LIFE CYCLE ASSESSMENT (LCA) OF KNAUF EARTHWOOL® 1000° PIPE INSULATION AND MANSON ALLEY-K™ PIPE INSULATION

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1 INTRODUCTION

1.1 Opportunity

Knauf Insulation North America (Knauf) is committed to the development and commercialization of products and solutions that support the construction industry's transition to a low-energy and sustainable built environment [1]. As part of this commitment, Knauf has conducted a company-specific Life Cycle Assessment (LCA) to evaluate the environmental impacts of selected products throughout their entire life cycle, from raw materials to manufacturing and end-of-life.

The objective of the LCA is to identify the full range of environmental impacts of Knauf's insulation products, renew their environmental declarations for use in business-to-consumer communications, and identify areas where impacts can be reduced. This project is critical to Knauf's commitment to providing the market with the necessary information to evaluate the environmental impacts of their products.

To achieve a comprehensive understanding of the product's impact, Knauf has adopted a cradle-to-installation with end of life approach in conducting the LCA. This approach ensures that pertinent life cycle stages are included, providing the necessary information to guide impact reduction efforts.

Knauf intends to use the LCA results to develop Sustainable Minds Transparency Reports™ (TRs), which are ISO 14025 Type III Environmental Declarations (EPDs) that can be used for communication with other companies, architects, and consumers. Additionally, the TRs can be utilized in whole building LCA tools, in conjunction with the LCA background report and Life Cycle Inventory (LCI). The study aims to comply with the requirements of ISO 14040/14044, ISO 21930 standards, and UL'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: Mechanical, Specialty, Thermal, and Acoustic Insulation Product EPD Requirements, First Edition [2] [3].

Knauf has engaged Sustainable Minds, an external practitioner, to develop an LCA for faced and unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation products. The objective is to communicate environmental information to the market, acquire data for future product improvements, and contribute towards satisfying credits in the Leadership in Energy and Environmental Design (LEED®) building rating system.

1.2 Life cycle assessment

This LCA report follows an attributional approach and comprises four key phases:

- Goal and scope definition
- Life cycle inventory analysis
- Life cycle impact assessment
- Interpretation of results

For Type III Environmental Declarations, a critical review of the LCA and an independent verification of the Transparency Reports (TRs) are mandatory. This project includes both.

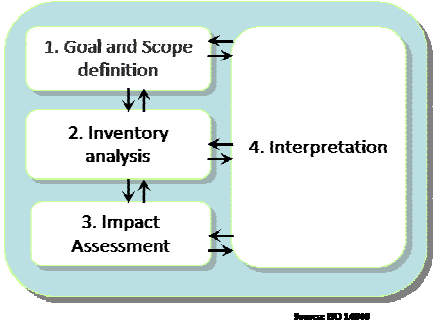

Figure 1. Phases in an LCA

1.3 Status

The information presented in this LCA report is based on the inputs and outputs provided by Knauf at the time of data collection, and Sustainable Minds and Knauf adhered to best practices in transforming the inventory into this report.

The data used in this report covers the annual manufacturing data for the year 2019 from Knauf's plants located in Shelbyville, IN, along with secondary data from contracted vendors and literature data to complete the inventory and fill gaps as necessary. Data was provided for the insulation material, the jacket, and the self-sealing lap and butt strip.

In instances where data was not available, assumptions were made based on manufacturing data from Knauf's resources and other literature data, and expertise from Knauf employees were utilized to develop estimates or assumptions for other upstream or downstream activities as needed.

The LCA review and verification of the Sustainable Minds Transparency Report / EPD were carried out by Terrie Boguski, Harmony Environmental, LLC, and found to be compliant with ISO 14040/14044 and the relevant PCRs.

1.4 Team

This LCA report is the outcome of the efforts of the project team, led by Chris Mahin and Gabriela Fleury on behalf of Knauf, with support from Knauf personnel during the data collection, reporting, and interpretation phases.

The development of the LCA model, results, and report was spearheaded by Kim Lewis, Sustainable Minds with support from Naji Kasem, LCA World.

1.5 Structure

The subsequent sections of this LCA report are structured as follows:

Chapter 2: Goal and scope definition
Chapter 3: Life cycle inventory analysis
Chapter 4: Life cycle impact assessment methods
Chapter 5: Results and interpretation

This report incorporates LCA terminology. To facilitate comprehension, special consideration has been given to list definitions of significant terms used at the end of this report.

2 GOAL AND SCOPE

This chapter outlines the objective and scope of the LCA study. The goal and scope establish the boundaries of the analysis and define the level of detail and comprehensiveness of the assessment for the product in question.

2.1 Intended application and audience

This LCA report aims to illustrate the application of the LCA methodology to Knauf's pipe insulation product's life cycle. The report serves both internal and external purposes and is intended for a diverse audience. This audience includes the program operator (Sustainable Minds) and reviewer responsible for assessing the LCA for conformance to the PCR, as well as Knauf's internal stakeholders in marketing and communications, operations, and design.

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

2.2 Product description

As a leading manufacturer of fiberglass insulation products with a wealth of experience spanning over 30 years, Knauf Insulation North America is dedicated to promoting sustainability and transparency in its reporting of the cradle-to-installation with end-of-life environmental impacts of its products. This LCA report provides a detailed analysis of select Knauf's products, as shown in Table 1, with information on their facing options, manufacturing locations, type of declaration, and previous LCA studies. Additional product details for each item can be found in Table 2.

This report focuses on Earthwool® 1000° Pipe Insulation, a one-piece molded insulation composed of resilient, inorganic glass fibers bonded with ECOSE® Technology, as pictured in Figure 2. By examining the environmental impact of this product, Knauf aims to demonstrate its commitment to continuously improve sustainability in production and encourage transparency in the industry.

In addition to the Knauf-branded product, the Manson-branded product is also being evaluated in this study. The Knauf-branded unfaced Earthwool® 1000° Pipe Insulation is exactly the same as the unfaced Manson-branded ALLEY-K™ Pipe Insulation except for branding (i.e., the way ink is printed on the packaging).

Table 1. Product name, facing option, manufacturing location, and type of declaration

Product name	Transparency Report name	Facing options	Previous LCA	Manufacturing location	Type of declaration
Earthwool® 1000° Pipe Insulation ALLEY-K™ Pipe Insulation	Earthwool® 1000° Pipe Insulation ALLEY-K™ Pipe Insulation	Unfaced, ASJ+ (Earthwool® 1000° only)	Yes	Shelbyville, IN	A specific product from a manufacturer's plant

Figure 2. Visual representation of Earthwool® 1000° Pipe Insulation and unfaced ALLEY-K™ Pipe Insulation

Table 2. Other product information

Transparency Report name	CSI MasterFormat® classification	Application	Specifications compliance
Earthwool® 1000° Pipe Insulation ALLEY-K™ Pipe Insulation	23 07 19	Suitable for insulating iron, copper, stainless steel, PVC, and CPVC piping in both hot and cold systems. It can be used for both concealed and exposed piping systems, operating at temperatures ranging from 0°F to 1000°F (-18°C to 538°C). For outdoor use, additional weather protection is required.	USA • ASTM C547; Type I, Type IV • ASTM C585 • ASTM C1136 (jacket); Type I, II, III, IV, VII, VIII, X • NFPA 90A and 90B • Conformity for fit Marine Equipment IMO 1408 • MIL-DTL-32585; Type 1, Form 4, Facing A and D • USCG 164.109/4/1 • UL/ULC Classified • Listed and Labeled Pipe Insulation by Underwriter Laboratories (UL) File No. R8583, Category: Insulated Plastic Pipe Assemblies (BSMP) for installation over PVC, Polypropylene, and CPVC meeting “FHC 25/50” with minimum 1 inch insulation thickness. • ASTM C795, MIL-I-24244, NRC Reg. Guide 1.36 (Certification needs to be specified at the time of order) Canada • CAN/ULC S102 • CGSB 51-GP-9M • CGSB 51-GP-52M (jacket) • CAN/CGSB-51.9 (obsolete, replaced by ASTM C547)

Table 3 provides detailed information about the properties of Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation. Figure 3 provides the requirements according to ASHRAE 90.1-2016.

Table 3. Properties of Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation

Property (unit)	Test	Value / performance
Design density of declared unit (size dependent) (kg/m^3)	N/A	50 – 120
Corrosiveness	ASTM C665	Does not accelerate corrosion of steel
Corrosion	ASTM C1617	Pass
Maximum Service Temperature	ASTM C411 + ASTM C447	1000° F (538° C)
Water Vapor Permeance	ASTM E96, Procedure A	0.01 perms or less
Water Vapor Sorption (by weight)	ASTM C1104	Less than 5%
Shrinkage	ASTM C356	Negligible
Mold Growth	ASTM C1338	Pass
Surface Burning Characteristics (flame spread/smoke developed)	ASTM E84, UL 723, CAN/ULC S102	UL/ULC Classified FHC 25/50

ASHRAE 90.1-2016 REQUIREMENTS

MINIMUM PIPE INSULATION THICKNESS

Fluid Operating Temperature Range and Usage	Insulation Conductivity		Nominal Pipe or Tube Size				
	Conductivity Range BTU-in./(hr · ft² · °F)	Mean Temperature Rating	<1"	1"–<1½"	1½"–<4"	4"–<8"	≥8"
Heating and Hot Water Systems (Steam, Steam Condensate, Hot-Water Heating and Domestic Water Systems)[a, b, c, d]							
Above 350° F	0.32–0.34	250° F	4½"	5"	5"	5"	5"
251–350° F	0.29–0.31	200° F	3"	4"	4½"	4½"	4½"
201–250° F	0.27–0.30	150° F	2½"	2½"	2½"	3"	3"
141–200° F	0.25–0.29	125° F	1½"	1½"	2"	2"	2"
105–140° F	0.22–0.28	100° F	1"	1"	1½"	1½"	1½"
Cooling Systems (Chilled Water, Brine, Refrigerant)[a, b, c, d]							
40–60° F	0.21–0.27	75° F	½"	½"	1"	1"	1"
Below 40° F	0.20–0.26	50° F	½"	1"	1"	1"	1½"

a. For insulation outside the stated conductivity range, the minimum thickness (T) shall be determined as follows: $T=r\{(1+t/r)^{(K/k)}-1\}$, where T=minimum insulation thickness (in.), r=actual outside radius of pipe (in.), t=insulation thickness listed in this table for applicable fluid temperature and pipe size, K=conductivity of alternate material at mean rating temperature indicated for the applicable fluid temperature (Btu · in./(h · ft² · °F)), and k=the upper value of the conductivity range listed in this table for the applicable fluid temperature.

b. These thicknesses are based on energy efficiency considerations only.

c. For piping smaller than 1½" and located in partitions within conditioned spaces, reduction of these thicknesses by 1" shall be permitted (before thickness adjustment required in footnote a) but not to thicknesses below 1". These thicknesses are based on energy efficiency considerations only. Issues such as water vapor permeability or surface condensation sometimes require vapor retarders or additional insulation.

d. The table is based on steel pipe. Non-metallic pipes schedule 80 thickness or less shall use the table values. For other non-metallic pipes having thermal resistance greater than that of steel pipe, reduced insulation thicknesses are permitted if documentation is provided showing that the pipe with the proposed insulation has no more heat transfer per foot than a steel pipe of the same size with the insulation thickness shown on the table.

Figure 3. ASHRAE 90.1-2016 requirements

2.3 Declared unit

In accordance with the PCR, a declared unit must be used when assessing the environmental impact of mechanical insulation, as the configuration of pipe insulation can significantly affect its thermal resistivity. Therefore, it is not feasible to define a single, generic functional unit that can represent all possible configurations.

For piping applications, the declared unit is 1 meter (m) of pipe insulation material, including packaging, with an expected service life (ESL) of at least 75 years.

This study includes Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation available unfaced, plus Earthwool® 1000° Pipe Insulation with a factory-applied ASJ+ jacket. Pipe insulation is offered in several different thicknesses to accommodate different piping applications, as shown in Table 37 and the appendix. The results included in this study represent an average performance for all available options, using a production-weighted average for all pipe insulation produced in CY2019. These properties are used to calculate the mass reference flow, which was normalized to 1 kg for unfaced pipe insulation including packaging. By using this approach, impact results can be reported and transparently scaled to pipe insulation of varying sizes.

When considering the declared unit for pipe insulation, it is important to note that the amount of insulation material in faced and unfaced versions of the product is the same. The amount of self-sealing lap (SSL) is dependent on the length of insulation but not the diameter or thickness. The faced Earthwool® 1000° Pipe Insulation includes a facer material (ASJ+) that is adhered to the surface of the fiberglass insulation during manufacture, and the amount of facer is dependent on pipe diameter, insulation thickness, and length. This facer is then connected to other sections using an added adhesive strip to the seams (butt strip), and the amount of butt strip is dependent on the outer diameter. For this reason, results are presented per several declared units.

For the insulation, in order to capture the thickness and outer diameter of a 1 m pipe insulation section weighing 1 kg including packaging, several product sizes that have similar characteristics were identified. Since packaging makes up about 11.4% of the final declared unit, the ideal weight of a 1 m section of unpackaged and unfaced insulation for the purposes of identifying declared unit properties is 0.886 kg. It was observed that three of the four sizes with a design weight closest to 0.886 kg per 1m section had an outer diameter of 12.57 cm. Therefore, it was assumed that a trend line could be established at that diameter to estimate the pipe insulation thickness for a 1 m unpackaged unfaced pipe insulation section. The resulting declared unit properties are shown in Table 4.

For the ASJ+ facer add-on, the declared unit is 1 square meter (m^2), while the declared unit for the SSL and butt strip add-ons is 1 m, as shown in Table 4. This approach allows for consistent reporting of the environmental impacts of Earthwool® 1000° Pipe Insulation with or without a facer, while still ensuring that the declared unit remains consistent with the requirements of the PCR. By including these add-ons in the declared unit, Knauf aims to provide transparent and accurate information about the environmental impact of its products.

