refers to transportation fuel. (Please provide units of measurement if different)

Fuel	Unit	Quantity
Total electricity for hardboard/EWST plant	kWh	
Purchased steam	lbs (°F)	
Wood Fuel *Self-generated*	Tons / (%MC)	/
Wood Fuel *Purchased*	Tons / (%MC)	/
Natural Gas	1000 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 produces any of the following for use onsite or for sale, please fill out the table. Enter N/A if not applicable.

Energy	Unit	Quantity (used onsite)	Quantity (sold off-site)
Electricity	kWh		
Steam	lbs (°F)		

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					

Hardboard/EWST Plant Annual Onsite 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					
		Feedstock prep	Boiler	Finishing	Support vehicles	Other	Units
Off-road diesel							Gallons
On-road diesel							Gallons
Propane							Gallons
Gasoline							Gallons
Electricity							Gallons
Other							kWh

Other Hardboard/EWST Plant Annual Use Data

Formulation and usage of resins, 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
Phenol-formaldehyde resin			
Alum			
Paraffin emulsion (wax)			
Carbon black			
Clay			
Other binder: __________			
Other: ___________			
Other: ___________			
Other: ___________			
Other: ___________			

Transportation method and distance for PF resin			
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 paraffin emulsion			
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 hot press: direct or in-direct heating (circle one)		
Fuel Source	**Unit**	**Annual fuel use**
Natural Gas	1000 ft^3	
Electricity	kWh	
Propane	gallon	
Wood fuel	tons / %MC	

For hot presses, what is used as a heating medium if indirect? Hot oil or steam (circle one)

Source of heat for ovens: direct or in-direct heating (circle one)		
Fuel Source	**Unit**	**Annual fuel use**
Natural Gas	1000 ft^3	
Electricity	kWh	
Propane	gallon	
Wood fuel	tons / %MC	

For ovens, what is used as a heating medium if indirect? Hot oil or steam (circle one)

Hardboard/EWST properties

1. Moisture content of board mats into hot press ______________ %MC (dry basis)
2. Moisture content of board mats out of hot press ______________ %MC (dry basis)
3. Hardboard/EWST produced per hour out of the board dryer ______________ Msf/hr
4. Density of hardboard/EWST leaving hot press ________ lb/ft^3 __________ lb/Msf
5. Moisture content out of oven if applicable ______________ %MC (dry basis)
6. Density of hardboard/EWST leaving oven ________ lb/ft^3 __________ lb/Msf
7. Moisture content out of board cooler ______________ %MC (dry basis
8. Moisture content out of humidification kiln ______________ %MC (dry basis
9. Density of hardboard/EWST before packaging ________ lb/ft^3 (6 may equal 9)
10. Hourly production of hardboard/EWST ______________ Msf/hr (3 may equal 10)

____________________percent coated product

Hardboard/EWST Plant Annual Wood Residue Production

Wood residues are any wood material produced in conjunction with making hardboard/EWST and are called co-products in this survey. For each of the co-products produced at your plant, please indicate the weight (tons) of **annual** 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 per Msf of hardboard/EWST ___________tons per Msf of hardboard/EWST

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)						
Culled boards						
Sander dust						
Cyclone dust						
Bag house dust						
Other						

Hardboard/EWST 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	Drying	Finishing	Packaging
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	%	%	%	%	%	%	%	%	%	%
Other ___________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%
Other ___________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%
Other ___________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%
Other ___________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%

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

Hardboard/EWST 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]		Sampling method or source[2]	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**		**Feedstock prep**	**Steam digester**	**Boiler**	**Refiner**	**Washer**	**Stock chest**	**Wet former**	**Drying**	**Finishing**	**Packaging**
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[3]: _____	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Inorganic[4]: ____	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%

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

[2] Sampling methods might be Method 25A, Method 5, NCASI 105. Estimates might be based on AP42, Standard Air Contaminate Discharge Permit or other source.

[3] Non-HAP organics that are not included in VOC value.

[4] Inorganics such as chlorine, mercury sulfur.

Hardboard/EST 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[1] (lb/yr)	How amount was found? Mark one[2]		Sampling method or source[3]	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	Dryer	Finishing	Packaging
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		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%

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

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

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

Hardboard/EWST 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[1] (lb/yr)	How amount was found? Mark one[2]			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	Dryer	Dry former	Heat treatment	Finishing	Packaging
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 organic	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other non-organic	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%

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

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

Hardboard/EWST Plant Annual Water Use

Recycling rate of water helps reduce the water footprint. A water footprint refers to the amount of water that a facility uses to produce a certain quantity of product (e.g. 250 gallons per Msf @ 3/8" of OSB). If water is recycled by 50%, the product's water footprint is reduced by 50%.

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. We would like to know where the water goes as well as where it is used. The more data we acquire, the more accurate the water footprint we will report.

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

Hardboard/EWST 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, hot press, oven, 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 evaporator, **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			
Hot press			
Oven			
High-pressure water jets			
Trim saws			
Sanders			
Coating system			

Hardboard/Engineered Wood Siding/Engineered Wood Trim (EWST) Plants – Dry Process

2013

This survey was sent to you as part of a larger collaboration between the USDA FS Forest Products Laboratory, the Composite Panel Association, the University of Tennessee-Knoxville and the American Wood Council (AWC).

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. The completion time for the questionnaire could range from 8 to 16 hours depending if the requested data are easily accessible.

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 hardboard/EWST 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 Friday, August 2nd</u>. In addition, contact Rick Bergman at the listed phone/email with any questions about the survey.

