LIFE CYCLE ASSESSMENT (LCA) OF SANCTUARY® BLOW-IN OR SPRAY-APPLIED INSULATUON

Status Final

Client Applegate-Greenfiber

Date October 2022

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1 INTRODUCTION

1.1 Opportunity

Applegate-Greenfiber is continuously striving to change the way people live, sleep, relax, and feel. That's why they developed the first all-in-one fiber insulation, SANCTUARY® Blow-In or Spray-Applied Insulation by Greenfiber®. With SANCTUARY in attics, walls, ceilings and floors, you can reduce the power of sound in homes by up to 60%, regulate temperatures from room-to-room, and lower heating and cooling costs.

In line with their commitment to quality and sustainability, it was important for Applegate-Greenfiber to conduct a Life Cycle Assessment (LCA) to evaluate the environmental impacts of its SANCTUARY Insulation in all life cycle stages, from raw materials to manufacturing and through to the end of life. The goal of creating this LCA is to discover the full range of environmental impacts that the SANCTUARY Insulation product has in order to identify processes to reduce overall impacts. This project is important to Applegate-Greenfiber's commitment to provide information to the market to assess the environmental impacts associated with SANCTUARY Insulation.

To understand the total impacts of SANCTUARY through all life cycle stages, Applegate-Greenfiber has decided to use a cradle-to-grave approach in conducting the LCA. By including all life cycle stages, more information becomes available for understanding how to reduce impacts.

Applegate-Greenfiber intends to use the results of the LCA to develop a Sustainable Minds Transparency Report™ (TR), an ISO 14025 Type III Environmental Declaration (EPD) that can be used for communication with and amongst other companies, architects, and consumers and that can be utilized in whole building LCA tools in conjunction with the LCA background report and Life Cycle Inventory (LCI). This study is conformant to the requirements of ISO 14040/14044, ISO 21930 standards, as well as UL Environment's product category rules (PCRs) for Building-Related Products and Services Part A: Life Cycle Assessment Calculation Rules and Report Requirements, version 4.0; and Part B: Building Envelope Thermal Insulation EPD Requirements, version 2.0 [1, 2].

Applegate-Greenfiber commissioned Sustainable Minds, an external practitioner, to develop an LCA for its SANCTAURY Insulation product.

1.2 Life cycle assessment

This LCA follows the ISO 14044 standard [3]. This study includes the following phases:

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

This study has undergone a third-party LCA review by Jack Geibig, President, Ecoform, LLC to the standards and PCRs noted in the section above.

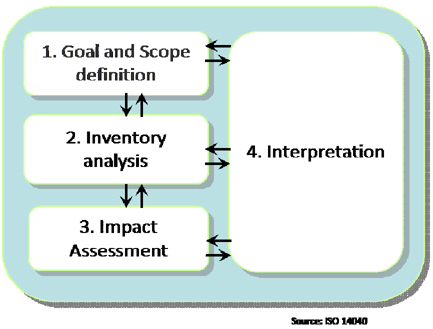

Figure 1. Life cycle assessment approach

1.3 Status

All information in this report reflects the inputs and outputs provided by Applegate-Greenfiber at the time it was collected, and best practices were followed by Sustainable Minds and Applegate-Greenfiber team members to transform the inventory into this LCA report. The data covers annual manufacturing data for calendar year 2021 for six manufacturing locations: Mesa, AZ; Norfolk, NE; Salt Lake City, UT; Tampa, FL; Waco, TX; and Wilkes-Barre, PA.

This study includes primary data from processes at six manufacturing facilities. Applegate-Greenfiber resources and other literature data were used to develop estimates or assumptions for other upstream or downstream activities where necessary to complete the inventory and fill gaps.

1.4 Structure

The remaining sections of this report are organized as follows:
Chapter 2: Goal and scope
Chapter 3: Inventory analysis
Chapter 4: Impact assessment
Chapter 5: Interpretation
Chapter 6: References

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 SANCTUARY Insulation manufactured by Applegate-Greenfiber. 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 Applegate-Greenfiber's 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). The EPD is intended to be used for a business-to-consumer (B2C) audience.

2.2 Product description

Applegate-Greenfiber joined forces on January 3rd, 2022, to form the largest nationally recognized manufacturer and marketer of cellulose insulation in the North American market. Their long-standing reputations for innovative products and industry leadership has grown and strengthened the cellulose insulation category, and more importantly, ensured a focus on product innovation that will generate better and additional feature-rich products in the marketplace. With sixteen manufacturing plants located throughout the United States and Canada, they're able to quickly and efficiently serve the needs of local homeowners, contractors, and builders.

SANCTUARY is primarily made of postconsumer paper and can be either blown-in or spray-applied in attics, walls, floors, and ceilings. This is the first all-in-one fiber insulation that is suitable for all climates and conditions. SANCTUARY is engineered to fill tiny crevices and gaps, creating a dense, scientifically advanced barrier capable of reducing the power of sound and also heating and cooling costs. It can be easily filled over existing insulation and is designed to fill every gap, void, and hard-to-reach place without time consuming cutting and fitting. For more information on SANCTUARY, go to https://www.greenfiber.com/products/sanctuary.

Of the sixteen facilities operated by Applegate-Greenfiber, prior to joining forces: six facilities had been manufacturing SANCTUARY, seven facilities had been manufacturing a product very similar to SANCTUARY, and three had not been manufacturing SANCTUARY nor a similar product. The six facilities manufacturing SANCTUARY prior to Applegate-Greenfiber joining forces are included in this study and located in Mesa, AZ; Norfolk, NE; Salt Lake City, UT; Tampa, FL; Waco, TX; and Wilkes-Barre, PA.

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 [2], the functional unit is:

> 1 m^2 of installed insulation materials with a thickness that gives an average thermal resistance RSI of 1 $m^2 \cdot K/W$ and with a building service life of 75 years (packaging included)

Building envelope thermal insulation is assumed to have a reference service life equal to that of the building, which in this case is 75 years [2]. Therefore, the insulation does not need to be replaced, and 1 m^2 of SANCTUARY Insulation is required to fulfill the functional unit. This reference service life applies for the reference in-use conditions only. The mass and thickness of SANCTUARY needed to meet the functional unit for loose-filled and stabilized application are indicated in Table 2.3.a. and are used as a baseline for the calculation of life cycle impacts. Mass per functional unit varies for different applications (loose-filled application for attics; dense pack application for sidewalls and floors; and spray applied application for sidewalls). Factors for scaling the results presented in this report to different applications, R-values, and thicknesses are given in section 2.4.

Table 2.3.a Functional unit properties for loose-filled and stabilized applications

Name	Value
Functional unit	1 m^2 of installed insulation materials with a thickness that gives an average thermal resistance RSI of 1 $m^2 \cdot K/W$.
Density at RSI of 1 $m^2 \cdot K/W$	17.1 kg per m^3
Mass (including packaging)	0.653 kg
Thickness needed to achieve functional unit	0.0378 m

Reference flows express the mass of the product required to fulfill the functional unit and are calculated based on the nominal insulation density for the R-value closest to RSI of 1 $m^2 \cdot K/W$, which varies for each facility because of varying scrap rates. Reference flows are listed in Table 2.3.b.

Table 2.3.b. Reference flows (in kg)

Materials	Mesa, AZ	Norfolk, NE	Salt Lake City, UT	Tampa, FL	Waco, TX	Wilkes-Barre, PA
Post-consumer paper	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Calcium sulfate	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Oil	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Starch	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Plastic bag	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Boric acid	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

2.4 Scaling factors

Scaling factors can be used to determine the impacts of each R-value of SANCTUARY Insulation based on different applications (loose and stabilized, dense pack, or spray-filled application). Loose-fill cellulose insulation is typically applied to enclosed areas, unfinished attic floors, and other hard to reach places, so the results per functional unit are presented for a loose-filled and stabilized application at RSI=1 $m^2 \cdot K/W$. The scaling factors below are based on the mass and thickness of SANCTUARY and can be used to determine the impacts for each R-value when multiplied by the functional unit. To calculate the environmental impact potentials per square meter of the product, simply multiply the results presented for the base functional unit results by the scaling factors shown in Table 2.4.a for the specific R-value.

Table 2.4.a SANCTUARY Insulation scaling factors

Application	R-value	Installed thickness (in)	Density (kg/m^3)	Functional mass (kg)	Scaling factor
Loose-filled and stabilized application	11	[redacted]	[redacted]	[redacted]	1.09
	13	[redacted]	[redacted]	[redacted]	1.10
	19	[redacted]	[redacted]	[redacted]	1.12
	22	[redacted]	[redacted]	[redacted]	1.13
	26	[redacted]	[redacted]	[redacted]	1.18
	30	[redacted]	[redacted]	[redacted]	1.22
	32	[redacted]	[redacted]	[redacted]	1.25
	38	[redacted]	[redacted]	[redacted]	1.33
	40	[redacted]	[redacted]	[redacted]	1.35
	44	[redacted]	[redacted]	[redacted]	1.39
	48	[redacted]	[redacted]	[redacted]	1.43
	49	[redacted]	[redacted]	[redacted]	1.43
	50	[redacted]	[redacted]	[redacted]	1.43
	60	[redacted]	[redacted]	[redacted]	1.51
Dense pack application	13	[redacted]	[redacted]	[redacted]	3.28
	21	[redacted]	[redacted]	[redacted]	3.27
	28	[redacted]	[redacted]	[redacted]	3.28
Spray-applied application	13	[redacted]	[redacted]	[redacted]	2.54
	21	[redacted]	[redacted]	[redacted]	2.54

2.5 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. The building's operational energy and water use are considered out of this study's scope; any impact the use of insulation may have on a building's energy consumption is neither calculated nor incorporated into this analysis.

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 [2].

Error! Reference source not found. represents the life cycle stages for the entire life cycle of this product. Table 2.5.a lists specific inclusions and exclusions for the system boundary.

