

EXECUTIVE SUMMARY

Isolatek International is committed to responsible environmental practice and operating in a sustainable manner. Isolatek is committed to reducing its environmental impact while continually improving its environmental performance as an integral part of their business and operations. They encourage customers, suppliers, and other stakeholders to join them with this continuing and evolving environmental and business responsibility. As Isolatek aims to reduce any impacts from their operations on the environment and local communities in which they operate, the company commissioned this study to evaluate the potential environmental impacts of CELLU-SHIELD® using a cradle-to-grave approach.

The functional unit of spray-applied cellulose material was determined to be 1 m² of installed insulation material with a thickness that gives an average thermal resistance RSI = 1 m²K/W with a 75-year reference service life (RSL). Life cycle assessment (LCA) was conducted conforming to the relevant product category rules (PCR) and applicable ISO standards using a cradle-to-grave approach. The cradle-to-grave scope includes life cycle stages from raw material supply (A1-A3), distribution to end users (A4), product installation (A5), use (B1-B7), and end-of-life disposal (C1-C4).

A high-level summary of the findings of this study is illustrated in the table below which shows impacts per functional unit. The table presents potential CO₂-equivalent emissions and SM single score results for each product type across the various life cycle modules. For other impact categories and a breakdown by each life cycle stage, refer to the tables in the full report. Overall, the study found that environmental performance is driven primarily by the raw material supply phase (A1-A3) for Isolatek CELLU-SHIELD®. This phase contributes to >60% of potential CO₂-equivalent emissions from cradle to gate, followed by the end-of-life phase (C1-C4), accounting for ~20% of the total impact, and the construction phase (A4-A5) phase which accounts for 16.2% of the total impact.

Product	Impact category	Unit	Raw material supply	Construction / Installation	Use	End of life	Total
			A1-A3	A4-A5	B1-B7	C1-C4	
CELLU-SHIELD®	<i>Global warming</i>	kg CO ₂ eq	3.22E+00	8.20E-01	0.00E+00	1.02E+00	5.06E+00
		%	63.6%	16.2%	0%	20.1%	100%
	<i>SM single figure score</i>	mPts	1.85E-01	4.49E-02	0.00E+00	3.30E-02	2.63E-01
		%	70.44%	17.04%	0%	12.52%	100%

CONTENTS

1.	BACKGROUND	1
1.1.	OPPORTUNITY	1
1.2.	LIFE CYCLE ASSESSMENT (LCA)	1
1.3.	TEAM	3
1.4.	STATUS	3
2.	GOAL AND SCOPE	4
2.1.	INTENDED APPLICATION AND AUDIENCE	4
2.2.	PRODUCT DESCRIPTION	4
2.3.	FUNCTIONAL UNIT	5
2.4.	SYSTEM BOUNDARY	6
2.4.1	<i>Production stage (A1-A3)</i>	<i>7</i>
2.4.2	<i>Production stage (A4-A5)</i>	<i>7</i>
2.4.3	<i>B1-B7: Use</i>	<i>8</i>
2.4.4	<i>C1-C4: Disposal/reuse/recycling</i>	<i>8</i>
2.4.5	<i>D: Benefits and loads beyond the system boundary</i>	<i>8</i>
3.	LIFE CYCLE INVENTORY ANALYSIS	9
3.1.	DATA COLLECTION PROCEDURES	9
3.2.	PRIMARY DATA AND PCR GUIDELINES	9
3.2.1.	<i>Raw materials acquisition and transportation (A1-A2)</i>	<i>9</i>
3.2.2.	<i>Manufacturing (A3)</i>	<i>10</i>
3.2.3.	<i>Product distribution (A4)</i>	<i>11</i>
3.2.4.	<i>Installation (A5)</i>	<i>11</i>
3.2.5.	<i>Use (B1-B7)</i>	<i>12</i>
3.2.6.	<i>Deconstruction (C1)</i>	<i>12</i>
3.2.7.	<i>End-of-life transport (C2)</i>	<i>13</i>
3.2.8.	<i>Waste processing (C3)</i>	<i>13</i>
3.2.9.	<i>Final disposal (C4)</i>	<i>13</i>
3.3.	BACKGROUND DATA	13
3.3.1.	<i>Materials</i>	<i>13</i>
3.3.2.	<i>Transportation</i>	<i>14</i>
3.3.3.	<i>Fuels and energy</i>	<i>15</i>
3.3.4.	<i>Disposal</i>	<i>15</i>
3.4.	CUT-OFF CRITERIA	15
3.5.	ALLOCATION	16
3.6.	DISCUSSION OF DATA QUALITY	16
3.7.	COMPARABILITY	17
3.8.	ASSUMPTIONS AND LIMITATIONS	18
4.	IMPACT ASSESSMENT METHODS	19
4.1.	IMPACT ASSESSMENT CHARACTERIZATION	19
4.2.	NORMALIZATION AND WEIGHTING	20
5.	ASSESSMENT AND INTERPRETATION	21
5.1.	DATA QUALITY ASSESSMENT	21
5.2.	RESOURCE USE AND WASTE FLOWS	21
5.3.	LIFE CYCLE IMPACT ASSESSMENT (LCIA)	24
5.4.	SENSITIVITY ANALYSIS	26
5.5.	OVERVIEW OF RELEVANT FINDINGS	27
5.6.	CONCLUSION AND RECOMMENDATIONS	27
6.	REFERENCES	29

1. BACKGROUND

1.1. Opportunity

Isolatek International is the world's leading single source manufacturer of passive fireproofing and cellulose thermal insulation for the construction industry. Isolatek has been working towards low energy and sustainably built products and solutions that will be important for the construction sector of the marketplace. In fulfilling their commitment to sustainability, it is important for Isolatek to conduct life cycle assessments (LCAs). These life cycle assessments will evaluate the environmental impacts of products for the life cycle stages from raw materials to product installation or cradle to grave. The goal of conducting the life cycle assessment is to understand the scope of environmental impacts from the products and to recognize ways to improve the process and reduce overall impacts. Isolatek International intends to provide information that the market needs to be able to accurately assess the environmental impacts of their products and solutions.

Isolatek International has chosen the cradle-to-grave approach for the life cycle assessment of its products. By conducting a cradle-to-grave life cycle assessment, Isolatek will be informed on how to reduce the environmental impacts for each of their products from raw material acquisition to manufacturing.

Isolatek is interested in having LCA data available for its CELLU-SHIELD® product to be able to obtain a Sustainable Minds Transparency Report [EPD]™ (TR), which is an ISO 14025 Type III [1] environmental declaration that can be used for communication with and amongst other companies, architects, and consumers, and that can also be utilized in whole building LCA tools in conjunction with the LCA background report and life cycle inventory (LCI). This study conforms to the requirements of ISO 14040/14044 [2], ISO 21930:2017 [3], and UL's PCR Part A [4] and Part B for Building Envelope Thermal Insulation [5].

1.2. Life cycle assessment (LCA)

LCA is performed to comprehensively explore, quantify, and interpret the potential environmental impacts associated with a product or service throughout its entire life cycle. A product's life cycle consists of various stages, starting from raw material acquisition and manufacturing to product use and maintenance, plus final product disposal. Depending on the inclusion and exclusion of life cycle stages, an LCA could be cradle to gate (from raw material acquisition to the manufactured product ready to be shipped), cradle to gate with options (which also optionally includes other modules such as shipment and installation), and cradle to grave (which includes all other stages including the use phase and disposal once the useful life is over).

Any LCA conducted with the intention of publishing EPDs needs to comply with the internationally accepted ISO 14040 and ISO 14044 standards. ISO 14040 provides principles and frameworks for conducting an LCA, while ISO 14044 specifies requirements and provides guidelines for an LCA. ISO 14040 sets out a four-phase methodology framework for completing a LCA, as depicted in **Figure 1**.

