Gate-to-gate Life-Cycle Inventory of Hardboard Production in North America

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Abstract

Whole-building life-cycle assessments (LCAs) populated by life-cycle inventory (LCI) data are incorporated into environmental footprint software tools for establishing green building certification by building professionals and code. However, LCI data on some wood building products are still needed to help fill gaps in the data and thus provide a more complete picture for whole-buildings LCAs. Specifically, no LCI data are available in North America on producing hardboard and engineered wood siding and trim (EWST). This study used the internationally recognized LCI method to develop the gate-to-gate LCI data needed. Primary data were collected from four hardboard/EWST plants that represented over 42% of North American production. The primary data were then weight-averaged on a per-unit basis of 1.0 m^3 of uncoated hardboard/EWST (768 ovendry (OD) kg/m^3) to calculate material flows and energy use. Cumulative allocated energy consumption associated with manufacturing 1.0 m^3 of uncoated hardboard/EWST from 843 OD kg of various woody biomass feedstocks was found to be 30.2 GJ, with 42% of the primary energy provided by burning wood residues. Emission data produced through modeling the production process found that estimated biomass and fossil carbon dioxide emissions were 1,070 and 705 kg/m^3, respectively. Calculations estimated that 1.0 m^3 of uncoated hardboard/EWST stores 1,340 kg CO_2-equivalents, assuming carbon content of wood is 50%. Therefore, the amount of carbon stored in hardboard/EWST is about 75% of the total carbon dioxide emitted during manufacturing. Once peer-reviewed and formatted, these LCI data will be uploaded to the U.S. LCI Database for other LCA practioners and environmental footprint software providers to use in developing whole-building LCAs.

Introduction

Life-cycle inventory (LCI) data are the fundamental requirement for subsequent development of product life-cycle assessments (LCAs) and whole building LCAs. LCAs describe the total environmental impact for a particular product, referred to as "cradle-to-mill gate output" (raw material extraction to production plant product out) or as "cradle-to-grave" (raw material extraction to waste disposal) analyses. LCI measures all raw material and energy inputs and outputs associated with the manufacture of a product on a per-unit basis within carefully defined system boundaries. These boundaries may be limited to only one stage within the product lifecycle (e.g., gate-to-gate). Multiple sequential LCI stages are included in a cradle-to-gate or a cradle-to-grave LCA. 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 2014). Conducting whole-building LCAs provides 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.

LCI data have been collected for a large number of wood products but not for hardboard. The goal of this study is to document the gate-to-gate LCI of hardboard production for North America. In this study, hardboard and engineered wood siding and trim (EWST) are considered the same composite wood product category and in the remainder of this paper will be referred to as hardboard for simplicity. The LCI data will be weight-averaged values for hardboard panels for all surveyed North American mills, including dry and wet process operations. Results will show material flows, energy type and use, emissions to air and water, and industrial waste production for the hardboard manufacturing process on a per unit volume basis.

Manufacturing hardboard in North America currently uses either a wet or dry production processes to create high-density wood composition panels (Composite Panel Association 2012a,b). (In the past, hardboard was produced in North America using a semidry process, which was used to lower resin and water usage while maintaining more of the properties found in wet-process hardboard (Myers 1986).) Density for final products ranges from 800 to 1,100 kg/m^3 (U.S. Environmental Protection Agency 2002; Bowyer et al. 2007; Gonzalez-Garcia et al. 2009; Stark et al. 2010). Thermo-mechanical processes reduce the wood chip raw material to fibers. Resins are added to the fiber 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 (Suchsland and Woodson 1986). Final products made from uncoated hardboard, commonly called “dealer board,” include case-goods, paneling, and pegboard.

Primary mill data were collected through a questionnaire mailed to hardboard plants. This survey tracked raw material inputs (including energy), product and by-product outputs, pertinent emissions to water and air, and industrial waste production. An industry-standard production unit (i.e., functional unit) was incorporated that could be translated to a metric production unit. Hardboard is typically measured in thousand square feet (Msf) on a 1/8-in basis. One cubic meter equals 3.4 Msf of hardboard on a 1/8-in basis. Secondary data, such as pre-mill gate processes (e.g., wood and electricity production), will be obtained from peer-reviewed literature per Consortium for Research on Renewable Industrial Materials guidelines (CORRIM 2010). Material and energy balances were calculated from primary and secondary data. Using these material and energy data, the environmental impact was estimated by modeling emissions using the software package SimaPro 8 (PRé Consultants 2014), which follows internationally accepted standards, and using the U.S. LCI Database (National Renewable Energy Laboratory 2014).