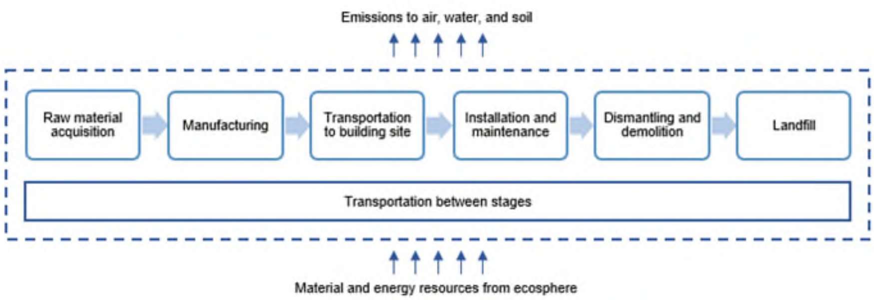

Figure 2. Applied system boundary for SANCTUARY Insulation

Table 2.5.a. System boundary inclusions and exclusions

Included	Excluded
• Raw material acquisition and processing • Processing of materials • Energy production • Transport of raw materials • Outbound transportation of products • Overhead energy (heating, lighting, forming, finishing, etc.) of manufacturing facilities when separated data were not available • Packaging of final products • Installation and maintenance, including material loss, energy use, and auxiliary material requirements • End-of-life, including transportation	• Construction of major capital equipment • Maintenance and operation of support equipment • Human labor and employee transport • Manufacture and transport of packaging materials not associated with final product • Disposal of packaging materials not associated with final product • Building operational energy and water use • Overhead energy (e.g., heating, lighting) of manufacturing facility, when separated data were available

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

Raw materials acquisition and transportation (A1-A2) These stages start when the material is extracted from nature. This stage includes raw material extraction and ends when the materials reach the gate of the production facility. The A1-A2 stage includes the following processes:

- Extraction and processing of raw materials
- Average transport of raw materials from extraction/production to manufacturer
- Processing of recycled materials
- Transport of recycled/used materials to manufacturer

Manufacturing (A3) The manufacturing/production stage starts when the raw materials enter the production site and ends with the final product leaving the production site. This stage includes:

- Manufacturing SANCTUARY Insulation
- Packaging
- Releases to environmental media (air, soil, ground, and surface water)
- Waste from the manufacturing process

2.5.2. A4-A5: Distribution and installation

Distribution (A4) Product distribution starts with the product leaving the gate of the production facility and ends after the product reaches the customer/building site.

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:

- Installation into the building including any materials specifically required for installation

- Construction and installation waste
- Releases to environmental media (air, soil, ground and surface water) of the product during installation and life of the product, which will be declared in accordance with current U.S. national standards and practices

2.5.3. B1-B7: Use

The use stage begins when the consumer starts using the product. The use stage includes:

- Product use (B1)
- Maintenance (B2)
- Repair (B3)
- Replacement (B4)
- Refurbishment (B5)
- Operational energy use (B6)
- Operational water use (B7)

Maintenance (B2) is related to any activities to maintain the function of the product in its lifetime. The estimated service life of buildings (ESL) is 75 years. A product's reference service life (RSL) depends on the product properties and reference in-use conditions. 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.

Operational energy use (B6) and operational water use (B7) are not relevant for SANCTUARY Insulation.

2.5.4. 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 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) This stage includes the dismantling/demolition of the product.

Transport (C2) This stage includes transport of the product or disassembled product components from the building site to final disposition.

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

Disposal (C4) This stage includes final disposition (recycling/reuse/landfill/waste incineration/conversion to energy).

2.5.5. 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 a complete life cycle inventory calculation workbook, which catalogs the flows crossing the system boundary and provides the starting point for life cycle impact assessment, see the appendix.

3.1 Data collection

Data used for this project represents a mix of primary data collected from Applegate-Greenfiber facilities and background data 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.

- **Gate-to-gate:** Data on the processing materials and manufacturing of SANCTUARY 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 individual Applegate-Greenfiber facilities. Inventory calculations were developed by an analyst at Sustainable Minds and reviewed internally.

- **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 relevant sections of this report. Detailed database documentation for ecoinvent can be accessed at: https://www.ecoinvent.org/database/database.html.

All primary data were provided by Applegate-Greenfiber facility operations for the 2021 calendar year. 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 individual facility participants to resolve any questions.

3.2 Primary data

SANCTUARY Insulation is produced in several manufacturing steps that involve the blending of fibers, adding the fire retardant in liquid form to the fibers, and then drying and milling the fibers before placing them into bags.

The finished products are then distributed to construction sites where they are installed, and the packaging is disposed. Building envelope thermal insulation has a 75-year reference service life, which is equal to that of the building. At end of life, the insulation is removed and disposed in a landfill. The flow chart in Figure 3 illustrate the life cycle of SANCTUARY Insulation.

Data used in this analysis represent SANCTUARY production at six Applegate-Greenfiber facilities. The inventory was first developed for the production of one 25lb bag of SANCTUARY for each facility and was later scaled to reflect the functional unit.

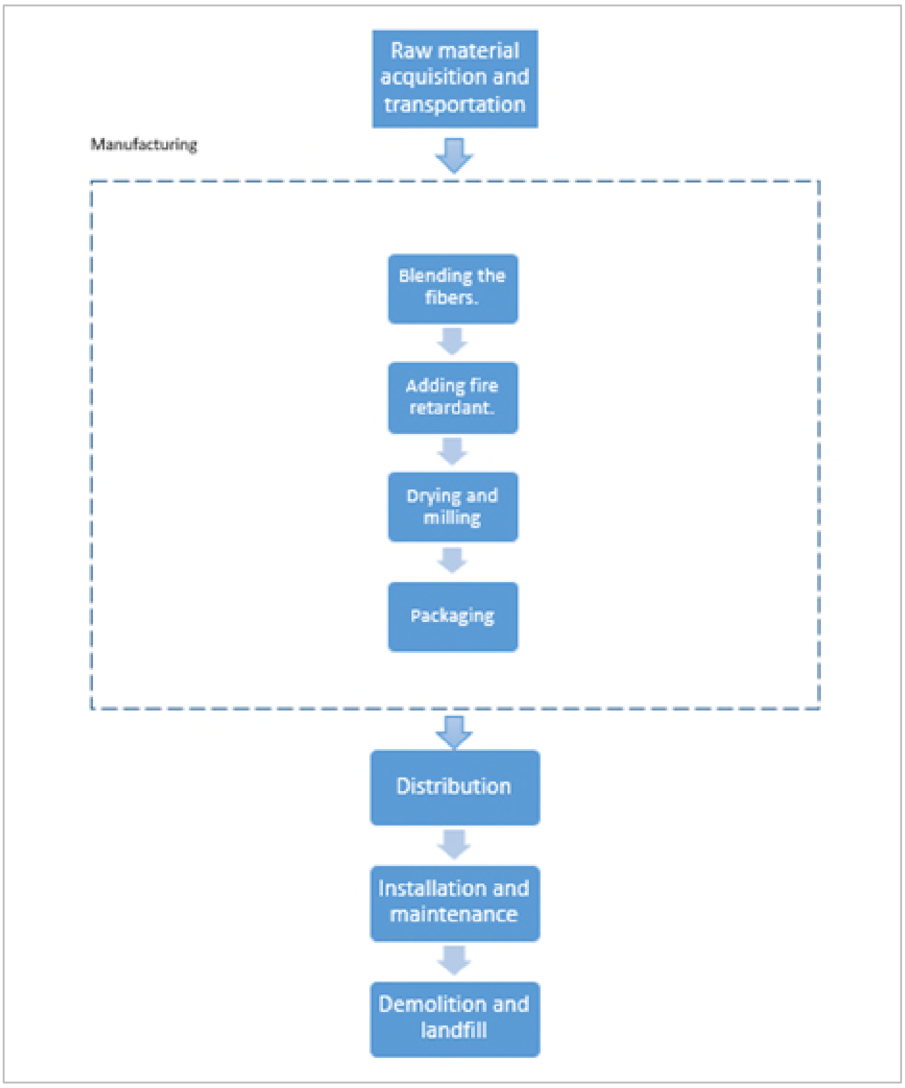

Figure 3. Life cycle flow chart of SANCTUARY Insulation

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

Raw materials acquisition and transportation represents the first stage of the insulation product life cycle.

Waste papers, boric acid, calcium sulfate, mineral oil, and other raw materials are transported to manufacturing facilities. Raw material inputs for the products are listed in Table 3.2.a to Table 3.2.f. Since wastepaper is a secondary material, it is assumed to arrive at the facilities burden-free aside from the transportation necessary to deliver it.

The product does not contain substances that are identified as hazardous according to standards or regulations of the Resource Conservation and Recovery Act (RCRA), Subtitle C, nor does it (or its associated processes) release dangerous, regulated substances that affect health and environment, including indoor air emissions, gamma or ionizing radiation emissions, or chemicals released to the air or leached to water and soil.

It should be noted that the plastic bag used for final packaging is also included as a raw material input, and its impacts also lie within the raw material acquisition stage for this study. Since the functional unit includes packaging, it is simpler to compare the reference flow to the percentage of each input.

Raw materials are transported to Applegate-Greenfiber facilities via truck, rail, and tankers. Transport data were collected for each flow and are shown in Table 3.2.a to Table 3.2.f. Wastepaper comes with bale packaging, which is assumed to be recycled and not included in the study. Calcium sulfate comes with tote bags, assumed to be made of nylon, while starch comes in paper bags. Primary information on upstream transportation was not available for the raw material packaging.

