ENVIRONMENTAL PRODUCT DECLARATION

Polyiso Roof Insulation Boards

For more than 30 years, the Polyisocyanurate Insulation Manufacturers Association (PIMA) has served as the voice of the North American rigid polyiso industry, and as a proactive advocate for safe, cost-effective, sustainable, and energy-efficient high-performance building construction. PIMA is one of the foremost industry advocates for building energy-efficiency practices and policies.

PIMA membership includes manufacturers of polyiso insulation products, raw material suppliers to the industry, and businesses that provide third-party testing services to manufacturers. PIMA members produce the majority of polyiso used in commercial roof and wall applications, and residential, institutional and industrial construction throughout the United States and Canada. PIMA represents the rigid polyiso industry in the development of product technical standards, certification programs, and energy efficiency advocacy.

As a leading advocate for building energy efficiency, PIMA has received many environmental awards, including the U.S. Environmental Protection Agency's Climate Protection Award in 2007 for the Association's leadership in promoting energy efficiency and climate protection. The U.S. EPA also awarded PIMA the Stratospheric Ozone Protection Award in 2002 for leadership in the CFC phase-out in polyiso insulation and in recognition of exceptional contributions to global environmental protection.

Date of Issue: November 4, 2020
Period of Validity: 5 years
Declaration Number: EPD10465

Certified Environmental Product Declaration
www.nsf.org

Primary data from the following PIMA manufacturer members were used for the underlying life cycle assessment. Results in this declaration represent the combined weighted average production for these members.

Atlas Roofing Corporation
2000 River Edge Parkway, Suite 800
Atlanta, GA 30328
www.atlasroofing.com

Carlisle Construction Materials
1285 Ritner Highway
Carlisle, PA 17013
www.carlisleconstructionmaterials.com

Firestone Building Products
200 4th Avenue South
Nashville, TN 37201
www.firestonebpco.co

GAF
1 Campus Drive
Parsippany, NJ 07054
www.gaf.com

IKO
40 Hansen Road South
Brampton, Ontario, Canada L6W 3H4
www.iko.com

Johns Manville
717 17th Street
Denver, CO 80202
www.jm.com

Rmax - A Sika Brand
13524 Welch Road
Dallas, TX 75244
www.rmax.com

Soprema, Inc. (USA)
310 Quadral Drive
Wadsworth, OH 44281
www.soprema.us

Soprema, Inc.
1688 Jean-Berchmans-Michaud
Drummondville, Quebec, Canada J2C 8E9
www.soprema.ca

PIMA manufacturer members provided primary data for products marketed by the following companies.

Carlisle SynTec
1285 Ritner Highway
Carlisle, PA 17013
www.carlislesyntec.com

CertainTeed Corporation
20 Moores Road
Malvern, PA 19355
www.certainteed.com

Conklin Company Inc.
3951 N. Kimball Drive
Kansas City, MO 64161
www.conklin.com

Derbigum Americas Inc.
4800 Blue Parkway
Kansas City, MO 64130
www.derbigum.us

Duro-Last, Inc.
525 Morley Drive
Saginaw, MI 48601
www.duro-last.com

FiberTite/Seaman Corporation
1000 Venture Blvd.
Wooster, OH 44691
www.fibertite.com

Flex Membrane International Corp.
2670 Leiscz's Bridge Road, Suite 400
Leesport, PA 19533
www.flexroofingsystems.com

Hunter Panels
15 Franklin Street
Portland, ME 04101
www.hunterpanels.com

IB Roof Systems
8181 Jetstar Drive, Suite 150
Irving, TX 75063
www.ibroof.com

Loadmaster Systems, Inc.
3100 E. Northwoods Place
Peachtree Corners, GA 30071
www.loadmaster.net

Mule-Hide Products Co., Inc.
1195 Prince Hall Drive
Beloit, WI 53511
www.mulehide.com

Polyglass USA, Inc.
1111 W. Newport Center Drive
Deerfield Beach, FL 33442
www.polyglass.us

Sika Sarnafil
100 Dan Road
Canton, MA 02021
usa.sika.com/sarnafil

Siplast
1000 Rochelle Blvd.
Irving, TX 75062
www.siplast.com

Soprema, Inc. (USA)
310 Quadral Drive
Wadsworth, OH 44281
www.soprema.us

Tremco Incorporated
3735 Green Road
Beachwood, OH 44122
www.tremcoinc.com

Versico Roofing Systems
1285 Ritner Highway
Carlisle, PA 17013
www.versico.com

Viking Products Group, Inc.
3812 E. 91st Street
Cleveland, OH 44105
www.vikingpg.com

WeatherBond Roofing
P.O. Box 251
Plainfield, PA 17081
www.weatherbondroofing.com

GENERAL INFORMATION

EPD Program Operator (NSF Certified Environmental Product Declaration www.nsf.org)	NSF Certification, LLC 789 N. Dixboro Road Ann Arbor, Michigan, 48105, USA www.nsf.org
Refererence PCRs	Product Category Rules for Building-Related Products and Services Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL 10010, Version 3.2), and Product Category Rule (PCR) Guidance for Building-Related Products and Services Part B: Building Thermal Insulation EPD Requirements (UL10010-1, Version 2.0), and ISO 21930: 2017
Declaration Holder	Polyisocyanurate Insulation Manufacturers Association 3330 Washington Boulevard, Suite 200 Arlington, Virginia, 22201, USA www.polyiso.org
LCA & Declaration Preparer	Shelly Severinghaus, LCACP Long Trail Sustainability 830 Taft Road Huntington, Vermont, 05462, USA www.ltsexperts.com
Declaration Number	EPD10465
Product	Polyisocyanurate Roof Insulation Boards
Intended Applications and Use	Commercial, light commercial, residential and industrial roof construction
Markets of Applicability	United States and Canada
Product RSL Description	40 years
Declared Product & Function Unit	1 m^2 of installed insulation material with a thickness that gives an average thermal resistance R_{SI} = 1 $m^2 \cdot K/W$ (5.678 $ft^2 \cdot °F \cdot h/Btu$) and with a building service life of 75 years (packaging included)
PCR Review was Conducted by:	– Part A – UL Technical Advisory Panel – Part B – Thomas Gloria, PhD (chair)
Date of Issue	November 4, 2020
Period of Validity	5 years from date of issue
EPD Type	Industry-average
EPD Scope	Cradle-to-grave
Range of Dataset Variability	Industry-average
Year(s) of Reported Manufacturer Primary Data	2017
LCA Completion	Life Cycle Assessment of Rigid Polyisocyanurate Foam Board Insulation, August 2020
LCA Software & Version Number	SimaPro (Version 9.0.0.35)
LCI Databases & Version Number	ecoinvent v3.5, Cut-off at Classification (ecoinvent centre, 2018), US LCI (NREL, 2015) and DATASMART v2018.1 (Long Trail Sustainability, 2018)
LCIA Methodology & Version Number	TRACI 2.1 version 1.05
This EPD was independently verified by NSF in accordance with ISO 14025: 2006 and ISO 21930:2017: ☐ Internal ☒ External	Jenny Oorbeck – NSF joorbeck@nsf.org [signature]
This life cycle assessment was conducted in accordance with ISO 14044: 2006, reference PCR, and ISO 21930: 2017	Long Trail Sustainability shelly@ltsexperts.com [signature]
This life cycle assessment was independently verified in accordance with ISO 14044: 2006 and the reference PCR by:	Terrie Boguski, P.E. – Harmony Environmental tboguski@harmonyenviro.com [signature]

Limitations: Environmental declarations from different programs (ISO 14025) based upon different PCRs may not be comparable. Comparison of the environmental performance of Building Envelope Thermal Insulation using EPD information shall be based on the product's use and impacts at the building level, and therefore EPDs may not be used for comparability purposes when not considering the building energy use phase as instructed under this PCR. Full conformance with the PCR for Building Envelope Thermal Insulation allows EPD comparability only when all stages of a life cycle have been considered, when they comply with all referenced standards, use the same sub-category PCR, and use equivalent scenarios with respect to construction works. However, variations and deviations are possible. When comparing EPDs created using this PCR, variations and deviations are possible. Examples of variations include different LCA software and background LCI datasets that may lead to different results for upstream or downstream segments of the life cycle stages declared.

EPD SUMMARY

This declaration is an industry-average, Type III Environmental Product Declaration (EPD) by the Polyisocyanurate Insulation Manufacturers Association (PIMA) conducted in accordance with ISO 14025. The products presented in this EPD are representative for the product range for all PIMA member manufacturers identified in this study. The study covers 36 polyiso manufacturing facilities in the United States and Canada. Each facility's annual electricity use, natural gas use, water use and wastewater, polyiso packaging (shrink wrap), and solid waste data were divided by its annual production in board-feet (BF). Facility details such as location (to specify grid mix) and facility emissions handling were also included in the calculation. Finally, a production-weighted average across all manufacturing facilities was created to represent the industry average manufacturing of polyiso.

This document is based on the Life Cycle Assessment (LCA) study developed for PIMA by Long Trail Sustainability in accordance with industry accepted standards: Product Category Rules for Building-Related Products and Services Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL 10010, Version 3.2), and Product Category Rule (PCR) Guidance for Building-Related Products and Services Part B: Building Thermal Insulation EPD Requirements (UL10010-1, Version 2.0), ISO 14040, ISO 14044 and ISO 21930. This EPD provides users with information on environmental impacts of polyiso roof insulation products during their life cycle.

LIFE CYCLE ASSESSMENT SCOPE AND BOUNDARIES

System Boundary: Cradle-to-Grave.

This declaration is a cradle-to-grave and the following life cycle stages are included as part of the system boundary: production, construction, use, and end-of-life. Each life cycle stage includes the following modules:

Production Stage

- **Supply of raw materials (A1):** Extraction, upstream processing and production of raw materials and energy associated with the production of polyiso roof insulation boards.
- **Transport of raw materials (A2):** Transport of materials (all chemical and material inputs including packaging) to polyiso roof insulation board manufacturing facilities.
- **Manufacturing of products (A3):** Production of polyiso roof insulation boards (including associated emissions from production facilities).

Construction Stage

- **Transport from gate to site (A4):** Transport of polyiso roof insulation boards in bundles from the manufacturing facilities to product distributor sites or directly to project job sites.
- **Assembly/Install (A5):** Installation of polyiso roof insulation boards including: unloading from the truck or all terrain forklift to a staging area on a job site prior to moving bundles onto rooftop using a crane, removal of all protective packaging, placement and attachment of individual roof insulation boards to the roof deck by a roofing crew, and removal and transport of installation waste scrap to a local landfill for disposal.

Use Stage

- **Use (B1):** Upon installation the product remains in place in the roof assembly and provides resistance to transfer of energy in and out of the building. There is no activity associated during the use of polyiso roof insulation boards.
- **Maintenance (B2):** Polyiso roof insulation boards are installed permanently within a weather protected exterior building envelope and therefore no maintenance is required to retain the functional performance of the product.
- **Repair (B3):** When the weather protection components of the building envelope are designed and installed properly and adequately maintained, it is reasonable to expect that the polyiso roof insulation boards will not incur damage affecting its performance. Therefore, repair activity is not required.
- **Replacement (B4):** The building service life as defined in the PCR is 75 years, and as rationalized in the reference service life one replacement is required.
- **Refurbishment (B5):** Polyiso roof insulation boards require no refurbishment activity.
- **Operational Energy Use of Building Integrated System During Product Use (B6) and Operational Water Use of Building Integrated System During Product Use (B7):** Polyiso roof insulation boards alone are not integrated technical systems and have no declared activity in either of the modules.