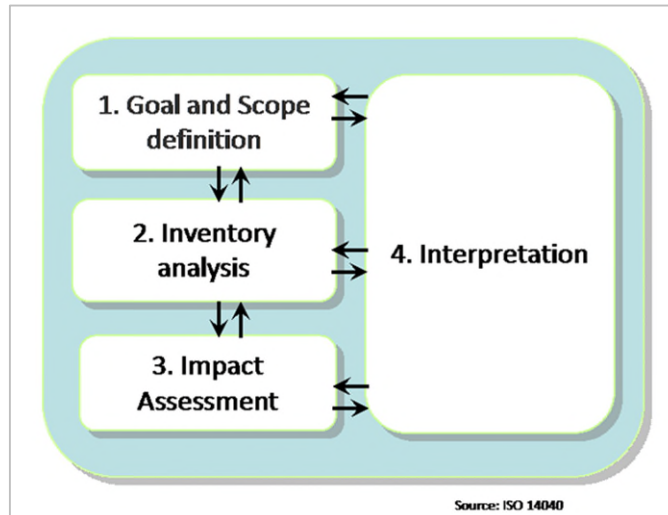


Figure 1. Phases of an LCA

- Goal and scope definition:** Goals refer to establishing the purpose of the LCA, and they define the environmental aspects to be studied and the intended audience. Scope outlines the system boundaries, the functional unit of analysis, and the life cycle stages to be included. System boundaries set up inclusions and exclusions in an LCA. PCRs usually specify whether the boundary must be cradle-to-gate, cradle-to-installation, or cradle-to-grave.
- Life cycle inventory analysis:** In this step, a detailed inventory of all the environmental inputs and outputs associated with each stage of the product's life cycle is compiled. Primary data about materials, energy, and emissions assessing the upstream supply chain, company's manufacturing operations, and downstream processes (after product leaves the factory gate) are collected via LCI data collection templates or tools. Annual data is suggested in most cases to be representative of the manufacturing operations. In the case of multi outputs, resources can be allocated to the product of interest via mass or volume, or as relevant. The inventory is then scaled to meet the functional unit of the LCA.
- Life cycle impact assessment:** The compiled LCI is then modeled using an LCA software like SimaPro, GaBi, openLCA, or others using suitable background data sets available on their databases. Each is assigned to categories according to different impact methodologies, and the software provides final impact values for those different environmental impact categories. Several LCIA methodologies exist in the market including ReCiPe, TRACI, CML, and ILCD, which differ in terms of their approaches, characterization factors, evaluated impact categories, and modeling assumptions. Practitioners can choose a combination of LCIA methodologies to provide a holistic view of the environmental performance of a product.
- Interpretation of results:** In this step, the LCIA results are analyzed and presented via an LCA report. This stage helps draw conclusions about the environmental performance of the product, identify any environmental hotspots, make recommendations, and assess the significance of the findings. Sensitivity analysis, scenario studies, and uncertainty assessment are often included as a part of the interpretation to ensure the reliability and robustness of the results. LCA, if well interpreted and evaluated, presents a number of opportunities for the manufacturer in developing sustainability goals and initiatives.

This LCA study follows an attributional approach and uses a cradle-to-grave system boundary. This report incorporates LCA terminology. To assist the readers in understanding LCA, special attention has been given to list definitions of important terms used at the end of this report.

A critical review of the LCA and an independent verification of the TR are required for ISO 14025 Type III environmental declarations. Both are included in this project.

1.3. Team

This LCA report is the outcome of the efforts of the project team led by Cole Swanson and Daniel Eehalt on behalf of Isolatek, with support from Isolatek personnel during the data collection, reporting, and interpretation phases. Sustainable Minds led the development of the LCA results, LCA report, and TR.

1.4. Status

All information in this report reflects the best possible data inventory by Isolatek at the time it was collected, and Sustainable Minds and Isolatek adhered to best practices in transforming the inventory into this report.

Primary data was provided for manufacturing activities from August 2023 through July 2024 from Isolatek and its suppliers. Where data was missing, assumptions were made for the facility based on expertise from Isolatek and its upstream suppliers. This study also includes background data to complete the inventory and fill gaps where necessary.

This is a supporting LCA report for the Transparency Report [EPD][™] of Isolatek CELLU-SHIELD[®] and was evaluated for conformance to the PCRs according to the ISO 14025 and ISO 14040/14044 standards. The LCA review and verification of the Sustainable Minds Transparency Report [EPD][™] were carried out by Terrie Boguski, Harmony Environmental, LLC to determine conformance to ISO 14040/14044, ISO 21930:2017, and the relevant PCRs. ■■■■

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 aims to define the specific application of the LCA methodology to the life cycle of Isolatek's CELLU-SHIELD® product. The report serves both internal and external purposes and is intended for a diverse audience. The intended audience includes the program operator (Sustainable Minds) and reviewers who will be assessing the LCA for conformance to the PCR, as well as Isolatek's internal stakeholders involved in marketing and communications, operations, and design.

The results presented in this document are not meant to support comparative claims. The outcomes will be made available to the public in a Sustainable Minds Transparency Report [EPD]™ (Type III environmental declaration per ISO 14025), which is intended for communication between businesses and consumers (B2C).

2.2. Product description

The product covered in this report is Isolatek's CELLU-SHIELD®, which is a spray-applied cellulose product developed specifically to meet thermal and acoustical needs. CELLU-SHIELD® is ideally suited for light gauge steel panels, concrete slab construction, the underside of roof decks, cold storage facilities, or when a high thermal value (R-value) is required. In addition to its thermal properties, CELLU-SHIELD® can be effectively used for acoustical treatment due to the material's high noise reduction coefficient (NRC).

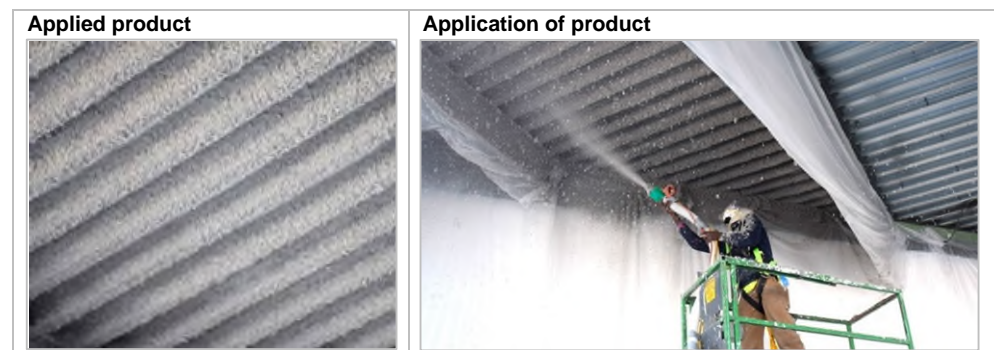


Figure 2. Visual representation of CELLU-SHIELD® and its application

Table 1 and **Table 2** list the product information in accordance with the PCR, including the declaration name, CSI MasterFormat® classification, manufacturing location, the type of declaration, and other relevant information.

Table 1. Declared product and type of declaration

Transparency Report [EPD]™ name	Product name	Manufacturing location(s)	Type of declaration
CELLU-SHIELD®	CELLU-SHIELD®	Warren, Indiana	Specific product from a manufacturer's plant

For more information about the product, including details about the materials that conform to the relevant standards, visit <https://www.isolatek.com/cellu-shield/>.

Table 2. Other product information

Transparency Report name	CSI MasterFormat® classification	Application	Product Specification
CELLU-SHIELD®	07 21 29	The application of CELLU-SHIELD® consists of conditioning the material through the application equipment and pneumatically conveying it through the hose to the nozzle. The CELLU-SHIELD is mixed with the CELLU-SHIELD Admix at the nozzle and the spray is directed at the substrate and applied in an even, uninterrupted pattern.	<ul style="list-style-type: none"> • Bond strength shall be greater than 150 psf per ASTM E 736. • Product shall be Class 1 Class A per ASTM E 84/ UL 723. Flame Spread Index: 0 Smoke Development: 10 • Non-corrosive per ASTM C 739. • Bond Deflection per ASTM E 759: 1" Deflection in 10' Span – No Spalling or Delamination. • R-Value to be 3.9 per inch per ASTM C 518. • Comply with 2018 IBC Section 803.14 stability requirements for interior finishes. • Meet ASTM C 1149

For more information about the product specifications, visit <https://www.astm.org/> and https://codes.iccsafe.org/content/IBC2021P2/chapter-8-interior-finishes#IBC2021P2_Ch08_Sec803.14.

2.3. Functional unit

In accordance with the PCR, the functional unit in this study was determined to be 1 m² of installed insulation material with a thickness that gives an average thermal resistance RSI = 1 m²K/W.

CELLU-SHIELD® is assumed to have a reference service life equal to that of the building when installed per manufacturer's instructions, which in this case is 75 years [4]. Therefore, the insulation does not need to be replaced, and 1 m² of insulation and the associated packaging is required to fulfill the functional unit. This reference service life applies for the reference in-use conditions only.

According to Isolatek's technical data sheet, the thermal performance of CELLU-SHIELD® is 3.90 R/inch thickness at the standard density for less than a 3-inch thickness. To convert the R-value to an RSI value, the R-value is divided by 5.678. Therefore, the 3.90 R/inch thickness is equivalent to 0.69 RSI/inch thickness, and a thickness of 1.45 inches (0.037 m) is needed to meet the RSI = 1 m²·K/W value as specified in the PCR.