Table 3.2.a Raw material inputs for Applegate-Greenfiber facility in Mesa, AZ

Material flow	Mass percentage	Transportation mode	Distance (miles)
Wastepaper	[redacted]	Pick-up truck	200
Calcium sulfate	[redacted]	Pick-up truck	510
Oil	[redacted]	Tanker truck	1239
Starch	[redacted]	Pick-up truck	1685
Plastic bag (packaging)	[redacted]	Pick-up truck	1179
Boric acid	[redacted]	Pick-up truck	410
Raw material packaging			
Tote bag for calcium sulfate	[redacted]	NA	NA
Paper bag for starch	[redacted]	NA	NA

Table 3.2.b. Raw material inputs for Applegate-Greenfiber facility in Norfolk, NE

Material flow	Mass percentage	Transportation mode	Distance (miles)
Wastepaper	[redacted]	Pick-up truck	200
Calcium sulfate	[redacted]	Pick-up truck	540
Oil	[redacted]	Tanker truck	1030
Starch	[redacted]	Pick-up truck	700
Plastic bag (packaging)	[redacted]	Pick-up truck	930
Boric acid	[redacted]	Rail	1430
Raw material packaging			
Tote bag for calcium sulfate	[redacted]	NA	NA
Paper bag for starch	[redacted]	NA	NA

Table 3.2.c. Raw material inputs for Applegate-Greenfiber facility in Salt Lake City, UT

Material flow	Mass percentage	Transportation mode	Distance (miles)
Wastepaper	[redacted]	Truck and trailer	200
Calcium sulfate	[redacted]	Truck and trailer	134
Oil	[redacted]	Tanker truck	811
Starch	[redacted]	Truck and trailer	1538
Plastic bag (packaging)	[redacted]	Truck and trailer	1476
Boric acid	[redacted]	Rail	534
Raw material packaging			
Tote bag for calcium sulfate	[redacted]	NA	NA
Paper bag for starch	[redacted]	NA	NA

Table 3.2.d. Raw material inputs for Applegate-Greenfiber facility in Tampa, FL

Material flow	Mass percentage	Transportation mode	Distance (miles)
Wastepaper	[redacted]	Truck and trailer	250
Calcium sulfate	[redacted]	Truck and trailer	1000
Oil	[redacted]	Tanker truck	550
Starch	[redacted]	Truck and trailer	700
Plastic bag (packaging)	[redacted]	Truck and trailer	950
Boric acid	[redacted]	Rail	550
Raw material packaging			
Tote bag for calcium sulfate	[redacted]	NA	NA
Paper bag for starch	[redacted]	NA	NA

Table 3.2.e. Raw material inputs for Applegate-Greenfiber facility in Waco, TX

Material flow	Mass percentage	Transportation mode	Distance (miles)
Wastepaper	[redacted]	Truck and trailer	200
Calcium sulfate	[redacted]	Truck and trailer	338
Oil	[redacted]	Tanker truck	717
Starch	[redacted]	Truck and trailer	993
Plastic bag (packaging)	[redacted]	Truck and trailer	151
Boric acid	[redacted]	Tanker truck	78
Raw material packaging			
Tote bag for calcium sulfate	[redacted]	NA	NA
Paper bag for starch	[redacted]	NA	NA

Table 3.2.f. Raw material inputs for Applegate-Greenfiber facility in Mesa, PA

Material flow	Mass percentage	Transportation mode	Distance (miles)
Wastepaper	[redacted]	Truck and trailer	200
Calcium sulfate	[redacted]	Truck and trailer	346
Oil	[redacted]	Tanker truck	326
Starch	[redacted]	Truck and trailer	630
Plastic bag (packaging)	[redacted]	Truck and trailer	1561
Boric acid	[redacted]	Tanker truck	2555
Raw material packaging			
Tote bag for calcium sulfate	[redacted]	NA	NA
Paper bag for starch	[redacted]	NA	NA

3.2.2. Manufacturing (A3)

After raw materials are transported to Applegate-Greenfiber facilities, the incoming wastepaper is shredded. Wastepaper (fiber) is placed into a fiber handling system, which supplies the fiber to the initial size reduction line that initially shreds the fiber. Fiber then moves to the finish mills, where the final grind is conducted and the dry fire-retardant chemicals are added. The fire retardants are granular and pulverized in the chemical subsystem. The treated fiber is moved using air through a series of loops, where a liquid fire retardant is added.

The finished product is moved to the packaging subsystem, which hydraulically compresses the insulation in the final package. Each facility has a dust collection system which traps the dust from the wastepaper processing and is later sent for recycling along with production scrap.

Annual data was collected for each facility, which was later normalized using the annual production mass. Inventory was developed for one 25lb bag of SANCTUARY from each facility as shown in Table 3.2.g. Emissions associated with the production of electricity has been accounted for in the ecoinvent background process.

Table 3.2.g. Manufacturing inputs for Applegate-Greenfiber facilities per 25lb bag

	Flow	Unit	Facility locations					
			Mesa, AZ	**Norfolk, NE**	**W. Valley City, UT**	**Tampa, FL**	**Waco, TX**	**Wilkes-Barre, PA**
Input	Electricity	kWh	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Plastic stretch wraps	kg	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Output	Packaged product	kg	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Paper scrap	kg	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	Dust	kg	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

3.2.3. Distribution (A4)

Products are packaged in the manufacturing plant and shipped directly to distributors, dealers, and showrooms for purchase by end users. Primary data has been collected from all facilities for the average distribution transportation distance as listed in Table 3.2.h.

Table 3.2.h. Distribution distance for Applegate-Greenfiber facilities

Flow	Unit	Facility locations					
		Mesa, AZ	**Norfolk, NE**	**W. Valley City, UT**	**Tampa, FL**	**Waco, TX**	**Wilkes-Barre, PA**
Transport distance	km	558	711	1069	729	470	645
Liters of fuel	l/100 km	42					
Fuel type	-	Diesel					
Vehicle type	-	Standard freight trailer					
Capacity utilization	%	76					
Gross density of product transported	kg/m^3	144 (compressed in bag)					

3.2.4. Installation (A5)

At the installation site, insulation products are unpackaged and installed with a blowing machine. In the absence of primary data, 0.003 kWh electricity is assumed to be consumed during installation of a square meter of SANCTUARY Insulation, as is consistent with other EPDs for blown-in insulation [4]. Since installers commonly use scrap pieces to fill gaps such that very little scrap remains, a small installation waste of 1% has been assumed. Scrap is considered to be sent for landfilling with a waste transportation distance of 100 km.

For the disposal of packaging waste, the PCR prescribes product disposal assumptions by region. However, more recent data from US EPA are available and were used for this study. Based on US EPA's data on packaging waste, a landfilling rate of 37.1% and recycling rate of 53.9% have been used [5]. For each 25lb bag of SANCTUARY installed, 0.0130kg of plastic stretch wraps and the 0.0816kg plastic bag are assumed to be sent to disposal. Regardless of disposal scenarios, waste transport distance for both installation scrap and packaging waste is assumed to be 100 km.

3.2.5. Use (B1-B7)

The reference service life for SANCTUARY Insulation 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. Since the installed product is expected to remain undisturbed during the life of the building, there are assumed to be no impacts associated with the use stage.

3.2.6. Deconstruction (C1)

Removal at the end of life requires human labor only and therefore does not contribute to the lifetime environmental impacts.

3.2.7. End-of-life transportation (C2)

After removal, the insulation is assumed to be transported 100 km to the disposal site to be landfilled.

3.2.8. Waste processing (C3)

We assume that no waste processing is required before being landfilled.

3.2.9. Final disposal (C4)

After removal, the insulation is assumed to be landfilled. Since removal is typically associated with demolition or remodeling activities, the insulation is not assumed to be reused or recycled.

Table 3.2.i. Information on end-of-life scenarios for SANCTUARY Insulation

Name		Value	Unit
Assumptions for scenario development		Manual deconstruction, sent to landfill by truck	
Collection process	Collected separately	0	kg
	Collected with mixed construction waste	0.648	kg
Recovery	Reuse	0	kg
	Recycling	0	kg
	Landfill	0	kg
Waste transport		100	km
Final Disposal		0.648	kg
Removal of biogenic carbon (excluding packaging)		0	kg CO_2

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 for raw materials, upstream transportation, and manufacturing inputs; and estimates and assumptions for other life cycle stages. Measured primary data is considered to be of the highest precision, followed by calculated and estimated data. 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 worked extensively with the individual facilities to obtain a comprehensive set of primary data associated with the raw material inputs and manufacturing processes. 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 Table 2.5.a.

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 about 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. All facilities provided primary data for calendar year 2021 (January 2021 thru December 2021). This annual data is able to represent typical operations of the manufacturing facilities. Background data for upstream and downstream processes (e.g., raw materials, energy resources, and transportation) were obtained from the ecoinvent databases (including US ecoinvent database).

Technology coverage. Primary data were collected for SANCTUARY production at Applegate-Greenfiber facilities in the US. Where secondary data were required, data sets that best reflect the technology used for SANCTUARY production were chosen.

Geographical coverage. Applegate-Greenfiber has several facilities across the United States and Canada. As such, the geographical coverage for this study is based on North American system boundaries for all processes and products. Whenever US or Canadian background data were not readily available, other geographies were used as proxies. Following production, insulation is shipped for use within North America. Use and end-of-life impacts were modeled using background data that represents average conditions for this region.

3.4 Background data

This section details background datasets used in modeling the environmental performance of SANCTUARY Insulation. Each table lists dataset purpose, name, source, reference year, and location. Where data were missing from the databases employed, proxy datasets were identified.

3.4.1. Fuels and energy

National and regional averages for electricity grid mixes were obtained from databases in SimaPro. For manufacturing electricity, specific eGRID regions were identified and used. For installation, the US average electricity dataset was used. Table 3.4.a shows the most relevant LCI datasets used in modeling the product systems.

Table 3.4.a. Key energy datasets used in inventory analysis

Energy source	Dataset used	Primary source	Reference year	Geography
Electricity	Electricity- WECC	US EI 2.2	2018	US WECC
Electricity	Electricity- MRO	US EI 2.2	2018	US MRO
Electricity	Electricity- FRCC	US EI 2.2	2018	US FRCC
Electricity	Electricity- SERC	US EI 2.2	2018	US SERC
Electricity	Electricity- RFC	US EI 2.2	2018	US RFC
Electricity - installation	Electricity – US avg	Ecoinvent v3	2021	US

3.4.2. Raw materials extraction

Datasets for all upstream raw material production were obtained from the ecoinvent v3.8 database. Table 3.4.b shows the LCI datasets used in modeling the raw materials.

Table 3.4.b. Material datasets used in inventory analysis

Materials	Dataset used	Primary source	Reference year	Geography
Product	Gypsum, mineral (Proxy for calcium sulfate)	EI v3	2012	Rest of the World
Product	White mineral oil	EI v3	2018	North America
Product	Maize starch (Proxy for starch)	EI v3	2019	Rest of the World
Product packaging (bags)	High density polyethylene	EI v3	2019	Rest of the World
Product	Boric acid	EI v3	2021	Rest of the World
Product packaging (wraps)	Low density ethylene	EI v3	2019	Rest of the World

3.4.3. Transportation

The following datasets were used to represent typical transport modes. Global datasets have been used whenever possible.