Rick Bergman
Research Forest Products Technologist,
Economics, Statistics, and Life Cycle Analysis Unit
USDA Forest Service Forest Products Laboratory
One Gifford Pinchot Dr,
Madison, WI 53726-2398
(608) 231-9477 (ph)/(608) 231-9508 (fax)
rbergman@fs.fed.us

General Plant Information

8. 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
O	O	chipper(s) #_______
O	O	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	Blowline
		additives
O	O	phenol-formaldehyde resin
O	O	urea-formaldehyde resin
O	O	other resins __________
O	O	Tube dryer(s)#_______
O	O	primary # _______
O	O	direct-heated
O	O	indirect-heated
O	O	secondary # _____
		direct-heated
		indirect-heated
O	O	Rotary dryer(s) # _______
O	O	Dry forming machine(s) #_____
		width: 4’, 8’, 12’ (circle one)
O	O	Pre-press

Yes	No	Equipment in mill
		Hot press(es) #______
O	O	batch
O	O	continuous
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	Board cooler(s) # __________
O	O	additive – linseed oil
		Tempering oven(s) # __________
O	O	direct-heated
O	O	Indirect-heated
O	O	Humidification kiln(s) # _____
O	O	Boiler(s) # ________
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	sander(s) # ______
O	O	coating
		Emission controls
O	O	Dust collection system(s) # ___
O	O	Thermal oxidizer(s) # ______
O	O	Catalytic oxidizer(s) # ______
O	O	Scrubber(s) # ______
O	O	Biofiltration systems(s) # _____
		Packaging
O	O	plastic wrapping (bags)
O	O	metal strapping
O	O	plastic strapping

9. Log storage – wet or dry (circle one)

10. Average log diameter ________________ inches

11. Average log length _______________feet

12. What type of log scaling is used? Weight, Electronic, Doyle, Scribner Decimal C, International ¼, other (circle one)

13. Volume of incoming logs _________________ bf

Hardboard/EWST Plant Annual Wood Usage/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%	

14. 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				
Other				
Other				
Total non-log feedstock sources			100%	

Hardboard/EWST Annual Production			
(Please provide units of measurement if different than stated)			Total Production
Annual Hardboard/EWST production, 2012		ft^3	
Annual Hardboard/EWST production, 2012		ft^2 @ ½" basis	
Annual Hardboard/EWST 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? Sawmill trim, sawdust, planar shavings, other __________________ (circle one)			
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? Sawmill trim, sawdust, planar shavings, other __________________ (circle one)			
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? Sawmill trim, sawdust, planar shavings, other __________________ (circle one)			
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? Sawmill trim, sawdust, planar shavings, other __________________ (circle one)			
Truck (% of total)		Average delivery miles	
Rail (% of total)		Average delivery miles	
Other (% of total)		Average delivery miles	
Total (%)	100%		

Hardboard/EWST 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 (non-transport fuel) energy consumption and the second section refers to transportation fuel. (Please provide units of measurement if different)

Fuel	**Unit**	**Quantity**
Total electricity for hardboard/EWST plant	kWh	
Purchased steam	lbs (°F)	
Wood Fuel *Self-generated*	Tons / (%MC)	/
Wood Fuel *Purchased*	Tons / (%MC)	/
Natural Gas	1000 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 produces any of the following for use onsite or for sale, please fill out the table. Enter N/A if not applicable.

Energy	**Unit**	**Quantity (used onsite)**	**Quantity (sold off-site)**
Electricity	kWh		
Steam	lbs (°F)		

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					

Hardboard/EWST Plant Annual Onsite 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					
		Feedstock prep	Boiler	Finishing	Support vehicles	Other	Units
Off-road diesel							Gallons
On-road diesel							Gallons
Propane							Gallons
Gasoline							Gallons
Electricity							Gallons
Other							kWh

Other Hardboard/EWST Plant Annual Use Data

Formulation and usage of resins, 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
Phenol-formaldehyde resin			
Other resin __________			
Other resin ________			
Alum			
Paraffin emulsion (wax)			
Carbon black			
Clay			
Linseed oil			
Other: ___________			
Other: ___________			

Transportation method and distance for PF resin			
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 resin ___________			
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 resin _____________			
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 paraffin emulsion			
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 linseed oil			
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 dryers: direct or in-direct heating (circle one)		
Fuel source	**Unit**	**Annual fuel use**
Natural Gas	1000 ft^3	
Electricity	kWh	
Propane	gallon	
Wood fuel	tons / %MC	
Other	?	

For dryers, what is used as a heating medium if indirect? Hot oil or steam (circle one)

Source of heat for hot presses: direct or in-direct heating (circle one)		
Fuel source	**Unit**	**Annual fuel use**
Natural Gas	1000 ft^3	
Electricity	kWh	
Propane	gallon	
Wood fuel	tons / %MC	
Other	?	

For hot presses, what is used as a heating medium if indirect? Hot oil or steam (circle one)

Source of heat for ovens: direct or in-direct heating (circle one)		
Fuel source	**Unit**	**Annual fuel use**
Natural Gas	1000 ft^3	
Electricity	kWh	
Propane	gallon	
Wood fuel	tons / %MC	
Other	?	

