LIFE CYCLE ASSESSMENT (LCA) OF BIOEDGE® EDGEBANDING FOR BIOPLASTIC SOLUTIONS

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Client	BioPlastic Solutions
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1 INTRODUCTION

1.1 Opportunity

BioPlastic Solutions designs and manufactures eco-friendly edgebanding called BioEdge® edgebanding. BioEdge® is a competitively priced alternative to petro-chemical based plastics with a deep commitment to sustainability. BioEdge® is made with renewable materials — corn or sugar cane. In line with their commitment to quality and sustainability, it was important that BioPlastic Solutions conducts a Life Cycle Assessment (LCA) to evaluate the environmental impacts of their product through all stages of the life cycle. This project enabled BioPlastic Solutions to assess BioEdge® for environmental and human health impacts to identify areas of improvement and product solutions.

To understand the total impact of the product through life cycle stages, BioPlastic Solutions used a cradle-to-grave approach in conducting this LCA. By including all life cycle stages, more information becomes available for understanding how to reduce impacts on a broader scale.

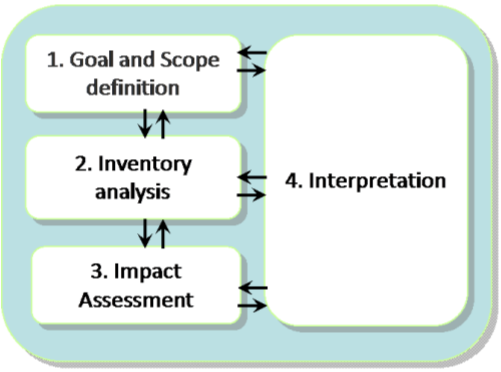
BioPlastic Solutions intends to use the results of the LCA to develop a Sustainable Minds Transparency Report™, a Type III Environmental Declaration that can be used for communication with and amongst other companies, architects and consumers and can be utilized in whole building LCA tools in conjunction with the LCA background report and Life Cycle Inventory (LCI).

BioPlastic Solutions commissioned Sustainable Minds, an external practitioner, to develop an LCA for their BioEdge® edgebanding.

1.2 Life Cycle Assessment

This LCA follows the BIFMA PCR for Office Furniture Workspace Products: UNCPC 3814 [1]. This report includes the following phases:

- Goal and Scope
- Inventory Analysis
- Impact Assessment
- Interpretation



An ISO 14040-44 third-party LCA review and an independent critical review are required for Type III Environmental Declarations. Both are included in this project.

1.3 Status

All information in this report reflects the inputs and outputs provided by BioPlastic Solutions. Sustainable Minds and BioPlastic Solutions followed best practices according to ISO 14044. BioEdge® is manufactured in Ellendale, MN. The inventory and impact assessment results reflect a functional unit of one square meter of floorspace for a period of 10 years. Since a square meter of floorspace can contain a range of product configurations, we present a few scenarios in the results to demonstrate some typical configurations.

This study includes primary data from the processes at the manufacturing facility, transportation distances for raw materials to the manufacturing facility, transportation distance to a representative building site, and estimates or assumptions for other upstream or downstream activities where necessary.

The LCA review and Sustainable Minds Transparency Report / EPD verification was performed by Harmony Environmental, LLC and was determined to be in conformance to ISO 14040/14044 and the BIFMA PCR. The critical review statement has been added to this LCA report.

1.4 Structure

This report follows the following structure:
Chapter 2: Goal and scope
Chapter 3: Inventory analysis
Chapter 4: Impact assessment
Chapter 5: Interpretation
Chapter 6: Sources

This report includes LCA terminology. To assist the reader, special attention has been given to list definitions of important terms used at the end of this report.

2 GOAL AND SCOPE

This chapter explains the goal and scope of the study. The aim of the goal and scope is to define the product under study and the depth and breadth of the analysis.

2.1 Intended Application and Audience

This report intends to describe the application of the LCA methodology to the life cycle of BioEdge® product manufactured by BioPlastic Solutions. It is intended for both internal and external purposes. The intended audience includes the program operator (Sustainable Minds) and reviewer who will be assessing the LCA for conformance to the PCR, as well as BioPlastic Solutions' internal stakeholders involved in marketing and communications, operations, and design. Results presented in this document are not intended to support comparative assertions. The results will be disclosed to the public in a Sustainable Minds Transparency Report / EPD (Type III environmental declaration per ISO 14025).

2.2 Product Description

BioEdge® edgebanding is a furniture product which seals exposed and raw edges. This study considers the installation of BioEdge® into three different reference products: table, kitchenette, and classroom cabinet. For the purpose of satisfying the PCR categories, the table is considered benching while kitchenette and classroom cabinet are considered panels in addition with other office components. The reference flows used in this LCA is to support 4 occupants for table and kitchenette, while classroom cabinet supports 6 occupants and the data reported is based on 1 m^2 of floorspace. Figure 2.2a, 2.2b, and 2.2c represents table, kitchenette, and classroom cabinet into which the edgebanding is installed. Only the edgebanding portion is considered for this LCA study.

Figure 2.2a Reference Product – Table

Figure 2.2a Reference Product – Kitchenette

Figure 2.2 Reference Product - Classroom cabinet

The BioEdge® manufacturing location is listed in Table 2.2a. The declaration name with product represented and type of declaration, and other product information are listed in Tables 2.2b and 2.2c, respectively.

Table 2.2a Product name and manufacturing location

Product name	Manufacturing location
BioEdge®	Ellendale, MN, USA

Table 2.2b Declaration names with products represented and type of declaration

Transparency Report	Product name	Type of declaration
BioEdge® Edgebanding	BioEdge®	Product specific

Table 2.2c Other product information

Transparency Report name	CSI MasterFormat® classification	Application
BioEdge® Edgebanding	**06 40 23** **06 41 16** **12 32 16** **12 35 53** **12 36 23** **12 51 16** **12 51 23** **12 56 33**	BioEdge® edgebanding is used to seal the exposed and raw edges of plywood and is ideal for tables, office workstations or cabinetry. It is a complete bio-replacement for petrochemical based edgebands, like PVC and ABS.

2.3 Functional Unit

The results in this report are expressed in terms of a functional unit, as it covers the entire life cycle of the product. Per the PCR [1], the functional unit is one square meter of workspace for a period of 10 years. 1 m^2 refers to the floorspace the office workspace product occupies.

BioEdge® is integrated into three categories of furniture: table, kitchenette, and classroom cabinet, each representing a declared product. BioEdge® can be applied as three different configurations: tabletop, cabinet drawer/door, and countertop edge.

A circular table with BioEdge® around the outer edges and on the legs is the most common table. Kitchenette and classroom cabinet configurations vary because each project is customized to meet customer needs. The amount of BioEdge® per square meter of floorspace varies based on the furniture design/configuration and size of BioEdge® used. A kitchenette can have countertop section with cabinet doors/drawers only below or both above and below the countertop. The number of cabinet doors/ drawers will also vary for each project. Classroom cabinets might only include BioEdge® in the countertop or it could be applied to cabinet doors/drawers as well. The manufacturer reached out to multiple clients in different categories and a range of data was collected as shown in Table 2.3a. The amount of BioEdge® in each individual project of kitchenette and classroom cabinet is collected and the range per m^2 is established by dividing the amounts by floorspace covered. High end and low end of floorspace are taken for the range.

Table 2.3a Range of BioEdge®

Declared Product	Physical Floorspace (m^2)	BioEdge® applied (lb per m^2)	Linear length (ft per m^2)
Table	0.785	0.425	10
Kitchenette	2.229 – 5.574	2.276 – 2.62	52.5 – 61.4
Classroom cabinet	4.645 – 6.968	1.75 – 2.075	41 – 49.2

For the purposes of modeling a baseline, reference flow (lb per m^2) is calculated by dividing the total lbs of BioEdge® for sample projects within each category (kitchenette and classroom cabinet) with total physical floorspace for each category, which comes out to be — 2.45 lbs per m^2 with an average length of 60 ft of edging for kitchenette and 1.90 lbs per m^2 with an average length of 44 ft per m^2 for classroom cabinet. This mass of the declared product that meets the functional unit of 1 m^2 floorspace is also indicated in Table 2.3b.

Table 2.3b Reference flows

Name	Value	Unit
Functional unit	1 square meter	
Table	0.425	lb
Kitchenette	2.450	lb
Classroom cabinet	1.900	lb

To facilitate understanding with reference to the furniture items, one functional unit represents:

- 1.274 tables, or
- 0.179 – 0.449 kitchenettes, or
- 0.144 – 0.215 classroom cabinets.

BioEdge® will remain in use for the life of the furniture — typically longer than 10 years. Most will not be disposed of until the furniture product is disposed. BioEdge® has been and can be a component of furniture that meets ANSI/BIFMA X5.5-2021 Desk/Table Products. An example is appended to the LCA report. Per technical data sheet, if all guidelines for installation and application of hot melt adhesives to the edging are followed correctly, BioEdge® will remain a permanent component to any casework, cabinetry, or furniture it is applied to[1]. Following above guidelines, the edging will remain on the unit permanently and warranty will be extended to the same timeframe as the end unit. For these reasons, BioEdge® is intended and assumed to have a reference life equal to the functional unit of 10 years [1].

2.4 System Boundaries

This section describes the system boundary for the product. The system boundary defines which life cycle stages are included and which are excluded.

This LCA's system boundary include the following life cycle stages:

I. **A1-A5**
  - Raw materials acquisition, transportation, and manufacturing
  - Distribution and installation

II. **B1-B7**
  - Use

III. **C1-C4**
  - Disposal/reuse/recycling

This boundary applies to the modeled product and can be referred to as 'cradle-to-grave', which means that it includes all life cycle stages and modules as identified in the PCR [1]. The life cycle includes all industrial processes from raw material acquisition and pre-processing, production, product distribution, use and maintenance, and end-of-life management. The system boundary for BioEdge® is detailed below. Figure 2.4 represents the life cycle stages for BioEdge®. Table 2.4 lists specific inclusions and exclusions for the system boundary.