Table 3.4.c. Transportation datasets used in inventory analysis

Transportation	Dataset name	Primary source	Reference year	Geography
Pick up truck	Transport, lorry, 3.5-7.5 metric ton	EI v3	2014	Global
Tanker truck (for oil transport)	Transport, lorry, 16-32 metric ton	EI v3	2014	Global
Truck and trailer	Transport, lorry, 16-32 metric ton	EI v3	2014	Global
Waste transport	Transport, lorry, 7.5-16 metric ton	EI v3	2014	Rest of the World
Rail	Transport, freight, train	EI v3	2021	Global

3.4.4. Disposal

Disposal processes were also obtained from the ecoinvent database to represent disposal scenarios in the US. Table 3.4.d shows the relevant disposal datasets used in the model.

Table 3.4.d. Disposal datasets used in inventory analysis

Material & Disposition	Dataset name	Primary Source	Reference year	Geography
Solid waste to landfill	Disposal, inert waste to inert materials landfill	US EI-2.2	2019	US
Hazardous waste to landfill	Disposal, hazardous waste, for underground deposit	US EI-2.2	2019	US

3.4.5. Emissions to air, water, and soil

Dust is generated during the manufacturing process in all facilities. The facilities have all installed a dust collection system to avoid the generated dust from being emitted to the atmosphere. The collected fiber dust is sent to recycling plants later along with wastepaper scraps.

Data for all upstream materials and electricity were obtained from the ecoinvent database. The emissions due to the use of electricity are accounted for within the database processes. Emissions associated with transportation were determined by capturing the logistical operations.

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:

- 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. The completeness of the bill of materials defined in this report satisfies the above defined cut-off criteria.

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 PCRs prescribe to report where and how allocation occurs in the modeling of the LCA. The allocation methods used were re-examined according to the updated allocation rules in ISO 21930:2017 and were determined to be in conformance; therefore, no updates to allocation methods were made. In this LCA, the following rules have been applied.

The model used in this report ensures that the sum of the allocated inputs and outputs of a unit process shall be 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.

All the facilities in this study provided annual data for one product: SANCTUARY Insulation. Manufacturing inputs were allocated by mass by the Applegate-Greenfiber team using the amount of SANCTUARY produced compared to total production for CY2021. Based on annual production mass, the inventory (material and resources inputs and outputs) was developed for each facility for the production of a 25lb bag of SANCTUARY Insulation, which was later scaled to meet the functional unit. No further allocation was performed by Sustainable Minds in these calculations.

3.8 Software and database

The LCA model was created using SimaPro Developer 9.4. Ecoinvent and other databases listed in section 3.4 provide the life cycle inventory data for the raw materials and processes for modeling the products.

3.9 Critical review

This is a supporting LCA report for the Applegate-Greenfiber SANCTUARY Insulation Transparency Report which will be evaluated for conformance to the PCRs according to ISO 14025 and the ISO 14040/14044 standards [3, 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.a). The impact indicators are derived using the 100-year time horizon[1] 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.a. 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	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	Carcinogens have the potential to form cancers in humans.
Non-carcinogenics	CTUh	Non-Carcinogens 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.

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

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.

[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 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.

4.2 Normalization and weighting

To arrive to a single score indicator, normalization [9] and weighting [10] as shown in Table 4.2.a conforming to the SM 2013 Methodology were applied.

Table 4.2.a. 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 product studied. It details the results per product per functional unit and concludes with recommendations. The results are presented per functional unit (per m^2 of installed insulation with an R-value of RSI=1 $m^2 \cdot K/W$).

5.1 Resource use and waste flows

Resource use indicators, output flows, 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 electricity grid mixes used, and no energy was recovered.

Table 5.1.a to Table 5.1.f show resource use, output and waste flows, and carbon emissions and removals per functional unit for SANCTUARY Insulation produced at various production facilities.

Table 5.1.a. Resource use, output and waste flows, and carbon emissions and removals per functional unit of SANCTUARY Insulation – Production at Mesa, AZ facility

	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	5.18E-02	1.55E-03	2.33E-01	7.20E-04	6.73E-04	0	0	0	0	0	0	0	0	1.55E-04	0	3.50E-05	2.88E-01
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	2.00E-01	5.65E-04	2.56E-02	0	2.05E-04	0	0	0	0	0	0	0	0	0	0	0	2.27E-01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	2.52E-01	2.11E-03	2.58E-01	7.20E-04	8.78E-04	0	0	0	0	0	0	0	0	1.55E-04	0	3.50E-05	5.14E-01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	1.98E+00	1.62E+00	1.26E+00	7.55E-01	1.22E-02	0	0	0	0	0	0	0	0	1.62E-01	0	2.23E-02	5.81E+00
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	1.75E-04	4.85E-06	2.37E-06	0	2.40E-08	0	0	0	0	0	0	0	0	0	0	0	1.82E-04
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	1.98E+00	1.62E+00	1.26E+00	7.55E-01	1.22E-02	0	0	0	0	0	0	0	0	1.62E-01	0	2.23E-02	5.81E+00
Secondary materials (SM)	kg	5.67E-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.67E-01
Renewable secondary fuels (RSF)	MJ, LHV	0	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	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net freshwater resources (FW)	m^3	1.79E-01	8.05E-03	4.84E-03	3.74E-03	2.98E-03	0	0	0	0	0	0	0	0	8.04E-04	0	3.92E-06	1.99E-01
Output flows and waste category indicat																		
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	0	0	1.86E-03	0	8.50E-03	0	0	0	0	0	0	0	0	0	0	0	1.04E-02
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	2.18E-05	5.59E-07	3.06E-06	2.60E-07	8.10E-07	0	0	0	0	0	0	0	0	5.58E-08	0	2.39E-09	2.65E-05
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	5.09E-08	2.40E-07	3.00E-08	1.12E-07	1.17E-09	0	0	0	0	0	0	0	0	2.40E-08	0	2.52E-11	4.58E-07
Components for re-use (CRU)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling (MR)	kg	0	0	1.78E-02	0	6.47E-03	0	0	0	0	0	0	0	0	0	0	0	2.43E-02
Materials for energy recovery (MER)	kg	0	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	0
Carbon emissions and removals																		
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	1.04E+00	0	5.76E-02	0	0	0	0	0	0	0	0	0	0	0	0	0	1.10E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	0	0	2.06E-02	0	3.69E-03	0	0	0	0	0	0	0	0	0	0	9.98E-01	1.02E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	2.54E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.54E-04
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions (CCE)	kg CO_2	0	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	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	0

Table 5.1.b Resource use, output and waste flows, and carbon emissions and removals per functional unit of SANCTUARY Insulation – Production at Norfolk, NE facility

	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	5.18E-02	2.54E-03	2.23E-01	9.17E-04	6.80E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	2.79E-01
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	2.00E-01	6.16E-04	1.86E-02	0	2.05E-04	0	0	0	0	0	0	0	0	0	0	0	2.20E-01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	2.52E-01	3.16E-03	2.42E-01	9.17E-04	8.85E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	4.99E-01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	1.98E+00	1.42E+00	1.46E+00	9.62E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	6.01E+00
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	1.87E-04	1.75E-04	6.22E-06	0	2.87E-06	0	0	0	0	0	0	0	0	0	0	0	3.71E-04
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	1.98E+00	1.42E+00	1.46E+00	9.62E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	6.01E+00
Secondary materials (SM)	kg	5.83E-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.83E-01
Renewable secondary fuels (RSF)	MJ, LHV	0	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	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net freshwater resources (FW)	m^3	1.79E-01	1.27E-02	6.09E-03	4.77E-03	2.98E-03	0	0	0	0	0	0	0	0	8.04E-04	0	3.92E-06	2.06E-01
Output flows and waste category indicat																		
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	0	0	1.86E-03	0	8.50E-03	0	0	0	0	0	0	0	0	0	0	0	1.04E-02
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	2.20E-05	1.14E-06	3.33E-06	3.34E-07	8.10E-07	0	0	0	0	0	0	0	0	5.58E-08	0	2.39E-09	2.77E-05
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	5.14E-08	2.12E-07	3.30E-08	1.44E-07	1.17E-09	0	0	0	0	0	0	0	0	2.40E-08	0	2.52E-11	4.65E-07
Components for re-use (CRU)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling (MR)	kg	0	0	3.34E-02	0	6.47E-03	0	0	0	0	0	0	0	0	0	0	0	3.98E-02
Materials for energy recovery (MER)	kg	0	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	0
Carbon emissions and removals																		
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	1.07E+00	0	5.76E-02	0	0	0	0	0	0	0	0	0	0	0	0	0	1.13E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	0	0	3.85E-02	0	3.69E-03	0	0	0	0	0	0	0	0	0	0	9.98E-01	1.04E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	2.54E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.54E-04
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions (CCE)	kg CO_2	0	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	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	0

Table 5.1.c. Resource use, output and waste flows, and carbon emissions and removals per functional unit of SANCTUARY Insulation – Production at Salt Lake City, UT facility

	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	5.18E-02	9.07E-04	1.46E-01	1.38E-03	6.80E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	2.01E-01
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	2.00E-01	2.14E-04	1.60E-02	0	2.05E-04	0	0	0	0	0	0	0	0	0	0	0	2.17E-01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	2.52E-01	1.12E-03	1.62E-01	1.38E-03	8.85E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	4.17E-01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	1.98E+00	4.85E-01	8.12E-01	1.44E+00	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	4.92E+00
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	1.75E-04	2.19E-06	2.36E-06	0	2.42E-08	0	0	0	0	0	0	0	0	0	0	0	1.79E-04
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	1.98E+00	4.85E-01	8.12E-01	1.44E+00	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	4.92E+00
Secondary materials (SM)	kg	5.64E-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.64E-01
Renewable secondary fuels (RSF)	MJ, LHV	0	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	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net freshwater resources (FW)	m^3	1.79E-01	4.53E-03	4.23E-03	7.16E-03	2.98E-03	0	0	0	0	0	0	0	0	8.04E-04	0	3.92E-06	1.99E-01
Output flows and waste category indicat																		
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	0	0	1.86E-03	0	8.50E-03	0	0	0	0	0	0	0	0	0	0	0	1.04E-02
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	2.18E-05	4.04E-07	2.07E-06	4.97E-07	8.10E-07	0	0	0	0	0	0	0	0	5.58E-08	0	2.39E-09	2.56E-05
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	5.09E-08	7.16E-08	1.91E-08	2.14E-07	1.17E-09	0	0	0	0	0	0	0	0	2.40E-08	0	2.52E-11	3.81E-07
Components for re-use (CRU)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling (MR)	kg	0	0	1.49E-02	0	6.47E-03	0	0	0	0	0	0	0	0	0	0	0	2.14E-02
Materials for energy recovery (MER)	kg	0	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	0
Carbon emissions and removals																		
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	1.04E+00	0	5.76E-02	0	0	0	0	0	0	0	0	0	0	0	0	0	1.10E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	0	0	1.72E-02	0	3.69E-03	0	0	0	0	0	0	0	0	0	0	9.98E-01	1.02E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	2.54E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.54E-04
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions (CCE)	kg CO_2	0	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	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	0