Table 4. Declared unit properties for unfaced ALLEY-K™ Pipe Insulation, and faced or unfaced Earthwool® 1000° Pipe Insulation and its add-ons

Attribute	Pipe insulation	ASJ+ facer	SSL	Butt strip
Declared unit	1 kg packaged unfaced insulation	1 m^2 of facer	1 m of fastening adhesive tape	1 m of sealing butt strip
Mass of declared unit (kg)	1.00	0.156	0.0031	0.0161
Density at declared unit (kg/m^3)	77.7	N/A	N/A	N/A
Thickness of declared unit (cm)	4.49			
Outer diameter of declared unit (cm)	12.57			
Scaling factors (piping application)	See Table 37			

To account for the different sizes of pipe insulation used for varying applications, and to facilitate the additional impacts of the SSL and facer add-ons, scaling factors have been provided in section 5 of this report. In order to calculate results per one lineal foot of pipe insulation having a specific inside diameter (ID) and wall thickness with or without the ASJ+ facer, use the following equation:

$$\textbf{\textit{Total results per lineal foot of pipe}}\ (\mathbf{1}\ \boldsymbol{ft}) =$$

Unfaced pipe insulation

$$\left(\begin{matrix}Unfaced\ insulation\ impact\\ Table\ 25\end{matrix}\right) * \left(\begin{matrix}Unfaced\ insulation\ scaling\ factor\\ Table\ 37, scaling\ factor\ INS\end{matrix}\right) + \left(\begin{matrix}SSL\ impact\\ Table\ 28\end{matrix}\right) * (0.3048)$$

Plus ASJ+ facer with butt strip

$$+\left(\begin{matrix}ASJ\ impact\\ Table\ 31\end{matrix}\right) * \left(\begin{matrix}ASJ\ scaling\ factor\\ Table\ 37, scaling\ factor\ ASJ\end{matrix}\right) + \left(\begin{matrix}Butt\ strip\ impact\\ Table\ 34\end{matrix}\right) * \left(\begin{matrix}Butt\ strip\ scaling\ factor\\ Table\ 37, scaling\ factor\ BUT\end{matrix}\right)$$

2.4 System Boundaries

This section describes the system boundaries for the modeled products. The system boundaries define which life cycle stages are included and which are excluded. Building operational energy and water use are considered outside of this study's scope; any impact the use of insulation may have on a building's energy consumption is not calculated nor incorporated into this analysis.

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

I. A1-A5
- Raw materials acquisition, transportation, processing, and fabrication
- Distribution and installation

II. C1-C4
- Disposal/reuse/recycling

These boundaries apply to the modeled products and can be referred to as "cradle-to-installation with end of life" which means that it includes the life cycle stages and modules in the product stage, construction process stage, and end of life stage as identified in the PCR. The life cycle includes all industrial processes from raw materials acquisition and pre-processing, production, product distribution, installation, and end-of-life management.

The system boundaries for Knauf pipe insulation are detailed below. Figure 4 represents the life cycle stages included in this study. Table 5 lists specific inclusions and exclusions for the system boundaries.

	PRODUCT STAGE			CONSTRUCT-ION PROCESS STAGE		USE STAGE					END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY	
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D	Reference Service Life
	Raw material supply	Transport	Manufacturing	Transport from gate to site	Assembly/Install	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling Potential	
						B6 Operational Energy Use of Building Integrated System During Product Use										
						B7 Operational Water Use of Building Integrated System During Product Use										
Cradle to installation with end of life	X	X	X	X	X	MND	MND	MND	MND	MND	X	X	X	X	MND	75 years

Figure 4. Applied system boundaries for the modeled pipe insulation

Table 5. Applied system boundary for pipe insulation

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

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

Raw materials acquisition and transportation (A1-A2) The product stage includes, where relevant, 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

A description of the most important modeling parameters is included below.

Manufacturing (A3) The manufacturing stage includes the following:

- Manufacturing of pipe insulation product
- Packaging
- Releases to environmental media (air, soil, ground and surface water)
- Manufacturing waste

Some overhead energy was included in the system boundary, as operational energy data were not able to be separated for one of the two buildings on site.

2.4.2. A4-A5: Distribution and installation

Distribution (A4) Product distribution starts with the product leaving the gate of the production facility and ends 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. The installation process is considered to be manual (no energy use). This stage includes:

- Any materials specifically required for installation
- Packaging waste during installation
- Installation scrap (a default assumption of 5% is used)
- Waste transport and treatment as applicable

2.4.3. B1-B7: Use

This study does not account for the use stage.

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

A product's reference service life (RSL) depends on the product properties and reference in-use conditions. Due to the nature of insulation, it is anticipated that pipe insulation will last for the lifetime of the building, so the RSL is considered to be 75 years.

2.4.4. C1-C4: Disposal/reuse/recycling

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

When insulation is done being used, it is collected as construction and demolition waste.

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

Deconstruction (C1) This stage includes dismantling/demolition of the product. Since the dismantling is assumed to be manual, there is no energy use during deconstruction.

Transport (C2) This stage includes transportation of the product or disassembled product components from the building site to final disposition. The waste transport distance is assumed to be 100 miles.

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

Disposal (C4) This stage includes final disposition (recycling or reuse). An end-of-life scenario of 100% landfilling was used in accordance with the PCR.

2.4.5. D: Benefits and loads beyond the system boundary

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

3 INVENTORY ANALYSIS

This chapter includes an overview of the obtained data and data quality that has been used in this study. 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, can be found in the appendix.

3.1 Data collection

Data used for this project represents a mix of primary data collected from Knauf on the production of the insulation products (gate-to-gate) and background data from the LCA for Experts (formerly known as GaBi) 2023 databases. Overall, the quality of the data used in this study is considered to be high and representative of the described systems. All appropriate means were employed to guarantee the data quality and representativeness as described below.

- **Gate-to-gate:** Data on processing materials and manufacturing the insulation 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 Knauf. Data were collected at Knauf's Shelbyville, IN facilities. Inventory calculations were developed by an analyst at Sustainable Minds and subsequently checked by a supporting consultant.
- **Background data:** All data from the LCA for Experts 2023 databases were created with consistent system boundaries and upstream data. Expert judgment and advice was used in selecting appropriate datasets to model the materials and energy for this study and has been noted in the preceding sections. Detailed database documentation for the LCA for Experts datasets can be accessed at https://sphera.com/product-sustainability-gabi-data-search/.

This LCA utilized primary data provided by Knauf. The data were thoroughly reviewed upon receipt to ensure their completeness and plausibility through various methods, including mass balance, stoichiometry, and benchmarking. In the case of any gaps, outliers, or other inconsistencies, Sustainable Minds engaged in productive discussions with Knauf to address and resolve any open issues in a timely and efficient manner.

3.2 Primary data

The insulation products represented in this study are produced in several manufacturing steps that involve melting the glass materials, forming the fibers, and shaping them into the final products; for these products, binder is added to hold the glass fibers together.

The finished products are then distributed to construction sites where they are installed, and the packaging is disposed. Pipe insulation has a 75-year reference service life, equal to that of the building. At end of life, the insulation is removed and disposed in a landfill. The flow charts in Figure 5 illustrate the life cycle of the insulation product.

Data used in this analysis represents pipe insulation production at Knauf. All available thicknesses and R-values were included. Results were then scaled to reflect the declared unit.

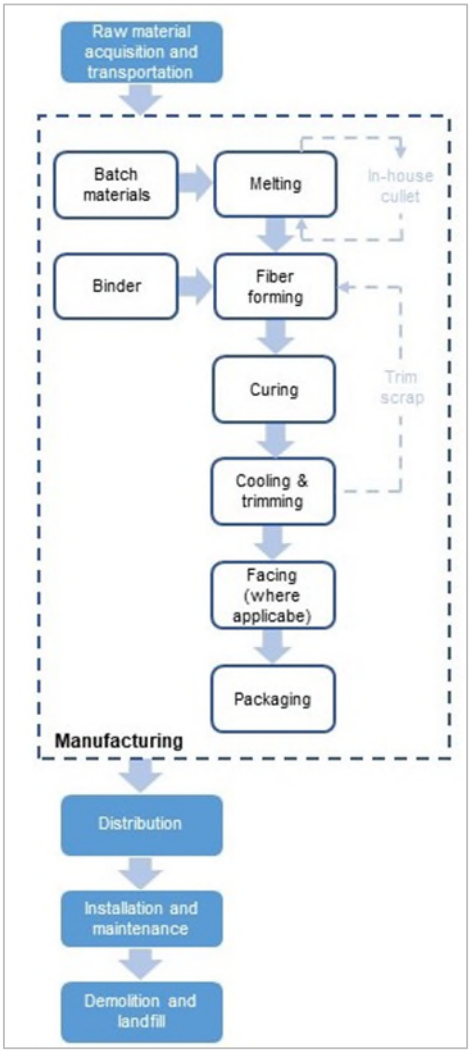

Figure 5. Life cycle flow chart of insulation products production

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

Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation consist of two major components: glass fibers and a binder. Glass fibers are made from various inorganic minerals, which make up the batch. The primary material used in the batch is recycled plate, bottle cullet, and internally recycled cullet which results in a total recycled content of roughly 48% in the final product. The binder consists of both renewable and non-renewable organic chemicals. Earthwool® 1000° Pipe Insulation is produced either faced with factory-applied ASJ+ or unfaced. ALLEY-K™ Pipe Insulation is produced unfaced.

Raw materials are transported to Knauf's facilities. As indicated in the tables, Knauf uses both in-house and post-consumer plate and bottle cullet in its batch. Internal cullet represents glass that is recycled internally, assumed to make up 11.7% of batch inputs, whereas Knauf obtains post-consumer cullet from external sources. Plate and bottle cullet is assumed to arrive at Knauf burden-free aside from the transportation necessary to deliver it to Knauf's facilities. Knauf has removed phenol formaldehyde from its binder and currently uses a bio-based formulation.

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.

Raw materials are transported to Knauf's facilities via both rail, truck and trailer, and ocean freighter. Transport data were collected for each flow and are shown in Tables 6-9 for transportation to Shelbyville, IN. All ingredients for the ASJ+ facer, SLL, and butt strip were modeled.

Packaging is supplied to Knauf from Thomasville, NC and Nashville, TN at an approximately even amount. Therefore, the distance for packaging was assumed to be an average of the two distances.

Table 6. Raw material inputs per declared unit of unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation

Material Inputs	Mass %	Transportation mode	Distance (mi)
Batch			
Cullet	45-50%	[redacted]	[redacted]
Sand	10-13%	[redacted]	[redacted]
Borate	6-9%	[redacted]	[redacted]
Soda ash	6-9%	[redacted]	[redacted]
Silicate	2-5%	[redacted]	[redacted]
Oxides	2-5%	[redacted]	[redacted]
Binder			
Sugars	3-6%	[redacted]	[redacted]
Catalyst	1-2%	[redacted]	[redacted]
Others	<1%	[redacted]	[redacted]
Packaging			
Cardboard	11.4%	[redacted]	[redacted]

Table 7. Raw material inputs per 1 m^2 of ASJ+ facer

Material Inputs	Mass %	Transportation Mode	Distance (mi)
Paper	35-40%	[redacted]	[redacted]
Polypropylene	10-15%		
Aluminum foil	10-15%		
Fiberglass	10-15%		
Synthetic polymer	10-15%		
Alumina	<10%		
Flame retardant	<5%		
Antimony trioxide	<5%		

Table 8. Raw material inputs per 1 m of SSL

Material inputs	Mass %	Transportation mode	Distance (mi)
PET	15-25%	[redacted]	[redacted]
Polymer	75-80%		

Table 9. Raw material inputs per 1 m of butt strip

Material inputs	Mass %	Transportation mode	Distance (mi)
Cellulose	25-30%	[redacted]	[redacted]
Synthetic polymer	25-30%		
Adhesive	15-20%		
Polypropylene	<10%		
Fiberglass	<10%		
Aluminum foil	<10%		
Antimony trioxide	<5%		
Coating	<1%		

3.2.2. Manufacturing (A3)

Upon transporting the batch materials to Knauf's facilities, they undergo a melting process in a furnace. During this phase, a fusion loss in glass takes place, resulting in approximately a 90% yield. The molten glass is then conveyed to a fiberizer, which converts the melt into glass fibers. As these fibers form, they are coated with additives. For all other insulation products included in this study, a binder is introduced to serve as an adhesive, binding the fibers together. The products are then compressed into continuous "rolls."

These rolls are guided through a curing oven, followed by a cooling process, and then ultimately trimmed to the desired size. In the case of pipes, the rolls are transported internally to another building on site where they are molded around mandrels and undergo curing. Post-curing, the exterior is sanded to ensure a smooth surface for facing application. The facing for faced products is applied prior to packaging the pipe insulation, which is then shipped to various distribution centers or job sites.

Manufacturing inputs and outputs for the product can be found in Table 10. There are no additional manufacturing impacts associated with the addition of facing; therefore, results are presented independently of facing type. Water in the manufacturing stage is used to quench the fibers during fiberizing and to dilute the binder when spraying it onto the fibers. This dilution water is reused within the same process. The majority of water consumed is evaporated in the curing oven for products which are cured. Emissions associated with the production of electricity and the combustion of natural gas are accounted for in the LCA for Experts background processes. Stack emissions for carbon monoxide, NOx, and total particulate matter were provided based on Knauf's annual report to the Indiana Department of Environmental Management. Carbon dioxide emissions from heating the batch were calculated using the emission factors for decomp products (see section 3.5.5 for more details).

Table 10. Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation annual manufacturing inputs and outputs

	Flow	Amount	Unit
Inputs	Electricity	[redacted]	MJ
	Natural gas	[redacted]	MJ
	Water	[redacted]	L
Outputs	Total product	[redacted]	kg
	Total particulate	[redacted]	kg
	Nitrogen oxides	[redacted]	kg
	Carbon monoxide	[redacted]	kg
	Carbon dioxide	[redacted]	kg

3.2.3. Distribution (A4)

Products are packaged in the manufacturing plant and shipped directly to distributors, dealers, and showrooms for purchase by the end users in the US. Average distance from Shelbyville to installation sites is 680 miles (1,094 km) by truck and trailer. Capacity utilization was assumed to be 27% by mass. The insulation products arrive finished and require no further assembly. Relevant technical information is shown in Table 11.

Table 11. Relevant technical information for distribution (A4) per declared units

Name	Value	Unit
Fuel type	Diesel	-
Vehicle type	Truck and trailer	-
Transport distance	1,094	km
Capacity utilization	27	%
Gross density of products transported	Insulation: 64.1 ASJ+: 0.156 SSL: 0.097 Butt strip: 0.209	kg/m3
Capacity utilization volume factor	1	-

3.3 Secondary data

For life cycle stages after the transport of insulation to the building sites, secondary data sources are used to develop assumptions and generate the results.

3.3.1. Installation (A5)

At the installation site, insulation products are unpackaged and installed. There are no additional installation materials used to install pipe insulation. Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation are packaged in cardboard cartons. 7.6% of the product is assumed to be lost or wasted due to over-ordering, cut pieces that are too small to piece in, change of product, quality, breakdown, packaging damage, and others. Modeled at the installation stage, it was assumed that scrap composition is the same as the packaged product composition. After installation, packaging is sent 12.6 miles to Morristown, IN to be landfilled or recycled, or an assumed 100 miles to an incineration facility. Disposal rates for packaging waste treatment methods were prescribed by the PCR and are shown in Table 12.

Table 12. Disposal rates used and waste treatment method

Material type	Recycling rate	Landfill rate	Incineration rate
Pulp (cardboard)	75%	20%	5%

The relevant technical information for installation is shown in Table 13.

Table 13. Relevant technical scenarios for installation (A5) per declared units

Name	Value	Unit
Waste materials at the construction site before waste processing, generated by product installation	Insulation: 0.076 Others: N/A	kg
Mass of packaging waste (cardboard)	Cardboard: 0.058 Others: N/A	kg
GWP based in biogenic carbon content of paper packaging	-8.80E-02	kg CO_2e

3.3.2. Deconstruction (C1)

Although reuse and recycling of fiberglass pipe insulation at its end of life is possible, there are no formal programs for collection and transport. It is assumed that all product is sent to landfill at end of life. Removal at end of life requires human labor only and therefore does not contribute to the lifetime environmental impacts. There will be no operational energy use and thus, no impacts associated with the deconstruction work after the service life ends.