Figure 2.4 Applied system boundary for the modeled BioEdge® [1]

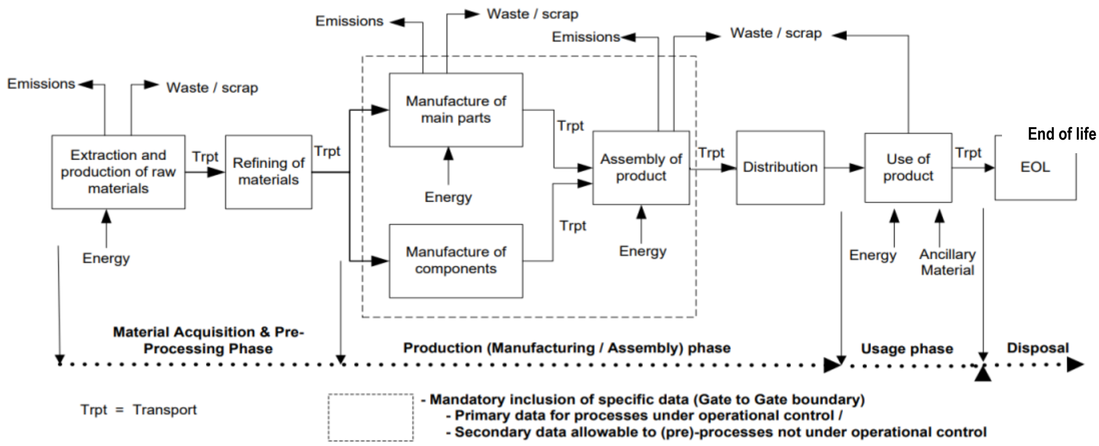


Table 2.4 System boundary inclusions and exclusions

Included	Excluded
• Raw material extraction	• Construction of major capital equipment
• Processing of raw materials	• Maintenance and operation of support equipment
• Energy production	• Human labor and employee transport

[1] BioEdge® Technical Datasheet https://bioplasticsolutions.com/wp-content/uploads/2022/02/Technical-Data-Sheet.pdf

● Transport of raw materials ● Outbound transportation of products ● Packaging of final products ● Installation ● End-of-life, including transportation ● Water usage during electricity generation	● Building operational energy and water use not associated with product manufacturing ● Overhead energy (e.g., heating, lighting) of manufacturing facility

2.4.1. A1-A3: Raw materials acquisition, transportation, and manufacturing

Raw materials acquisition and transportation (A1-A2) These stages start when the material is extracted from the nature and ends when the material in component form reaches the gate of the production facility or service delivery operation.

A2 stage includes the transportation of raw materials and their packaging (corrugated cardboard, wood pallets, plastics) from extraction/production to the manufacturing plant. All transportation, including interfacility transport, prior to the material being shipped to the production stage shall be included.

To incorporate waste and scrap created during raw material acquisition and pre-processing, where scrap data is unknown, a 10% scrap rate shall be used. When primary data or other secondary data are not available for the transportation of waste material to end-of-centers, an average transport end-of-life distance of 32 kilometers (20 miles) should be used, as provided by US EPA WARM model [2].

Manufacturing (A3) Manufacturing/Production stage starts when the product components enter the production site and ends with the final product leaving the production site.

This stage includes:

- Manufacturing of BioEdge®
- Upstream extraction, processing, and transport of packaging materials (for final product) to the manufacturing site.
- Any additional preparation of the final product, including forming, surface treatment, machining, and/or other processes, as appropriate,
- Manufacturing waste transport and treatment as applicable.

Waste and scrap created during manufacturing shall be included in the LCA model. A scrap rate of 21.8% was used for BioEdge® based on primary data.
Waste transport distance is 20 miles (32 kilometers), an average transport end of life value provided by USEPA WARM model [2].

2.4.2. A4-A5: Distribution and installation

Distribution (A4) Product distribution starts with the product leaving the gate of the production facility and ends when the customer takes possession of the product.

Installation (A5) Product installation occurs after the customer takes possession of the product and before the customer can start using the product.

This stage includes:

- Integration into furniture and any materials specifically required for installation
- Installation waste product and packaging
- Waste transport and treatment as applicable.

Like in A3, the waste transport distance is 20 miles (32 kilometers) [2].

2.4.3. B1-B7: Use

The use stage begins when the consumer starts using the product. This stage includes:
- Product use (B1)
- Maintenance (B2)
- Repair (B3)
- Replacement (B4)
- Refurbishment (B5)
- Operational energy use (B6)
- Operational water use (B7)

As mentioned in Section 2.3, BioEdge® is integrated into tables, kitchenette, and classroom cabinet. The configurations can be tabletop, cabinet drawer and/or countertop edges. In all these configurations, BioEdge® edgebanding is permanently adhered and under normal operating conditions BioEdge® requires no repair, replacement, or refurbishment for a period of 10 years. Periodic surface cleaning is required, and the cleaning agent used is hot water with soap. This periodic cleaning is included in stage B2.

2.4.4. C1-C4: Disposal/reuse/recycling

The end-of-life stage begins when the used product is ready for disposal, recycling, reuse, etc. and ends when the product is landfilled, returned to nature, or transformed to be recycled or reused. Processes that occur because of the disposal are also included within the end-of-life stage.

When the furniture product is done being used it often goes into the municipal waste stream or construction and demolition waste, which we assume is a ratio of 80% landfill and 20% incineration, as determined by the US EPA [2].

The following life cycle stages are used to describe the end-of-life processes.

Deconstruction (C1) This stage includes dismantling/demolition of the product. Since furniture is not attached to a building, there are no activities (or impacts) associated with this stage.

Transport (C2) This stage includes transport of the product or disassembled product components from building site to final disposition. The waste transport distance is 20 miles (32 kilometers), as prescribed by the PCR.

Waste processing (C3) This stage includes processing required before final disposition.

Disposal (C4) This stage includes final disposition (recycling or reuse). An end-of-life scenario of 80% landfilling and 20% incineration is considered [2].

2.4.5. D: Benefits and loads beyond the system boundary

This study does not account for benefits and loads beyond the system boundary.

3 INVENTORY ANALYSIS

This chapter includes an overview of the obtained data and data quality that has been used in this study. For the complete life cycle inventory, which catalogs the flows crossing the system boundary and provides the starting point for life cycle impact assessment, see the attached LCI spreadsheet [3].

3.1 Data Collection

Data used for this project represents a mix of primary data collected from BioPlastic Solutions and their polylactic acid (PLA) supplier, NatureWorks LLC. Gate to gate production data of BioEdge® was provided by BioPlastic Solutions, while the eco-profile data for PLA was obtained from an LCA study conducted by NatureWorks [4]. Other background data was obtained from databases available in SimaPro, primarily ecoinvent. Overall, the quality of the data used in this study is considered to be good and representative of the described systems. All appropriate means were employed to obtain the data quality and representativeness as described below.

- **PLA eco-profile**: PLA is a major constituent of BioEdge®. NatureWorks LLC, manufacturer and supplier of PLA, has publicly published the eco-profile for PLA production and this cradle-to-gate data was directly used to model PLA production [4]. Although the data is of 2009, NatureWorks confirmed that this eco-profile remains representative of their current operations and the PLA they supply to BioPlastic Solutions.

- **Gate-to-gate:** Data on processing materials and manufacturing the BioEdge® were collected in a consistent manner and level of detail to ensure high quality data. All submitted data were checked for quality multiple times on the plausibility of inputs and outputs. All questions regarding data were resolved with BioPlastic Solutions. Data was collected at the Ellendale, MN facility. Data was collected by the Vice President of the facility in a spreadsheet. Resulting inventory calculations were developed by an Analyst at Sustainable Minds and subsequently checked by a supporting consultant.

- **Background data:** The model was constructed in SimaPro with consistency in mind. Expert judgment was used in selecting appropriate datasets to model the materials and energy for this study and has been noted in the preceding sections. Detailed database documentation for ecoinvent can be accessed at: https://www.ecoinvent.org/database/database.html.

All primary data were provided by BioPlastic Solutions and from operations between October 2020 and September 2021. Upon receipt, data were cross-checked for completeness and plausibility using mass balance and benchmarking. If gaps, outliers, or other inconsistencies occurred, Sustainable Minds engaged with BioPlastic Solutions to resolve any questions.

3.2 Primary Data

BioEdge® is produced in several manufacturing steps that involve processing the PLA polymer. The steps that involve processing the PLA polymer into BioEdge® include extrusion, cooling, drying, and spooling.

BioEdge® is then packaged and distributed to the building sites where the product is installed with an edge banding machine and hot-melt adhesive. The product packaging is disposed (sent to landfill or recycled or incinerated). For this LCA, based on US EPA's WARM model, we assumed 15.4% of cardboard packaging is landfilled, 80.9% is recycled, and 3.7% is incinerated. In case of wood pallets, 26.9% is recycled, 58.8% is landfilled, and 14.3% is incinerated. At the end of life, the product is disposed using the assumptions stated in section 2.4.4. The flow chart in Figure 3.2 illustrates the life cycle of BioEdge®.

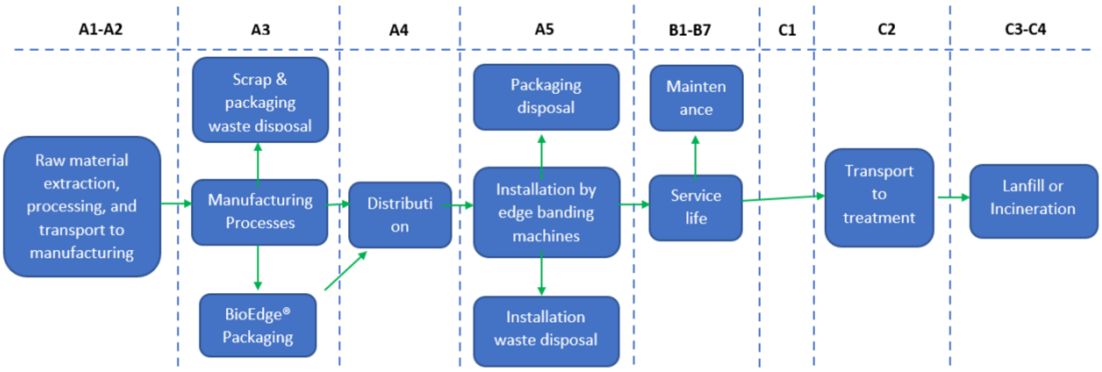


Figure 3.2. Life cycle flow chart of BioEdge®

For this LCA, we quantified the inventory inputs and outputs per pound of BioEdge® produced and then scaled the results to reflect the functional unit of one square meter in various configurations.

