ENVIRONMENTAL PRODUCT DECLARATION

EARTHWOOL 1000° PIPE INSULATION

GLASS MINERAL WOOL
WITH ASJ+ AND REDI-KLAD FACING OPTIONS

KNAUF INSULATION
it's time to save energy

We are proud to introduce the world's first EPD for pipe insulation.

When engaging the architectural community, we found that the mechanical insulation in commercial buildings is largely ignored by the architectural design firm. Rather, the insulation for the mechanical system is specified by the mechanical design firm.

Does this make sense? No, frankly it makes no sense to us to have a formaldehyde free strategy for a building, and then load the mechanical room with formaldehyde containing products.

We are hopeful that this EPD will help reconcile the process of selecting the insulation for the mechanical room so that it synergistic with the building's design as a whole.

Knauf Insulation's Earthwool Pipe Insulation is the solution and we believe it is the best engineered glass mineral wool pipe insulation on the market today.

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According to ISO 14025

This declaration is an environmental product declaration (EPD) in accordance with ISO 14025. EPDs rely on Life Cycle Assessment (LCA) to provide information on a number of environmental impacts of products over their life cycle. Exclusions: EPDs do not indicate that any environmental or social performance benchmarks are met, and there may be impacts that they do not encompass. LCAs do not typically address the site-specific environmental impacts of raw material extraction, nor are they meant to assess human health toxicity. EPDs can complement but cannot replace tools and certifications that are designed to address these impacts and/or set performance thresholds – e.g. Type 1 certifications, health assessments and declarations, environmental impact assessments, etc. Accuracy of Results: EPDs regularly rely on estimations of impacts, and the level of accuracy in estimation of effect differs for any particular product line and reported impact. Comparability: EPDs are not comparative assertions and are either not comparable or have limited comparability when they cover different life cycle stages, are based on different product category rules or are missing relevant environmental impacts. EPDs from different programs may not be comparable.

PROGRAM OPERATOR	UL Environment
DECLARATION HOLDER	Knauf Insulation
DECLARATION NUMBER	4786058564.101.1
DECLARED PRODUCT	Earthwool® 1000° Pipe Insulation
REFERENCE PCR	PCR for preparing an EPD for poduct groups: Building Envelope Thermal Insulation v1.3 (June 1, 2014)
DATE OF ISSUE	September 12, 2014
PERIOD OF VALIDITY	5 Years
CONTENTS OF THE DECLARATION	Product definition and information about building physics Information about basic material and the material's origin Description of the product's manufacture Indication of product processing Information about the in-use conditions Life cycle assessment results Testing results and verifications

The PCR review was conducted by:	UL Environment
	PCR was Reviewed by panel
	333 Pfingsten Rd Northbrook, IL 60062
This declaration was independently verified in accordance with ISO 14025 by Underwriters Laboratories ☐ INTERNAL ☒ EXTERNAL	
	Wade Stout, UL Environment
This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by:	
	Tom Gloria, Life-Cycle Services, LLC

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Product Definition

Company Description

Knauf Insulation North America is part of the Knauf Group; a large family-owned business based in Iphofen, Germany. The insulation portion of the Knauf Group was founded in North America in Shelbyville, Indiana in 1978. All insulation products sold in North America are made in the United States.

Since 1978, the Knauf Insulation business has grown into a global entity, located in 36 countries and has become the second largest glass mineral wool producer in the world today. Knauf Insulation is known for encouraging sustainable development due to its advocacy regarding the positive impact that insulation has on the potential of climate change. In 2008 Knauf Insulation launched a green chemistry initiative known as Ecose® Technology where the traditional phenol/formaldehyde binders where replaced by a bio-based based substitute. The entire glass mineral wool industry has tried to follow with bio-based efforts.

By 2010, Knauf Insulation had implemented Ecose® Technology across all of its insulation product lines and is the only company that offers formaldehyde free, bio-based products for all traditional glass mineral wool applications. Today Ecose® Technology is a separate entity of the Knauf Group, sharing bio-based application development with other industries. Knauf Insulation prides itself upon higher density, high quality products. For more information on Earthwool Pipe Insulation, see http://www.knaufinsulation.us/content/earthwool-1000-pipe-insulation-data-sheet and http://www.knaufinsulation.us/content/earthwool-redi-klad-1000-pipe-insulation-ecose-technology-data-sheet.

Product Description

Knauf Insulation Earthwool® 1000° pipe glass mineral wool (GMW) insulation is a molded, heavy-density, one-piece insulation made from inorganic glass strands bonded with Ecose® Technology. It is produced in 3’ lengths with and without factory-applied All-Service-Jacket (ASJ+). The ASJ+ jacketing system on Earthwool pipe is step-up from traditional ASJ because it has a polymer film coating to facilitate cleaning and resist the potential detrimental effects of dew point excursion or even wetting from rain exposure during the construction process. The Redi-Klad jacketing option is designed to replace 0.016 aluminum jacketing systems typical of outdoor piping systems. Redi-Klad is also an excellent, premium choice for indoor chilled water applications. All Earthwool products provide a formaldehyde-free option for the mechanical room of buildings having a low VOC strategy.

Manufacturing Locations

This Environmental Product Declaration (EPD) represents the production of pipe insulation at Knauf Insulation’s facility in Shelbyville, IN.

Application and Uses

Knauf Insulation Earthwool® Pipe Insulation is used to insulate iron and copper piping in industrial applications and commercial and institutional buildings. Earthwool 1000° Pipe Insulation is suitable for hot, cold, concealed and exposed piping systems operating at temperatures from 0°F to 1000°F (-18°C to 538°C). Additional weather protection is needed when ASJ+ is used outdoors, although the Redi-Klad option is designed for indoor and outdoor use.