For ovens, what is used as a heating medium if indirect? Hot oil or steam (circle one)

Hardboard/EWST properties

1.	Moisture content of fiber into dryers	____________	%MC (dry basis)
2.	Moisture content of fiber out of dryers	____________	%MC (dry basis)
3.	Moisture content of board mats into hot press	____________	%MC (dry basis)
4.	Moisture content of board mats out of hot press	____________	%MC (dry basis)
5.	Hardboard/EWST produced per hour out of the hot press	____________	Msf/hr
6.	Density of hardboard/EWST leaving hot press	_______ lb/ft^3	_________ lb/Msf
7.	Moisture content out of oven if applicable	____________	%MC (dry basis)
8.	Density of hardboard/EWST leaving oven	_______ lb/ft^3	_________ lb/Msf
9.	Moisture content out of board cooler	____________	%MC (dry basis
10.	Moisture content out of humidification kiln	____________	%MC (dry basis
11.	Density of hardboard/EWST before packaging	_______ lb/ft^3	(8 may equal 11)
12.	Hourly production of hardboard/EWST	____________	Msf/hr (5 may equal 12)

____________________percent coated product

Hardboard/EWST Plant Annual Wood Residue Production

Wood residues are any wood material produced in conjunction with making hardboard/EWST and are called co-products in this survey. For each of the co-products produced at your plant, please indicate the weight (tons) of **annual** 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 per Msf of hardboard/EWST ___________tons per Msf of hardboard/EWST

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)						
Culled boards						
Sander dust						
Cyclone dust						
Bag house dust						
Other						

Hardboard/EWST Plant Ancillary Material Inputs

	Used			How amount was found? Mark one[1]		Where the ancillary material is used as a percent Estimation is ok. If not able to estimate, please leave blank									
Ancillary Material	Yes	No	Amount	M	E	Feedstock prep	Steam digester	Boiler	Refiner	Washer	Dryer	Dry former	Heat treatment	Finishing	Packaging
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	%	%	%	%	%	%	%	%	%	%
Other ________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%
Other ________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%
Other ________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%
Other ________	O	O	lb/yr	O	O	%	%	%	%	%	%	%	%	%	%

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

Hardboard/EWST 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[2]**	**Feedstock prep**	**Steam digester**	**Boiler**	**Refiner**	**Washer**	**Dryer**	**Dry former**	**Heat treatment**	**Finishing**	**Packaging**
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[3]: _____	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Inorganic[4]: ____	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%

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

[2] Sampling methods might be Method 25A, Method 5, NCASI 105. Estimates might be based on AP42, Standard Air Contaminate Discharge Permit or other source.

[3] Non-HAP organics that are not included in VOC value.

[4] Inorganics such as chlorine, mercury sulfur.

Hardboard/EWST 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[1] (lb/yr)	How amount was found? Mark one[2]		Sampling method or source[3]	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	Dryer	Dry former	Heat treatment	Finishing	Packaging
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		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%	%

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

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

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

Hardboard/EWST 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[1] (lb/yr)	How amount was found? Mark one[2]			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	Dryer	Dry former	Heat treatment	Finishing	Packaging
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 organic	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other non-organic	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%
Other: ________	L / R		O	O	O	%	%	%	%	%	%	%	%	%	%

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

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

Hardboard/EWST Plant Annual Water Use

Recycling rate of water helps reduce the water footprint. A water footprint refers to the amount of water that a facility uses to produce a certain quantity of product (e.g. 250 gallons per Msf @ 3/8" of OSB). If water is recycled by 50%, the product's water footprint is reduced by 50%.

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. We would like to know where the water goes as well as where it is used. The more data we acquire, the more accurate the water footprint we will report.

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

Hardboard/EWST 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, hot press, oven, 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 evaporator, **write N/A**. **Estimates are ok.**

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

APPENDIX C: HARDBOARD LIFE-CYCLE INVENTORY FLOWS

SimaPro 8.0.3.14	Inventory	Date:	1/9/2015	Time:	2:56:00 PM	
Project	EWP					
Calculation:	Compare					
Results:	Inventory					
Product 1:	1.324 m3 Forest harvest, hardboard, at forest road, NA (of project EWP)					
Product 2:	728 kg Wood residue, at mill, hardboard, NA (of project EWP)					
Product 3:	786 kg Hardboard, at hardboard 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	Hardboard production
1	Carbon dioxide, in air	Raw	kg	1.57E-02	1.23E+02	1.01E+03
2	Carbon, organic, in soil or biomass stock	Raw	kg	0.00E+00	0.00E+00	1.44E+03
3	Coal, 26.4 MJ per kg	Raw	kg	3.42E-01	8.78E+00	1.68E+02
4	Energy, from hydro power	Raw	MJ	2.14E-02	1.31E+01	1.41E+02
5	Energy, geothermal	Raw	MJ	0.00E+00	4.01E-02	6.04E-05
6	Energy, kinetic (in wind), converted	Raw	MJ	3.54E-03	5.76E+00	2.46E+01
7	Energy, solar, converted	Raw	MJ	0.00E+00	1.43E-01	3.73E-06
8	Gas, natural/kg	Raw	kg	0.00E+00	0.00E+00	8.08E-01
9	Gas, natural/m3	Raw	m3	2.86E-01	1.08E+00	5.61E+01
10	Limestone	Raw	kg	0.00E+00	0.00E+00	2.97E+01
11	Occupation, arable, conservation tillage	Raw	m2a	0.00E+00	0.00E+00	3.23E-03
12	Occupation, arable, conventional tillage	Raw	m2a	0.00E+00	0.00E+00	3.54E-03
13	Occupation, arable, reduced tillage	Raw	m2a	0.00E+00	0.00E+00	2.17E-03
14	Oil, crude	Raw	kg	5.17E+00	3.61E+00	7.83E+01
15	Potassium chloride	Raw	kg	0.00E+00	0.00E+00	4.63E+00
16	Scrap, external	Raw	kg	0.00E+00	0.00E+00	4.08E-01
17	Sodium carbonate	Raw	kg	0.00E+00	0.00E+00	2.07E-03
18	Sodium chloride	Raw	kg	0.00E+00	0.00E+00	7.55E-03
19	Sodium sulfate	Raw	kg	0.00E+00	0.00E+00	7.99E-03
20	Sulfur	Raw	kg	0.00E+00	0.00E+00	4.10E-04
21	Uranium	Raw	kg	0.00E+00	0.00E+00	1.23E-05
22	Uranium oxide, 332 GJ per kg, in ore	Raw	kg	6.56E-06	2.20E-04	5.50E-03
23	Water, cooling, surface	Raw	kg	0.00E+00	0.00E+00	1.00E+04
24	Water, river	Raw	m3	0.00E+00	0.00E+00	3.62E-05
25	Water, unspecified natural origin/m3	Raw	m3	0.00E+00	2.56E-06	3.58E-03
26	Water, well, in ground	Raw	m3	0.00E+00	0.00E+00	2.68E-01