Table 5.1.d. Resource use, output and waste flows, and carbon emissions and removals per functional unit of SANCTUARY Insulation – Production at Tampa, FL facility

	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	5.18E-02	6.61E-04	1.19E-02	9.40E-04	6.80E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	6.61E-02
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	2.00E-01	2.41E-04	4.68E-02	0	2.05E-04	0	0	0	0	0	0	0	0	0	0	0	2.48E-01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	2.52E-01	9.02E-04	5.87E-02	9.40E-04	8.85E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	3.14E-01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	1.98E+00	6.93E-01	1.98E+00	9.86E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	5.83E+00
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	1.75E-04	2.07E-06	2.38E-06	0	2.42E-08	0	0	0	0	0	0	0	0	0	0	0	1.79E-04
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	1.98E+00	6.93E-01	1.98E+00	9.86E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	5.83E+00
Secondary materials (SM)	kg	5.83E-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.83E-01
Renewable secondary fuels (RSF)	MJ, LHV	0	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	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net freshwater resources (FW)	m^3	2.07E-01	3.44E-03	1.25E-02	4.89E-03	2.99E-03	0	0	0	0	0	0	0	0	8.04E-04	0	1.54E-04	2.32E-01
Output flows and waste category indicat																		
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	0	0	1.86E-03	0	8.50E-03	0	0	0	0	0	0	0	0	0	0	0	1.04E-02
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	2.18E-05	2.38E-07	4.76E-06	3.39E-07	8.10E-07	0	0	0	0	0	0	0	0	5.58E-08	0	2.39E-09	2.80E-05
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	5.09E-08	1.03E-07	4.98E-08	1.46E-07	1.17E-09	0	0	0	0	0	0	0	0	2.40E-08	0	2.52E-11	3.74E-07
Components for re-use (CRU)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling (MR)	kg	0	0	3.34E-02	0	6.47E-03	0	0	0	0	0	0	0	0	0	0	0	3.98E-02
Materials for energy recovery (MER)	kg	0	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	0
Carbon emissions and removals																		
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	1.07E+00	0	5.76E-02	0	0	0	0	0	0	0	0	0	0	0	0	0	1.13E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	0	0	3.85E-02	0	3.69E-03	0	0	0	0	0	0	0	0	0	0	9.98E-01	1.04E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	2.54E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.54E-04
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions (CCE)	kg CO_2	0	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	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	0

Table 5.1.e. Resource use, output and waste flows, and carbon emissions and removals per functional unit of SANCTUARY Insulation – Production at Waco, TX facility

	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	5.35E-02	4.42E-04	2.54E-02	6.06E-04	6.80E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	8.08E-02
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	2.01E-01	1.61E-04	3.45E-02	0	2.05E-04	0	0	0	0	0	0	0	0	0	0	0	2.36E-01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	2.54E-01	6.04E-04	5.99E-02	6.06E-04	8.85E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	3.16E-01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	2.00E+00	4.64E-01	1.61E+00	6.35E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	4.91E+00
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	1.80E-04	1.39E-06	2.38E-06	0	2.42E-08	0	0	0	0	0	0	0	0	0	0	0	1.84E-04
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	2.00E+00	4.64E-01	1.61E+00	6.35E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	4.91E+00
Secondary materials (SM)	kg	5.83E-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.83E-01
Renewable secondary fuels (RSF)	MJ, LHV	0	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	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net freshwater resources (FW)	m^3	1.85E-01	2.30E-03	4.86E-03	3.15E-03	2.98E-03	0	0	0	0	0	0	0	0	8.04E-04	0	3.92E-06	1.99E-01
Output flows and waste category indicat																		
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	0	0	1.65E-03	0	8.50E-03	0	0	0	0	0	0	0	0	0	0	0	1.01E-02
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	2.25E-05	1.60E-07	6.88E-06	2.19E-07	8.10E-07	0	0	0	0	0	0	0	0	5.58E-08	0	2.39E-09	3.07E-05
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	5.26E-08	6.86E-08	7.31E-08	9.41E-08	1.17E-09	0	0	0	0	0	0	0	0	2.40E-08	0	2.52E-11	3.14E-07
Components for re-use (CRU)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling (MR)	kg	0	0	3.31E-02	0	6.47E-03	0	0	0	0	0	0	0	0	0	0	0	3.96E-02
Materials for energy recovery (MER)	kg	0	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	0
Carbon emissions and removals																		
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	1.07E+00	0	5.76E-02	0	0	0	0	0	0	0	0	0	0	0	0	0	1.13E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	0	0	3.82E-02	0	3.69E-03	0	0	0	0	0	0	0	0	0	0	9.98E-01	1.04E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	2.54E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.54E-04
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions (CCE)	kg CO_2	0	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	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	0

Table 5.1.f. Resource use, output and waste flows, and carbon emissions and removals per functional unit of SANCTUARY Insulation – Production at Wilkes-Barre, PA facility

	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	5.38E-02	8.92E-04	1.54E-02	8.32E-04	6.80E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	7.18E-02
Renewable primary resources with energy content used as material (RPRM)	MJ, LHV	2.01E-01	3.25E-04	1.05E-02	0	2.05E-04	0	0	0	0	0	0	0	0	0	0	0	2.12E-01
Total use of renewable primary resources with energy content (RPRT)	MJ, LHV	2.55E-01	1.22E-03	2.59E-02	8.32E-04	8.85E-04	0	0	0	0	0	0	0	0	1.56E-04	0	3.54E-05	2.84E-01
Non-renewable primary resources used as an energy carrier (fuel) (NRPRE)	MJ, LHV	1.84E+00	9.35E-01	1.04E+00	8.73E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	4.89E+00
Non-renewable primary resources with energy content used as material (NRPRM)	MJ, LHV	1.84E-04	2.80E-06	2.37E-06	0	2.42E-08	0	0	0	0	0	0	0	0	0	0	0	1.89E-04
Total use of non-renewable primary resources with energy content (NRPRT)	MJ, LHV	1.84E+00	9.35E-01	1.04E+00	8.73E-01	1.23E-02	0	0	0	0	0	0	0	0	1.64E-01	0	2.26E-02	4.89E+00
Secondary materials (SM)	kg	5.74E-01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.74E-01
Renewable secondary fuels (RSF)	MJ, LHV	0	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	0
Recovered energy (RE)	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Use of net freshwater resources (FW)	m^3	2.12E-01	4.64E-03	3.70E-02	4.33E-03	2.99E-03	0	0	0	0	0	0	0	0	8.04E-04	0	1.54E-04	2.62E-01
Output flows and waste category indicat																		
Hazardous waste disposed (HWD)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-hazardous waste disposed (NHWD)	kg	0	0	1.27E-03	0	8.50E-03	0	0	0	0	0	0	0	0	0	0	0	9.77E-03
High-level radioactive waste, conditioned, to final repository (HLRW)	kg	2.29E-05	3.22E-07	5.24E-06	3.00E-07	8.10E-07	0	0	0	0	0	0	0	0	5.58E-08	0	2.39E-09	2.97E-05
Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)	kg	5.28E-08	1.38E-07	5.44E-08	1.29E-07	1.17E-09	0	0	0	0	0	0	0	0	2.40E-08	0	2.52E-11	4.00E-07
Components for re-use (CRU)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling (MR)	kg	0	0	1.86E-02	0	6.47E-03	0	0	0	0	0	0	0	0	0	0	0	2.51E-02
Materials for energy recovery (MER)	kg	0	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	0
Carbon emissions and removals																		
Biogenic Carbon Removal from Product (BCRP)	kg CO_2	1.05E+00	0	5.76E-02	0	0	0	0	0	0	0	0	0	0	0	0	0	1.11E+00
Biogenic Carbon Emission from Product (NCEP)	kg CO_2	0	0	2.15E-02	0	3.73E-03	0	0	0	0	0	0	0	0	0	0	1.01E+00	1.03E+00
Biogenic Carbon Removal from Packaging (BCRK)	kg CO_2	2.54E-04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.54E-04
Biogenic Carbon Emission from Packaging (BCEK)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes (BCEW)	kg CO_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions (CCE)	kg CO_2	0	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	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	0

5.2 Life cycle impact assessment

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 SANCTUARY Insulation manufactured by Applegate-Greenfiber. 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 [8]. USEtox indicators are used to evaluate human toxicity and ecotoxicity, which will be reported in the TR under additional environmental information. 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 [7].

The six impact categories 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 TR users shall not use additional measures for comparative purposes. Impact categories which were not required by the PCR are included in part to allow for the calculation of 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.

5.2.1. Impact assessment results

The impact results have been calculated per functional unit of SANCTUARY for each facility per life cycle stage in Table 5.2.a to Table 5.2.f.

For SANCTUARY Insulation, the cradle-to-gate stages (A1-A3) dominate the results for all impact categories. Following the A1-A3 stages, the next highest impacts come from the transportation of product from the manufacturing facilities to the building sites. The impacts stemming from raw material extraction (A1) are mainly from boric acid and oil, which are used for the processing of wastepaper into the insulation. The electricity required to operate the facilities is the largest contributor to the impacts in the manufacturing (A3) stage. The use of trucks and rails for upstream transport of raw materials leads to the emissions in the upstream transport stage (A2), and same is the case for downstream transport (A4). The only impacts associated with the installation and maintenance stage, though insignificant, are due to the disposal of packaging and the insulation blower machine used to install the product. End-of-life stages make little contribution to the overall life cycle impacts.