Installation

At Elevated Temperatures:
This product can be installed while the system is in operation, at all temperatures up to 1000°F (538°C). For insulation

thicknesses greater than 6" (152 mm), Knauf Insulation recommends that the temperature be increased from 500°F (260°C) to maximum temperature at a rate not exceeding 100°F (56°C) per hour. During the initial heat-up to operating temperatures above 350°F (177°C), a slight odor and some smoke may be given off as a portion of the bonding material used in the insulation begins to undergo a controlled decomposition. If natural convection is not adequate in confined areas, then forced ventilation should be provided in order to protect against any harmful fumes and vapors that might be generated. Care must also be taken when using sealants solvents or flammable adhesive during installation at elevated temperatures.

At Below-Freezing Temperatures:
On below-freezing applications, and in high-abuse areas, the ASJ+ jacket should be protected with a PVC vapor retarding outer jacket. In addition, exposed ends of insulation shall be sealed with vapor barrier mastic installed per the mastic manufacturer's instructions. Vapor seals at butt joints shall be applied at 12' to 21' intervals at the Engineer's discretion and at each fitting to isolate any water incursion.

Health, Safety, and Environmental Aspects during Installation

Glass mineral wool fibers are a potential mechanical irritant to skin. Long sleeves, gloves and goggles reduce dermal contact. OSHA regulations do not require respiratory protection as long as the exposure to glass mineral wool does not exceed 1 fiber/cubic centimeter (f/cc) TWA (8-hour time weighted average). Installers and fabricators should be aware of their exposure levels and take appropriate actions if needed per recommended work practices. Guidance on typical fiber exposures for various applications can be obtained from the North American Insulation Manufacturers Association, http://www.NAIMA.org. The health and safety aspects of all Knauf Insulation products are certified by the EUCEB exoneration process, http://www.euceb.org. Knauf Insulation recommends following all safe work practices while working with and/or installing glass mineral wool products. The data from the exposure database relating to glass mineral wool installation is listed in Table 1.

The material safety datasheets for Knauf Insulation's Ecose products can be found at http://www.knaufinsulation.us/content/insulation-board-ecose-technology-msds

Table 1: Glass mineral wool installation from exposure database

Job	Sample Size	Mean	Standard Deviation	Median	Range
Installers	114	0.05 fibers / cm^3	0.1	0.02	0.01 – 0.70

Potential Health Effects:

- **Acute:** Mechanical irritation of the skin, eyes and upper respiratory system. Glass mineral wool fibers are classified as a nuisance dust by OSHA.
- **Chronic:** None
- **Skin Contact:** There are confirmed reports of contact dermatitis.
- **Eye Contact:** A mechanical irritant which can cause moderate to severe eye irritation.
- **Ingestion:** Non-hazardous, but potentially a mild irritant to the GI tract if excessive quantity is ingested.

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Production

Material Content

Knauf Insulation's glass mineral wool is manufactured from two key components: the inorganic glass batch and the organic binder. The batch consists of minerals used to form the glass fibers, and includes post-consumer cullet (e.g. recycled bottles). The binder, which holds the fibers together and gives the product shape, is manufactured from predominantly renewable sources (sugars) and some non-renewable materials. Earthwool pipe insulation can also have an All Service Jacket (ASJ+), which provides a facer material for an attractive finish for mechanical rooms. ASJ+ is washable and provides protection against vapor intrusion, and has a permeance rating of ≤ 0.02 perms[1]. Earthwool pipe insulation is also available with the Redi-Klad option, which provides a very durable and resilient facer material that is suitable for outdoor or indoor use, and has a water vapor permeance rating of 0.0 (zero) perms.

Table 2 lists raw material inputs per declared unit and inbound transportation distances of each material to Knauf's manufacturing facility.

Table 2: Raw material inputs per 1 kg of glass fiber and 1 m² of ASJ+ or Redi-Klad jacket

Component	Wt. % ASJ+	Wt. % Redi-Klad	Recycled Resource	Mineral Resource	Renewable	Origin	Inbound Distance (mi)
Batch							
Post-consumer cullet	43%	40%	x			North America	238
Sand	17%	16%		x		North America	347
Borax	7.2%	6.7%		x		North America	2,050
Soda ash	6.9%	6.4%		x		North America	347
Dolomite	2.6%	2.4%		x		North America	336
Nepheline syenite	2.1%	2.0%		x		North America	1,020
Limestone	1.6%	1.5%		x		North America	336
Manganese dioxide	< 1%	< 1%		x		North America	1,940
Binder							
Sugars	6.6%	6.1%			x	North America	174
Diammonium phosphate	2.3%	2.1%		x		North America	187
Silane	< 1%	< 1%		x		North America	2,580
Jacket							
Aluminum	1%	6.5%	x	x		North America	500
Kraft paper	3.8%	< 1%	x		x	North America	500
Polyester	–	8.1%		x		North America	500
Other jacket materials	3.8%	1%		x		North America	500

[1] A US perm is defined as one (1) grain of water vapor per hour, per square foot, per inch of mercury.