27	Wood and wood waste, 20.9 MJ per kg, ovendry basis	Raw	kg	0.00E+00	0.00E+00	5.39E+02
28	Wood, feedstock	Raw	kg	0.00E+00	0.00E+00	1.83E+00
29	Wood, hard, NE-NC, standing	Raw	m3	0.00E+00	4.96E-02	0.00E+00
30	Wood, soft, US SE, standing/m3	Raw	m3	0.00E+00	7.10E-02	1.15E-02
31	2-Chloroacetophenone	Air	kg	4.93E-13	1.44E-11	1.40E-09
32	2-Methyl-4-chlorophenoxyacetic acid	Air	kg	0.00E+00	0.00E+00	2.13E-10
33	2,4-D	Air	kg	0.00E+00	0.00E+00	1.14E-08
34	5-methyl Chrysene	Air	kg	3.28E-12	8.33E-11	1.60E-09
35	Acenaphthene	Air	kg	7.61E-11	1.93E-09	3.70E-08
36	Acenaphthylene	Air	kg	3.73E-11	9.47E-10	1.81E-08
37	Acetaldehyde	Air	kg	6.99E-05	8.47E-05	4.74E-02
38	Acetochlor	Air	kg	0.00E+00	0.00E+00	1.58E-07
39	Acetone	Air	kg	0.00E+00	0.00E+00	1.54E-02
40	Acetophenone	Air	kg	1.06E-12	3.09E-11	2.99E-09
41	Acrolein	Air	kg	8.47E-06	2.35E-06	2.08E-02
42	Alachlor	Air	kg	0.00E+00	0.00E+00	1.56E-08
43	Aldehydes, unspecified	Air	kg	2.10E-04	1.50E-04	2.60E-03
44	alpha-Pinene	Air	kg	0.00E+00	0.00E+00	7.14E-06
45	Ammonia	Air	kg	1.06E-04	1.15E-04	1.84E-03
46	Ammonium chloride	Air	kg	3.48E-07	1.17E-05	2.92E-04
47	Anthracene	Air	kg	3.13E-11	7.95E-10	1.52E-08
48	Antimony	Air	kg	2.69E-09	6.82E-08	1.31E-06
49	Arsenic	Air	kg	8.27E-08	1.60E-06	3.65E-05
50	Atrazine	Air	kg	0.00E+00	0.00E+00	3.09E-07
51	Bentazone	Air	kg	0.00E+00	0.00E+00	1.26E-09
52	Benzene	Air	kg	8.52E-05	1.66E-05	2.92E-04
53	Benzene, chloro-	Air	kg	1.55E-12	4.53E-11	4.39E-09
54	Benzene, ethyl-	Air	kg	6.62E-12	2.00E-10	4.04E-05
55	Benzo(a)anthracene	Air	kg	1.19E-11	3.03E-10	5.80E-09
56	Benzo(a)pyrene	Air	kg	5.67E-12	1.44E-10	2.76E-09
57	Benzo(b,j,k)fluoranthene	Air	kg	1.64E-11	4.16E-10	7.98E-09
58	Benzo(g,h,i)perylene	Air	kg	4.03E-12	1.02E-10	1.96E-09
59	Benzyl chloride	Air	kg	4.93E-11	1.44E-09	1.40E-07
60	Beryllium	Air	kg	4.08E-09	9.77E-08	1.82E-06
61	Biphenyl	Air	kg	2.54E-10	6.44E-09	1.23E-07
62	Bromoform	Air	kg	2.75E-12	8.03E-11	7.78E-09
63	Bromoxynil	Air	kg	0.00E+00	0.00E+00	2.76E-09
64	BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspecified ratio	Air	kg	7.05E-05	2.66E-04	1.38E-02
65	Butadiene	Air	kg	3.56E-06	4.80E-07	2.26E-06
66	Cadmium	Air	kg	1.90E-08	2.36E-07	6.58E-06
67	Carbofuran	Air	kg	0.00E+00	0.00E+00	2.36E-09
68	Carbon dioxide	Air	kg	0.00E+00	2.61E-02	5.25E-03
69	Carbon dioxide, biogenic	Air	kg	1.57E-02	4.49E-01	9.59E+02
70	Carbon dioxide, fossil	Air	kg	1.68E+01	3.05E+01	5.81E+02
71	Carbon disulfide	Air	kg	9.16E-12	2.68E-10	2.59E-08
72	Carbon monoxide	Air	kg	3.44E-06	4.16E-05	8.56E-01
73	Carbon monoxide, biogenic	Air	kg	0.00E+00	0.00E+00	1.73E+00
74	Carbon monoxide, fossil	Air	kg	1.45E-01	8.26E-02	1.05E+00
75	Chloride	Air	kg	1.20E-11	3.44E-10	7.95E-09
76	Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	Air	kg	0.00E+00	0.00E+00	5.36E-08
77	Chlorine	Air	kg	0.00E+00	0.00E+00	3.24E-08

