Life-Cycle Inventory Analysis of Cellulosic Fiberboard Production in North America

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Abstract

Documenting the environmental performance of building products is becoming widespread because of many green-marketing claims made without scientific merit (i.e., green-washing). Developing environmental product declarations (EPDs) for building products is one way to accomplish this objective for scientific documentation and to counter green-washing. EPDs are based on life-cycle assessment (LCA) data and are similar to nutritional labels for food. To develop a business-to-business (B2B) EPD for uncoated cellulosic fiberboard, gate-to-gate life-cycle inventory (LCI) data must be developed to construct the cradle-to-gate LCA. This study used the internationally recognized LCI method to develop the needed gate-to-gate LCI data. Primary data were collected from seven cellulosic fiberboard plants that represented over 96% of cellulosic fiberboard production in North America. The primary data were then weight-averaged on a per-unit basis of one cubic meter of uncoated cellulosic fiberboard (254 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 cellulosic fiberboard from 244 OD kg of various feedstocks was found to be 8.63 GJ/m^3, with 6% 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 43.2 and 298 kg/m^3, respectively. Our analysis estimated that 1.0 m^3 of uncoated cellulosic fiberboard stores 477 kg CO_2-equivalents, assuming carbon content of wood to be 50%. The amount of carbon stored in cellulosic fiberboard exceeds the total carbon dioxide emissions during manufacturing by 30%. Therefore, cellulosic fiberboard's ability to store carbon when in use as a building product is a positive environmental attribute. From this study, the needed gate-to-gate LCI data can now be incorporated into the cradle-to-gate LCA to develop the B2B EPD.

***Keywords*:** environmental product declaration, cellulosic fiberboard, LCA, life-cycle inventory, wood.

Introduction

Documenting the environmental performance of building products is becoming widespread because of many green-marketing claims made without scientific merit (i.e., green-washing). Developing environmental product declarations (EPDs) for building products is one way to accomplish this objective for scientific documentation and to counter green-washing (Bergman and Taylor 2011). Life-cycle inventory (LCI) data are the underlying data for subsequent development of life-cycle assessments (LCAs) and EPDs. EPDs are similar to nutritional labels for food. At present, there are many EPDs for structural wood products made in North America.

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 usually included in an LCA. LCAs describe the total environmental impact for a particular product, referred to either as cradle-to-gate (raw material extraction to mill gate output) or as cradle-to-grave (raw material extraction to waste disposal) analysis.

Manufacturing cellulosic fiberboard uses a wet process that produces a low-density wood composition panel. Density for the final products ranges from 190 to 380 kg/m^3 (Suchsland and Woodson 1986; USEPA 2002; Stark et al. 2010; ASTM International 2012). A thermo-mechanical process reduces the wood chip raw material and binds the fibers with a starch for recombination into cellulosic fiberboard. Other additives may include alum, clay, and wax. Asphalt may be added to improve strength properties. Furthermore, cellulosic fiberboard may be coated with asphalt for exterior uses. Final products include sheathing, sound-deadening board, roof fiberboards, and a wide variety of other products. Water is used to create a slurry (similar to the paper-making process) that produces the fiber mat. Large dryers are used to remove water; this process also releases volatile organic compounds into the atmosphere. Water usage is of particular concern because plants without any water conservation can use 100 tonnes of water per tonne (22,700 L/m^3) of cellulosic fiberboard (Suchsland and Woodson 1986).

The goal of this paper is to document the gate-to-gate LCI of cellulosic fiberboard production for North America as part of a cradle-to-gate LCA. The paper documents material flow, energy type and use, emissions to air and water, solid waste production, and water impacts for the cellulosic fiberboard manufacturing process on a per unit volume basis of 1.0 cubic meter. Primary mill data were collected through a survey questionnaire mailed to cellulosic fiberboard plants. This survey tracked raw material inputs (including energy), product and by-product outputs, and pertinent emissions to water, air, and land for those unit processes. An industry-standard production unit (i.e., functional unit) was incorporated that can be translated to a metric production unit. Secondary data, such as pre-mill gate processes (e.g., wood and electricity production), were from peer-reviewed literature per CORRIM 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 uses the U.S. LCI Database (NREL 2014).