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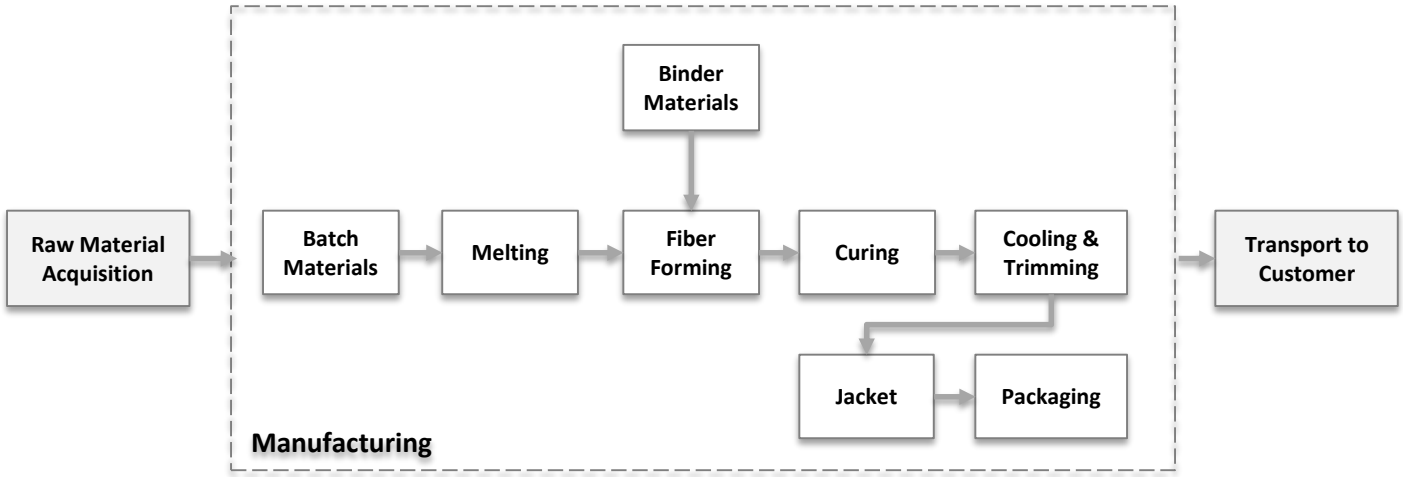
Manufacturing Process

Figure 1: Pipe glass mineral wool insulation manufacturing



Health, Safety, and Environmental Aspects during Production

Knauf Insulation management is committed to providing a safe work environment for all employees. Employee safety training is considered critical to achieving a safe working environment. Knauf Insulation management has charged the Corporate Environmental, Health and Safety group with a mission "to monitor specific business activities within Knauf Insulation and to provide advice and guidance to minimize the impact of those activities…" This includes our compliance with State and Federal OSHA standards, as well as our Best Practices. Knauf Insulation North America has environmental management and production certifications for ISO 14001:2004, ISO 50001:2011, and ISO 9001:2008.

Life Cycle Assessment – Product System and Modeling

A "cradle-to-grave" life cycle assessment (LCA) was conducted for this EPD. The analysis was done according to the product category rule (PCR) for building envelope thermal insulation and followed LCA principles, requirements and guidelines laid out in the ISO 14040/14044 standards. As such, EPDs of construction products may not be comparable if they do not comply with the same PCR or if they are from different programs.

While the intent of the PCR is to increase comparability, there may still be differences among EPDs that comply with the same PCR (e.g., due to differences in system boundaries, background data, etc.).

Functional Unit

Per the product category rules, the declared unit for this analysis is 1 kg of insulation material plus 1 m^2 ASJ+ with a building service life of 60 years. Results for 1 kg of insulation material plus 1 m^2 Redi-Klad are also included. A declared unit is being used in place of a functional unit because the physical configuration of the pipe insulation affects thermal resistivity; thus, it is virtually impossible to define a single, generic functional unit that is representative of all possible configurations.

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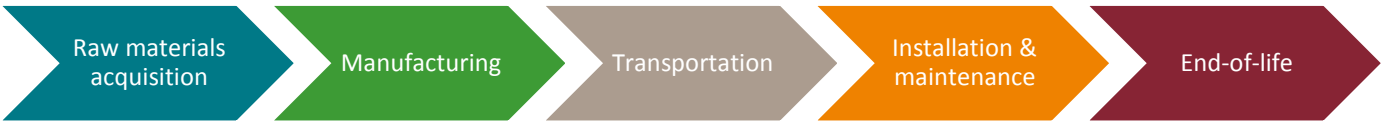
Life Cycle Stages Assessed

A cradle-to-grave life cycle analysis was conducted, from extraction of natural resources to final disposal. Within these boundaries the following stages were included:

- **Raw materials acquisition:** Raw material supply (including virgin and recycled materials), inbound transport
- **Manufacturing:** Production of insulation, packaging of finished product, manufacturing waste, releases to the environment
- **Transportation:** Distribution of the insulation product from the manufacturer to a distributor (if applicable) and from there, to the building site
- **Installation and Maintenance:** Installation process, installation wastes and releases to the environment, maintenance under normal conditions
- **End-of-Life:** Dismantling/demolition, transport to final disposal site, final disposition

Figure 2: Life cycle stages included in system boundary



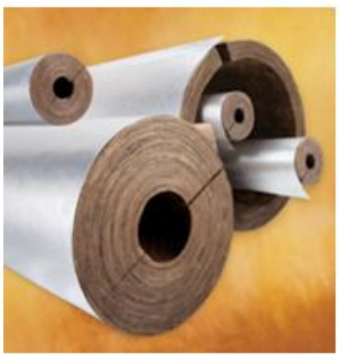
System Boundaries

This study covers the entire life cycle of the products, including raw material acquisition and manufacturing, transportation to the building site, installation and maintenance, and finally End-of-Life treatment. Additionally, transportation between stages has been accounted for, including raw material transport to the manufacturing facility and end-of-life transport to the landfill. Manufacturing facility overhead is included. Building operational energy and water use are considered outside of this study's scope: any impact that the use of insulation may have on a building's energy consumption is not calculated or incorporated into the analysis.

Assumptions

The analysis uses the following assumptions:

- GMW insulation is assumed to have a 60-year reference service life, equal to that of the building.
- Installation is done by hand and assumed to have a negligible scrap rate (0%).



Cut-off Criteria

Processes or activities that contribute no more than 2% of the total mass and 1% of the total energy may be omitted under PCR cut-off criteria. If omitted material flows have relevant contributions to the selected impact categories, their exclusion must be justified by a sensitivity analysis.