End-of-Life Stage

- **Deconstruction (C1):** At the end-of-life, the polyiso roof insulation boards are removed from the roof deck. Although, the insulation may be recovered from the roof system and reused, this activity is not considered in this study.
- **Transport (C2):** Transport of polyiso roof insulation boards to a landfill.
- **Waste Processing (C3):** Polyiso roof insulation boards do not require waste processing.
- **Disposal (C4):** Disposal of polyiso roof insulation boards in a landfill.

Allocation Method: Mass allocation method was used to allocate input/output for sub-processes involving co-products. No allocation was necessary in the manufacturing of facers and polyiso foam that comprise roof insulation products because there are no co-products for these materials. The allocations are already applied to the secondary data (i.e., ecoinvent data) included in this study (ecoinvent center, 2019).

PRODUCT DESCRIPTION

Polyisocyanurate (polyiso) is a cellular closed-cell rigid foam plastic insulation. The polyiso roof insulation boards consist of a foam core sandwiched between two facers (top and bottom). The foam core is comprised of a thermoset polymer that hardens by curing from a viscous liquid prepolymer. The rigid foam is produced through the reaction of methylene diphenylene diisocyanate (MDI) with polyester polyol. Other additives such as catalyst, surfactant, flame retardant, and blowing agent (pentane or pentane blends) are part of the formulation. Pentane is a hydrocarbon with negligible ozone depletion potential (ODP) (U.S. EPA, 2018) and low global warming potential (GWP) (U.S. EPA, 2020). For nearly 20 years, the polyiso industry has only utilized pentane or pentane blends in product formulations. Upon mixing of the components, the viscous pre-polymer is laid between the facers, and a chemical reaction cross-links polymer chains creating a rigid and durable cellular structure. For roofing applications, the most common facer is a glass fiber reinforced cellulosic facer (GRF) produced predominantly from recycled post-consumer and/or post-industrial fibers. Polyiso roof insulation is also manufactured with polymer-bonded coated glass facer (CGF), consisting of a glass fiber mat coated with polymers. Both facer types play a critical role in accommodating a continuous manufacturing process.

Features and Benefits

The versatile, durable and sustainable polyiso roof insulation boards offer the following benefits:

- High thermal resistance
- Continuous thermal insulation
- Condensation control
- Direct-to-steel deck application without a thermal barrier
- Improved water management (tapered products)
- Compatibility with roof system adhesives
- Resistance to construction traffic
- Lightweight and easy to install

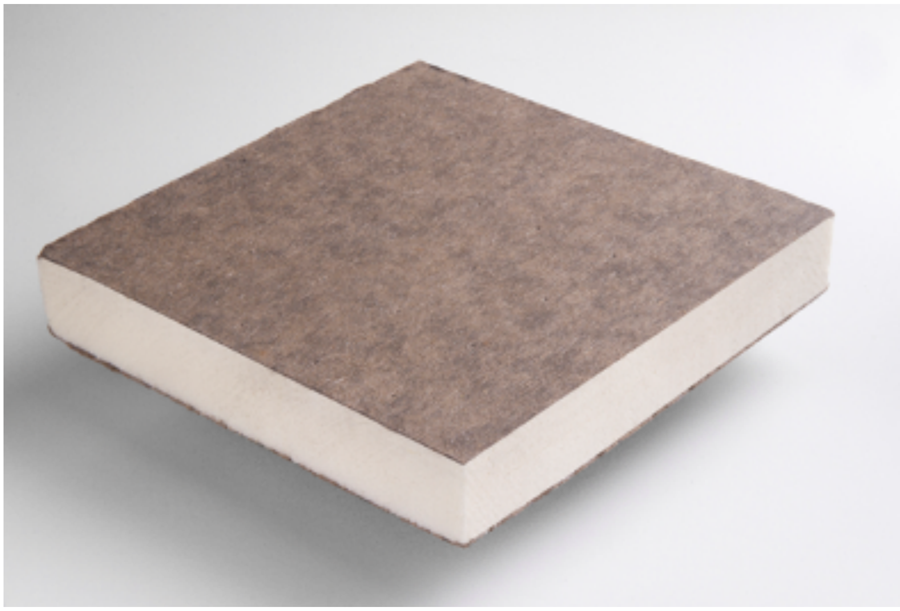

Image 1.
Polyiso Roof Insulation Board with GRF Facer.

Image 2.
Polyiso Roof Insulation Board with CGF Facer.

APPLICATION

Polyiso roof insulation boards may be used in residential, light commercial, commercial, and industrial roof construction projects on new buildings and on existing buildings during reroofing. Polyiso is the most widely used type of insulation in above-deck commercial roof applications in the United States and Canada. In commercial roof systems, one or more layers of polyiso are installed (with board joints staggered) direct-to-deck (i.e., steel, concrete, or wood) and below the membrane to provide continuous insulation. On low-slope roof applications, polyiso can be installed as a flat stock or as tapered product to provide improved slope and more effectively manage rainwater drainage. Polyiso may be attached to the roof deck using mechanical fasteners or adhesives to achieve the desired system performance. Polyiso is a versatile insulation, and it is compatible with all low-slope roof covering types including: single-ply membranes systems (i.e., TPO, PVC and EPDM), modified bitumen system, built-up roofing, standing-seam metal roofing and metal panels. The roof systems may be mechanically attached through the polyiso insulation, adhered to the polyiso facer or held in place with ballast. A typical roof system with a metal deck is illustrated below. Many factors and design consideration impact the selection of a roof system, and additional components such as air barrier, vapor retarder, thermal barrier and cover board may be required in specific applications. Polyiso insulation may be installed in direct-to-deck applications without a thermal or ignition barrier. On steep-slope roof applications, polyiso can be used as a part of vented nail base system below asphalt, composite and metal shingles and metal panels.

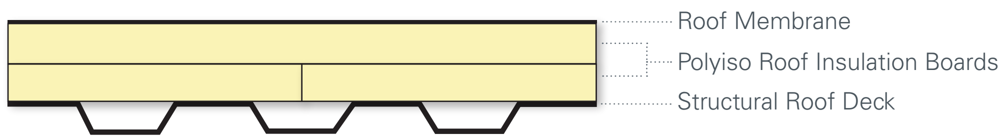

Figure 1.
Typical Roof Assembly with Polyiso Roof Insulation Boards Installed Direct-to-Steel Deck.

TECHNICAL REQUIREMENTS

Polyiso roof insulation boards are manufactured to meet the requirements of industry consensus product specifications and standards in the United States and Canada. Compliance with model building codes does not always ensure compliance with state or local building codes, which may be amended versions of these model codes. Always check with local building code officials to confirm compliance. Typical physical properties for polyiso roof insulation boards are listed in Table 1.

- ASTM C1289 – Standard Specification for Faced Rigid Cellular Polyisocyanurate Thermal Insulation.
- CAN/ULC-S704.1 – Standard for Thermal Insulation, Polyurethane and Polyisocyanurate, Boards, Faced.
- CSI and CSA MasterFormat® Reference: 072200 Roof and Deck Insulation.

Table 1.

Typical Physical Properties of Polyiso Roof Insulation and Corresponding Requirements Listed in ASTM C1289 and CAN/ULC-S704.1 Standards.

PHYSICAL PROPERTY	STANDARD DESIGNATION	ASTM C1289 (TYPE II, CLASS 1 & 2)	CAN/ULC S704.1 (TYPE 1, 2 & 3)
Thermal Resistance (R-value or long-term thermal resistance), °F·ft²·h/Btu (K·m²/W), min	→	Class 1 / Class 2 For 1.0-inch (25.4 mm): 5.6 (0.97) / 5.3 (0.93) For 1.5-inch (25.4 mm): 8.4 (1.48) / 8.0 (1.41) For 2.0-inch (25.4 mm): 11.2(1.97) / 10.6(1.87) measured per ASTM C518 at 75°F (24°C) after 180 conditioning period	10.22 (1.80) for 1.97-inch (50-mm) thick board measured per CAN/ULC-S770 long-term thermal resistance
Compressive Strength, psi (kPa), min	ASTM D1621	16 (110)	16 (110)
Flexural Strength, psi (kPa), min	ASTM C203	40 (275)	24.7 (170)
Tensile Strength, psf (kPa), min	→	500 (24) measured per ASTM C209	500 (24) measured per ASTM D1623
Dimensional Stability, % Linear Change, Thickness, Max	ASTM D2126	-40°F (-40°C) / ambient RH: 4.0 158°F (70°C) / 97% RH: 4.0 200°F (93°C) / ambient RH: 4.0	Not Applicable
Dimensional Stability, % Linear Change, Length and Width, max	ASTM D2126	-40°F (-40°C) / ambient RH: 2.0 158°F (70°C) / 97% RH: 2.0 200°F (93°C) / ambient RH: 2.0	-20°F (-29°C) / ambient RH: 2.0 158°F (70°C) / 97% RH: 2.0 176°F (80°C) / ambient RH: 2.0
Water Absorption, % by Volume, max	→	1.0 measured per ASTM C1763 – Procedure B	3.5 measured per ASTM D2842 – Procedure B
Water Vapor Permeance, perm (ng/Pa·s·m²)	ASTM E96/E96M Desiccant Method	Class 1: ≤1.5 (≤85.8) Class 2: ≤4.0 (≤228.8)	Class 1: ≤0.26 (≤15) Class 2: ≥0.26, ≤1.05 (≥15, ≤60) Class 3: > 1.05 (>60)

Thermal Performance: The recognized consensus approach for determining the thermal resistance of permeable-faced closed-cell foam insulation with captive blowing agents such as polyiso relies on the concept of Long-Term Thermal Resistance (LTTR) as described in CAN/ULC-S770 "Standard Test Method for Determination of Long-Term Thermal Resistance of Closed-Cell Thermal Insulating Foams" and ASTM C1303/C1303M "Standard Test Method for Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation." LTTR provides a laboratory method of accelerating the aging of closed-cell thermal insulation products with captive blowing agents to estimate the long-term aged thermal resistance. This approach is based on a scientific theory of aging plastic foams with captive blowing agents developed in the 1990's followed by a robust evaluation of the methodology spearheaded by Oak Ridge National Laboratory (Stovall, T., et. al., 2012). The polyiso industry has adopted the LTTR methodology for quantifying thermal resistance of permeable-faced polyiso roof insulation boards. Additional information regarding LTTR methodology is available on the PIMA website *(www.polyiso.org)*.

PROPERTIES OF DECLARED PRODUCT AS DELIVERED

The manufactured and cured polyiso roof insulation boards are typically shipped and delivered to jobsites stacked in bundles protected by a plastic wrap, plastic bag or both. The boards are typically 1.2 m by 2.4 m (4 feet by 8 feet) in size and stacked one on top of another to form a bundle. The number of polyiso boards in a bundle will vary depending on product thickness. Typically, the bundles are 1.2 m (48-inches) in height. For example, twice the number of 2.54 cm (1.0-inch-thick) boards can be stacked to make up the same height bundle compared to 5.08 cm (2.0-inch-thick) insulation boards. Typically, 48 boards at 2.54 cm (1.0-inch-thick), 24 boards at 5.08 cm (2.0-inch-thick) or 16 boards at 7.62 cm (3.0-inch-thick) comprise a bundle of polyiso roof insulation.

