2023 Carbon Leadership Forum

North American Material Baselines

CATEGORY APPENDICES v2 | AUGUST 2023

Carbon Leadership Forum

About the Carbon Leadership Forum

The Carbon Leadership Forum, hosted at the University of Washington, accelerates the transformation of the building sector to radically reduce the greenhouse gas emissions attributed to materials, also known as embodied carbon, used in buildings and infrastructure. We research, educate, and foster cross-collaboration to bring the embodied carbon of buildings and infrastructure down to zero.

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A1: GUIDELINES FOR USING THE APPENDICES

Organization

The appendices are organized into nested groups organized by material division. Each material division includes multiple categories, each with its own appendix. Products within one category are often used similarly in construction, made up of similar ingredients, and/or produced using similar processes.

Categories may be further divided into multiple product types. Some appendices include product types grouped by function, such as the Blanket Insulation appendix with functionally similar (but materially different) product types: fiberglass and mineral wool blanket insulations. And some appendices have product types grouped by material ingredients, such as the Structural Steel appendix with materially similar (but functionally different) product types: hot-rolled sections, plate steel, and hollow structural sections.

Because some categories include multiple functionally similar product types (e.g., fiberglass and mineral wool blanket insulation), it may be appropriate for users to draw comparisons between product types within a category. In such cases, the user should do their due diligence to ensure the products are **functionally equivalent** and adhere to the comparability requirements outlined in ISO 21930:2017 Section 5.5 and outlined in Section 7 of the main report.

Functional equivalence

Functional equivalence is necessary for appropriate product-to-product comparisons based on EPD data. Products are considered "functionally equivalent" if they meet an equivalent (but not necessarily identical) level of function or service in the context of a building project. Further, there must be equivalence for such factors as: the quantity of product required, and any impacts outside of the scope of the comparison such as in additional life cycle stages or due to other products in an assembly. See ISO 21930:2017 Section 5.5 Comparability of EPDs for construction products.

Individual Appendix Organization

This section mirrors the structure of a typical appendix in the report (Appendices B - L). It provides context for each section, including what kind of content to expect, what data are included in the analyses, and how to interpret the accompanying tables and figures.

A1.1 Category Overview

Category Description

This section describes the material type, how it is used in construction, and any key ingredients. If the material category is further divided into different product types, those product types and their distinguishing characteristics are listed here.

Production Processes and Key Drivers of Carbon Emissions

This section describes the production processes involved in each life cycle stage of a product. At a minimum, EPDs account for life cycle stages A1-A3, which is also known as a cradle-to-gate system boundary or the *product stage*. Some EPDs include additional life cycle stages beyond the product stage. The stages included in this section's description and in the bar graph below generally align with the scope of the industry-wide EPD(s) for the category.

The stacked bar charts in Figure 2 provide the overall and individual life cycle stage GWP per product type, to the extent that the available data source reports. For many product types, this means a total A1-A3 result broken out by individual stage (A1, A2, and A3), based on the IW-EPD's reported data and as pictured in the example above.

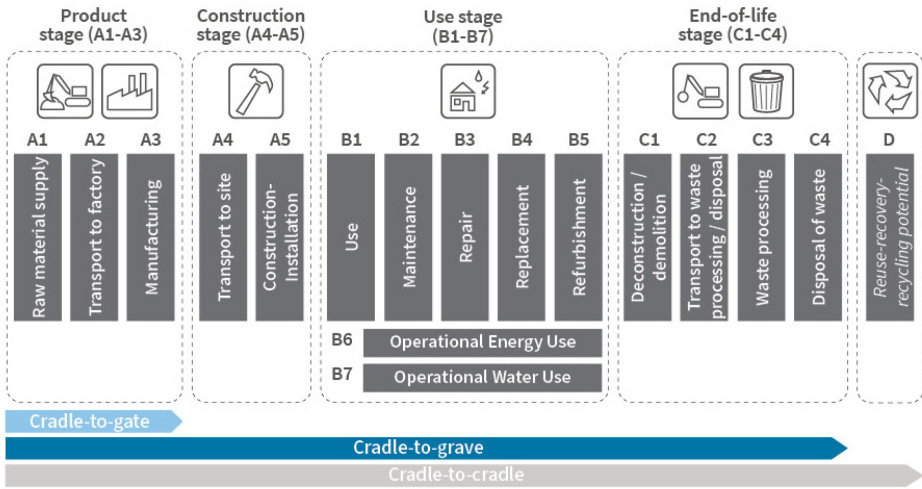


Figure 1. Life cycle stages of building materials in LCA.

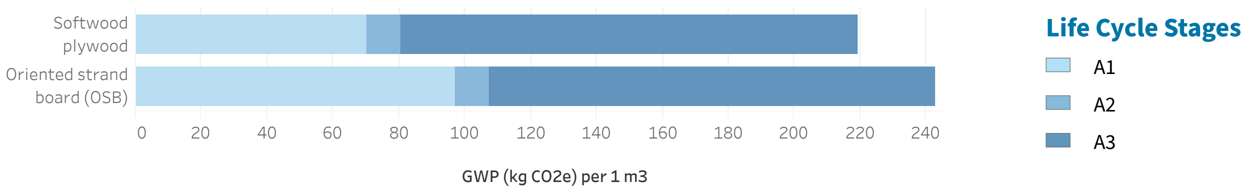


Figure 2. [Example] GWP Contribution by Life Cycle Stage.

Some data sources report the A1:A3 GWP result only as one aggregated value, and in those cases, the individual stages A1, A2, and A3 are not differentiated in the bar charts. Some data sources report results for additional life cycle stages beyond A1-A3, and in those cases, the additional life cycle stages are included in the bar chart.

A1.2 Data Availability and Representativeness

PCR

A primary Product Category Rule (PCR) document is listed for each material category. For North American PCRs, ISO 21930:2017 typically serves as the "core PCR" for developing EPDs for construction products and services.[1] Program operators publish individual category-specific PCRs in accordance with ISO 21930. Some program operators, including UL Environment in North America, publish both a single Part A that applies to all building-related products and services (and is also sometimes referred to as a "core PCR"), and multiple Part B category-specific PCRs. For any UL Environment PCR, the appendix lists only the category-specific Part B PCR (also sometimes referred to as the "sub-category PCR").[2]

Unless otherwise noted, the PCR listed in each appendix represents the current North American PCR used in the creation of North American EPDs for the material category. There are cases where currently valid North American EPDs are based on a different PCR than the one listed. This includes cases where the EPD is based on an obsolete PCR

1. ISO. (2017). *ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services.* International Organization for Standardization (ISO). https://www.iso.org/standard/61694.html

2. UL Environment. (2023). Product category rules (PCRs). https://www.ul.com/services/product-category-rules-pcrs

that has expired and/or been replaced and cases where a North American manufacturer creates an EPD based on an international (non-North-America-specific) PCR.

Industry-wide EPD

This section lists the available North American industry-wide EPD(s) (IW-EPDs) for each product type within the material category. Unless otherwise noted, any IW-EPDs listed in this section are based on the PCR listed above. In some cases, additional IW-EPDs that are not based on the primary PCR may be disclosed and discussed in the “Additional Notes and Guidance” section.

> Under each IW-EPD is a short narrative description of the IW-EPD’s representativeness of the industry. This description is roughly based on ISO 21930:2017’s standards regarding average EPD representativeness. The description may include the number of manufacturing plants included in the EPD, the percentage of total industry production volume used in the IW-EPD’s primary data set, or other relevant information as available in the IW-EPD.

Other Industry Data

This section lists other relevant data, reports, or publications that provide LCA results.