A statistically significant sampling frame was required to attain valid results that could be generalized to the hardboard industry. CORRIM (2010) protocol targets a minimum of 10% to 50% of total production. Because there are relatively few hardboard manufacturers, this study could realistically attain these levels by requesting participation and cooperation from the seven plants operated by Composite Panel Association (CPA) members. One of the seven North American plants was located in Canada and the remainder in the United States.

Method

Scope

This study covered the manufacturing stage of North American hardboard from the forest landing to the final product leaving the mill according to ISO 14040 and 14044 standards

(International Organization for Standardization 2006a,b; International Reference Life Cycle Data 2010). LCI data from this study will be made available in the U.S. LCI Database (National Renewable Energy Laboratory 2014). To construct a cradle-to-gate LCA, this manufacturing LCI will be linked to forest resources (upstream) from the U.S. LCI Database. The manufacturing stage LCI provided a gate-to-gate analysis of cumulative energy of manufacturing as well as transportation of raw materials. Analyses included hardboard's contribution to cumulative energy consumption and emission data.

Four hardboard plants producing 270,000 m^3 and representing over 42% of hardboard production provided 2012 primary data. In 2013, site visits were conducted at two plants. Three plants produced wet-process hardboard, and the remaining plant produced dry-process hardboard. The surveyed plants provided detailed annual production data on their facilities, including on-site energy consumption, electrical usage, log and chip volumes, resin usage, and hardboard production for 2012.

Functional unit

Defining system boundaries determined the unit processes to include and to standardize material flows, energy use, and emission data. The present study selected a functional unit of 1.0 m^3 of generic hardboard. Board density varied by plant. Hardboard was produced to meet CPA standards (Composite Panel Association 2012a,b). Cumulative energy consumption and emission data were reported per 1.0 m^3 of the final product, hardboard.

Unit processes

Eleven main unit processes were identified in manufacturing hardboard for both the wet and dry process. For the wet process, these included (1) resource transportation, (2) yard storage, (3) feedstock preparation, (4) refining, (5) washing, (6) mixing, (7) wet forming, (8) 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, (5) drying, (6) fiber storage, (7) dry forming, (8) hot pressing, (9) tempering, (10) humidifying, and (11) finishing, with energy generation considered an auxiliary process. All emissions (i.e., environmental outputs) and energy consumed were assigned to hardboard. All co-products such as culled boards are consumed within the process.

System boundary

Boundary selection helps to better track material and energy flows crossing the boundary. To track flows tied to hardboard production, two system boundaries were considered. First, the cumulative system boundary (shown by the solid line in Figure 1) includes both on- and off-site emissions for all material and energy consumed. Fuel resources used for the cradle-to-gate production of energy and electricity were included within the cumulative system boundary. Second, the on-site system boundary (shown by the dotted line in Figure 1) covered emissions occurring only at the mill from the 11 unit processes involved. Off-site emissions include grid electricity production, transportation of chips and logs to the mill, and fuels produced off-site but consumed onsite. Ancillary material data such as motor oil, paint, and hydraulic fluid were collected and were part of the analysis.