Cut-off criteria were applied to capital equipment production and maintenance under the assumption that the impacts associated with these aspects were sufficiently small enough to fall below cut-off when scaled down to the functional unit. Packaging for inbound raw materials to Knauf Insulation's facility was also excluded from the analysis. Otherwise, all energy and material flow data available were included in the model.

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Transportation

Average transportation distances via truck and rail included for the transport of the raw materials to the production facility. Transport of the finished product to the construction site is also accounted for, along with the transportation construction wastes and the deconstructed product at end-of-life to disposal facilities. Distribution of the finished product is assumed to be volume-limited rather than mass-limited, with a utilization rate of 22% of mass capacity.

Period under Consideration

Primary data were collected on insulation production between February 2013 and January 2014.

Background Data

The LCA model was created using the GaBi 6 Software system for life cycle engineering, developed by PE INTERNATIONAL. The GaBi 2012 LCI database provided the life cycle inventory data for upstream and downstream processes of the background system. Proxy data used in the LCA model were limited to background data for raw material production. US background data were used whenever possible, with European or global data substituted as proxies as necessary.

Data Quality

Data quality and representativeness are considered to be good to high. Foreground data were collected from Knauf Insulation's manufacturing facility, with seasonal variations accounted for by collecting 12 months-worth of data. Aside from capital equipment, no data were omitted under cut-off criteria. All primary data were collected with the same level of detail while all background data were sourced from the GaBi databases. Allocation and other methodological choices were made consistently throughout the model.

Allocation

Knauf Insulation's Shelbyville facility manufactures multiple products. Allocation of manufacturing material and energy inputs was done on a mass-basis—the one exception being the jacket, which was allocated based on product surface area. Allocation of trucks used for distribution was based on weight, but accounted for cargo volume as it restricted the total amount a truck could transport.

For recycled content and disposal at end-of-life, system boundaries were drawn consistently with the cut-off allocation approach. Post-consumer cullet (waste glass), which is used as part of Knauf Insulation'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 GMW life cycle. Likewise, the system boundary was drawn to include landfilling of GMW at end-of-life (following the polluter-pays-principle), but exclude any avoided burden from material or energy recovery.

Use

Pipe insulation is assumed to have a reference service life of 60 years, equal to that of the building. Once installed, insulation does not directly consume energy, and requires no maintenance. There are no parts to repair or refurbish. Any reduction in building operational energy consumption associated with insulation use need to be considered on the

level of the individual building and are considered outside the scope of the LCA.

End-of-Life

At end-of-life, insulation is removed from the deconstructed building. Wastes are then transported 20 miles and disposed in a landfill. While GMW insulation can be recycled, doing so is not common practice in the industry. Therefore, after removal, the insulation is transported to the disposal site and landfilled.

Life Cycle Assessment Results and Analysis

Use of Material and Energy Resources

Tables 3 and 4 show the primary energy demands per functional unit. Energy resource consumption is broken down by type and by resource. Figures 3 and 4 illustrate the results graphically.

Table 3: Primary energy demand per functional unit (by type)

Total Primary Energy	Unit	Pipe with ASJ+	Pipe with Redi-Klad
Non-renewable, fossil	MJ	79.3	96.1
Non-renewable, nuclear	MJ	8.83	11.5
Renewable, biomass	MJ	0.0443	0.0
Renewable, wind, solar, geothermal	MJ	13.8	12.9
Renewable, hydro	MJ	1.49	5.17
Total	**MJ**	**103**	**126**

Table 4: Primary energy demand per functional unit (by resource)

Total Primary Energy	Unit	Pipe with ASJ+	Pipe with Redi-Klad
Non-renewable resources			
Fossil oil	MJ	17.0	23.9
Coal	MJ	25.8	29.6
Natural gas	MJ	36.5	42.6
Uranium	MJ	8.83	11.5
Renewable resources			
Biomass	MJ	0.0443	0.0
Geothermal	MJ	0.0222	0.0276
Hydro power	MJ	1.49	5.17
Solar power	MJ	13.1	12.1
Wind power	MJ	0.635	0.76
Total	**MJ**	**103**	**126**

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Figure 3: Non-renewable primary energy resources