Product EPDs

A count of applicable product EPDs is listed for each material category or product type. “Product EPD” refers here to any EPD that represents products made by a single manufacturer or company. The counts are based on EPD data from the EC3 database, reviewed by CLF staff.[3] Some EPD documents (i.e., published PDFs) contain multiple unique GWP results for different products in a product family, or for different facilities. In the context of this report and in the EC3 tool, one “EPD” corresponds to one unique GWP result. Thus one EPD document may correspond to multiple EPDs in this context. Additionally, in cases where an EPD document reports one average GWP result for a family of similar products, or for multiple facilities within the same company, this is counted here as one EPD.

This report defines “applicable product EPDs” as product EPDs that are valid (as of January 1, 2023), represent products manufactured in North America, are appropriately categorized within the material category or product type, conform to an appropriate PCR (where “appropriate” typically means currently valid and North American), and pass the EC3 quality controls for EPDs (including EPDs with a designated status of “OK” or “W” in the EC3 database).

All EPD counts in this report, particularly the product EPD counts, are from a specific point in time (Fall 2022). EC3 serves as the primary data source for the product EPDs presented and analyzed in this report. Because the EC3 database is constantly changing (as new EPDs are added, older ones expire, and the EC3 team continues to fix bugs and revise performance filters), live EPD counts reflected in the EC3 tool at any given time may not match the EPD counts documented in this report.

3. Building Transparency. (2022). Embodied carbon in construction calculator (EC3) tool. https://buildingtransparency.org/ec3

EC3 status

The EC3 category status serves as one indicator of data quality. For the large majority of material categories in this report, the EC3 status is "public," meaning the category has undergone quality assurance from the EC3 team, has relevant performance filters in place, and is available to all users. For these cases, the status is excluded here. However, if the EC3 status is not "public," we disclose the status here and any notes about what this status means for the quality of the data presented in this report.

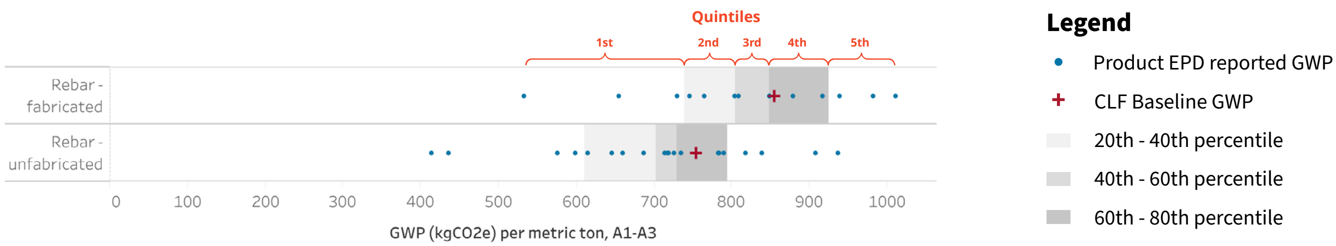


Figure 3. [Example one-dimensional scatter plot] Range of applicable product EPDs and CLF Baselines.

The one-dimensional scatter plot provides a graphical view of all applicable product EPD GWP values and their distribution by quintiles, and the CLF Baseline where applicable. The EPD GWP values are represented as blue dots. Minimum and maximum values are self-evident, and the 20th, 40th, 60th, and 80th percentiles form the boundaries of the shaded boxes. The 20th percentile is the point where approximately 20 percent of the applicable EPDs fall below this GWP (and similarly for the other percentile values). The first quintile is the range from the minimum value to the 20th percentile; the second quintile is the range from the 20th to the 40th percentile, etc.

Complementing the graphical display of these calculated data points for the set of applicable product EPDs (minimum, 20th, 40th, 60th, 80th, and maximum), the following table provides these same points – as well as the product EPD calculated mean and the CLF Baseline – as numerical values. The CLF uses Tableau to calculate percentiles using its default inclusive, interpolated approach.[4,5] The appendix does not include summary statistics for product types with fewer than five applicable product EPDs.

	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
Rebar - fabricated	532	739	804	828	848	925	1010	818	854
Rebar - unfabricated	413	611	702	717	729	795	936	704	753

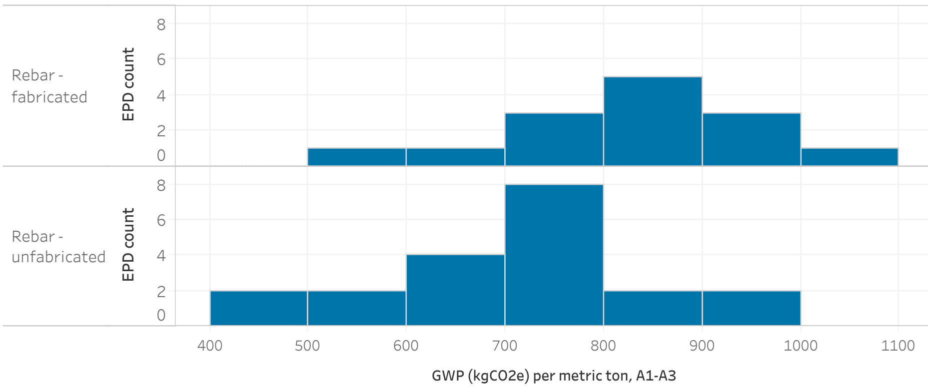
Figure 4. [Example] Summary statistics of product EPDs and CLF Baseline.

The histogram in Figure 5 provides an additional graphical view of the distribution of applicable product EPDs. The CLF set the bin size (i.e., the fixed interval along the horizontal axis that corresponds with one vertical bar) per category with the aim to provide as meaningful a visualization as possible. However, the size and number of bins is a judgment call, and the same data can look quite different depending on the chosen bin size. The appendix does not include histograms for product types with very few EPDs.

Figure 5. [Example histogram] Distribution of applicable product EPDs.

4. Tableau. (2023). Tableau desktop (version 2022.4). Tableau Software, LLC. https://www.tableau.com/products/desktop

5. There are multiple methods to calculate percentiles, which yield different results for a given data set. The differences are more significant for smaller data sets (most of the categories in this report) and further from the median (so more significant for the 20th and 80th than for the 40th and 60th). The following webpage provides a brief description of percentile calculation methods, including the meanings of "inclusive" (as opposed to "exclusive") and "interpolated" (as opposed to "nearest-rank"). Interworks. (2021). Some basics of percentile calculations. https://interworks.com/blog/2021/03/04/using-excel-percentile-functions-in-tableau/



A1.3 CLF Baseline

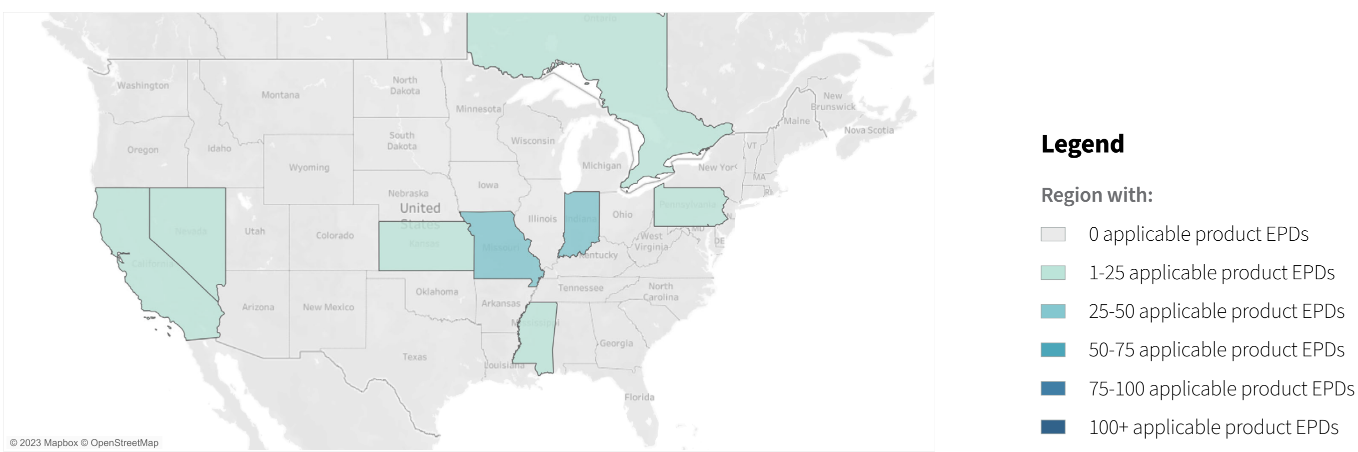
Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Open-web steel joists	1,430	Industry	Steel Joist Institute (SJI). (2022). *Environmental product declaration - Open web steel joists and joist girders.*

Figure 6. [Example] CLF Baselines for the category.

