United States Department of Agriculture

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

Kamalakanta Sahoo
Richard Bergman

All cover photos used with permission from Blue Ridge Fiberboard, Inc.

Forest Service | Forest Products Laboratory | Research Paper FPL–RP–709 | August 2021

Abstract

Global demand for construction materials from population growth and higher standards of living stresses the climate. Natural solutions such as renewable construction materials from wood aid in sustainable growth and decrease our environmental footprint. Wood can be used along the entire supply chain in producing these renewable products. Lower quality logs, sawmill residues, and construction waste are forms of wood resources processed to make engineered wood products such as cellulosic fiberboard. These engineered wood products are used in building construction and can store carbon for decades. This study quantified the environmental impacts associated with manufacturing cellulosic fiberboard in North America using the life-cycle assessment approach. System boundaries in this study included modules [A1] raw material extraction, [A2] raw material transportation, and [A3] product manufacturing. The declared unit was 1 m³ of cellulosic fiberboard packaged and ready for shipment. The cradle-to-gate life-cycle inventory results showed that 196 kg CO_2eq was released in the production of 1 m³ of cellulosic fiberboard. Each unit (1 m³) of cellulosic fiberboard stored 439 kg CO_2eq in wood material offsetting these [A1-A3] emissions. The product manufacturing phase of cellulosic fiberboard [A3] consumed 96% of total cradle-to-gate primary energy and generated about 93.8% of global warming (GW) impact. The GW impact showed that cellulosic fiberboard production had a negative impact when considering the carbon stored in cellulosic fiberboard acting as a carbon sink. To aid in mitigating climate change, the building industry is an ideal application for cellulosic fiberboard because of the low carbon footprint and long-term carbon storage ability of this product.

Keywords: Wood; life-cycle assessment; environmental product declaration; product category rule; engineered panel

August 2021 [Erratum: Appendix added, pp. 25-38, January 2022]

Sahoo, Kamalakanta; Bergman, Richard. 2021. Cradle-to-gate life-cycle assessment of North American cellulosic fiberboard production. Research Paper. FPL-RP-709. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 38 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents

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

Kamalakanta Sahoo, Assistant Scientist
Richard Bergman, Supervisory Research Forest Products Technologist
USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

1 Executive Summary

1.1 Study Goals

The goal of this study was to perform a cradle-to-gate life-cycle assessment (LCA) and update the environmental impacts associated with cellulosic fiberboard production in North America (United States and Canada). A comparative proclamation was not a goal of this study.

1.2 Methodology

This study followed the International Organization for Standardization (ISO) 14040 and 14044 standards and the product category rule (PCR) for North American Structural and Architectural Wood Products to develop life-cycle inventory (LCI) and conduct an LCA. The system boundary in this study started with raw material extraction, included transportation and product manufacturing, and ended with packaging for customer delivery at the mill gate. A declared unit (functional unit) of 1 m^3 of cellulosic fiberboard was used to translate the LCA results. The authors collected 2019 primary data from cellulosic fiberboard production facilities, developed LCI, and performed LCA to quantify the environmental impacts. Surveys were used to collect primary mill operation data. Surveys collected all inputs (including raw materials, heat, electricity, fuels, and chemicals), outputs (main product and coproducts), related direct emissions to water and air, and generation of solid waste. After analysis of the survey data by the LCA experts, multiple rounds of digital and telephonic communications were performed with the representatives of the plants to verify numbers in the mill surveys (if there were uncertainties about the appropriateness of values of certain information) and to revise them based on provided information. Secondary data were used from peer-reviewed literature and public databases. The LCA modeling software, SimaPro (contains DATASMART database) was used to construct North American cellulosic fiberboard LCI to perform life-cycle impact assessment (LCIA). The LCI development was preceded by a mass and energy balance that used a mass-allocations approach to assign environmental impacts to the product (cellulosic fiberboard) and coproducts (mill residues sold to outside customers). The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) 2.1, CML-baseline, and cumulative energy demand (CED) methods were used to determine the LCIA results and primary energy consumption, respectively.

1.3 Life-Cycle Inventory

The product life stages within the boundary of the LCA included resource extraction, product manufacturing, and product packaging to prepare it for dispatch to customers at the plant gate. The stages within the system boundary of cellulosic fiberboard's cradle-to-gate LCA study included (1) resource extraction [A1], (2) resource transportation [A2], and (3) cellulosic fiberboard manufacturing and packaging [A3]. Three types of feedstocks were used to make cellulosic fiberboards: logs, mill residues, and construction waste. Logs included impacts from forest management and forestry operations. Mill residues used in the production of cellulosic fiberboard included allocated impacts from forest management, forestry operations, log transport, and sawmill operations. It was assumed that wood construction waste did not carry any upstream impacts. The LCI was developed considering the system modeling approach, where all input and output quantities were assigned to a reference flow.

1.4 Life-Cycle Impact Assessment

The following seven impact categories were examined: global warming potential [GWP (kg CO_2eq)], acidification potential [AP (kg SO_2eq)], eutrophication potential [EP (kg Neq)], ozone depletion potential [ODP (kg chlorofluorocarbons-11eq)], photochemical smog (kg NO_xeq), abiotic depletion potential for fossil resources (ADP fossil) (MJ), and fossil fuel depletion [FFD (MJ surplus)]. The LCI also provided additional information such as primary energy resources consumption [energy consumption from nonrenewable (fossil fuels), nonrenewable (nuclear fuels), renewable (biomass), renewable (wind, solar, and geothermal), and renewable (hydro)], water use, and indicators describing waste.

1.5 Key Findings

Among all phases in the life cycle, the manufacturing phase [A3] contributed the most to the total cradle-to-gate environmental impacts of cellulosic fiberboard. The cradle-to-gate LCI results showed that 196.13 kg of fossil CO_2 was released in the production of 1 m^3 of cellulosic fiberboard as shown in Table 1. But each unit (1 m^3) of cellulosic fiberboard stored 439 kg CO_2eq in wood material. Cellulosic fiberboard manufacturing consumed about 96% of total cradle-to-gate primary energy. The recent production of cellulosic fiberboard had much lower environmental footprint and primary energy use compared with the previous study. About 85% of the total primary energy used in the production of cellulosic fiberboard came from nonrenewables, especially fossil resources.

1.6 Sensitivity Analysis

A sensitivity analysis was completed per ISO 14040 to model the effects of raw material transport distance and consumption of energy including electricity, natural gas, diesel, gasoline, and starch to produce cellulosic fiberboard. A 20% change (increase or decrease) in input parameters (such as electricity, starch, and on-site natural gas consumption used to produce fiberboard) changed the results (i.e., environmental impacts) to more than ±11%. A much smaller change of ±0% to 3% was noted for the seven environmental impacts for a 20% change in the feedstock transport distance and on-site diesel and gasoline consumption.

1.7 Interpretation

The results of this study provide the cradle-to-gate environmental impacts of cellulosic fiberboard production. The authors compared energy inputs from the current study (2019 data) with the earlier study that used 2012 data. About a 46% decrease in use of primary energy was observed in this study compared with the previous study. There was a large decrease in environmental impacts including global warming compared with the previous study, which was caused by the lower use of electricity and fossil fuel resources.

1.8 Acknowledgments

We gratefully acknowledge those North American Fiberboard Association cellulosic fiberboard companies and their employees that participated in the surveys from which we obtained the production data. This project was financially supported by a joint venture agreement between the USDA Forest Service Forest Products Laboratory and the U.S. Endowment for Forestry & Communities, Inc., Endowment Green Building Partnership—Phase 1, no. 16-JV-11111137-094. Any opinions, findings, conclusions, or recommendations expressed in this report do not necessarily reflect the views of the contributing entities.

Table 1—Life-cycle impact assessment for 1 m^3 of cellulosic fiberboard, cradle-to-gate, mass allocation

	Units	Total
Impact category		
Global warming potential – TRACI 2.1	kg CO_2eq	196.13
Global warming potential – w/ biogenic CO_2	kg CO_2eq	196.13
Depletion potential of the stratospheric ozone layer	kg CFC-11eq	7.13E–06
Acidification potential of soil and water sources	kg SO_2eq	0.63
Eutrophication potential	kg Neq	0.29
Formation potential of tropospheric ozone	kg O_3eq	8.46
Abiotic depletion potential for fossil resources	MJ, NCV[a]	2,581.24
Fossil fuel depletion	MJ surplus	375.67
Primary energy consumption[b]		
Nonrenewable, fossil	MJ	2,581.94
Nonrenewable, nuclear	MJ	700.50
Renewable, biomass	MJ	326.73
Renewable, wind, solar, geothermal	MJ	9.88
Renewable, hydro	MJ	231.64

[a]NCV, net calorific value.

[b]Values based on lower heating values.

2 Introduction

The global demand for construction materials is predicted to grow because of world-wide ever-growing gross domestic product (GDP), increasing population, and rising standard of living (Bringezu and others 2017, Sahoo and others 2019). Raw materials, especially for buildings and construction account for more than 35% of global primary energy use and nearly 40% of energy-related CO_2 emissions (Abergel and others 2017). To achieve the United Nations goal of sustainable development, various stakeholders are showing interest in consuming materials with lower environmental impacts. Because of environmental awareness and regulations, and the advent of Environmental Preferential Purchasing (EPP), documenting the environmental performance of building products using life-cycle assessment (LCA) has become a widespread global trend. Moreover, LCA studies are used for various product certifications including green building certifications (Bergman and Taylor 2011, ISO 2006a). The scientific documentation, such as environmental product declarations (EPDs), provides verified data on the environmental performance of products and services to stakeholders including consumers, architects and builders, regulating agencies, and policy makers. LCAs not only provide the required environmental performance of a product but also identify the environmental hot spots for continuous improvements in the manufacturing products and providing services. Update of EPDs (every five years) is mandatory for products that fall under the scope of the various certifications, and thus, new or updated LCA data are required (ISO 2017, ULE 2018).

This LCA study followed International Organization for Standardization (ISO) standards (ISO 2006b, 2006c, 2017) and wood products product category rules (PCR) (ULE 2018, 2019). This report forms the basis for the development of industry average EPD for cellulosic fiberboard in North America. Three methods were used to conduct the life-cycle impact assessment (LCIA) and calculate the required indicators as defined by ISO 21930 and PCR (ISO 2017, ULE 2019): the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) (Bare 2011), the Center of Environmental Science (CML) baseline, and cumulative energy demand (CED) (Frischknecht and others 2007). This LCA report focuses on the production of cellulosic fiberboard in North America and uses data from the year 2019. An attributional system modeling LCA approach was followed, and the life-cycle inventory (LCI) was developed using mass allocation. The LCI included all inputs (raw materials, energy, fuel, etc.) and outputs (direct emissions to air, soil, and water) associated with the manufacturing of cellulosic fiberboard on a per-unit basis (i.e., declared unit of 1 m^3 of cellulosic fiberboard).

2.1 Abbreviations

BF	Board feet
db	Dry basis
EPDs	Environmental product declarations
GWP	Global warming potential
ISO	International Organization for Standardization
LCA	Life-cycle assessment
LCI	Life-cycle inventory
LCIA	Life-cycle impact assessment
m^3	Cubic meter
MBF	Thousand board feet
MMBF	Million board feet
MSF	Thousand square feet
odkg	Oven-dry weight wood in kilograms
PCR	Product category rules
tkm	Metric ton – kilometers

2.2 Glossary of Terms

Allocation - A way of dividing emissions and resource use among the different products of a process. The partitioning can be made on a weight basis, energy content, or economic value.

Cradle-to-gate - LCA model that includes the upstream part of the product life cycle, i.e., all steps from raw material extraction to product at the factory gate.

Declared unit - Quantity of a wood building product for use as a reference unit, e.g., mass or volume, for the expression of environmental information needed in information modules.

Functional unit - Expresses the function of the studied product in quantitative terms and serves as a basis for calculations. It is the reference flow to which other flows in the LCA are related. It also serves as a unit of comparison in comparative studies.

Life-cycle assessment (LCA) - Method for the environmental assessment of products covering their life cycle from raw material extraction to waste treatment.