The reference flow indicates the mass of CELLU-SHIELD® material plus the applied and cured adhesive (without water content) after application required to fulfill the functional unit. The reference flow was calculated based on the nominal insulation density and is shown in **Table 3**.

Table 3. Reference flow

Product as applied and cured	Product (kg)	Thickness (m)
CELLU-SHIELD®	2.43	0.037

The CELLU-SHIELD® cellulose material is used in conjunction with the adhesive. The mass of cellulose material needed per functional unit is 1.94 kg and uncured adhesive needed is 0.994 kg. Since water accounts for approximately 51% of the adhesive composition by weight and will evaporate once the product is applied and

cured, the weight of cured product per functional unit is 2.43 kg (1.94 kg cellulose material plus 0.487 kg cured adhesive). Detailed adhesive composition information is listed in Error! Reference source not found..

2.4. System boundary

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

This LCA's system boundary is from cradle to grave. Therefore, the life cycle activities and related processes shall include all life cycle stage modules from A1-C4 as illustrated in **Figure 3**. **Table 4** lists specific inclusions and exclusions for the system boundary. This study follows the modularity principle, where all environmental impacts and potential impacts are declared in the life cycle stage where they can be attributed.

Scope	PRODUCTION STAGE			CONSTRUCTION STAGE		USE STAGE					END-OF-LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY	Reference Service Life
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D	
	Extraction and upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction/Demolition	Transport to waste processing or disposal	Waste processing	Disposal of waste	Reuse, Recovery, Recycling Potential	
						B6 Operational energy use										
B7 Operational water use																
Cradle to grave	X	X	X	X	X	X	X	X	X	X	X	X	X	X	MND	75 years

Figure 3. Applied system boundary

Table 4. System boundary inclusions and exclusions

Included	Excluded
<ul style="list-style-type: none"> Raw material extraction for components Transport of raw materials/ purchased components to the manufacturing facility Processing of raw materials into components (for externally purchased and in-house manufactured) Material, manufacture and transport of packaging materials associated with final product Packaging of raw materials and their disposal Energy production Manufacturing scrap and its disposal Deconstruction, transport, and disposal of final product at end of life 	<ul style="list-style-type: none"> Construction of major capital equipment Maintenance and operation of support equipment Human labor and employee transport Building operational energy and water use

CELLU-SHIELD® consists of cellulose and adhesive components. These cellulose materials and adhesives are transported to the end-user site for installation. During the installation process, water and electricity are consumed by the adhesive pump and installation machine while blending the ingredients. Once installed, the product requires no periodic cleaning, repair, or replacement throughout its reference service life. Per the PCR, the product is assumed to be landfilled at the end of life. **Figure 4** provides an overview of the product flow during its life cycle.

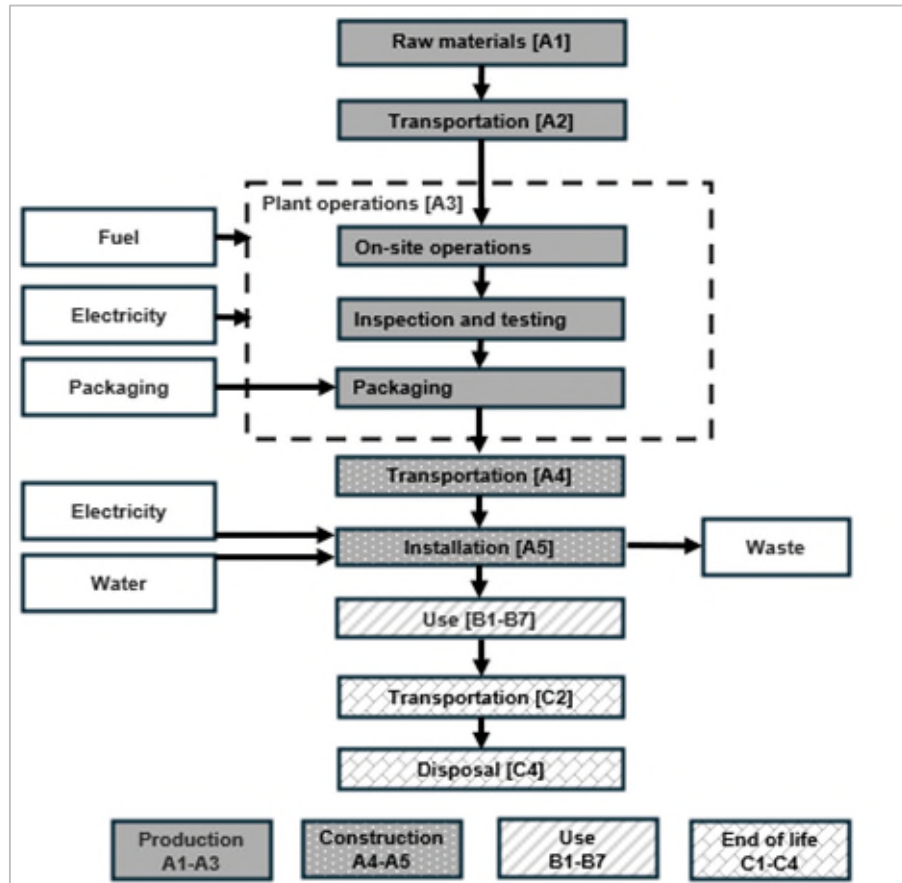


Figure 4. Product flow diagram of CELLU-SHIELD®

2.4.1 Production stage (A1-A3)

The production stage starts when raw materials are extracted from nature and ends when the product is packaged and ready to be loaded onto a transport vehicle at the facilities.

The production stage includes three product life cycle modules:

- I. **Extraction and upstream preprocessing (A1)**
 - Extraction and processing of raw materials
 - Transport of raw materials from extraction/production to suppliers
 - Energy and water consumption for finished building envelope thermal insulation components manufacturing
 - Product packaging inputs for finished building envelope thermal insulation components
 - Releases to environmental media (air, soil, ground, & surface water)
- II. **Transport to factory (A2)**
 - Transportation of components from suppliers to Isolatek
- III. **Manufacturing (A3)**
 - Component inbound acceptance and inspection
 - Final product preparation for outbound shipment

2.4.2 Construction stage (A4-A5)

- IV. **Distribution (A4)** The distribution stage includes the following:
 - Transportation of building envelope thermal insulation products from warehouse to building sites

- V. Installation (A5)** The installation stage includes the following:
- Installation in the building including materials specifically required for installation
 - The reference service life of the building is defined as 75 years for building envelope thermal insulation, and the number of replacements of the insulation products will be declared accordingly. The number of replacements shall be calculated by dividing the reference service life of the building by the product service life, as defined by the manufacturer's specifications.
 - Releases to environmental media during application (air, soil, ground, & surface water)
 - Installation and packaging waste transportation from building site to disposal site
 - Installation waste (scrap) and packaging waste disposal

2.4.3 B1-B7: Use

The use stage includes:

- Product use
- Maintenance
- Repair
- Replacement
- Refurbishment
- Operational energy use
- Operational water use

Use stage environmental benefits of insulation during building operations can be significant as low thermal conductivity and air sealing attributes of insulation limit utility consumption and associated environmental impacts. During its service life, insulation significantly reduces the energy use in a building, thereby reducing the impact on the environment. The exclusion of the building heating and cooling during the insulation material's use phase severely underestimates the benefits that insulation has on the environment.

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 insulation is done being used, it is collected as construction and demolition waste. The following life cycle stages are used to describe the end-of-life processes.

Deconstruction (C1) The deconstruction stage includes dismantling/demolition.

Transport (C2) The transport stage includes transport from building site to final disposition.

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

Disposal (C4) The disposal stage includes final disposition (e.g., recycling, reuse, landfill, waste incineration, or conversion to energy).

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. LIFE CYCLE INVENTORY ANALYSIS

This chapter includes an overview of the obtained data and data quality that has been used in this study. A comprehensive life cycle inventory calculation workbook, which catalogs the flows crossing the system boundary and serves as the starting point for life cycle impact assessment, can be found in the appendix.

3.1. Data collection procedures

Primary data was provided by Isolatek representing the supply chain (A1-A2), manufacturing (A3), and construction (A4-A5) for the product. The assumptions for end-of-life processes (C1–C4) are based on the guidelines provided in the PCR. Data was collected in a consistent manner and level of detail to ensure high-quality data. All questions regarding data, including gaps, outliers, and any inconsistencies, were resolved with Isolatek and their suppliers; for the product, the results represent a plant-specific, product-specific process where the product is shipped from an Indiana warehouse to construction sites in the US. Twelve months of data (August 2023 to July 2024) was collected. The resulting inventory calculations were developed by an analyst at Sustainable Minds and subsequently checked internally.