The CLF Baselines table provides the key documentation for the Baselines per product type. This section may include additional notes and documentation, particularly where the CLF used a calculation to arrive at the Baseline GWP value.

A1.4 Additional Notes and Guidance

Figure 7. [Example Map] Count of Product EPDs by location: The counts of available product EPDs are expressed as a range to provide a rough approximation of available data rather than a static count. As much



as possible, the ranges and colors are aligned across appendices to give users a quick sense of which material categories have a lot of applicable product EPDs, and which have only a handful of applicable product EPDs.

Additional notes and guidance may include a discussion of gaps in the data, differences between data availability in North America and other parts of the world, guidelines for interpreting or applying the data provided in the appendix, or other topics as they relate to the specific category.

A2: CHANGES BETWEEN 2021 AND 2023 CLF BASELINES

Major methodology and documentation updates:

Number of Baselines

- The 2021 report displayed a low, median, and high Baseline value, which were intended to give a rough order of magnitude of embodied carbon impacts per category reflecting the significant variability of product manufacturing and uncertainty of LCA data available. Collectively, these values represented the expected range of embodied carbon impacts for most products in their category, taking variability and uncertainty into account.
- The 2023 report simplifies the approach and presents a single Baseline value for each product type that aims to represent the embodied carbon of industry-average North American production per product type. In place of the low and high values, the range of EPD results is evaluated and displayed in the Appendices.

Removed uncertainty:

- The 2021 report utilized EC3's uncertainty-adjusted values, which use a "burden of doubt" approach to assign a percent increase to declared values in the EPDs based on several factors related to the specificity of manufacturer, plant, product, and supply chain data. While this was appropriate for use in the EC3 tool, we found that the report was used by a wide range of users, many of whom wanted to evaluate the declared EPD values without uncertainty included and others who used the baseline data without understanding the nuances of the uncertainty and ranges presented.
- The 2023 report does not use the uncertainty factors anywhere in the report. Since the purpose of the report shifted from reflecting the range of potential results within a product category for use in the EC3 tool to reflecting average North American production within a category, CLF decided to evaluate industry-average EPDs and product EPDs based on declared values without the uncertainty factors applied. **Baseline values in this report are not directly comparable to past reports.**

Declared units match EPDs:

- The 2021 report utilized units reported in the EC3 database. For some materials, these units did not match the declared units required by the PCR.
- The 2023 report matches declared units required in the PCR and reported in EPDs.

Methodology changes:

- The 2021 report used 3 methods to calculate the low/median/high estimates for the embodied carbon range for each product type. These methods used a combination of industry-wide data (if the range of results were reported), averages of groups of product EPDs when more than 20 existed for a category, and a combination of methods when less than 20 product EPDs existed. Refer to the 2021 report for a more detailed description of these methods. Some of the 2021 and earlier baseline methods incorporated uncertainty-adjusted GWP values from the EC3 database.

- The 2023 report used a hierarchy for applying methods. First, the Industry method was used if an industry-wide EPD was available. Second, the Product method was used for collections of product EPDs if and only if that collection of EPDs was determined to be adequately representative of average North American production for that product type. None of the 2023 methods included the uncertainty factors that the EC3 tool adds to EPDs.

Reference to additional life cycle stages:

- The 2021 report did not include information on any additional lifecycle stages except life cycle stage B and C impacts of the blowing agents for foam board and foamed-in-place insulation.
- The 2023 report provides summaries of additional life cycle stages in the appendix of each product type if reported in industry-wide EPDs. However, the appendices generally do not provide details on additional life cycle stages reported in product EPDs for those same product types because the data was not available to the CLF through the data received through EC3. This has been identified as an area of future improvement for the Appendices.

Geographic shift to North American production:

- The 2021 report drew from a combination of data sources representing North American and global (non North–American) production. While the particular data sources were often noted in the citation for each category, this methodological inconsistency weakened the clarity and usability of the document.
- The 2023 report exclusively focuses on North American production and aims to represent the embodied carbon of industry-average North American–manufactured construction materials.

Addition of detailed appendix for each product category:

- The 2021 report did not include any appendices, making it difficult to interpret the results or replicate conclusions.
- The 2023 report provides detailed appendices for each product category. The Appendices include descriptions of the embodied carbon impacts, the available EPDs, and summary statistics.

Categorization:

- The 2021 report generally followed the material categorization scheme in EC3. There were many cases where one set of baseline GWP values (i.e., a low, a typical, and a high baseline value) was assigned to a category that included multiple functionally similar product types. For example, there was one set of 2021 CLF Baselines (a low, a typical, and a high) for "board insulation." This aimed to represent many product types, such as mineral wool board insulation, EPS board insulation, etc.
- The 2023 report defaults to splitting similar product types into separate baseline groups. For example, there are separate 2023 CLF Baseline GWP values for mineral wool board insulation, EPS board insulation, etc.

B1: CONCRETE OVERVIEW

B1.1 Category Overview

This report includes separate appendices for different concrete types, including ready-mixed concrete (Appendix B-2, including normal and lightweight), flowable fill (B-3), shotcrete (B-4), and cement grout (B-5). Different concrete types have different functions and associated performance characteristics. This range in performance characteristics has some correlation to a range of embodied carbon across those concrete types. Figure 1 provides an overview of all the types together and describes the GWP and count of USA concrete product EPDs by concrete type and compressive strength.

The concrete appendices that follow provide detailed information about GWP and EPD counts within the given concrete product types.