Life-cycle inventory (LCI) - LCA study that goes as far as an inventory analysis but does not include impact assessment.

Life-cycle impact assessment (LCIA) - Phase of an LCA study during which the environmental impacts of the product are assessed and evaluated.

Product category rules (PCR) - Set of specific rules, requirements, and guidelines for the development of type III environmental declarations for one or more product categories (ISO 14025).

System boundary - A set of criteria that specifies which unit processes are part of a product system (adapted from ISO 104044).

3 Goals and Scope

3.1 Goals

According to ISO 14040/14044, identification and framing of goals and scope are critical for an LCA study (ISO 2006b, 2006c). The goal of this study was to quantify the environmental impacts of producing cellulosic fiberboard. Along with the environmental impacts, the PCR mandated additional indicators such as energy use, water use, and waste generation (ULE 2019), which were also included in this study.

3.2 Intended Audience

The primary audience for this LCA report includes the American Wood Council, Canadian Wood Council, North American Fiberboard Association (NAFA) and their members, building developers and owners, architects, and other LCA practitioners.

3.3 Comparative Assertions

This report does not include product use and end-of-life phases, which are required for comparative assertions relative to substitute products. If future comparative studies are intended and disclosed to the public, the LCA boundary would need to be expanded to include the use and end-of-life phases consistent with the ISO 14044 (ISO 2006c) guidelines and principles and ISO 21930 (ISO 2017) core rules for EPDs and compliance with the wood products PCR, Part A (ULE 2018) and Part B (ULE 2019).

3.4 Functional and Declared Unit

The main purpose of the functional or declared unit is to provide a reference to which all inputs and outputs are quantified to the service delivered by the product system. The functional unit is used for the development of EPDs and covers all (i.e., cradle-to-grave) life-cycle stages of a product. A declared unit was used in place of a functional unit. 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 (ISO 2006b, 2017; ULE 2019). Under the PCR and ISO standards, the declared unit for cellulosic fiberboard is one cubic meter (1.0 m^3) of product ready for delivery to the customer.

3.5 System Boundaries

The scope of this study was to develop a cradle-to-gate LCA of cellulosic fiberboard production in North America. The scope covered resource extraction (A1), resource transportation (A2), and manufacturing of products (A3).

The cradle-to-gate system boundary of cellulosic fiberboard is shown in Figure 1. The system boundary begins with resource extraction (A1), which included procurement of raw materials. In this case, raw material included roundwood chips, sawmill residues (green chips), and wood construction waste. The roundwood chips and sawmill residues included forest management, which may include site preparation, planting seedlings, fertilization and thinning, and final harvest (i.e., logging). Roundwood chips also considered the chipping operation at the forest roadside. It was assumed that wood construction waste materials did not have any resource extraction impacts. Roundwood chips, sawmill residues, and wood construction waste were transported (A2) in tractor-trailers to the cellulosic fiberboard mills. All woody raw materials were broken down into fibers, and cellulosic fiberboard was manufactured (A3) and then packaged for shipment to customers.

The cellulosic fiberboard production complex was modeled as a single unit process. However, the detailed manufacturing process and unit operations (A3) to produce cellulosic fiberboard are shown in Figure 2. The cellulosic fiberboard plant generated residues such as board trims, fines, and culled boards, which were sold to outside mill

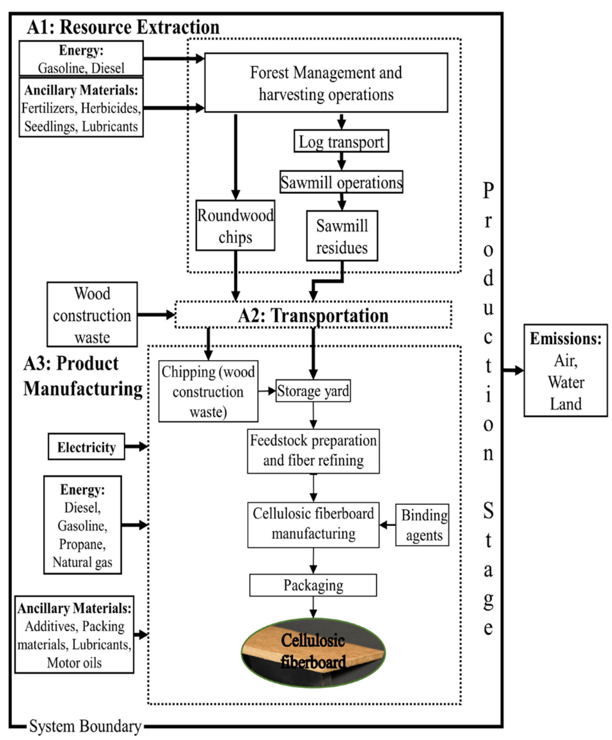

Figure 1. Cradle-to-gate system boundary for production of cellulosic fiberboard in North America.

customers. This study did not include the impacts of plant infrastructure and equipment, maintenance, and end of life (Table 2).

3.6 Allocation Rules

Allocation of inputs to multiple outputs is necessary if a process produces more than one product. Mass, energy, and economic allocations are generally used for this purpose. The wood products PCR recommends a mass allocation (ULE 2019), and thus, inputs and direct emissions were allocated to various outputs (i.e., cellulosic fiberboard and its coproducts) based on their respective oven-dry (OD) mass, and LCI was generated for further use in the development of the model in the LCA software.

3.7 Cut Off Rules

According to the PCR, if the mass (or energy) of a flow is less than 1% of the cumulative mass (or energy) of the model flow, it may be excluded, provided its environmental relevance is minor. However, 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 product's manufacturing process. Under Title III of the Clean Air Act Amendments of 1990, the U.S. Environmental Protection Agency (EPA) has designated the HAPs that wood products facilities are required to report as surrogates for all HAPs. These are methanol, acetaldehyde, formaldehyde, propionaldehyde (propanal), acrolein, and phenol. All HAPs were included in the LCI, with no cut-off rules applied in this study.

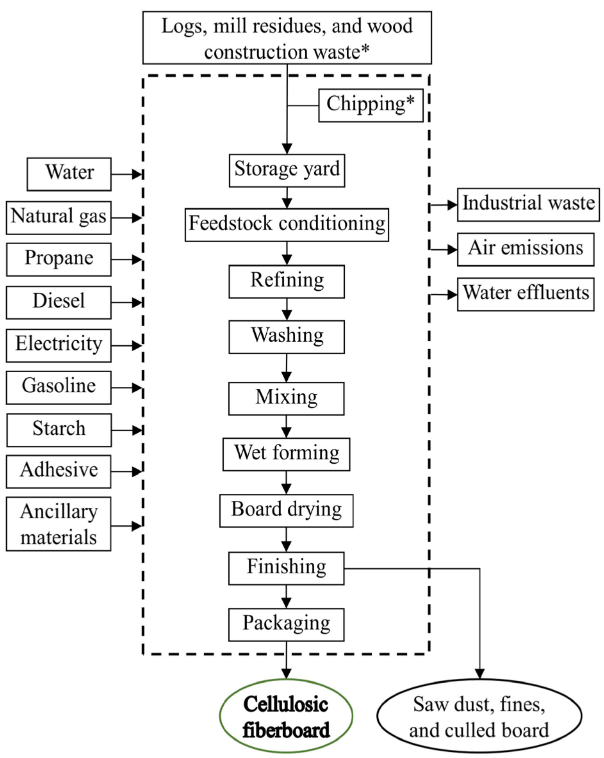

Figure 2. Process flow diagram of the manufacturing process of cellulosic fiberboard (*wood construction waste was chipped in the plant before using for cellulosic fiberboard manufacturing).

3.8 Data Collection and Calculation Methods

A statistically significant sampling frame is required to attain valid results that can be generalized to the cellulosic fiberboard industry. There are four cellulosic fiberboard manufacturing facilities in North America (two mills in Canada and two in the United States). Two manufacturing facilities (one from Canada and one from the United States) participated in this LCA study.

Questionnaires were used to collect primary data on cellulosic fiberboard manufacturing (Appendix). The data from the surveys were assimilated and converted to a unit production basis of volume in the SI unit of cubic meters. The participants of this study provided cellulosic fiberboard production in square feet (0.5-in. (12.7-mm) thickness) as well as a mass (U.S. tons) basis. Similarly, all input data were converted to SI units, and a weighted average of input data was calculated based on total cellulosic fiberboard outputs of the two surveyed production facilities. This approach resulted in a cellulosic fiberboard complex that represents a composite of the North American mills surveyed but may not represent any production facility.

Table 2—System boundary inclusions and exclusions for the cradle-to-gate life-cycle analysis of cellulosic fiberboard production

Included	Excluded
• Production of upstream processes for all resources, raw materials, fuels, and energy for cellulosic fiberboard production	• Fixed capital equipment and facilities
• Transportation of materials throughout the cradle-to-gate manufacturing life stages	• Transportation of employees
• Packaging	• Construction, maintenance, use, and end-of-life treatment

The primary data obtained from the surveys were weight-averaged using

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

where $\overline{P}_{\mathrm{w}}$ is the weighted average of the values reported by the mills, P_i is the reported mill value, and x_i is the fraction of the mill's value to the total production of the surveyed mills for that specific value. Whenever missing data occurred for survey items, they were checked with facility personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros. Any outliers were resolved by contacting mill personnel. DATASMART (LTS 2019) and ecoinvent 3.6 databases were used to assess off-site impacts associated with the used materials and energy to produce cellulosic fiberboard. SimaPro, version 9.1 (PRé Consultants 2020) was used as the accounting program to track all the materials and fuels. Missing data were defined as data not reported in surveys by the cellulosic fiberboard facilities.

Because the surveyed mill data varied between facilities, a statistical analysis was conducted. In this study, the weighted coefficient of variation ($\mathrm{CoV_w}$) was calculated (NIST ITL 1996). The $\mathrm{CoV_w}$ is the weighted standard deviation ($\mathrm{sd_w}$) divided by the weighted mean ($\overline{P}_{\mathrm{weighted}}$):

$$\mathrm{sd_w} = \sqrt{\frac{\sum_{i=11}^{N} w_i \left(x_i - \overline{x}_w\right)^2}{\left[\left(N'-1\right)\sum_{i=1}^{N} w_i\right] / N'}} \tag{2}$$

$$\mathrm{CoV_w} = \frac{\mathrm{sd}_w}{\overline{P}_{\mathrm{weighted}}} \tag{3}$$

where w_i is the weight of the ith observation, N is the number of nonzero weights, and $\overline{x}_w$ is the weighted mean of the observations.

4 Description of Industry and Products

4.1 Cellulosic Fiberboard Industry and Production Statistics

Cellulosic fiberboard, which is usually called insulation board, has various exterior and interior uses in buildings. Manufacturing of cellulosic fiberboard started during World War I, but it wasn't introduced into the United States until the early 1950s (Suchsland and Woodson 1986). Initial manufacturing efforts used the byproducts of wood products manufacturing facilities, such as sawmill residues, and fiber residues (oversize fiber bundles removed from groundwood pulp) from pulp and paper industries as the raw materials. Previously, mill residues and wood construction waste were used as fuel or sent to landfills. With the invention of fiberboard manufacturing technology and engineered products designed to meet specific end-user requirements, these materials were used to make cellulosic fiberboard. The production of cellulosic fiberboard grew rapidly until 1970, then slowly decreased until mid1990, and then remained stable. Production and trade of cellulosic fiberboard have been flat since 1993 (Howard and Liang 2019).

There are only four manufacturing facilities that produce various types of cellulosic fiberboards and cater to customers in North America. In 2019, cellulosic fiberboard production in North America was about 46.45 $\times 10^6$ m^2 at 12.7-mm basis equaling 589,934 m^3 of uncoated cellulosic fiberboard. The mills that responded to the surveys produced 355,264 m^3 in 2019, representing 60.2% of total production in North America). This study collected data from representative cellulosic fiberboard manufacturers in North America that use average technology for their regions. The production facilities surveyed were selected to be representative of North American production practices.