78	Chloroform	Air	kg	4.16E-12	1.22E-10	1.18E-08
79	Chlorpyrifos	Air	kg	0.00E+00	0.00E+00	1.81E-08
80	Chromium	Air	kg	5.83E-08	1.04E-06	2.41E-05
81	Chromium VI	Air	kg	1.18E-08	2.99E-07	5.73E-06
82	Chrysene	Air	kg	1.49E-11	3.79E-10	7.26E-09
83	Cobalt	Air	kg	1.06E-07	4.94E-07	3.64E-05
84	Copper	Air	kg	9.49E-10	3.50E-08	3.12E-07
85	Cresol	Air	kg	0.00E+00	0.00E+00	6.81E-04
86	Cumene	Air	kg	3.74E-13	1.09E-11	1.06E-09
87	Cyanazine	Air	kg	0.00E+00	0.00E+00	2.72E-09
88	Cyanide	Air	kg	1.76E-10	5.15E-09	4.99E-07
89	Dicamba	Air	kg	0.00E+00	0.00E+00	1.60E-08
90	Dimethenamid	Air	kg	0.00E+00	0.00E+00	3.79E-08
91	Dinitrogen monoxide	Air	kg	1.33E-05	3.96E-04	1.06E-02
92	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	kg	3.51E-13	3.82E-12	1.34E-10
93	Dipropylthiocarbamic acid S-ethyl ester	Air	kg	0.00E+00	0.00E+00	2.59E-08
94	Ethane, 1,1,1-trichloro-, HCFC-140	Air	kg	4.86E-10	3.80E-10	9.82E-09
95	Ethane, 1,2-dibromo-	Air	kg	8.46E-14	2.47E-12	2.39E-10
96	Ethane, 1,2-dichloro-	Air	kg	2.82E-12	8.24E-11	7.98E-09
97	Ethane, chloro-	Air	kg	2.96E-12	8.65E-11	1.60E-05
98	Ethene, tetrachloro-	Air	kg	7.58E-09	1.67E-07	3.49E-06
99	Fluoranthene	Air	kg	1.06E-10	2.69E-09	5.15E-08
100	Fluorene	Air	kg	1.36E-10	3.45E-09	6.60E-08
101	Fluoride	Air	kg	1.10E-08	6.52E-07	1.56E-05
102	Formaldehyde	Air	kg	1.08E-04	1.72E-05	9.09E-02
103	Formic acid	Air	kg	0.00E+00	0.00E+00	6.93E-02
104	Furan	Air	kg	6.91E-13	1.87E-11	3.58E-10
105	Glyphosate	Air	kg	0.00E+00	0.00E+00	3.40E-08
106	HAPs	Air	kg	0.00E+00	0.00E+00	3.37E-03
107	Heat, waste	Air	MJ	0.00E+00	0.00E+00	1.98E+00
108	Hexanal	Air	kg	0.00E+00	0.00E+00	1.40E-02
109	Hexane	Air	kg	4.72E-12	1.38E-10	1.34E-08
110	Hydrazine, methyl-	Air	kg	1.20E-11	3.50E-10	3.39E-08
111	Hydrocarbons, unspecified	Air	kg	2.01E-06	6.75E-05	1.76E+00
112	Hydrogen	Air	kg	0.00E+00	0.00E+00	2.67E-07
113	Hydrogen chloride	Air	kg	1.90E-04	4.58E-03	9.12E-02
114	Hydrogen fluoride	Air	kg	2.24E-05	5.68E-04	1.09E-02
115	Hydrogen sulfide	Air	kg	3.89E-13	1.11E-11	2.57E-10
116	Indeno(1,2,3-cd)pyrene	Air	kg	9.10E-12	2.31E-10	4.43E-09
117	Isophorone	Air	kg	4.09E-11	1.19E-09	1.16E-07
118	Isoprene	Air	kg	3.95E-04	1.13E-02	2.61E-01
119	Kerosene	Air	kg	1.67E-07	5.60E-06	1.40E-04
120	Lead	Air	kg	8.99E-08	1.69E-06	1.33E-04
121	Limonene	Air	kg	0.00E+00	0.00E+00	6.39E-04
122	Magnesium	Air	kg	1.64E-06	4.16E-05	7.98E-04
123	Manganese	Air	kg	1.21E-07	1.95E-06	5.06E-05
124	Mercaptans, unspecified	Air	kg	1.45E-08	4.45E-07	4.33E-05
125	Mercury	Air	kg	1.58E-08	3.41E-07	8.20E-06
126	Metals, unspecified	Air	kg	4.47E-14	1.28E-12	2.95E-11
127	Methane	Air	kg	2.19E-02	5.23E-02	1.34E+00
128	Methane, biogenic	Air	kg	0.00E+00	0.00E+00	1.20E-02
129	Methane, bromo-, Halon 1001	Air	kg	1.13E-11	3.29E-10	3.19E-08
130	Methane, dichloro-, HCC-30	Air	kg	1.21E-07	1.38E-06	4.60E-05
131	Methane, dichlorodifluoro-, CFC-12	Air	kg	5.99E-10	4.19E-10	7.21E-09