Expert judgment was used in selecting appropriate data sets to model the associated activities in this study, including materials and energy, which have been noted in the following sections. Databases adopted in the model include ecoinvent v3.10 and US-EI 2.2 databases. 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 guarantee the data quality and representativeness as described below.

3.2. Primary data and PCR guidelines

Primary data were collected for the A1-C4 modules, and PCR guidelines were used for the remaining product life cycle stages. Primary data were collected using either direct measurement or the manufacturing facility representative personnel's best engineering estimates based on actual production if measurements were not available.

3.2.1. Raw materials acquisition and transportation (A1-A2)

These modules represent raw materials extraction, preprocessing/upstream processing, and transportation to the manufacturing facility. The full bills of material (BOMs) were provided with a detailed breakdown of the products into raw materials for each component. Raw materials are extracted and manufactured [REDACTED]. Supply chain primary data, including information on shipping distances to the final manufacturing plant, was provided. Waste and scrap created during raw material manufacturing and the emissions associated with transporting waste and scrap to the point of disposal were included in the background data sets used to model the raw materials.

For CELLU-SHIELD®, the cellulose material is used in conjunction with the adhesive. [REDACTED] The exact material composition of the adhesive is considered confidential business information, and the composition is therefore reported as

ranges of the main components. Actual formulations were provided to the third-party reviewer. The material composition is reported in **Table 5** [REDACTED].

Table 5. CELLU-SHIELD® material composition

Part	Material	%wt.
Cellulose material	Recycled newspaper	50-55%
Cellulose material	Boric acid	5-10%
Cellulose material	Mineral oil	2-5%
Uncured adhesive	VAE polymer	13-17%
Uncured adhesive	PVA solution	1-2%
Uncured adhesive	Biocide	<1%
Uncured adhesive	Organic defoamer	<1%
Uncured adhesive	Water	15-20%

[REDACTED]

CELLU-SHIELD® does not contain hazardous substances according to the standards or regulations of the Resource Conservation and Recovery Act (RCRA), Subtitle C. The reference flow and reference service life for CELLU-SHIELD® are reported in **Table 6**. Finished goods are packaged, stacked, and stretch wrapped before being distributed to an Isolatek warehouse in Indiana.

Table 6. CELLU-SHIELD® mass per functional unit and reference service life

Top-level assembly name	Mass (kg)	Thickness (m)	Reference service life
CELLU-SHIELD®	2.43	0.037	75 years

The biobased organic defoamer and wooden pallets are assumed to enter the product system as primary materials. Recycled newspapers are assumed to enter the product system as a secondary material, reported with an input of biogenic carbon removals characterized with -1kg CO₂e/kg CO₂ of biogenic carbon. The biogenic carbon removals from nature are detailed in **Table 17**, under the sections "Biogenic Carbon Removal from Product" and "Biogenic Carbon Removal from Packaging" in the A1 stage.

3.2.2. Manufacturing (A3)

This module incorporates the manufacturing operations in the product manufacturing facility. Cellulose material and adhesive are distributed to a warehouse in Indiana, where they are stored until an order is placed. At that point, equipment is used to pull the materials from the shelves and move them to the shipping area. The energy inputs for operations [REDACTED] were collected. **Table 7** presents the manufacturing inputs needed per functional unit of CELLU-SHIELD®.

Table 7. Manufacturing inputs needed per functional unit of CELLU-SHIELD®

Resource category	Flow	Amount	Unit
Energy	Electricity	█	kWh
Equipment fuels	Propane (forklifts)	█	kg
	Diesel fuel (loader)	█	kg

3.2.3. Product distribution (A4)

This module refers to the transport and delivery of products from the manufacturing facility to the sites where the products are installed and used. The average transportation distance is 1,207 km, which was calculated based on Isolatek's yearly order history. Relevant technical information is shown in **Table 8**.

Table 8. Relevant technical information for distribution (A4)

Name	Value	Unit
Fuel type	Diesel	
Vehicle type	Truck and trailer (16-32 metric ton)	
Liters of fuel	34.5	L/100 km
Transportation distance		
Average distance from manufacturing to installation site	1,207	km
Capacity utilization	50	%
Gross density		
CELLU-SHIELD® cellulose material	1,709.5	kg/m ³
CELLU-SHIELD® uncured adhesive	1,198.3	kg/m ³

3.2.4. Installation (A5)

CELLU-SHIELD® is a spray-applied cellulose material developed specifically to meet thermal and acoustical needs. This module represents the installation of the product, making it ready for use.

At the installation site, cellulose material is delivered in 13.6 kg (30 lb) bags, with a minimum order of 36 bags per pallet. The adhesive is packaged in a 55-gallon plastic drum designed to be used with one pallet of cellulose material. The application machine consists of an adhesive pump and an application machine. The installer mixes the adhesive component with water according to the manufacturer's instructions, and the diluted adhesive solution is sprayed with the cellulose material onto a surface. The energy consumption needed for installing CELLU-SHIELD® is 0.09 kWh with 3.32 kg water consumption per functional unit.

Energy consumption during application is calculated based on the approved equipment listed in Isolatek's application guidance. The inputs in this module include the disposal of product scrap and packaging waste with a waste transportation distance of 100 km. The disposal scenario is assumed to be 100% landfilled per the PCR.

Cellulose materials are packaged in plastic bags, while adhesives are packaged in plastic drums. Two separate wooden pallets are used for shipping the cellulose materials and the adhesive drum(s). For a shipment of 490 kg (1,080 lb) of cellulose material and the corresponding adhesive, it was assumed that two 24 kg pallets would be used.

The pallet mass required for 1.94 kg of cellulose material plus 0.102 kg of cellulose material lost during installation (5% scrap) is approximately 0.2 kg. The biogenic carbon emissions associated with the pallet portion of the packaging are 0.37 kg CO₂ per functional unit. This calculation is based on a wood carbon content of 0.1 kg (50% by weight, as specified in the ACLCA guidance for calculating the ISO 21930:2017 metrics). 0.1 kg of carbon is then converted to 0.37 kg of CO₂ (calculated as 0.1 kg C × 44 kg CO₂ / 12 kg C).

The approved installation equipment is capable of applying up to 1,496 kg (3,300 lb) of mixed cellulose insulation product per hour and comes with a 5-year warranty covering the blowers, gearboxes, and engines [6]. Since the separate components required to fulfill one functional unit of CELLU-SHIELD® weigh a total of 6.25 kg (including 1.94 kg of cellulose material, 0.99 kg of adhesive, and 3.32 kg of water), the equipment can apply approximately 240 functional units of CELLU-SHIELD® per hour. Consequently, the impacts from manufacture of the application machine and adhesive pump are expected to be negligible.

The mass of waste is shown in **Table 10**. Packaging waste includes the plastic drum, bag, and pallet. A 5% installation scrap rate is assumed.

Table 9. Relevant technical scenarios for installation (A5) per functional unit

Product	Mass of packaging waste		Biogenic carbon content of pallet portion of packaging	
	Value	Unit	Value	Unit
CELLU-SHIELD® cellulose material and adhesive	0.24	kg	0.37	kg CO ₂
	Mass of scrap waste		VOC content	
	Value	Unit	Value	Unit
	0.128	kg	≤ 500	µg/m ³

Since water accounts for approximately 51% of the uncured adhesive's weight and evaporates after the product is applied and cured, the final product weight per functional unit is 2.43 kg. Accounting for a 5% product loss during application, users will need 2.558 kg of additional cured product to fulfill the requirements of one functional unit. Consequently, 0.128 kg of scrap waste is generated after application.

The packaging mass for one functional unit of the product is 0.23 kg, which includes the plastic bag for the cellulose material, the plastic drum for the uncured adhesive, and pallets for both. Considering a 5% scrap rate, the resulting packaging waste is 0.24 kg.

3.2.5. Use (B1-B7)

Insulation's reference service life is assumed to be equal to that of the building, which is 75 years for building envelope thermal insulation. No maintenance or replacement is required to achieve this product lifespan. Because the installed product is expected to remain undisturbed during the life of the building, there are assumed to be no impacts associated within the use stage.

3.2.6. Deconstruction (C1)

Although reuse and recycling of cellulose thermal insulation at its end of life is possible, there are no formal programs for collection and transport. It is assumed that all product is sent to landfill at the end of life [4]. Removal at end of life primarily requires human labor, and any use of equipment for removal of the

insulation is negligible; therefore, product removal does not contribute impacts associated with the deconstruction work after the service life ends.

3.2.7. End-of-life transport (C2)

While cellulose thermal insulation can be recycled, doing so is not common practice in the industry. Therefore, after removal, the insulation is assumed to be landfilled. In the absence of primary data, a conservative assumption of 100 km to the disposal site was used.