Table 5.2.a. Potential impact results per functional unit of SANCTUARY Insulation – Production at Mesa, AZ

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	6.01E-09	2.73E-08	2.29E-09	1.27E-08	8.70E-11	0	0	0	0	0	0	0	0	2.76E-09	0	2.74E-10	5.15E-08
Global warming	kg CO_2 eq	8.82E-02	1.16E-01	8.33E-02	5.34E-02	7.53E-04	0	0	0	0	0	0	0	0	1.17E-02	0	1.61E-03	3.55E-01
Smog (SFP)	kg O_3 eq	1.02E-02	2.37E-03	2.80E-03	1.19E-03	2.40E-05	0	0	0	0	0	0	0	0	2.53E-04	0	4.68E-04	1.73E-02
Acidification (AP)	kg SO_2 eq	1.07E-03	1.94E-04	3.24E-04	9.28E-05	1.93E-06	0	0	0	0	0	0	0	0	2.00E-05	0	1.55E-05	1.72E-03
Eutrophication (EP)	kg N eq	1.02E-04	4.12E-05	2.72E-05	1.93E-05	4.48E-07	0	0	0	0	0	0	0	0	4.18E-06	0	1.52E-06	1.96E-04
Carcinogenics	CTUh	2.67E-09	9.13E-11	1.62E-10	4.90E-11	2.66E-12	0	0	0	0	0	0	0	0	9.85E-12	0	4.71E-13	2.99E-09
Non-carcinogenics	CTUh	3.82E-08	1.11E-08	2.73E-09	7.49E-09	5.15E-11	0	0	0	0	0	0	0	0	1.35E-09	0	1.86E-11	6.09E-08
Respiratory effects	kg $PM_{2.5}$ eq	1.69E-04	3.05E-05	1.96E-05	1.87E-05	1.20E-06	0	0	0	0	0	0	0	0	3.52E-06	0	2.01E-06	2.44E-04
Ecotoxicity	CTUe	3.07E-01	2.15E-01	6.78E-03	1.52E-01	6.27E-04	0	0	0	0	0	0	0	0	2.68E-02	0	1.53E-04	7.08E-01
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.54E-01	2.43E-01	1.12E-01	1.13E-01	1.03E-03	0	0	0	0	0	0	0	0	2.45E-02	0	3.41E-03	7.51E-01

Table 5.2.b. Potential impact results per functional unit of SANCTUARY Insulation – Production at Norfolk, NE

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	6.01E-09	2.36E-08	3.16E-09	1.62E-08	8.62E-11	0	0	0	0	0	0	0	0	2.73E-09	0	2.72E-10	5.20E-08
Global warming	kg CO_2 eq	8.82E-02	1.01E-01	1.06E-01	6.80E-02	7.46E-04	0	0	0	0	0	0	0	0	1.15E-02	0	1.59E-03	3.78E-01
Smog (SFP)	kg O_3 eq	1.02E-02	3.36E-03	4.35E-03	1.52E-03	2.38E-05	0	0	0	0	0	0	0	0	2.50E-04	0	4.63E-04	2.01E-02
Acidification (AP)	kg SO_2 eq	1.07E-03	2.10E-04	5.13E-04	1.18E-04	1.91E-06	0	0	0	0	0	0	0	0	1.98E-05	0	1.54E-05	1.95E-03
Eutrophication (EP)	kg N eq	1.02E-04	3.82E-05	4.58E-05	2.46E-05	4.43E-07	0	0	0	0	0	0	0	0	4.14E-06	0	1.50E-06	2.17E-04
Carcinogenics	CTUh	2.67E-09	8.27E-11	2.61E-10	6.24E-11	2.64E-12	0	0	0	0	0	0	0	0	9.75E-12	0	4.67E-13	3.09E-09
Non-carcinogenics	CTUh	3.82E-08	9.40E-09	4.29E-09	9.55E-09	5.10E-11	0	0	0	0	0	0	0	0	1.34E-09	0	1.85E-11	6.28E-08
Respiratory effects	kg $PM_{2.5}$ eq	1.69E-04	2.98E-05	2.94E-05	2.38E-05	1.19E-06	0	0	0	0	0	0	0	0	3.49E-06	0	1.99E-06	2.58E-04
Ecotoxicity	CTUe	3.07E-01	1.80E-01	1.07E-02	1.93E-01	6.21E-04	0	0	0	0	0	0	0	0	2.65E-02	0	1.51E-04	7.17E-01
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.54E-01	2.11E-01	8.96E-02	1.44E-01	1.02E-03	0	0	0	0	0	0	0	0	2.43E-02	0	3.38E-03	7.28E-01

Table 5.2.c. Potential impact results per functional unit of SANCTUARY Insulation–Production at Salt Lake City, UT

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	6.01E-09	8.06E-09	1.46E-09	2.43E-08	8.62E-11	0	0	0	0	0	0	0	0	2.73E-09	0	2.72E-10	4.30E-08
Global warming	kg CO_2 eq	8.82E-02	3.44E-02	5.28E-02	1.02E-01	7.46E-04	0	0	0	0	0	0	0	0	1.15E-02	0	1.59E-03	2.91E-01
Smog (SFP)	kg O_3 eq	1.02E-02	1.24E-03	1.79E-03	2.28E-03	2.38E-05	0	0	0	0	0	0	0	0	2.50E-04	0	4.63E-04	1.62E-02
Acidification (AP)	kg SO_2 eq	1.07E-03	7.44E-05	2.05E-04	1.77E-04	1.91E-06	0	0	0	0	0	0	0	0	1.98E-05	0	1.54E-05	1.57E-03
Eutrophication (EP)	kg N eq	1.02E-04	1.32E-05	1.72E-05	3.70E-05	4.43E-07	0	0	0	0	0	0	0	0	4.14E-06	0	1.50E-06	1.76E-04
Carcinogenics	CTUh	2.67E-09	3.24E-11	1.05E-10	9.37E-11	2.64E-12	0	0	0	0	0	0	0	0	9.75E-12	0	4.67E-13	2.91E-09
Non-carcinogenics	CTUh	3.82E-08	4.65E-09	1.74E-09	1.43E-08	5.10E-11	0	0	0	0	0	0	0	0	1.34E-09	0	1.85E-11	6.03E-08
Respiratory effects	kg $PM_{2.5}$ eq	1.69E-04	1.31E-05	1.26E-05	3.58E-05	1.19E-06	0	0	0	0	0	0	0	0	3.49E-06	0	1.99E-06	2.37E-04
Ecotoxicity	CTUe	3.07E-01	9.33E-02	4.66E-03	2.90E-01	6.21E-04	0	0	0	0	0	0	0	0	2.65E-02	0	1.51E-04	7.22E-01
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.54E-01	7.23E-02	7.32E-02	2.16E-01	1.02E-03	0	0	0	0	0	0	0	0	2.43E-02	0	3.38E-03	6.45E-01

Table 5.2.d. Potential impact results per functional unit of SANCTUARY Insulation – Production at Tampa, FL

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	6.01E-09	1.17E-08	2.36E-09	1.66E-08	8.70E-11	0	0	0	0	0	0	0	0	2.76E-09	0	2.74E-10	3.98E-08
Global warming	kg CO_2 eq	8.82E-02	4.90E-02	1.16E-01	6.97E-02	7.53E-04	0	0	0	0	0	0	0	0	1.17E-02	0	1.61E-03	3.37E-01
Smog (SFP)	kg O_3 eq	1.02E-02	1.09E-03	2.43E-03	1.55E-03	2.40E-05	0	0	0	0	0	0	0	0	2.53E-04	0	4.68E-04	1.60E-02
Acidification (AP)	kg SO_2 eq	1.07E-03	8.51E-05	2.32E-04	1.21E-04	1.93E-06	0	0	0	0	0	0	0	0	2.00E-05	0	1.55E-05	1.55E-03
Eutrophication (EP)	kg N eq	1.02E-04	1.77E-05	1.75E-05	2.52E-05	4.48E-07	0	0	0	0	0	0	0	0	4.18E-06	0	1.52E-06	1.69E-04
Carcinogenics	CTUh	2.67E-09	4.49E-11	1.07E-10	6.39E-11	2.66E-12	0	0	0	0	0	0	0	0	9.85E-12	0	4.71E-13	2.90E-09
Non-carcinogenics	CTUh	3.82E-08	6.88E-09	2.07E-09	9.78E-09	5.15E-11	0	0	0	0	0	0	0	0	1.35E-09	0	1.86E-11	5.83E-08
Respiratory effects	kg $PM_{2.5}$ eq	1.69E-04	1.72E-05	1.52E-05	2.44E-05	1.20E-06	0	0	0	0	0	0	0	0	3.52E-06	0	2.01E-06	2.32E-04
Ecotoxicity	CTUe	3.07E-01	1.39E-01	5.82E-03	1.98E-01	6.27E-04	0	0	0	0	0	0	0	0	2.68E-02	0	1.53E-04	6.77E-01
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.54E-01	1.04E-01	2.45E-01	1.48E-01	1.03E-03	0	0	0	0	0	0	0	0	2.45E-02	0	3.41E-03	7.79E-01

Table 5.2.e. Potential impact results per functional unit of SANCTUARY Insulation – Production at Waco, TX

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	6.21E-09	7.81E-09	3.59E-09	1.07E-08	8.62E-11	0	0	0	0	0	0	0	0	2.73E-09	0	2.72E-10	3.14E-08
Global warming	kg CO_2 eq	9.01E-02	3.28E-02	8.43E-02	4.49E-02	7.46E-04	0	0	0	0	0	0	0	0	1.15E-02	0	1.59E-03	2.66E-01
Smog (SFP)	kg O_3 eq	1.05E-02	7.31E-04	2.65E-03	1.00E-03	2.38E-05	0	0	0	0	0	0	0	0	2.50E-04	0	4.63E-04	1.56E-02
Acidification (AP)	kg SO_2 eq	1.10E-03	5.70E-05	2.94E-04	7.81E-05	1.91E-06	0	0	0	0	0	0	0	0	1.98E-05	0	1.54E-05	1.57E-03
Eutrophication (EP)	kg N eq	1.04E-04	1.19E-05	2.47E-05	1.63E-05	4.43E-07	0	0	0	0	0	0	0	0	4.14E-06	0	1.50E-06	1.63E-04
Carcinogenics	CTUh	2.73E-09	3.01E-11	1.52E-10	4.12E-11	2.64E-12	0	0	0	0	0	0	0	0	9.75E-12	0	4.67E-13	2.97E-09
Non-carcinogenics	CTUh	3.99E-08	4.60E-09	2.63E-09	6.31E-09	5.10E-11	0	0	0	0	0	0	0	0	1.34E-09	0	1.85E-11	5.49E-08
Respiratory effects	kg $PM_{2.5}$ eq	1.74E-04	1.15E-05	1.83E-05	1.57E-05	1.19E-06	0	0	0	0	0	0	0	0	3.49E-06	0	1.99E-06	2.26E-04
Ecotoxicity	CTUe	3.11E-01	9.30E-02	7.60E-03	1.27E-01	6.21E-04	0	0	0	0	0	0	0	0	2.65E-02	0	1.51E-04	5.67E-01
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.57E-01	6.95E-02	1.27E-01	9.52E-02	1.02E-03	0	0	0	0	0	0	0	0	2.43E-02	0	3.38E-03	5.77E-01