4.2 Description of Product

Cellulosic fiberboard falls within the engineered wood products category or wood insulating board (i.e., fiberboard) in which wooden elements of varying sizes are held together by an adhesive bond or adhesive material (Stark and others 2010). Cellulosic fiberboard is used in building construction for roofing substrate, structural wall sheathing, sound-deadening board, and other specialty-use materials in North America (NAFA 2021a). Cellulosic fiberboard is classified by the following standards: (1) ASTM C208 (Standard Specification for Cellulosic Fiber Insulating Board) (ASTM 2017) and (2) ULC CAN-S706.1 (Standard for Insulating Wood Fibre Boards for Buildings) (ULC 2020). The Construction Specifications Institute (CSI) codes for cellulosic fiberboard are 06-16-13 (insulating sheathing), 06-16-00 (sheathing), 07-22-16 (roof board insulation), and 09-81-13 (acoustic board insulation). The production of cellulosic fiberboard falls into the Standard Industrial Classification (SIC) Code 321219, reconstituted wood products, which includes other wood composite products such as hardboard, medium-density fiberboard, particleboard, and oriented strandboard (USCB 2017). Applicable United Nations Standard Product and Services Codes (UNSPSC) included for cellulosic fiberboard are 14121505 (fiberboard) and 30103604 (wood sheathing or sheets). Cellulosic fiberboard can be coated with asphalt, but that product was excluded from this study. Figure 3 shows the final product of (uncoated) cellulosic fiberboard.

Cellulosic fiberboard panels are available in various dimensions (NAFA 2021b) of 1.21-m width, 12.7- or 18.83-mm thickness, and 2.44- or 2.74-m length (Table 3).

Sawmill residues such as chips from primary log breakdown, wood construction waste from the building industry, and roundwood (bole) chips from chipping the stem of whole trees (usually pulp-grade logs) are the main feedstock for the production of cellulosic fiberboard. These feedstocks are broken down through wet process fiber manufacturing in which a thermomechanical process converts wood raw material to fibers and adheres the fibers with a binder to form cellulosic fiberboard. This process produces a low-density wood panel often referred to as insulation board (Fig. 4). Density varies between 190 and 380 kg/m^3 (Suchsland and Woodson 1986). In this study, the density of cellulosic fiberboard varied between 222 and 238 kg/m^3.

A slurry of fiber is created by adding water similar to the process of papermaking, and then the slurry is transformed into a fiber mat that passes through the press without heat to make cellulosic fiberboard. Later, large dryers are used to remove water and moisture. Cellulosic fiberboard also includes additives such as asphalt, alum, and wax. Asphalt and other external coatings can be used to improve the strength and moisture resistance properties of cellulosic fiberboard.

4.3 Conversion Efficiencies

For the conversion of units from the U.S. industry measure to metric, 1.0 MSF (1,000 square feet) at a 0.5-in. (12.7-mm) basis is equal to 1.18 m^3. (Cellulosic fiberboard manufacturers report their production on a 0.5-in basis.) All input and output data were allocated to the declared unit of the product based on the mass of products and coproducts following standards for conducting LCAs (ISO 2006a, 2006c).

4.4 Typical Emission Control Measure by Plant Type

Emission control devices such as baghouses, cyclones, electrostatic precipitators, and wet scrubbers were used throughout the mills. Typically, air emissions from the cellulosic fiberboard manufacturing facilities were fiber fractions from dryer of fibers, solid particles resulting from the combustion process, and small volatile condensation particles of volatile materials evaporated from board drying. Emission of larger particles such as fibers and fiber fractions can be controlled with relative ease by the installation of cyclones, filters, and scrubbers. In this study, cellulosic fiberboard manufacturers provided data on major emissions and their quantity for the year 2019.

4.5 General Types of Emissions and Wastes

Emissions and waste tracked as substances are part of this LCA analysis. No dangerous substances falling under ISO

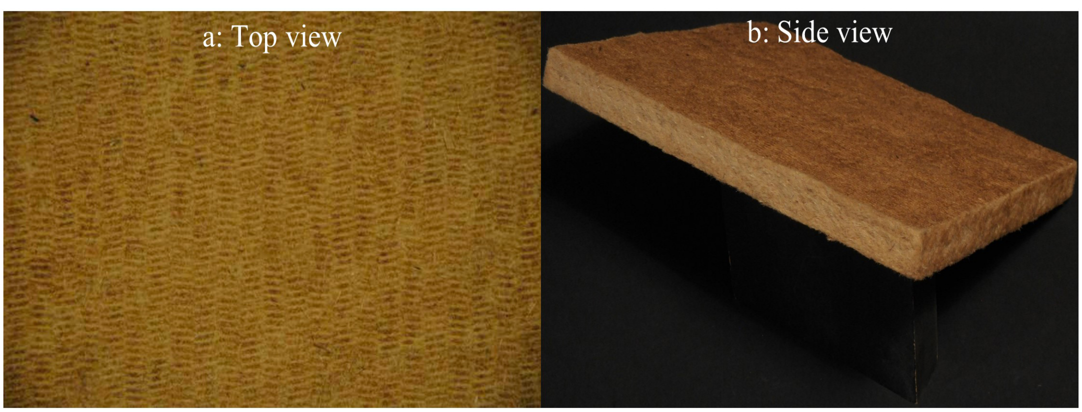

Figure 3. Uncoated cellulosic fiberboard: (a) top view and (b) side view.

Table 3—Available dimensions of cellulosic fiberboard produced in North America (NAFA 2021)

	U.S. customary units			SI units		
	Width (ft)	Length (ft)	Thickness (in.)	Width (m)	Length (m)	Thickness (mm)
Sound-deadening/ insulation board	4	8, 9	0.5	1.219	2.438, 2.743	12.7
Wall sheathing	4	8, 9	0.5, 0.78	1.219	2.438, 2.743	12.7, 19.837
Roofing	Custom					

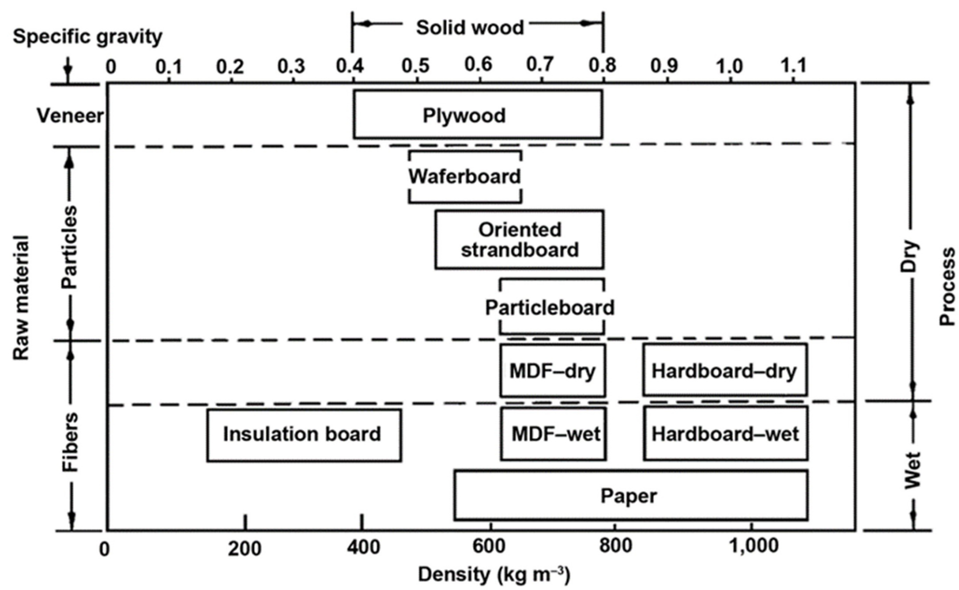

Figure 4. Classification of wood composite panels by particle size, density, and process (Suchsland and Woodson 1986).

21930 (ISO 2017) were reported by industry. The air emissions reported by most mills include dust, particulate matter (PM), volatile organic compounds (VOCs), and HAPs. Mills classed as major sources under EPA rules are required to report methanol, formaldehyde, phenol, acetaldehyde, propionaldehyde, and acrolein, which are on EPA's HAPs list. Other emissions to air were reported in surveys, but they varied considerably among mills. Only one mill reported liquid emissions. These included suspended solids, biological oxygen demand (BOD), chemical oxygen demand (COD), and oil and grease. During cellulosic fiberboard manufacturing, various types of solid waste are generated on-site including discarded wood, plastic packaging materials, metals, and others. Solid wastes are either landfilled or recycled, especially metals.

4.6 Wood Species

In this study, cellulosic fiberboard manufacturers used wood construction waste, sawmill residues, and roundwood chips. Sawmill residues and roundwood chips primarily came from loblolly pine (*Pinus taeda* L.). Generally, wood construction waste contains mixed wood species, mostly softwoods, but the types were not recorded by the cellulosic fiberboard mills.

4.7 Moisture Content

The moisture content of the feedstocks (roundwood chips, sawmill residues, and wood construction waste) ranged from 20% to 100% dry basis (db). The moisture content of cellulosic fiberboard produced before any drying was between 50% and 52% (db), and the moisture content of the final product and coproducts produced after drying was decreased to between 3% and 8% (db).

5 Life-Cycle Inventory Analysis

5.1 A1: Resource Extraction

Table 4 shows the contribution of different feedstocks to produce 1 m^3 of cellulosic fiberboard in North America by mass and by percent. Roundwood chips (53.73%, 128.24 oven-dry kg) represent the largest fraction of total feedstock followed by sawmill chips (14.44%, 41.62 oven-dry kg) and wood construction waste (28.84%, 68.84 oven-dry kg).

5.1.1 Roundwood Chips

The plants procured roundwood chips coming from logs that included the establishment, growth, and harvest of trees in the U.S. southeast (SE) region. Data for the forest resources management component of this analysis came from the research of Johnson and other (2005), as updated in Puettmann and others (2016). Chipping of roundwood at the forest roadside was included in this study. Table 5 provides the detailed fuel used for each operation including forest management, harvest, and chipping of roundwood.

5.1.2 Mill Residues and Construction Waste

Mill residues used in the production of cellulosic fiberboard were sourced from sawmills that produce lumber located in the U.S. SE region. The primary product is dimension lumber, but they produce a significant amount of mill residues or coproducts. The mill residues can be in the form of bark, sawdust, wood chips, and hogged fuel.

Construction waste refers to wood waste generated during the construction of wood-framed buildings and other infrastructure that contains wood materials that can be separated from nonwood materials. For wood construction waste, this study considered no impacts for the wood product "first life" or cradle-to-construction impacts.

5.2 A2: Resource and Material Transport

Roundwood chips, sawmill chips, and wood construction waste were the three types of feedstocks used for cellulosic fiberboard in this study. All wood feedstocks were transported in trucks, i.e., diesel tractor-trailers, from source to the mill. Various ancillary materials and additives were used in the production of cellulosic fiberboard, and these materials were also transported in diesel tractor-trailers only. Table 6 shows the weighted average haul distance for feedstocks along with other materials used in the manufacturing process.

5.3 A3: Cellulosic Fiberboard Manufacturing

5.3.1 Material Flows

The mass balance for cellulosic fiberboard is shown in Table 7. The final product, uncoated cellulosic fiberboard, has an average oven-dry density of 239.5 kg/m^3, representing 92% of main products and 8% of coproducts. On a mass basis, roundwood chips are the dominant input at 128 OD kg followed by construction waste and sawmill chips at 69 and 42 OD kg, respectively.