3.2.1. Raw materials extraction, processing, and transportation (A1-A2)

Raw materials extraction, processing, and transportation represent the first stage of the BioEdge® life cycle. BioEdge® uses PLA polymer as its main ingredient, which is manufactured by NatureWorks LLC and is shipped in cardboard gaylords on pallets to Ellendale for manufacturing into final product. Raw material inputs (and associated packaging) for the products are listed in Table 3.2.1. A scrap rate of 10% is used for all the incoming raw materials and associated packaging [1].

Raw materials are transported to Ellendale via truck & trailer. Transport data were collected for each flow and are also shown in Table 3.2.1.

Table 3.2.1 BioEdge® input materials and associated packaging for 1 lb of BioEdge®

Flow	Mass (lb)	Mass (%)	Transportation	Distance (mi)
PLA polymer	1.067	76.09%	Truck and trailer, 16-32T	214
Colorant	0.048	3.46%	Truck and trailer, 16-32T	787
Masterbatch	0.097	6.92%	Truck and trailer, 16-32T	93
Primer	0.046	3.25%	Truck and trailer, 16-32T	798
Acetone thinner	0.010	0.69%	Truck and trailer, 16-32T	798
Talc	0.073	5.19%	Truck and trailer, 16-32T	93
Corrugated cardboard	0.020	1.45%	Truck and trailer, 16-32T	214
Wood Pallet	0.038	2.70%	Truck and trailer, 16-32T	214
High Density Polyethylene	0.001	0.09%	Truck and trailer, 16-32T	787
Steel	0.002	0.16%	Truck and trailer, 16-32T	798

3.2.2. Manufacturing (A3)

The incoming raw materials are offloaded and stored before processing.

At the Ellendale facility, there are a total of five extrusion lines and only one smaller line produces BioEdge®. To accurately allocate electricity to the BioEdge® line, the total annual electricity consumption in the plant (obtained from utility bills) was allocated to different lines using equipment power ratings and run time logs for all the equipment, which was obtained from the facility's logging system. Using this approach, approximately 4.1% of the facility's electricity is used for BioEdge® production.

Raw materials are mixed and added to the hopper on the extruder. Raw materials are put into the industrial dryers usually the night before. In the morning, the extrusion screw is started, and the materials go through it. In the meantime, downstream equipment (texture wheel, cooling/drying fan, primer wheel, and puller) are started. Material comes out of the die and is then pulled down through the color wheel, up over the primer wheel, through the drying chamber and into the puller. Once size is dialed in, scrap is set aside, and primer is added. At the end of the line, spooling of the finished product is done. Spooled BioEdge® is stored as finished goods to be shipped to customers.

BioEdge® is manufactured in different sizes. It can be either thick (thickness of 2 mm or 3 mm) or can be thin (thickness of 0.5 mm or 1 mm). Regardless of the thickness, end-product application, and configuration, same amount of input raw materials, packaging materials, and manufacturing inputs go into the production of 1 pound of BioEdge®. Based on the sizes, packaging of the final product differs, but a weighted average is reported here using the production share.

Based on the primary data, BioEdge® scrap produced during manufacturing is reported at 21.8% on an annual basis, which is sent directly to landfill. Edgebanding production system produces three types of scrap:

- Production scrap from start up, shut down, and if a quality problem were to be discovered. This represents 8% of annualized scrap.
- Scrap from testing and implementation of process changes, improvements, and equipment problem resolutions (particularly around size trimming, size variation control, new cooling etc. and extruder machine electrical and mechanical issues). This represents 48% of annualized scrap.
- Scrap from new tool sizes, tooling flow, and texture improvements. This represents 44% of annualized scrap.

The processes for non-production time and equipment maintenance/improvements occur often as the product is growing and equipment & processes are constantly being upgraded/improved. BioPlastic Solutions is planning to grind and reuse this scrap which will significantly reduce waste and reduce impacts from batch materials.

Cardboard and wood pallets used for raw material packaging are recycled internally for shipment of various products made at the facility, while steel buckets are reused. For HDPE, we used the US EPA's WARM model to assume an end-of-life scenario of 13.63% recycling, 69.44% landfill, and 16.93% incineration [2]. All manufacturing inputs and outputs for the production of 1 pound of BioEdge® is provided in Table 3.2.2.

Table 3.2.2 Manufacturing inputs and outputs for 1 pound of BioEdge®

Category	Flow	Amount	Unit
Energy Input	Electricity	1.17753	kWh/lb
Water Input	Water	2.6005	gallons/lb
Packaging material Inputs	Wood pallet	0.0203	lb/lb (weighted average)
	Corrugated Cardboard	0.0378	lb/lb (weighted average)

Output packaging material	High Density Polyethylene	0.00113	lb/lb
Output scrap material	BioEdge® scrap	0.21827	lb/lb
Output material transport to recycling/waste processing	Truck, 7.5-16T	20*	miles
			*prescribed by the PCR

3.2.3. Distribution (A4)

Products are packaged in the manufacturing plant and shipped directly to distributors, installers, and end-users across the US. An average transportation distance of 815 miles was provided by BioPlastic Solutions based on sales data. Transportation distances vary based on destination. Based on its records, all products are shipped by a combination truck and trailer. This information is listed in Table 3.2.3.

Table 3.2.3 Average distribution distance for BioEdge®

Transport Mode	Value	Unit
Truck and trailer transport	815	miles

3.2.4. Installation (A5)

At the installation site, BioEdge® is installed using an edge banding machine and hot-melt adhesives.

Installation data was provided for 3 different configurations of BioEdge®: tabletop, cabinet drawer/door, and countertop edge. Average data has been reported in Table 3.2.4.

Corrugated cardboard packaging waste is assumed to have an end-of-life scenario of 80.9% recycling, 15.4% landfilling, and 3.7% incinerating, as suggested by US EPA's WARM model [2].

We assume 5% of the BioEdge® is milled off the edges while it goes through the edgebanding machine. The data was provided by the installers.

Table 3.2.4 provides the material outputs and associated transport for the installation.

Table 3.2.4 Installation inputs and outputs for 1 pound of BioEdge®

Category	Flow	Amount	Unit
Installation material inputs	Electricity	0.0625	kWh/lb
	Hot-melt adhesive	0.0432	lb/lb
Packaging material waste output	Corrugated cardboard	0.0378	lb/lb
	Wood Pallet	0.0203	lb/lb
Output scrap material	BioEdge®	0.05	lb/lb
Transport to waste processing	Truck and trailer, 7.5-16T	20*	miles
			*prescribed by the PCR

3.2.5. Use (B1-B7)

The product reference service life is assumed to be equal to the functional unit, which is 10 years. Under normal operating conditions, BioEdge® only requires periodic cleaning and the cleaning agent used is hot water with soap. Other than this maintenance, it requires no repair, replacement, or refurbishment during its service life. It also does not consume energy during its operation.

Cleaning data was provided again for three configurations of BioEdge®: tabletop, cabinet drawer/door, and countertop edge and an average data has been reported in the table below.

Table 3.2.4 Maintenance (B2) inputs for 1 pound of BioEdge® (for 10 years)

Category	Flow	Amount	Unit
Cleaning inputs	Soap	0.0273	liters
	Water	7.3845	liters

3.2.6. Deconstruction (C1)

Since furniture is not attached to a building, there is no deconstruction or demolition activity and therefore has no associated input or output flows.

3.2.7. Transport (C2)

After disposal, since BioEdge® cannot be disassembled into constituent materials, following the PCR guidance, an end-of-life scenarios of 80% landfill and 20% incineration is considered [1]. We also assumed that the transport for final waste disposal is 20 miles by truck and trailer as required by the PCR.

3.2.8. Waste processing (C3)

We assume that no waste processing is required before either the landfill or the incineration process.

3.2.9. Disposal (C4)

Per the PCR, BioEdge® is assumed to be 80% landfilled and 20% incinerated. Table 3.2.9 provides the breakdown by material and disposal method.

Table 3.2.9 Disposal assumptions for 1 pound of BioEdge®

Material	Mass (lb)	Disposal method share (%)	Mass per disposal method (lb)
BioEdge®	1 lb	80% landfilled	0.8 lb
		20% Incinerated	0.2 lb

3.3 Data selection and quality

Data requirements provide guidelines for data quality in the LCA and are important to ensure data quality is consistently tracked. Data quality considerations include precision, completeness, and representativeness.

Precision describes the variability of the inventory data. This study applies a combination of primary data, estimates and assumptions for manufacturing mass and energy inputs and transportation and associated modes. We apply secondary data for life cycle inventory values associated with embodied emissions of upstream material extraction and processing (except PLA, which is based on primary data). Since the mass of materials and energy consumption were directly measured by the BioPlastic Solutions team, we consider inventory data to have good precision.

Completeness is a measure of the flows (mass, energy, emissions) that are included in the study in relation to the total flows covered in the scope of the product life cycle. We developed a data collection workbook and worked extensively with the BioPlastic Solutions team to obtain a comprehensive set of data associated with the manufacturing processes. We considered the dataset complete based on our understanding of the manufacturing site and a review with key stakeholders on the BioPlastic Solutions team. Even though we observe cut-off criteria consistent with those prescribed in the PCR, no known flows are deliberately excluded from this analysis other than those defined to be outside the system boundary as stated in Table 2.4.