MATERIAL COMPOSITION

Polyiso roof insulation boards are comprised of a foam core and two facers on the top and bottom surfaces. The foam core consists of the average weighted formulation by mass listed in Table 2. More than half of the foam formulation consists of MDI which reacts with polyester polyol containing other chemicals including blowing agent, flame retardant, surfactant, catalyst and water. The chemical reaction forms a rigid cellular foam structure following a curing process. The two most common types of facers in polyiso roof insulation and used in this study are: (1) glass fiber reinforced cellulosic facer (GRF) and (2) coated polymer-bonded glass fiber (CGF). The GRF is comprised of a cellulosic fiber felt containing glass fiber for added strength. The CGF facer is composed of a glass fiber mat bonded with organic polymer binder and coated with polymer coatings.

Table 2.
Weighted Average Foam Formulation Ranges
for Polyiso Roof Insulation Boards.

COMPONENT	FORMULATION RANGE (% BY MASS)
MDI	57.4 - 57.8
Polyester Polyol	29.5 – 29.9
Blowing Agent (Pentane)	6.9
Flame Retardant (TCPP)	3.8
Surfactant	0.5
Catalyst	1.7-1.9
Water	0.1

(Note: Percentages may not total 100 due to rounding),

MANUFACTURING

This module includes manufacturing of polyiso roof insulation boards, packaging, manufacturing waste, and associated releases to the air, soil, ground, and surface water. The raw materials transported to the polyiso manufacturing plant consist of chemical liquids stored in onsite tanks or totes. The chemicals for the “A” side (MDI), the “B” side (polyester polyol plus catalyst, surfactant, and flame retardant) and the blowing agent (pentane) are pumped from storage into process tanks. The “B” side and blowing agent are then pumped to a mixer and then to a mix head where they are combined with the “A” side and injected between the top and bottom facers on the pour table. The mixed chemicals react rapidly to form a closed-cell foam board with a foam core sandwiched between the top and bottom facers. The rigid foam board moves through a heated laminator, which controls thickness and aids in cell formation, curing, and facer adhesion. The board exits the laminator and is fed through saws that trim the board to the desired width and then through a cross-cut saw that cuts the board to the desired lengths. The finished rigid boards are then stacked, packaged with plastic wrap, labeled, and moved via fork truck to a warehouse area for storage and eventual loading onto trucks for shipment. The manufacturing process for polyiso roof insulation boards at a typical manufacturing plant is illustrated in Figure 2. Bundles of polyiso roof insulation boards are wrapped and/or bagged in plastic prior to shipment from the manufacturing facility. Packaging used to wrap/shroud bundles is made from extruded low-density polyethylene (LDPE) film. Data was collected directly from each facility participating in this study on the wrap factor basis (pound of wrap per board foot). *(Note: Board foot is a unit of measure for the volume of material in the United States and Canada. It is the volume of: 1-foot (30.48 cm) length, 1-foot (30.48 cm) width and 1.0-inch (2.54 cm) thickness),*

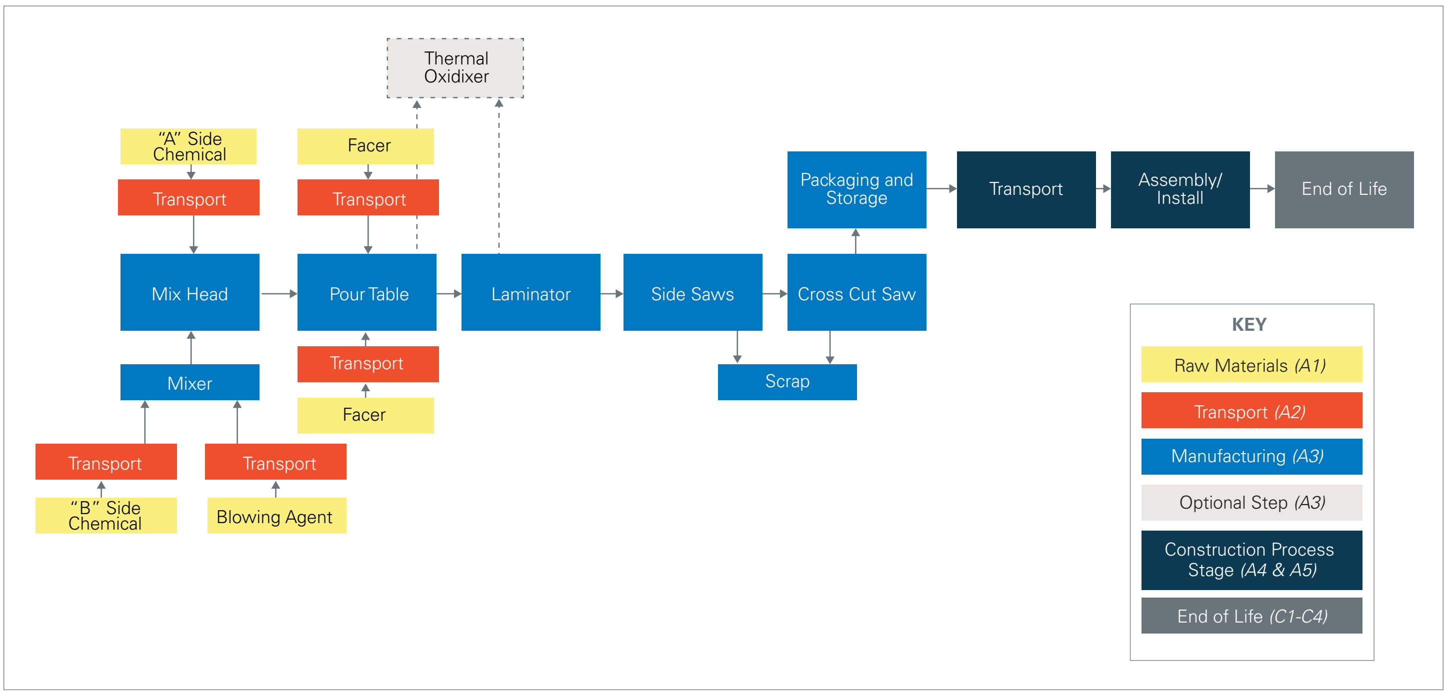

Figure 2.
Process Flow Diagram for Polyiso Roof Insulation.
(Note: Currently 44% of participating polyiso manufacturing facilities operate with thermal oxidizers for emissions control of pentane),

TRANSPORTATION

The polyiso roof insulation boards are transported in wrapped bundles from the manufacturing facilities to product distributor sites or directly to project job sites by a diesel-powered truck with a flatbed trailer. The average transport distance from production facility is 645 km (401 miles). Additional transportation details are reported in Table 3.

PRODUCT INSTALLATION

Upon delivery to the jobsite, the bundles of polyiso are unloaded from the truck to the rooftop using a crane or all terrain forklift, all packaging is removed (assumed to be landfilled), and the individual roof insulation boards are placed on the roof deck by a roofing crew. The polyiso roof insulation boards are secured to the roof deck prior to the installation of the roofing membrane. The waste scrap from installation is collected and transported to a local landfill for disposal. Disposal of installation waste scrap to a local landfill was modeled as 1% of the board foot. Additional installation details are reported in Table 4.

USE & REFERENCE SERVICE LIFE

The use phase follows the installation of polyiso roof insulation boards. In a roofing system, the insulation is located on top of a roof deck and below the roof membrane. The roof membrane when installed properly and adequately maintained, protects the insulation from the environmental elements and weather during its use. Therefore, it is expected that polyiso will not sustain damage that affects its performance and function, and does not require maintenance. As defined in the governing PCR, the Building Estimated Service Life (ESL) is 75 years. The necessary steps for providing weather protection are specified by manufacturer installation instructions and are mandated by model building codes. The roof membrane's useful life span is influenced by many variables including roof system design, quality of the installation, type and durability of the membrane, roof system component configuration and maintenance as well as weather conditions and events. Assuming that variables are sufficiently addressed through the membrane and the roof system design and installation, the insulation will serve its functional purpose for the 75-year life span of the building. However, the real-world reroofing scenarios, building owner tendencies, and the expected service life of roof membranes all indicate that reroofing activity will take place during the 75-year building ESL.

Reroofing activity may initially occur at 15-30 years after the installation of the original system and driven by recurring roof leaks that cannot be remedied by patch repairs of the membrane. When reroofing is required, options are available to address the need for a new roof membrane without the need to replace the insulation. The model building codes, describe a "Roof Recover" as an acceptable reroofing practice, which occurs when a new roof covering is installed on top of the existing roof system without disturbing or removing the existing roof covering or the insulation below. Roof Recover, as defined by industry practices, involves visual examination and appropriate testing to ensure that all roof components, including insulation, have not sustained damage or deterioration. This approach allows the insulation to be reused instead of being disposed of into a landfill. The Roof Recover approach is a common practice in the roofing industry, it is permitted by model building codes, and allows the service life of a roof system to be extended (without the need to replace the insulation). Although, the Roof Recover approach is a common practice, it is often not captured in reroofing studies available in the public domain, which typically contemplate a full roof replacement. Pertinent to this declaration, PIMA recognizes a 20-year life span for the original installation of the membrane followed by a Roof Recover, which extends the life of the original roof system to 40 years. This practice establishes a 40-year RSL for polyiso roof insulation boards. The model building codes allow a roof to be recovered only once. Where two roof membranes are installed on an existing roof, a reroofing process referred to as a "Roof Replacement" is required. This process involves the removal of all roof components down to the roof deck. Depending on the condition of the insulation or cover board, these materials can be reused on site, resold on secondary markets or landfilled. Typically, roof demolition is preferred to alleviate the labor required to separate materials for reuse. Therefore, this study conservatively assumes all insulation is disposed in the landfill during a Roof Replacement. Therefore, the polyiso roof insulation boards' cradle-to-grave assessment incorporates all life cycle stage environmental impacts connected with the original building construction, a Roof Recover operation at 20-years, as well as the building's Roof Replacement operation at 40-years. This translates to 1.9 replacement cycles during the 75-year building ESL (75-year ESL/40-year RSL = 1.9 replacement cycles).

END OF LIFE

At the end of building service life and during roof replacement, the polyiso roof insulation boards may be re-used, recovered and repurposed, or disposed. This study does not take re-use and recovery into account and it is assumed that insulation is removed when the building is decommissioned and disposed in a landfill. At the time of building deconstruction, insulation is removed manually or by cranes and transported 32 km (20 miles) to landfill sites by truck for disposal (Pavlovich, et. al., 2011). A United States specific dataset for landfilling plastic waste was used in this analysis.

CUT-OFF RULES

The cut-off criteria used for material and energy flows in this study ensures that all relevant environmental impacts are represented. In accordance with ISO 21930 Section 7.1.8 – "Criteria for the inclusion and exclusion of inputs and outputs", the cut-off rules applied in this study are described by the following [paraphrased]:

- All inputs and outputs to a (unit) process [are] included in the calculation…for which data is available.
- Data gaps [are] filled by worst-case estimates with proxy data [as is the case for catalysts]. [The] assumptions for such choices [are] documented.
- [All known material and energy flows are reported; no known flows are deliberately excluded.]
- Particular care [is] taken to include material and energy flows [known to contribute emissions into air, water or soil related to the environmental indicators of this standard]. [Conservative assumptions in combination with plausibility considerations and expert judgement can be used to demonstrate compliance with these criteria].