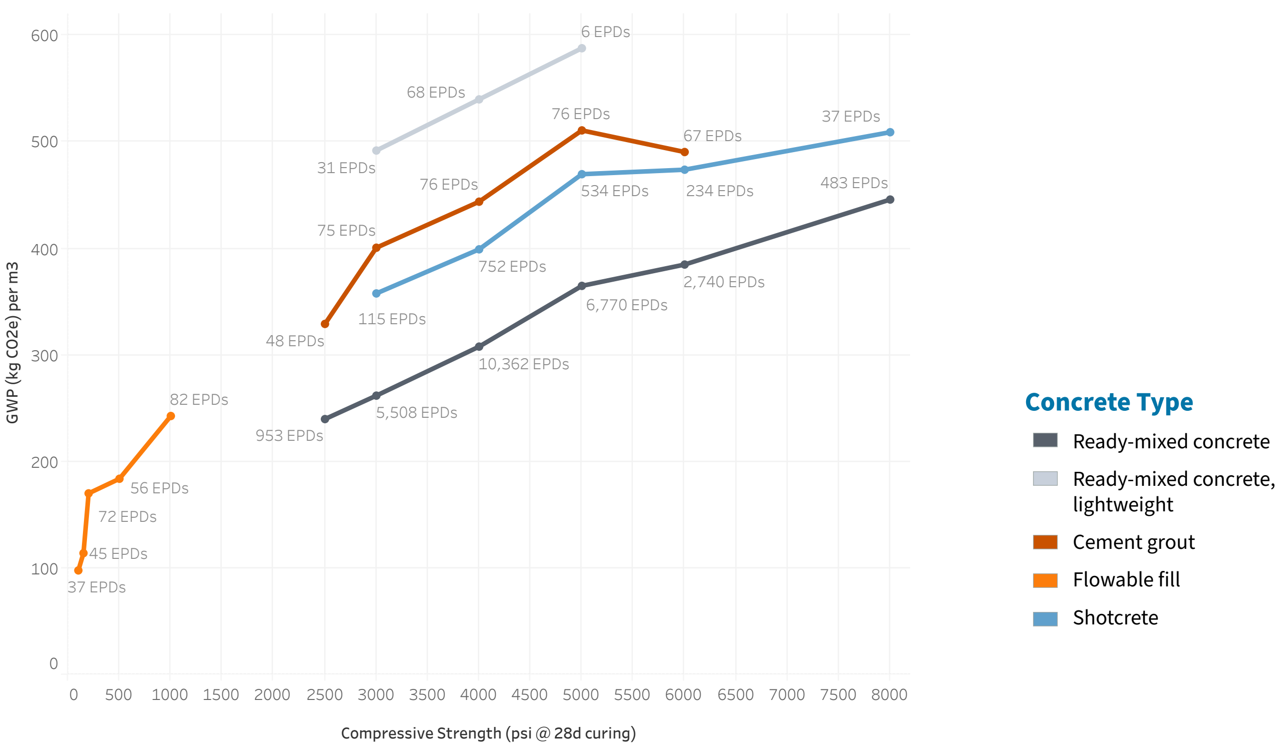


Figure 1. Concrete GWP and EPD count by type and compressive strength. This chart describes USA concrete EPDs. Each type–compressive strength data point (e.g., shotcrete–4000 psi) includes a count of the applicable product EPDs in CLF's data set and the average A1-A3 GWP per m^3 (location along the y-axis).

B2: READY-MIXED CONCRETE

B2.1 Category Overview

Category Description

Ready-mixed concrete (also called ready-mix concrete or RMC) refers to concrete that is ready to pour at job sites. The primary mixing of ingredients may happen at a central batching plant, in a transit truck, or at the site from a volumetric mixer truck. Ready-mix concrete is poured wet into formwork to harden and cure. Each batch of ready-mix concrete is developed to meet a specified compressive strength and other performance criteria. Concrete mixes are often comprised of natural and crushed aggregates, portland cement, supplementary cementitious materials (SCMs), batch water, and admixtures. There are thousands of different concrete mixes designed to balance the cost and performance of concrete for a wide variety of applications, including, but not limited to, building foundations, floor slabs, and retaining walls.[1]

This report identifies ready-mix concrete baselines based on a declared unit of 1 m^3 of ready-mix concrete. Because ready-mix concrete is sourced from local batch plants, data that reflects regional differences in mix designs is extremely important. This appendix provides an overview of the ready-mix concrete, considering all applicable EPDs across all regions. Section B2.5 is made up of many sub-sections, each of which pertains to a specific region in the United States (US) or Canada.

For USA regions, the CLF summarized Baseline values and information about the background data for normal-weight mixes with a range of discrete compressive strengths (2500 psi, 3000 psi, 4000 psi, 5000 psi, 6000 psi, and 8000 psi) and lightweight mixes for compressive strengths of 3000 psi, 4000 psi, and 5000 psi. For Canadian regions, the CLF summarized Baseline values and information about the background data for concrete mixes with and without air added. The range of discrete compressive strengths (reported in mPa) with CLF Baselines varies depending on the specific Canadian region. Guidelines for interpolating GWP based on compressive strengths not identified in this report can be found in Section B2.4 “Additional Notes and Guidance.”

Production Processes and Key Drivers of Carbon Emissions

Ready-mix concrete is commonly comprised of (in order of greatest mass per mix) natural and crushed aggregates, cement, batch water, and other admixtures.[2] The North American industry-wide EPD for ready-mix concrete covers the product stage (A1-A3). A1 includes the extraction, handling, and processing of the raw materials and fuels used in the production of concrete. The raw materials are then transported from the supplier to the concrete plant (A2), where they are further processed into ready-mix concrete (A3). When the primary mixing of concrete happens in the mixer truck, a portion of the fuel used during transport is attributed to the “manufacturing” stage (A3).[1]

At the concrete plant, energy is used to power equipment used to store, move, batch, and mix the raw materials. These processes and others that go into operating the concrete plant contribute to a relatively low proportion of the concrete’s overall emissions.

1. Athena Sustainable Materials Institute (ASMI). (2022). *A Cradle-to-gate life cycle assessment of ready-mixed concrete manufactured by NRMCA members - version 3.2, appendix C: NRMCA member national and regional LCA benchmark (industry average) report - V3.2* (pp. 51–101). National Ready Mixed Concrete Association (NRMCA).

2. National Ready Mixed Concrete Association (NRMCA). (2022). *NRMCA member industry-average EPD for ready mixed concrete.*

The production of portland cement, a key ingredient in concrete, is typically the dominant contributor to concrete emissions. Overall, the upstream supply chain emissions of cement manufacturing can contribute up to 95% of the carbon impacts of a typical concrete mix.[2] The high carbon emissions associated with cement production stem from the burning of fuels used to heat the cement kiln and from the carbon dioxide released in the calcination process (see Appendix B6 Cement, for additional information).[3]

3. NSF International. (2021). *Product category rule for environmental product declarations: PCR for concrete.*

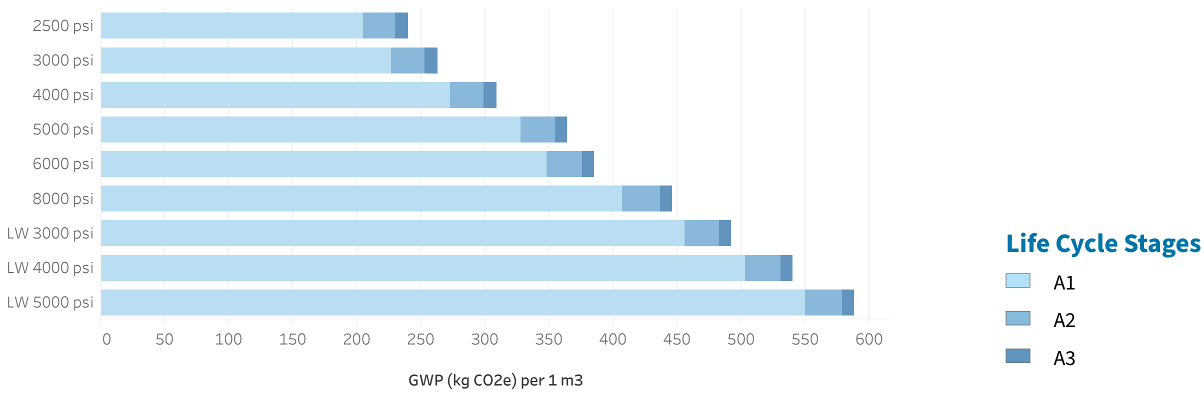


Figure 1. GWP contribution by life cycle stage. This chart is an approximation. Total GWP values are based on the NRMCA USA national benchmark GWP values per 28-day strength class. CLF calculated the approximate industry-average percent contribution by life cycle stage per strength class by averaging the minimum and maximum percent contributions by strength class provided in Table 15 of the NRMCA industry EPD background LCA report.[1]

B2.2 Data Availability and Representativeness

PCR

NSF International. (2021). *Product category rule for environmental product declarations: PCR for concrete.*

Industry-wide EPDs - USA

National Ready Mixed Concrete Association (NRMCA). (2022). *NRMCA member industry-average EPD for ready mixed concrete.*

> This IW-EPD covers 72 ready mixed concrete products (six normal weight compressive strength ranges and three lightweight compressive strength ranges, with eight mix designs for each) representing national (USA) average mix designs and their environmental impacts. A total of 1961 plants were deemed eligible to be covered by the EPD. In total, 489 facilities provided data that are used in this EPD. Based on a sample size of 489 plants and a total population of 1961 plants the margin of error was calculated to be 4.29%. The sample size represents approximately 6% of all US RMC plants (8,000) and 8% of NRMCA members' RMC plants (6,000).