132	Methane, fossil	Air	kg	1.55E-03	2.25E-03	9.16E-02
133	Methane, monochloro-, R-40	Air	kg	3.74E-11	1.09E-09	1.51E-04
134	Methane, tetrachloro-, CFC-10	Air	kg	5.99E-11	4.19E-11	1.78E-09
135	Methanol	Air	kg	0.00E+00	1.29E-04	2.76E-01
136	Methyl ethyl ketone	Air	kg	2.75E-11	8.03E-10	3.01E-03
137	Methyl methacrylate	Air	kg	1.41E-12	4.12E-11	3.99E-09
138	Metolachlor	Air	kg	0.00E+00	0.00E+00	1.25E-07
139	Metribuzin	Air	kg	0.00E+00	0.00E+00	5.80E-10
140	Naphthalene	Air	kg	2.18E-08	8.05E-08	3.78E-05
141	Nickel	Air	kg	1.33E-06	2.72E-06	4.30E-04
142	Nitrogen oxides	Air	kg	3.05E-01	1.53E-01	3.59E+01
143	Nitrogen, total	Air	kg	0.00E+00	5.89E-06	9.74E-07
144	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	kg	1.02E-02	7.97E-03	1.40E-01
145	Organic acids	Air	kg	1.28E-09	4.30E-08	1.07E-06
146	Organic substances, unspecified	Air	kg	9.27E-07	2.35E-05	4.57E-04
147	Other Organic	Air	kg	0.00E+00	0.00E+00	1.13E-04
148	PAH, polycyclic aromatic hydrocarbons	Air	kg	1.53E-05	2.06E-06	9.71E-06
149	Paraquat	Air	kg	0.00E+00	0.00E+00	2.53E-09
150	Parathion, methyl	Air	kg	0.00E+00	0.00E+00	1.91E-09
151	Particulates, < 10 um	Air	kg	0.00E+00	0.00E+00	3.32E-01
152	Particulates, < 2.5 um	Air	kg	0.00E+00	0.00E+00	7.46E-02
153	Particulates, > 10 um	Air	kg	0.00E+00	0.00E+00	1.69E-07
154	Particulates, > 2.5 um, and < 10um	Air	kg	9.39E-03	3.21E-03	4.15E-02
155	Particulates, unspecified	Air	kg	1.69E-03	3.68E-01	2.23E+00
156	Pendimethalin	Air	kg	0.00E+00	0.00E+00	1.30E-08
157	Permethrin	Air	kg	0.00E+00	0.00E+00	1.17E-09
158	Phenanthrene	Air	kg	4.03E-10	1.02E-08	1.96E-07
159	Phenol	Air	kg	1.13E-12	1.33E-05	1.06E-01
160	Phenols, unspecified	Air	kg	6.12E-08	2.71E-07	2.00E-05
161	Phorate	Air	kg	0.00E+00	0.00E+00	5.99E-10
162	Phosphate	Air	kg	0.00E+00	1.34E-07	2.19E-08
163	Phthalate, dioctyl-	Air	kg	5.14E-12	1.50E-10	1.46E-08
164	Propanal	Air	kg	2.68E-11	7.83E-10	4.68E-02
165	Propene	Air	kg	2.35E-04	3.16E-05	1.49E-04
166	Propylene oxide	Air	kg	0.00E+00	5.38E-12	8.39E-09
167	Pyrene	Air	kg	4.92E-11	1.25E-09	2.39E-08
168	Radioactive species, unspecified	Air	Bq	8.45E+03	2.14E+05	4.10E+06
169	Radionuclides (Including Radon)	Air	kg	9.33E-06	3.13E-04	7.82E-03
170	Selenium	Air	kg	2.07E-07	5.02E-06	9.84E-05
171	Simazine	Air	kg	0.00E+00	0.00E+00	8.22E-09
172	Styrene	Air	kg	1.76E-12	5.15E-11	4.99E-09
173	Sulfur	Air	kg	0.00E+00	0.00E+00	3.44E-05
174	Sulfur dioxide	Air	kg	9.42E-03	1.36E-01	3.53E+00
175	Sulfur monoxide	Air	kg	1.69E-02	1.26E-02	3.77E-01
176	Sulfur oxides	Air	kg	0.00E+00	0.00E+00	1.94E-02
177	Sulfuric acid, dimethyl ester	Air	kg	3.38E-12	9.88E-11	9.58E-09
178	t-Butyl methyl ether	Air	kg	2.47E-12	7.21E-11	6.98E-09
179	Tar	Air	kg	1.36E-11	3.87E-10	8.94E-09
180	Terbufos	Air	kg	0.00E+00	0.00E+00	2.05E-08
181	TOC, Total Organic Carbon	Air	kg	0.00E+00	0.00E+00	9.88E-03
182	Toluene	Air	kg	3.73E-05	5.02E-06	1.66E-03
183	Toluene, 2,4-dinitro-	Air	kg	1.97E-14	5.77E-13	5.59E-11