A 1% mass cut-off of the mass composition of the weighted average products were used to calculate renewable and non-renewable primary resources with energy content used as material inventory metrics. No known flows are deliberately excluded from this EPD.

DATA SOURCES

This study uses a combination of primary and secondary data. The primary data was collected from manufacturers and specific facilities for production of polyester polyol, GRF and CGF facers, and polyiso roof insulation boards. In instances when the primary data is not available, ecoinvent v3.5, Cut-off at Classification (ecoinvent centre, 2018), US LCI (NREL, 2015) and DATASMART v2018.1 (Long Trail Sustainability, 2018), which contain detailed peer reviewed LCI data were used.

DATA QUALITY

The quality of the data is representative of the processes modeled as the primary data comes from day-to-day production of polyiso roof insulation boards. Additional information regarding time, geographic and technology coverage is provided below:

TIME COVERAGE: Primary data for production of polyester polyol, facers, and polyiso roof insulation boards (including energy, water and raw material inputs, transportation distances and modes for raw materials, direct emissions, wastewater and manufacturing scrap), was collected in 2018 for the reference year 2017.

GEOGRAPHIC COVERAGE: The geographic coverage of this study includes manufacturing, distribution and installation of polyiso roof insulation boards in the United States and Canada.

TECHNOLOGY COVERAGE: The process technology modeled is based on polyiso manufacturers, polyester polyol manufacturers, and facer manufacturers representing production in United States and Canada. Primary data was collected for production of polyester polyols, GRF and CGF facers, and manufacturing of polyiso roof insulation boards (including energy, water and raw material inputs, transportation distances and modes for raw materials, direct emissions, wastewater and manufacturing waste).

PERIOD UNDER REVIEW

The primary data collected and used in this study represents the manufacture of polyester polyols, GRF and CGF facers, and polyiso roof insulation boards during the 2017 calendar year.

ESTIMATES AND ASSUMPTIONS

The material and energy input for production of polyiso roof insulation boards were modeled with data collected from the 36 manufacturing facilities in the Unites States and Canada. MDI was used to model catalyst impacts and is a worst-case estimate. The amount of MDI used to approximate each catalyst is doubled; 1 kg of catalyst is modeled with 2 kg of MDI as a proxy. The disposal of installation waste scrap sent to the landfill was assumed to be 1% of board foot. The impacts associated with installing and removing boards on building roof were estimated using data collected from a previous LCA project, as the installation methods have not changed (Pavlovich, et. al., 2011), and are described in greater detail in the LCA report. At the end of service life, the transport distance to the landfill for disposed insulation is estimated at 32 km (20 miles).

LCA SCENARIOS AND ADDITIONAL TECHNICAL INFORMATION

The following technical information was considered in the life cycle assessment.

Table 3.
Transport to building site details (A4).

NAME	VALUE	UNIT
Fuel Type	Diesel	
Vehicle Type	Unspecified freight lorry	
Transport distance*	652	Km
Weight of products transported	Dependent on product	
Volume of products transported	Dependent on product	
*Data on average transportation distance to building site was collected from each polyiso manufacturing facility. NOTE: Liters of fuel, capacity utilization, gross density of products transported and capacity utilization volume factor determined by the ecoinvent transportation process used: *Transport, freight, lorry, unspecified.*		

Table 4.
Installation into the Building (A5).

NAME	VALUE	UNIT
Diesel for construction equipment	2.36E-04	Gallons diesel/ft^2
VOC content	N/A	ųg/m3
Product loss per functional unit	1	%
Output materials resulting from on-site waste processing, generated by packaging waste (assumed landfilled)	0.00351	kg
Product: Glass Fiber Reinforced Cellulosic Facer (GRF) Polyiso Roof Insulation		
Waste materials at the construction site before waste processing, generated by product installation (assumed landfilled)	0.00846	kg
Product: Coated Glass Facer (CGF) Polyiso Roof Insulation		
Waste materials at the construction site before waste processing, generated by product installation (assumed landfilled)	0.00941	kg
Note	The data for VOC content is not available and it is designated with a symbol N/A.	

Table 5.
Reference Service Life.

NAME	VALUE	UNIT
RSL	40	years
Declared product properties (at the gate) and finishes, etc.	1	m^2
	1	R_{SI}

Table 6.
Replacement (B4).

NAME	VALUE	UNIT
Replacement Cycle	1	Number/RSL
Replacement Cycle	1.9	Number/ESL

Table 7.
Disposal/End of life (C1-C4).

NAME	VALUE	UNIT
Landfill	100	%

LCA RESULTS

Functional Unit: The functional unit for building envelope thermal insulation as defined by the PCR (Part B, Section 3.1) is: 1 m^2 of installed insulation with a thickness providing a thermal resistance of 1 $m^2 \cdot K/W$ and with a building service life of 75 years (packaging included). In the United States, thermal resistance (RIP) is commonly reported in imperial system unit of measure ($ft^2 \cdot °F \cdot h/Btu$) with 1 $m^2 \cdot K/W$ equivalent to (5.678 $ft^2 \cdot °F \cdot h/Btu$). The R-value of polyiso roof insulation boards increases slightly on a per inch basis with increasing product thickness. Similarly, the influence of the facers on the polyiso impact profile decreases with increasing product thickness. Therefore, a commonly specified intermediate thickness of product is chosen for the functional unit to represent the LCA results. The data for a 0.066 m (2.6-inch) thick, GRF and CGF faced polyiso roof insulation boards with 2.6 $m^2 \cdot K/W$ (15 $ft^2 \cdot °F \cdot h/Btu$) R-value is normalized to a thermal resistance of 1 $m^2 \cdot K/W$ (5.678 $ft^2 \cdot °F \cdot h/Btu$). Table 8 provides the characteristics of the functional unit.

Table 8.
Functional Unit Properties.

NAME	VALUE	UNIT
Functional Unit	1 m^2 (10.76 ft^2) of installed insulation with a thickness providing a thermal resistance of 1 $m^2 \cdot K/W$ (5.678 ft2·°F·h/Btu)	
Product: Glass Fiber Reinforced Cellulosic Facer (GRF) Polyiso Roof Insulation		
Mass	0.846 (1.87)	kg (lb)
Thickness to achieve functional unit	0.025 (0.984)	m (in)
Product: Coated Glass Facer (CGF) Polyiso Roof Insulation		
Mass	0.941 (2.07)	kg (lb)
Thickness to achieve functional unit	0.025 (0.984)	m (in)

This declaration is cradle-to-grave and all information modules are declared. As discussed in the Life Cycle Assessment Scope and Boundaries Section, Modules B1, B2, B3, B5, B6, B7, C1 and C3 do not contribute to impacts and are declared as zero. Optional Module D – Benefits and Loads Beyond the System Boundary – is not included in this LCA study. In the interest of conciseness, the tables with results in this section do not include these modules.

Table 9.
Description of the System Boundary Modules.

PRODUCT STAGE			CONSTRUCTION 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
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	Building Operational Energy Use During Product Use			X					
					B7	Building Operational Water Use During Product Use			X					
X	X	X	X	X	X	X	X	X	X	X	X	X	X	MND
MND = module not declared														

The following tables detail the results of the roof products by functional unit RSI=1 $m^2 \cdot K/W$, including the impact assessment results using the TRACI 2.1 impact assessment method and the inventory metrics required by the PCR. These six impact categories are globally deemed mature enough to be included in Type III environmental declarations. Other categories are being developed and defined, and the LCA practice should continue making advances in their development. However, the EPD users shall not use additional measures for comparative purposes. LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

Product: Glass Fiber Reinforced Cellulosic Facer (GRF) Polyiso Roof Insulation (Tables 10, 11, 12 and 13).

Table 10.
TRACI 2.1 Impact Categories – Functional Unit for all Life Cycle Stages Totals.

IMPACT CATEGORY	UNIT	TOTAL VALUE
GWP: Global Warming Potential	kg CO_2 eq	4.36E+00
ODP: Ozone Depletion Potential	kg CFC-11 eq	3.25E-07
AP: Acidification Potential	kg SO_2 eq	2.14E-02
EP: Eutrophication Potential	kg N eq	3.22E-02
POCP: Photochemical Oxidant Creation Potential	kg O_3 eq	2.49E-01
ADP_{fossil}: Abiotic Resource Depletion Potential of Non-renewable energy resources	MJ, LHV	1.23E+01

Table 11.
TRACI 2.1 Impact Categories – Functional Unit by System Boundary Module.

IMPACT CATEGORY	UNIT	A1	A2	A3	A4	A5	B4	C2	C4
GWP	kg CO_2 eq	1.86E+00	6.46E-02	1.84E-01	7.12E-02	2.35E-02	2.07E+00	3.72E-03	9.10E-02
ODP	kg CFC-11 eq	1.23E-07	1.38E-08	1.44E-08	1.77E-08	4.47E-11	1.54E-07	9.26E-10	1.63E-09
AP	kg SO_2 eq	9.61E-03	5.58E-04	3.17E-04	3.65E-04	3.10E-04	1.02E-02	1.91E-05	1.08E-04
EP	kg N eq	2.78E-03	1.16E-04	8.02E-04	8.53E-05	2.41E-05	1.52E-02	4.46E-06	1.31E-02
POCP	kg O_3 eq	8.64E-02	1.55E-02	6.61E-03	9.19E-03	1.00E-02	1.18E-01	4.81E-04	2.65E-03
ADP_{fossil}	MJ, LHV	5.92E+00	1.25E-01	1.74E-01	1.59E-01	4.76E-02	5.81E+00	8.33E-03	2.37E-02

Table 12.
Resource Use Indicators – Functional Unit by System Boundary Module.

RESOURCE INDICATOR	UNIT	A1	A2	A3	A4	A5	B4	C2	C4
RPRE	MJ, LHV	9.63E-01	1.86E-02	8.33E-02	1.15E-02	7.27E-04	9.74E-01	6.00E-04	4.39E-03
RPRM	MJ, LHV	3.54E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-01	0.00E+00	0.00E+00
NRPRE	MJ, LHV	2.47E+01	9.27E-01	1.95E+00	1.12E+00	3.22E-01	2.63E+01	5.83E-02	1.91E-01
NRPRM	MJ, LHV	1.95E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.75E+01	0.00E+00	0.00E+00
SM	kg	1.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-01	0.00E+00	0.00E+00
FW	m^3	7.84E-03	2.01E-04	4.77E-04	1.88E-04	2.93E-05	8.07E-03	9.83E-06	2.30E-04
RSF	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NRSF	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RE	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Abbreviations	RPRE: Renewable primary resources used as an 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 used as material; SM: Secondary Materials; FW: Use of net fresh water resources; RSF: Renewable secondary fuels; NRSF: Non-renewable secondary fuels; RE: Recovered energy.								
Note	The data for following resource indicators; RSF: Renewable secondary fuels; NRSF: Non-renewable secondary fuels; RE: Recovered energy, is not available and it is designated with a symbol N/A.								

Table 13.
Waste and Other Outputs – Functional Unit by System Boundary Module.