Since the water content in the adhesive evaporates once the product is cured, the weight of the waste product per functional unit is 2.43 kg. This includes 1.94 kg of cellulose material (comprising 1.59 kg of recycled newspaper and 0.35 kg of other chemicals) plus 0.49 kg of cured adhesive.

3.2.8. Waste processing (C3)

It was assumed that no waste processing is required before landfilling.

3.2.9. Final disposal (C4)

The PCR [4] prescribes that 100% of the insulation is landfilled.

Since the mass of recycled newspaper is 1.59 kg per functional and the carbon content of recycled newspaper is assumed to be 52% by weight (according to the Phyllis2 Database, created by Energy Research Centre of the Netherlands Biomass & Energy Efficiency), the carbon content of newspaper is calculated to be 0.827 kg per functional unit. This carbon is expected to convert to 3.03 kg of CO₂ (0.827 kg C × 44 kg CO₂ / 12 kg C) and leave the product system at the end of life, as the product is 100% landfilled.

3.3. Background data

This section details the background data sets used for modeling all relevant activities associated with the cradle-to-grave life cycle of CELLU-SHIELD®. Each table lists the data set name, database, reference year, and geography. The LCA model was created using SimaPro Developer 9.6 software. The ecoinvent v3.10 and US-EI 2.2 databases provided the life cycle inventory data for the raw materials and processes for modeling the products.

3.3.1. Materials

Data representing upstream and downstream raw materials were obtained from the ecoinvent v3.10 and US-EI 2.2 databases. Data sets matching each transportation mode were found in the available databases. Where country-specific data were unavailable, global or rest-of-world averages were used to represent transportation in those locations. Where data sets matching the raw materials were unavailable, proxy data sets were chosen to represent those materials. **Table 10** lists the most relevant LCI data sets used in modeling the raw materials.

Table 10. Key material data sets used in inventory analysis

Raw material	Data set	Database	Technology	Reference year	Geography ¹
Cellulose fibers (post-consumer newspaper)	<i>Empty data set representing the use of secondary material</i> (Post-consumer newspaper serves as the sole source of cellulose fibers, and transportation is included)	N/A	N/A	N/A	N/A
Boric acid	Boric acid, anhydrous, powder {RoW} boric acid production, anhydrous, powder Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Mineral dedust oil	Paraffin {RoW} paraffin production Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Vinyl Acetate Ethylene (VAE)	Ethylene vinyl acetate copolymer {RoW} ethylene vinyl acetate copolymer production Cut-off, U <i>(modified data set to adjust vinyl acetate content to 77.5% and an ethylene content to 22.5%)</i>	Ecoinvent v3.10	Appropriate technology	2024	RoW
Polyvinyl alcohol (PVOH)	Vinyl acetate {RoW} vinyl acetate production Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Biocide	Biocides, for paper production, unspecified, at plant/US- US-EI U	US-EI 2.2	Appropriate technology	2021	US
Organic defoamer	Palm kernel oil, crude {RoW} palm oil mill operation Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Wood pallet	EUR-flat pallet {RoW} EUR-flat pallet production Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Packaging film (Polypropylene)	Packaging film, low density polyethylene {RoW} packaging film production, low density polyethylene Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Plastic Drum (Polypropylene)	Polyethylene, high density, granulate {RoW} polyethylene production, high density, granulate Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
	Blow moulding {GLO} market for blow moulding Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	GLO
Municipal water	Tap water, at user/RER with US electricity U	US-EI 2.2	Appropriate technology	2020	US
Industry water	Water, deionised {RoW} market for water, deionised Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW

¹ 'GLO' stands for global geography; 'RoW' stands for Rest of World (non-Europe) geography; 'US' stands for United States

3.3.2. Transportation

Raw materials are transported to the product manufacturing facility from the suppliers via different transportation modes. Raw materials are shipped by road and train. The typical vehicles used for shipment via road are a 16-32 metric ton truck, and a freight train for shipment via railway. As the transportation data sets represent load factors as an average of empty and fully loaded (i.e., average load factor), empty backhauls are accounted for in the model. **Table 11** shows the most relevant LCI data sets used in modeling transportation.

Table 11. Transportation data sets used in inventory analysis

Transport mode & legs	Data set	Database	Technology	Reference year	Geography ¹
Railway	Transport, freight train {US} transport, freight train, diesel Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	US
Road transport	Transport, freight, lorry 16-32 metric ton, EURO6 {RoW} transport, freight, lorry 16-32 metric ton, EURO4 Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	ROW

¹ 'RoW' stands for Rest of World (non-Europe) geography; 'US' stands for United States

3.3.3. Fuels and energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from SimaPro. The grid mix used was the most recent from eGRID for the subregion. [REDACTED] For the general US region, the US electricity mix data set was used. **Table 12** shows the most relevant LCI data sets used in modeling the product systems.

Table 12. Key energy data sets used in inventory analysis

Energy source	Data set	Database	Reference year	Geography ¹
Manufacturing electricity	Electricity mix, eGrid subregion, [REDACTED]/US U	US-EI 2.2	2023	[REDACTED]
	Electricity mix 2021/US US-EI U	US-EI 2.2	2021	US
Forklift fuel	Propane, burned in building machine {GLO} market for propane, burned in building machine Cut-off, U	Ecoinvent v3.10	2024	GLO
Loader fuel	Diesel, burned in building machine {GLO} market for diesel, burned in building machine Cut-off, U	Ecoinvent v3.10	2024	GLO
Natural gas	Heat, district or industrial, natural gas {RoW} market for heat, district or industrial, natural gas Cut-off, U	Ecoinvent v3.10	2024	RoW

¹ 'GLO' stands for global geography; 'RoW' stands for Rest of World (non-Europe) geography; 'US' stands for United States

3.3.4. Disposal

Disposal processes were obtained from the ecoinvent v3.10 database. Processes specific to waste types were selected to correspond to the disposal of facility waste streams, packaging waste, and waste product treatment. **Table 13** lists the relevant disposal data sets used in the model.

Table 13. Key disposal data sets used in inventory analysis

Disposal activity	Data set	Database	Technology	Reference year	Geography ¹
Road transport for collecting municipal waste	Municipal waste collection service by 21 metric ton lorry {RoW} municipal waste collection service by 21 metric ton lorry Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Landfilled plastics/adhesives	Waste plastic, mixture {RoW} treatment of waste plastic, mixture, sanitary landfill Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Landfilled cellulose material	Waste paperboard {RoW} treatment of waste paperboard, sanitary landfill Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Landfilled polyethylene	Waste polyethylene {RoW} treatment of waste polyethylene, sanitary landfill Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW
Landfilled wood	Waste wood, untreated {RoW} treatment of waste wood, untreated, sanitary landfill Cut-off, U	Ecoinvent v3.10	Appropriate technology	2024	RoW

¹ 'RoW' stands for Rest of World (non-Europe) geography

3.4. Cut-off criteria

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. Assumptions and proxies, whenever used, have been explained in this report.

- Mass – If a flow is less than 1% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern. No known mass flow has been omitted in this study.
- Energy – If a flow is less than 1% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern. No known energy flow has been omitted in this study.
- Environmental relevance – If a flow meets the above criteria for exclusion, yet it is thought to potentially have a significant environmental impact, it is included. No known mass or energy flow has been omitted in this study.
- Hazardous and toxic materials – The study shall include all hazardous and toxic materials in the inventory therefore the cutoff rules shall not apply to such substances. No substances required to be reported as hazardous are associated with the production of this product including upstream raw material supply and raw material manufacturing.
- The sum of the neglected material flows does not exceed 5% of mass, energy or environmental relevance for flows indirectly related to the process (e.g., operating materials). No known mass flow has been omitted in this study.

In this report, no known flows are deliberately excluded; therefore, these criteria have been met. The completeness of the bill of materials defined in this report satisfies the above-defined cut-off criteria.

3.5. 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 to report where and how allocation occurs in the modeling of the LCA. The model used in this report ensures that the sum of the allocated inputs and outputs of a unit process are equal to the inputs and outputs of the unit process before allocation. This means that no double counting or omissions of inputs or outputs through allocation is occurring. The allocation procedures used in background data sets were accepted without modification.

■ only facility level energy data was available for the Isolatek manufacturing facility. Allocation among the facility's co-products was necessary to determine the energy consumption associated with CELLU-SHIELD® production. Allocation of energy was done on a mass basis for all products. Allocation of transportation was based on weight, since volume is not assumed to be limiting factor.

For recycled content and disposal at end of life, system boundaries were drawn consistent with the cut-off allocation approach. Recycled newspaper, which is used as the cellulose material, is assumed to enter the system burden-free in that burden associated with the production of virgin cellulose is not allocated to the cellulose material life cycle. Likewise, the system boundary was drawn to include landfilling of the cellulose material at end-of-life (following the polluter pays principle) but exclude any credits from material or energy recovery.