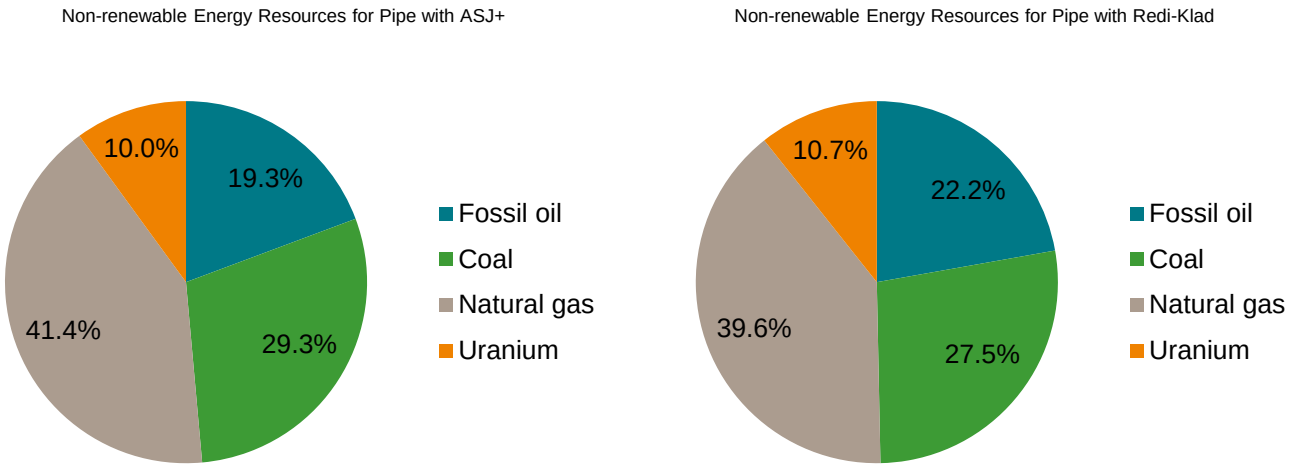
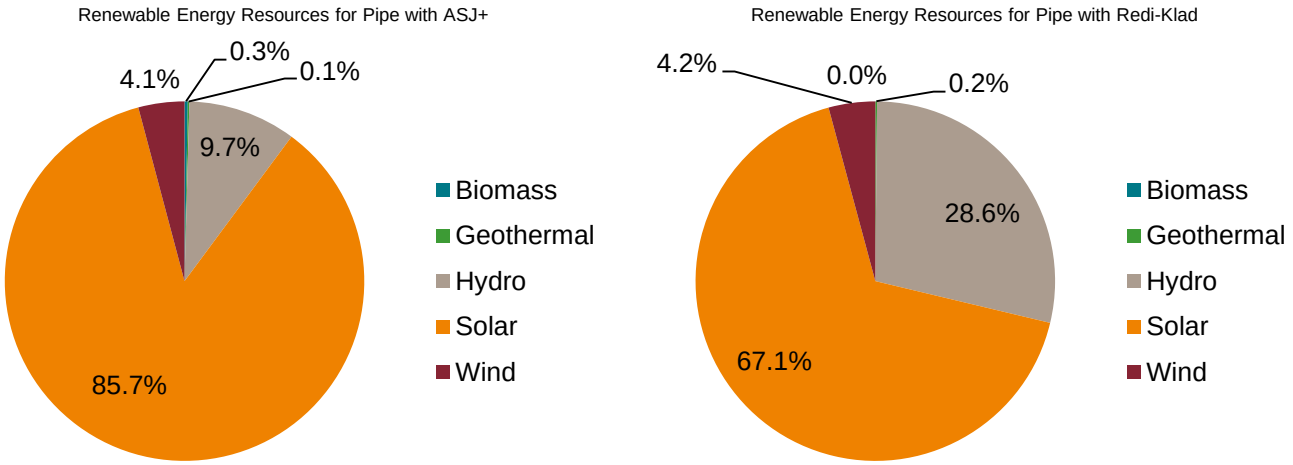


Figure 4: Renewable primary energy resources



Primary Energy by Life Cycle Stage

A breakdown of non-renewable primary energy demand by life cycle stage is shown in Figure 5. The majority of primary energy consumption is attributed to energy consumed during raw materials production and manufacturing. More energy is required for distribution than for inbound transport of materials due to longer shipping distances as well as lower truck capacity utilization.

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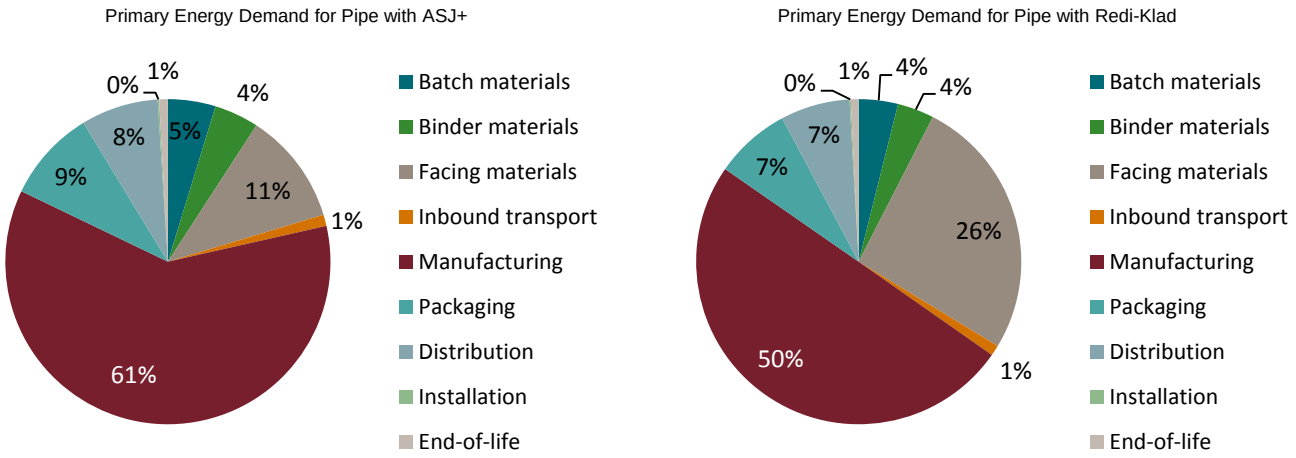
Figure 5: Primary energy demand breakdown by life cycle stage



Life Cycle Impact Assessment

Table 5 contains life cycle impact assessment results per declared unit. Impact results were calculated using the TRACI 2.0 methodology.

Table 5: Life cycle impact category results per functional unit (TRACI 2.0)