Athena Sustainable Materials Institute. (2022). *A Cradle-to-gate life cycle assessment of ready-mixed concrete manufactured by NRMCA members - version 3.2, appendix C: NRMCA member national and regional LCA benchmark (industry average) report - V3.2* (pp. 51–101). National Ready Mixed Concrete Association (NRMCA).

This background LCA report to the industry EPD provides (USA) national and regional benchmarks for discrete compressive strengths of ready-mixed concrete. Because ready-mixed concrete is sourced from local batch plants, data that reflects regional differences in mix designs is extremely important. Additionally, linking discrete compressive strengths (rather than ranges of compressive strengths) to environmental impacts allows users to estimate the impacts of their ready-mixed concrete more accurately. For these reasons, **the CLF Baseline values for regions within the USA are based on the Industry Average U.S. regional benchmark values provided in Appendix C of the NRMCA Member National and Regional LCA Benchmark Report.**

Region	Pacific South-west	Pacific North-west	Rocky Mountain	South Central	North Central	South-east	Great Lake	East
Number of Plants	51	32	22	91	28	131	69	65

Figure 2. Number of plants used in NRMCA benchmark report study by region. See Figure 8 for a map of regions and corresponding appendix sections. The 2023 CLF Baselines for USA ready-mixed concrete are based on the NRMCA national and regional benchmark values.

Industry EPDs – Canada by region

Concrete BC. (2022). *Concrete BC member industry-wide EPD for ready-mixed concrete.* ASTM International.

Concrete Alberta. (2022). *Concrete Alberta member industry-wide EPD for ready-mixed concrete.* ASTM International.

Concrete Saskatchewan. (2022). *Member industry-wide EPD for ready-mixed concrete.* ASTM International.

Concrete Manitoba. (2022). *Concrete Manitoba Member industry-wide EPD for ready-mixed concrete.* ASTM International.

Concrete Ontario. (2022). C*oncrete Ontario Member industry-wide EPD for ready-mixed concrete.* ASTM International.

Association béton Québec. (2022). *Association beton Quebec (ABQ) Member industry-wide EPD for ready-mixed concrete.* ASTM International.

Atlantic Concrete Association. (2022). *Atlantic Concrete Member industry-wide EPD for ready-mixed concrete.* ASTM International.

These Canadian regional industry-wide EPD documents include baseline GWP values for a range of mix designs and compressive strengths. Figure 5 provides for each region the number of plants and that number as a percentage of total member plants used in the study. Table B2.3.2 describes the compressive strength values studied in each regional industry EPD document.

Region	British Columbia	Alberta	Saskatch-ewan	Manitoba	Ontario	Quebec	Atlantic
Number of plants	24	25	15	13	80	27	22
% of total member plants	21	20	28	21	30	21	21

Figure 3. Number of plants and proportion of total member plants used in Canadian IW-EPDs. See Figure 8 for a map of regions and corresponding appendix sections.

Product EPDs: See Section B2.5 "Product EPD Data by Region."

B2.3 CLF Baselines

The 2023 CLF Baselines for ready-mixed concrete are specified at the regional level. The USA regional and national values are from the NRMCA member national and regional LCA benchmark (industry average) report - V3.2.[1] The Canadian values are from the seven Canadian industry-wide EPD documents outlined above.

	2500 psi (17.2 Mpa)	3000 psi (20.7 MPa)	4000 psi (27.6 MPa)	5000 psi (34.5 MPa)	6000 psi (41.4 MPa)	8000 psi (55.1 MPa)	LW 3000 psi (20.7 MPa)	LW 4000 psi (27.6 MPa)	LW 5000 psi (34.5 MPa)
Pacific Southwest	257	279	323	378	401	456	500	546	594
Pacific Northwest	235	261	316	386	408	487	518	575	632
Rocky Mountains	232	255	301	358	379	440	484	532	580
South Central	226	245	286	336	356	409	468	510	555
North Central	241	264	312	372	394	460	487	537	591
Southeastern	247	268	309	360	382	435	478	521	562
Great Lakes	232	255	303	363	383	452	499	551	603
Eastern	240	264	314	378	399	472	517	573	628
National	240	262	308	365	385	446	492	540	588

Figure 4. CLF Baseline for ready-mix concrete by USA region (kg CO_2e/m^3).

	15 MPa	20 MPa	25 MPa	30 MPa	32 MPa	35 MPa	40 MPa	45 MPa	50 MPa	55 MPa	60 MPa	70 MPa	80 MPa
British Columbia													
GWP	--	193.86	230.52	269.83	285.31	310.51	344.04	355.65	345.16	402.11	421.88	--	--
Mix with AEAs	--	(N) GU 20 SCM	(F-2) GU 20 SCM	(F-2) GU 20 SCM	(C-2) GU 20 SCM	(F-2) GU 20 SCM	(C-1) GU 20 SCM	(C-1) GU 25 SCM	(C-XL) GU 30 SCM	(C-XL) GU 25 SCM	(C-1) GU 25 SCM	--	--
GWP	179.42	194.73	219.7	258.92	272.44	293.75	329	335.06	359.49	376.56	400.43	--	--
Mix without AEAs	(N) GU 30 SCM	(N) GU 20 SCM	(N) GU 20 SCM	(N) GU 20 SCM	(N) GU 20 SCM	(N) GU 20 SCM	(N) GU 20 SCM	(N) GU 25 SCM	(N) GU 25 SCM	(N) GU 25 SCM	(N) GU 25 SCM	--	-
Alberta													
GWP	--	273.04	318.42	368.87	396.85	409.82	426.88	464.66	488.29	466.27	--	--	--
Mix with AEAs	--	GU/HS 10 FA	GU/HS 10 FA	GU/HS 10 FA	0.45 W/CM ratio; (C-2) GU	GU/HS 15 FA	GU/HS 15 F	GU/HS 15 FA	GU/HS 15 FA	GU/HS 15 FA	--	--	--
GWP	--	260.95	306.32	334.47	313.61	328.02	418.44	--	447.4	--	--	--	--
Mix without AEAs	--	GU/HS 10 FA	0.55 W/CM ratio; (N-CF) GU/HS 10	GU/HS 10 FA	(S-2) GU	(S-1) GU	GU/HS 15 FA	--	GU/HS 15 FA	--	--	--	--
Saskatchewan													
GWP	--	--	312.83	346.17	379.55	417.21	441.57	473.78	--	--	--	--	--
Mix with AEAs	--	--	GU 15 FA	GU 15 FA	0.45 W/CM (C-2) GU 15 FA	GU 15 FA	GU 15 FA	GU 15 FA	--	--	--	--	--
GWP	--	--	296.06	317.39	338.27	358.43	414.04	458.41	--	--	--	--	--
Mix without AEAs	--	--	GU 15 FA	GU 15 FA	GU 15 FA	GU 15 FA	GU 15 FA	GU 15 FA	--	--	--	--	--
Manitoba													
GWP	--	203.52	229.86	252.54	277.07	297.58	308.87	361.69	395.93	--	--	--	--
Mix with AEAs	--	GU 20 FA	GU 20 FA	GU 20 FA	0.45 W/CM (C-2, S-2) GU 20 FA	GU 20 FA	GU 20 FA	GU 20 FA	GU 20 FA	--	--	--	--
GWP	--	202.25	223.41	245.92	--	268.42	289.75	333.45	367.01	--	--	--	--
Mix without AEAs	--	GU 20 FA	GU 20 FA	GU 20 FA	--	GU 20 FA	GU 20 FA	GU 20 FA	GU 20 FA	--	--	--	--
Ontario													
GWP	--	227.16	260.64	292.72	326.46	334.49	361.65	379.45	456.93	--	--	--	--
Mix with AEAs	--	0.70 W/CM GU 10 SL	0.55 W/CM (F-2) GU 10 SL	0.50 W/CM (F-1) GU 15 SL	0.45 W/CM (C-2) GU 10 SL	GU 15 SL	GU 15 SL	GU 15 SL	GUbSF 20 SL	--	--	--	--
GWP	--	220.29	254.05	264.38	264.38	295.46	326.25	349.88	335.76	354.67	361.25	354.42	--
Mix without AEAs	--	GU 10 SL	GU 10 SL	GU 15 SL	GU 15 SL	GU 15 SL	GU 15 SL	GU 15 SL	GUbSF 20 SL	GUbSF 20 SL	GUbSF 20 SL	GUbSF 25 SL	--
Quebec													
GWP	--	278.1	298.87	342.52	362.8	393.24	396.62	413.72	410.8	--	444.71	--	--
Mix with AEAs	--	--	(F-2)	(F-1)	0.45 W/CM (C-2)	(C-2) and lower	(C-1)	(C-1)	(C-1)	--	(C-1)	--	--
GWP	--	263.8	287.42	307.09	--	345.4	364.24	381.16	404.38	--	424.74	--	485.72
Mix without AEAs	--	(N)	(N)	0.55 W/CM (N-CF/C-4)		(N)	(N)	(N)	(N)	--	(N)	--	(N)
Atlantic													
GWP	--	343.96	360.99	394.38	438.78	447.25	474.19	528.55	551.01	--	--	--	--
Mix with AEAs	--	GU 10 FA	GU 10 FA	GU 10 FA	0.45 W/CM (C-2) GU 10 FA	GU 10 FA	GU 10 FA	GU 10 FA	GU 10 FA	--	GU 10 FA	--	--
GWP	--	336.63	354.02	379.12	--	422.25	449.16	501.86	536.01	--	580.21	--	--
Mix without AEAs	--	GU 10 FA	GU 10 FA	GU 10 FA	--	GU 10 FA	GU 10 FA	GU 10 FA	GU 10 FA	--	GU 10 FA	--	--