3.6. Discussion of 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).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the ecoinvent v3.10 and US-EI 2.2 databases were used.

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 the ecoinvent v3.10, U.S. LCI, and US-EI 2.2 databases with documented precision to the extent available.
- *Completeness:* Sustainable Minds worked with Isolatek to obtain a comprehensive set of primary data associated with the manufacturing processes. The product system was checked for mass balance and completeness of the inventory. The data set was considered complete based on our understanding of the manufacturing site and a review with key stakeholders on the Isolatek team, and cut-off criteria were observed consistent with those prescribed in the PCR. Besides capital equipment, no data was 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. 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, data set 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:* All primary data were collected for August 2023 to July 2024, ensuring the representativeness of the manufacturing process. Secondary data were obtained from the ecoinvent v3.10 and US-EI 2.2 databases and are typically representative of recent years.
- *Geographical:* The geographical coverage for this study is based on United States system boundaries for all processes and products. Whenever US background data was not readily available, rest of world (non-Europe) data or global data were used. Input and output data for modeling come from the manufacturing facility which is responsible for production.
- *Technological:* All primary and secondary data were modeled to be specific to the technologies under study. Technological representativeness is considered to be high.

3.7. Comparability

ISO 21930:2017 section 5.5 highlights the following limitations and clarifications in EPD comparability: EPDs are comparable only if they use the same PCR (or sub-category PCR where applicable), include all relevant information modules, and are based on equivalent scenarios with respect to the context of construction works.

EPDs can only be compared when the same functional requirements between products are ensured and the requirements of ISO 21930:2017 section 5.5 are met. However, variations and deviations are possible. For example, different LCA software and background LCI data sets may lead to different results for the life cycle stages declared.

3.8. Assumptions and limitations

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

- Primary data were modeled based on the information provided by Isolatek. The data covers annual manufacturing data from August 2023 to July 2024 from Isolatek and their suppliers.
- Variations in color choices are assumed to be negligible.
- Since energy inputs were not available on a per-product basis, electricity consumption was allocated proportionately based on the percentage of production for CELLU-SHIELD® versus total site outputs. It was later scaled down per kg of product using the total production units of products.
- Generic data sets used for material inputs, transportation, 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.

4. IMPACT ASSESSMENT METHODS

4.1. Impact assessment characterization

The environmental indicators as required by the PCR are included as well as other indicators required to use the SM2013 Methodology [7] (see **Table 14**). The impact indicators are derived using the 100-year time horizon¹ 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 indicators² are used to evaluate toxicity. Emissions from waste disposal are considered part of the product system under study, according to the “polluter pays principle”.

Table 14. Selected impact categories and units

Impact category	Unit	Description
Acidification	kg SO ₂ eq (sulphur dioxide)	Acidification processes increase the acidity of water and soil systems and causes damage to lakes, streams, rivers and various plants and animals as well as building materials, paints, and other human-built structures.
Ecotoxicity	CTUe	Ecotoxicity causes negative impacts to ecological receptors and, indirectly, to human receptors through the impacts to the ecosystem.
Eutrophication	kg N eq (nitrogen)	Eutrophication is the enrichment of an aquatic ecosystem with nutrients (nitrates and phosphates) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass.
Global warming (GWP 100)	kg CO ₂ eq (carbon dioxide)	Global warming is an average increase in the temperature of the atmosphere near the Earth’s surface and in the troposphere.
Ozone depletion	kg CFC-11 eq	Ozone depletion is the reduction of ozone in the stratosphere caused by the release of ozone depleting chemicals.
Carcinogenics	CTUh	Carcinogenics have the potential to form cancers in humans.
Non-carcinogenics	CTUh	Non-Carcinogenics have the potential to causes non-cancerous adverse impacts to human health.
Respiratory effects	kg PM _{2.5} eq (fine particulates)	Particulate matter concentrations have a strong influence on chronic and acute respiratory symptoms and mortality rates.
Smog	kg O ₃ eq (ozone)	Smog formation (photochemical oxidant formation) is the formation of ozone molecules in the troposphere by complex chemical reactions.
Fossil fuel depletion	MJ surplus	Fossil fuel depletion is the surplus energy to extract minerals and fossil fuels.
ADP _{fossil}	MJ, LHV	Abiotic Resource Depletion Potential of Non-renewable (fossil) energy resources

With respect to global warming potential, biogenic carbon is included in impact category calculations. The biogenic carbon measured in this study originates from packaging materials and recycled newspaper. Greenhouse gas emissions from land-use change are expected to be insignificant and were not reported. Carbon emissions during carbonation and calcination were also considered in this study, and no carbonation or calcination is expected to occur during the production and

¹ The 100-year period relates to the period in which the environmental impacts are modeled. This is different from the time period of the declared unit. The two periods are related as follows: all environmental impacts that are created in the period of the declared unit are modeled through life cycle impact assessment using a 100-year time horizon to understand the impacts that take place.

² USEtox is available in TRACI and at <http://www.usetox.org/>

manufacture of the insulation. No delayed emissions from a temporary carbon sequestration are expected to occur.

It shall be noted that the above impact categories represent impact potentials. They are approximations of environmental impacts that could occur if the emitted molecules 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).

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 at a single score indicator, normalization [9] and weighting [10] as shown in **Table 15** conforming to the SM 2013 Methodology were applied. The SM 2013 Methodology uses TRACI 2.1 impact categories developed by U.S. EPA, and North American normalization and weighting values developed by EPA and NIST respectively, to calculate single figure LCA results. Sustainable Minds recognizes that weighting is socially defined based on the importance that society attaches to the different environmental impact categories. However, these single score indicators serve as an easy starting point to get to know the product under consideration across all impact categories, rather than focusing all efforts on just one impact category (like global warming potential). The interpretation of the results starts with the Sustainable Minds single score results and then allows users to further explore the underlying impact categories individually. Details including the characterization models, factors, and methods used, including all assumptions and limitations, can be found in the SM 2013 Methodology Report [7].

Table 15. 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
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 functional unit, outlines the sensitivity analysis, and concludes with recommendations.

5.1. Data quality assessment

The quality of inventory data is evaluated based on its precision, completeness, consistency, and representativeness. The data used in this study is regarded as reliable and representative of the described systems, as well as their geographical, temporal, and technological contexts. When direct measurements were unavailable, the best engineering estimates based on actual production were applied. Every effort was made to ensure the highest data quality.

5.2. Resource use and waste flows

Resource use indicators, output flows and waste category indicators, and carbon emissions and removals are presented in this section. These life cycle inventory (LCI) indicators reflect the flows from and to nature for the product system, prior to characterization using an impact assessment methodology to calculate life cycle impact assessment (LCIA) results (as shown in section 5.2).

LCI flows were calculated with the help of American Center for Life Cycle Assessment's (ACLCA) guidance for calculating the ISO 21930:2017 metrics [10]. The consumption of freshwater indicator, which was calculated in accordance with this guidance, is reported in compliance with ISO 14046. Use of renewable and non-renewable energy resources with energy content were calculated using the Cumulative Energy Demand (LHV) impact assessment methodology [12]. Abiotic depletion potential was calculated using the CML impact assessment methodology [13]. LCI flows were reported in conformance to ISO 21930:2017.

Resource use indicators represent the amount of materials consumed to produce not only the product itself but also the raw materials, electricity, natural gas, 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 the total water used over the entire life cycle. No renewable energy was used in production beyond that accounted for in the eGRID datasets, and no energy was recovered.

Hazardous and non-hazardous wastes are calculated based on the amount of waste generated during the life cycle of the product, mainly during the installation of the product. Waste treatments in models were assumed to be 100% landfilled. Waste treatments included within the system boundary are reported. Unrecyclable wastes either are disposed of in landfills or incinerated. **Table 16** represents all the resource use and waste flow indicators, with the acronyms used, evaluated in this study.

Table 16. Resource use and waste flow indicators

Indicators	Acronyms used
Resource use indicators	
Renewable primary energy used as energy carrier (fuel)	RPR _E
Renewable primary resources with energy content used as material	RPR _M
Total use of renewable primary resources with energy content	RPR _{total}
Non-renewable primary resources used as an energy carrier (fuel)	NRPR _E
Non-renewable primary resources with energy content used as material	NRPR _M
Total use of non-renewable primary resources with energy content	NRPR _{total}
Secondary materials	SM
Renewable secondary fuels	RSF
Non-renewable secondary fuels	NRSF
Recovered energy	RE
Use of net fresh water resources	FW
Abiotic depletion potential for fossil resources	ADP _{fossil}
Output flows and waste category indicators	
Hazardous waste disposed	HWD
Non-hazardous waste disposed	NHWD
High-level radioactive waste, conditioned, to final repository	HLRW
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW
Components for re-use	CRU
Materials for recycling	MR
Materials for energy recovery	MER
Exported energy	EE
Carbon emissions and removals	
Biogenic Carbon Removal from Product	BCRP
Biogenic Carbon Emission from Product	BCEP
Biogenic Carbon Removal from Packaging	BCRK
Biogenic Carbon Emission from Packaging	BCEK
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	BCEW
Calcination Carbon Emissions	CCE
Carbonation Carbon Removals	CCR
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	CWNR
Units	
Megajoules, net calorific value	MJ, MCV

Resource use, output flows, waste categories, and carbon emissions & removals have been tabulated in the sections below.