Impact Category	Units	Raw Materials	Production	Transport	Installation	End-of-Life	Total
Pipe with ASJ+							
Global Warming	kg CO_2 eq	8.69E-01	3.84E+00	5.34E-01	4.61E-01	1.88E-01	**5.89E+00**
Acidification	kg mol H^+ eq	3.01E-01	5.84E-01	3.78E-02	2.80E-02	1.91E-02	**9.71E-01**
Eutrophication	kg N eq	5.32E-04	6.21E-04	4.32E-05	1.08E-04	3.94E-05	**1.34E-03**
Smog Creation	kg O_3 eq	6.51E-02	1.16E-01	1.17E-02	2.39E-03	3.81E-03	**1.99E-01**
Ozone Depletion	kg CFC-11 eq	2.38E-10	1.30E-09	1.57E-11	1.11E-12	6.25E-12	**1.56E-09**
Waste to Landfill	kg	–	–	–	2.05E-01	1.16E+00	**1.36E+00**
Metered Water	L	–	6.84E+00	–	–	–	**6.84E+00**
Primary Energy	MJ	2.22E+01	7.22E+01	7.95E+00	1.56E-01	8.83E-01	**1.03E+02**
Pipe with Redi-Klad							
Global Warming	kg CO_2 eq	2.09E+00	3.84E+00	5.83E-01	4.61E-01	8.39E-02	**7.06E+00**
Acidification	kg mol H^+ eq	5.45E-01	5.84E-01	4.13E-02	2.80E-02	1.40E-02	**1.21E+00**
Eutrophication	kg N eq	5.85E-04	6.21E-04	4.72E-05	1.08E-04	1.44E-05	**1.38E-03**
Smog Creation	kg O_3 eq	1.09E-01	1.16E-01	1.27E-02	2.39E-03	3.72E-03	**2.45E-01**
Ozone Depletion	kg CFC-11 eq	6.96E-10	1.30E-09	1.72E-11	1.11E-12	6.92E-12	**2.02E-09**
Waste to Landfill	kg	–	–	–	2.05E-01	1.28E+00	**1.49E+00**
Metered Water	L	–	6.84E+00	–	–	–	**6.84E+00**
Primary Energy	MJ	4.36E+01	7.22E+01	8.67E+00	1.56E-01	9.77E-01	**1.26E+02**

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Waste to Disposal

Non-hazardous waste generated from production and at end-of-life is shown in Table 6, along with metered water consumption results per functional unit. There is no hazardous waste associated with this product.

Table 6: Non-hazardous waste and water usage per functional unit

Impact Category	Units	Raw Materials	Production	Transport	Installation	End-of-Life	Total
Pipe with ASJ+							
Non-Hazardous Waste	kg	–	–	–	0.205	1.16	**1.36**
Water Consumption	gal	–	1.807	–	–	–	**1.807**
Pipe with Redi-Klad							
Non-Hazardous Waste	kg	–	–	–	0.205	1.28	**1.49**
Water Consumption	gal	–	1.807	–	–	–	**1.807**

Scaling to Various Pipe Sizes

This report uses a declared unit in place of a functional unit due to the difficulty in defining a single, generic functional unit that is representative of all possible pipe insulation configurations. Environmental impacts per linear foot of common pipe insulation diameters and thicknesses can be calculated by multiplying the above results, summarized in Table 7, by the scaling factors presented in Table 8. Scaling factors for the jacket are included in Table 9. Note that impact results in Table 7 include not only materials, but transportation and disposal. Additionally, Redi-Klad jacket impact results are included in addition to ASJ+ jacket results used in the EPD body.

Pipe insulation impact per ft. = GMW scaling factor × GMW impact per kg + Jacket scaling factor × Jacket impact per sqm

Table 7: GMW impact per kilogram and jacket impact per square meter

Impact Category	Units	GMW	ASJ+	Redi-Klad
Primary energy demand, non-renewable	MJ	7.78E+01	1.03E+01	2.98E+01
Primary energy demand, renewable	MJ	1.29E+01	2.45E+00	5.23E+00
Global warming potential	kg CO_2-eq	5.24E+00	6.55E-01	1.82E+00
Ozone depletion potential	kg CFC 11-eq	1.40E-09	1.60E-10	6.20E-10
Acidification potential	kg mol H^+-eq	8.40E-01	1.30E-01	3.73E-01
Eutrophication potential	kg N-eq	1.16E-03	1.88E-04	2.20E-04
Smog creation potential	kg O_3-eq	1.72E-01	2.74E-02	7.27E-02

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Table 8: GMW scaling factors to one linear foot of pipe

Pipe Insulation Thickness										
Iron Pipe Size [in]	Copper Pipe Size [in]	1"	1.5"	2"	2.5"	3"	3.5"	4"	4.5"	5"
0.5	0.875	0.097	–	0.277	–	–	–	–	–	–
–	0.625	0.103	0.142	0.232	–	–	–	–	–	–
0.75	1.125	0.090	0.176	0.271	–	–	–	–	–	–
1	1.375	0.135	0.220	0.332	0.437	0.576	–	–	–	–
1.25	1.625	0.124	0.268	0.322	0.428	–	–	–	–	–
1.5	–	0.162	0.257	0.462	0.558	0.726	0.915	1.15	–	–
2	–	0.168	0.298	0.433	0.532	0.700	0.889	1.13	1.37	1.61
---	2.125	0.134	0.244	0.449	0.547	0.715	0.904	1.14	1.39	1.63
2.5	–	0.192	0.422	0.566	0.671	0.860	1.10	1.33	1.34	1.93
---	2.625	0.155	0.271	0.421	0.522	0.690	0.879	1.12	1.36	1.62
3	–	0.217	0.356	0.521	0.631	0.820	1.06	1.29	1.55	1.89
–	3.125	0.177	0.386	0.552	0.659	0.848	1.09	1.32	1.32	1.92
3.5	–	0.330	0.478	0.593	0.782	1.02	1.25	1.51	1.51	1.86
–	3.625	0.207	0.308	0.455	0.623	0.812	1.05	1.28	1.54	1.88
4	–	0.277	0.380	0.548	0.737	0.976	1.21	1.46	1.81	2.11
–	4.125	0.317	0.414	0.582	0.771	1.01	1.24	1.24	1.50	1.84
4.5	–	0.392	0.498	0.687	0.926	1.16	1.41	1.41	1.76	2.06
5	–	0.311	0.430	0.619	0.858	1.09	1.35	1.69	1.99	2.31
–	5.125	0.356	0.484	0.673	0.912	1.15	1.40	1.40	1.75	2.37
6	–	0.330	0.482	0.721	0.954	1.21	1.56	1.86	2.18	2.52
–	6.125	0.406	0.550	0.788	1.02	1.28	1.62	1.62	1.92	2.59
7	–	0.373	0.570	0.803	1.06	1.40	1.71	2.03	2.37	2.73
8	–	0.442	0.627	0.881	1.23	1.53	1.85	2.19	2.56	2.94
9	–	0.497	0.696	1.04	1.34	1.67	2.01	2.37	2.76	3.16
10	–	0.500	0.792	1.09	1.41	1.76	2.12	2.50	2.92	3.34