184	Vinyl acetate	Air	kg	5.36E-13	1.57E-11	1.52E-09
185	VOC, volatile organic compounds	Air	kg	7.99E-03	9.79E-03	1.77E+00
186	Xylene	Air	kg	2.60E-05	3.50E-06	8.42E-05
187	Zinc	Air	kg	6.33E-10	1.32E-07	2.26E-07
188	2-Hexanone	Water	kg	1.26E-07	1.06E-07	2.89E-06
189	2-Methyl-4-chlorophenoxyacetic acid	Water	kg	0.00E+00	0.00E+00	9.13E-12
190	2-Propanol	Water	kg	0.00E+00	0.00E+00	5.23E-09
191	2,4-D	Water	kg	0.00E+00	0.00E+00	4.89E-10
192	4-Methyl-2-pentanone	Water	kg	8.10E-08	6.83E-08	1.86E-06
193	Acetochlor	Water	kg	0.00E+00	0.00E+00	6.78E-09
194	Acetone	Water	kg	1.93E-07	1.63E-07	4.43E-06
195	Acids, unspecified	Water	kg	2.53E-10	7.22E-09	3.25E-04
196	Alachlor	Water	kg	0.00E+00	0.00E+00	6.68E-10
197	Aluminium	Water	kg	1.67E-03	1.31E-03	2.95E-02
198	Ammonia	Water	kg	3.61E-04	2.93E-04	7.24E-03
199	Ammonia, as N	Water	kg	1.27E-10	3.63E-09	8.39E-08
200	Ammonium, ion	Water	kg	7.45E-08	2.50E-06	6.24E-05
201	Antimony	Water	kg	1.04E-06	7.58E-07	1.69E-05
202	Arsenic	Water	kg	5.28E-06	4.64E-06	1.15E-04
203	Atrazine	Water	kg	0.00E+00	0.00E+00	1.32E-08
204	Barium	Water	kg	2.28E-02	1.67E-02	3.76E-01
205	Bentazone	Water	kg	0.00E+00	0.00E+00	5.39E-11
206	Benzene	Water	kg	3.23E-05	2.73E-05	7.43E-04
207	Benzene, 1-methyl-4-(1-methylethyl)-	Water	kg	1.93E-09	1.62E-09	4.43E-08
208	Benzene, ethyl-	Water	kg	1.82E-06	1.53E-06	4.18E-05
209	Benzene, pentamethyl-	Water	kg	1.44E-09	1.22E-09	3.32E-08
210	Benzenes, alkylated, unspecified	Water	kg	9.11E-07	6.65E-07	1.48E-05
211	Benzoic acid	Water	kg	1.95E-05	1.65E-05	4.49E-04
212	Beryllium	Water	kg	2.94E-07	2.33E-07	5.90E-06
213	Biphenyl	Water	kg	5.90E-08	4.30E-08	9.58E-07
214	BOD5, Biological Oxygen Demand	Water	kg	3.52E-03	2.95E-03	1.85E+00
215	Boron	Water	kg	6.05E-05	5.10E-05	1.39E-03
216	Bromide	Water	kg	4.13E-03	3.48E-03	9.49E-02
217	Bromoxynil	Water	kg	0.00E+00	0.00E+00	7.14E-11
218	Cadmium	Water	kg	7.80E-07	7.57E-07	1.75E-05
219	Calcium	Water	kg	6.19E-02	5.22E-02	1.42E+00
220	Carbofuran	Water	kg	0.00E+00	0.00E+00	1.01E-10
221	CFCs, unspecified	Water	kg	0.00E+00	0.00E+00	5.23E-09
222	Chloride	Water	kg	6.96E-01	5.87E-01	1.60E+01
223	Chlorpyrifos	Water	kg	0.00E+00	0.00E+00	7.78E-10
224	Chromium	Water	kg	4.39E-05	3.11E-05	6.35E-04
225	Chromium III	Water	kg	3.31E-06	3.72E-06	1.24E-04
226	Chromium VI	Water	kg	1.85E-07	1.29E-07	2.22E-06
227	Cobalt	Water	kg	4.27E-07	3.60E-07	9.82E-06
228	COD, Chemical Oxygen Demand	Water	kg	6.69E-03	5.48E-03	6.92E+00
229	Copper	Water	kg	5.49E-06	6.68E-06	1.61E-04
230	Cyanazine	Water	kg	0.00E+00	0.00E+00	1.17E-10
231	Cyanide	Water	kg	1.39E-09	1.20E-09	3.26E-08
232	Decane	Water	kg	5.62E-07	4.74E-07	1.29E-05
233	Detergent, oil	Water	kg	1.62E-05	1.41E-05	3.98E-04
234	Dibenzofuran	Water	kg	3.66E-09	3.09E-09	8.42E-08
235	Dibenzothiophene	Water	kg	3.15E-09	2.64E-09	7.12E-08
236	Dicamba	Water	kg	0.00E+00	0.00E+00	6.87E-10
237	Dimethenamid	Water	kg	0.00E+00	0.00E+00	1.62E-09
238	Dipropylthiocarbamic acid S-ethyl	Water	kg	0.00E+00	0.00E+00	6.70E-10

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239	Disulfoton	Water	kg	0.00E+00	0.00E+00	4.00E-11
240	Diuron	Water	kg	0.00E+00	0.00E+00	1.12E-11
241	DOC, Dissolved Organic Carbon	Water	kg	7.77E-13	2.22E-11	1.97E-04
242	Docosane	Water	kg	2.06E-08	1.74E-08	4.74E-07
243	Dodecane	Water	kg	1.07E-06	8.99E-07	2.45E-05
244	Eicosane	Water	kg	2.93E-07	2.48E-07	6.75E-06
245	Fluorene, 1-methyl-	Water	kg	2.19E-09	1.85E-09	5.04E-08
246	Fluorenes, alkylated, unspecified	Water	kg	5.28E-08	3.85E-08	8.57E-07
247	Fluoride	Water	kg	1.21E-06	7.88E-04	1.14E-03
248	Fluorine	Water	kg	2.61E-08	1.92E-08	4.34E-07
249	Furan	Water	kg	0.00E+00	0.00E+00	1.92E-10
250	Glyphosate	Water	kg	0.00E+00	0.00E+00	1.46E-09
251	Hexadecane	Water	kg	1.16E-06	9.81E-07	2.67E-05
252	Hexanoic acid	Water	kg	4.05E-06	3.41E-06	9.31E-05
253	Hydrocarbons, unspecified	Water	kg	9.72E-13	2.77E-11	1.93E-07
254	Iron	Water	kg	3.32E-03	2.69E-03	6.25E-02
255	Lead	Water	kg	1.11E-05	9.09E-06	2.21E-04
256	Lead-210/kg	Water	kg	2.00E-15	1.69E-15	4.60E-14
257	Lithium	Water	kg	9.93E-04	3.68E-03	1.91E-01
258	m-Xylene	Water	kg	5.84E-07	4.92E-07	1.34E-05
259	Magnesium	Water	kg	1.21E-02	1.02E-02	2.78E-01
260	Manganese	Water	kg	2.17E-05	8.78E-05	1.98E-03
261	Mercury	Water	kg	1.83E-08	2.03E-08	3.77E-07
262	Metallic ions, unspecified	Water	kg	1.19E-11	3.39E-10	1.74E-08
263	Methane, monochloro-, R-40	Water	kg	7.76E-10	6.54E-10	1.78E-08
264	Methyl ethyl ketone	Water	kg	1.55E-09	1.31E-09	3.57E-08
265	Metolachlor	Water	kg	0.00E+00	0.00E+00	5.36E-09
266	Metribuzin	Water	kg	0.00E+00	0.00E+00	2.48E-11
267	Molybdenum	Water	kg	4.43E-07	3.74E-07	1.02E-05
268	n-Hexacosane	Water	kg	1.29E-08	1.09E-08	2.96E-07
269	Naphthalene	Water	kg	3.51E-07	2.96E-07	8.06E-06
270	Naphthalene, 2-methyl-	Water	kg	3.05E-07	2.57E-07	7.02E-06
271	Naphthalenes, alkylated, unspecified	Water	kg	1.49E-08	1.09E-08	2.42E-07
272	Nickel	Water	kg	5.21E-06	4.25E-06	1.04E-04
273	Nitrate	Water	kg	8.52E-14	2.43E-12	1.42E-06
274	Nitrate compounds	Water	kg	3.43E-12	9.79E-11	2.26E-09
275	Nitric acid	Water	kg	7.69E-09	2.20E-07	5.08E-06
276	Nitrogen, total	Water	kg	1.85E-07	6.22E-06	2.14E-04
277	o-Cresol	Water	kg	5.54E-07	4.68E-07	1.27E-05
278	Octadecane	Water	kg	2.87E-07	2.42E-07	6.61E-06
279	Oils, unspecified	Water	kg	4.45E-04	3.80E-04	9.92E-03
280	p-Cresol	Water	kg	5.98E-07	5.05E-07	1.38E-05
281	Paraquat	Water	kg	0.00E+00	0.00E+00	1.09E-10
282	Parathion, methyl	Water	kg	0.00E+00	0.00E+00	8.20E-11
283	Pendimethalin	Water	kg	0.00E+00	0.00E+00	5.58E-10
284	Permethrin	Water	kg	0.00E+00	0.00E+00	5.01E-11
285	Phenanthrene	Water	kg	5.35E-09	4.10E-09	9.85E-08
286	Phenanthrenes, alkylated, unspecified	Water	kg	6.19E-09	4.52E-09	1.00E-07
287	Phenol	Water	kg	8.18E-06	5.72E-06	1.20E-04
288	Phenol, 2,4-dimethyl-	Water	kg	5.40E-07	4.55E-07	1.24E-05
289	Phenols, unspecified	Water	kg	1.55E-06	2.33E-06	9.34E-05
290	Phorate	Water	kg	0.00E+00	0.00E+00	1.55E-11
291	Phosphate	Water	kg	0.00E+00	5.63E-04	2.01E-04