Table 17 shows resource use, output and waste flows, and carbon emissions and removals for CELLU-SHIELD® at each stage of the life cycle.

Table 17. Resource use, output and waste flows, and carbon emissions and removals for CELLU-SHIELD® per functional unit

Parameters	Unit	Production			Construction/ Installation		Use B1- B7	End of life				Total
		A1	A2	A3	A4	A5		C1	C2	C3	C4	
Resource use indicators												
RPR _E	MJ, NCV	5.41E+00	3.95E-03	4.02E-04	1.35E-02	8.45E-02	0	0	8.06E-03	0	1.12E-02	5.53E+00
RPR _M	MJ, NCV	3.39E+01	0	0	0	0	0	0	0	0	0	3.39E+01
RPR _{total}	MJ, NCV	3.93E+01	3.95E-03	4.02E-04	1.35E-02	8.45E-02	0	0	8.06E-03	0	1.12E-02	3.94E+01
NRPR _E	MJ, NCV	1.92E+01	2.58E+00	1.03E-01	8.80E+00	1.80E+00	0	0	4.47E+00	0	6.66E-01	3.76E+01
NRPR _M	MJ, NCV	4.68E+01	0	0	0	0	0	0	0	0	0.00E+00	4.68E+01
NRPR _{total}	MJ, NCV	6.60E+01	2.58E+00	1.03E-01	8.80E+00	1.80E+00	0	0	4.47E+00	0	6.66E-01	8.45E+01
SM	kg	1.67E+00	0	0	0	0	0	0	0	0	0	1.67E+00
RSF	MJ, NCV	0	0	0	0	0	0	0	0	0	0	0.00E+00
NRSF	MJ, NCV	0	0	0	0	0	0	0	0	0	0	0.00E+00
RE	MJ, NCV	0	0	0	0	0	0	0	0	0	0	0.00E+00
FW	m ³	1.21E+01	3.99E-02	3.14E-03	1.36E-01	3.27E-01	0	0	9.16E-02	0	7.02E-02	1.27E+01
ADP _{fossil}	MJ, NCV	5.74E+01	2.42E+00	9.50E-02	8.26E+00	1.40E+00	0	0	4.19E+00	0	6.11E-01	7.44E+01
Output flows and waste category indicators												
HWD	kg	0	0	0	0	0	0	0	0	0	0	0.00E+00
NHWD	kg	0	0	0	0	3.44E-01	0	0	0	0	2.43E+00	2.77E+00
HLRW	kg	1.62E-05	2.89E-08	2.17E-09	9.88E-08	8.76E-07	0	0	5.70E-08	0	6.54E-08	1.73E-05
ILLRW	kg	3.77E-05	5.66E-08	5.26E-09	1.94E-07	1.96E-06	0	0	1.30E-07	0	1.64E-07	4.02E-05
CRU	kg	0	0	0	0	0	0	0	0	0	0	0.00E+00
MR	kg	0	0	0	0	0	0	0	0	0	0	0.00E+00
MER	kg	0	0	0	0	0	0	0	0	0	0	0.00E+00
EE	MJ	0	0	0	0	0	0	0	0	0	0	0.00E+00
Carbon emissions and removals												
BCRP	kg CO ₂	3.19E+00	0	0	0	0	0	0	0	0	0	3.19E+00
BCEP	kg CO ₂	0	0	0	0	1.60E-01	0	0	0	0	3.03E+00	3.19E+00
BCRK	kg CO ₂	3.65E-01	0	0	0	0	0	0	0	0	0	3.65E-01
BCEK	kg CO ₂	0	0	0	0	3.65E-01	0	0	0	0	0	3.65E-01
BCEW	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0.00E+00
CCE	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0.00E+00
CCR	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0.00E+00
CWNR	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0.00E+00

5.3. 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 molecules 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, the exceeding of thresholds, safety margins, or risks.

Life cycle impact assessment (LCIA) results are presented per functional unit for CELLU-SHIELD®. 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. 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.

These six TRACI impact categories 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. All impact categories from TRACI are used to calculate single score millipoints using the SM2013 Methodology, but it should be noted that there are known limitations related to these impact categories due to their high degree of uncertainty.

It is important to note that the LCIA indicators for carcinogenics, non carcinogenics (CTUh), and ecotoxicity (CTUe) are subject to significant uncertainty. EN 15804 includes the following disclaimer: *"The results of this environmental impact indicator shall be used with care, as the uncertainties associated with these results are high, or there is limited experience with the indicator."*

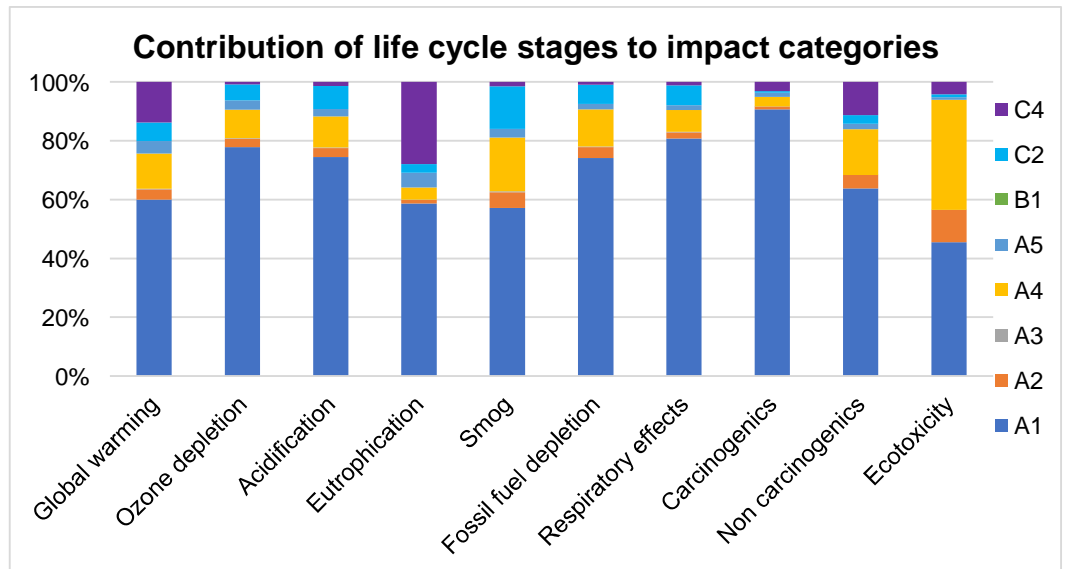
The LCIA results of CELLU-SHIELD® per functional unit are shown in **Table 19**. The percent contribution of each of the cradle-to-grave life cycle modules to the total impacts is tabulated in **Table 19** and is also presented in **Figure 5**.

Table 18. Life cycle impact assessment results for CELLU-SHIELD® per functional unit

Impact category	Unit	A1	A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Global warming	kg CO ₂ eq	3.03E+00	1.78E-01	6.97E-03	6.07E-01	2.13E-01	0	0	3.21E-01	0	6.96E-01	5.06E+00
Ozone depletion	kg CFC-11 eq	7.61E-08	2.78E-09	1.24E-10	9.49E-09	3.15E-09	0	0	5.31E-09	0	7.70E-10	9.77E-08
Acidification	kg SO ₂ eq	1.50E-02	6.21E-04	4.48E-05	2.12E-03	4.97E-04	0	0	1.57E-03	0	2.84E-04	2.01E-02
Eutrophication	kg N eq	2.00E-03	4.14E-05	2.84E-06	1.41E-04	1.70E-04	0	0	9.93E-05	0	9.48E-04	3.40E-03
Smog	kg O ₃ eq	1.90E-01	1.77E-02	1.42E-03	6.05E-02	9.96E-03	0	0	4.82E-02	0	4.83E-03	3.33E-01
Fossil fuel depletion	MJ surplus	6.84E+00	3.42E-01	1.37E-02	1.17E+00	1.73E-01	0	0	6.02E-01	0	8.16E-02	9.23E+00
Additional environmental information												
Respiratory effects	kg PM _{2.5} eq	2.36E-03	6.28E-05	6.12E-06	2.14E-04	4.82E-05	0	0	1.96E-04	0	3.49E-05	2.92E-03
Carcinogenics	CTUh	90.7%	1.0%	0.02%	3.3%	1.3%	0%	0%	0.6%	0%	3.1%	100.0%
Non carcinogenics	CTUh	63.8%	4.6%	0.01%	15.6%	1.8%	0%	0%	2.9%	0%	11.3%	100.0%
Ecotoxicity	CTUe	45.6%	10.9%	0.01%	37.4%	0.9%	0%	0%	1.0%	0%	4.2%	100.0%