3.3.3. End-of-life transport (C2)

While fiberglass pipe insulation can be recycled, doing so is not common practice in the industry. Therefore, after removal, the insulation is assumed to be transported 100 miles to the disposal site to be landfilled.

3.3.4. Waste processing (C3)

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

3.3.5. Final disposal (C4)

After removal, the insulation is assumed to be landfilled.

A summary of the relevant technical information for end of life is shown in Table 14.

Table 14. Relevant technical scenarios for end of life (C1-C4) per declared units

Name		Value	Unit
Assumptions for scenario development	Following manual removal of the pipe insulation, it was assumed to be transported 100 miles to disposal. The PCR prescribes that 100% of the insulation is sent to landfill, where no prior waste processing is reuiqred.		
Collection process	Collected with mixed construction waste	Insulation: 1.00 ASJ+: 0.156 SSL: 0.0031 Butt strip: 0.0161	kg
Disposal	Product for final deposition in landfill	Insulation: 1.00 ASJ+: 0.156 SSL: 0.0031 Butt strip: 0.0161	kg

3.4 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. The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data is considered to be of high precision, followed by calculated and estimated data. Since the inputs/outputs were directly measured by Knauf, we consider inventory data to have good precision.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. Wherever data were available on material and energy flows, these were included in the model. No known flows are deliberately excluded from this analysis other than those defined to be outside the defined system boundaries. Data collection forms were used to obtain a comprehensive set of primary data associated with the raw materials acquisition and manufacturing processes. Inquiries were made to the Knauf team and a review with key stakeholders leads to the conclusion that the dataset is complete.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results occur due to actual differences between product systems, and not due to inconsistencies in modeling choices, data sources, emission factors, or other.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope.

An evaluation of the data quality with regard to these requirements is provided in the interpretation chapter of this report.

Time coverage:
Primary data were collected on insulation production for January 2019 to December 2019. Background data for upstream and downstream processes (i.e., raw materials, energy resources, transportation, and ancillary materials) were obtained from the LCA for Experts databases.

Technology coverage:
Data was collected for fiberglass pipe insulation production at Knauf's facility in the US.

Geographical coverage:
Knauf's facility is located in Shelbyville, IN. As such, the geographical coverage for this study is based on United States system boundaries for all processes and products. Whenever US background data sets were not readily available, European data or global data were used as proxies. Following production, insulation is shipped for use within the continental United States. Use and end-of-life impact were modeled using background data that represents average conditions for this region.

3.5 Background data

This section details background datasets used in modeling insulation product environmental performance. Each table lists dataset purpose, name, source, reference year, and location.

All data from the LCA for Experts 2023 databases were created with consistent system boundaries and upstream data. Expert judgment and advice was used in selecting appropriate datasets to model the materials and energy for this study. Detailed database documentation for the LCA for Experts datasets can be accessed at https://sphera.com/product-sustainability-gabi-data-search/.

3.5.1. Fuels and energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from the LCA for Experts 2023 databases. The grid mixes used for electricity are from the eGrid subregion (RFCW) for Shelbyville, IN. Table 15 shows the most relevant LCI datasets used in modeling the product systems.

Table 15. Key energy datasets used in inventory analysis

Energy	Dataset name	Primary source	Reference year	Geography
Electricity	Electricity grid mix – RFCW	Sphera	2020	US RFCW
Technical heat	Thermal energy from natural gas	Sphera	2019	US
Diesel	Diesel mix at refinery	Sphera	2019	US
Fuel oil	Heavy fuel oil at refinery	Sphera	2019	RSA

3.5.2. Raw materials extraction and transport

Data for up- and down-stream raw materials were obtained from the LCA for Experts 2023 databases. Table 16 shows the most relevant LCI datasets used in modeling the product systems. Documentation for the Sphera datasets can be found at https://sphera.com/life-cycle-assessment-lca-software/. Data sets older than 10 years old (nepheline, manganese dioxide, alumina, and corrugated product) were chosen because they closest represent the technology used to manufacture the material and are assumed to be more accurate than other proxies with more precise geography and temporal representativeness.

Table 16. Key material datasets used in inventory analysis

Raw material	Dataset name	Primary source	Reference year	Geography
Batch	Silica sand (Excavation and processing)	Sphera	2022	US
Batch	Soda (Na2CO3)	Sphera	2022	US
Batch	Limestone (CaCO3; washed)	Sphera	2022	US
Batch	Dolomite (ground)	Sphera	2022	US
Batch	Nepheline grinded*	PE	2008	US
Batch	Borax (dehydrated)	Sphera	2022	US
Batch	Manganese oxide*	PE	2008	AU
Batch	Aplite (Excavation and processing)	Sphera	2022	US
Binder	Glucose (via starch hydrolysis)	Sphera	2022	US
Binder	Trichlorosilane by-product chlorosilanes	Sphera	2022	RER
Binder	Diammonium phosphate (DAP, 18% N, 46% P2O5)	Fertilizers Europe	2022	RER
ASJ+, Butt strip	Polypropylene granulate (PP)	Sphera	2022	US
ASJ+, SSL, Butt strip	Lubricants at refinery	Sphera	2019	US
ASJ+, Butt strip	Aluminum foil	Sphera	2022	RER
ASJ+	Kraftliner 2018; by-products: tall oil, turpentine; cut-off EoL; [mass allocation]	Sphera/ FEFCO	2022	RER
ASJ+, Butt strip	Glass fibres	Sphera	2022	US
ASJ+, SSL, Butt strip	Rubber sealing compound (EN15804 A1-A3)	Sphera	2022	DE
ASJ+	Tris(2-chloroisopropyl)phosphate (TCPP)	Sphera	2022	US
ASJ+, Butt strip	Aluminium hydroxide from aluminium sulphate	Sphera	2022	DE
ASJ+	Alumina, at plant*	USLCI	1998	US
SSL	Polyethylene terephthalate bottle grade granulate (PET) via PTA	Sphera	2022	US
Butt strip	Cellulose fibre blowing insulation material (EN15804 A1-A3)	Sphera	2022	DE
Butt strip	Polyvinyl alcohol (from vinyl acetate) (PVAL)	Sphera	2022	US
Butt strip	Ethylene/methacrylic acid ionomer (EMAA)	Sphera	2022	US
Packaging	Corrugated product*	Sphera/ AF&PA	2012	US
Water	Process water from groundwater	Sphera	2022	RER
Water	Water deionized (reverse-osmosis/electro-deionization)	Sphera	2022	US

*Data sets older than 10 years old (nepheline, manganese dioxide, alumina, and corrugated product) were chosen because they closest represent the technology used to manufacture the material and are assumed to be more accurate than other proxies with more precise geography and temporal representativeness.

3.5.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials to production facilities. Transport of the finished product to the construction site is also accounted for, along with the transportation of construction wastes and the deconstructed product at end of life to disposal facilities. Typical vehicles used include trailers and rail cars.

The LCA for Experts datasets for transportation vehicles and fuels were used to model transportation. Truck transportation within the United States was modeled using the

LCA for Experts US truck transportation datasets. Rail transportation and ocean freight were modeled using global transportation datasets.

3.5.4. Disposal

Disposal processes were obtained from the LCA for Experts 2023 databases. These processes were chosen to correspond to the material being disposed, specifically fiberglass and cardboard packaging. There are no energy recovery credits used from landfill gas capture and combustion. The 'Glass/inert on landfill' data set was used for the fiberglass plus facing, as it was assumed to represent both faced and unfaced landfilled product. Table 17 reviews relevant disposal datasets used in the model.

Table 17. Key disposal datasets used in inventory analysis

Material disposed	Dataset name	Primary source	Year	Geography
Insulation	Inert matter (Glass) on landfill	Sphera	2022	US
Plastic	Plastic waste on landfill, post-consumer	Sphera	2022	US
Paper	Paper waste on landfill, post-consumer	Sphera	2022	US
Paper	Paper waste (water 0%) in waste incineration plant	Sphera	2022	US

3.5.5. Emissions to air, water, and soil

All gate-to-gate emissions reported by Knauf for the manufacturing stage are taken into account for this study. Emissions measured and reported by Knauf are detailed under primary data collection. Batch carbon dioxide emissions generated from certain materials (e.g., dolomite, limestone, soda ash) are not typically tracked or reported by glass mineral wool manufacturers. The batch composition dictates the quantity of carbon dioxide emitted at each facility due to decomposition and oxidation in the furnace. In this study, these emissions were calculated based on stoichiometry and are displayed in Table 18.

Table 18. Emission factors for batch materials

Batch material	Chemical formula	CO_2 emission factor*
Dolomite	$CaMg(CO_3)_2$	0.477 kg CO_2 / kg
Limestone	$CaCO_3$	0.440 kg CO_2 / kg
Soda ash	Na_2CO_3	0.415 kg CO_2 / kg

*Assumes all carbon contained in batch materials is converted to carbon dioxide

All data for all upstream materials, electricity, and energy carriers were obtained from the LCA for Experts 2023 databases. The emissions due to the use of electricity are accounted for within the database processes. Likewise, emissions from natural gas combustion are accounted for within the database process.

3.6 Limitations

Conducting a life cycle assessment (LCA) of a product system is an extensive and intricate process that inherently necessitates certain assumptions and simplifications. The study's limitations should be acknowledged as follows:

- Pipe insulation is presumed to have a reference service life equivalent to that of the building. For instance, if the building has a

75-year service life, the insulation is similarly assumed to last 75 years without maintenance or replacements.

- Proxy data used in the LCA model were restricted to background data for raw material production. US background data were employed whenever feasible, while European or global data were used as proxies when necessary.
- The categories employed in the impact assessment methodology do not encompass all possible environmental impact categories.
- Characterization factors within the impact assessment methodology may exhibit varying degrees of uncertainty.
- LCA results are expressed in relative terms and do not predict impacts on category endpoints, threshold exceedances, safety margins, or risks.

3.7 Criteria for the exclusion of inputs and outputs

While packaging for inbound raw materials to Knauf was excluded, primary data for this was not provided, nor was it required under the scope of the PCR. Otherwise, all energy and material flow data available were included in the model and comply with the cut-off criteria.

The cut-off criteria on a unit process level can be summarized as follows:

- All inputs and outputs to a (unit) process shall be included in the calculation of the pre-set parameters results, for which data are available. Data gaps shall be filled by conservative assumptions with average, generic or proxy data. Any assumptions for such choices shall be documented.
- 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% of non-renewable 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 judgement 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.

Capital goods such as mixers, furnaces, fiberizers, curing ovens, and packaging lines are expected to last for the life of the plant, and the plant is expected to last at least 30 years. If 32,082,108 lb of products are made in one year, then 962.5 million lb of products are made over the lifetime of the capital goods.

Even if all other products being made at the plant are ignored, a declared unit reference flow of 1 kg means that only about 2.28E-06% of the capital goods and infrastructure are used per declared unit. Therefore, they are assumed not to significantly affect the conclusions of the LCA nor additional environmental information.

3.8 Allocation

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

The Knauf manufacturing facility included in this report produces multiple products. Since only facility-level data were available, allocation among the facility's other co-products was necessary to determine the input and output flows associated with each product. Allocation of materials and energy was done on a mass basis for all products except for the facing, SSL, and butt strip which were allocated based on product area, length, or number of pieces. Allocation of transportation was based on weight.

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

3.9 Software and database

The LCA model was created using the LCA for Experts v10.7 software system for life cycle engineering, developed by Sphera. The LCA for Experts LCI databases provide the life cycle inventory data for several of the raw and process materials obtained from the background system [4].

3.10 Critical review

This is a supporting LCA report for the pipe insulation Transparency Report. Both this background report and the Transparency Report were evaluated for conformance to the PCR according to ISO 14025 [5] and the ISO 14040/14044 standards [6]. Critical review was performed by Terrie Boguski, Harmony Environmental, and access to a public version of this critically reviewed report can be found linked in the references section of the Transparency Report.

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 19). 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[2] are used to evaluate toxicity. Emissions from waste disposal are considered part of the product system under study, according to the "polluter pays principle".

Table 19. 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, LHV	Fossil fuel depletion is the surplus energy to extract minerals and fossil fuels.

With respect to global warming potential, biogenic carbon is included in impact category calculations. Greenhouse gas emissions from land-use change are expected to be insignificant and were not reported.

[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.

[2] USEtox is available in TRACI and at http://www.usetox.org/

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

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

4.2 Normalization and weighting

To arrive at a single score indicator, normalization [9] and weighting [10] as shown in Table 20 conforming to the SM 2013 Methodology were applied.

Table 20. 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 declared unit, provides scaling factors, outlines the sensitivity analysis, and concludes with recommendations.

5.1 Life cycle inventory results

Resource use indicators, output flows and waste category indicators, and carbon emissions and removals are presented in this section. LCI flows were calculated with the help of the draft American Center for Life Cycle Assessment guide to the ISO 21930:2017 metrics [11]. The consumption of freshwater indicator, which was calculated in accordance with this guidance, is reported in compliance with ISO 14046.

Resource use indicators represent the amount of materials consumed to produce not only the insulation itself, but also the raw materials, electricity, natural gas, etc. that go into the product's life cycle. Secondary materials used in the production of insulation include external recycled cullet.

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 taken into account when calculating primary energy demand from process energy consumption. Water use represents total water used over the entire life cycle. No energy was recovered.

Non-hazardous waste is calculated based on the amount of waste generated during the manufacturing, installation, and disposal life cycle stages. There is no hazardous or radioactive waste associated with the life cycle. Additionally, all materials are assumed to be landfilled at the end of life rather than incinerated or reused/recycled, so no materials are available for energy recovery or reuse/recycling. Waste occurs at product end-of-life when it is disposed of in a landfill.

The biogenic carbon content of bio-based materials was reported per module. CO_2 from calcination and carbonation does not apply to this study. Carbon emissions from combustion arose from bio-based packaging materials going to incineration.

Tables 20-24 show resource use, output flow and waste categories, and carbon emissions and removals for Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation as well as ASJ+ facer add-ons (facer, butt strip, and SSL) per declared units.