OUTPUT FLOWS	UNIT	A1	A2	A3	A4	A5	B4	C2	C4
HWD	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E-06	0.00E+00	4.58E-06
NHWD	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.02E-03	0.00E+00	1.00E-02
MR	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-04	0.00E+00	1.98E-04
HLRW	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ILLRW	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRU	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MER	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EE	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Abbreviations	HWD: Hazardous waste disposed; NHWD: Non-hazardous waste disposed: MR: Materials for Recycle; HLRW: High level radioactive waste disposed; ILLRW: Intermediate- and low-level radioactive waste, conditioned, to final repository; CRU: Components for re-use; MER: Materials for energy recovery; EE: Exported energy.								
Note	No substances required to be reported as hazardous are associated with the production of this product, however a small percentage of the manufacturing waste is disposed of as hazardous waste. The data the following output flows; for HLRW: High level radioactive waste disposed; ILLRW: Intermediate- and low-level radioactive waste, conditioned, to final repository; CRU: Components for re-use; MER: Materials for energy recovery; EE: Exported energy, is not available and it is designated with symbol N/A.								

Product: Coated Glass Facer (CGF) Polyiso Roof Insulation (Tables 14, 15, 16 and 17).

Table 14.
TRACI 2.1 Impact Categories – Functional Unit for all Life Cycle Stages Totals.

IMPACT CATEGORY	UNIT	TOTAL VALUE
GWP: Global Warming Potential	kg CO_2 eq	5.96E+00
ODP: Ozone Depletion Potential	kg CFC-11 eq	4.39E-07
AP: Acidification Potential	kg SO_2 eq	2.83E-02
EP: Eutrophication Potential	kg N eq	3.79E-02
POCP: Photochemical Oxidant Creation Potential	kg O_3 eq	3.37E-01
ADP_{fossil}: Abiotic Resource Depletion Potential of Non-renewable energy resources	MJ, LHV	1.37E+01

Table 15.
TRACI 2.1 Impact Categories – Functional Unit by System Boundary Module.

IMPACT CATEGORY	UNIT	A1	A2	A3	A4	A5	B4	C2	C4
GWP	kg CO_2 eq	2.70E+00	6.46E-02	1.84E-01	7.12E-02	2.35E-02	2.83E+00	3.72E-03	9.10E-02
ODP	kg CFC-11 eq	1.83E-07	1.38E-08	1.44E-08	1.77E-08	4.47E-11	2.08E-07	9.26E-10	1.63E-09
AP	kg SO_2 eq	1.32E-02	5.58E-04	3.17E-04	3.65E-04	3.10E-04	1.34E-02	1.91E-05	1.08E-04
EP	kg N eq	5.79E-03	1.16E-04	8.02E-04	8.53E-05	2.41E-05	1.79E-02	4.46E-06	1.31E-02
POCP	kg O_3 eq	1.33E-01	1.55E-02	6.61E-03	9.19E-03	1.00E-02	1.59E-01	4.81E-04	2.65E-03
ADP_{fossil}	MJ, LHV	6.67E+00	1.25E-01	1.74E-01	1.59E-01	4.76E-02	6.49E+00	8.33E-03	2.37E-02

Table 16.
Resource Use Indicators – Functional Unit by System Boundary Module.

RESOURCE INDICATOR	UNIT	A1	A2	A3	A4	A5	B4	C2	C4
RPRE	MJ, LHV	1.65E+00	1.86E-02	8.33E-02	1.15E-02	7.27E-04	1.59E+00	6.00E-04	4.39E-03
RPRM	MJ, LHV	3.54E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-01	0.00E+00	0.00E+00
NRPRE	MJ, LHV	3.65E+01	9.27E-01	1.95E+00	1.12E+00	3.22E-01	3.70E+01	5.83E-02	1.91E-01
NRPRM	MJ, LHV	1.95E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.75E+01	0.00E+00	0.00E+00
SM	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FW	m^3	1.33E-02	2.01E-04	4.77E-04	1.88E-04	2.93E-05	1.30E-02	9.83E-06	2.30E-04
RSF	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NRSF	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RE	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Abbreviations	RPRE: Renewable primary resources used as an 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 used as material; SM: Secondary Materials; FW: Use of net fresh water resources; RSF: Renewable secondary fuels; NRSF: Non-renewable secondary fuels; RE: Recovered energy.								
Note	The data for following resource indicators; RSF: Renewable secondary fuels; NRSF: Non-renewable secondary fuels; RE: Recovered energy, is not available and it is designated with a symbol N/A.								

Table 17.
Waste and Other Outputs – Functional Unit by System Boundary Module.

OUTPUT FLOWS	UNIT	A1	A2	A3	A4	A5	B4	C2	C4
HWD	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E-06	0.00E+00	4.58E-06
NHWD	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.02E-03	0.00E+00	1.00E-02
MR	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-04	0.00E+00	1.98E-04
HLRW	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ILLRW	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CRU	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MER	kg	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EE	MJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Abbreviations	HWD: Hazardous waste disposed; NHWD: Non-hazardous waste disposed: MR: Materials for Recycle; HLRW: High level radioactive waste disposed; ILLRW: Intermediate- and low-level radioactive waste, conditioned, to final repository; CRU: Components for re-use; MER: Materials for energy recovery; EE: Exported energy								
Note	No substances required to be reported as hazardous are associated with the production of this product, however a small percentage of the manufacturing waste is disposed of as hazardous waste. The data the following output flows; for HLRW: High level radioactive waste disposed; ILLRW: Intermediate- and low-level radioactive waste, conditioned, to final repository; CRU: Components for re-use; MER: Materials for energy recovery; EE: Exported energy, is not available and it is designated with symbol N/A.								

LCA INTERPRETATION

Module Impact Analysis

The life cycle assessment results inform the users on the cradle-to-grave environmental profile for polyiso roof insulation boards. As described in the Use and Reference Service Life section of this declaration, all life cycle stage environmental impacts for polyiso are connected with the original building construction with a "Roof Recover" operation at 20-years as well as the building's "Roof Replacement" operation at 40-years. This translates to 1.9 replacement cycles during the 75-year building ESL. The complete replacement of the originally installed polyiso roof insulation boards, module B4, "Roof Replacement", incudes a large portion of the environmental profile impacts. The impacts associated with the production of raw materials represent a predominant portion of the environmental profile for the original installation and the roof replacement operation. The environmental profile for the initial 40-years for polyiso roof insulation boards is captured in modules A1 through A5, C2 and C4. This distinction allows a closer examination of the impacts that the individual modules have on the overall environmental profile of polyiso roof insulation boards.

When assessing environmental profiles of products, Global Warming Potential (GWP) is an important Impact Category. The relative impact of modules on GWP for polyiso roof insulation boards with GRF facer is illustrated in Figure 3. Module A1 (raw materials) is the most dominant module accounting for (81%) of the impacts. Module A3 (manufacturing of polyiso) contributes 8%. The remaining modules A2, A4, A5, C2 and C4, each contribute less than 5%.

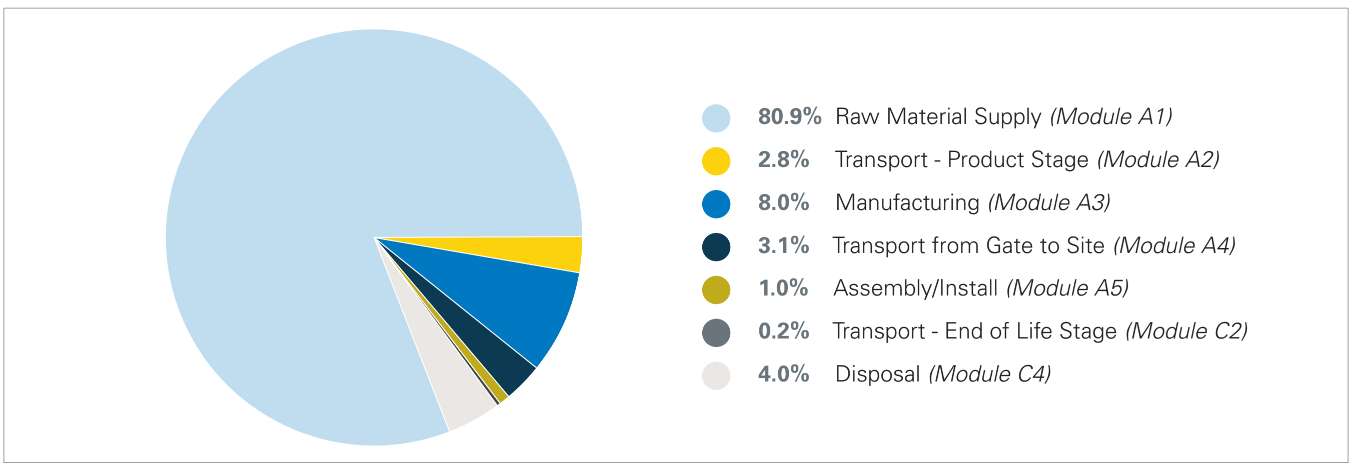

Figure 3.
Relative Impact of Modules on Global Warming Potential for GRF Faced Polyiso Roof Insulation Boards.

The relative impact of modules on GWP was also examined for polyiso roof insulation boards with CGF facer and the results are illustrated in Figure 4. Similarly, Module A1 (raw materials) is the most dominant module accounting for 86.0% of the impacts. Module A3 (manufacturing of polyiso) contributes 5.9%. The remaining modules A2, A4, A5, C2 and C4, each contribute less than 3.0%. The slightly higher impacts in Module A1 (raw materials), are attributed to the facer type.

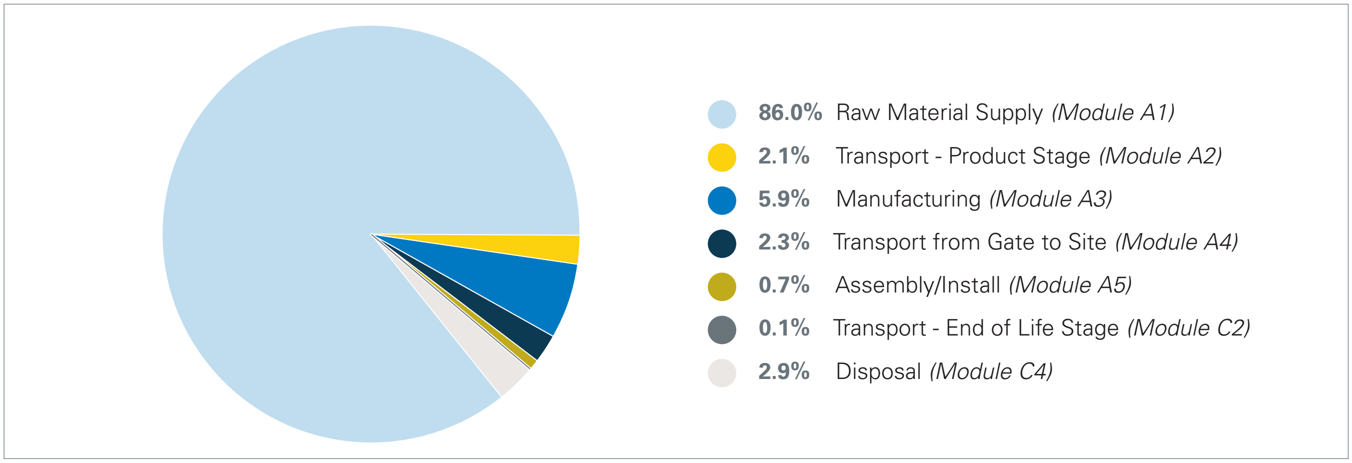

Figure 4.
Relative Impact of Modules in Global Warming Potential for CGF Faced Polyiso Roof Insulation Boards.