Table 19. Percent contributions of each life cycle stage to each impact category for CELLU-SHIELD® per functional unit

Impact category	Unit	A1	A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Global warming	kg CO ₂ eq	60.0%	3.5%	0.1%	12.0%	4.2%	0%	0%	6.4%	0%	13.8%	100%
Ozone depletion	kg CFC-11 eq	77.9%	2.8%	0.1%	9.7%	3.2%	0%	0%	5.4%	0%	0.8%	100%
Acidification	kg SO ₂ eq	74.5%	3.1%	0.2%	10.5%	2.5%	0%	0%	7.8%	0%	1.4%	100%
Eutrophication	kg N eq	58.7%	1.2%	0.1%	4.2%	5.0%	0%	0%	2.9%	0%	27.9%	100%
Smog	kg O ₃ eq	57.1%	5.3%	0.4%	18.2%	3.0%	0%	0%	14.5%	0%	1.5%	100%
Fossil fuel depletion	MJ surplus	74.2%	3.7%	0.1%	12.7%	1.9%	0%	0%	6.5%	0%	0.9%	100%
Additional environmental information												
Respiratory effects	kg PM _{2.5} eq	80.7%	2.1%	0.2%	7.3%	1.6%	0%	0%	6.7%	0%	1.2%	100%
Carcinogenics	CTUh	90.7%	1.0%	0.02%	3.3%	1.3%	0%	0%	0.6%	0%	3.1%	100%
Non carcinogenics	CTUh	63.8%	4.6%	0.01%	15.6%	1.8%	0%	0%	2.9%	0%	11.3%	100%
Ecotoxicity	CTUe	45.6%	10.9%	0.01%	37.4%	0.9%	0%	0%	1.0%	0%	4.2%	100%


Figure 5. Contribution analysis of each impact category for CELLU-SHIELD® per functional unit

The SM2013 Methodology single figure millipoint (mPt) score by life cycle module for this product is presented in **Table 20**. In terms of single figure scores and overall environmental impacts, the raw material acquisition phase (A1–A2) has the greatest impact, contributing approximately 70% to the results. This is followed by

the construction phase (A4–A5), which accounts for around 14%, and the end-of-life phase (C1–C4), making up about 13% of the total.

Table 20. SM millipoint scores for CELLU-SHIELD® per functional unit

	Unit	Raw material acquisition	Manufacturing	Transportation	Installation and maintenance	Disposal/reuse/recycling	Total
		A1-A2	A3	A4	A5, B1-B7	C1-C4	
SM single figure score	mPts	1.85E-01	3.12E-04	3.82E-02	6.69E-03	3.30E-02	2.63E-01
	%	70.32%	0.12%	14.50%	2.54%	12.52%	100%

In the cradle-to-grave life cycle of the product, the raw material acquisition phase (A1-A2) dominates the results for all impact categories, followed by the construction phase (A4-A5) and end-of-life phase (C1-C4). The total potential CO₂-equivalent emissions generated during the cradle-to-grave stage of CELLU-SHIELD® is 5.06E+00 kg CO₂ eq. The raw material extraction and pre-processing phase (A1) contributes 3.03E+00 kg CO₂ eq, which accounts for 60% of the total CO₂-equivalent emissions. Waste disposal (C4) is the second major contributor to global warming potential, which contributes 6.96E-01 kg CO₂ eq, accounting for ~14% of the total impact. For eutrophication, the waste disposal phase (C4) is also the second major impact contributor, accounting for ~28% of the total impacts.

5.4. Sensitivity analysis

Sensitivity analyses were performed to check the robustness of the results where the highest potential environmental impacts are occurring. Among the ten TRACI impact categories, global warming potential, ozone depletion, and eutrophication were selected for analysis.

Since the majority of impacts are attributed to raw material supply, and the adhesive used in CELLU-SHIELD® is a major contributor to those impacts, the adhesive was selected for sensitivity analysis due to its relatively higher contribution to the overall results. The mass of adhesive was changed by +/-20%. This change in mass resulted in a +/-14.2% change in total global warming potential, a +/-14.3% change in ozone depletion, and a +/-12.9% change in eutrophication. The results are tabulated in **Table 21**.

Table 21. Sensitivity of adhesive mass on total impact assessment results per functional unit

Adhesive consumption	Global warming		Ozone depletion		Eutrophication	
	kg CO ₂ eq emissions	% change	kg CFC-11 eq emissions	% change	kg N eq emissions	% change
CELLU-SHIELD®						
Baseline	5.06E+00	N/A	9.77E-08	N/A	3.40E-03	N/A
+20% CELLU-SHIELD® adhesive	5.48E+00	+14.2%	1.09E-07	+14.3%	3.71E-03	+16%
-20% CELLU-SHIELD® adhesive	4.63E+00	-14.2%	8.69E-08	-14.3%	3.09E-03	-16%

The results of the sensitivity analyses show that the cradle-to-grave life cycle impacts are highly sensitive to the amount of CELLU-SHIELD® adhesive used. While the adhesive admix accounts for ~35% of the total mass of the applied and cured product, decreasing the mass of adhesive by 20% could result in a potential decrease of total impacts by approximately 14%.

5.5. Overview of relevant findings

This life cycle assessment (LCA) report assessed a multitude of inventory and environmental indicators. The primary finding was that the raw material extraction and pre-processing activities were responsible for much of the impacts in each impact category.

The second highest contributor to four out of the six major impact categories was the end-of-life phase, when insulation is manually removed from the building and landfilled. For most impact categories, the impacts associated with landfilling the insulation at the end of life are only slightly higher than the impacts associated with transporting it to the landfill, which reflects the relatively low end-of-life impacts for these products.

Outbound transportation and product installation also account for a notable impact to most impact categories. A large distribution network via trucks is responsible for impacts from distribution, and impacts during installation occur primarily due to the installation scrap and disposal of packaging materials.

5.6. Conclusion and recommendations

The goal of this study was to conduct a cradle-to-grave LCA on Isolatek's CELLU-SHIELD[®] so as to develop a Transparency Report [EPD][™]. The creation of this TR 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 primarily driven by the raw material extraction and pre-processing phase, which makes up >60% of the total global warming potential impacts and is a significant contributor among the ten TRACI 2.1 categories. End-of-life activities also contribute notably to the impacts, ranging from 5-30%.

This study did not consider the energy savings associated with the use of insulation in a building. It is expected that these savings, compared to a building that does not use insulation, would far outweigh the impacts attributed to the manufacturing, transportation, and installation of the product.

The results show that the greatest opportunity for reducing product environmental impact lies in the raw material supply phase. This is an important area for Isolatek to focus its efforts on and one which it can influence. LCIA results show that the adhesive used constitutes one-third of the total weight of CELLU-SHIELD[®], as cured and applied to buildings, yet it accounts for ~70% of the total CO₂-equivalent emissions in the A1 phase. It is recommended that Isolatek explore biobased or other more environmentally friendly adhesives, and that they work to design products which require less adhesive.

Product and packaging disposal activities also play a role. While landfilling at the end of life is currently common practice and not under the control of Isolatek, disposal activities at other stages of the life cycle can be influenced. Implementing a formal pallet and drum takeback program may reduce packaging waste, and strategies for a lower scrap rate during installation may reduce product waste, which would both have a notable impact on the total LCIA results.

Additionally, regular updates to this LCA and the associated Transparency Report [EPD][™] would enable high-quality year-over-year comparisons and serve as the

basis for a potential optimized EPD, which is assigned a higher credit value under the Materials and Resources category in LEED and would help customers looking to increase the performance of their building projects. A post-study review may provide opportunities for improving the data collection process in future years and for continuing to align with Isolatek's goals for sustainability.

6. REFERENCES

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ACRONYMS

ACLCA	American Center for Life Cycle Assessment
BOM	Bill of materials
ESL	Estimated service life
ISO	International Standardization Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact analysis
PCR	Product Category Rule document
REC	Renewable energy certificates
RSL	Reference service life
TR	Transparency Report [EPD]™
NCV	Net calorific value

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
Functional unit	Quantity of a product for use as a reference unit in an EPD based on one or more information modules
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