5.3.2 Product Manufacturing

Figure 2 outlines the manufacturing of cellulosic fiberboard (Bergman 2015), and major unit operations include

Table 4—Wood feedstock inputs (types and source) in cellulosic fiberboard production

Wood residue type	Region	Amount (kg/m^3)	Contributions (%)
Roundwood chips, softwood, green	United States, southeast	128.24	53.73
Sawmill chips, softwood, green	United States, southeast	41.62	17.44
Wood construction waste	Canada	68.84	28.84
Total (weighted average)		238.70	100

Table 5—Fuel and electricity consumption per cubic meter of cellulosic fiberboard during forest resource management (regeneration and thinning) and harvesting in the southeast United States

Processes	Unit	Seedling, site prep, plant, precommercial thinning	Commercial thinning and final harvest	Chipping at roadside	Total
Diesel and gasoline	L	0.52	2.93	1.14	4.59
Lubricants	L	0.009	0.05	0.02	0.079
Electricity	kWh	0.455	0	—	0.455

Table 6—Weighted average delivery distance (one-way) for materials to cellulosic fiberboard mills in North America

Input material	Mode of transport	Weighted average transport distance (km)
Feedstocks		
Roundwood chips, softwood, green	Truck	54.7
Sawmill chips, green	Truck	54.7
Wood construction waste	Truck	11.5
Nonfeedstock materials (additives)		
Starch	Truck	105.7
Alum	Truck	164.1
Wax	Truck	120.9
Carbon black	Truck	109.4
Clay	Truck	1,860.0
FLOC (loose cellulose flakes)	Truck	742.8
Iron oxide	Truck	652.0

(1) resource transport, (2) storage of resources, (3) feedstock preparation, (4) refining, (5) washing, (6) mixing, (7) wet forming, (8) board drying, (9) finishing, and (10) packaging.

5.3.2.1 Storage Yard

The storage yard acts as a buffer for the mill. In the storage yard, feedstock was weight-scaled and moisture contents were determined. Logistical equipment, such as front-end loaders, was used to move chips from the storage yard to the mill. Additional mobile equipment was used to move all feedstock for further processing. Inputs included for the operations in the storage yard were feedstock, electricity, fuel, and lubricants. Outputs were feedstock moved to mills and any direct emissions, such as particulate and fossil CO_2.

5.3.2.2 Feedstock Conditioning

Feedstocks uniformity and homogeneity are crucial for the mill. Large chips were broken down into small pieces to produce homogeneous feedstock. Construction waste was also chipped. Chips were screened to remove over-sized chips, rechipped, and then washed to remove dirt and other foreign substances. Cleaned chips were stored in storage bins. Steam digesters and steaming screws are typically used for conditioning chips and other wood raw material. Inputs for modeling this process included prepared feedstock, water, steam, and electricity, and outputs included cleaned chips and direct emissions.

5.3.2.3 Pulping and Refining

The pulping process converted cleaned chips to fibers. The mills used mechanical pulping, and no chemicals were added. Chips were mechanically broken down by shearing, using two rotating metal disks. The fibers (pulp fibers) were generated by thermally softening the lignin. Refining (segregation of fibers from the slurry of pulp and water) is a fossil-energy-intensive process, and the average specific energy consumption may vary between 250 and

Table 7—Mass balance of cellulosic fiberboard manufacturing per cubic meter in North America (unallocated)

	Inputs	
	Oven-dry mass (kg)	Contribution (%)
Feedstock		
Sawmill residues (chips), green	41.62	15.99
Roundwood chips, green	128.24	49.27
Wood construction waste	68.84	26.44
Total, feedstock	**238.70**	**91.70**
Additives		
Starch	13.24	5.09
Alum	1.25	0.48
Wax	3.73	1.43
Carbon black	1.02	0.39
Clay	1.06	0.41
FLOC (loose cellulosic flakes)	1.10	0.42
Iron oxide	0.21	0.08
Total, additives	**21.61**	**8.30**
Total, inputs	**260.31**	**100**
	Outputs	
	Oven-dry mass (kg)	Contribution (%)
Products		
Cellulosic fiberboard	239.46	91.99
Coproducts		
Board trim (sawdust)	0.00	0.00
Culled boards	2.48	0.95
Pins and fines	11.11	4.27
Other, not specified	7.26	2.79
Total, coproducts	**20.85**	**8.01**
Total, outputs	**260.31**	**100**

380 kWh/metric ton (Suchsland and Woodson 1986). Inputs to this process included cleaned chips, electricity, and heat (Fig. 2). Outputs included pulp fiber and water vapor.

5.3.2.4 Washing

In the pulping process along with fibers, dissolved solids (i.e., hemicellulose) were generated, which were removed through washing (Fig. 2). Washing removes dirt and other foreign material that might remain in the pulp fibers. Inputs were pulp fibers and water. Outputs were clean pulp fibers, wastewater, and solid waste.

5.3.2.5 Mixing

During the mixing step, water was added to the pulp fibers along with additives (alum, asphalt, starch, and wax) for bonding the pulp fibers in stock chests to create a slurry for further processing (Fig. 2). No resins are added to produce cellulosic fiberboards. Lignin, a natural component of wood, aids the additives in bonding the pulp fibers. Inputs included clean pulp fiber, water, and additives (Fig. 2), and outputs included a pulp–water low-consistency slurry (washed pulp) along with additives.

5.3.2.6 Wet Forming

The slurry with approximately 2% pulp fiber was sent to forming machines where it was metered onto a wire screen. Two percent solids consistency in the slurry provides the highest bonding strength of the final board (Lampert 1967). Gravity and a vacuum applied gradually to the bottom of the wire screen removed the water from the slurry mix and produced a fiber mat. The fiber mat (after the slurry reached about 25% solid consistency) was cut to length and trimmed by high-pressure water jets (Fig. 2). The wet-formed mat was pressed using continuous rollers at room temperature, which removed additional water, until the board was formed, except for a shrinkage allowance in drying. Most of the collected water was recycled. Inputs included washed pulp with embedded additives, water, and electricity, and outputs included a fiber mat, trim residue, water, and steam.

5.3.2.7 Board Drying

The wet fiberboard generated in the forming process must pass through a drying process. Board drying is a continuous process with intensive energy requirements (Fig. 2). The fiber mats, which are around 65% to 75% moisture content (db), move along a conveyor into a heated enclosure where their moisture content is decreased to approximately 4%. In total, approximately 2 metric tons of water are removed per metric ton of dry board. Roller dryers operate with inlet temperatures of approximately 230 °C and outlet temperatures of approximately 160 °C. Inputs included wet boards (fiber mat), electricity, and natural gas, and outputs included (untrimmed) dry boards, steam, and air emissions.

5.3.2.8 Finishing

Dry fiberboard was trimmed to final standard dimensions (Fig. 2). Inputs included untrimmed dry boards and electricity. Outputs included final product, culled boards, and wood dust. Finished fiberboard density ranged from 222 to 238 kg/m^3. This study did not include the coating of the finished boards.

5.3.2.9 Packaging

Finished cellulosic fiberboard is packaged for transport. Inputs included the final product (i.e., cellulosic fiberboard), electricity, and packaging material such as plastic wrapping, cardboard, and runners. Outputs included packaged uncoated cellulosic fiberboard. The total mass of packing materials represented less than 1% of the cumulative mass of the final product (packaged uncoated cellulosic fiberboard). The runners or wooden spacers make up the bulk of this mass, representing 93% of the total packaging material (Table 8). The plastic wrapping, plastic strapping, and carboard packaging made up 4%, 2%, and 1% of the remaining mass, respectively.

5.3.3 Heat, Electricity, and Fuel

Energy (heat and electricity) to produce cellulosic fiberboard comes from grid electricity and natural gas. Primarily, natural gas was used to heat refiners and dryers (Table 9). Electricity from the grid was used to power equipment within the plant, including conveyors, refiners, fan motors, hydraulic press motors, high-pressure water jets, rollers, and emission control systems. Emission control devices such as baghouses, cyclones, electrostatic precipitators, and wet scrubbers were used throughout the mills. Other fuels such as diesel, liquid propane gas (LPG), and gasoline were used to operate transport equipment within the mill. In this study, electricity use considered regional variations (68% from Virginia, USA, and 32% from Quebec, Canada) during the development of LCI.

Table 8—Materials used in packaging and shipping per cubic meter of cellulosic fiberboard in North America (unallocated)

Material	Value (kg/m³)
Wrapping material	0.107
PET strapping	0.053
Cardboard packaging	0.027
Wooden spacers	2.544
Total	2.731

Table 9—On-site energy inputs for cellulosic fiberboard manufacturing, gate-to-gate (unallocated)

Energy inputs	Unit	Quantity	CoV_w (%)
Electricity	kWh	186.46	10.12
Natural gas	m^3	39.27	10.47
Diesel	L	0.28	10.84
Propone	L	0.34	9.24
Gasoline	L	0.02	97.13

5.3.4 Gate-to-Gate LCI of the Cellulosic Fiberboard Manufacturing System

Table 10 summarizes the gate-to-gate LCI flows associated with North American cellulosic fiberboard production. These flows are linked to the upstream processes for forestry operations, feedstock production, transportation, fuels, and electricity to calculate cradle-to-gate environmental impacts for cellulosic fiberboard.

5.4 Data Sourcing and Averaging

Secondary data were used for resource extractions including forest management and harvesting. The LCI for forest management and harvesting were derived from earlier studies on forest operations in the U.S. SE (Johnson and others 2005, Puettmann and others 2016). The data included a weighted average of various harvesting and forest management methods in the U.S. SE. Sawmill residue production data used in this study were derived from CORRIM data using SE softwood lumber (Milota 2015) (Table 11). The LCA incorporated an appropriate diesel tractor-trailer and diesel locomotive LCI from the U.S. LCI database based on transportation distances and mass of chips, mill residues, and construction waste for each mill location. Table 11 lists the secondary LCI data sources used in this LCA study for raw material inputs, ancillary materials and packaging, transportation of materials and resources, fuels and energy for manufacturing, water sources, and waste streams.

6 Life-Cycle Impact Assessment

The LCIA is the crucial phase of the LCA study. The LCIA phase establishes links between the LCI results and potential environmental impacts. The significance of the potential environmental impacts was evaluated based on the LCI using the TRACI, CED, and CML methods (Bare 2011, Frischknecht and others 2007). Table 12 summarizes the source and scope of each impact category reported in this report as required to be in conformance with the PCR (ULE 2019).

These impact indicators provide general, but quantifiable, indications of potential environmental impacts. This LCIA does not make value judgments about the impact indicators, meaning comparison indicator values are not valid. Additionally, each impact indicator value was stated in units that are not comparable with others. For the same reasons, indicators should not be combined or added. Additionally, the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks. The primary fuels are categorized into nonrenewable (fossil and nuclear) and renewable (biomass, geothermal, solar, wind, and hydro).

Table 13 shows the cradle-to-gate environmental performance results for all reporting indicators for cellulosic fiberboard. The LCIA results are in absolute values for various life-cycle stages (A1 resource extraction, A2 transportation, and A3 product manufacturing) of cellulosic fiberboard. The cradle-to-gate global warming potential (GWP) was about 196 kg CO_2eq/m^3 of cellulosic fiberboard. The GWP impacts from resource extraction, transportation, and product manufacturing were 5.34, 6.75, and 184.04 kg CO_2eq/m^3 of cellulosic fiberboard. Overall, the contribution of the A3 stage (i.e., product manufacturing) was substantial or very high among all stages in the cradle-to-gate environmental impacts of cellulosic fiberboard.

Table 13 also provides indicators related to energy use, material resource consumption, and waste generated. The amounts of energy usage for cradle-to-gate renewable and nonrenewable energy were 568 and 3,282 MJ/m^3 of cellulosic fiberboard, respectively. Total cradle-to-gate fresh water use was 1.38 m^3, and most of the fresh water use was in the manufacturing of cellulosic fiberboard (A3 life-cycle stage). Overall, product manufacturing was the most dominant stage among all life-cycle stages of cellulosic fiberboard.

7 Interpretation

According to ISO 14040, life-cycle interpretation is the final phase of the LCA, and results of LCI or LCIA, or both, are combined consistently and summarized as a basis for conclusions and recommendations with the defined goal and scope of the study. This phase in the LCA reports the significant issues based on the results of the LCI and LCIA of this report. Additional components report an evaluation that considers completeness, sensitivity, and consistency checks of the LCI and LCIA results and conclusions, limitations, and recommendations.