Table 21. Resource use, output and waste flows, and carbon emissions and removals for Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation (1 m at 1 kg)

	Unit	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Resource use indicators										
RPRe	MJ, LHV	4.79E+00	1.62E-02	5.67E-03	MND	0	5.24E-03	0	3.12E-02	**4.85E+00**
RPRm	MJ, LHV	3.86E-08	-1.32E-12	7.78E-13	MND	0	-4.27E-13	0	6.22E-12	**3.86E-08**
NRPRe	MJ, LHV	3.14E+01	4.16E-01	7.20E-02	MND	0	1.35E-01	0	2.66E-01	**3.23E+01**
NRPRm	MJ, LHV	8.91E-08	1.66E-09	2.32E-10	MND	0	5.36E-10	0	6.64E-10	**9.22E-08**
SM	kg	3.82E-01	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**3.82E-01**
RSF	MJ, LHV	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NRSF	MJ, LHV	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
RE	MJ, LHV	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
FW	m3	1.12E-02	5.63E-05	3.03E-05	MND	0	1.82E-05	0	3.30E-05	**1.13E-02**
Output flows and waste category indicators										
HWD	kg	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NHWD	kg	0.00E+00	0.00E+00	2.85E-02	MND	0	0.00E+00	0	7.05E-01	**7.33E-01**
HLRW	kg	2.02E-06	1.21E-09	6.57E-10	MND	0	3.92E-10	0	3.29E-09	**2.02E-06**
ILLRW	kg	1.69E-03	1.02E-06	5.75E-07	MND	0	3.30E-07	0	2.95E-06	**1.69E-03**
CRU	kg	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
MR	kg	0.00E+00	0.00E+00	8.54E-02	MND	0	0.00E+00	0	0.00E+00	**8.54E-02**
MER	kg	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
EE	MJ, LHV	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
Carbon emissions and removals										
BCRP	kg CO2	4.22E-03	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**4.22E-03**
BCEP	kg CO2	2.13E-02	0.00E+00	0.00E+00	MND	0	0.00E+00	0	1.37E-03	**2.26E-02**
BCRK	kg CO2	1.73E-01	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**1.73E-01**
BCEK	kg CO2	0.00E+00	0.00E+00	5.52E-03	MND	0	0.00E+00	0	0.00E+00	**5.52E-03**
BCEW	kg CO2	0.00E+00	0.00E+00	8.81E-03	MND	0	0.00E+00	0	0.00E+00	**8.81E-03**
CCE	kg CO2	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CCR	kg CO2	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CWNR	kg CO2	0.00E+00	0.00E+00	0.00E+00	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**

- [RPRE - Renewable primary energy used as energy carrier (fuel)];
- [RPRM - Renewable primary resources with energy content used as material];
- [NRPRE - Non-renewable primary resources used as an energy carrier (fuel)];
- [NRPRM - Non-renewable primary resources with energy content used as material];
- [SM - Secondary materials];
- [RSF - Renewable secondary fuels];
- [NRSF - Non-renewable secondary fuels];
- [RE - Recovered energy];
- [FW - Use of net fresh water resources]
- [HWD - Hazardous waste disposed];
- [NHWD - Non-hazardous waste disposed];
- [HLRW - High-level radioactive waste, conditioned, to final repository];
- [ILLRW - Intermediate- and low-level radioactive waste, conditioned, to final repository];
- [CRU - Components for re-use];
- [MR - Materials for recycling];
- [MER - Materials for energy recovery];
- [EE - Exported energy];
- [BCRP - Biogenic Carbon Removal from Product];
- [BCEP - Biogenic Carbon Emission from Product];
- [BCRK - Biogenic Carbon Removal from Packaging];
- [BCEK - Biogenic Carbon Emission from Packaging];
- [BCEW - Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes];
- [CCE - Calcination Carbon Emissions];
- [CCR - Carbonation Carbon Removals];
- [CWNR - Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes]

Table 22. Resource use, output and waste flows, and carbon emissions and removals for ASJ+ facer (1 m^2)

	Unit	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Resource use indicators										
RPRe	MJ, LHV	3.11E+00	2.53E-03	0	MND	0	1.03E-03	0	6.12E-03	**3.12E+00**
RPRm	MJ, LHV	1.49E-10	-2.06E-13	0	MND	0	-8.37E-14	0	1.22E-12	**1.50E-10**
NRPRe	MJ, LHV	7.69E+00	6.49E-02	0	MND	0	2.64E-02	0	5.22E-02	**7.84E+00**
NRPRm	MJ, LHV	3.23E-08	2.59E-10	0	MND	0	1.05E-10	0	1.30E-10	**3.28E-08**
SM	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
RSF	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NRSF	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
RE	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
FW	m3	3.63E-03	8.78E-06	0	MND	0	3.57E-06	0	6.47E-06	**3.65E-03**
Output flows and waste category indicators										
HWD	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NHWD	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	1.56E-01	**1.56E-01**
HLRW	kg	1.89E-07	1.89E-10	0	MND	0	7.69E-11	0	6.46E-10	**1.90E-07**
ILLRW	kg	2.48E-04	1.59E-07	0	MND	0	6.48E-08	0	5.78E-07	**2.49E-04**
CRU	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
MR	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
MER	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
EE	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
Carbon emissions and removals										
BCRP	kg CO2	8.52E-02	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**8.52E-02**
BCEP	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	2.68E-04	**2.68E-04**
BCRK	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCEK	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCEW	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CCE	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CCR	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CWNR	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**

Table 23. Resource use, output and waste flows, and carbon emissions and removals for self-sealing lap (SSL) (1 m)

	Unit	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Resource use indicators										
RPRe	MJ, LHV	1.03E-02	4.99E-05	0	MND	0	2.03E-05	0	1.21E-04	**1.05E-02**
RPRm	MJ, LHV	3.50E-12	-4.06E-15	0	MND	0	-1.65E-15	0	2.41E-14	**3.52E-12**
NRPRe	MJ, LHV	2.68E-01	1.28E-03	0	MND	0	5.21E-04	0	1.03E-03	**2.71E-01**
NRPRm	MJ, LHV	3.00E-10	5.10E-12	0	MND	0	2.08E-12	0	2.57E-12	**3.10E-10**
SM	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
RSF	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NRSF	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
RE	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
FW	m3	4.25E-05	1.73E-07	0	MND	0	7.05E-08	0	1.28E-07	**4.29E-05**
Output flows and waste category indicators										
HWD	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NHWD	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	3.08E-03	**3.08E-03**
HLRW	kg	2.22E-09	3.73E-12	0	MND	0	1.52E-12	0	1.28E-11	**2.24E-09**
ILLRW	kg	2.35E-06	3.14E-09	0	MND	0	1.28E-09	0	1.14E-08	**2.37E-06**
CRU	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
MR	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
MER	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
EE	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
Carbon emissions and removals										
BCRP	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCEP	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCRK	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCEK	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCEW	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CCE	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CCR	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CWNR	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**

Table 24. Resource use, output and waste flows, and carbon emissions and removals for butt strip add-on for Earthwool® 1000° Pipe Insulation (1 m)

	Unit	A1-A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Resource use indicators										
RPRe	MJ, LHV	1.81E-01	2.61E-04	0	MND	0	1.06E-04	0	6.32E-04	**1.82E-01**
RPRm	MJ, LHV	1.59E-11	-2.13E-14	0	MND	0	-8.66E-15	0	1.26E-13	**1.60E-11**
NRPRe	MJ, LHV	9.41E-01	6.71E-03	0	MND	0	2.73E-03	0	5.40E-03	**9.56E-01**
NRPRm	MJ, LHV	1.58E-09	2.67E-11	0	MND	0	1.09E-11	0	1.35E-11	**1.63E-09**
SM	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
RSF	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NRSF	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
RE	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
FW	m3	3.62E-04	9.08E-07	0	MND	0	3.69E-07	0	6.69E-07	**3.64E-04**
Output flows and waste category indicators										
HWD	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
NHWD	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	1.61E-02	**1.61E-02**
HLRW	kg	1.58E-08	1.95E-11	0	MND	0	7.95E-12	0	6.68E-11	**1.59E-08**
ILLRW	kg	2.01E-05	1.65E-08	0	MND	0	6.70E-09	0	5.97E-08	**2.02E-05**
CRU	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
MR	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
MER	kg	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
EE	MJ, LHV	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
Carbon emissions and removals										
BCRP	kg CO2	1.90E-03	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**1.90E-03**
BCEP	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	2.77E-05	**2.77E-05**
BCRK	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCEK	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
BCEW	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CCE	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CCR	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**
CWNR	kg CO2	0.00E+00	0.00E+00	0	MND	0	0.00E+00	0	0.00E+00	**0.00E+00**

5.2 Life cycle impact assessment (LCIA)

It shall be reiterated at this point that the reported impact categories represent impact potentials; they are approximations of environmental impacts that could occur if the emitted substances would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen declared 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 Knauf's pipe insulation product. Unlike life cycle inventories, which only report sums for individual inventory flows, the LCIA includes a classification of individual emissions with regard to the impacts they are associated with and subsequently a characterization of the emissions by a factor expressing their respective contribution to the impact category indicator. The end result is a single metric for quantifying each potential impact, such as "Global Warming Potential".

The impact assessment results are calculated using characterization factors published by the United States Environmental Protection Agency. The TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.1) methodology is the most widely applied impact assessment method for U.S. LCA studies. The SM 2013 Methodology is also applied to calculate 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.

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 EPD 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.

In this section, we present the results of the life cycle impact assessment (LCIA) using TRACI, which quantifies the potential environmental impacts associated with the product under study. By evaluating a comprehensive range of environmental categories, we provide a robust and insightful understanding of the overall ecological footprint. The findings outlined below serve as a valuable resource for decision-makers, enabling them to identify areas for improvement and optimize resource allocation, ultimately contributing to more sustainable practices. Tables 25-36 show the contributions of each stage of the life cycle and the single score results for the unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation, ASJ+ facer, SSL, and butt strip per declared units.

5.2.1. Impact assessment results – Unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation

Tables 25-26 provide a comprehensive assessment of the environmental impacts associated with the life cycle of Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation per declared unit, along with the contribution of each life cycle stage. Global warming potential is the highest contributing impact category in both the raw materials acquisition and manufacturing stages.

The results indicate that the manufacturing stage has the most significant contribution to all impact categories, primarily due to the energy required to melt the glass and produce the glass fibers. The raw material acquisition stage is the second highest contributor for most impact categories, but it ranks third for ecotoxicity and fourth for non-carcinogenics. The raw materials acquisition stage impact is largely due to the borax, manganese oxide, and soda ash in the batch and the dextrose in the binder. In contrast, the manufacturing stage shows significant contributions to all impact categories. The contributions to outbound transportation are primarily driven by the use of trucks and rail transport. Outbound transportation is the second highest contributor to ecotoxicity impacts. The disposal stage is associated with landfilling of discarded products, which has a small but notable impact on the non-carcinogenics impact category. The impacts associated with installation are also minimal, except for the non-carcinogenics impact category, where installation ranks second-highest in the results.

Table 25. LCIA results for unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation (1 m at 1 kg)

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Ozone depletion (ODP)	kg CFC-11 eq	9.78E-12	4.58E-14	6.56E-17	1.19E-16	MND	0	2.12E-17	0	8.18E-16	**9.83E-12**
Global warming	kg CO_2 eq	2.07E-01	1.53E+00	2.94E-02	3.25E-02	MND	0	9.51E-03	0	1.66E-02	**1.82E+00**
Smog (SFP)	kg O_3 eq	1.14E-02	5.48E-02	5.17E-03	6.00E-04	MND	0	6.48E-04	0	1.61E-03	**7.42E-02**
Acidification (AP)	kg SO_2 eq	1.13E-03	2.63E-03	1.51E-04	7.69E-05	MND	0	2.84E-05	0	8.83E-05	**4.10E-03**
Eutrophication (EP)	kg N eq	2.42E-04	3.53E-04	1.29E-05	1.12E-05	MND	0	2.91E-06	0	3.87E-06	**6.26E-04**
Respiratory effects	kg $PM_{2.5}$ eq	8.98E-05	6.16E-04	7.37E-06	2.28E-06	MND	0	1.06E-06	0	6.81E-06	**7.24E-04**
Additional environmental information											
Carcinogenics	CTUh	18.0%	69.6%	1.1%	1.5%	MND	0%	0.3%	0%	9.5%	**100%**
Non-carcinogenics	CTUh	27.7%	53.2%	1.3%	2.1%	MND	0%	0.4%	0%	15.2%	**100%**
Ecotoxicity	CTUe	27.2%	66.2%	3.5%	0.5%	MND	0%	1.1%	0%	1.4%	**100%**
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	2.82E-01	2.76E+00	5.51E-02	9.23E-03	MND	0	1.78E-02	0	3.35E-02	**3.15E+00**

Table 26. Percent contributions of each life cycle stage of unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation to each impact category

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4
Ozone depletion (ODP)	kg CFC-11 eq	100%	0%	0%	0%	MND	0%	0%	0%	0%
Global warming	kg CO_2 eq	11%	84%	2%	2%	MND	0%	1%	0%	1%
Smog (SFP)	kg O_3 eq	15%	74%	7%	1%	MND	0%	1%	0%	2%
Acidification (AP)	kg SO_2 eq	28%	64%	4%	2%	MND	0%	1%	0%	2%
Eutrophication (EP)	kg N eq	39%	56%	2%	2%	MND	0%	0%	0%	1%
Respiratory effects	kg $PM_{2.5}$ eq	12%	85%	1%	0%	MND	0%	0%	0%	1%
Additional environmental information										
Carcinogenics	CTUh	18%	70%	1%	1%	MND	0%	0%	0%	9%
Non-carcinogenics	CTUh	28%	53%	1%	2%	MND	0%	0%	0%	15%
Ecotoxicity	CTUe	27%	66%	4%	1%	MND	0%	1%	0%	1%
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	9%	87%	2%	0%	MND	0%	1%	0%	1%

Single score results

The SM millipoint score by life cycle phase for this product is presented below (Table 27). They confirm the trends in the results using the impact assessment results before normalization and weighting.

Table 27. SM millipoint scores for unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation by life cycle stage

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
SM single figure score	mPt	5.92E-03	4.06E-02	5.44E-04	2.45E-04	MND	0	9.61E-05	0	4.74E-04	**4.79E-02**

5.2.2. Impact assessment results – ASJ+ facer

Tables 28-29 provide a comprehensive assessment of the environmental impacts associated with the life cycle of the ASJ+ facer per declared unit, along with the contribution of each life cycle stage. Global warming potential is primarily driven by materials acquisition and transportation to Knauf (97%), with only minor contributions from the outbound transportation (1%) and end-of-life stages (2%). A similar trend is observed for acidification potential, smog formation potential, fossil fuel depletion potential, carcinogenics, non-carcinogenics, respiratory effects, and ecotoxicity. Ozone depletion potential is entirely attributed to the raw materials acquisition and transportation stage (100%). Eutrophication potential exhibits a slightly different

distribution, with 75% of the impact occurring during raw materials acquisition and transportation, 2% during outbound transportation, and a more considerable 24% during the end-of-life stage.