Figure 5. CLF Baseline for ready-mix concrete by Canadian region (kg CO_2e/m^3). Regional Canadian industry–wide EPDs serve as the sources for the CLF Baselines below. For each compressive strength (MPa) of ready-mix, the IW-EPD highlights one or more average concrete mix designs for that strength. Where available, CLF included baseline values for one mix with air-entraining admixtures (AEAs) and one without. AEAs are often used to increase the durability of concrete in areas with freeze-thaw conditions. This table provides the basic mix design description (as documented in the industry EPD) for each GWP value presented. For specific details on the components of the selected mix design, refer to the industry-wide EPDs.

B2.4 Additional Notes and Guidance

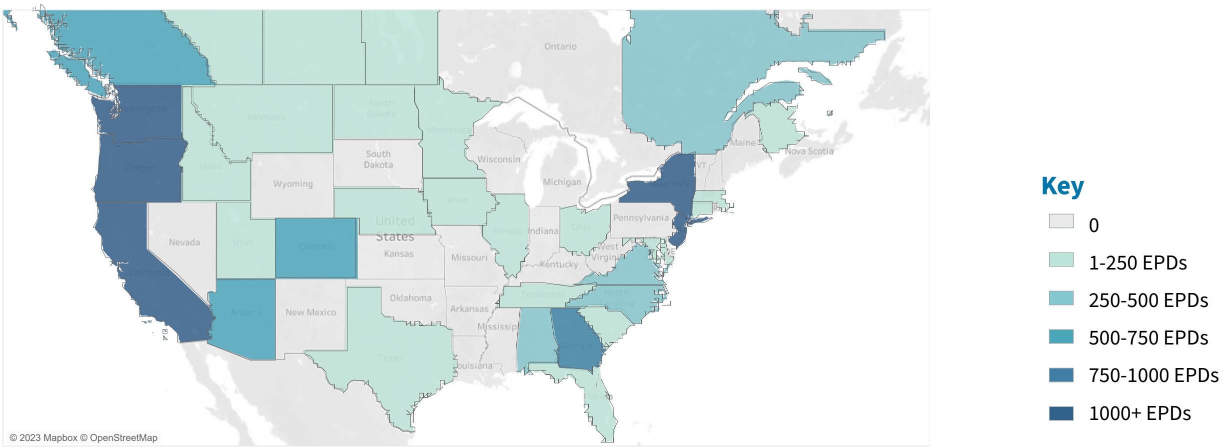


Figure 6. Product EPDs by location. The estimated counts include applicable EPDs across all North American ready-mix designs, weights, and strengths.

Discrete Strengths

Based on stakeholder recommendations and to align with the NRMCA's National and Regional LCA Benchmark (Industry Average) Report, the 2023 CLF North American Material Baselines includes one GWP baseline for each discrete compressive strength included in the NRMCA report (2500 psi, 3000 psi, 4000 psi, 5000 psi, 6000 psi, 8000 psi, 3000 psi (LW), 4000 psi (LW), 5000 psi (LW)) for USA regions.[1] This appendix also provides guidance for interpolating between these discrete compressive strength values (e.g., between 3000 psi and 4000 psi) in order to satisfy the need of mapping any given concrete mix (e.g., one at 3500 psi) to a Baseline GWP value. (See "Interpolation," below.) Guidance to extrapolate outside of this overall range (i.e., below 2500 psi or above 8000 psi) is not provided at this time.

Interpolation

The method described below allows users to interpolate GWP values for ready-mix concrete that falls between two adjacent compressive strengths identified for each region. Though the example below is based on USA industry-average data for normal weight mix designs, the same method could be applied to data representing different regions and ready-mix weights.

To interpolate between any two adjacent compressive strengths, users can generate an equation for a straight line that connects the industry-average values for each discrete compressive strength.

The line shall follow the format: $y = mx + b$,

Where, y = estimated GWP (kg CO_2e/m^3)

> m = the slope of the line, which represents the estimated change in GWP for each corresponding change in compressive strength

x = the desired compressive strength for which the user wants to estimate the GWP

b = the point where the line for interpolation intersects the y-axis.

In this equation, “y” will be the output, “x” will be a user-provided input, and the user will need to calculate “m” and “b.” The “m” and “b” values will need to be recalculated whenever the user wants to interpolate between a different set of adjacent compressive strength values. To calculate “m,” users would divide the difference in GWP between two adjacent compressive strengths by the difference between the compressive strengths, see Figure 7 below for sample “m” calculations for interpolating between the compressive strengths.

Compressive strength at 28d	**2500 psi**	**3000 psi**	**4000 psi**	**5000 psi**	**6000 psi**	**8000 psi**
GWP (kgCO2e/m^3)	240	262	308	365	385	446

	262 -240	308 -262	365 -308	385 -365	446 -385
Change in GWP (Δ_{GWP})	*22*	*46*	*57*	*20*	*61*
Change in psi (Δ_{psi})	*500*	*1000*	*1000*	*1000*	*2000*
“m” (Δ_{GWP} / Δ_{psi})	*0.044*	*0.046*	*0.057*	*0.020*	*0.031*

Figure 7. USA national average mix design GWP by compressive strength with interpolation variables. The GWP values have been rounded to the nearest whole number to simplify the sample calculations.[1]

To take a more specific example, if a user wanted to find the equation for a line that would allow them to interpolate between 5000 and 6000 psi concrete, they would take the following steps:

- Plug the “m” value (calculated based on the steps above) into the standard equation for a straight line: y = 0.02x + b
- Plug a known (x, y) coordinate into the equation and solve for “b.” In this example, the user knows that the industry-average GWP for a 5000 psi mix is 365 kg CO_2e/m^3. Their coordinates then are (5000, 365): 365 = 0.02 x 5000 + b. If they then solve the equation, they find their y-intercept or “b” to be 265.
- Rewrite the equation based on the calculated slope and y-intercept values: y = 0.02x + 265.