Table 5.2.f. Potential impact results per functional unit of SANCTUARY Insulation – Production at Wilkes-Barre, PA

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	6.29E-09	1.58E-08	2.78E-09	1.47E-08	8.62E-11	0	0	0	0	0	0	0	0	2.73E-09	0	2.72E-10	4.26E-08
Global warming	kg CO_2 eq	8.65E-02	6.61E-02	5.13E-02	6.17E-02	7.46E-04	0	0	0	0	0	0	0	0	1.15E-02	0	1.59E-03	2.79E-01
Smog (SFP)	kg O_3 eq	1.03E-02	1.47E-03	1.89E-03	1.38E-03	2.38E-05	0	0	0	0	0	0	0	0	2.50E-04	0	4.63E-04	1.58E-02
Acidification (AP)	kg SO_2 eq	1.10E-03	1.15E-04	2.24E-04	1.07E-04	1.91E-06	0	0	0	0	0	0	0	0	1.98E-05	0	1.54E-05	1.58E-03
Eutrophication (EP)	kg N eq	1.03E-04	2.39E-05	1.88E-05	2.23E-05	4.43E-07	0	0	0	0	0	0	0	0	4.14E-06	0	1.50E-06	1.74E-04
Carcinogenics	CTUh	2.59E-09	6.07E-11	1.19E-10	5.66E-11	2.64E-12	0	0	0	0	0	0	0	0	9.75E-12	0	4.67E-13	2.84E-09
Non-carcinogenics	CTUh	3.94E-08	9.28E-09	1.82E-09	8.66E-09	5.10E-11	0	0	0	0	0	0	0	0	1.34E-09	0	1.85E-11	6.06E-08
Respiratory effects	kg $PM_{2.5}$ eq	1.77E-04	2.32E-05	1.36E-05	2.16E-05	1.19E-06	0	0	0	0	0	0	0	0	3.49E-06	0	1.99E-06	2.42E-04
Ecotoxicity	CTUe	2.83E-01	1.88E-01	5.62E-03	1.75E-01	6.21E-04	0	0	0	0	0	0	0	0	2.65E-02	0	1.51E-04	6.79E-01
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.34E-01	1.40E-01	6.38E-02	1.31E-01	1.02E-03	0	0	0	0	0	0	0	0	2.43E-02	0	3.38E-03	5.97E-01

Single score results

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below in Table 5.2.g. The scores are consistent with the trends in the results using the impact assessment results before normalization and weighting. The cradle-to-gate stages (A1-A3) contribute the biggest share of impacts for all facilities, followed by the product's transport to the building sites. The installation (A5) and end-of-life stages (C1-C4) make insignificant contributions to SM single figure scores.

Table 5.2.g. SM 2013 scores for SANCTUARY Insulation by life cycle stage per functional unit

Facility location	Unit	Raw material extraction	Upstream Transport	Manufacturing	Transport to building site	Installation	End of life transport	Final disposal
		A1	A2	A3	A4	A5	C2	C4
Mesa, AZ	mPts	1.45E-02	6.26E-03	2.90E-03	3.47E-03	3.93E-05	6.87E-04	8.65E-05
Norfolk, CE	mPts	1.45E-02	5.47E-03	3.62E-03	4.41E-03	3.89E-05	6.80E-04	8.57E-05
Salt Lake City, UT	mPts	1.45E-02	2.22E-03	1.87E-03	6.63E-03	3.89E-05	6.80E-04	8.57E-05
Tampa, FL	mPts	1.45E-02	3.18E-03	4.05E-03	4.52E-03	3.93E-05	6.87E-04	8.65E-05
Waco, TX	mPts	1.48E-02	2.13E-03	2.97E-03	2.92E-03	3.89E-05	6.80E-04	8.57E-05
Wilkes-Barre, PA	mPts	1.41E-02	4.29E-03	1.84E-03	4.01E-03	3.89E-05	6.80E-04	8.57E-05

5.2.2. Contribution analysis

The contribution of life cycle stages for each impact category is shown in Table 5.2.h to Table 5.2.m for each facility.

For SANCTUARY manufactured in Mesa, AZ, upstream transport (A2) of the raw materials to the manufacturing facility makes the largest share in potential CO2-equivalent emissions, followed by manufacturing operations (A3) and raw materials extraction (A1). Cradle-to-gate stages make up 81% of potential CO_2-equivalent emissions for the entire life cycle. In the case of fossil fuel depletion, raw materials extraction contributes the largest share, followed by upstream transport and manufacturing operations at the facility. Cradle-to-gate stages also make up 81% of potential fossil fuel depletion for the entire life cycle. Within A1, boric acid and oil make up 54% and 28% of potential CO2-equivalent emissions; the share is 29% and 50% respectively in the case of fossil fuel depletion. For the A3 stage, electricity consumed during manufacturing operations contribute to 98% of potential CO_2-equivalent emissions and 93% of fossil fuel depletion.

Table 5.2.h. Percent contributions of each stage to each impact category (Mesa, AZ)

Impact category	A1	A2	A3	A4	A5	C2	C4
Ozone depletion	12%	53%	4%	25%	<1%	5%	1%
Global warming	25%	33%	23%	15%	<1%	3%	<1%
Smog	59%	14%	16%	7%	<1%	1%	3%
Acidification	62%	11%	19%	5%	<1%	1%	1%
Eutrophication	52%	21%	14%	10%	<1%	2%	1%
Carcinogenics	89%	3%	5%	2%	<1%	<1%	<1%
Non-carcinogenics	63%	18%	4%	12%	<1%	2%	<1%
Respiratory effects	69%	12%	8%	8%	<1%	1%	1%
Ecotoxicity	43%	30%	1%	21%	<1%	4%	<1%
Fossil fuel depletion	34%	32%	15%	15%	<1%	3%	<1%

For SANCTUARY manufactured in Norfolk, NE, manufacturing operations contribute the largest share to potential CO_2-equivalent emissions, followed by upstream transport and raw materials extraction. Cradle-to-gate stages make up 78% of potential CO_2-equivalent emissions for the entire life cycle. In the case of fossil fuel depletion, raw materials extraction contributes the largest share, followed by upstream transport and transport to the building site. Cradle-to-gate stages also make up 76% of potential fossil fuel depletion for the entire life cycle. Within A1, boric acid and oil make up 54% and 28% of potential CO_2-equivalent emissions; the share is 29% and 50% respectively in the case of fossil fuel depletion. For the A3 stage, electricity consumed during manufacturing operations contribute to 98% of potential CO_2-equivalent emissions and 90% of fossil fuel depletion.

Table 5.2.i. Percent contributions of each stage to each impact category (Norfolk, NE)

Impact category	A1	A2	A3	A4	A5	C2	C4
Ozone depletion	12%	45%	6%	31%	<1%	5%	1%
Global warming	23%	27%	28%	18%	<1%	3%	<1%
Smog	51%	17%	22%	8%	<1%	1%	3%
Acidification	55%	11%	26%	6%	<1%	1%	1%
Eutrophication	47%	18%	21%	11%	<1%	2%	1%
Carcinogenics	86%	3%	8%	2%	<1%	<1%	<1%
Non-carcinogenics	61%	15%	7%	15%	<1%	2%	<1%
Respiratory effects	65%	12%	11%	9%	<1%	1%	1%
Ecotoxicity	43%	25%	1%	27%	<1%	4%	<1%
Fossil fuel depletion	35%	29%	12%	20%	<1%	3%	<1%

For SANCTUARY manufactured in Salt Lake City, UT, raw material extraction contributes the largest share to potential CO_2-equivalent emissions, followed by manufacturing operations and transport to the building site. The cradle-to-gate stages make up 60% of potential CO_2-equivalent emissions for the entire life cycle. In the case of fossil fuel depletion, raw materials extraction contributes the largest share, followed by transport to the building site and manufacturing operations at the facility. The cradle-to-gate stages also make up 61% of potential fossil fuel depletion for the entire life cycle. Within A1, boric acid and oil make up 54% and 28% of potential CO_2-equivalent emissions; the share is 29% and 50% respectively in the case of fossil fuel depletion. For A3 stage, electricity consumed during manufacturing operations contributes to 96% of potential CO_2-equivalent emissions and 89% of fossil fuel depletion.

Table 5.2.j. Percent contributions of each stage to each impact category (Salt Lake City, UT)

Impact category	A1	A2	A3	A4	A5	C2	C4
Ozone depletion	14%	19%	3%	57%	<1%	6%	1%
Global warming	30%	12%	18%	35%	<1%	4%	1%
Smog	63%	8%	11%	14%	<1%	2%	3%
Acidification	68%	5%	13%	11%	<1%	1%	1%
Eutrophication	58%	8%	10%	21%	<1%	2%	1%
Carcinogenics	92%	1%	4%	3%	<1%	<1%	<1%
Non-carcinogenics	63%	8%	3%	24%	<1%	2%	<1%
Respiratory effects	71%	6%	5%	15%	<1%	1%	1%
Ecotoxicity	42%	13%	1%	40%	<1%	4%	<1%
Fossil fuel depletion	39%	11%	11%	34%	<1%	4%	<1%

For SANCTUARY manufactured in Tampa, FL, manufacturing operations contribute the largest share to potential CO_2-equivalent emissions, followed by raw material extraction and transport to the building site. The cradle-to-gate stages make up 75% of potential CO_2-equivalent emissions for the entire life cycle. In the case of fossil fuel depletion, raw materials extraction contributes to the largest share, followed by manufacturing operations and transport to the building site. The cradle-to-gate stages also make up 77% of potential fossil fuel depletion for the entire life cycle. Within A1, boric acid and oil make up 54% and 28% of potential CO_2-equivalent emissions; the share is 29% and 50% respectively in the case of fossil fuel depletion. For the A3 stage, electricity consumed during manufacturing operations contributes to 98% of potential CO_2-equivalent emissions and 96% of fossil fuel depletion.