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Table 9: Jacket scaling factors to one linear foot of pipe

Pipe Insulation Thickness										
Iron Pipe Size [in]	Copper Pipe Size [in]	1"	1.5"	2"	2.5"	3"	3.5"	4"	4.5"	5"
0.5	0.875	0.078	0.104	0.128	–	–	–	–	–	–
–	0.625	0.078	0.092	0.117	–	–	–	–	–	–
0.75	1.125	0.078	0.104	0.128	–	–	–	–	–	–
1	1.375	0.092	0.115	0.142	0.166	0.191	–	–	–	–
1.25	1.625	0.092	0.128	0.142	0.166	–	–	–	–	–
1.5	–	0.104	0.128	0.166	0.191	0.215	0.238	0.264	–	–
2	–	0.115	0.142	0.166	0.191	0.215	0.238	0.264	0.289	0.317
---	2.125	0.104	0.128	0.166	0.191	0.215	0.238	0.264	0.289	0.317
2.5	–	0.129	0.166	0.191	0.215	0.238	0.264	0.289	0.289	0.342
---	2.625	0.115	0.142	0.166	0.191	0.291	0.238	0.264	0.289	0.317
3	–	0.142	0.166	0.191	0.215	0.238	0.264	0.289	0.317	0.342
–	3.125	0.129	0.166	0.191	0.215	0.238	0.264	0.289	0.289	0.342
3.5	–	0.166	0.191	0.215	0.238	0.264	0.289	0.317	0.317	0.342
–	3.625	0.142	0.166	0.191	0.215	0.238	0.264	0.289	0.317	0.342
4	–	0.166	0.191	0.215	0.238	0.264	0.289	0.317	0.342	0.366
–	4.125	0.166	0.191	0.215	0.238	0.264	0.289	0.289	0.317	0.342
4.5	–	0.191	0.215	0.238	0.264	0.289	0.317	0.317	0.342	0.366
5	–	0.191	0.215	0.238	0.264	0.289	0.317	0.342	0.366	0.389
–	5.125	0.191	0.215	0.238	0.264	0.289	0.317	0.313	0.342	0.389
6	–	0.216	0.238	0.264	0.289	0.317	0.342	0.366	0.389	0.414
–	6.125	0.216	0.238	0.264	0.289	0.317	0.342	0.342	0.366	0.414
7	–	0.238	0.264	0.289	0.317	0.342	0.366	0.389	0.414	0.438
8	–	0.265	0.289	0.317	0.342	0.366	0.389	0.414	0.438	0.461
9	–	0.289	0.317	0.342	0.366	0.389	0.414	0.438	0.461	0.485
10	–	0.318	0.342	0.366	0.389	0.414	0.438	0.461	0.485	0.508

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Additional Environmental Information

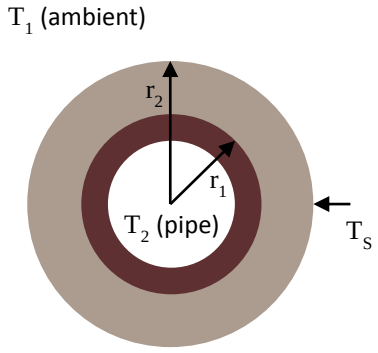
Indoor Environment

Earthwool 1000° Pipe Insulation products are interior friendly. These products are certified for indoor air quality as a low emitting product by The GREENGUARD Environmental Institute to both the GREENGUARD Certification Program[SM] and the more stringent GREENGUARD Gold standard. Earthwool pipe is validated as formaldehyde-free, both with and without facing materials.

Building Use Stage Benefits

In the following commercial building use phase example, the 3E Plus® Insulation Thickness Computer Program[2] was used to model pipes both with and without insulation with an ASJ+ jacket. The goal was to determine the time that the insulation must be in service in order to recover the life cycle energy primary energy demand (PED) and the life cycle global warming potential (GWP). In this analysis, 3E Plus is used to calculate the thermal performance and the greenhouse gas emissions associated with maintaining fluid temperature of both insulated and bare (not insulated) piping.

The formula used in the 3E Plus program to calculate heat loss or gain for pipes is:



$$Q = \frac{T_1 - T_2}{\frac{r_2 \ln[r_2/r_1]}{k} + R_S}$$

Where:

- Q = Heat gain or loss at the outer surface of insulation [Btu /(hr.ft^2)]
- r_1 = Inner radius of insulation [inches]
- r_2 = Outer radius of insulation [inches]
- T_1 = Operating temperature of the pipe [°F]
- T_2 = Ambient temperature [°F]
- T_S = Surface temperature of pipe insulation [°F]
- k = Thermal conductivity at mean temperature [Btu.in/(hr.ft^2.°F)]
- R_S = Air film resistance [Btu/(hr.ft^2.°F)]