Table 28. LCIA results for ASJ+ facer (1 m^2)

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Ozone depletion (ODP)	kg CFC-11 eq	1.31E-10	0	1.02E-17	0	MND	0	4.16E-18	0	1.60E-16	**1.31E-10**
Global warming	kg CO_2 eq	3.11E-01	0	4.58E-03	0	MND	0	1.86E-03	0	3.26E-03	**3.21E-01**
Smog (SFP)	kg O_3 eq	2.02E-02	0	8.07E-04	0	MND	0	1.27E-04	0	3.16E-04	**2.14E-02**
Acidification (AP)	kg SO_2 eq	1.47E-03	0	2.35E-05	0	MND	0	5.56E-06	0	1.73E-05	**1.52E-03**
Eutrophication (EP)	kg N eq	8.93E-05	0	2.01E-06	0	MND	0	5.70E-07	0	2.77E-05	**1.20E-04**
Respiratory effects	kg $PM_{2.5}$ eq	1.15E-04	0	1.15E-06	0	MND	0	2.09E-07	0	1.33E-06	**1.17E-04**
Additional environmental information											
Carcinogenics	CTUh	94.8%	0%	0.4%	0%	MND	0%	0.2%	0%	4.6%	**100%**
Non-carcinogenics	CTUh	91.7%	0%	0.3%	0%	MND	0%	0.1%	0%	7.9%	**100%**
Ecotoxicity	CTUe	96.4%	0%	0.7%	0%	MND	0%	0.3%	0%	2.6%	**100%**
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	8.90E-01	0	8.59E-03	0	MND	0	3.50E-03	0	6.57E-03	**9.09E-01**

Table 29. Percent contributions of each life cycle stage of ASJ+ facer to each impact category

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4
Ozone depletion (ODP)	kg CFC-11 eq	100%	0%	0%	0%	MND	0%	0%	0%	0%
Global warming	kg CO_2 eq	97%	0%	1%	0%	MND	0%	1%	0%	1%
Smog (SFP)	kg O_3 eq	94%	0%	4%	0%	MND	0%	1%	0%	1%
Acidification (AP)	kg SO_2 eq	97%	0%	2%	0%	MND	0%	0%	0%	1%
Eutrophication (EP)	kg N eq	75%	0%	2%	0%	MND	0%	0%	0%	23%
Respiratory effects	kg $PM_{2.5}$ eq	98%	0%	1%	0%	MND	0%	0%	0%	1%
Additional environmental information										
Carcinogenics	CTUh	95%	0%	0%	0%	MND	0%	0%	0%	5%
Non-carcinogenics	CTUh	92%	0%	0%	0%	MND	0%	0%	0%	8%
Ecotoxicity	CTUe	96%	0%	1%	0%	MND	0%	0%	0%	3%
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	98%	0%	1%	0%	MND	0%	0%	0%	1%

Single score results

The SM millipoint score by life cycle phase for this product is presented below (Table 30). They confirm the trends in the results using the impact assessment results before normalization and weighting.

Table 30. SM millipoint scores for ASJ+ facer by life cycle stage

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
SM single figure score	mPt	7.77E-03	0	8.49E-05	0	MND	0	1.89E-05	0	9.57E-05	**7.97E-03**

5.2.3. Impact assessment results – SSL

Tables 31-32 provide a comprehensive assessment of the environmental impacts associated with the life cycle of the self-sealing lap (SSL) per declared unit, along with the contribution of each life cycle stage. Global warming potential, ozone depletion potential, fossil fuel depletion potential, carcinogenics, non-carcinogenics, and ecotoxicity are predominantly driven by raw materials acquisition and transportation to Knauf, ranging from 90% to 99%. In these categories, only minor contributions are observed from the outbound transportation and end-of-life stages. Acidification potential and smog formation potential display a similar trend, with raw materials acquisition and

transportation contributing to 92% and 91% of the impact, respectively. However, outbound transportation (4% and 6%) and end-of-life stages (4% and 3%) contribute slightly more than in other categories. Eutrophication potential presents a distinct distribution, with 63% of the impact associated with material acquisition and transportation, 2% during outbound transportation, and a significant 35% during the end-of-life stage.

Table 31. LCIA results for SSL (1 m)

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Ozone depletion (ODP)	kg CFC-11 eq	3.47E-16	0	2.02E-19	0	MND	0	8.22E-20	0	3.17E-18	**3.51E-16**
Global warming	kg CO_2 eq	9.02E-03	0	9.04E-05	0	MND	0	3.68E-05	0	6.44E-05	**9.21E-03**
Smog (SFP)	kg O_3 eq	2.41E-04	0	1.59E-05	0	MND	0	2.51E-06	0	6.23E-06	**2.65E-04**
Acidification (AP)	kg SO_2 eq	1.10E-05	0	4.64E-07	0	MND	0	1.10E-07	0	3.42E-07	**1.19E-05**
Eutrophication (EP)	kg N eq	1.02E-06	0	3.98E-08	0	MND	0	1.13E-08	0	5.47E-07	**1.62E-06**
Respiratory effects	kg $PM_{2.5}$ eq	4.81E-07	0	2.27E-08	0	MND	0	4.12E-09	0	2.64E-08	**5.34E-07**
Additional environmental information											
Carcinogenics	CTUh	98.2%	0%	0.1%	0%	MND	0%	0.1%	0%	1.6%	**100%**
Non-carcinogenics	CTUh	97.3%	0%	0.1%	0%	MND	0%	0.04%	0%	2.5%	**100%**
Ecotoxicity	CTUe	96.2%	0%	0.7%	0%	MND	0%	0.3%	0%	2.7%	**100%**
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	3.72E-02	0	1.70E-04	0	MND	0	6.90E-05	0	1.30E-04	**3.76E-02**

Table 32. Percent contributions of each life cycle stage of SSL to each impact category

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4
Ozone depletion (ODP)	kg CFC-11 eq	99%	0%	0%	0%	MND	0%	0%	0%	1%
Global warming	kg CO_2 eq	98%	0%	1%	0%	MND	0%	0%	0%	1%
Smog (SFP)	kg O_3 eq	91%	0%	6%	0%	MND	0%	1%	0%	2%
Acidification (AP)	kg SO_2 eq	92%	0%	4%	0%	MND	0%	1%	0%	3%
Eutrophication (EP)	kg N eq	63%	0%	2%	0%	MND	0%	1%	0%	34%
Respiratory effects	kg $PM_{2.5}$ eq	90%	0%	4%	0%	MND	0%	1%	0%	5%
Additional environmental information										
Carcinogenics	CTUh	98%	0%	0%	0%	MND	0%	0%	0%	2%
Non-carcinogenics	CTUh	97%	0%	0%	0%	MND	0%	0%	0%	3%
Ecotoxicity	CTUe	96%	0%	1%	0%	MND	0%	0%	0%	3%
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	99%	0%	0%	0%	MND	0%	0%	0%	0%

Single score results

The SM millipoint score by life cycle phase for this product is presented below (Table 33). They confirm the trends in the results using the impact assessment results before normalization and weighting.

Table 33. SM millipoint scores for SSL by life cycle stage

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
SM single figure score	mPt	6.43E-05	0	1.68E-06	0	MND	0	3.72E-07	0	1.89E-06	**6.82E-05**

5.2.4. Impact assessment results – Butt strip

Tables 34-35 provide a comprehensive assessment of the environmental impacts associated with the life cycle of butt strips per declared unit, along with the contribution of each life cycle stage. Global warming potential, ozone depletion potential, acidification potential, fossil fuel depletion potential, carcinogenics, non-carcinogenics, and respiratory effects are primarily driven by raw materials acquisition and transportation to

Knauf, with contributions ranging from 93% to 99%. In these categories, only minor contributions are observed from outbound transportation and end-of-life stages. Smog formation potential exhibits a similar trend, with material acquisition and transportation contributing 92% of the impact. However, the outbound transportation (5%) and end-of-life stages (3%) contribute slightly more than in other categories. Eutrophication potential presents a distinct distribution, with 63% of the impact associated with material acquisition and transportation, 2% during outbound transportation, and a significant 34% during the end-of-life stage.

Table 34. LCIA results for butt strip (1 m)

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
Ozone depletion (ODP)	kg CFC-11 eq	1.65E-15	0	1.06E-18	0	MND	0	4.30E-19	0	1.66E-17	**1.67E-15**
Global warming	kg CO_2 eq	3.31E-02	0	4.74E-04	0	MND	0	1.93E-04	0	3.37E-04	**3.41E-02**
Smog (SFP)	kg O_3 eq	1.58E-03	0	8.34E-05	0	MND	0	1.31E-05	0	3.26E-05	**1.71E-03**
Acidification (AP)	kg SO_2 eq	1.07E-04	0	2.43E-06	0	MND	0	5.75E-07	0	1.79E-06	**1.12E-04**
Eutrophication (EP)	kg N eq	5.38E-06	0	2.08E-07	0	MND	0	5.89E-08	0	2.87E-06	**8.52E-06**
Respiratory effects	kg $PM_{2.5}$ eq	6.93E-06	0	1.19E-07	0	MND	0	2.16E-08	0	1.38E-07	**7.21E-06**
Additional environmental information											
Carcinogenics	CTUh	97.0%	0%	0.2%	0%	MND	0%	0.1%	0%	2.7%	**100%**
Non-carcinogenics	CTUh	95.3%	0%	0.2%	0%	MND	0%	0.1%	0%	4.4%	**100%**
Ecotoxicity	CTUe	93.2%	0%	1.3%	0%	MND	0%	0.5%	0%	4.9%	**100%**
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	1.19E-01	0	8.88E-04	0	MND	0	3.62E-04	0	6.80E-04	**1.21E-01**

Table 35. Percent contributions of each life cycle stage of butt strip to each impact category

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4
Ozone depletion (ODP)	kg CFC-11 eq	99%	0%	0%	0%	MND	0%	0%	0%	1%
Global warming	kg CO_2 eq	97%	0%	1%	0%	MND	0%	1%	0%	1%
Smog (SFP)	kg O_3 eq	92%	0%	5%	0%	MND	0%	1%	0%	2%
Acidification (AP)	kg SO_2 eq	96%	0%	2%	0%	MND	0%	1%	0%	2%
Eutrophication (EP)	kg N eq	63%	0%	2%	0%	MND	0%	1%	0%	34%
Respiratory effects	kg $PM_{2.5}$ eq	96%	0%	2%	0%	MND	0%	0%	0%	2%
Additional environmental information										
Carcinogenics	CTUh	97%	0%	0%	0%	MND	0%	0%	0%	3%
Non-carcinogenics	CTUh	95%	0%	0%	0%	MND	0%	0%	0%	4%
Ecotoxicity	CTUe	93%	0%	1%	0%	MND	0%	1%	0%	5%
Fossil fuel depletion (ADP_{fossil})	MJ, LHV	98%	0%	1%	0%	MND	0%	0%	0%	1%

Single score results

The SM millipoint score by life cycle phase for this product is presented below (Table 36). They confirm the trends in the results using the impact assessment results before normalization and weighting.

Table 36. SM millipoint scores for butt strip by life cycle stage

Impact category	Unit	A1-A2	A3	A4	A5	B1-B7	C1	C2	C3	C4	Total
SM single figure score	mPt	5.30E-04	0	8.78E-06	0	0	0	1.95E-06	0	9.90E-06	**5.51E-04**

5.3 Scaling factors

Results provided in this report may be scaled to various pipe insulation diameters and thicknesses. In order to calculate results per one lineal foot of unfaced Earthwool® 1000°

Pipe Insulation and ALLEY-K™ Pipe Insulation having a specific inside diameter (ID) and wall thickness with or without the ASJ+ facer (Earthwool® only), use the following equation:

$$\boldsymbol{Total\ results\ per\ lineal\ foot\ of\ pipe}\ (\mathbf{1}\ \boldsymbol{ft}) =$$

Unfaced pipe insulation

$$\left(\begin{matrix}Unfaced\ insulation\ impact\\ Table\ 25\end{matrix}\right) * \left(\begin{matrix}Unfaced\ insulation\ scaling\ factor\\ Table\ 37, scaling\ factor\ INS\end{matrix}\right)$$
$$+ \left(\begin{matrix}SSL\ impact\\ Table\ 28\end{matrix}\right) * (0.3048)$$

Plus ASJ+ facer with butt strip

$$+ \left(\begin{matrix}ASJ\ impact\\ Table\ 31\end{matrix}\right) * \left(\begin{matrix}ASJ\ scaling\ factor\\ Table\ 37, scaling\ factor\ ASJ\end{matrix}\right)$$
$$+ \left(\begin{matrix}Butt\ strip\ impact\\ Table\ 34\end{matrix}\right) * \left(\begin{matrix}Butt\ strip\ scaling\ factor\\ Table\ 37, scaling\ factor\ BUT\end{matrix}\right)$$

Table 37. Pipe insulation thicknesses for various iron and copper pipe sizes and their associated scaling factors