Representativeness describes the ability of the data to reflect the system in question. We measure representativeness with the time, technology, and geographic coverage of the data. An evaluation of the data quality with regard to these requirements is provided in the interpretation chapter of this report.

Time coverage. Time coverage describes the age of the inventory data, and the period of time over which data is collected. Annual non-energy primary data were collected on BioPlastic Solutions manufacturing facility during July 2020 through June 2021. Annual energy data was obtained from utility provider from October 2020 through September 2021 and was allocated effectively between the production lines. The production team is confident that allocated electricity consumption is representative of typical operations over a longer time period. Background data for upstream and downstream processes (i.e., raw materials, energy resources, transportation, and ancillary materials) were obtained from the ecoinvent database and U.S. Life Cycle Inventory (USLCI) database.

Technology coverage. Data were collected for BioPlastic Solutions production facility in the US.

Geographical coverage. BioPlastic Solutions' manufacturing facility is in Ellendale, MN. As such, the geographical coverage for this study is based on North American conditions. Whenever geographically relevant background data were not readily available, other geographies were used as proxies. Following production, BioEdge® is shipped for use within North America. Installation, use and end-of-life impact were modeled using background data that represents average conditions.

3.4 Background data

This section details background datasets used in modeling for BioEdge®. Each table lists dataset purpose, name, source, reference year, and location.

3.4.1. Fuels and energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from SimaPro. For manufacturing, the grid mix used is from the North American Regional Reliability Councils and Interconnections (NERC). For Ellendale, MN, the MRO electric grid is used. Table 3.4.1 shows the most relevant LCI datasets used in modeling the product systems. For installation stage, generic at grid electricity dataset for US is used. It is sourced from National Renewable Energy Laboratory (NREL).

Electricity datasets used include the water usage during electricity generation.

Table 3.4.1 Key energy datasets used in inventory analysis

Energy	Dataset name	Primary source	Reference year	Geography
Electricity - Manufacturing	Electricity, low voltage {MRO, US ONLY}	NERC	2014	US MRO
Electricity - Installation	Electricity, at grid, US NREL/US U	NREL	2018	US

3.4.2. Raw materials production

Data for the primary component, PLA, was obtained from the NatureWorks eco-profile. Data for other up- and down-stream raw materials were obtained from the ecoinvent database. Table 3.4.2 shows the LCI datasets used in modeling the raw materials.

Table 3.4.2 Material datasets used in inventory analysis

Raw material	Dataset name	Source	Year of publication	Geography
PLA Polymer	Eco-profile for PLA	NatureWorks LLC	2009	US
Acetone thinner	Acetone, liquid	US EI 2.2	2018	US
Talc (in masterbatch and colorant)	Limestone (Proxy)	US EI 2.2	2018	US
[redacted]	[redacted]	ecoinvent v3	2019	Rest of World (non-Europe)
[redacted]	[redacted]	ecoinvent v3	2019	Global
[redacted]	[redacted]	ecoinvent v3	2019	Global
Toluene (in primer)	Toulene	ecoinvent v3	2019	Rest of World (non-Europe)
Ethyl acetate (in primer)	Ethyl acetate	ecoinvent v3	2019	Global
HDPE packaging	Polyethylene, high density	ecoinvent v3	2019	Global
Wood pallet	Sawnwood, hardwood, raw, dried (u=10%)	ecoinvent v3	2019	Rest of World (non-Europe)
Cardboard	Corrugated board box	ecoinvent v3	2019	Rest of World (non-Europe)
Steel buckets	Steel, unalloyed	ecoinvent v3	2019	Global
Hot melt adhesive	Polyurethane adhesive	ecoinvent v3	2019	Global
Soap	Soap	ecoinvent v3	2019	Global

3.4.3. Transportation

The following data sets were used to represent typical transport modes for land and rail.

Table 3.4.3 Transportation datasets used in inventory analysis

Transportation	Dataset name	Source	Year of publication	Geography
Transport of raw material and packaging to manufacturing facility and of product to building site	Transport, freight, lorry, 16-32 metric ton, EURO6	ecoinvent v3	2019	Rest of World (non-Europe)
Transport of waste/scrap to end of life scenarios	Transport, freight, lorry 7.5-16 metric ton, EURO6	ecoinvent v3	2019	Rest of World (non-Europe)

3.4.4. Disposal

Disposal processes were obtained from the ecoinvent database. These processes were chosen to correspond to the materials being disposed. Table 3.4.4 presents the relevant disposal datasets used in the model.

Table 3.4.4 Disposal datasets used in inventory analysis

Material & Disposition	Dataset name	Source	Year of publication	Geography
Input raw materials landfill	Waste plastic, mixture | treatment of waste plastic, mixture, sanitary landfill	ecoinvent v3	2019	Rest of World (non-Europe)
Input raw materials incineration	Waste plastic, mixture | treatment of waste plastic, mixture, municipal incineration	ecoinvent v3	2019	Rest of World (non-Europe)
HDPE landfill	Waste polyethylene | treatment of waste polyethylene, sanitary landfill	ecoinvent v3	2019	Rest of World (non-Europe)
HDPE incineration	Waste polyethylene | treatment of waste polyethylene, municipal incineration	ecoinvent v3	2019	Rest of World (non-Europe)
Wastewater	Treatment, sewage, to wastewater treatment	US EI 2.2	2018	US
BioEdge scrap waste	Waste plastic, mixture | treatment of waste plastic, mixture, sanitary landfill	ecoinvent v3	2019	Rest of World (non-Europe)
Cardboard in landfill	Waste paperboard | treatment of sanitary landfill	ecoinvent v3	2019	Rest of World (non-Europe)
Cardboard to incineration	Waste paperboard | treatment of municipal incineration	ecoinvent v3	2019	Rest of World (non-Europe)

3.4.5. Emissions to air, water, and soil

BioPlastic Solutions reported no direct emissions to air, water, or soil.

3.5 Limitations

A life cycle assessment of a product system is broad and complex, and inherently requires assumptions and simplifications. The following limitations of the study should be recognized:

- PLA was modeled based on the raw material and manufacturing inputs contained in the eco-profile published in 2009. It was confirmed to be representative of the current PLA production.
- Primer was modeled based on the information contained in the safety data sheet provided by the supplier. Proxy materials were used when matching secondary data sets were not identified.
- Material input and transportation distances are averages and do not reflect changes in material efficiency and supplier locations.
- Generic data sets used for material inputs, transport, and waste processing are considered good quality, but actual impacts from material suppliers, transport carriers, and local waste processing may vary.
- The impact assessment methodology categories do not represent all possible environmental impact categories.
- Characterization factors used within the impact assessment methodology may contain varying levels of uncertainty.
- LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

3.6 Criteria for the exclusion of inputs and outputs

All energy and material flow data available were included in the model and comply with the PCR cut-off criteria. No known flows were excluded from the analysis.

- The cut-off criteria on a unit process level can be summarized as follows: All inputs and outputs to a (unit) process shall be included in the calculation of the pre-set parameters results, for which data are available. Data gaps shall be filled by conservative assumptions with average, generic or proxy data. Any assumptions for such choices shall be documented.

- Particular care should be taken to include material and energy flows that are known or suspected to release substances into the air, water or soil in quantities that contribute significantly to any of the pre-set indicators of this document. In cases of insufficient input data or data gaps for a unit process, the cut-off criteria shall be 1 % of renewable primary resource (energy), 1 % nonrenewable primary resource (energy) usage, 1 % of the total mass input of that unit process and 1 % of environmental impacts. The total of neglected input flows per module shall be a maximum of 5 % of energy usage, mass and environmental impacts. When assumptions are used in combination with plausibility considerations and expert judgment to demonstrate compliance with these criteria, the assumptions shall be conservative.

- All substances with hazardous and toxic properties that can be of concern for human health and/or the environment shall be identified and declared according to normative requirements in standards or regulation applicable in the market for which the EPD is valid, even though the given process unit is under the cut-off criterion of 1 % of the total mass.

In this report, no known flows are deliberately excluded; therefore, these criteria have been met.

3.7 Allocation

Whenever a system boundary is crossed, environmental inputs and outputs have to be assigned to the different products. Where multi-inputs or multi-outputs are considered, the same applies. The PCR prescribes where and how allocation occurs in the modeling of the LCA.

In this LCA, the only manufacturing input that needed allocation was electricity since there is only a single meter that includes production of multiple products including BioEdge®. The allocation of electricity is described in section 3.2.2. Other inputs and outputs are specific to BioEdge® and did not require allocation.

3.8 Software and database

The LCA model was created using SimaPro Analyst 9.2. The ecoinvent and other data sets listed in section 3.4 provide the life cycle inventory data of the raw materials and processes for modeling the products.

3.9 Critical review

This is a supporting LCA report for BioEdge® edgebanding Transparency Report and will be evaluated for conformance to the PCR according to ISO 14025 [5] and the ISO 14040/14044 standards [6].

4 IMPACT ASSESSMENT METHODS

4.1 Impact assessment

The environmental indicators as required by the PCR are included as well as other indicators required to derive the SM2013 single score [7] (see Table 4.1). The impact indicators are derived using the 100-year time horizon[2] factors, where relevant, as defined by TRACI 2.1 classification and characterization [8]. Long-term emissions (> 100 years) are not taken into consideration in the impact estimate. USEtox indicators are used to evaluate toxicity.

Table 4.1 Selected impact categories and units

Impact category	Unit
Acidification	kg SO2 eq (sulphur dioxide)
Ecotoxicity	CTUe
Eutrophication	kg N eq (nitrogen)
Global warming	kg CO2 eq (carbon dioxide)
Ozone depletion	kg CFC-11 eq
Carcinogenics	CTUh
Non-carcinogenics	CTUh
Respiratory effects	kg PM2.5 eq (fine particulates)
Smog	kg O3 eq (ozone)
Fossil fuel depletion	MJ surplus

With respect to global warming potential, biogenic carbon is included in impact category calculations and also reported separately.

It shall be noted that the above impact categories represent impact potentials. They are approximations of environmental impacts that could occur if the emitted substances would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures the environmental load that corresponds to the chosen functional unit.