7.1 Identification of Significant Issues

The objective was to structure the results from the LCI or the LCIA phases to help determine the significant issues found in the results and presented in previous sections of this report. A contribution analysis was applied for the interpretation phase of this LCA study. Contribution analysis examines the contribution of life-cycle stages (A1 to A3), unit process contributions in a multi-unit

Table 10—Unit process inputs–outputs to produce 1 m^3 of cellulosic fiberboard in North America (unallocated)

	Value	Unit/m^3	Mass allocation (%)
Inputs – materials and fuels			
Sawmill chips, green, average North America	41.62	OD kg	
Roundwood chips, average North America	128.24	OD kg	
Wood construction waste, average North America	68.83	OD kg	
Starch, 100% solids	13.24	kg	
Wax	3.73	kg	
Clay	1.06	kg	
Alum	1.25	kg	
Carbon black	1.02	kg	
FLOC (loose cellulosic flakes)	1.10	kg	
Iron oxide	0.21	kg	
Electricity, at grid	186.46	kWh	
Diesel, combusted in industrial equipment	0.28	L	
Gasoline, combusted in equipment	0.02	L	
Hydraulic fluid	0.15	kg	
Oils and grease	0.002	kg	
Lubricant and oil	0.087	kg	
Marking paint and ink	0.0001	kg	
Propane, combusted in industrial equipment	0.34	L	
Natural gas, combusted in industrial boiler, direct-fired	39.27	m^3	
Transport, combination truck, diesel-powered, wood feedstock	55.94	tkm	
Transport, combination truck, diesel-powered, starch	3.78	tkm	
Transport, combination truck, diesel-powered, wax	1.48	tkm	
Transport, combination truck, diesel-powered, clay	5.79	tkm	
Transport, combination truck, diesel-powered, alum	0.97	tkm	
Transport, combination truck, diesel-powered, carbon black	0.50	tkm	
Transport, combination truck, diesel-powered, FLOC	2.40	tkm	
Inputs - water			
Water, municipal	514.91	L	
Outputs – products and coproducts			
Cellulosic fiberboard	1	m^3	91.99
Culled boards	2.48	OD kg	0.95
Pins and fines	11.11	OD kg	4.27
Other, not specified	7.26	OD kg	2.79
Outputs - emissions to air			
VOC, volatile organic compounds	1.62E–01	kg	
Acetaldehyde	1.02E–03	kg	
Acrolein	3.44E–04	kg	
Limonene	3.50E–03	kg	
Particulates, >2.5 um, and <10 um	7.65E–03	kg	
Propanal	1.77E–01	kg	
Sulfur dioxide	5.62E–03	kg	
Toluene	1.83E–01	kg	

Table 10—Unit process inputs–outputs to produce 1 m^3 of cellulosic fiberboard in North America (unallocated)—continued

	Value	Unit/m^3	Mass allocation (%)
Outputs - emissions to water			
BOD5, biological oxygen demand	0.321	kg	
Oils, unspecified	0.003	kg	
Suspended solids, unspecified	0.089	kg	
Outputs - waste to treatment			
Waste to an inert landfill	1.920	kg	
Waste to recycling	0.082	kg	

manufacturing process, or specific substances that contribute an impact.

7.2 Life-Cycle Phase Contribution Analysis

Table 14 shows the contribution of three life-cycle stages of cellulosic fiberboard product production. About 93.8% of global warming impact (CO_2 equivalent emissions) came from the product manufacturing phase of cellulosic fiberboard (A3). The resource extraction (A1) and transportation (A2) phases contributed about 2.7% and 3.4% of total cradle-to-gate GWP of cellulosic fiberboard, respectively.

The contribution of the A3 phase was substantial and consistent among all the core mandatory impact categories. Most of the renewable fuels were used in the A3 life-cycle stage (Tables 15 and 16). The A3 phase consumed about 96% of the total primary energy used in the manufacturing of cellulosic fiberboard. This was caused by most of the heat, electricity, and fuels used during the manufacturing process. About 84.6% of the total energy used in the A3 phase came from nonrenewable resources, and the rest came from renewable sources such as water, wind, solar, geothermal, and biomass.

In this study, mills did not use biomass as a source of energy or heat. However, the 8.5% of total energy contributed by renewable biomass was from carryover impacts of sawmill residues used in this study as a feedstock for cellulosic fiberboard. About 99% of the energy used in A1 and A2 phases came from nonrenewable resources (Table 15).

Table 16 shows the contribution of each category of energy resources among three life-cycle phases of cellulosic fiberboard production. Among the six categories of energy sources, most energy usage was from manufacturing of cellulosic fiberboard.

7.3 Uncertainty Analysis

The uncertainty and sensitivity analyses aim to assess the reliability of the results. Some degree of uncertainty in the results was inevitable because of the variation among different data providers. The uncertainty analysis investigates input data variations within the sample of production facilities. Statistics for key inventory results, i.e., electricity, on-site diesel, natural gas, and starch consumption, are shown in Table 17. The standard deviation for each of these factors was calculated based on the sample data and was used to perform sensitivity analysis on these parameters.

In the sensitivity analysis, significant inventory parameters are altered to investigate the effect on the LCIA results. In this case, log transport distance, electricity, on-site diesel, gasoline, natural gas, and starch consumption were increased and decreased by 20%. The changes in LCIA results are presented in Table 18. It shows that a change in electricity inputs had significant effects on the results. For example, a 20% increase in electricity increased GWP, ODP, and EP by 7.6%, 11.1%, and 10.2%, respectively. Similar changes in impacts for GWP, FFD, and ADP fossil were seen with changes in natural gas usage. Other inputs of log transport distance and usage of diesel and gasoline did not have much effect on the environmental impacts of cellulosic fiberboard production.

7.4 Completeness and Consistency Checks

The completeness and consistency checks and sensitivity help to establish and enhance confidence in the study. These improve the reliability of the results of the LCA study, including the significant issues identified in the interpretation.

The objective of the completeness check was to ensure that all relevant information and data needed for the interpretation are available and complete. Three selected information modules (“harvesting and forest management”, “resource and material transportation”, and “manufacturing of cellulosic fiberboard”) were checked for data completeness including all elements such as raw and ancillary material input, energy input, transportation, water consumption, product and coproducts outputs, emissions to air, water and land, and waste disposal. All the input and output data were found to be complete, and no data gaps were identified.

The objective of the consistency check was to determine whether the assumptions, methods, models, and data are consistent with the goal and scope of the study. Through a rigorous process, consistency was ensured to fulfill the goal of the study in terms of assumptions, methods, models, and

Table 11—Secondary data sources and data quality assessment[a]

	LCI data source	Geography	Year	Data quality assessment
A1: Raw material inputs				
Forestry and harvesting: logs	*Database:* CORRIM dataset SE softwood forestry operations *Process:* Roundwood, softwood, harvested, average intensity, at forest road, U.S.-SE	North America – region specific	2005–2019	*Technology*: Good. Process models region-specific technology. *Time*: Good. Some data are less than 5 years old. *Geography*: Very good. Data are representative of regional production.
Sawmill residues	*Database:* CORRIM dataset *Process:* Sawmill chips, softwood, at the sawmill, U.S.-SE	North America – region specific	2005–2019	*Technology*: Good. Process models region-specific technology. *Time*: Good. Some data are less than 5 years old. *Geography*: Very good. Data are representative of regional production.
A2: Raw material transportation				
Trucking	*Database:* U.S. EI 2.2 (LTS 2019) *Process:* Transport, combination truck, diesel-powered NREL/U.S. U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American trucking.
A3: Manufacturing, energy inputs				
Electricity	Database: U.S. EI 2.2 (LTS 2019) and ecoinvent 3.6 Process: Electricity, low voltage, at grid, Virginia/U.S. U.S.-EI U Electricity, low voltage (CA-QC)| market for | cut-off, U	North America – region specific	2019	*Technology*: Very good. Process models average electricity technology specific to regional grids. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of regional electricity generation in North America.
Gasoline	Database: U.S. EI 2.2 (LTS 2019) Process: Gasoline, combusted in equipment NREL/U.S. U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American propane production and combustion.
Natural gas	Database: U.S. EI 2.2 (LTS 2019) Process: Natural gas, combusted in industrial boiler NREL/U.S. U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American propane production and combustion.
Propane	Database: U.S. EI 2.2 (LTS 2019) Process: Natural gas, combusted in industrial equipment NREL/RNA U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American propane production and combustion.
Diesel	Database: U.S. EI 2.2 (LTS 2019) Process: Diesel, combusted in industrial equipment NREL/U.S. U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American diesel production and combustion.
Ancillary materials and packaging				
Hydraulic fluid	Database: U.S. EI 2.2 (LTS 2019) Process: Lubricating oil, at plant/U.S.- U.S.-EI U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American processes.

Table 11—Secondary data sources and data quality assessment[a]—continued

	LCI data source	Geography	Year	Data quality assessment
Starch	Database: ecoinvent 3.6 Process: Maize starch (GLO)| market for | cut-off, U	Global	2019	*Technology*: Very good. Process models average North American technology *Time*: Very good. Data are less than 5 years old *Geography*: very good. Data are representative of global processes.
Wax	Database: CORRIM data Process: Slack wax AWC	North America	2012	*Technology*: Good. Process models average North American technology. *Time*: Very good. Data are less than 10 years old. *Geography*: Very good. Data are representative of North American production and combustion.
Alum	Aluminum sulphate, powder, at plant/U.S.- U.S.-EI U	North America	2019	*Technology*: Good. Process models average North American technology. *Time*: Very good. Data are less than 10 years old. *Geography*: Very good. Data are representative of North American production and combustion.
FLOC (flocculation)	Aluminum sulphate, powder, at plant/U.S.- U.S.-EI U	North America	2019	*Technology*: Good. Process models average North American technology. *Time*: Very good. Data are less than 10 years old. *Geography*: Very good. Data are representative of North American production and combustion.
Plastic strap	Database: U.S. EI 2.2 (LTS 2019) Process: Polyethylene, HDPE, granulate, at plant/U.S.- U.S.-EI U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American processes.
Wrapping material	Database: CORRIM data Process: Packaging - wrapping material, EWP, for CFB	North America	2014	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 10 years old. *Geography*: Very good. Data are representative of North American processes.
Stickers/runners	Database: CORRIM data Process: Sawn lumber, hardwood, rough, kiln-dried, SE, USA, U	North America	2012	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 10 years old. *Geography*: Very good. Data are representative of North American processes.
Cardboard	Database: CORRIM data Process: Cardboard - EWP, CFB	North America	2014	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 10 years old. *Geography*: Very good. Data are representative of North American processes.
Greases and oils	Database: U.S. EI 2.2 (LTS 2019) Process: Lubricating oil, at plant/U.S.- U.S.-EI U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American processes.
Paint	Database: U.S. EI 2.2 (LTS 2019) Process: Alkyd paint, white, 60% in solvent, at plant/U.S.- U.S.-EI U	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American processes.
Carbon black	Database: U.S. EI 2.2 (LTS 2019) Process: Carbon black, at plant/GLO U.S.-EI U, CFB	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American processes.

Table 11—Secondary data sources and data quality assessment[a]—continued

	LCI data source	Geography	Year	Data quality assessment
Clay	Database: U.S. EI 2.2 (LTS 2019) Process: clay, at mine/kg/CH	North America	2019	*Technology*: Very good. Process models average North American technology. *Time*: Very good. Data are less than 5 years old. *Geography*: Very good. Data are representative of North American processes.

[a]LCI, life-cycle inventory; SE, southeast; CORRIM, consortium on renewable and recyclable industrial materials; NREL, National Renewable Energy Laboratory; RNA, region North America; GLO, global; AWC, American Wood Council; HDPE, high-density polyethylene; EWP, engineered wood products; CFB, cellulose fiberboard; CA-QC, Canada-Quebec.

data quality including data source, accuracy, data age, time-related coverage, technology, and geographical coverage.

7.5 Limitations

This LCA was created using industry average data for upstream materials. Variation can result from differences in supplier locations, manufacturing processes, manufacturing efficiency, and fuel type used. This LCA does not report all the environmental impacts caused by the manufacturing of the product but rather reports the environmental impacts for those categories with established LCA-based methods to track and report. Unreported environmental impacts include (but are not limited to) factors attributable to human health, land-use change, and habitat destruction. To assess the local impacts of product manufacturing, additional analysis is required.