					Scaling factor INS	Scaling factor ASJ	Scaling factor BUT
Iron pipe size (in)	**Copper pipe size (in)**	**Nominal pipe insulation thickness (in)**	**Actual pipe insulation thickness (in)**	**Actual pipe insulation thickness (cm)**	Pipe insulation scaling factor to one lineal foot of pipe from the declared unit (1m at 1kg)	ASJ+ scaling factor to one lineal foot of pipe from the declared unit (1m2)	Butt strip scaling factor to one lineal foot of pipe from the declared unit (1m)
1/2	7/8	1/2	4.85E-01	1.23E+00	5.01E-02	4.49E-02	5.05E-02
	5/8	1/2	4.95E-01	1.26E+00	4.20E-02	3.93E-02	4.42E-02
3/4	1 1/8	1/2	4.95E-01	1.26E+00	6.02E-02	5.11E-02	5.75E-02
1	1 3/8	1/2	4.75E-01	1.21E+00	6.55E-02	5.60E-02	6.30E-02
1 1/4	1 5/8	1/2	5.15E-01	1.31E+00	7.70E-02	6.43E-02	7.23E-02
1 1/2		1/2	4.65E-01	1.18E+00	7.56E-02	6.79E-02	7.63E-02
2		1/2	4.60E-01	1.17E+00	9.21E-02	8.09E-02	9.10E-02
	2 1/8	1/2	4.85E-01	1.23E+00	8.12E-02	7.47E-02	8.41E-02
2 1/2		1/2	4.65E-01	1.18E+00	1.01E-01	9.29E-02	1.05E-01
	2 5/8	1/2	4.85E-01	1.23E+00	9.63E-02	8.65E-02	9.74E-02
3		1/2	4.60E-01	1.17E+00	1.16E-01	1.06E-01	1.20E-01
	3 1/8	1/2	4.85E-01	1.23E+00	1.02E-01	9.84E-02	1.11E-01
3 1/2		1/2	4.70E-01	1.19E+00	1.22E-01	1.18E-01	1.33E-01
	3 5/8	1/2	4.85E-01	1.23E+00	1.16E-01	1.10E-01	1.24E-01
4		1/2	5.00E-01	1.27E+00	1.45E-01	1.31E-01	1.48E-01
	4 1/8	1/2	4.85E-01	1.23E+00	1.24E-01	1.22E-01	1.37E-01
4 1/2		1/2	5.10E-01	1.30E+00	1.55E-01	1.44E-01	1.62E-01
5		1/2	4.75E-01	1.21E+00	1.60E-01	1.57E-01	1.76E-01
	5 1/8	1/2	4.85E-01	1.23E+00	1.51E-01	1.46E-01	1.64E-01
6		1/2	4.45E-01	1.13E+00	1.75E-01	1.80E-01	2.03E-01
	6 1/8	1/2	4.65E-01	1.18E+00	1.70E-01	1.69E-01	1.90E-01
7		1/2	4.50E-01	1.14E+00	1.73E-01	2.04E-01	2.30E-01
8		1/2	4.35E-01	1.10E+00	1.88E-01	2.28E-01	2.56E-01
9		1/2	4.90E-01	1.24E+00	2.35E-01	2.53E-01	2.85E-01
10		1/2	4.30E-01	1.09E+00	2.28E-01	2.78E-01	3.13E-01
1/2	7/8	1	9.45E-01	2.40E+00	9.70E-02	6.67E-02	7.50E-02
	5/8	1	1.08E+00	2.73E+00	1.03E-01	6.67E-02	7.50E-02
3/4	1 1/8	1	8.25E-01	2.10E+00	9.00E-02	6.67E-02	7.50E-02
1	1 3/8	1	1.02E+00	2.58E+00	1.35E-01	8.16E-02	9.18E-02
1 1/4	1 5/8	1	8.80E-01	2.24E+00	1.24E-01	8.16E-02	9.18E-02
1 1/2		1	1.01E+00	2.55E+00	1.62E-01	9.34E-02	1.05E-01
2		1	9.75E-01	2.48E+00	1.68E-01	1.05E-01	1.18E-01
	2 1/8	1	8.80E-01	2.24E+00	1.34E-01	9.34E-02	1.05E-01
2 1/2		1	9.75E-01	2.48E+00	1.92E-01	1.17E-01	1.32E-01
	2 5/8	1	8.80E-01	2.24E+00	1.55E-01	1.05E-01	1.18E-01
3		1	9.65E-01	2.45E+00	2.17E-01	1.30E-01	1.47E-01
	3 1/8	1	8.80E-01	2.24E+00	1.77E-01	1.17E-01	1.32E-01
3 1/2		1	1.26E+00	3.19E+00	3.30E-01	1.55E-01	1.75E-01
	3 5/8	1	9.10E-01	2.31E+00	2.07E-01	1.30E-01	1.47E-01
4		1	1.01E+00	2.55E+00	2.77E-01	1.55E-01	1.75E-01
	4 1/8	1	1.19E+00	3.02E+00	3.17E-01	1.55E-01	1.75E-01
4 1/2		1	1.26E+00	3.19E+00	3.92E-01	1.79E-01	2.01E-01
5		1	9.50E-01	2.41E+00	3.11E-01	1.79E-01	2.01E-01
	5 1/8	1	1.19E+00	3.02E+00	3.56E-01	1.79E-01	2.01E-01
6		1	9.20E-01	2.34E+00	3.30E-01	2.03E-01	2.28E-01
	6 1/8	1	1.17E+00	2.97E+00	4.06E-01	2.03E-01	2.28E-01
7		1	9.20E-01	2.34E+00	3.73E-01	2.26E-01	2.55E-01
8		1	9.70E-01	2.46E+00	4.42E-01	2.53E-01	2.85E-01
9		1	9.90E-01	2.51E+00	4.97E-01	2.77E-01	3.11E-01
10		1	9.05E-01	2.30E+00	5.00E-01	3.00E-01	3.38E-01
11		1	1.05E+00	2.65E+00	6.32E-01	3.30E-01	3.71E-01
12		1	1.04E+00	2.63E+00	6.75E-01	3.54E-01	3.98E-01

14		1	9.10E-01	2.31E+00	6.42E-01	3.77E-01	4.24E-01
15		1	9.10E-01	2.31E+00	6.84E-01	4.01E-01	4.51E-01
16		1	9.10E-01	2.31E+00	7.27E-01	4.24E-01	4.77E-01
17		1	9.10E-01	2.31E+00	7.69E-01	4.48E-01	5.04E-01
18		1	9.10E-01	2.31E+00	8.12E-01	4.72E-01	5.31E-01
19		1	9.10E-01	2.31E+00	8.55E-01	4.95E-01	5.57E-01
20		1	9.10E-01	2.31E+00	8.97E-01	5.19E-01	5.84E-01
21		1	9.10E-01	2.31E+00	9.40E-01	5.43E-01	6.10E-01
22		1	9.10E-01	2.31E+00	9.82E-01	5.66E-01	6.37E-01
23		1	9.10E-01	2.31E+00	1.03E+00	5.90E-01	6.64E-01
24		1	9.10E-01	2.31E+00	1.07E+00	6.14E-01	6.90E-01
25		1	9.10E-01	2.31E+00	1.11E+00	6.37E-01	7.17E-01
26		1	9.10E-01	2.31E+00	1.15E+00	6.61E-01	7.43E-01
27		1	9.10E-01	2.31E+00	1.20E+00	6.85E-01	7.70E-01
28		1	9.10E-01	2.31E+00	1.24E+00	7.08E-01	7.97E-01
29		1	9.10E-01	2.31E+00	1.28E+00	7.32E-01	8.23E-01
30		1	9.10E-01	2.31E+00	1.32E+00	7.56E-01	8.50E-01
1/2	7/8	1 1/2	1.51E+00	3.84E+00	1.70E-01	9.34E-02	1.05E-01
	5/8	1 1/2	1.39E+00	3.53E+00	1.42E-01	8.16E-02	9.18E-02
3/4	1 1/8	1 1/2	1.39E+00	3.53E+00	1.76E-01	9.34E-02	1.05E-01
1	1 3/8	1 1/2	1.52E+00	3.85E+00	2.20E-01	1.05E-01	1.18E-01
1 1/4	1 5/8	1 1/2	1.63E+00	4.14E+00	2.68E-01	1.17E-01	1.32E-01
1 1/2		1 1/2	1.51E+00	3.82E+00	2.57E-01	1.17E-01	1.32E-01
2		1 1/2	1.51E+00	3.82E+00	2.98E-01	1.30E-01	1.47E-01
	2 1/8	1 1/2	1.38E+00	3.51E+00	2.44E-01	1.17E-01	1.32E-01
2 1/2		1 1/2	1.79E+00	4.53E+00	4.22E-01	1.55E-01	1.75E-01
	2 5/8	1 1/2	1.41E+00	3.58E+00	2.71E-01	1.30E-01	1.47E-01
3		1 1/2	1.50E+00	3.80E+00	3.56E-01	1.55E-01	1.75E-01
	3 1/8	1 1/2	1.69E+00	4.29E+00	3.86E-01	1.55E-01	1.75E-01
3 1/2		1 1/2	1.76E+00	4.46E+00	4.78E-01	1.79E-01	2.01E-01
	3 5/8	1 1/2	1.44E+00	3.66E+00	3.08E-01	1.55E-01	1.75E-01
4		1 1/2	1.51E+00	3.82E+00	3.80E-01	1.79E-01	2.01E-01
	4 1/8	1 1/2	1.69E+00	4.29E+00	4.14E-01	1.79E-01	2.01E-01
4 1/2		1 1/2	1.76E+00	4.46E+00	4.98E-01	2.03E-01	2.28E-01
5		1 1/2	1.45E+00	3.68E+00	4.30E-01	2.03E-01	2.28E-01
	5 1/8	1 1/2	1.69E+00	4.29E+00	4.84E-01	2.03E-01	2.28E-01
6		1 1/2	1.42E+00	3.61E+00	4.82E-01	2.26E-01	2.55E-01
	6 1/8	1 1/2	1.67E+00	4.24E+00	5.50E-01	2.26E-01	2.55E-01
7		1 1/2	1.49E+00	3.77E+00	5.70E-01	2.53E-01	2.85E-01
8		1 1/2	1.47E+00	3.73E+00	6.27E-01	2.77E-01	3.11E-01
9		1 1/2	1.49E+00	3.78E+00	6.96E-01	3.00E-01	3.38E-01
10		1 1/2	1.53E+00	3.89E+00	7.92E-01	3.30E-01	3.71E-01
11		1 1/2	1.55E+00	3.92E+00	8.63E-01	3.54E-01	3.98E-01
12		1 1/2	1.54E+00	3.90E+00	9.22E-01	3.77E-01	4.24E-01
14		1 1/2	1.41E+00	3.58E+00	9.13E-01	4.01E-01	4.51E-01
15		1 1/2	1.41E+00	3.58E+00	9.72E-01	4.24E-01	4.77E-01
16		1 1/2	1.41E+00	3.58E+00	1.03E+00	4.48E-01	5.04E-01
17		1 1/2	1.41E+00	3.58E+00	1.09E+00	4.72E-01	5.31E-01
18		1 1/2	1.41E+00	3.58E+00	1.15E+00	4.95E-01	5.57E-01
19		1 1/2	1.41E+00	3.58E+00	1.21E+00	5.19E-01	5.84E-01
20		1 1/2	1.41E+00	3.58E+00	1.27E+00	5.43E-01	6.10E-01
21		1 1/2	1.41E+00	3.58E+00	1.32E+00	5.66E-01	6.37E-01
22		1 1/2	1.41E+00	3.58E+00	1.38E+00	5.90E-01	6.64E-01
23		1 1/2	1.41E+00	3.58E+00	1.44E+00	6.14E-01	6.90E-01
24		1 1/2	1.41E+00	3.58E+00	1.50E+00	6.37E-01	7.17E-01
25		1 1/2	1.41E+00	3.58E+00	1.56E+00	6.61E-01	7.43E-01
26		1 1/2	1.41E+00	3.58E+00	1.62E+00	6.85E-01	7.70E-01
27		1 1/2	1.41E+00	3.58E+00	1.68E+00	7.08E-01	7.97E-01
28		1 1/2	1.41E+00	3.58E+00	1.74E+00	7.32E-01	8.23E-01

29		1 1/2	1.41E+00	3.58E+00	1.79E+00	7.56E-01	8.50E-01
30		1 1/2	1.41E+00	3.58E+00	1.85E+00	7.79E-01	8.76E-01
1/2	7/8	2	2.01E+00	5.11E+00	2.77E-01	1.17E-01	1.32E-01
	5/8	2	1.92E+00	4.86E+00	2.32E-01	1.06E-01	1.20E-01
3/4	1 1/8	2	1.89E+00	4.80E+00	2.71E-01	1.17E-01	1.32E-01
1	1 3/8	2	2.05E+00	5.19E+00	3.32E-01	1.30E-01	1.47E-01
1 1/4	1 5/8	2	1.91E+00	4.85E+00	3.22E-01	1.30E-01	1.47E-01
1 1/2		2	2.32E+00	5.88E+00	4.62E-01	1.55E-01	1.75E-01
2		2	2.04E+00	5.17E+00	4.33E-01	1.55E-01	1.75E-01
	2 1/8	2	2.19E+00	5.56E+00	4.49E-01	1.55E-01	1.75E-01
2 1/2		2	2.29E+00	5.80E+00	5.66E-01	1.79E-01	2.01E-01
	2 5/8	2	1.94E+00	4.93E+00	4.21E-01	1.55E-01	1.75E-01
3		2	2.00E+00	5.07E+00	5.21E-01	1.79E-01	2.01E-01
	3 1/8	2	2.19E+00	5.56E+00	5.52E-01	1.79E-01	2.01E-01
3 1/2		2	2.26E+00	5.73E+00	5.93E-01	2.03E-01	2.28E-01
	3 5/8	2	1.94E+00	4.93E+00	4.55E-01	1.79E-01	2.01E-01
4		2	2.01E+00	5.09E+00	5.48E-01	2.03E-01	2.28E-01
	4 1/8	2	2.19E+00	5.56E+00	5.82E-01	2.03E-01	2.28E-01
4 1/2		2	2.26E+00	5.73E+00	6.87E-01	2.26E-01	2.55E-01
5		2	1.95E+00	4.95E+00	6.19E-01	2.26E-01	2.55E-01
	5 1/8	2	2.19E+00	5.56E+00	6.73E-01	2.26E-01	2.55E-01
6		2	1.99E+00	5.04E+00	7.21E-01	2.53E-01	2.85E-01
	6 1/8	2	2.24E+00	5.68E+00	7.88E-01	2.53E-01	2.85E-01
7		2	1.99E+00	5.04E+00	8.03E-01	2.77E-01	3.11E-01
8		2	1.97E+00	5.00E+00	8.81E-01	3.00E-01	3.38E-01
9		2	2.12E+00	5.37E+00	1.04E+00	3.30E-01	3.71E-01
10		2	2.03E+00	5.16E+00	1.09E+00	3.54E-01	3.98E-01
11		2	2.05E+00	5.19E+00	1.18E+00	3.77E-01	4.24E-01
12		2	2.04E+00	5.17E+00	1.26E+00	4.01E-01	4.51E-01
14		2	1.91E+00	4.85E+00	1.28E+00	4.24E-01	4.77E-01
15		2	1.91E+00	4.85E+00	1.36E+00	4.48E-01	5.04E-01
16		2	1.91E+00	4.85E+00	1.44E+00	4.72E-01	5.31E-01
17		2	1.91E+00	4.85E+00	1.51E+00	4.95E-01	5.57E-01
18		2	1.91E+00	4.85E+00	1.59E+00	5.19E-01	5.84E-01
19		2	1.91E+00	4.85E+00	1.67E+00	5.43E-01	6.10E-01
20		2	1.91E+00	4.85E+00	1.75E+00	5.66E-01	6.37E-01
21		2	1.91E+00	4.85E+00	1.83E+00	5.90E-01	6.64E-01
22		2	1.91E+00	4.85E+00	1.91E+00	6.14E-01	6.90E-01
23		2	1.91E+00	4.85E+00	1.99E+00	6.37E-01	7.17E-01
24		2	1.91E+00	4.85E+00	2.07E+00	6.61E-01	7.43E-01
25		2	1.91E+00	4.85E+00	2.15E+00	6.85E-01	7.70E-01
26		2	1.91E+00	4.85E+00	2.23E+00	7.08E-01	7.97E-01
27		2	1.91E+00	4.85E+00	2.31E+00	7.32E-01	8.23E-01
28		2	1.91E+00	4.85E+00	2.39E+00	7.56E-01	8.50E-01
29		2	1.91E+00	4.85E+00	2.47E+00	7.79E-01	8.76E-01
30		2	1.91E+00	4.85E+00	2.55E+00	8.03E-01	9.03E-01
1	1 3/8	2 1/2	2.61E+00	6.62E+00	4.37E-01	1.57E-01	1.76E-01
1 1/4	1 5/8	2 1/2	2.47E+00	6.27E+00	4.28E-01	1.57E-01	1.76E-01
1 1/2		2 1/2	2.82E+00	7.15E+00	5.58E-01	1.79E-01	2.01E-01
2		2 1/2	2.54E+00	6.44E+00	5.32E-01	1.79E-01	2.01E-01
	2 1/8	2 1/2	2.69E+00	6.83E+00	5.47E-01	1.79E-01	2.01E-01
2 1/2		2 1/2	2.79E+00	7.07E+00	6.71E-01	2.03E-01	2.28E-01
	2 5/8	2 1/2	2.44E+00	6.20E+00	5.22E-01	1.79E-01	2.01E-01
3		2 1/2	2.50E+00	6.34E+00	6.31E-01	2.03E-01	2.28E-01
	3 1/8	2 1/2	2.69E+00	6.83E+00	6.59E-01	2.03E-01	2.28E-01
3 1/2		2 1/2	2.76E+00	7.00E+00	7.82E-01	2.26E-01	2.55E-01
	3 5/8	2 1/2	2.44E+00	6.20E+00	6.23E-01	2.03E-01	2.28E-01
4		2 1/2	2.51E+00	6.36E+00	7.37E-01	2.26E-01	2.55E-01
	4 1/8	2 1/2	2.69E+00	6.83E+00	7.71E-01	2.26E-01	2.55E-01