The results from the impact assessment indicate potential environmental effects and do not predict actual impacts on category endpoints, the exceedance of thresholds, or safety margins or risks.

4.2 Normalization and weighting

To arrive to a single score indicator, normalization [9] and weighting [10] conforming to the SM 2013 Methodology were applied.

Table 4.2 Normalization and weighting factors

Impact category	Normalization	Weighting (%)
Acidification	90.9	3.6
Ecotoxicity	11000	8.4
Eutrophication	21.6	7.2
Global warming	24200	34.9

[2] The 100-year period relates to the period in which the environmental impacts are modeled. This is different from the time period of the functional unit. The two periods are related as follows: all environmental impacts that are created in the period of the functional unit are modeled through life cycle impact assessment using a 100-year time horizon to understand the impacts that take place.

Ozone depletion	0.161	2.4
Carcinogenics	5.07E-05	9.6
Non carcinogenics	1.05E-03	6.0
Respiratory effects	24.3	10.8
Smog	1390	4.8
Fossil fuel depletion	17300	12.1

5 ASSESSMENT AND INTERPRETATION

This chapter includes the results from the LCA for the products studied. It details the results per product per functional unit and concludes with recommendations. The results are presented per functional unit.

Results were first calculated for 1 lb of BioEdge®, which was later scaled to meet the functional unit for three scenarios: table, kitchenette, and classroom cabinet as indicated in Table 2.3b.

5.1 Resource use and waste flows

Resource use indicators, output flows and waste category indicators, and carbon emissions and removals are presented in this section. LCI flows were calculated with the help of the American Center for Life Cycle Assessment guidance to the ISO 21930:2017 metrics [11].

Resource use indicators represent the amount of materials consumed to produce not only the product itself, but the raw materials, electricity, etc. that go into the product's life cycle.

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process and is expressed in energy demand from renewable and non-renewable resources. Efficiencies in energy conversion are considered when calculating primary energy demand from process energy consumption. Water use represents total water used over the entire life cycle. No renewable energy was used in production beyond that accounted for in the MRO electricity grid mix, and no energy was recovered.

Tables 5.1a-c show resource use, output and waste flows, and carbon emissions and removals per functional unit for tables, kitchenette, and classroom cabinet.

Table 5.1a Resource use, output and waste flows, and carbon emissions and removals per functional unit for Tables [11].

		Material Acq. & transport	Manufacturing	Distribution		Use							End-of-life				
	Unit	A1-A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	Total
Resource use indicators																	
Renewable primary energy used as energy carrier (fuel) (RPRE)	MJ, LHV	7.46E+00	7.49E-01	6.68E-04	6.74E-01	0	3.39E-01	0	0	0	0	0	0	2.00E-05	0	9.00E-04	9.22E+00
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	4.10E+00	1.79E-01	0	2.14E-01	0	0	0	0	0	0	0	0	0	0	0	4.49E+00
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	1.16E+01	9.28E-01	6.68E-04	8.88E-01	0	3.39E-01	0	0	0	0	0	0	2.00E-05	0	9.00E-04	1.37E+01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	7.25E+00	4.02E+00	5.19E-01	1.81E+00	0	2.55E-01	0	0	0	0	0	0	1.55E-02	0	2.65E-02	1.39E+01
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	7.59E-01	0	0	3.79E-02	0	0	0	0	0	0	0	0	0	0	0	7.97E-01
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	8.01E+00	4.02E+00	5.19E-01	1.84E+00	0	2.55E-01	0	0	0	0	0	0	1.55E-02	0	2.65E-02	1.47E+01
Secondary materials (SM)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels (RSF)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels (NRSF)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources (FW)	m3	1.88E+00	3.82E-01	1.14E-02	4.83E-01	0	3.40E-01	0	0	0	0	0	0	3.42E-04	0	1.75E-02	3.11E+00
Output flows and waste category indicators																	
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	1.88E-02	4.22E-02	0	1.11E-02	0	0	0	0	0	0	0	0	0	0	1.54E-01	2.26E-01
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	6.64E-05	1.31E-04	1.97E-07	2.10E-05	0	6.19E-06	0	0	0	0	0	0	5.88E-09	0	3.64E-07	2.26E-04
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	2.73E-07	1.45E-07	7.73E-08	5.80E-08	0	1.33E-08	0	0	0	0	0	0	2.31E-09	0	2.00E-09	5.72E-07
Components for re-use (CRU)	kg	3.98E-04	0	0	1.99E-05	0	0	0	0	0	0	0	0	0	0	0	4.18E-04
Materials for recycling (MR)	kg	1.02E-02	2.95E-05	0	7.46E-03	0	0	0	0	0	0	0	0	0	0	0	1.77E-02
Materials for energy recovery (MER)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy (EE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals																	
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	3.77E-01	0	0	1.88E-02	0	0	0	0	0	0	0	0	0	0	0	3.96E-01
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	3.77E-02	5.45E-02	0	4.61E-03	0	0	0	0	0	0	0	0	1.26E-06	0	2.88E-01	3.85E-01
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	2.06E-02	2.05E-02	0	2.05E-03	0	0	0	0	0	0	0	0	0	0	0	4.31E-02
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	2.06E-02	0	0	2.16E-02	0	0	0	0	0	0	0	0	0	0	0	4.21E-02
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	7.54E-03	1.51E-02	0	1.42E-03	0	0	0	0	0	0	0	0	0	0	0	2.41E-02
Calcination Carbon Emissions (CCE)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals (CCR)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes (CWNR)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.1b Resource use, output and waste flows, and carbon emissions and removals per functional unit for Kitchenette [11].

		Material Acq. & transport	**Manufacturing**	**Distribution**		**Use**							**End-of-life**				
	Unit	**A1-A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**Total**
Resource use indicators																	
Renewable primary energy used as energy carrier (fuel) (RPRE)	MJ, LHV	4.30E+01	4.32E+00	3.85E-03	3.89E+00	0	1.95E+00	0	0	0	0	0	0	1.15E-04	0	5.19E-03	5.32E+01
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	2.36E+01	1.03E+00	0	1.23E+00	0	0	0	0	0	0	0	0	0	0	0	2.59E+01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	6.66E+01	5.35E+00	3.85E-03	5.12E+00	0	1.95E+00	0	0	0	0	0	0	1.15E-04	0	5.19E-03	7.91E+01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	4.18E+01	2.32E+01	2.99E+00	1.04E+01	0	1.47E+00	0	0	0	0	0	0	8.95E-02	0	1.53E-01	8.01E+01
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	4.37E+00	0	0	2.19E-01	0	0	0	0	0	0	0	0	0	0	0	4.59E+00
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	4.61E+01	2.32E+01	2.99E+00	1.06E+01	0	1.47E+00	0	0	0	0	0	0	8.95E-02	0	1.53E-01	8.47E+01
Secondary materials (SM)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels (RSF)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels (NRSF)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources (FW)	m3	1.08E+01	2.20E+00	6.59E-02	2.78E+00	0	1.96E+00	0	0	0	0	0	0	1.97E-03	0	1.01E-01	1.79E+01
Output flows and waste category indicators																	
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	1.08E-01	2.43E-01	0	6.40E-02	0	0	0	0	0	0	0	0	0	0	8.89E-01	1.30E+00
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	3.83E-04	7.57E-04	1.14E-06	1.21E-04	0	3.57E-05	0	0	0	0	0	0	3.39E-08	0	2.10E-06	1.30E-03
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	1.58E-06	8.37E-07	4.46E-07	3.35E-07	0	7.68E-08	0	0	0	0	0	0	1.33E-08	0	1.15E-08	3.30E-06
Components for re-use (CRU)	kg	2.29E-03	0	0	1.15E-04	0	0	0	0	0	0	0	0	0	0	0	2.41E-03
Materials for recycling (MR)	kg	5.88E-02	1.71E-04	0	4.30E-02	0	0	0	0	0	0	0	0	0	0	0	1.02E-01
Materials for energy recovery (MER)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy (EE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals																	
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	2.17E+00	0	0	1.09E-01	0	0	0	0	0	0	0	0	0	0	0	2.28E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	2.17E-01	3.14E-01	0	2.66E-02	0	0	0	0	0	0	0	0	7.24E-06	0	1.66E+00	2.22E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	1.19E-01	1.18E-01	0	1.18E-02	0	0	0	0	0	0	0	0	0	0	0	2.49E-01
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	1.19E-01	0	0	1.24E-01	0	0	0	0	0	0	0	0	0	0	0	2.43E-01
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	4.35E-02	8.73E-02	0	8.20E-03	0	0	0	0	0	0	0	0	0	0	0	1.39E-01
Calcination Carbon Emissions (CCE)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals (CCR)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes (CWNR)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5.1c Resource use, output and waste flows, and carbon emissions and removals per functional unit for Classroom Cabinet [11].