This sample equation can now be used to calculate the GWP for any compressive strength that falls between 5000 and 6000 psi, where x is your specified strength mix. For example, if x = 5500 psi, then y = (0.02)(5500)+265, where y = 375 kg CO_2e/m^3.

Concrete Carbonation

Within LCA modeling practice, the treatment of carbon dioxide utilization through active or passive carbonation has received increased attention due to its potential to offset some of the emissions associated with cement manufacturing. Carbonation is a mineralization pathway in which atmospheric CO_2 can react with hydrated cement, permanently storing CO_2 within cementitious materials.[4] The data sources used in the creation of the 2023 CLF Baselines do not account for concrete carbonation. Concrete manufacturers may choose to report the carbonation of concrete voluntarily in the "Additional Information" section of EPDs. Carbonation in ready-mix concrete can occur slowly and is highly dependent on exposed surface area and climate conditions. This is an active area of research.

B2.5 Product EPD Data by Region

This section provides product EPD data by region in the USA and Canada. Figure 8 identifies the regions and their corresponding sub-sections in this appendix. Each sub-section by region includes the count of **applicable product EPDs*** for that region, a scatter plot of applicable EPDs per strength class, and a summary statistics table. The summary statistics tables include data for strength classes with five or more product EPDs.

> *Applicable EPDs are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs. Because there are so many ready-mixed concrete product EPDs, the CLF's review of EC3 data for this category was relatively coarse, not as exhaustive as the CLF's review of most of the categories with relatively few EPDs.

4. IVL Swedish Environmental Research Institute. (2021, June 29). *Carbonation of concrete.* Retrieved February 9, 2023, from https://www.ivl.se/projektwebbar/co2-concrete-uptake/carbonation-of-concrete.html

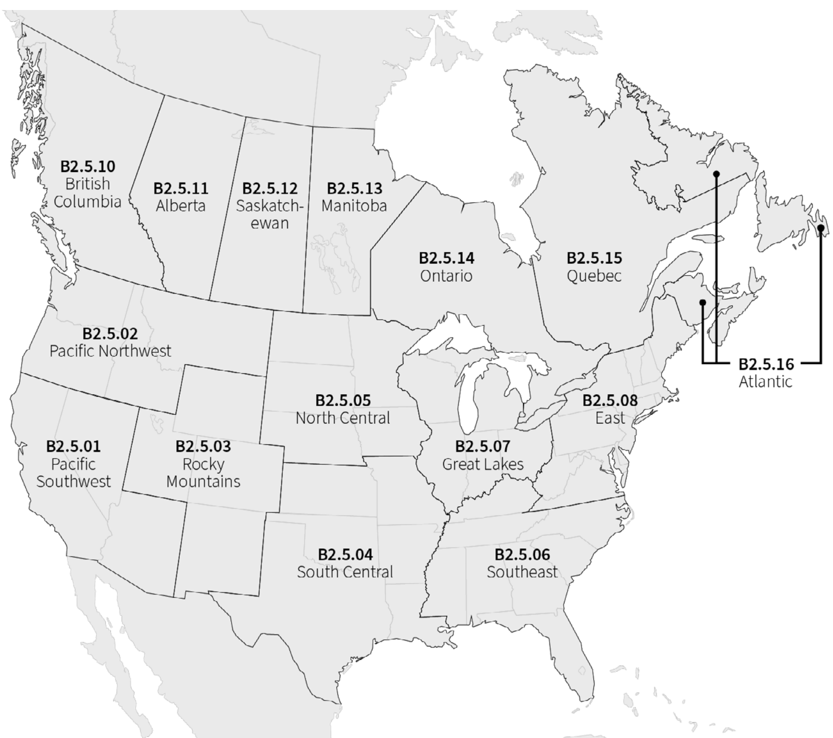


Figure 8. North American regions for ready-mix concrete. The designated regions are based on USA regions set in the LCA Benchmark (Industry Average) Report by NRMCA and the corresponding industry-wide EPDs for Canadian regions. The bolded text labels refer to the relevant appendix sections in this document.[1]

B2.5.00 United States, National

Number of applicable product EPDs: 36,609

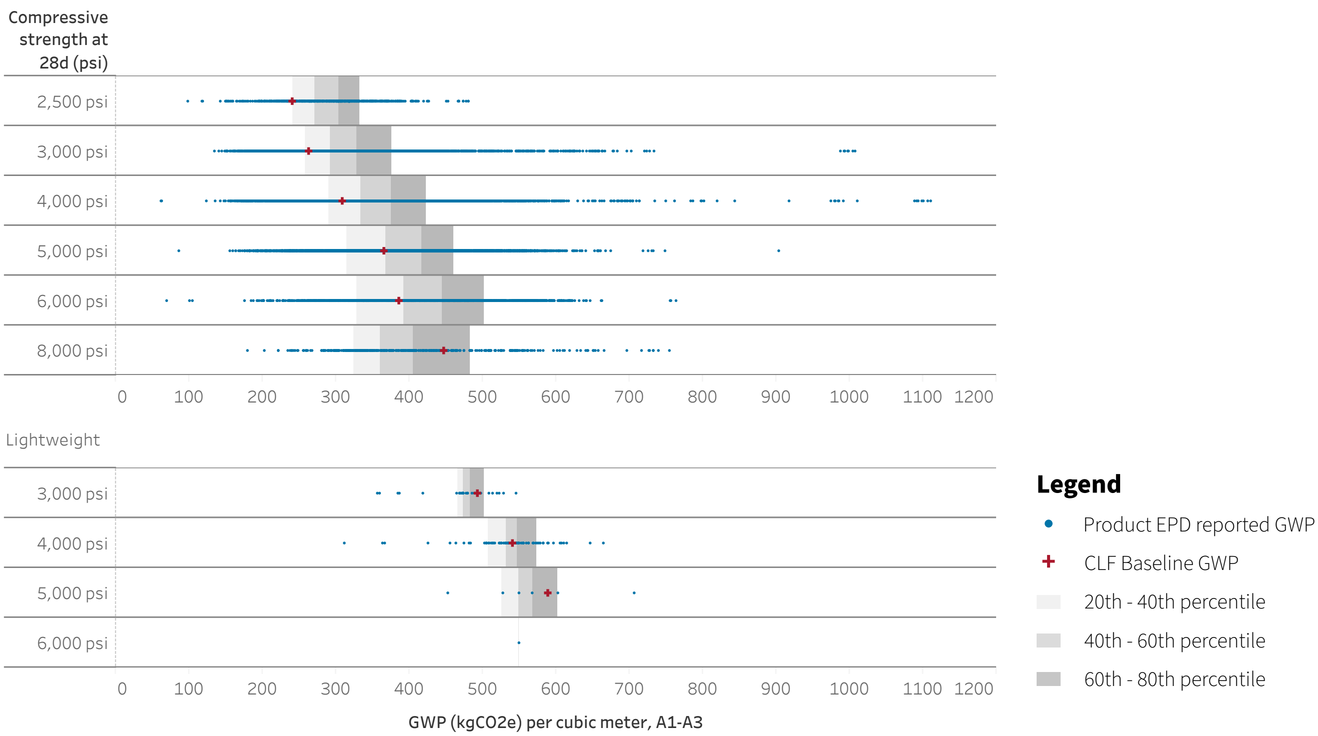


Figure 9. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
2,500 psi	98	241	272	291	304	331	480	289	240
3,000 psi	134	258	292	310	328	375	1,007	320	262
4,000 psi	61	291	334	356	375	422	1,110	359	308
5,000 psi	86	315	367	391	417	460	903	390	365
6,000 psi	69	329	392	418	445	502	763	418	385
8,000 psi	179	324	361	389	406	483	754	404	446
Lightweight									
3,000 psi	356	466	473	477	484	501	545	471	492
4,000 psi	311	508	532	544	548	574	664	535	540
5,000 psi	452	527	549	558	567	602	706	567	588