4 1/2		2 1/2	2.82E+00	7.16E+00	9.26E-01	2.53E-01	2.85E-01
5		2 1/2	2.52E+00	6.39E+00	8.58E-01	2.53E-01	2.85E-01
	5 1/8	2 1/2	2.76E+00	7.00E+00	9.12E-01	2.53E-01	2.85E-01
6		2 1/2	2.49E+00	6.31E+00	9.54E-01	2.77E-01	3.11E-01
	6 1/8	2 1/2	2.74E+00	6.95E+00	1.02E+00	2.77E-01	3.11E-01
7		2 1/2	2.49E+00	6.31E+00	1.06E+00	3.00E-01	3.38E-01
8		2 1/2	2.60E+00	6.59E+00	1.23E+00	3.30E-01	3.71E-01
9		2 1/2	2.62E+00	6.64E+00	1.34E+00	3.54E-01	3.98E-01
10		2 1/2	2.53E+00	6.43E+00	1.41E+00	3.77E-01	4.24E-01
11		2 1/2	2.55E+00	6.46E+00	1.53E+00	4.01E-01	4.51E-01
12		2 1/2	2.54E+00	6.44E+00	1.63E+00	4.24E-01	4.77E-01
14		2 1/2	2.41E+00	6.12E+00	1.66E+00	4.48E-01	5.04E-01
15		2 1/2	2.41E+00	6.12E+00	1.76E+00	4.72E-01	5.31E-01
16		2 1/2	2.41E+00	6.12E+00	2.09E+00	4.95E-01	5.57E-01
17		2 1/2	2.41E+00	6.12E+00	1.96E+00	5.19E-01	5.84E-01
18		2 1/2	2.41E+00	6.12E+00	2.06E+00	5.43E-01	6.10E-01
19		2 1/2	2.41E+00	6.12E+00	2.16E+00	5.66E-01	6.37E-01
20		2 1/2	2.41E+00	6.12E+00	2.26E+00	5.90E-01	6.64E-01
21		2 1/2	2.41E+00	6.12E+00	2.36E+00	6.14E-01	6.90E-01
22		2 1/2	2.41E+00	6.12E+00	2.46E+00	6.37E-01	7.17E-01
23		2 1/2	2.41E+00	6.12E+00	2.56E+00	6.61E-01	7.43E-01
24		2 1/2	2.41E+00	6.12E+00	2.66E+00	6.85E-01	7.70E-01
25		2 1/2	2.41E+00	6.12E+00	2.77E+00	7.08E-01	7.97E-01
26		2 1/2	2.41E+00	6.12E+00	2.87E+00	7.32E-01	8.23E-01
27		2 1/2	2.41E+00	6.12E+00	2.97E+00	7.56E-01	8.50E-01
28		2 1/2	2.41E+00	6.12E+00	3.07E+00	7.79E-01	8.76E-01
29		2 1/2	2.41E+00	6.12E+00	3.17E+00	8.03E-01	9.03E-01
30		2 1/2	2.41E+00	6.12E+00	3.27E+00	8.26E-01	9.30E-01
1	1 3/8	3	3.08E+00	7.81E+00	5.76E-01	1.79E-01	2.01E-01
1 1/2		3	3.32E+00	8.42E+00	7.26E-01	2.03E-01	2.28E-01
2		3	3.04E+00	7.71E+00	7.00E-01	2.03E-01	2.28E-01
	2 1/8	3	3.19E+00	8.10E+00	7.15E-01	2.03E-01	2.28E-01
2 1/2		3	3.29E+00	8.34E+00	8.60E-01	2.26E-01	2.55E-01
	2 5/8	3	2.94E+00	7.47E+00	6.90E-01	2.03E-01	2.28E-01
3		3	3.00E+00	7.61E+00	8.20E-01	2.26E-01	2.55E-01
	3 1/8	3	3.19E+00	8.10E+00	8.48E-01	2.26E-01	2.55E-01
3 1/2		3	3.32E+00	8.43E+00	1.02E+00	2.53E-01	2.85E-01
	3 5/8	3	2.94E+00	7.47E+00	8.12E-01	2.26E-01	2.55E-01
4		3	3.07E+00	7.80E+00	9.76E-01	2.53E-01	2.85E-01
	4 1/8	3	3.26E+00	8.27E+00	1.01E+00	2.53E-01	2.85E-01
4 1/2		3	3.32E+00	8.43E+00	1.16E+00	2.77E-01	3.11E-01
5		3	3.02E+00	7.66E+00	1.09E+00	2.77E-01	3.11E-01
	5 1/8	3	3.26E+00	8.27E+00	1.15E+00	2.77E-01	3.11E-01
6		3	2.99E+00	7.58E+00	1.21E+00	3.00E-01	3.38E-01
	6 1/8	3	3.24E+00	8.22E+00	1.28E+00	3.00E-01	3.38E-01
7		3	3.11E+00	7.90E+00	1.40E+00	3.30E-01	3.71E-01
8		3	3.10E+00	7.86E+00	1.53E+00	3.54E-01	3.98E-01
9		3	3.12E+00	7.91E+00	1.67E+00	3.77E-01	4.24E-01
10		3	3.03E+00	7.70E+00	1.76E+00	4.01E-01	4.51E-01
11		3	3.05E+00	7.73E+00	1.89E+00	4.24E-01	4.77E-01
12		3	3.04E+00	7.71E+00	2.01E+00	4.48E-01	5.04E-01
14		3	2.91E+00	7.39E+00	2.07E+00	4.72E-01	5.31E-01
15		3	2.91E+00	7.39E+00	2.19E+00	4.95E-01	5.57E-01
16		3	2.91E+00	7.39E+00	2.31E+00	5.19E-01	5.84E-01
17		3	2.91E+00	7.39E+00	2.43E+00	5.43E-01	6.10E-01
18		3	2.91E+00	7.39E+00	2.55E+00	5.66E-01	6.37E-01
19		3	2.91E+00	7.39E+00	2.67E+00	5.90E-01	6.64E-01
20		3	2.91E+00	7.39E+00	2.79E+00	6.14E-01	6.90E-01
21		3	2.91E+00	7.39E+00	2.91E+00	6.37E-01	7.17E-01

22		3	2.91E+00	7.39E+00	3.04E+00	6.61E-01	7.43E-01
23		3	2.91E+00	7.39E+00	3.16E+00	6.85E-01	7.70E-01
24		3	2.91E+00	7.39E+00	3.28E+00	7.08E-01	7.97E-01
25		3	2.91E+00	7.39E+00	3.40E+00	7.32E-01	8.23E-01
26		3	2.91E+00	7.39E+00	3.52E+00	7.56E-01	8.50E-01
27		3	2.91E+00	7.39E+00	3.64E+00	7.79E-01	8.76E-01
28		3	2.91E+00	7.39E+00	3.76E+00	8.03E-01	9.03E-01
29		3	2.91E+00	7.39E+00	3.88E+00	8.26E-01	9.30E-01
30		3	2.91E+00	7.39E+00	4.01E+00	8.50E-01	9.56E-01
1 1/2		3 1/2	3.82E+00	9.69E+00	9.15E-01	2.26E-01	2.55E-01
2		3 1/2	3.54E+00	8.98E+00	8.89E-01	2.26E-01	2.55E-01
	2 1/8	3 1/2	3.69E+00	9.37E+00	9.04E-01	2.26E-01	2.55E-01
2 1/2		3 1/2	3.85E+00	9.78E+00	1.10E+00	2.53E-01	2.85E-01
	2 5/8	3 1/2	3.44E+00	8.74E+00	8.79E-01	2.26E-01	2.55E-01
3		3 1/2	3.56E+00	9.04E+00	1.06E+00	2.53E-01	2.85E-01
	3 1/8	3 1/2	3.76E+00	9.54E+00	1.09E+00	2.53E-01	2.85E-01
3 1/2		3 1/2	3.82E+00	9.70E+00	1.25E+00	2.77E-01	3.11E-01
	3 5/8	3 1/2	3.51E+00	8.90E+00	1.05E+00	2.53E-01	2.85E-01
4		3 1/2	3.57E+00	9.07E+00	1.21E+00	2.77E-01	3.11E-01
	4 1/8	3 1/2	3.76E+00	9.54E+00	1.24E+00	2.77E-01	3.11E-01
4 1/2		3 1/2	3.82E+00	9.70E+00	1.41E+00	3.00E-01	3.38E-01
5		3 1/2	3.52E+00	8.93E+00	1.35E+00	3.00E-01	3.38E-01
	5 1/8	3 1/2	3.76E+00	9.54E+00	1.40E+00	3.00E-01	3.38E-01
6		3 1/2	3.61E+00	9.17E+00	1.56E+00	3.30E-01	3.71E-01
	6 1/8	3 1/2	3.86E+00	9.80E+00	1.62E+00	3.30E-01	3.71E-01
7		3 1/2	3.61E+00	9.17E+00	1.71E+00	3.54E-01	3.98E-01
8		3 1/2	3.60E+00	9.13E+00	1.85E+00	3.77E-01	4.24E-01
9		3 1/2	3.62E+00	9.18E+00	2.01E+00	4.01E-01	4.51E-01
10		3 1/2	3.53E+00	8.97E+00	2.12E+00	4.24E-01	4.77E-01
11		3 1/2	3.55E+00	9.00E+00	2.28E+00	4.48E-01	5.04E-01
12		3 1/2	3.54E+00	8.98E+00	2.42E+00	4.72E-01	5.31E-01
14		3 1/2	3.41E+00	8.66E+00	2.49E+00	4.95E-01	5.57E-01
15		3 1/2	3.41E+00	8.66E+00	2.63E+00	5.19E-01	5.84E-01
16		3 1/2	3.41E+00	8.66E+00	2.78E+00	5.43E-01	6.10E-01
17		3 1/2	3.41E+00	8.66E+00	2.92E+00	5.66E-01	6.37E-01
18		3 1/2	3.41E+00	8.66E+00	3.06E+00	5.90E-01	6.64E-01
19		3 1/2	3.41E+00	8.66E+00	3.20E+00	6.14E-01	6.90E-01
20		3 1/2	3.41E+00	8.66E+00	3.34E+00	6.37E-01	7.17E-01
21		3 1/2	3.41E+00	8.66E+00	3.49E+00	6.61E-01	7.43E-01
22		3 1/2	3.41E+00	8.66E+00	3.63E+00	6.85E-01	7.70E-01
23		3 1/2	3.41E+00	8.66E+00	3.77E+00	7.08E-01	7.97E-01
24		3 1/2	3.41E+00	8.66E+00	3.91E+00	7.32E-01	8.23E-01
25		3 1/2	3.41E+00	8.66E+00	4.05E+00	7.56E-01	8.50E-01
26		3 1/2	3.41E+00	8.66E+00	4.20E+00	7.79E-01	8.76E-01
27		3 1/2	3.41E+00	8.66E+00	4.34E+00	8.03E-01	9.03E-01
28		3 1/2	3.41E+00	8.66E+00	4.48E+00	8.26E-01	9.30E-01
29		3 1/2	3.41E+00	8.66E+00	4.62E+00	8.50E-01	9.56E-01
1 1/2		4	4.38E+00	1.11E+01	1.15E+00	2.53E-01	2.85E-01
2		4	4.10E+00	1.04E+01	1.13E+00	2.53E-01	2.85E-01
	2 1/8	4	4.26E+00	1.08E+01	1.14E+00	2.53E-01	2.85E-01
2 1/2		4	4.35E+00	1.10E+01	1.33E+00	2.77E-01	3.11E-01
	2 5/8	4	4.01E+00	1.02E+01	1.12E+00	2.53E-01	2.85E-01
3		4	4.06E+00	1.03E+01	1.29E+00	2.77E-01	3.11E-01
	3 1/8	4	4.26E+00	1.08E+01	1.32E+00	2.77E-01	3.11E-01
3 1/2		4	4.32E+00	1.10E+01	1.51E+00	3.00E-01	3.38E-01
	3 5/8	4	4.01E+00	1.02E+01	1.28E+00	2.77E-01	3.11E-01
4		4	4.07E+00	1.03E+01	1.46E+00	3.00E-01	3.38E-01
	4 1/8	4	3.76E+00	9.54E+00	1.24E+00	2.77E-01	3.11E-01
4 1/2		4	3.82E+00	9.70E+00	1.41E+00	3.30E-01	3.71E-01