This LCA report documents the results of a cradle-to-gate analysis and reports no comparative analysis. This LCA does not make any statements that the product covered by the LCA is better or worse than any other product.

8 Treatment of Biogenic Carbon

Forests are understood as a natural system with multiple functions, the production of timber being one of them. Therefore, natural growth and decay processes including natural disturbances, etc., are not attributable to the production function of forests and are therefore not considered in LCA. Harvesting operations lead to temporal decreases in forest carbon pools in the respective stand. Impacts on forest carbon pools resulting from the sustainable or unsustainable management of forests, however, cannot be defined or assessed on the stand level, but these decisions require the consideration of carbon pool changes on the landscape level, i.e., the level at which management decisions are made. Resulting from the fundamental principle of sustainable forest management to preserve the production function of forest, total forest carbon pools can be considered stable (or increasing) under sustainable forest management. This is because temporal decreases of forest carbon pools resulting from harvesting on one site are compensated by increases of carbon pools on other sites, forming together the forest area under sustainable forest management (Brashaw and Bergman 2021).

It is acknowledged that excessive extraction of slash, litter, or roots for bioenergy generation can lead to decreases in forest carbon pools. These activities, however, are not causally linked to the extraction of timber for the material use of wood. Effects on forest carbon pools related to the extraction of slash, litter, or roots are not attributable to the material use of wood and are therefore not considered in this document.

To reflect the biogenic nature of wood, its renewability, and its potential carbon neutrality, the system boundary between nature and the product system under study is defined as follows:

- Wood entering the product system from nature accounts for the energy content and the biogenic carbon content as material inherent properties.
- All technical processes related to forestry operations intended to produce timber (e.g., stand establishment, tending, thinning(s), harvesting, establishment, and maintenance of forest roads) are considered within the system boundary and are subject to coproduct allocations as outlined in the reference PCR (ULE 2019).
- Potential implications caused by the unknown origin of wood or unsustainably produced timber are considered.
- Human-induced impacts on forest carbon pools resulting in deforestation are not included. However, the forest inventory in the United States and Canada is increasing and managed sustainably. Therefore, it is safe to assume that deforestation does not occur in North America, and there is no or minimal indirect negative impact caused by deforestation.

Because the degradation of forest carbon pools resulting from unsustainable management of forests cannot be attributed to a specific log but is a process on a landscape level, the effect of forest degradation is considered by not assuming carbon neutrality. In the case of land-use changes from forests to other land uses (e.g., deforestation), the loss of carbon in the forest carbon pools is to be considered.

Table 12—Selected impact indicators, characterization models, and impact categories

Reporting category per tables E1-E5 in ISO 21930	Indicator name	Abbreviation	Units
Core Mandatory Impact Indicators	Global warming potential, fossil	GWP_{TRACI}	kg CO_2eq
Core Mandatory Impact Indicators	Global warming potential, w/ biogenic[a]	GWP_{BIO}	kg CO_2eq
Core Mandatory Impact Indicators	Depletion potential of the stratospheric ozone layer	ODP	kg CFC-11eq
Core Mandatory Impact Indicators	Acidification potential of soil and water sources	AP	kg SO_2eq
Core Mandatory Impact Indicators	Eutrophication potential	EP	kg PO_4eq
Core Mandatory Impact Indicators	Formation potential of tropospheric ozone	SFP	kg O_3eq
Core Mandatory Impact Indicators	Abiotic depletion potential for fossil resources	ADP fossil	MJ, NCV
Core Mandatory Impact Indicators	Fossil fuel depletion	FFD	MJ surplus
Use of Primary Resources	Renewable primary energy carrier used as energy	RPRE	MJ, NCV
Use of Primary Resources	Renewable primary energy carrier used as material	RPRM	MJ, NCV
Use of Primary Resources	Nonrenewable primary energy carrier used as energy	NRPRE	MJ, NCV
Use of Primary Resources	Renewable primary energy carrier used as material	NRPRM	MJ, NCV
Secondary material, secondary fuel and recovered energy	Secondary material	SM	kg
Secondary material, secondary fuel and recovered energy	Renewable secondary fuel	RSF	MJ, NCV
Secondary material, secondary fuel and recovered energy	Nonrenewable secondary fuel	NRSF	MJ, NCV
Secondary material, secondary fuel and recovered energy	Recovered energy	RE	MJ, NCV
Mandatory Inventory Parameters	Consumption of fresh water resources	FW	m^3
Indicators Describing Waste	Hazardous waste disposed	HWD	kg
Indicators Describing Waste	Nonhazardous waste disposed	NHWD	kg
Indicators Describing Waste	High-level radioactive waste, conditioned, to final repository	HLRW	kg or m^3
Indicators Describing Waste	Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	kg or m^3
Indicators Describing Waste	Components for re-use	CRU	kg
Indicators Describing Waste	Materials for recycling	MR	kg
Indicators Describing Waste	Materials for energy recovery	MER	kg
Indicators Describing Waste	Recovered energy exported from the product system	EE	MJ, NCV
Additional Inventory Parameters for Transparency	Biogenic carbon removal from product	BCRP	kg CO_2eq
Additional Inventory Parameters for Transparency	Biogenic carbon emission from product	BCEP	kg CO_2eq
Additional Inventory Parameters for Transparency	Biogenic carbon removal from packaging	BCRK	kg CO_2eq
Additional Inventory Parameters for Transparency	Biogenic carbon emission from packaging	BCEK	kg CO_2eq
Additional Inventory Parameters for Transparency	Biogenic carbon emission from combustion of waste from renewable sources used in production processes	BCEW	kg CO_2eq
Additional Inventory Parameters for Transparency	Carbon emissions from combustion of waste from nonrenewable sources used in production processes	CWNR	kg CO_2eq

[a]ISO 21930 requires a demonstration of forest sustainability to characterize carbon removals with a factor of –1 kg CO_2eq/kg CO_2. ISO 21930 Section 7.2.1 Note 2 states the following regarding demonstrating forest sustainability: “Other evidence such as national reporting under the United Nations Framework Convention on Climate Change (UNFCCC) can be used to identify forests with stable or increasing forest carbon stocks.” Canada’s UNFCCC annual report table 6-1 provides annual net greenhouse gas flux estimates for different land use categories. This reporting indicates nondecreasing forest carbon stocks and thus the source forests meet the conditions for characterization of removals with a factor of –1 kg CO_2eq/kg CO_2.

Table 13—Cradle-to-gate environmental performance of 1 m³ cellulosic fiberboard based on mass allocation for North America

	Abbreviations	Units	Total	A1	A2	A3
Core mandatory impact indicator						
Global warming potential – TRACI 2.1	GWP_{TRACI}	kg CO_2eq	196.13	5.34	6.75	184.04
Global warming potential – w/ biogenic CO_2	GWP_{BIO}	kg CO_2eq	196.13	–471.89	6.75	661.27
Depletion potential of the stratospheric ozone layer	ODP	kg CFC-11eq	7.13E–06	9.85E–08	1.19E–08	7.02E–06
Acidification potential of soil and water sources	AP	kg SO_2eq	0.63	0.05	0.04	0.54
Eutrophication potential	EP	kg Neq	0.29	0.01	0.00	0.27
Formation potential of tropospheric ozone	SFP	kg O_3eq	8.46	1.43	1.07	5.96
Abiotic depletion potential for fossil resources	ADP fossil	MJ, NCV[a]	2,581.24	67.85	84.50	2,428.89
Fossil fuel depletion	FFD	MJ surplus	375.67	9.58	12.69	353.40
Use of primary resources						
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	568.24	0.90	0.19	567.15
Renewable primary energy carrier used as material	RPRM	MJ, NCV	4,591.48	4,591.48	0.00	0.00
Nonrenewable primary energy carrier used as energy	NRPRE	MJ, NCV	3,282.45	73.64	85.74	3123.08
Nonrenewable primary energy carrier used as material	NRPRM	MJ, NCV	0.00	0.00	0.00	0.00
Mandatory inventory parameters						
Consumption of fresh water resources	FW	m^3	1.38E+00	1.10E–02	6.80E–04	1.37E+00
Indicators describing waste						
Hazardous waste disposed	HWD	kg	3.74E–02	6.66E–04	1.03E–04	3.66E–02
Nonhazardous waste disposed	NHWD	kg	93.11	0.49	0.66	91.96
Materials for recycling	MR	kg	0.08	0.00	0.00	0.08
High-level radioactive waste, conditioned, to final repository	HLRW	m^3	1.06E–07	5.31E–09	0.00E+00	1.01E–07
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	m^3	4.72E–06	7.66E–08	7.08E–09	4.64E–06

[a]NCV, net calorific value.

Consideration of the biogenic carbon neutrality of wood is valid for North American wood products because national level inventory reporting shows overall increasing and/or neutral forest carbon stocks in recent years (FAO 2015, 2020; Oswalt and others 2019; Sahoo and others 2019).

Using the previously described method, –437.62 kg CO_2eq (A1) were removed in the production of 1 m^3 of cellulosic fiberboard (Table 19). That same 1 m^3 of cellulosic fiberboard stores 109.8 kg of carbon or +403 kg CO_2eq (C3/C4) (219.6 OD kg/m^3 × 0.5 = 109.8 OD kg C/m^3; 109.8 OD kg C/m^3 × 44/12 = 402.6 kg CO_2eq/m^3). The coproducts produced during fiberboard production account for an additional +35.1 kg CO_2eq (A3) for a total "emission" in wood products leaving the system boundary of +437.6 kg CO_2eq. In summary, total removals were –437.6 kg CO_2eq, which was equal to the total "emissions" from cradle-to-gate (A1-A3) (Table 19). Following ISO 21930 (ISO 2017), emission from packaging (BCEK) is reported in A5, and emission from the main product is reported in C3/C4 end-of-life modules. The system boundary for this LCA only includes modules A1-A3.

9 Discussion

The goal of this study was to perform a cradle-to-gate LCA and estimate the environmental impacts of manufacturing cellulosic fiberboard in North America using the data collected for the year 2019. This is an update of the previous study (Bergman 2015, Puettmann and others 2016), which used 2012 industry data. Table 20 shows the comparison between the previous study by Puettmann and others (2016) and this study.

Compared with the previous study (Bergman 2015, Puettmann and others 2016), this study showed a substantial decrease (except for EP) in the environmental impacts of manufacturing cellulosic fiberboard. Overall, a ~35% decrease in the total primary energy use in the production of cellulosic fiberboard (27% and 60% decrease in the use of nonrenewable and renewable energy, respectively) occurred

Table 14—Cradle-to-gate life-cycle inventory analysis contribution analysis for three life-cycle stages of North American cellulosic fiberboard production, mass allocation (A1 resource extraction, A2 transportation, and A3 manufacturing of cellulosic fiberboard)

			Contribution (%)			
	Abbreviations	Units	Total	A1	A2	A3
Core mandatory impact indicator						
Global warming potential – TRACI 2.1	GWP_{TRACI}	kg CO_2eq	100	2.72	3.44	93.84
Depletion potential of the stratospheric ozone layer	ODP	kg CFC-11eq	100	1.38	0.17	98.45
Acidification potential of soil and water sources	AP	kg SO_2eq	100	7.94	6.35	85.71
Eutrophication potential	EP	kg Neq	100	3.57	0.00	96.43
Formation potential of tropospheric ozone	SFP	kg O_3eq	100	16.90	12.65	70.45
Abiotic depletion potential for fossil resources	ADP fossil	MJ, NCV[a]	100	2.63	3.27	94.10
Fossil fuel depletion	FFD	MJ surplus	100	2.55	3.38	94.07
Use of primary resources						
Renewable primary energy carrier used as energy	RPRE	MJ, NCV	100	0.16	0.03	99.81
Renewable primary energy carrier used as material	RPRM	MJ, NCV	100	100.00	0.00	0.00
Nonrenewable primary energy carrier used as energy	NRPRE	MJ, NCV	100	2.24	2.61	95.14
Nonrenewable primary energy carrier used as material	NRPRM	MJ, NCV	—	—	—	—
Mandatory inventory parameters						
Consumption of fresh water resources	FW	m^3	100	0.80	0.05	99.15
Indicators describing waste						
Hazardous waste disposed	HWD	kg	100	1.78	0.28	97.94
Nonhazardous waste disposed	NHWD	kg	100	0.53	0.71	98.76
Materials for recycling	MR	kg	100	0.00	0.00	100.00
High-level radioactive waste, conditioned, to final repository	HLRW	m^3	100	4.99	0.00	95.01
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	m^3	100	1.62	0.15	98.23