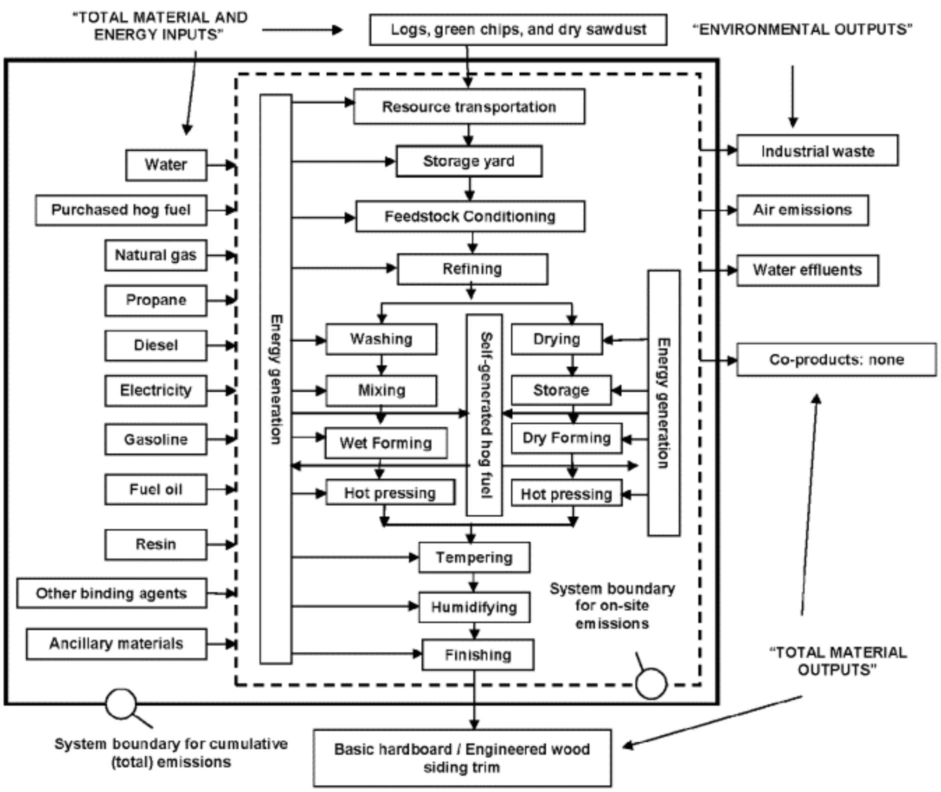

Figure1: System boundaries for hardboard manufacturing

Results and Discussion

By surveying four hardboard plants in 2012, detailed primary data on mass flow, energy consumption, resin usage, and fuel types and usage provided life-cycle information. Direct air emission data from the production processes were also included. SimaPro 8 modeled weight-averaged survey data to estimate non-wood raw material use and emission data on a 1-m^3 unit basis.

Material

To confirm the data quality, a mass balance was performed; the results are summarized in Table 1. In performing the mass balance for hardboard, all unit processes located within the on-site system boundary were considered. Using a weight-averaged approach, 843 ovendry (OD) kg of incoming woody biomass feedstock and 46 OD kg of binding agents (additives) produced 1.0 m^3 (768 OD kg) of hardboard along with some co-products (121 OD kg). Co-products were consumed within the production processes and therefore did not leave the site. Green chips made up the largest portion of feedstock at the facilities at 624 OD kg per m^3 of hardboard made, with logs (168 OD kg) and dry sawdust (51 OD kg) coming in distant second and third, respectively. The top three additive components were phenol-formaldehyde resin (15.3 OD kg/m^3), paraffin/wax emulsion (13.6 OD kg/m^3), and zinc borate (6.9 OD kg/m^3).

Table 1: Mass balance of hardboard manufacturing in North America, per m^3 (768 OD kg)

	Inputs (OD kg)	Mass (%)	CoV[a] (%)		Outputs (OD kg)	Mass (%)	CoV[a] (%)
Feedstocks				Products			
Logs	168	18.9	120	Hardboard	768	86.3	12.0
Chips, green	624	70.1	86.7	Co-Products			
Sawdust, dry	51	5.8	-	Bag house dust, fuel	46.7	5.3	171
TOTAL, FEEDSTOCK	843	94.8	13.8	Culled boards, wood fuel	33.8	3.8	-
				Sander dust, fuel	18.7	2.1	116
Additives				Dry sawdust, wood fuel	5.9	0.7	143
Phenol-formaldehyde resin	15.3	1.7	45.9	Bag house dust, re-pulped	1.4	0.2	-
Paraffin/wax emulsion	13.6	1.5	81.3	Other, not specified	15	1.7	-
Zinc borate	6.9	0.8	-	TOTAL, CO-PRODUCTS	121	13.7	84.2
Alum	5.1	0.6	76.4	TOTAL, OUT	889	100	15.3
Compregnite	4.2	0.5	-				
Release agent	0.5	0.1	-				
Slack wax	0.3	0.0	-				
Linseed oil	0.1	0.0	-				
TOTAL, ADDITIVES	46	5.2	15.9				
TOTAL, IN	889	100.0	13.1				