Table 5.2.k. Percent contributions of each stage to each impact category (Tampa, FL)

Impact category	A1	A2	A3	A4	A5	C2	C4
Ozone depletion	15%	29%	6%	42%	<1%	7%	1%
Global warming	26%	15%	34%	21%	<1%	3%	<1%
Smog	64%	7%	15%	10%	<1%	2%	3%
Acidification	69%	5%	15%	8%	<1%	1%	1%
Eutrophication	61%	10%	10%	15%	<1%	2%	1%
Carcinogenics	92%	2%	4%	2%	<1%	<1%	<1%
Non-carcinogenics	65%	12%	4%	17%	<1%	2%	<1%
Respiratory effects	73%	7%	7%	11%	1%	2%	1%
Ecotoxicity	45%	21%	1%	29%	<1%	4%	<1%
Fossil fuel depletion	33%	13%	31%	19%	<1%	3%	<1%

For SANCTUARY manufactured in Waco, TX, raw material extraction contributes the largest share to potential CO_2-equivalent emissions, followed by manufacturing operations and transport to the building site. The cradle-to-gate stages make up 78% of potential CO_2-equivalent emissions for the entire life cycle. In the case of fossil fuel depletion, raw materials extraction contributes the largest share, followed by manufacturing operations and transport to the building site. Cradle-to-gate stages also make up 79% of potential fossil fuel depletion for the entire life cycle. Within A1, boric acid and oil make up 55% and 27% of potential CO_2-equivalent emissions; the share is 30% and 49% respectively in the case of fossil fuel depletion. For the A3 stage, electricity consumed during manufacturing operations contributes to 97% of potential CO_2-equivalent emissions and 93% of fossil fuel depletion.

Table 5.2.l. Percent contributions of each stage to each impact category (Waco, TX)

Impact category	A1	A2	A3	A4	A5	C2	C4
Ozone depletion	20%	25%	11%	34%	<1%	9%	1%
Global warming	34%	12%	32%	17%	<1%	4%	1%
Smog	67%	5%	17%	6%	<1%	2%	3%
Acidification	70%	4%	19%	5%	<1%	1%	1%
Eutrophication	64%	7%	15%	10%	<1%	3%	1%
Carcinogenics	92%	1%	5%	1%	<1%	<1%	<1%
Non-carcinogenics	73%	8%	5%	11%	<1%	2%	<1%
Respiratory effects	77%	5%	8%	7%	1%	2%	1%
Ecotoxicity	55%	16%	1%	23%	<1%	5%	<1%
Fossil fuel depletion	45%	12%	22%	17%	<1%	4%	1%

For SANCTUARY manufactured in Wilkes-Barre, PA, raw material extraction contributes the largest share to potential CO_2-equivalent emissions, followed by upstream transport of raw materials to the manufacturing facility and transport to the building site. The cradle-to-gate stages make up 73% of potential CO_2-equivalent emissions for the entire life cycle. In the case of fossil fuel depletion, raw materials extraction contributes the largest share, followed by transport to the building site and upstream transport. The cradle-to-gate stages also make up 73% of potential fossil fuel depletion for the entire life cycle. Within A1, boric acid and oil make up 59% and 22% of potential CO_2-equivalent emissions; the share is 33% and 43% respectively in the case of fossil fuel depletion. For the A3 stage, electricity consumed during manufacturing operations contributes to 96% of potential CO_2-equivalent emissions and 87% of fossil fuel depletion.

Table 5.2.m. Percent contributions of each stage to each impact category (Wilkes-Barre, PA)

Impact category	A1	A2	A3	A4	A5	C2	C4
Ozone depletion	15%	37%	7%	34%	<1%	6%	1%
Global warming	31%	24%	18%	22%	<1%	4%	1%
Smog	65%	9%	12%	9%	<1%	2%	3%
Acidification	69%	7%	14%	7%	<1%	1%	1%
Eutrophication	59%	14%	11%	13%	<1%	2%	1%
Carcinogenics	91%	2%	4%	2%	<1%	<1%	<1%
Non-carcinogenics	65%	15%	3%	14%	<1%	2%	<1%
Respiratory effects	73%	10%	6%	9%	1%	1%	1%
Ecotoxicity	42%	28%	1%	26%	<1%	4%	<1%
Fossil fuel depletion	39%	23%	11%	22%	<1%	4%	1%

5.2.3. Sensitivity analysis

The electricity consumed at the production facilities drives the overall impacts in each impact category. Since the manufacturing stage is one of the major contributors to life cycle impacts as described in section 5.2.2, a sensitivity analysis was conducted by changing the amount of electricity consumed at each site by ± 20%. As tabulated in Table 5.2.n, increasing the electricity consumption by 20% will increase potential CO_2-equivalent emissions in the A3 stage by 18% for each facility. This will increase the overall emissions by 4% for the AZ facility; 3% for the UT and PA facilities; 5% for the NE facility, and 6% for the FL and TX facilities. On decreasing the electricity consumption by 20%, potential CO_2-equivalent emissions in the A3 stage decrease by 20% for all facilities except for AZ, which decreases by 21%. This will decrease the overall emissions by 4% for the PA facility; 5% for the AZ facility; 6% for the TX and NE facilities; and 7% for the FL facility.

Table 5.2.n. Sensitivity analysis of LCIA results, per functional unit for each facility

Facility	A3 CO_2 emissions					Total CO_2 emissions				
	Base electricity	20% more elec.	% with base	20% less elec.	% with base	Base electricity	20% more elec.	% with base	20% less elec.	% with base
Mesa, AZ	8.33E-02	9.84E-02	118%	6.62E-02	79%	3.55E-01	3.70E-01	104%	3.38E-01	95%
Norfolk, CE	1.06E-01	1.26E-01	118%	8.48E-02	80%	3.78E-01	3.97E-01	105%	3.56E-01	94%
Salt Lake City, UT	5.28E-02	6.22E-02	118%	4.20E-02	80%	2.91E-01	3.01E-01	103%	2.81E-01	96%
Tampa, FL	1.16E-01	1.37E-01	118%	9.21E-02	80%	3.37E-01	3.58E-01	106%	3.13E-01	93%
Waco, TX	8.43E-02	9.96E-02	118%	6.72E-02	80%	2.66E-01	2.81E-01	106%	2.49E-01	94%
Wilkes-Barre, PA	5.13E-02	6.04E-02	118%	4.09E-02	80%	2.79E-01	2.89E-01	103%	2.69E-01	96%

5.3 Overview of relevant findings

This study assessed a multitude of inventory and environmental indicators. The overall results are consistent with the expectations for insulation products' life cycles, as these products are not associated with energy consumption during their use stage. The primary finding, across the environmental indicators and for the product considered, was that cradle-to-gate impacts (A1-A3) contribute the most impacts to most categories, which is mostly driven by the extraction of incoming raw materials and electricity consumed during manufacturing. Boric acid and oil use are the raw materials that contribute to higher environmental impacts than the others.

The A1-A3 stage covers the largest portion of overall impacts, which is followed by the A4 stage. The impacts associated with outbound transport are comparatively higher than that for inbound due to the further transportation distances.

Installation accounts for a small fraction of overall life cycle impacts. The only installation impacts are associated with packaging disposal and the energy used for an installation blower machine. There is no impact associated with the use stage. While insulation can influence building energy performance, this aspect is assumed to be outside the scope of this study. Additionally, it is assumed that insulation does not require any maintenance to achieve its reference service life, which is modeled as being equal to that of the building. No replacements are necessary; therefore, results represent the production of one square meter of insulation at a thickness defined by the functional unit.

At the end of life, insulation is removed from the building and landfilled. For all products, waste was dominated by the final disposal of the product. Non-hazardous waste also accounts for waste generated during manufacturing and installation. No hazardous waste is created by the product system.

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). Primary data has been used, when available, for all unit processes.

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. Seasonal variations were balanced out by collecting annual data. Background data are from ecoinvent databases with documented precision to the extent available.

- *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. 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*: Assumptions, methods, and data were found to be consistent with the study's goal and scope. Primary data were collected with a similar level of detail, while background data were sourced primarily from the ecoinvent database, and 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. System boundaries, allocation rules, and impact assessment methods have also been applied uniformly.

- *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 high.
- *Geographical*: Primary data are representative of Applegate-Greenfiber's facilities in North America (US and Canada). Global datasets have been used for most of the materials. Specific eGRID datasets have been used for each facility to represent electricity consumption. Geographical representativeness is considered to be good.
- *Technological*: All primary and secondary data were modeled to be specific to the technologies under study. Technological representativeness is considered to be high.

5.5 Conclusions and recommendations

The goal of this study was to conduct a cradle-to grave LCA on Applegate-Greenfiber's SANCTUARY Insulation to develop an SM Transparency Report (EPD). The creation of this Transparency Report 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 cradle-to-gate activities and the distribution of the final product.

Since upstream and downstream transportation both have a major impact on the results, this is an important area for Applegate-Greenfiber to focus its efforts. Although they are not directly in control of these transportation operations, an opportunity exists to work with shipping partners who use electric or hybrid fleets, for example.

The electricity consumed during manufacturing is by far the largest contributor to that stage. In addition to working to reduce the use of electricity, it is recommended that Applegate-Greenfiber work with energy providers using greener energy mixes or consider installing solar panels to reduce the potential impacts to the environment.

There are two ingredients in SANCTUARY, boric acid and oil, that contribute the most to the impacts in the raw materials extraction and processing phase. Applegate- Greenfiber should consider alternatives to these raw materials in order to reduce potential impacts from its raw materials.

6 REFERENCES

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ACRONYMS

ISO	International Standardization Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact analysis
PCR	Product Category Rule document
RCRA	Resource Conservation and Recovery Act
TR	Transparency Report / EPD™

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

- Applegate_Inventory.xlsx
- Applegate_Greenfiber_LCA results.xlsx