As shown in Figure 6, the thermal conductivity of Earthwool pipe insulation, like all insulation, changes with temperature. In the case of glass mineral wool, thermal conductivity increases as temperature increases. This characteristic is well described by a second order polynomial equation:

$$k = 9 \times 10^{-7} MT + 0.0002 MT + 0.214$$

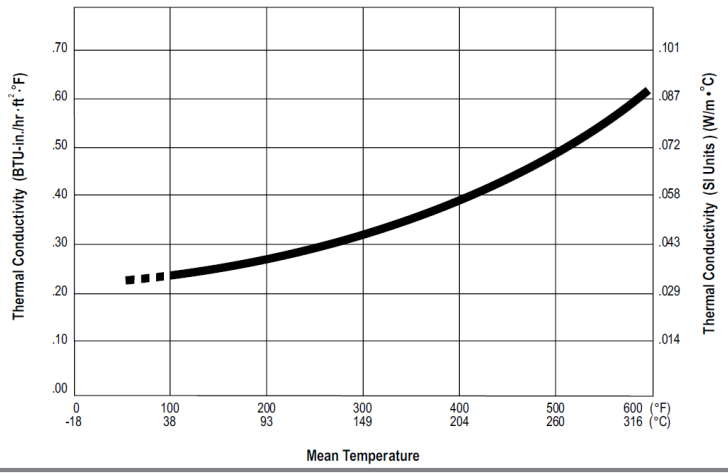
Where k is the thermal conductivity in [Btu.in/(hr.ft^2.°F)] and MT the mean temperature in Fahrenheit. This equation is used by the 3E Plus software so that the exact thermal profile is characterized by the model. The emittance of the ASJ+ jacketing material (0.81) is also easily accommodated by the model.

[2] 3E Plus is an energy management tool developed by the North American Insulation Manufacturers Association (NAIMA) to simplify the task of determining the optimal amount of insulation necessary to use less energy, reduce emissions, and improve system process efficiency. The program is based upon the architecture defined by ASTM C680.

Figure 6: Pipe insulation thermal conductivity as a function of temperature

Thermal Efficiency (ASTM C 335)

Mean Temperature	k	k (SI)
75°F (24°C)	.23	.033
100°F (38°C)	.24	.035
200°F (93°C)	.28	.040
300°F (149°C)	.34	.049
400°F (204°C)	.42	.061
500°F (260°C)	.51	.074
600°F (316°C)	.62	.089



ASHRAE Standard 90.1-2013 was also utilized for this assessment. The 90.1 standard forms the technical basis for code requirements of commercial buildings by providing insulation thickness recommendations given fluid operating temperatures. A 2-inch nominal iron pipe transporting fluid at temperatures from 45°F to 350°F was used for this analysis.

Table 10 summarizes the primary energy demand and global warming potential per linear foot of pipe insulation with an ASJ+ jacket. The calculation is repeated for multiple fluid temperatures. 3E Plus results, along with days to recover upfront pipe insulation environmental impact (calculated in Table 10), are shown in Table 11. Since fluid at 45°F is chilled rather than heated, electricity savings rather than natural gas savings are realized. Non-renewable primary energy demand and global warming potential per unit of electricity and natural gas are detailed in Table 12.

Table 10: Primary energy demand (PED) and global warming potential (GWP) of pipe insulation

Nominal Pipe Size [in]	Fluid Temperature [°F]	ASHRAE Thickness [in]	GMW Scaling Factor	Jacket Scaling Factor	Insulation PED [MJ / ft]	Insulation GWP [kg CO_2-eq / ft]
2	45	1.0	0.168	0.115	14.3	0.956
2	140	1.5	0.298	0.142	24.6	1.65
2	200	2.0	0.433	0.166	35.4	2.38
2	250	2.5	0.532	0.191	43.4	2.91
2	350	4.5	1.13	0.264	90.6	6.09

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Table 11: Days to recover primary energy demand or global warming impact based on 3E Plus electricity and natural gas savings

Fluid Temperature [°F]	Energy savings [MJ / (hr.ft)]	Avoided non-renewable PED [MJ / (hr.ft)]	Days to recover PED	Avoided GWP [kg CO_2-eq. / (hr.ft)]	Days to recover GWP
Electricity					
45	0.264	0.0698	8.5	0.00470	8.5
Natural Gas					
140	0.076	0.0873	12	0.00523	13
200	0.177	0.203	7.2	0.0122	8.1
250	0.279	0.321	5.6	0.0192	6.3
350	0.537	0.617	6.1	0.0370	6.9

Table 12: Unit energy impact factors from GaBi 6

Metric	Electricity	Natural Gas
PED, non-renewable	9.53 MJ / kWh	1.15 MJ / MJ
GWP	0.641 kg CO_2 eq / kWh	0.0689 kg CO_2 eq / MJ

Other Relevant Information

- ASTM C547 Standard Specification for Mineral Fiber Pipe Insulation
- ASTM C1136 Standard Specification for Flexible, Low Permeance Vapor Retarders for Thermal Insulation
- HH-I-1030B; Class B (Federal Specification for vapor retarders/facing materials)
- GREENGUARD Environmental Institute™
- GREENGUARD Gold

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According to ISO 14025

References

3E Plus	Insulation Thickness Computer Program. http://www.pipeinsulation.org/
ASHRAE 90.1	ASHRAE Standard 90.1-2013 (I-P Edition) — Energy Standard for Buildings except Low-Rise Residential Buildings.
ASTM C680	Standard Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs
GaBi 6 2012	PE INTERNATIONAL AG, GaBi 6: Software-System and Database for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdingen, 1992-2012.
ISO 14025	ISO 14025:2011-10, Environmental labels and declarations — Type III environmental declarations — Principles and procedures.
ISO 14040	ISO 14040:2009-11, Environmental management — Life cycle assessment — Principles and framework.
ISO 14044	ISO 14044:2006-10, Environmental management — Life cycle assessment — Requirements and guidelines.
ULE 2013	UL Environment, Product Category Rules for preparing an Environmental Product Declaration (EPD) for the Product Category: Building Envelope Thermal Insulation, UL, 2013.

LCA Development

The EPD and background LCA were prepared with support from PE INTERNATIONAL, Inc.

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