[a]NCV, net calorific value.

in this study (4,100.25 MJ/m^3) compared with the previous cradle-to-gate study (6,273.84 MJ/m^3) by Puettmann and others (2016). The previous study used higher heating values (HHVs) of fuels, whereas this study used lower heating values (LHVs) to estimate total primary energy use in the production of cellulosic fiberboard. Moreover, the mass allocation between the product and coproduct (92% this study and 96% previous study), product density (240 kg/m^3 this study and 254 kg/m^3 previous study), and estimation of water use methods are different between this study and the previous. Considering the differences in the calculation methods, a modest difference was expected in

Table 15—Cradle-to-gate energy use contribution analysis of life-cycle phases of North American cellulosic fiberboard, mass allocation (A1 resource extraction, A2 transportation, and A3 manufacturing of cellulosic fiberboard)

		Contribution (%)			
	Unit	Total	A1	A2	A3
Nonrenewable, fossil	MJ	67.05	91.04	98.34	65.84
Nonrenewable, nuclear	MJ	18.19	7.75	1.44	18.79
Nonrenewable, biomass	MJ	0.00	0.00	0.00	0.00
Renewable, biomass	MJ	8.48	0.72	0.05	8.84
Renewable, wind, solar, geothermal	MJ	0.26	0.11	0.05	0.26
Renewable, water	MJ	6.02	0.38	0.13	6.27
Total		100.00	100.00	100.00	100.00

Table 16—Cradle-to-gate energy use contribution analysis of sources of energy in each life-cycle phase of North American cellulosic fiberboard, mass allocation (A1 resource extraction, A2 transportation, and A3 manufacturing of cellulosic fiberboard)

		Contribution (%)			
	Unit	Total	A1	A2	A3
Nonrenewable, fossil	MJ	100.00	2.63	3.27	94.10
Nonrenewable, nuclear	MJ	100.00	0.82	0.18	99.00
Nonrenewable, biomass	MJ	100.00	0.28	0.00	99.71
Renewable, biomass	MJ	100.00	0.16	0.01	99.82
Renewable, wind, solar, geothermal	MJ	100.00	0.86	0.44	98.70
Renewable, water	MJ	100.00	0.12	0.05	99.83

Table 17—Uncertainty analysis of selected inventory results

Inventory parameter	Units	Sample mean	Weighted coefficient of variation (%)	Sample minimum	Sample maximum
Electricity - A3 input	kWh	186.46	10.12	167.04	195.62
Diesel - A3 input	L	0.28	10.84	0.25	0.29
Gasoline - A3 input	L	0.02	97.13	0.00	0.03
Natural gas - A3 input	m^3	39.27	10.47	37.28	43.51
Starch - A3 input	kg	13.24	18.17	10.77	14.41
Transport distance (wood feedstock) - A2 input	t-km	55.94	69.76	36.02	80.50

Table 18—Sensitivity analysis

			Difference in results (%)											
			Log transport distance		Electricity		Diesel		Gasoline		Natural gas		Starch	
Impact indicator[a]	Unit	Baseline results	–20%	+20%	–20%	+20%	–20%	+20%	–20%	+20%	–20%	+20%	–20%	+20%
ODP	kg CFC-11eq	7.13E–06	0.0	0.0	–11.1	11.1	0.0	0.0	–0.2	0.2	–0.1	0.1	–2.8	2.8
GWP	kg CO_2eq	196.11	–0.7	0.7	–7.6	7.6	–0.1	0.1	0.0	0.0	–9.4	9.4	–1.0	1.0
SFP	kg O_3eq	8.46E+00	–2.5	2.5	–5.8	5.8	–0.8	0.8	–0.1	0.1	–4.3	4.3	–1.4	1.4
AP	kg SO_2eq	0.63	–1.2	1.2	–8.0	8.0	–0.3	0.3	–0.1	0.1	–2.3	2.3	–4.1	4.1
EP	kg Neq	0.29	–0.2	0.2	–10.2	10.2	–0.1	0.1	0.0	0.0	–0.6	0.6	–6.4	6.4
FFD	MJ surplus	375.57	–0.7	0.7	–5.8	5.8	–0.1	0.1	–0.1	0.1	–11.3	11.3	–0.7	0.7
ADP fossil	MJ, NCV[b]	2,580.60	–0.7	0.7	–7.0	7.0	–0.1	0.1	–0.1	0.1	–9.9	9.9	–0.8	0.8
RPRE	MJ, NCV	568.24	0.0	0.0	–11.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	–9.0	9.0
NRPRE	MJ, NCV	3,532.02	–0.5	0.5	–9.4	9.4	–0.1	0.1	–0.1	0.1	–8.0	8.0	–0.7	0.7

[a]ODP, ozone depletion; GWP, global warming potential; SFP, smog formation potential; AP, acidification potential; EP, eutrophication potential; FFD, fossil fuel depletion; ADP fossil, abiotic depletion potential for fossil resources; RPRE, renewable primary energy resources; NRPRE, nonrenewable primary energy resources.

[b]NCV, net calorific value.

Table 19—Biogenic carbon inventory parameters

Additional inventory parameters	Unit	Total	A1	A2	A3	A5	C3/C4
Biogenic carbon removal from product (BCRP)	kg CO_2	–437.62	–437.62	—	—	—	—
Biogenic carbon emission from products (including residues) (BCEP)	kg CO_2	437.62	—	—	35.06	—	402.56
Biogenic carbon removal from packaging (BCRK)	kg CO_2	–4.66	—	—	–4.66	—	—
Biogenic carbon emission from packaging (BCEK)	kg CO_2	0.76	—	—	—	0.76	—

Table 20—Life-cycle inventory analysis comparison between previous (Puettmann and others 2016) [based on 2012 industry surveys] and current (based on 2019 industry surveys) studies on cellulosic fiberboard production in North America

Impact category	Unit	Current study	Past study	Percentage change
Ozone depletion potential	kg CFC-11eq	7.02E–06	0.00E+00	—
Global warming potential, fossil	kg CO_2eq	184.02	295.49	–38
Eutrophication potential	kg Neq	2.70E–01	8.00E–02	237
Smog potential	kg O_3eq	5.96	21.44	–72
Nonrenewable fossil and nuclear	MJ	3,282.45[a] (3,532.02[b])	4,844.15[b]	–27[b]
Renewables (solar, wind, hydro, geothermal, and biomass)	MJ	568.24	1,429.67	–60
Fresh water	m^3	1.37	3.71	–63

[a]Considered lower heating value (LHV) of fuels.

[b]Considered higher heating value (HHV) of fuels.

the results between this study and the previous study. The reduced impact values for cellulosic fiberboard manufacturing can be attributed to the efficient process, better technology and productivity, and a decrease in the environmental impacts of the inputs, including fuel, electricity, and heat. For example, in a previous study (Bergman 2015), about 10% of total heat came from coal, which has great environmental impact.

10 Conclusions

This LCA considered three life-cycle phases: (1) resource extraction including forest management and harvesting, wood residues production, and construction waste production, (2) transportation of all inputs, and (3) manufacturing cellulosic fiberboard. This study includes the LCI of forest resources that rely on secondary and tertiary data. The LCI of manufacturing relied on primary survey data and secondary data for process inputs such as natural gas, diesel, and electricity. The survey results were representative of operations in North America that produce cellulosic fiberboard. The survey data in this study represented 60.2% of total production, 0.59 million m^3, of cellulosic fiberboard in North America for the year 2019.

The environmental impacts from the resource extraction (A1) and its transportation (A2) were very small compared with manufacturing (A3) of cellulosic fiberboard production. Emissions to land and water were small and negligible. Fiber production and drying were the two operations that used the most electricity and heat energy, respectively. More than 95% of primary energy was used in the manufacturing of cellulosic fiberboard compared with the rest of the life-cycle stages. Similarly, the majority of environmental impacts came from the manufacturing of cellulosic fiberboard. Except for EP, this study showed a substantial decrease in environmental impacts compared with the previous study (Puettmann and others 2016).

The amount of carbon stored in cellulosic fiberboard was more than twice that of the total cradle-to-gate GW impact.

11 Critical Review

11.1 Internal Review

The purpose of the internal review of the LCA is to check for errors and conformance with the PCR before submittal to external review. The technical and editorial comments of the reviewers were carefully considered and, in most instances, incorporated into the final document. The USDA Forest Service, Forest Products Laboratory (FPL), addressed the internal review comments, as appropriate, and maintains a record of all comments and responses for future reference.

The internal review of this document was performed by Dr. Maureen Puettmann, Director of Operations at the Consortium for Research on Renewable Industrial Materials (CORRIM).

11.2 External Review

The external review process is intended to ensure consistency between the completed LCA and the principals and requirements of the International Standards on LCA (ISO 2006b) and the product category rules for North American structural and architectural wood products (ULE 2018, 2019). Following FPL's internal review evaluation, documents were submitted to UL Environment for independent external review. The UL Environment independent external review was conducted by Thomas Gloria, Industrial Ecology Consultants.

12 Units and Conversions

Conversion factors for the units used in the LCA in this report are given in Table 21.

Table 21—Conversion factors for the units used in developing the cellulosic fiberboard life-cycle analysis

To convert from	to	multiply by
Cubic feet (ft^3)	Cubic meters (m^3)	0.02831685
Pounds (avdp) (lb)	Kilograms (kg)	0.4535924
Cubic inches (in^3)	Cubic centimeters (cm^3)	16.393
Btus	Joules (J)	1,054
Cubic yards (yd^3)	Cubic meters (m^3)	0.7645549
Feet (ft)	Meters (m)	0.305
Gallons (U.S.) (gal)	Liters (L)	3.785
Kilowatt-hours (kWh)	Megajoules (MJ)	3.6
Miles (mi)	Kilometers (km)	1.609
Ounces (avdp) (oz)	Kilograms (kg)	0.028
Square feet (ft^2)	Square meters (m^2)	0.093
Tons (short)	Kilograms (kg)	907.185
Tons (short)	Metric tons (t)	0.9071847
Pounds (lb)	Metric tons (t)	0.0004
Watts (W)	Joules/second (J/s)	1
Yards (yd)	Meters (m)	0.914
Acres (a)	Hectares (ha)	0.405

13 Literature Cited

Abergel, T.; Dean, B.; Dulac, J. 2017. Towards a zero-emission, efficient, and resilient buildings and construction sector: Global Status Report 2017. Paris, France: UN Environment, International Energy Agency.

ASTM. 2017. ASTM C208. Standard specification for cellulosic fiber insulating board. West Conshohocken, PA: American Society for Testing and Materials. 5 p.

Bare, J. 2011. TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Technologies and Environmental Policy. 13(5): 687-696.

Bergman, R.D. 2015. Cradle-to-gate life-cycle inventory of cellulosic fiberboard produced in North America. CORRIM final report. Seattle, WA: University of Washington. 57 pp.

Bergman, R.; Taylor, A. 2011. EPD-environmental product declarations for wood products—an application of life cycle information about forest products. Forest Products Journal. 61(3): 192-201.

Brashaw, B.; Bergman, R. 2021. Chapter 1: Wood as a renewable and sustainable resource. In: Wood handbook: wood as an engineering material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Bringezu, S.; Ramaswami, A.; Schandl, H.; et al. 2017. Assessing global resource use: A systems approach to resource efficiency and pollution reduction. International Resource Panel. Nairobi, Kenya: United Nations Environment Programme.

FAO. 2015. Global forest resources assessment 2015. Rome: United Nations, Food and Agricultural Organization.

FAO. 2020. Global forest resources assessment 2020 – key findings. Rome: United Nations, Food Agriculture Organization.