A statistically significant sampling frame is required to attain valid results that can be generalized to the cellulosic fiberboard industry. CORRIM (2010) protocol targets a minimum of 20% to 50% of total production. Because there are only a few cellulosic fiberboard manufacturers, this study could realistically attain these levels by requesting participation and cooperation from the eight plants operated by North American Fiberboard Association (NAFA) members. Three of the eight North American mills are located in Canada and the other five in the United States.

Methods

Scope. This study covered the manufacturing stage of cellulosic fiberboard from forest landing to final product leaving the mill according to ISO 14040 and 14044 standards (ISO 2006a,b; ILCD 2010). LCI data from this study will help conduct a cradle-to-gate LCA for cellulosic fiberboard in preparation for developing an EPD, a Type III LCA-based eco-label (ISO 2006c). To construct a cradle-to-gate LCA, this manufacturing LCI will be linked to forest resources (upstream) LCI data from the U.S. LCI Database (NREL 2014). This manufacturing stage LCI provided a gate-to-gate analysis of cumulative energy of manufacturing and transportation of raw materials. Analyses included cellulosic fiberboard's contribution to cumulative energy consumption and emission data.

Seven of eight North American cellulosic fiberboard plants representing 96% of 2012 cellulosic fiberboard production provided primary data. In 2013, a site visit was conducted at one plant. The surveyed plants provided detailed annual production data on their facilities, including on-site energy consumption, electrical usage, log/chip volumes, and fiberboard production for 2012.

Functional unit. Defining system boundaries determined the unit processes to include and standardized material flows, energy use, and emission data. The present study selected a functional unit of 1.0 m^3 of uncoated cellulosic fiberboard. Primary data and LCI flows were reported per 1.0 m^3 of the final product, uncoated cellulosic fiberboard.

Unit processes. Ten main unit processes were identified in manufacturing cellulosic fiberboard. These included (1) resource transport, (2) storage yard, (3) feedstock preparation, (4) refining, (5) washing, (6) mixing, (7) wet forming, (8) board drying, (9) finishing, and (10) packaging, with energy generation considered an auxiliary process. All emissions (i.e., environmental outputs) and energy consumed were assigned to the cellulosic fiberboard and none to the co-products (i.e., molasses, culled boards, and fines) because these co-products were less than 4% of the total mass.

System boundary. Boundary selection helps track the material and energy flows crossing the boundary precisely. To track flows tied to cellulosic fiberboard production, two system boundaries were considered. One—the cumulative system boundary—is shown by the solid line in Figure 1 and 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. The on-site system boundary (dotted line in Figure 1) covered emissions occurring only at the mill from the 10 unit processes involved. Off-site emissions include grid electricity production, transportation of feedstock and additives to the mill, and fuels produced off-site but consumed on-site. Ancillary material data such as motor oil, paint, and hydraulic fluid were collected and were part of the analysis.