[a] Coefficient of variation

Carbon

Hardboard stores carbon. Carbon content for wood products is assumed to be 50% by mass of ovendried (OD) wood. Therefore, the carbon stored in the wood portion of 1.0 m^3 (730 OD kg) of hardboard is equivalent to 1,340 kg CO_2[1] if left to decay.

Energy

Table 2 shows cumulative allocated energy consumption for a cubic meter of hardboard. Cumulative energy consumption for manufacturing hardboard was 30.2 GJ/m^3, with wood fuel accounting for about 42.1%. Natural gas (22.4%), coal (16.4%), and crude oil (12.4%) were the next three highest energy resources consumed for panel production. Self-generated and purchased wood fuels were consumed at a rate of 318 and 290 OD kg per cubic meter of hardboard produced, respectively. In comparison, restricting the analysis to energy used within the site system boundary, on-site energy consumption was estimated at 13.3 GJ/m^3, with wood fuel accounting for over 95.6% of the primary energy consumed.

Table 2: Cumulative energy (higher heating values (HHV)) consumed during production of hardboard—cumulative, allocated gate-to-gate LCI values[a]

Fuel[b,c]	(kg/m^3)	(MJ/m^3)	(%)
Wood fuel/wood waste	608	12,700	42.1
Natural gas[d]	124	6,770	22.4
Coal[d]	189	4,950	16.4
Crude oil[d]	82.43	3,750	12.4
Uranium[d]	0.00487	1,850	6.1
Hydro	-	150	0.5
Energy, unspecified	-	43	0.1
Total		30,200	100

[a] Includes fuel used for electricity production and for log transportation (unallocated).
[b] Values are unallocated and cumulative and based on HHV.
[c] Energy values were found using their HHV in MJ/kg: 20.9 for wood oven-dry, 26.2 for coal, 54.4 for natural gas, 45.5 for crude oil, and 381,000 for uranium.
[d] Materials as they exist in nature and have neither emissions nor energy consumption associated with them.

[1] 95%*768 OD kg hardboard*(0.5 kg carbon/1.0 OD kg wood)*(44 kg CO_2/kmole÷12 kg carbon/kmole) =1,340 kg CO_2e

Wood products typically consume more energy during the manufacturing stage than any other stage (Puettmann and Wilson 2005; Winistorfer et al. 2005; Puettmann et al. 2010). For making oriented strandboard (OSB) in the southeastern (SE) United States, cumulative allocated energy consumption for 1.0 m^3 (651 OD kg) of OSB is 11.0 GJ/m^3, with 38% from wood fuel (Kline 2005). For making softwood plywood in the southeastern United States, cumulative allocated energy consumption for 1.0 m^3 (555 OD kg) of plywood is 5.43 GJ/m^3, with 38% from wood fuel (Wilson and Sakimoto 2005; Puettmann and Wilson 2005). Bergman (2014) reports 8.63 GJ/m^3 for production of uncoated cellulosic fiberboard (254 OD kg/m^3). The values listed in Kline (2005) and Wilson and Sakimoto (2005) used mass allocation. The present study allocated all primary energy to the production of hardboard. Primary energy is energy embodied in the original resources such as crude oil and coal before conversion. Cumulative allocated energy consumption for hardboard production is about three and six times more than the cumulative allocated energy consumption of OSB and softwood plywood made in the SE, respectively. In addition, the mass basis for 1.0 m^3 of the listed engineered wood product does change, thus changing the quantity of energy consumed between a mass and volume basis. However, these products are sold and used on a volume basis, not a mass basis. Therefore, energy consumption on a volume basis would be the more appropriate reporting unit, although the mass basis does offer some additional insight.