		Material Acq. & transport	Manufacturing	Distribution		Use							End-of-life				
	Unit	A1-A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	Total
Resource use indicators																	
Renewable primary energy used as energy carrier (fuel) (RPRE)	MJ, LHV	3.33E+01	3.35E+00	2.99E-03	3.02E+00	0	1.51E+00	0	0	0	0	0	0	8.92E-05	0	4.02E-03	4.12E+01
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	1.83E+01	8.00E-01	0	9.56E-01	0	0	0	0	0	0	0	0	0	0	0	2.01E+01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	5.17E+01	4.15E+00	2.99E-03	3.97E+00	0	1.51E+00	0	0	0	0	0	0	8.92E-05	0	4.02E-03	6.13E+01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	3.24E+01	1.80E+01	2.32E+00	8.08E+00	0	1.14E+00	0	0	0	0	0	0	6.94E-02	0	1.19E-01	6.21E+01
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	3.39E+00	0	0	1.70E-01	0	0	0	0	0	0	0	0	0	0	0	3.56E+00
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	3.58E+01	1.80E+01	2.32E+00	8.25E+00	0	1.14E+00	0	0	0	0	0	0	6.94E-02	0	1.19E-01	6.57E+01
Secondary materials (SM)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels (RSF)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels (NRSF)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources (FW)	m3	8.40E+00	1.71E+00	5.11E-02	2.16E+00	0	1.52E+00	0	0	0	0	0	0	1.53E-03	0	7.81E-02	1.39E+01
Output flows and waste category indicators																	
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	8.40E-02	1.89E-01	0	4.96E-02	0	0	0	0	0	0	0	0	0	0	6.89E-01	1.01E+00
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	2.97E-04	5.87E-04	8.80E-07	9.40E-05	0	2.77E-05	0	0	0	0	0	0	2.63E-08	0	1.63E-06	1.01E-03
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	1.22E-06	6.49E-07	3.46E-07	2.59E-07	0	5.96E-08	0	0	0	0	0	0	1.03E-08	0	8.95E-09	2.56E-06
Components for re-use (CRU)	kg	1.78E-03	0	0	8.89E-05	0	0	0	0	0	0	0	0	0	0	0	1.87E-03
Materials for recycling (MR)	kg	4.56E-02	1.33E-04	0	3.33E-02	0	0	0	0	0	0	0	0	0	0	0	7.91E-02
Materials for energy recovery (MER)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy (EE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals																	
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	1.69E+00	0	0	8.43E-02	0	0	0	0	0	0	0	0	0	0	0	1.77E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	1.69E-01	2.44E-01	0	2.06E-02	0	0	0	0	0	0	0	0	5.61E-06	0	1.29E+00	1.72E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	9.19E-02	9.18E-02	0	9.19E-03	0	0	0	0	0	0	0	0	0	0	0	1.93E-01
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	9.19E-02	0	0	9.64E-02	0	0	0	0	0	0	0	0	0	0	0	1.88E-01
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	3.37E-02	6.77E-02	0	6.36E-03	0	0	0	0	0	0	0	0	0	0	0	1.08E-01
Calcination Carbon Emissions (CCE)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals (CCR)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes (CWNR)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.2 Life cycle impact assessment (LCIA)

It shall be reiterated at this point that the reported impact categories represent impact potentials; they are approximations of environmental impacts that could occur if the emitted substances would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Life cycle impact assessment (LCIA) results are shown for BioPlastic Solutions' BioEdge®. Unlike life cycle inventories, which only report sums for individual inventory flows, the LCIA includes a classification of individual emissions with regard to the impacts they are associated with and subsequently a characterization of the emissions by a factor expressing their respective contribution to the impact category indicator. The end result is a single metric for quantifying each potential impact, such as 'global warming potential.'

The impact assessment results are calculated using characterization factors published by the United States Environmental Protection Agency. The TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.1) methodology is the most widely applied impact assessment method for U.S. LCA studies. USEtox indicators are used to evaluate human toxicity and ecotoxicity, results will be reported only as a contribution analysis. The SM 2013 Methodology is also applied to come up with single score results for the sole purpose of representing total impacts per life cycle phase to explain where in the product life cycle greatest impacts are occurring and what is contributing to the impacts.

For global warming potential (GWP), as prescribed by the PCR, IPCC 2013 V1.03 (Intergovernmental panel on climate change) methodology is used considering both the 100 year and 20-year reporting period.

The five impact categories (global warming potential, acidification potential, smog, eutrophication potential, ozone depletion) required by the PCR are globally deemed mature enough to be included in Type III environmental declarations. Other categories are being developed and defined and LCA should continue making advances in their development; however, the EPD users shall not use additional measures for comparative purposes. There are several impact categories included in the SM 2013 Methodology not required by the PCR, but it should be noted that there are known limitations related to these impact categories due to their high degree of uncertainty.

5.2.1. Impact Assessment Results

For a complete set of LCA results per pound of BioEdge® and for three scenarios representing a square meter of floorspace, please refer to the attached spreadsheet[12].

Tables 5.2.1a-c show the contributions of each stage of the life cycle for tables, kitchenette, and classroom cabinet respectively.

For BioEdge®, the upstream production stage (A1-A3) dominates the results for all the impact categories except non carcinogenics. The impacts of the raw material acquisition stage (A1) are mostly due to the PLA polymer, and electricity use is the largest contributor to the manufacturing stage (A3). Installation (A5) is also responsible for a significant share in the impacts, primarily because of the use of hot-melt adhesives. For eutrophication and ecotoxicity, maintenance (B2) also generates significant impacts because of the use of soap for cleaning purpose. In case of non-carcinogenics, the upstream production stage (A1-A3) has negative value, because of the use of biogenic PLA material.

Table 5.2.1a Potential impact results per functional unit for Table

Impact category	Unit	A1-A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	Total
Ozone depletion (ODP)	kg CFC-11 eq	6.50E-08	9.83E-09	8.78E-09	1.12E-08	0	3.31E-09	0	0	0	0	0	0	2.62E-10	0	3.42E-10	9.88E-08
Global warming 100a (GWP100a)	kg CO2 eq	5.52E-01	3.54E-01	3.67E-02	1.19E-01	0	5.88E-02	0	0	0	0	0	0	1.10E-03	0	1.06E-01	1.23E+00
Global warming 20a (GWP20a)	kg CO2 eq	8.95E-01	3.86E-01	3.75E-02	1.57E-01	0	6.85E-02	0	0	0	0	0	0	1.13E-03	0	1.27E-01	1.67E+00
Smog (SFP)	kg O3 eq	2.55E-02	1.14E-02	8.22E-04	5.78E-03	0	2.27E-03	0	0	0	0	0	0	2.40E-05	0	7.80E-04	4.66E-02
Acidification (AP)	kg SO2 eq	2.34E-03	1.26E-03	6.40E-05	4.85E-04	0	1.90E-04	0	0	0	0	0	0	1.90E-06	0	2.76E-05	4.36E-03
Eutrophication (EP)	kg N eq	2.79E-03	5.66E-04	1.34E-05	2.51E-04	0	1.99E-03	0	0	0	0	0	0	3.99E-07	0	2.54E-05	5.64E-03
Carcinogenics	CTUh	3.51E-09	2.80E-09	3.36E-11	1.44E-09	0	6.03E-10	0	0	0	0	0	0	9.30E-13	0	4.92E-10	8.87E-09
Non-carcinogenics	CTUh	-3.88E-08	3.78E-08	5.15E-09	5.16E-09	0	1.38E-09	0	0	0	0	0	0	1.28E-10	0	2.74E-09	1.36E-08
Respiratory effects	kg PM2.5 eq	3.05E-04	1.68E-03	1.29E-05	1.46E-04	0	4.48E-05	0	0	0	0	0	0	3.35E-07	0	1.99E-06	2.19E-03
Ecotoxicity	CTUe	1.05E+00	1.22E-01	1.04E-01	1.15E-01	0	2.19E-01	0	0	0	0	0	0	2.54E-03	0	1.25E-01	1.73E+00
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	1.11E+00	1.73E-01	7.78E-02	1.80E-01	0	1.89E-02	0	0	0	0	0	0	2.32E-03	0	3.40E-03	1.57E+00

Table 5.2.1b Potential impact results per functional unit for Kitchenette

Impact category	Unit	A1-A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	Total
Ozone depletion (ODP)	kg CFC-11 eq	3.75E-07	5.67E-08	5.06E-08	6.48E-08	0	1.91E-08	0	0	0	0	0	0	1.51E-09	0	1.97E-09	5.69E-07
Global warming 100a (GWP100a)	kg CO2 eq	3.18E+00	2.04E+00	2.12E-01	6.85E-01	0	3.39E-01	0	0	0	0	0	0	6.37E-03	0	6.13E-01	7.08E+00
Global warming 20a (GWP20a)	kg CO2 eq	5.16E+00	2.23E+00	2.16E-01	9.07E-01	0	3.95E-01	0	0	0	0	0	0	6.50E-03	0	7.33E-01	9.64E+00
Smog (SFP)	kg O3 eq	1.47E-01	6.58E-02	4.74E-03	3.33E-02	0	1.31E-02	0	0	0	0	0	0	1.38E-04	0	4.49E-03	2.69E-01
Acidification (AP)	kg SO2 eq	1.35E-02	7.24E-03	3.69E-04	2.80E-03	0	1.09E-03	0	0	0	0	0	0	1.10E-05	0	1.59E-04	2.52E-02
Eutrophication (EP)	kg N eq	1.61E-02	3.26E-03	7.72E-05	1.45E-03	0	1.15E-02	0	0	0	0	0	0	2.30E-06	0	1.46E-04	3.25E-02
Carcinogenics	CTUh	2.02E-08	1.61E-08	1.93E-10	8.31E-09	0	3.48E-09	0	0	0	0	0	0	5.36E-12	0	2.83E-09	5.11E-08
Non-carcinogenics	CTUh	-2.24E-07	2.18E-07	2.97E-08	2.98E-08	0	7.97E-09	0	0	0	0	0	0	7.38E-10	0	1.58E-08	7.82E-08
Respiratory effects	kg PM2.5 eq	1.76E-03	9.66E-03	7.43E-05	8.44E-04	0	2.58E-04	0	0	0	0	0	0	1.93E-06	0	1.15E-05	1.26E-02
Ecotoxicity	CTUe	6.03E+00	7.04E-01	6.01E-01	6.61E-01	0	1.26E+00	0	0	0	0	0	0	1.46E-02	0	7.22E-01	1.00E+01
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	6.41E+00	9.95E-01	4.49E-01	1.04E+00	0	1.09E-01	0	0	0	0	0	0	1.34E-02	0	1.96E-02	9.03E+00

Table 5.2.1c Potential impact results per functional unit for Classroom cabinet

Impact category	Unit	A1-A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	Total
Ozone depletion (ODP)	kg CFC-11 eq	2.91E-07	4.40E-08	3.93E-08	5.03E-08	0	1.48E-08	0	0	0	0	0	0	1.17E-09	0	1.53E-09	4.42E-07
Global warming 100a (GWP100a)	kg CO2 eq	2.47E+00	1.58E+00	1.64E-01	5.31E-01	0	2.63E-01	0	0	0	0	0	0	4.94E-03	0	4.75E-01	5.49E+00
Global warming 20a (GWP20a)	kg CO2 eq	4.00E+00	1.73E+00	1.68E-01	7.03E-01	0	3.06E-01	0	0	0	0	0	0	5.04E-03	0	5.68E-01	7.48E+00