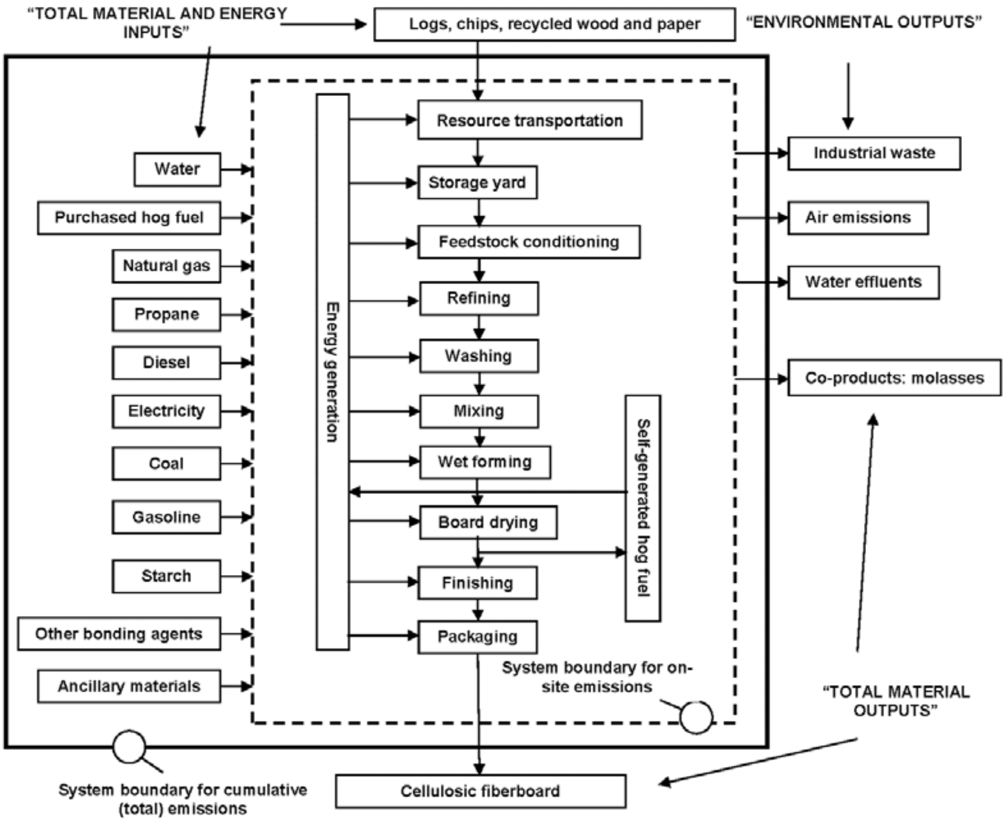

Figure 1 System boundaries for cellulosic fiberboard production

Results and Discussion

By surveying seven North American cellulosic fiberboard plants in 2012, detailed primary data on mass flow, energy consumption, and fuel types provided life-cycle information including air emission data. 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, and the results are summarized in Table 1. In performing the mass balance for cellulosic fiberboard, all unit processes located within the site system boundary were considered. Using a weight-averaged approach, 244 ovendry (OD) kg of incoming feedstock and 21 OD kg of binding agents (additives) produced 1.0 m^3 (254 OD kg) of cellulosic fiberboard along with some co-products (11 OD kg). Green chips made up the largest portion of feedstock at the facilities at 153 OD kg per m^3 of cellulosic fiberboard made, with construction waste (31 OD kg) and dry shavings (30 OD kg) coming in distant second and third. Asphalt flakes made up the largest component of the additives at 10 OD kg/m^3.

Table 1: Mass balance of cellulosic fiberboard manufacturing per m^3

	Inputs (OD kg)	Mass (%)	CoV[a] (%)		Outputs (OD kg)	Mass (%)	CoV[a] (%)
Feedstocks				Products			
Logs	23	8.8%	-	Cellulosic fiberboard	254	96.1%	11.6%
Chips, green	153	57.9%	134%	Co-Products			
Sawdust, dry	1	0.2%	-	Culled boards, wood fuel	1.1	0.4%	-
Mixed paper	5	1.9%	153%	Molasses	5.8	2.2%	-
Construction waste	31	11.8%	204%	Pins and fines	1.9	0.7%	-
Back to pulper	1	0.3%	-	Other, not specified	1.5	0.6%	-
Shavings, dry	30	11.3%	-	TOTAL,CO-PRODUCTS	11	3.9%	205%
TOTAL, FEEDSTOCK	244	92.1%	14.7%	TOTAL, OUT	265	100%	12.9%
Additives							
Starch	4.0	1.5%	148%				
Asphalt flake	10	3.9%	97.7%				
Alum	1.5	0.6%	122%				
Wax	2.9	1.1%	94.1%				
Carbon black	0.4	0.2%	216%				
Clay	1.6	0.6%	204%				
Sodium aluminate	0.15	0.1%	-				
Other	0.02	0.0%	-				
TOTAL, ADDITIVES	21	7.9%	49.7%				
TOTAL, IN	265	100.0%	13.7%				

[a] Coefficient of variation

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

Water. As mentioned previously, water impacts when producing cellulosic fiberboard have been a major concern because of the high volumes consumed. The cellulosic fiberboard industry has made substantial strides in reducing its water impacts. In this study, water was drawn from surface (1,230 L), ground (943 L), and municipality (353 L) sources for a total of 2,530 L/m^3, with 63% of incoming water recycled. This has reduced water consumption by a factor of greater than 10 when not considering recycling and greater than 20 when considering recycling (Suchsland and Woodson 1986).