The analysis in Tables 10 through 17 indicates that Module A1 (raw materials) dominates the environmental profile of polyiso roof insulation boards. The aggregated primary and secondary data indicate that extraction and processing of raw materials have the largest impact. The polyiso industry is characterized as having a large number of plants that produce polyiso roof insulation boards located throughout the Unites States and Canada. Many plants are located near large population centers with significant roof replacement and new roof construction activity, thus reducing the impacts from transportation.

Environmental Profiles for Common Polyiso Thicknesses Configurations

Polyiso Roof Insulation Boards with GRF and CGF facers are available in incremental RIP-values from 5.7 ft^2·°F·h/Btu to 27 ft^2·°F·h/Btu. For this declaration, cradle–to-grave environmental profiles were calculated on three popular thicknesses for the two facer types: 1.8-inch (RIP – 10.3 ft^2·°F·h/Btu), 2.6-inch (RIP – 15 ft^2·°F·h/Btu) and 3.5-inch (RIP – 20.5 ft^2·°F·h/Btu). The International Energy Conservation Code (IECC) requires roof insulation to be installed in multiple layers with staggered joints to enhance the thermal performance of the roof system. These requirements do not exist in Canada's National Energy Code for Buildings. To provide the users of this document the opportunity to assess common polyiso roof insulation configurations, the Impact and Indicator metrics are listed for all life cycle stages for four two-layer combinations corresponding to the minimum R-value requirements of the IECC and ASHRAE 90.1 Standard for insulation entirely above deck in all climate zones throughout the United States and Canada. The data for single board and two-layer combinations are provided in Tables 18 through 22. **Impact and Indicator values on any thickness of product between 1.8-inch and 3.5-inch can be calculated through linear extrapolation from the data in these Tables.**

Table 18.
Impacts/Indicators for All Life Cycle Stages of Common Roof Product Thicknesses.

Product: Glass Fiber Reinforced Cellulosic Facer (GRF) Polyiso Roof Insulation								
IMPACT CATEGORY / ENVIRONMENTAL INDICATOR		UNIT	1.8-inch Thick R_{IP}: 10.3		2.6 -inch Thick R_{IP}: 15		3.5-inch Thick R_{IP}: 20.5	
			Per 1 ft^2	Per 1 m^2	Per 1 ft^2	Per 1 m^2	Per 1 ft^2	Per 1 m^2
TRACI 2.1 IMPACT CATEGORIES	**GWP: Global Warming Potential**	kg CO_2 eq	7.64E-01	8.23E+00	1.07E+00	1.15E+01	1.43E+00	1.54E+01
	ODP: Ozone Depletion Potential	kg CFC-11 eq	5.74E-08	6.18E-07	7.98E-08	8.59E-07	1.06E-07	1.14E-06
	AP: Acidification Potential	kg SO_2 eq	3.73E-03	4.02E-02	5.26E-03	5.67E-02	7.03E-03	7.57E-02
	EP: Eutrophication Potential	kg N eq	5.86E-03	6.31E-02	7.89E-03	8.49E-02	1.02E-02	1.10E-01
	POCP: Photochemical Oxidant Creation Potential	kg O_3 eq	4.46E-02	4.80E-01	6.10E-02	6.57E-01	8.04E-02	8.65E-01
	ADP_{fossil}: Abiotic Resource Depletion Potential of Non-Renewable Energy Resources	MJ, LHV	2.11E+00	2.27E+01	3.01E+00	3.24E+01	4.06E+00	4.37E+01
RESOURCE USE INDICATORS	**RPR_E: Renewable Primary Resources Used as an Energy Carrier (Fuel)**	MJ, LHV	3.64E-01	3.92E+00	5.05E-01	5.43E+00	6.81E-01	7.33E+00
	RPR_M: Renewable Primary Resources with Energy Content Used as Material	MJ, LHV	1.15E-01	1.23E+00	1.65E-01	1.78E+00	2.27E-01	2.45E+00
	$NRPR_E$: Non-Renewable Primary Resources Used as an Energy Carrier (Fuel)	MJ, LHV	9.75E+00	1.05E+02	1.36E+01	1.47E+02	1.83E+01	1.97E+02
	$NRPR_M$: Non-Renewable Primary Resources Used as Material	MJ, LHV	6.24E+00	6.72E+01	9.07E+00	9.76E+01	1.23E+01	1.32E+02
	PED: Total Primary Energy Demand	MJ, LHV	1.65E+01	1.77E+02	2.34E+01	2.52E+02	3.15E+01	3.39E+02
	SM: Secondary Materials	kg	8.83E-02	9.51E-01	8.83E-02	9.51E-01	8.83E-02	9.51E-01
	FW: Use of Net Fresh Water Resources	m^3	3.00E-03	3.23E-02	4.18E-03	4.50E-02	5.67E-03	6.10E-02
WASTE OUTPUT	**HWD: Hazardous Waste Disposed**	kg	1.47E-06	1.59E-05	2.14E-06	2.30E-05	2.89E-06	3.11E-05
	NHWD: Non-Hazardous Waste Disposed	kg	3.23E-03	3.48E-02	4.67E-03	5.03E-02	6.34E-03	6.83E-02
	MR: Materials for Recycle	kg	6.38E-05	6.87E-04	9.24E-05	9.95E-04	1.25E-04	1.35E-03

Table 19.
Impacts/Indicators for All Life Cycle Stages of Common Two-Layer Roof Configurations.

Product: Glass Fiber Reinforced Cellulosic Facer (GRF) Polyiso Roof Insulation										
	IMPACT CATEGORY / ENVIRONMENTAL INDICATOR	UNIT	2 Layers of 1.8-inch Thick R_{IP}: 20.6		1 Layer of 1.8-inch & 1 Layer of 2.6-inch Thick R_{IP}: 25.3		2 Layers of 2.6-inch Thick R_{IP}: 30.0		1 Layers of 2.6 inch & 1 Layer of 3.5-inch Thick R_{IP}: 35.5	
			Per ft^2	Per m^2	Per ft^2	Per m^2	Per ft^2	Per m^2	Per ft^2	Per m^2
TRACI 2.1 IMPACT CATEGORIES	GWP: Global Warming Potential	kg CO_2 eq	1.53E+00	1.65E+01	1.84E+00	1.98E+01	2.14E+00	2.31E+01	2.50E+00	2.69E+01
	ODP: Ozone Depletion Potential	kg CFC-11 eq	1.15E-07	1.24E-06	1.37E-07	1.48E-06	1.60E-07	1.72E-06	1.86E-07	2.00E-06
	AP: Acidification Potential	kg SO_2 eq	7.46E-03	8.04E-02	9.00E-03	9.68E-02	1.05E-02	1.13E-01	1.23E-02	1.32E-01
	EP: Eutrophication Potential	kg N eq	1.17E-02	1.26E-01	1.38E-02	1.48E-01	1.58E-02	1.70E-01	1.81E-02	1.95E-01
	POCP: Photochemical Oxidant Creation Potential	kg O_3 eq	8.91E-02	9.59E-01	1.06E-01	1.14E+00	1.22E-01	1.31E+00	1.41E-01	1.52E+00
	ADP_{fossil}: Abiotic Resource Depletion Potential of Non-Renewable Energy Resources	MJ, LHV	4.22E+00	4.55E+01	5.12E+00	5.51E+01	6.02E+00	6.48E+01	7.07E+00	7.61E+01
RESOURCE USE INDICATORS	RPR_E: Renewable Primary Resources Used as an Energy Carrier (Fuel)	MJ, LHV	7.28E-01	7.83E+00	8.69E-01	9.35E+00	1.01E+00	1.09E+01	1.19E+00	1.28E+01
	RPR_M: Renewable Primary Resources with Energy Content Used as Material	MJ, LHV	2.29E-01	2.47E+00	2.80E-01	3.01E+00	3.30E-01	3.55E+00	3.93E-01	4.23E+00
	$NRPR_E$: Non-Renewable Primary Resources Used as an Energy Carrier (Fuel)	MJ, LHV	1.95E+01	2.10E+02	2.34E+01	2.52E+02	2.73E+01	2.93E+02	3.19E+01	3.44E+02
	$NRPR_M$: Non-Renewable Primary Resources Used as Material	MJ, LHV	1.25E+01	1.34E+02	1.53E+01	1.65E+02	1.81E+01	1.95E+02	2.14E+01	2.30E+02
	PED: Total Primary Energy Demand	MJ, LHV	3.29E+01	3.55E+02	3.98E+01	4.29E+02	4.67E+01	5.03E+02	5.48E+01	5.90E+02
	SM: Secondary Materials	kg	1.77E-01	1.90E+00	1.77E-01	1.90E+00	1.77E-01	1.90E+00	1.77E-01	1.90E+00
	FW: Use of Net Fresh Water Resources	m^3	6.00E-03	6.46E-02	7.18E-03	7.73E-02	8.37E-03	9.01E-02	9.85E-03	1.06E-01
WASTE OUTPUT	HWD: Hazardous Waste Disposed	kg	2.95E-06	3.17E-05	3.61E-06	3.88E-05	4.27E-06	4.60E-05	5.02E-06	5.41E-05
	NHWD: Non-Hazardous Waste Disposed	kg	6.47E-03	6.96E-02	7.91E-03	8.51E-02	9.35E-03	1.01E-01	1.10E-02	1.19E-01
	MR: Materials for Recycle	kg	1.28E-04	1.37E-03	1.56E-04	1.68E-03	1.85E-04	1.99E-03	2.17E-04	2.34E-03

Table 20.
Impacts/Indicators for All Life Cycle Stages of Common Roof Product Thicknesses.