Smog (SFP)	kg O3 eq	1.14E-01	5.10E-02	3.68E-03	2.58E-02	0	1.01E-02	0	0	0	0	0	0	1.07E-04	0	3.49E-03	2.08E-01
Acidification (AP)	kg SO2 eq	1.05E-02	5.62E-03	2.86E-04	2.17E-03	0	8.49E-04	0	0	0	0	0	0	8.49E-06	0	1.23E-04	1.95E-02
Eutrophication (EP)	kg N eq	1.25E-02	2.53E-03	5.98E-05	1.12E-03	0	8.91E-03	0	0	0	0	0	0	1.78E-06	0	1.13E-04	2.52E-02
Carcinogenics	CTUh	1.57E-08	1.25E-08	1.50E-10	6.45E-09	0	2.70E-09	0	0	0	0	0	0	4.16E-12	0	2.20E-09	3.97E-08
Non-carcinogenics	CTUh	-1.73E-07	1.69E-07	2.30E-08	2.31E-08	0	6.18E-09	0	0	0	0	0	0	5.72E-10	0	1.23E-08	6.06E-08
Respiratory effects	kg PM2.5 eq	1.36E-03	7.49E-03	5.76E-05	6.54E-04	0	2.00E-04	0	0	0	0	0	0	1.50E-06	0	8.88E-06	9.78E-03
Ecotoxicity	CTUe	4.68E+00	5.46E-01	4.66E-01	5.13E-01	0	9.80E+01	0	0	0	0	0	0	1.13E-02	0	5.60E-01	7.75E+00
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	4.97E+00	7.72E-01	3.48E-01	8.05E-01	0	8.43E-02	0	0	0	0	0	0	1.04E-02	0	1.52E-02	7.00E+00

Single score results

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 5.2.1d). The scores are consistent with the trends in the results using the impact assessment results before normalization and weighting. The raw material acquisition and transport (A1-A2) dominates the results (~44%) followed by manufacturing (A3) stage. Transportation to end of life (C2) has an insignificant contribution to the overall life cycle impacts.

Table 5.2.1d SM 2013 scores for table, kitchenette, and classroom cabinet by life cycle stage per functional unit [2]

Product	Impact category	Unit	Raw material acquisition & transport	Manufacturing	Distribution	Installation	Maintenance	Transportation to end of life	Disposal	Total
			A1-A2	A3	A4	A5	B2	C2	C4	
Table	SM single figure score	mPts	4.03E-02	2.49E-02	2.38E-03	8.71E-03	1.09E-02	6.51E-05	3.70E-03	9.09E-02
Kitchenette	SM single figure score	mPts	2.32E-01	1.43E-01	1.37E-02	5.02E-02	6.26E-02	3.75E-04	2.14E-02	5.24E-01
Classroom cabinet	SM single figure score	mPts	1.80E-01	1.11E-01	1.07E-02	3.89E-02	4.86E-02	2.91E-04	1.66E-02	4.06E-01

5.2.2. Contribution Analysis

As different amounts of BioEdge® are required to meet the functional unit of the scenarios — table, kitchenette, and classroom cabinet — total impacts per functional unit vary for each. However, the percentage contribution of individual life cycle stage on the final impacts is the same for all.

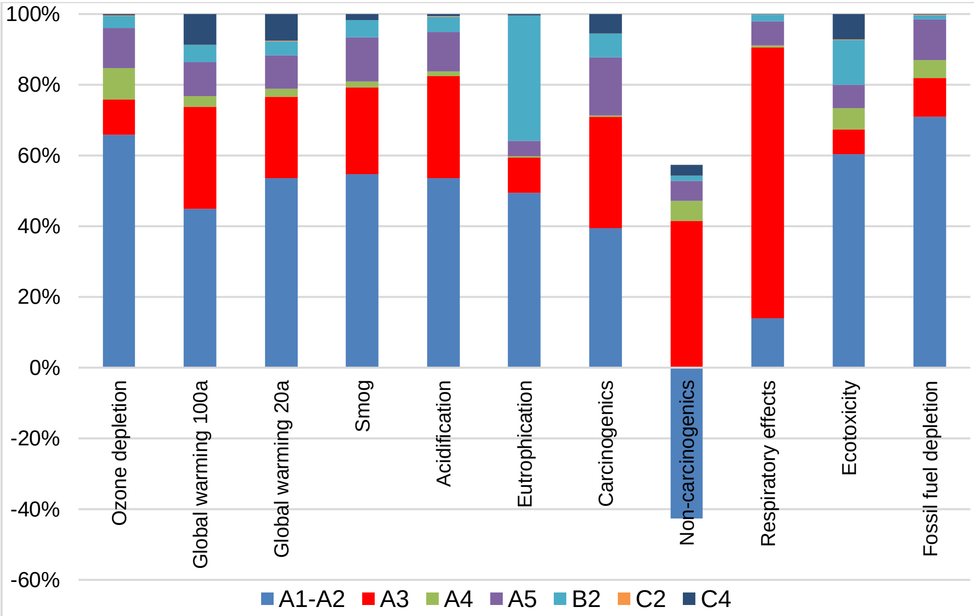
Table 5.2.2 and Figure 5.2.2 show the contributions of each stage of the life cycle.

Table 5.2.2 Percent contributions of each stage to each impact category

Impact category	A1-A2	A3	A4	A5	B2	C2	C4
Ozone depletion	66%	10%	9%	11%	4%	0%	0%
Global warming 100a	45%	29%	3%	10%	5%	0%	9%
Global warming 20a	53%	23%	2%	9%	5%	0%	8%
Smog	55%	24%	2%	12%	5%	0%	2%
Acidification	54%	29%	1%	11%	4%	0%	1%
Eutrophication	49%	10%	0%	4%	35%	0%	0%
Carcinogenics	40%	32%	0%	16%	7%	0%	6%

Non-carcinogenics	-300%	279%	38%	38%	10%	1%	20%
Respiratory effects	14%	77%	1%	7%	2%	0%	0%
Ecotoxicity	60%	7%	6%	7%	13%	0%	7%
Fossil fuel depletion	71%	11%	5%	11%	1%	0%	0%

Figure 5.2.2 Contribution of each life cycle stage to each impact category (100% stacked column)



Raw material acquisition and transport (A1-A2) stage is the highest contributor to all impact categories but non-carcinogenics and respiratory effects, followed by the manufacturing (A3), installation (A5), maintenance (B2), disposal (C4), and distribution stage (A4). A1-A2 stage contributes to ~50% of the total impacts in most of the impact categories except non-carcinogenics and respiratory effects. In case of non-carcinogenics impact, A1-A2 stage has negative contribution which means this stage absorbs more toxic chemicals from the environment than it releases. PLA polymer, a major ingredient for BioEdge®, is responsible for this negative value. Manufacturing (A3) stage contributes to much of the non-carcinogenics and respiratory effects.

Within A1-A2 stage, raw material acquisition stage (A1) is the main contributor, with less impacts coming from raw material transport (A2) stage. PLA polymer contributes to majority of the impacts in A1 stage. In case of manufacturing impacts, electricity used during production contributes to almost all the impacts.

A5 stage also contributes significantly to the overall life cycle impacts because of the use of hot-melt adhesives during installation. Together, stages A1-A2, A3, and A5, contribute more than 70% of overall impacts to all but eutrophication and non-carcinogenics. It is because maintenance (B2) also contributes significantly to those two impact categories. Use of soap is responsible for more than 95% of impacts within the B2 stage in all categories. Distribution (A4) contributes to about 38% of impacts in non-carcinogenics. The highest contribution of the disposal (C4) is approximately 20% to the non-carcinogenics category, followed by 9% to global warming. No contributions greater than 1% are made by waste transport (C2) stage.

5.3 Overview of relevant findings

This study assessed a multitude of inventory and environmental indicators. The primary finding, across the environmental indicators and for the products considered, was that raw material acquisition and transport (A1-A2) contribute the most impacts to most categories, which is mostly driven by the incoming PLA polymer. Impacts from manufacturing (A3) were also significant and electricity used during manufacturing shares the most impacts in this stage.

A1-A2 stage covers the large portion of overall impacts, which is followed by A3, A5, B2, C4, and A4 stages. Installation impacts are driven by hot-melt adhesives, while maintenance stage is driven by the soap.

At the end of life, the BioEdge® is landfilled or incinerated. Municipal treatment of the end waste makes up the impacts in disposal stage. Transportation to end of life sites had no significant impacts in this stage, because of the relatively short distances resulting in correspondingly small impacts to the overall life cycle result.

5.4 Discussion on data quality

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied on a study serving as a data source), and representativeness (geographical, temporal, and technological).

Precision and completeness

- Precision: As the relevant foreground data is primary data or modeled based on primary information sources of the owner of the technology, precision is considered to be high. Background data are from ecoinvent databases with documented precision to the extent available.
- Completeness: The product system was checked for mass balance and completeness of the inventory. Capital equipment was excluded as required by the PCR. Otherwise, no data were knowingly omitted.

Consistency and reproducibility

- Consistency: Primary data were collected with a similar level of detail, while background data were sourced primarily from the ecoinvent database, while other databases were used if data were not available in ecoinvent or the data set was judged to be more representative. Other methodological choices were made consistently throughout the model.
- Reproducibility: Reproducibility is warranted as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, a knowledgeable third party should be able to approximate the results of this study using the same data and modeling approaches.

Representativeness

- Temporal: Primary data were determined to be representative of typical operations. Secondary data were obtained from the ecoinvent databases and are typically representative of the recent years. Temporal representativeness is considered to be good.
- Geographical: Primary data are representative of BioPlastic Solutions's production and PLA production. When possible, secondary data were selected

to represent US conditions. However, in most cases data sets represent a global or sub-global average. Geographical representativeness is considered to be fair.