Raw material transportation. Feedstocks were transported a relatively short distance compared to the additives. The largest feedstock contributors, green chips, construction waste, and dry shaving, were transported 63, 29, and 33 km, respectively; starch and wax, which make up a far smaller portion of the uncoated cellulosic fiberboard, were transported 666 and 356 km, respectively.

Energy. Table 2 shows cumulative allocated energy consumption for a cubic meter of cellulosic fiberboard. Cumulative energy consumption for manufacturing cellulosic fiberboard was 8.63 GJ/m^3, with wood fuel accounting for about 6%. Natural gas (59.5%), coal (22.8%), and uranium (6.4%) were the three highest energy resources consumed during product production. All but one facility uses natural gas for drying boards. In addition, natural gas provides the most power to the grid except for coal. Therefore, natural gas has the highest energy consumption for making uncoated cellulosic fiberboards. On-site energy consumption was estimated at 4.53 GJ/m^3, with natural gas accounting for over 80% of the primary energy consumed.

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

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

Fuel[b,c]	(kg/m^3)	(MJ/m^3)	(%)
Natural gas[d]	94.5	5,139	59.5
Coal[d]	75.2	1,968	22.8
Uranium[d]	0.00146	556	6.4
Wood residue	24	502	5.8
Crude oil[d]	9.00	410	4.7
Hydro	-	47	0.5
Wind	-	11	0.1
Energy, other	-	3	0.0
Total		8,630	100

[a] Includes fuel used for electricity production and for log transportation.
[b] Values are allocated 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.

Wood products typically consume more energy during the manufacturing stage than any other stage (Puettmann and Wilson 2005; Winistorfer et al. 2005; Puettmann et al. 2010). For making oriented strandboard (OSB) in the southeastern (SE) United States, cumulative allocated energy consumption for 1.0 m^3 of OSB is 11.0 GJ/m^3, with 38% from wood fuel (Kline 2005). For making softwood plywood in the SE United States, cumulative allocated energy consumption for 1.0 m^3 of plywood is 5.43 GJ/m^3, with 38% from wood fuel (Wilson and Sakimoto 2005; Puettmann and Wilson 2005). The values listed in Kline (2005) and Wilson and Sakimoto (2005) use mass allocation. This study allocates all primary energy to cellulosic fiberboard and none to its residues. Primary energy is energy embodied in the original resources such as crude oil and coal before conversion. Energy consumption for cellulosic fiberboard falls between the cumulative allocated energy consumption of OSB and softwood plywood made in the SE United States.

Emissions. Table 3 lists allocated environmental outputs for manufacturing 1.0 m^3 of cellulosic fiberboard for the cumulative and on-site system boundaries. The cumulative values included all emissions and were higher than the on-site emissions. For the cumulative system boundary, biogenic CO_2 and fossil CO_2 were 43.2 and 298 kg/m^3, respectively. Therefore, the amount of carbon stored in cellulosic fiberboard if allowed to decay is equivalent to about 130% of the total CO_2 emissions released during manufacturing. In addition, fossil CO_2 for the cumulative case was over two (298/133) times the fossil CO_2 emitted for the on-site case. For on-site, burning natural gas to dry boards was the main source of fossil CO_2. Major sources of air emissions were from board drying (on-site) and from the energy generation auxiliary process that includes grid electricity (off-site) and boiler operations (on-site).

Table 3: Environmental outputs for manufacturing one m^3 of planed redwood decking