Product: Coated Glass Facer (CGF) Polyiso Roof Insulation								
	IMPACT CATEGORY / ENVIRONMENTAL INDICATOR	UNIT	1.8-inch Thick R_{IP}: 10.3		2.6-inch Thick R_{IP}: 15		3.5-inch Thick R_{IP}: 20.5	
			Per 1 ft^2	Per 1 m^2	Per 1 ft^2	Per 1 m^2	Per 1 ft^2	Per 1 m^2
TRACI 2.1 IMPACT CATEGORIES	**GWP: Global Warming Potential**	kg CO_2 eq	1.16E+00	1.25E+01	1.46E+00	1.58E+01	1.82E+00	1.96E+01
	ODP: Ozone Depletion Potential	kg CFC-11 eq	8.54E-08	9.19E-07	1.08E-07	1.16E-06	1.34E-07	1.44E-06
	AP: Acidification Potential	kg SO_2 eq	5.42E-03	5.83E-02	6.95E-03	7.48E-02	8.71E-03	9.38E-02
	EP: Eutrophication Potential	kg N eq	7.26E-03	7.82E-02	9.29E-03	1.00E-01	1.16E-02	1.25E-01
	POCP: Photochemical Oxidant Creation Potential	kg O_3 eq	6.61E-02	7.12E-01	8.26E-02	8.89E-01	1.02E-01	1.10E+00
	ADP_{fossil}: Abiotic Resource Depletion Potential of Non-Renewable Energy Resources	MJ, LHV	2.46E+00	2.65E+01	3.36E+00	3.62E+01	4.41E+00	4.75E+01
RESOURCE USE INDICATORS	**RPR_E: Renewable Primary Resources Used as an Energy Carrier (Fuel)**	MJ, LHV	6.82E-01	7.34E+00	8.23E-01	8.86E+00	1.00E+00	1.08E+01
	RPR_M: Renewable Primary Resources with Energy Content Used as Material	MJ, LHV	1.15E-01	1.23E+00	1.65E-01	1.78E+00	2.27E-01	2.45E+00
	$NRPR_E$: Non-Renewable Primary Resources Used as an Energy Carrier (Fuel)	MJ, LHV	1.53E+01	1.64E+02	1.92E+01	2.06E+02	2.38E+01	2.56E+02
	$NRPR_M$: Non-Renewable Primary Resources Used as Material	MJ, LHV	6.24E+00	6.72E+01	9.07E+00	9.76E+01	1.23E+01	1.32E+02
	PED: Total Primary Energy Demand	MJ, LHV	2.23E+01	2.40E+02	2.92E+01	3.14E+02	3.73E+01	4.02E+02
	SM: Secondary Materials	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	FW: Use of Net Fresh Water Resources	m^3	5.54E-03	5.96E-02	6.72E-03	7.24E-02	8.21E-03	8.84E-02
WASTE OUTPUT	**HWD: Hazardous Waste Disposed**	kg	1.47E-06	1.59E-05	2.14E-06	2.30E-05	2.89E-06	3.11E-05
	NHWD: Non-Hazardous Waste Disposed	kg	3.23E-03	3.48E-02	4.67E-03	5.03E-02	6.34E-03	6.83E-02
	MR: Materials for Recycle	kg	6.38E-05	6.87E-04	9.24E-05	9.95E-04	1.25E-04	1.35E-03

Table 21.
Impacts/Indicators for All Life Cycle Stages of Common Two-Layer Roof Configurations.

Product: Coated Glass Facer (CGF) Polyiso Roof Insulation										
	IMPACT CATEGORY / ENVIRONMENTAL INDICATOR	UNIT	2 Layers of 1.8-inch Thick R_{IP}: 20.6		1 Layer of 1.8-inch & 1 Layer of 2.6-inch Thick R_{IP}: 25.3		2 Layers of 2.6-inch Thick R_{IP}: 30.0		1 Layer of 2.6-inch & 1 Layer of 3.5-inch Thick R_{IP}: 35.5	
			Per ft^2	Per m^2	Per ft^2	Per m^2	Per ft^2	Per m^2	Per ft^2	Per m^2
TRACI 2.1 IMPACT CATEGORIES	GWP: Global Warming Potential	kg CO_2 eq	2.31E+00	2.49E+01	2.62E+00	2.82E+01	2.93E+00	3.15E+01	3.29E+00	3.54E+01
	ODP: Ozone Depletion Potential	kg CFC-11 eq	1.71E-07	1.84E-06	1.93E-07	2.08E-06	2.16E-07	2.32E-06	2.42E-07	2.60E-06
	AP: Acidification Potential	kg SO_2 eq	1.08E-02	1.17E-01	1.24E-02	1.33E-01	1.39E-02	1.50E-01	1.57E-02	1.69E-01
	EP: Eutrophication Potential	kg N eq	1.45E-02	1.56E-01	1.66E-02	1.78E-01	1.86E-02	2.00E-01	2.09E-02	2.25E-01
	POCP: Photochemical Oxidant Creation Potential	kg O_3 eq	1.32E-01	1.42E+00	1.49E-01	1.60E+00	1.65E-01	1.78E+00	1.85E-01	1.99E+00
	ADP_{fossil}: Abiotic Resource Depletion Potential of Non-Renewable Energy Resources	MJ, LHV	4.93E+00	5.31E+01	5.83E+00	6.27E+01	6.72E+00	7.24E+01	7.77E+00	8.37E+01
RESOURCE USE INDICATORS	RPR_E: Renewable Primary Resources Used as an Energy Carrier (Fuel)	MJ, LHV	1.36E+00	1.47E+01	1.51E+00	1.62E+01	1.65E+00	1.77E+01	1.82E+00	1.96E+01
	RPR_M: Renewable Primary Resources with Energy Content Used as Material	MJ, LHV	2.29E-01	2.47E+00	2.80E-01	3.01E+00	3.30E-01	3.55E+00	3.93E-01	4.23E+00
	$NRPR_E$: Non-Renewable Primary Resources Used as an Energy Carrier (Fuel)	MJ, LHV	3.06E+01	3.29E+02	3.44E+01	3.71E+02	3.83E+01	4.12E+02	4.30E+01	4.62E+02
	$NRPR_M$: Non-Renewable Primary Resources Used as Material	MJ, LHV	1.25E+01	1.34E+02	1.53E+01	1.65E+02	1.81E+01	1.95E+02	2.14E+01	2.30E+02
	PED: Total Primary Energy Demand	MJ, LHV	4.46E+01	4.80E+02	5.15E+01	5.55E+02	5.84E+01	6.29E+02	6.65E+01	7.16E+02
	SM: Secondary Materials	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	FW: Use of Net Fresh Water Resources	m^3	1.11E-02	1.19E-01	1.23E-02	1.32E-01	1.34E-02	1.45E-01	1.49E-02	1.61E-01
WASTE OUTPUT	HWD: Hazardous Waste Disposed	kg	2.95E-06	3.17E-05	3.61E-06	3.88E-05	4.27E-06	4.60E-05	5.02E-06	5.41E-05
	NHWD: Non-Hazardous Waste Disposed	kg	6.47E-03	6.96E-02	7.91E-03	8.51E-02	9.35E-03	1.01E-01	1.10E-02	1.19E-01
	MR: Materials for Recycle	kg	1.28E-04	1.37E-03	1.56E-04	1.68E-03	1.85E-04	1.99E-03	2.17E-04	2.34E-03

ADDITIONAL ENVIRONMENTAL INFORMATION

Fire Performance: The fire performance of low-slope roof assemblies is evaluated using assembly tests (from the deck to roof covering) with respect to both external and internal fire exposure. The fire exposures in tests simulates the type of fire exposure a roof may encounter during its service life, including interior building fires or exterior hazards. The resistance of a roof system to external fire exposure is evaluated using ASTM E108 "Standard Test Methods for Fire Tests of Roof Coverings," UL 790 "Standard Test Methods for Fire Tests of Roof Coverings" or the Canadian equivalent, CAN/ULC-S107 "Methods of Fire Tests of Roof Coverings." The test methods provide a basis for comparing roof assemblies under a simulated exterior fire. Roof assemblies restricted to noncombustible decks require only the spread-of-flame test, while roof assemblies used on combustible decks are evaluated for spread of flame, intermittent flame, and the burning brand tests. Roof assemblies can achieve a Class A, B, or C classification. Class A designates the resistance to relatively severe fire-test exposure. Class B designates resistance to relatively moderate fire-test exposure. Class C designates resistance to relatively light fire-test exposure.

Fires can also originate within the building interior and roof system response to fire exposure originating from the interior of the building may be evaluated using NFPA 276 "Standard Method of Fire Test for Determining the Heat Release Rate of Roofing Assemblies with Combustible Above-Deck Roofing Components," FM Approval 4470 "Single-Ply, Polymer-Modified Bitumen Sheet, Built-Up Roof (BUR) and Liquid Applied Roof: Assemblies for Use in Class 1 and Noncombustible Roof Deck Construction," UL 1256 "Fire Test of Roof Deck Construction," or CAN/ULC-S126 "Standard Method of Test for Fire Spread Under Roof-Deck Assemblies." The passing criteria is established by a limit-of-fuel contribution within a designated time period. Polyiso remains the only foam plastic roof insulation to earn FM Class 1 approval for direct-to-steel deck applications when tested in accordance with FM Approval 4470. Polyiso is also classified by UL under UL 1256 for direct-to-steel deck applications with both single-ply and asphalt-based roof coverings.

Building Use-Stage Environmental Benefits

Demonstration Summary: Polyiso's low thermal conductivity limits a building's operational energy consumption and associated environmental impacts. Quantifying the reduction in energy for heating, cooling, and ventilating a specific building design using polyiso versus a baseline design is important to demonstrating these benefits relative to the environmental impacts of the declared product. For this purpose, extensive analyses involving building energy simulations were conducted on Roof Replacement (RR) scenarios for twenty-two (22) locations spread throughout the climate zones of the United States and ten (10) locations throughout the geographic regions of Canada. The protocol for this comprehensive study is in accordance with the guidelines set forth in the PCR (Part B, Section 7.2), including the utilization of the whole-building energy simulation tool, EnergyPlus, the PNNL Strip Mall commercial building prototype model (ASHRAE 90.1-2004 compliant), and representative baseline scenarios.

Roof Replacement Background: Reroofing is one of the most common alteration projects conducted on any given existing commercial building with roof recover(s) and/or roof replacement(s) performed multiple times during its actual life. It is recognized that roofs on buildings of twenty (20) years or more of age are likely to be under-insulated by today's standards and minimum energy code requirements. For the framework of the declared unit of the polyiso roof insulation product, Roof Replacement (RR) is performed on the roof in which the product is installed forty (40) years after the building is constructed. Furthermore, the framework conservatively presumes that all of the polyiso is replaced with new product which remains in place for the remainder of the building's life span (ESL), meaning an additional thirty-five (35) years. The cradle-to-grave environmental profile of the new product is accounted for in its entirety under Use-stage Module 4B, Replacement.

Modelling Protocol: In this demonstration, three (3) original single-layer mechanically attached roof insulation baselines of R_{IP}-10, R_{IP}-12.5 and R_{IP}-15 are simulated for each location. A fourth model consists of a second layer of polyiso adhered to the original layer, which for the United States, brings the roof assembly in R-value compliance with current versions of the IECC and ASHRAE 90.1 for Roof Replacements depending on Climate Zone. For Canada, the fourth model consists of a second layer bringing the R-value to R_{IP}-30 (R_{SI}5.3) as there is currently no minimum requirement for Roof Replacements. See Tables 22 and 23 for further detail of the modelled scenarios for the United States and Canada, respectively. As such, each simulation provides an assessment of the energy savings benefits of the additional insulation installed compared to its embodied aspects extrapolated from Tables 19 and 20 for GRF polyiso insulation product.