Frischknecht, R.; Jungbluth, N.; Althaus, H.-J.; et al. 2007. Implementation of life cycle impact assessment methods. Data v2. 0 (2007). ecoinvent report No. 3. Dübendorf, Switzerland: Swiss Centre for Life Cycle Inventories. 151 p.

Howard, J.L.; Liang, S. 2019. U.S. timber production, trade, consumption, and price statistics, 1965-2017. Res. Pap. FPL-RP-701. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 96 p.

ISO. 2006a. ISO 14025. Environmental labels and declarations-type iii environmental declarations-principles and procedures. Geneva, Switzerland: International Organization for Standardization. 32 p.

ISO. 2006b. ISO 14040. Environmental management: life cycle assessment; principles and framework. Geneva, Switzerland: International Organization for Standardization. 28 p.

ISO. 2006c. ISO 14044. Environmental management: life cycle assessments: requirements and guidelines. Geneva, Switzerland: International Standardization Organization. 54 p.

ISO. 2017. ISO 21930. Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services. Geneva, Switzerland: International Standardization Organization. 90 p.

Johnson, L.R.; Lippke, B.; Marshall, J.D.; et al. 2005. Life-cycle impacts of forest resource activities in the Pacific Northwest and Southeast United States. Wood and Fiber Science. 37: 30-46.

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

LTS. 2019. DATASMART LCI package (US-EI SimaPro® Library). Huntington, VT: Long Trail Sustainability. https://ltsexperts.com/services/software/datasmart-life-cycle-inventory/.

Milota, M. 2015. Life cycle assessment for the production of southeastern softwood lumber, CORRIM report: Module C. Corvallis, OR: Consortium for Research on Renewable Industrial Materials. 72 p.

NAFA. 2021a. Products overview. Rolling Meadows, IL: North American Fiberboard Association http://fiberboard.org/index.php?page=products. (August 4, 2021).

NAFA. 2021b. North American Fiberboard Association. https://www.fiberboard.org. Rolling Meadows, IL: North American Fiberboard Association.

NIST ITL. 1996. Weighted standard deviation. Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology, Information Technology Laboratory. www.itl.nist.gov/div898/software/dataplot/refman2/ch2/weightsd.pdf.

Oswalt, S.N.; Smith, W.B.; Miles, P.D.; et al. 2019. Forest resources of the United States, 2017: A technical document supporting the Forest Service 2020 RPA Assessment. Washington, DC: U.S. Department of Agriculture, Forest Service.

PRé Consultants. 2020. SimaPro 9 life-cycle assessment software package, version 9.0. Amersfoort, the Netherlands: PRé Consultants.

Puettmann, M.; Bergman, R.; Oneil, E. 2016. Cradle to gate life cycle assessment of North American cellulosic fiberboard production. CORRIM final report. Seattle, WA: University of Washington. 66 p.

Sahoo, K.; Bergman, R.; Alanya-Rosenbaum, S.; et al. 2019. Life cycle assessment of forest-based products: a review. Sustainability (11): 4722.

Stark, N.M.; Cai, Z.; Carll, C. 2010. Chapter 11: 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-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

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

ULC. 2020. CAN-S706.1. Standard for insulating wood fibre boards for buildings. Toronto, Ontario, Canada: Underwriters Laboratories of Canada. 28 p.

ULE. 2018. Part A: life cycle assessment calculation rules and report requirements. Washington, DC: UL Environment. 47 p.

ULE. 2019. Guidance for building-related products and services: Part b: Structural and architectural wood products EPD requirements. Washington, DC: UL Environment. 31 p.

USCB. 2017. North American industry classification system: United States, 2017. Washington, DC: United States Census Bureau, Executive Office of the President, Office of Management and Budget. 961 p.

14 Appendix—Cellulosic Fiberboard Mill Survey [January 2022 Erratum: Appendix added]

Confidential

USDA FS Forest Products Laboratory/North American Fiberboard Association Survey

Cellulosic Fiberboard Plants
2020

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

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

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

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

Company: ______________________________

Facility Site (city, state): ______________________________

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

Name: ______________ Title: ______________

Telephone: ______________ Email: ______________

Please send the completed survey to the following email or address by February 15. In addition, if you have questions about the survey, contact Kamalakanta Sahoo at the listed phone/email. Email is preferred.

Kamalakanta Sahoo
Assistant Scientist,
Economics, Statistics, and Life Cycle Analysis Unit
USDA Forest Service Forest Products Laboratory
One Gifford Pinchot Dr,
Madison, WI 53726-2398
(608) 231-9272 (ph)/(608) 231-9508 (fax)
Email: kamalakanta.sahoo@usda.gov

Confidential

General Plant Information

Reporting Year: ________ Starting Month: ________ Ending Month: ________

Yes	No	Equipment in mill	Yes	No	Equipment in mill
		Feedstock conditioning	O	O	**Boiler**
O	O	steam digester	O	O	wood-fired boiler(s) #____
O	O	steaming screw			#1 size _______mmbtu/hr
O	O	**Refiner(s) #______**			#2 size _______mmbtu/hr
O	O	atmospheric	O	O	gas-fired boiler
O	O	pressurized			size __________mmbtu/hr
O	O	**Washer(s) #______**	O	O	oil-fired boiler
O	O	**Stock chest(s) #________**			size __________mmbtu/hr
		additives			**Finishing**
O	O	starch	O	O	trimmer(s) #______
O	O	alum	O	O	asphalt coater
O	O	wax	O	O	painted (white coat)
O	O	**Forming machine(s) #______**	O	O	rolled
		width: 4’, 8’, 12’ (circle one)	O	O	flooded on and rolled off
O	O	**Fiberboard board dryer**	O	O	top side coating only
O	O	direct-fired			**Packaging**
O	O	indirect-fired	O	O	plastic wrapping (bags)
O	O	conventional steam	O	O	metal strapping
O	O	high-pressure steam	O	O	plastic strapping
O	O	oil			
O	O	natural gas			
O	O	propane			

Cellulosic Fiberboard Plant Annual Production Data

Cellulosic Fiberboard Annual Production			
(Please provide units of measurement if different than stated)			Total Production
	Annual Cellulosic Fiberboard production, 2019	ft^3	
	Annual Cellulosic Fiberboard production, 2019	ft^2 @ ½" basis	
	Annual Cellulosic Fiberboard production, 2019	tons	

Cellulosic Fiberboard Plant Annual feedstock input Data

Feedstock sources

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				
Total feedstock sources			100%	

Confidential

Cellulosic Fiberboard Plant Feedstock <u>Annual</u> Transportation Data

SEE LIST ON PREVIOUS PAGE **Transportation method(s) and average delivery distance for feedstock #1: type?_________________**				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for feedstock #2: type?_________________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for feedstock #3: type?_________________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for other feedstocks: type?_________________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		
Transportation method(s) and average delivery distance for other feedstocks: type?_________________				
	Truck (% of total)		Average delivery miles	
	Rail (% of total)		Average delivery miles	
	Other (% of total)		Average delivery miles	
	Total (%)	100%		

Confidential

Cellulosic Fiberboard Plant Annual Energy Consumption

If you have completed a 2019 Annual Fuel and Energy Survey for AF&PA, you may want to attach the survey and skip to the next section entitled "Other Annual Production." The first section refers to energy generation (non-transport fuel). (Please provide units of measurement if different)

Fuel	Unit	Quantity
Total electricity for fiberboard plant	kWh	
Purchased steam	lbs (°F)	
Wood Fuel *Self-generated*	Tons / (%MC)	/
Wood Fuel *Purchased*	Tons / (%MC)	/
Natural Gas	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 has a boiler, please provide the following. Otherwise, enter N/A as applicable.

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

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

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

Confidential

Other Cellulosic Fiberboard Plant Annual Use Data

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

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

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

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

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

Confidential

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

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

Fiberboard properties

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

____________________percent coated product

Confidential

Cellulosic Fiberboard Plant Annual Wood Residue Production

Wood residues are any wood material produced in conjunction with making cellulosic fiberboard and are called co-products in this survey. For each of the co-products produced at your plant, please indicate the weight (tons) of **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 landfilled (estimates are acceptable). If zero, enter a dash (-). Please state units if other than tons like cubic yards. The final column (Total Quantity) should equal the sum of the individual rows.

Estimate amount of wood residue produced ___________tons/Msf cellulosic fiberboard

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

Confidential

Cellulosic Fiberboard Plant Ancillary Material Inputs

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

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

Confidential

Cellulosic Fiberboard Plant Air Emissions

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

Air emission	Tracked		Amount (lb/yr)	How amount was found? Mark one[3]		Sampling method or source[1]	Air emission is emitted as a percent of unit processes listed below. Estimation is ok. If not able to estimate, please leave blank								
	Yes	No		M	E		Feedstock prep	Steam digester	Boiler	Refiner	Washer	Stock chest	Wet former	Board dryer	Finishing
Dust	O	O		O	O		%	%	%	%	%	%	%	%	%
Particulate, PM10	O	O		O	O		%	%	%	%	%	%	%	%	%
Particulate, M2.5	O	O		O	O		%	%	%	%	%	%	%	%	%
VOC	O	O		O	O		%	%	%	%	%	%	%	%	%
Sulfur dioxide	O	O		O	O		%	%	%	%	%	%	%	%	%
HAP: Total	O	O		O	O		%	%	%	%	%	%	%	%	%
Methanol	O	O		O	O		%	%	%	%	%	%	%	%	%
Formaldehyde	O	O		O	O		%	%	%	%	%	%	%	%	%
Acetaldehyde	O	O		O	O		%	%	%	%	%	%	%	%	%
Propionaldehyde	O	O		O	O		%	%	%	%	%	%	%	%	%
Acrolein	O	O		O	O		%	%	%	%	%	%	%	%	%
Phenol	O	O		O	O		%	%	%	%	%	%	%	%	%
Acetone	O	O		O	O		%	%	%	%	%	%	%	%	%
HAP: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
HAP: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
Organic[2]: ______	O	O		O	O		%	%	%	%	%	%	%	%	%
Inorganic[4]: _____	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: _________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: _________	O	O		O	O		%	%	%	%	%	%	%	%	%

1 Sampling methods might be Method 25A, Method 5, NCASI 105. Estimates might be based on AP42, Standard Air Contaminate Discharge Permit or other sources.

2 Non-HAP organics that are not included in VOC value.

3 Estimated (E) / Measured (M)

4 Inorganics such as chlorine, mercury sulfur.

Confidential

Cellulosic Fiberboard Plant Water Emissions

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

Water emission	Tracked		Amount[2] (lb/yr)	How amount was found? Mark one[3]		Sampling method or source[1]	Water emission is emitted as a percent of unit processes listed below. Estimation is ok. If not able to estimate, please leave blank.								
	Yes	No		M	E		Feedstock prep	Steam digester	Boiler	Refiner	Washer	Stock chest	Wet former	Board dryer	Finishing
Suspended solids	O	O		O	O		%	%	%	%	%	%	%	%	%
BOD	O	O		O	O		%	%	%	%	%	%	%	%	%
COD	O	O		O	O		%	%	%	%	%	%	%	%	%
Oil and grease	O	O		O	O		%	%	%	%	%	%	%	%	%
HAPs	O	O		O	O		%	%	%	%	%	%	%	%	%
Chemicals in boiler blowdown (if not included above)	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%
Other: ________	O	O		O	O		%	%	%	%	%	%	%	%	%

[1] Sampling method is the type of water test or how estimate was obtained.
[2] Report the mass of material, not the mass of material and water.
[3] Estimated (E) / Measured (M).

Cellulosic Fiberboard Plant Solid Waste

If annual solid waste summary is available, please provide as an alternative to the following table.
Check here if summary is attached ☐

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

[1] Estimated (E) / Measured (M)/ Permit value (PV): For example, from landfill fees, a permit, or measurement.
[2] Report the mass of material, for example, report wood separately from dirt and rocks.

Cellulosic Fiberboard Plant Annual Water Use

Recycling rate of water helps reduce the water footprint.

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

Was water measured or estimated? ________________

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

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

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

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

Cellulosic Fiberboard Plant Emission Control Device (ECD)

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

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