Substance	Cumulative (kg/m^3)	On-site (kg/m^3)
Water effluents		
BOD5 (Biological oxygen demand)	0.734	0.691
Chloride	8.78	3.77E-09
COD (Chemical oxygen demand)	0.274	0.203
DOC (Dissolved organic carbon)	1.11	1.11
Oils, unspecified	0.0200	0.0152
Suspended solids, unspecified	14.1	0.223
Industrial waste[a]		
Waste in inert landfill	5.63	5.63
Waste to recycling	8.83	8.83
Solid waste[b]	0.659	0.24
Air emissions		
Acetaldehyde	2.01E-02	2.01E-02
Acrolein	7.92E-03	7.92E-03
Benzene	3.33E-03	3.04E-03
CO	0.434	0.315
CO_2 (biomass (biogenic))	43.2	42.1
CO_2 (fossil)	298	133
CH_4	0.932	7.00E-03
Formaldehyde	1.76E-02	1.75E-02
Mercury	1.36E-05	9.63E-06
Nitrous oxide	5.33E-02	4.87E-02
Non-methane VOC	1.51E-02	0
Particulate (PM10)	0.172	0.172
Particulate (unspecified)	0.777	0.193
Phenol	3.93E-03	3.93E-03
SO_x	2.62	0.591
VOC	.291	0.217

[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.

Conclusions

EPDs present life-cycle data in a clear and transparent format to enable industry to counter green-washing. This study provides the underlying gate-to-gate LCI data for a cellulosic fiberboard EPD. Future efforts will work on incorporating the LCI data into a cradle-to-gate LCA and then eventually into a Business-to-Business EPD for uncoated cellulosic fiberboard.

Wood products such as cellulosic fiberboard used in building construction can store carbon for long periods. The amount of carbon stored in cellulosic fiberboard if allowed to decay is equivalent to about 130% the total carbon dioxide emissions released during manufacturing.

Therefore, cellulosic fiberboard'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 in engineered wood products using a wet process such as that for cellulosic fiberboard manufacture has been substantially reduced over the past several decades. Therefore, industry water recycling efforts have been worthwhile in reducing water impacts, a critical environmental issue.

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References

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

Bergman, R.D. and A. Taylor. 2011. Environmental product declarations of wood products—An application of life cycle information about forest products. Forest Products Journal 61(3):192-201.

CORRIM. 2010. Research guidelines for life-cycle inventories. Consortium for Research on Renewable Industrial Materials (CORRIM), Inc., University of Washington, Seattle, WA. 40 pp.

ILCD. 2010. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment—Detailed guidance. EUR 24708 EN. European Commission–Joint Research Centre–Institute for Environment and Sustainability. Luxembourg. Publications Office of the European Union. 417 pp.

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

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

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

Kline, E.D. 2005. Gate-to-gate life-cycle inventory of oriented strandboard production. Wood and Fiber Science 37 (Special Issue):74-84.

NREL. 2014. Life-cycle inventory database project. National Renewable Energy Laboratory. https://www.lcacommons.gov/nrel/search. (accessed March 24, 2014).

PRé Consultants. 2014. SimaPro 8 Life-Cycle assessment software package, Version 7. Plotter 12, 3821 BB Amersfoort, The Netherlands. http://www.pre.nl/. (accessed March 22, 2014).

Puettmann, M.E. and J.B. Wilson. 2005. Life-cycle analysis of wood products: Cradle-to-gate LCI of residential wood building materials. Wood and Fiber Science 37 (Special Issue):18–29.

Puettmann, M.E., R.D. Bergman, S. Hubbard, L. Johnson, B. Lippke, and F.Wagner. 2010. Cradle-to-gate life-cycle inventories of US wood products production—CORRIM Phase I and Phase II Products. Wood and Fiber Science 42 (CORRIM Special Issue):15–28.

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

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

USEPA. 2002. AP 42 Section 10.6.4 Hardboard and fiberboard manufacturing. United States Environmental Protection Agency. pp. 10.6.4-1-38. http://www.epa.gov/ttn/chief/ap42/ch10/final/c10s0604.pdf (accessed March 22, 2014)

Wilson, J.B. and E.T. Sakimoto. 2005. Gate-to-gate life-cycle inventory of softwood plywood production. Wood and Fiber Science 37 (Special Issue):58-73.

Winistorfer, P., Z. Chen, B. Lippke, J. and N. Stevens. 2005. Energy consumption and greenhouse gas emissions related to use, maintenance, and disposal of a residemtial structure. Wood and Fiber Science 37 (Special Issue):128-139.

In: Proceedings of the 57th International Convention of Society of Wood Science and Technology June 23-27, 2014 - Zvolen, SLOVAKIA; 2014