Water

In this study, water was drawn from surface (11,300 L) and ground (303 L) sources for a total of 11,600 L/m^3, with 69% of incoming water being recycled. One wet-process plant used three to five times more water per final product of uncoated hardboard than the other three plants. Removing the high-water consuming plant reduced total water use from 11,600 to 3,670 L/m^3, a 68% decrease. Further investigation failed to provide any reason for this large discrepancy.

Emissions

Table 3 lists the allocated environmental outputs for manufacturing 1.0 m^3 of hardboard for the cumulative and on-site system boundaries. The cumulative values included all emissions and were higher than the on-site emissions, as expected. For the cumulative system boundary, biogenic CO_2 and fossil CO_2 were 1,070 and 705 kg/m^3, respectively. Therefore, the amount of carbon stored in hardboard if allowed to decay is equivalent to about 75%[2] of the total carbon dioxide emissions released during manufacturing. The biogenic CO_2 was derived from burning woody biomass on-site to provide thermal energy for various processes, including feedstock conditioning and board drying. Grid electricity released most of the fossil CO_2 emissions. Major sources of water effluents came from the wet process where large quantities of wood particles were discharged. Fossil CO_2 for the cumulative case was about eleven (705/64.8) times the fossil CO_2 emitted for the on-site case. For on-site, the major source of biogenic CO_2 came from burning woody biomass, while the major source of fossil CO_2 came from burning natural gas for emission control and drying boards. Because all the wood fuel was consumed on-site, the biogenic CO_2 emission was the same for the cumulative and on-site system boundaries.

[2] (1,340 kg CO_2e ÷ (1,070+705))*100% = 75%

Table 3: Environmental outputs for manufacturing 1.0 m^3 of hardboard (768 OD kg)

Substance	Cumulative (kg/m^3)	On-site (kg/m^3)
Water effluents		
BOD5 (Biological oxygen demand)	12.7	12.6
Chloride	20.6	1.03E-07
COD (Chemical oxygen demand)	7.84	7.66
DOC (Dissolved organic carbon)	1.65E-04	0
Oils, unspecified	1.24E-02	7.72E-06
Suspended solids, unspecified	30.2	3.80
Industrial waste[a]		
Waste in inert landfill	42.6	42.6
Waste to recycling	26.5	26.5
Solid waste[b]	6.17	6.08
Air emissions		
Acetaldehyde	5.76E-02	5.76E-02
Acrolein	4.49E-02	4.49E-02
Benzene	2.32E-02	2.31E-02
CO	5.11	3.37
CO_2 (biomass (biogenic))	1,071	1067
CO_2 (fossil)	705	64.8
CH_4	1.95	0.115
Formaldehyde	1.19E-01	9.35E-02
Mercury	2.72E-05	1.93E-05
NO_x	2.99E-03	1.80E-04
Non-methane VOC	1.56E-01	0.00E+00
Particulates, > 2.5 um, and < 10um	6.06E-08	2.75
Phenol	1.20E-01	9.42E-02
SO_x	4.01	0
VOC	1.49	1.41

[a] Includes solid materials not incorporated into the product or co-products but left the system boundary.
[b] Solid waste was boiler ash from burning wood. Wood ash is typically used a soil amendment or landfilled.

Summary and Conclusions

Building product LCI data are needed to populate whole-building LCA tools. Adding LCI data on building products including hardboard, as in this study, did fill in various data gaps. Additional building product LCI data enables more informed decision-making for building specifiers that use environmental footprint software incorporating whole-building LCAs.

Wood products, such as hardboard, used in building construction can store carbon for long periods. The amount of carbon stored in hardboard if allowed to decay naturally is equivalent to about 75% of the total carbon dioxide emissions released during hardboard manufacturing. Therefore, hardboard’s ability to store carbon when in use as a building product is a positive environmental attribute.

In the past, wet processes typically consumed huge volumes of water. However, water consumption for engineered wood products using a wet process, such as hardboard, has been substantially reduced over the past couple decades due primarily to internal water recycling. Therefore, industry water recycling efforts have been worthwhile in reducing water impacts, a critical environmental issue. Recycling efforts must continue, however, to make hardboard manufacturing an even lower-water consuming product.

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