292	Phosphorus	Water	kg	0.00E+00	0.00E+00	3.26E-05
293	Phosphorus compounds, unspecified	Water	kg	0.00E+00	0.00E+00	2.87E-07
294	Phosphorus, total	Water	kg	0.00E+00	0.00E+00	6.33E-06
295	Process solvents, unspecified	Water	kg	0.00E+00	0.00E+00	1.92E-08
296	Radioactive species, Nuclides, unspecified	Water	Bq	1.08E+01	3.63E+02	9.07E+03
297	Radium-226/kg	Water	kg	6.96E-13	5.88E-13	1.60E-11
298	Radium-228/kg	Water	kg	3.56E-15	3.01E-15	8.19E-14
299	Selenium	Water	kg	2.28E-07	1.02E-06	2.51E-05
300	Silver	Water	kg	4.05E-05	3.41E-05	9.30E-04
301	Simazine	Water	kg	0.00E+00	0.00E+00	3.52E-10
302	Sodium	Water	kg	1.96E-01	1.66E-01	4.51E+00
303	Solids, inorganic	Water	kg	1.96E-11	5.58E-10	1.29E-08
304	Solved substances, inorganic	Water	kg	0.00E+00	0.00E+00	2.60E-04
305	Strontium	Water	kg	1.05E-03	8.86E-04	2.42E-02
306	Styrene	Water	kg	0.00E+00	0.00E+00	2.43E-11
307	Sulfate	Water	kg	1.55E-03	6.25E-03	1.59E-01
308	Sulfide	Water	kg	9.49E-07	6.64E-07	1.55E-04
309	Sulfur	Water	kg	5.10E-05	4.31E-05	1.17E-03
310	Suspended solids, unspecified	Water	kg	9.09E-01	7.63E-01	2.40E+01
311	Tar	Water	kg	1.94E-13	5.53E-12	1.28E-10
312	Terbufos	Water	kg	0.00E+00	0.00E+00	5.29E-10
313	Tetradecane	Water	kg	4.67E-07	3.94E-07	1.07E-05
314	Thallium	Water	kg	2.19E-07	1.60E-07	3.55E-06
315	Tin	Water	kg	4.23E-06	3.26E-06	7.92E-05
316	Titanium	Water	kg	1.60E-05	1.16E-05	2.59E-04
317	TOC, Total Organic Carbon	Water	kg	0.00E+00	0.00E+00	2.43E-07
318	Toluene	Water	kg	3.05E-05	2.58E-05	7.02E-04
319	Vanadium	Water	kg	5.23E-07	4.41E-07	1.20E-05
320	Waste water/m3	Water	m3	0.00E+00	1.32E-02	2.54E-03
321	Xylene	Water	kg	1.64E-05	1.38E-05	3.72E-04
322	Yttrium	Water	kg	1.30E-07	1.10E-07	2.99E-06
323	Zinc	Water	kg	3.85E-05	3.21E-05	7.35E-04
324	Waste in inert landfill	Waste	kg	0.00E+00	0.00E+00	3.76E+01
325	Waste to recycling	Waste	kg	0.00E+00	0.00E+00	2.34E+01
326	Waste, solid	Waste	kg	0.00E+00	0.00E+00	1.32E-02
327	Bark	Soil	kg	0.00E+00	8.05E-01	8.21E-02