Result Metric Descriptions: The results of the analyses are presented for **Primary Energy Demand (PED)** and **Global Warming Potential (GWP).** The values expressed represent specific RR-to-baseline comparisons or averages amongst a group of comparisons. Terms used are described as follows:

- **Add'l Polyiso PED** – Cradle-to-Grave PED embodied in the full life cycle (LC) of the additional installed polyiso GRF roof insulation product (GJ/m^2 of roof area).
- **PED Savings** – The building operational PED savings over the 35-year life cycle of the additional installed polyiso GRF roof insulation product (GJ/m^2 of roof area).
- **PED Savings Ratio** – This is the ratio of PED Savings to Add'l Polyiso PED. The higher the ratio, the greater the benefit of the additional polyiso in regard to energy resource consumption.
- **PED Recoup Period** – The period of time estimated to recoup Add'l Polyiso PED following RR through PED Savings (Months).
- **Add'l Polyiso CO_2** – Cradle-to-Grave GWP emissions in the full life cycle (LC) of the additional installed Polyiso GRF roof insulation product (kg CO_2/m^2 of roof area).
- **CO_2 Avoidance** – The avoidance of GWP emissions associated with the building operational energy savings over the 35-year life cycle of the additional installed polyiso GRF roof insulation product (kg CO_2/m^2 of roof area).
- **CO_2 Avoidance Ratio** – This is the ratio of CO_2 Avoidance to Add'l Polyiso CO_2. The higher the ratio, the greater the benefit of the additional polyiso in regard to carbon emissions reduction.
- **CO_2 Recoup Period** – The period of time estimated to recoup Add'l Polyiso CO_2 following RR through CO_2 Avoidance (Months).

National Averages: Primary Energy Demand and Global Warming Potential national average results for the United States and Canada are presented in Figures 5 and 6, respectively. Averages were calculated for each United States Climate Zone and Canadian Region by averaging the three (3) baseline savings results for each location and by taking the average of all locations within each Zone/Region. National averages were calculated by weighting each Zone/Region on an estimated commercial floor area basis. Of special note for Canada, existing building floor area gives particularly heavy weighting to the Great Lakes Region (54%).

Primary Energy Demand Savings Ratios and Recoup Periods are shown in Figure 5. A ratio of 28 and a recoup of only 15 months of building operation provides context to the environmental benefits of polyiso in Roof Replacement applications. The overall colder climate of Canada provides even greater evidence of these benefits with a Ratio of 37 and a recoup of a year. This compelling argument, the energy savings and the key opportunity posed by reroofing of existing buildings, is valuable insight for the sustainable-minded designer, building owner and public official.

Governments, corporations and individuals across the planet are committed to lowering carbon emissions. Polyiso for newly constructed roofs and walls, as well as new roofs on existing buildings, plays a key role in meeting these commitments. Figure 6 demonstrates how the relatively low Global Warming Potential of additional insulation installed during roof replacement contributes to the avoidance of emissions associated with the building operational energy saved by it. The national averages for both the United States and Canada exhibit even greater beneficial environmental results in terms of greenhouse gas emissions reductions. The CO_2 Avoidance Ratio is 34 and the CO_2 Recoup Period is 13 months. For Canada, the Ratio indicates that for every square meter of roof area replaced, the emissions prevented are 45 kg of CO_2 equivalents times that of the cradle-to-grave encumbered impact of each square meter of the additional polyiso GRF roof insulation. Therefore, the life cycle insulation emissions are matched by those avoided as a result of energy savings in the first 9 months of the 35-years of remaining operation.

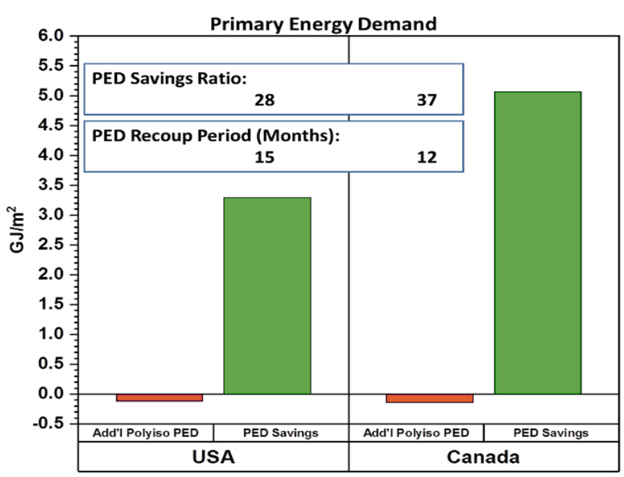

Figure 5.
National Average Results for Primary Energy Demand

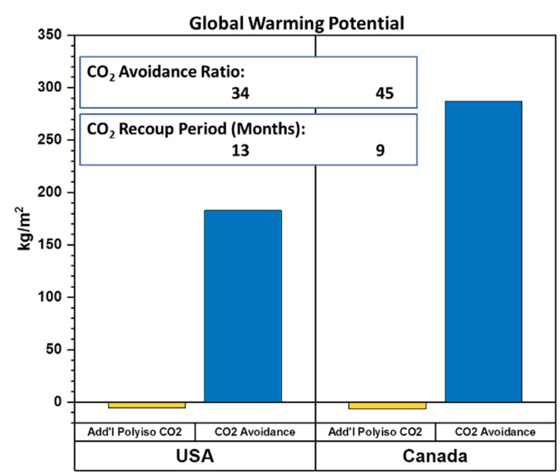

Figure 6.
National Average Results for Global Warming Potential.

United States Location Summary: See Figure 7 for United States GWP results noting the CO_2 Avoidance Ratios are represented by the scatter plot and the CO_2 Recoup Periods are represented by the columns. The Roof Replacement thermal performance for the twenty-two (22) United States locations established for these modelling analyses were based on the minimum roof insulation requirements of the model energy codes. They vary between R_{IP}-20 in Climate Zone 1 to R_{IP}-35 in Climate Zones 7 and 8. This creates a bit of a break in the continuity of the trends in the data. However, in general, the Ratio decreases slightly from very hot (CZ-1) to mild (CZ-4) climates. Yet still demonstrating being very emissions beneficial, the R-15 base cases for Philadelphia and New York registered the lowest Ratio (25) and highest Recoup Period (17 Months) of the sixty-six (66) United States scenarios modelled. Beginning with cold Climate Zone 5, the trend quite clearly and rapidly exhibits increasing Ratio and decreasing Recoup Period with increasing Heating Degree Days. For all locations, the R-10 baseline demonstrates providing the highest benefits with regard to limiting carbon emissions for a Roof Replacement alteration. The R-10 baseline for International Falls, MN registered the highest Ratio and lowest Recoup Period with 55 and 8 Months, respectively.

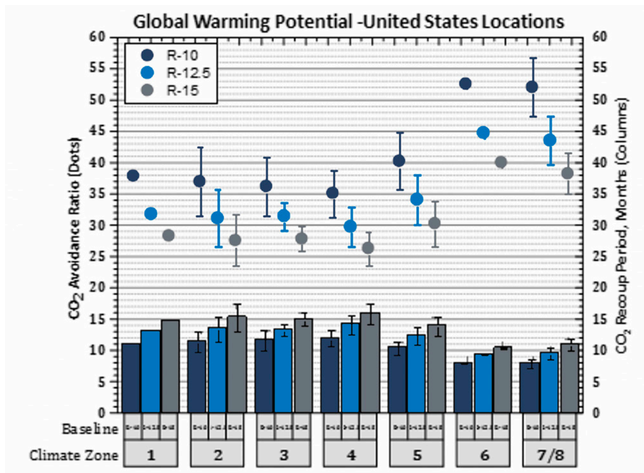

Figure 7.
U.S. Location Results for Global Warming Potential.

Canada Location Summary: See Figure 8 for Canada GWP results noting the CO_2 Avoidance Ratios are represented by the scatter plot and the CO_2 Recoup Periods are represented by the columns. The Roof Replacement thermal performance for the ten (10) Canadian locations for all modelling scenario comparisons is R_{SI}-5.3 (R_{IP}-30). As noted above, Canadian energy codes currently do not include minimum roof insulation requirements other than maintaining the existing R-value levels for a Roof Replacement project. **The results of this examination provide compelling evidence that the implementation of regulations by Canada and its provinces on levels of insulation for alterations to roofs on existing buildings is critical to supporting an aggressive national policy on reducing greenhouse gas emissions.**

Here, the 10 locations are grouped geographically with overlap of climate. Canada consists predominately of cold to very cold climate with regard to commercial building floor space. The results closely follow the trend of increasing Ratios and decreasing Recoup Periods as Heating Degree Days increase. Just two (2) of the thirty (30) scenarios (the R-15 baseline for Windsor and Toronto) registered Ratios below the United States average of 34. The remaining twenty-eight (28) scenarios were greater than thirty-five (35), up to an extraordinary sixty-seven (67) for the R_{SI}-1.8 (R_{IP}-10) baseline for Winnipeg. This scenario shows a CO_2 Recoup period of only six (6) months.

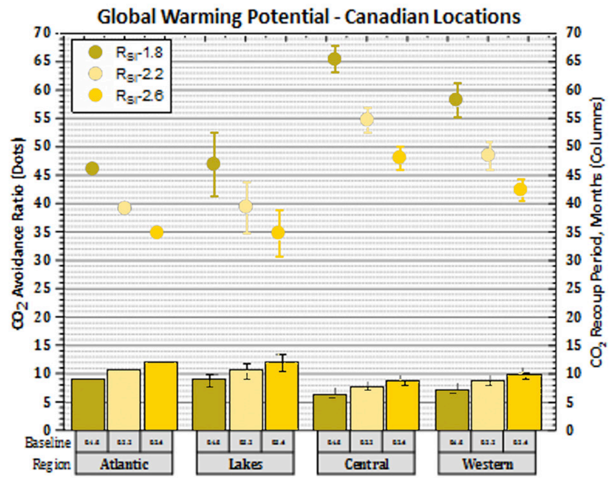

Figure 8.

Canada location results for Global Warming Potential.

Table 22.

Minimum Required Roof Insulation for Roof Replacement and 22 U.S. Locations Modelled by Climate Zone.

Climate Zone 1 - Roof Replacement R-value of R_{IP}-20
Location: Miami, FL
Climate Zone 2 - Roof Replacement R-value of R_{IP}-25
Locations: Tampa, FL; Dallas, TX.
Climate Zone 3 - Roof Replacement R-value of R_{IP}-25
Locations: Montgomery, AL; Atlanta, GA; Charlotte, NC.
Climate Zone 4 - Roof Replacement R-value of R_{IP}-30
Locations: Richmond, VA; Louisville, KY; Philadelphia, PA; New York, NY; Kansas City, KS; Indianapolis, IN.
Climate Zone 5 - Roof Replacement R-value of R_{IP}-30
Locations: Pittsburgh, PA; Hartford, CT; Chicago, IL; Buffalo, NY; Lansing, MI; Madison, WI.
Climate Zone 6 - Roof Replacement R-value of R_{IP}-30
Locations: St. Paul, MN; Rochester, MN.
Climate Zone 7/8 - Roof Replacement R-value of RIP-35
Locations: Duluth, MN; International Falls, MN.
*Locations are listed in increasing value of Heating Degree Day 65°F Basis (HDD65)

Table 23.

10 Canadian Locations Modelled by Region.

Region: Atlantic - Roof Replacement R-value of R_{IP}-30
Location: St. Johns, NB
Region: Great Lakes - Roof Replacement R-value of R_{IP}-30
Locations: Windsor, ONT; Toronto, ONT; Montreal, QB; Ottawa; Quebec City, QB
Region: Central - Roof Replacement R-value of R_{IP}-30
Locations: Regina, SK; Winnipeg, MB
Region: Western - Roof Replacement R-value of R_{IP}-30
Locations: Calgary, AB; Edmonton, AB

REFERENCES & STANDARDS

1. ASHRAE. (2019). Standard 90.1-2019 – Energy Standard for Buildings Except Low-Rise Residential Buildings.
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