- Technological: All primary and secondary data were modeled to be specific to the technologies under study. Technological representativeness is considered to be good.

5.5 Completeness, sensitivity, and consistency

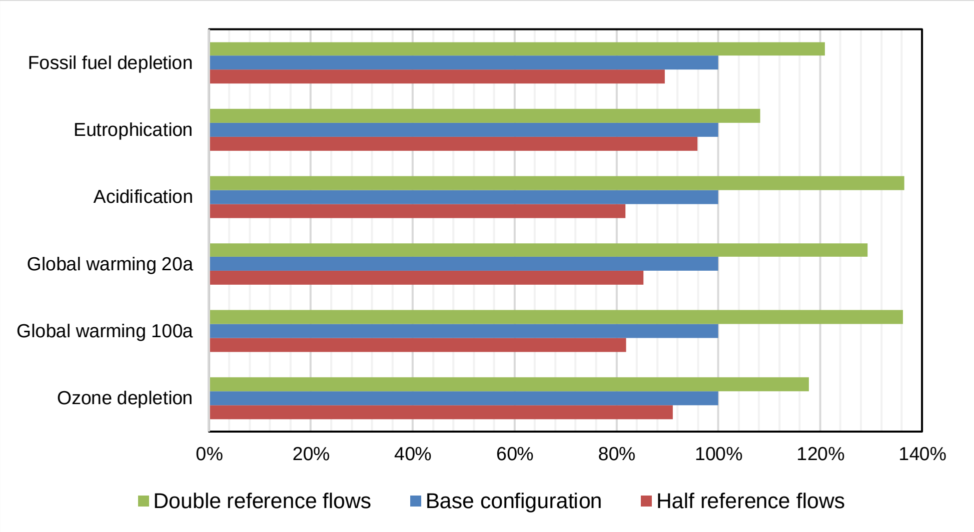
Completeness
All relevant process steps for the product system were considered and modeled. The process chain is considered sufficiently complete with regards to the goal and scope of this study.

Sensitivity
For this LCA study, only input that needed allocation was electricity used during manufacturing. Proxy data was used for [redacted]. A sensitivity analysis was performed using a range from half to twice the reference flows for manufacturing electricity input and raw material inputs for [redacted]. Table 5.5 provides the inputs used for three different scenarios and Figure 5.5 shows the variation of overall life cycle impacts for major impact categories, per PCR, in those scenarios.

Table 5.5 Electricity inputs for 1 pound of BioEdge® manufacturing

Scenario	Electricity (kWh)	[redacted]	[redacted]
Base configuration	1.177	[redacted]	[redacted]
Double reference flows	2.355	[redacted]	[redacted]
Half reference flows	0.588	[redacted]	[redacted]

Figure 5.5 Sensitivity analysis



Consistency
Assumption, methods, and data were found to be consistent with the study's goal and scope. Differences in background data quality were minimized by using LCI data from the ecoinvent and otherwise standard databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.6 Conclusions, limitations, and recommendations

The goal of this study was to conduct a cradle-to grave LCA on BioPlastic Solutions BioEdge® so as to develop an SM Transparency Report / EPD. The creation of these Transparency Reports will allow consumers in the building and construction industry to make better informed decisions about the environmental impacts associated with the products they choose. Overall, the study found that environmental performance is driven primarily by installation and cradle-to-gate activities. Installation of the product, raw materials and processing, and manufacturing drive environmental performance. Maintenance has lower but still significant impacts in some categories. The end-of-life stages account for minimal contribution to life cycle performance.

The major potential source of impact reduction is in A1-A3 stage. Within this stage, there are several opportunities. One of those is targeting the reduction of scrap waste. BioPlastic Solutions currently scraps approximately 21.8% during the manufacturing process and is sent directly to landfill. This issue should be periodically revisited to incorporate new technology considerations for further improvement; first to reduce the scrap rate, and second to reuse the scrap in the manufacturing. BioPlastic Solutions is already planning to make use of this scrap soon. If the product or process can be redesigned to provide the same functionality with less scrap, then BioPlastic Solutions can purchase less raw materials, including PLA polymer, thereby reducing environmental impacts and costs. BioPlastic Solutions can directly influence these areas so are great candidates for prioritizing reduction activity.

The next opportunity in A1-A3 stage could be reducing the amount of electricity consumed during manufacturing by using efficient machines and streamlining the manufacturing process.

Another opportunity for reduction of environmental impact is in the installation stage, though it is outside of BioPlastic Solutions gate. Installers should be encouraged to use more environment friendly adhesives. There is also an opportunity to reduce the installation waste. This will also significantly reduce the overall impacts.

The results show that periodic cleaning is also a significant source of impacts. BioPlastic Solutions should investigate how it can work with end users and consumers to improve the efficiency of cleaning which helps to reduce the frequency.

6 SOURCES

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[6] ISO 14044, "Environmental management - Life cycle assessment - Requirements and guidelines", ISO14044:2006

[7] Joep Meijer, Sustainable Minds SM2013 Methodology and Database, April 25, 2013. For a summary, see the Sustainable Minds single score page: http://www.sustainableminds.com/showroom/shared/learn-single-score.html

[8] Bare, J. 2014. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User's Guide. US EPA Office of Research and Development, Washington, DC, EPA/600/R-12/554, http://nepis.epa.gov/Adobe/PDF/P100HN53.pdf

[9] Ryberg, M., Vieira, M.D.M., Zgola, M. et al. (2014). 'Updated US and Canadian normalization factors for TRACI 2.1.' Clean Technologies and Environmental Policy 16: 329. doi:10.1007/s10098-013-0629-z

[10] Gloria, T. P., B. C. Lippiatt & J. Cooper (2007). 'Life cycle impact assessment weights to support environmentally preferable purchasing in the United States.' Environmental Science & Technology, 41(21), 7551-7557

[11] "ACLCA guidance to Calculating Non-LCA Inventory Metrics in Accordance with ISO 21930:2017", ACLCA, May 2019.

[12] "LCA results spreadsheets", Sustainable Minds, December 2021.

CRITICAL REVIEW STATEMENT

Harmony Environmental, LLC
Management • Analysis • Communication
Beyond Sustainability, Striving for Harmony

Critical Review Statement

Date: February 3, 2022

LCA Commissioned by: BioPlastic Solutions

LCA Conducted by: Tejan Adhikari, Sustainable Minds and Jim Mellentine, Thrive ESG

Report Title: Life Cycle Assessment (LCA) of Bioedge® Edgebanding for Bioplastic Solutions

Panel Review Conducted by: Terrie K. Boguski, Harmony Environmental, LLC

Referenced Standards: ISO ISO 14044:2006+Amd1:2017+Amd2:2020; ISO/TS 14071:2014; BIFMA PCR for Office Furniture Workspace Products: UNCPC 3814

Critical Review Process, Scope and Conclusion

In accordance with the international standard, ISO 14044:2006, a formal Critical Review was conducted by Terrie Boguski of the LCA report, *Life Cycle Assessment (LCA) of Bioedge® Edgebanding for Bioplastic Solutions*. The purpose of the LCA is to support an Environmental Product Declaration for Bioedge® Edgebanding. The review was an end-of-report review. Review was based on the stipulations in ISO 14044 and the BIFMA Product Category Rule (PCR) for Office Workspace Products. The review followed guidance in ISO 14071:2014.

The reviewer received the draft report on December 22, 2021 and provided initial comments on December 31, 2021. The reviewer received the revised report on February 1, 2022. The review was conducted by exchanging comments and responses via video conference and email. Comments were recorded in an Excel spreadsheet in tabular format based on Annex A of ISO/TS 14071:2014. All comments were addressed, and all open issues resolved to the extent possible.

The reviewer concluded that all required stipulations in ISO 14044:2006 6.3 were met in the revisions to the report (final version received February 1, 2022). In particular,

- The methods used to carry out the LCA are consistent with this International Standard,
- The methods used to carry out the LCA are scientifically and technically valid,
- The data used are appropriate and reasonable in relation to the goal of the study,
- The interpretations reflect the limitations identified and the goal of the study, and
- The study report is transparent and consistent.

The reviewer also concluded that the stipulations of BIFMA PCR for Office Furniture Workspace Products: UNCPC 3814 were followed.

The reviewer did not have access to LCA calculations or underlying data. Therefore, the review is primarily limited to the summary data and model results included in the report. Completing the critical review does not mean that the reviewer endorses the results of the LCA study, nor does it mean that she endorses any of the assessed products.

ISO 14044:2006 requires that this critical review statement, as well as the reviewer's comments and any responses to recommendations made by the reviewers be included in the final LCA report.

Submitted by

Terrie K Boguski

Terrie Boguski

ACRONYMS

ISO	International Standardization Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact analysis
PCR	Product Category Rule document
TR	Transparency Report / EPD™
IPCC	Intergovernmental Panel on Climate Change
USLCI	US Life Cycle Inventory

GLOSSARY

For the purposes of this report, the terms and definitions given in ISO 14020, ISO 14025, the ISO 14040 series, and ISO 21930 apply. The most important ones are included here:

Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems
Close loop & open loop	A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.
Cradle to grave	Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of life
Cradle to gate	Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of the production process ("gate of the factory"). It may also include transportation until use phase
Declared unit	Quantity of a product for use as a reference unit in an EPD based on one or more information modules
Functional unit	Quantified performance of a product system for use as a reference unit
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal
Life cycle assessment - LCA	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle
Life cycle impact assessment - LCIA	Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product
Life cycle inventory - LCI	phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle

Life cycle interpretation	Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations

APPENDIX

- Primary data –

  Data_collection_form_final.xlsx

- LCA results –

  Final_Results.xlsx

- ANSI/BIFMA X5.5-2021 Desk/Table Products Certification –

  ANSI_BIFMA-X5.5-2021 certification_Spec I

- Reviewer's comments and responses –

  BioPlastics Critical Review Comments_2(