5		4	4.14E+00	1.05E+01	1.69E+00	3.30E-01	3.71E-01
	5 1/8	4	3.76E+00	9.54E+00	1.40E+00	3.00E-01	3.38E-01
6		4	4.11E+00	1.04E+01	1.86E+00	3.54E-01	3.98E-01
	6 1/8	4	3.86E+00	9.80E+00	1.62E+00	3.30E-01	3.71E-01
7		4	4.11E+00	1.04E+01	2.03E+00	3.77E-01	4.24E-01
8		4	4.10E+00	1.04E+01	2.19E+00	4.01E-01	4.51E-01
9		4	4.12E+00	1.05E+01	2.37E+00	4.24E-01	4.77E-01
10		4	4.03E+00	1.02E+01	2.50E+00	4.48E-01	5.04E-01
11		4	4.05E+00	1.03E+01	2.68E+00	4.72E-01	5.31E-01
12		4	4.04E+00	1.02E+01	2.84E+00	4.95E-01	5.57E-01
14		4	3.91E+00	9.93E+00	2.94E+00	5.19E-01	5.84E-01
15		4	3.91E+00	9.93E+00	3.10E+00	5.43E-01	6.10E-01
16		4	3.91E+00	9.93E+00	3.26E+00	5.66E-01	6.37E-01
17		4	3.91E+00	9.93E+00	3.43E+00	5.90E-01	6.64E-01
18		4	3.91E+00	9.93E+00	3.59E+00	6.14E-01	6.90E-01
19		4	3.91E+00	9.93E+00	3.75E+00	6.37E-01	7.17E-01
20		4	3.91E+00	9.93E+00	3.92E+00	6.61E-01	7.43E-01
21		4	3.91E+00	9.93E+00	4.08E+00	6.85E-01	7.70E-01
22		4	3.91E+00	9.93E+00	4.24E+00	7.08E-01	7.97E-01
23		4	3.91E+00	9.93E+00	4.40E+00	7.32E-01	8.23E-01
24		4	3.91E+00	9.93E+00	4.57E+00	7.56E-01	8.50E-01
25		4	3.91E+00	9.93E+00	4.73E+00	7.79E-01	8.76E-01
26		4	3.91E+00	9.93E+00	4.89E+00	8.03E-01	9.03E-01
27		4	3.91E+00	9.93E+00	5.06E+00	8.26E-01	9.30E-01
28		4	3.91E+00	9.93E+00	5.22E+00	8.50E-01	9.56E-01
2		4 1/2	4.63E+00	1.17E+01	1.37E+00	2.78E-01	3.13E-01
	2 1/8	4 1/2	4.78E+00	1.21E+01	1.39E+00	2.78E-01	3.13E-01
2 1/2		4 1/2	4.38E+00	1.11E+01	1.34E+00	2.78E-01	3.13E-01
	2 5/8	4 1/2	4.53E+00	1.15E+01	1.36E+00	2.78E-01	3.13E-01
3		4 1/2	4.56E+00	1.16E+01	1.55E+00	3.00E-01	3.38E-01
	3 1/8	4 1/2	4.26E+00	1.08E+01	1.32E+00	2.77E-01	3.11E-01
3 1/2		4 1/2	4.32E+00	1.10E+01	1.51E+00	3.00E-01	3.38E-01
	3 5/8	4 1/2	4.51E+00	1.14E+01	1.54E+00	3.00E-01	3.38E-01
4		4 1/2	4.70E+00	1.19E+01	1.81E+00	3.30E-01	3.71E-01
	4 1/8	4 1/2	4.26E+00	1.08E+01	1.50E+00	3.00E-01	3.38E-01
4 1/2		4 1/2	4.45E+00	1.13E+01	1.76E+00	3.30E-01	3.71E-01
5		4 1/2	4.64E+00	1.18E+01	1.99E+00	3.54E-01	3.98E-01
	5 1/8	4 1/2	4.38E+00	1.11E+01	1.75E+00	3.30E-01	3.71E-01
6		4 1/2	4.61E+00	1.17E+01	2.18E+00	3.77E-01	4.24E-01
	6 1/8	4 1/2	4.36E+00	1.11E+01	1.92E+00	3.54E-01	3.98E-01
7		4 1/2	4.61E+00	1.17E+01	2.37E+00	4.01E-01	4.51E-01
8		4 1/2	4.60E+00	1.17E+01	2.56E+00	4.24E-01	4.77E-01
9		4 1/2	4.62E+00	1.17E+01	2.76E+00	4.48E-01	5.04E-01
10		4 1/2	4.55E+00	1.15E+01	2.92E+00	4.72E-01	5.31E-01
11		4 1/2	4.55E+00	1.15E+01	3.11E+00	4.95E-01	5.57E-01
12		4 1/2	4.54E+00	1.15E+01	3.29E+00	5.19E-01	5.84E-01
14		4 1/2	4.41E+00	1.12E+01	3.41E+00	5.43E-01	6.10E-01
15		4 1/2	4.41E+00	1.12E+01	3.59E+00	5.66E-01	6.37E-01
16		4 1/2	4.41E+00	1.12E+01	3.77E+00	5.90E-01	6.64E-01
17		4 1/2	4.41E+00	1.12E+01	3.96E+00	6.14E-01	6.90E-01
18		4 1/2	4.41E+00	1.12E+01	4.14E+00	6.37E-01	7.17E-01
19		4 1/2	4.41E+00	1.12E+01	4.32E+00	6.61E-01	7.43E-01
20		4 1/2	4.41E+00	1.12E+01	4.51E+00	6.85E-01	7.70E-01
21		4 1/2	4.41E+00	1.12E+01	4.69E+00	7.08E-01	7.97E-01
22		4 1/2	4.41E+00	1.12E+01	4.88E+00	7.32E-01	8.23E-01
23		4 1/2	4.41E+00	1.12E+01	5.06E+00	7.56E-01	8.50E-01
24		4 1/2	4.41E+00	1.12E+01	5.24E+00	7.79E-01	8.76E-01
25		4 1/2	4.41E+00	1.12E+01	5.43E+00	8.03E-01	9.03E-01
26		4 1/2	4.41E+00	1.12E+01	5.61E+00	8.26E-01	9.30E-01

27		4 1/2	4.41E+00	1.12E+01	5.79E+00	8.50E-01	9.56E-01
2		5	5.10E+00	1.30E+01	1.61E+00	3.00E-01	3.38E-01
	2 1/8	5	5.26E+00	1.33E+01	1.63E+00	3.00E-01	3.38E-01
2 1/2		5	5.48E+00	1.39E+01	1.93E+00	3.30E-01	3.71E-01
	2 5/8	5	5.03E+00	1.28E+01	1.62E+00	3.01E-01	3.39E-01
3		5	5.19E+00	1.32E+01	1.89E+00	3.30E-01	3.71E-01
	3 1/8	5	5.38E+00	1.37E+01	1.92E+00	3.30E-01	3.71E-01
3 1/2		5	4.95E+00	1.26E+01	1.86E+00	3.30E-01	3.71E-01
	3 5/8	5	5.13E+00	1.30E+01	1.88E+00	3.30E-01	3.71E-01
4		5	5.20E+00	1.32E+01	2.11E+00	3.54E-01	3.98E-01
	4 1/8	5	4.88E+00	1.24E+01	1.84E+00	3.30E-01	3.71E-01
4 1/2		5	4.95E+00	1.26E+01	2.06E+00	3.54E-01	3.98E-01
5		5	5.14E+00	1.31E+01	2.31E+00	3.77E-01	4.24E-01
	5 1/8	5	5.38E+00	1.37E+01	2.37E+00	3.77E-01	4.24E-01
6		5	5.11E+00	1.30E+01	2.52E+00	4.01E-01	4.51E-01
	6 1/8	5	5.36E+00	1.36E+01	2.59E+00	4.01E-01	4.51E-01
7		5	5.11E+00	1.30E+01	2.73E+00	4.24E-01	4.77E-01
8		5	5.10E+00	1.29E+01	2.94E+00	4.48E-01	5.04E-01
9		5	5.12E+00	1.30E+01	3.16E+00	4.72E-01	5.31E-01
10		5	5.03E+00	1.28E+01	3.34E+00	4.95E-01	5.57E-01
11		5	5.05E+00	1.28E+01	3.55E+00	5.19E-01	5.84E-01
12		5	5.04E+00	1.28E+01	3.76E+00	5.43E-01	6.10E-01
14		5	4.91E+00	1.25E+01	3.89E+00	5.66E-01	6.37E-01
15		5	4.91E+00	1.25E+01	4.10E+00	5.90E-01	6.64E-01
16		5	4.91E+00	1.25E+01	4.30E+00	6.14E-01	6.90E-01
17		5	4.91E+00	1.25E+01	4.51E+00	6.37E-01	7.17E-01
18		5	4.91E+00	1.25E+01	4.71E+00	6.61E-01	7.43E-01
19		5	4.91E+00	1.25E+01	4.92E+00	6.85E-01	7.70E-01
20		5	4.91E+00	1.25E+01	5.12E+00	7.08E-01	7.97E-01
21		5	4.91E+00	1.25E+01	5.33E+00	7.32E-01	8.23E-01
22		5	4.91E+00	1.25E+01	5.53E+00	7.56E-01	8.50E-01
23		5	4.91E+00	1.25E+01	5.74E+00	7.79E-01	8.76E-01
24		5	4.91E+00	1.25E+01	5.94E+00	8.03E-01	9.03E-01
25		5	4.91E+00	1.25E+01	6.14E+00	8.26E-01	9.30E-01
26		5	4.91E+00	1.25E+01	6.35E+00	8.50E-01	9.56E-01
2		6	5.73E+00	1.45E+01	1.96E+00	3.30E-01	3.71E-01
2 1/2		6	6.48E+00	1.64E+01	2.56E+00	3.77E-01	4.24E-01
	2 5/8	6	6.13E+00	1.56E+01	2.25E+00	3.54E-01	3.98E-01
3		6	6.19E+00	1.57E+01	2.52E+00	3.77E-01	4.24E-01
	3 1/8	6	6.38E+00	1.62E+01	2.54E+00	3.77E-01	4.24E-01
3 1/2		6	5.95E+00	1.51E+01	2.48E+00	3.77E-01	4.24E-01
	3 5/8	6	6.13E+00	1.56E+01	2.51E+00	3.77E-01	4.24E-01
4		6	6.20E+00	1.57E+01	2.78E+00	4.01E-01	4.51E-01
	4 1/8	6	6.38E+00	1.62E+01	2.81E+00	4.01E-01	4.51E-01
4 1/2		6	5.95E+00	1.51E+01	2.73E+00	4.01E-01	4.51E-01
5		6	6.14E+00	1.56E+01	3.02E+00	4.24E-01	4.77E-01
	5 1/8	6	6.38E+00	1.62E+01	3.08E+00	4.24E-01	4.77E-01
6		6	6.11E+00	1.55E+01	3.27E+00	4.48E-01	5.04E-01
	6 1/8	6	6.36E+00	1.62E+01	3.34E+00	4.48E-01	5.04E-01
7		6	6.11E+00	1.55E+01	3.52E+00	4.72E-01	5.31E-01
8		6	6.10E+00	1.55E+01	3.77E+00	4.95E-01	5.57E-01
9		6	6.12E+00	1.55E+01	4.03E+00	5.19E-01	5.84E-01
10		6	6.03E+00	1.53E+01	4.25E+00	5.43E-01	6.10E-01
11		6	6.05E+00	1.54E+01	4.51E+00	5.66E-01	6.37E-01
12		6	6.04E+00	1.53E+01	4.76E+00	5.90E-01	6.64E-01
14		6	5.91E+00	1.50E+01	4.93E+00	6.14E-01	6.90E-01
15		6	5.91E+00	1.50E+01	5.18E+00	6.37E-01	7.17E-01
16		6	5.91E+00	1.50E+01	5.43E+00	6.61E-01	7.43E-01
17		6	5.91E+00	1.50E+01	5.67E+00	6.85E-01	7.70E-01

18		6	5.91E+00	1.50E+01	5.92E+00	7.08E-01	7.97E-01
19		6	5.91E+00	1.50E+01	6.16E+00	7.32E-01	8.23E-01
20		6	5.91E+00	1.50E+01	6.41E+00	7.56E-01	8.50E-01
21		6	5.91E+00	1.50E+01	6.66E+00	7.79E-01	8.76E-01
22		6	5.91E+00	1.50E+01	6.90E+00	8.03E-01	9.03E-01
23		6	5.91E+00	1.50E+01	7.15E+00	8.26E-01	9.30E-01
24		6	5.91E+00	1.50E+01	7.40E+00	8.50E-01	9.56E-01

5.4 Sensitivity analysis

During the data collection process at the Shelbyville, IN plant, some of the energy reported was difficult or impossible to allocate to specific process steps. Since energy consumed during the manufacturing stage for insulation production is a major contributor to global warming, a sensitivity analysis was conducted by changing the amount of energy in the 'Other' category by ±100%. As shown in Table 38, changing 'Other' energy consumption by 100% changes the emissions in the manufacturing stage by 13%, which in turn changes the overall emissions across all life cycle stages by 11%. It is recommended that Knauf takes steps to create a more detailed breakdown of energy sources categorized as 'Other,' as it directly impacts the total life cycle impact assessment calculations.

Table 38. Sensitivity analysis of LCIA results, per declared unit for of unfaced Earthwool® 1000° Pipe Insulation and ALLEY-K™ Pipe Insulation

LCIA module	Base GWP kg CO_2 eq	-100% 'Other' energy	+100% 'Other' energy	% change
A3 emissions	1.53E+00	1.33E+00	1.72E+00	±13%
Total emissions	1.82E+00	1.62E+00	2.02E+00	±11%

5.5 Overview of relevant findings

This Life Cycle Assessment (LCA) report evaluates a wide range of inventory and environmental indicators. As is expected for insulation products, the primary finding is that manufacturing dominates the environmental impacts due to the energy required to melt the glass and produce the glass fibers.

Raw material production also constitutes a significant contribution to the impacts across all inventory and impact indicators. Borax, manganese oxide, and soda ash emerge as the three main contributors to the pipe insulation product studied.

Outbound transport accounts for a notable impact only in the global warming and smog formation impact categories. For other impact categories, outbound transport plays a minor role. The impact associated with outbound transport is consistently higher than that for inbound transport due to greater transportation distances.

Installation contributes a small fraction of the overall life cycle impact, with the only installation impacts being associated with packaging disposal. While insulation can influence building energy performance, this aspect is considered beyond the scope of this study. Furthermore, it is assumed that no replacements are necessary.

At the end of life, insulation is manually removed from the building and landfilled. For all products, waste is 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.

5.6 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).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the LCA for Experts LCI databases were used. The LCI datasets from the LCA for Experts 2023 databases are widely distributed and used with the LCA for Experts Software. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

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 12 months of data. All background data are from LCA for Experts databases with the documented precision.
- Completeness: Each unit process was checked for mass balance and completeness of the emission inventory. Capital equipment was excluded under cut-off criteria. Otherwise, no data were knowingly omitted.

Consistency and reproducibility

- Consistency: To ensure consistency, all primary data were collected with the same level of detail, while all background data were sourced from the LCA for Experts databases. Allocation and other methodological choices were made consistently throughout the model.
- Reproducibility: Reproducibility is warranted as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

Representativeness

- Temporal: All primary data were collected for CY2019 in order to ensure representativeness of post-consumer content. All secondary data were obtained from the LCA for Experts 2023 databases and are typically representative.
- Geographical: Primary data are representative of Knauf's production in the US. Data were collected from the Shelbyville facility. In general, secondary data were collected specific to the country under study. Where country-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- Technological: All primary and secondary data were modeled to be specific to the technologies under study. Technological representativeness is considered to be high.

5.7 Conclusions and recommendations

The goal of this study was to conduct a cradle-to-installation with end of life LCA on pipe insulation so as to develop an SM Transparency Report. 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 impacts. Manufacturing emissions and energy consumption drive environmental performance. Additionally, raw materials also account for a notable contribution to impacts. The gate-to-installation and end of life stages account for minimal contributions to life cycle performance.

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

The results show that the largest area for reduction of each product's environmental impact is in the manufacturing phase. This is an important area for Knauf to focus its efforts on and one which it can influence. A more detailed study of where and how gas and electricity are used will improve the quality of the LCIA results. Particularly, creating a more detailed breakdown of energy sources categorized as 'Other' could directly impact the quality of the life cycle impact assessment calculations. In addition, considering the large amount of energy consumed during the furnace and curing oven steps, incremental reductions in the total use of electricity and gas are expected to have a notable impact on the total LCIA results.

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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
SSL	Self-sealing lap
TR	Transparency Report / EPD™
USLCI	US Life Cycle Inventory

GLOSSARY

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

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

APPENDIX

- Compilation of data from Knauf and LCI development workbook: Primary data_Pipe.xlsx
- Knauf's LCA results workbook: LCA results - Pipe_Apr2023.xlsx
- Insulation thicknesses and outside diameter for piping applications: knauf-pipe-nesting-chart.pdf
- Scaling table calculations: Design Weight by Pipe Size for SM_2023.xlsx