Figure 10. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.01 United States, Pacific Southwest

Number of applicable product EPDs: 19,333

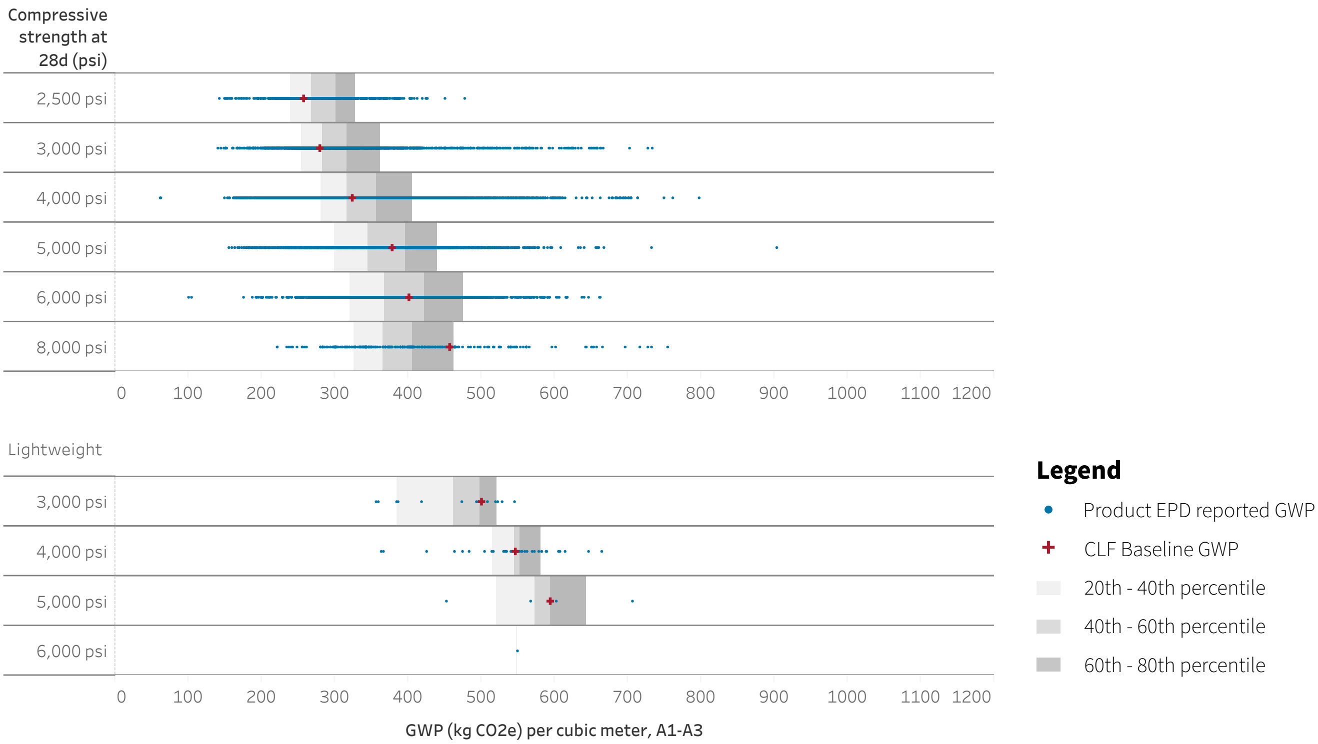


Figure 11. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
2,500 psi	142	239	267	284	303	329	477	285	257
3,000 psi	140	254	283	302	317	363	733	314	279
4,000 psi	61	281	317	338	357	406	797	344	323
5,000 psi	155	300	346	371	397	439	903	370	378
6,000 psi	100	320	368	393	423	475	662	396	401
8,000 psi	221	326	366	391	405	462	754	401	456
Lightweight									
3,000 psi	356	385	462	493	498	521	545	461	500
4,000 psi	363	516	545	548	552	582	664	542	546
5,000 psi	452	521	574	585	595	644	706	582	594

Figure 12. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.02 United States, Pacific Northwest

Number of applicable product EPDs: 4,650

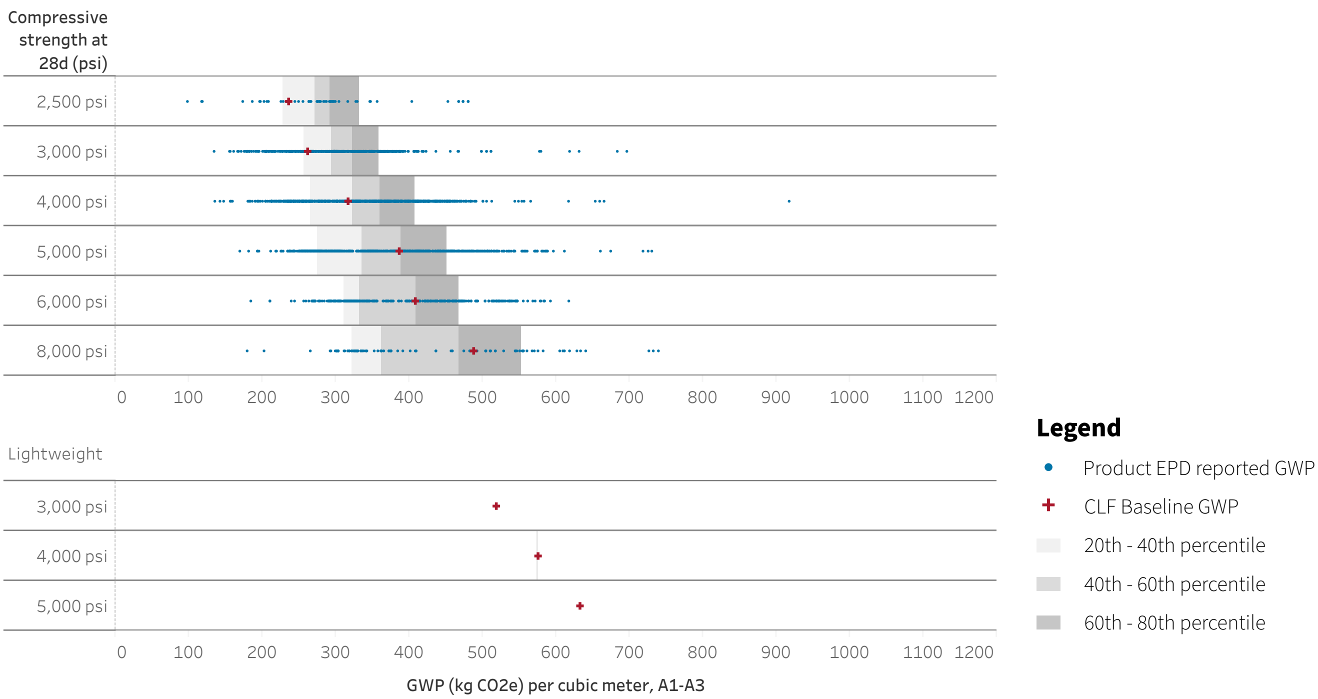


Figure 13. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
2,500 psi	98	227	271	279	292	332	480	288	235
3,000 psi	134	256	295	303	323	358	696	307	261
4,000 psi	135	266	323	341	360	408	917	340	316
5,000 psi	169	275	335	358	389	450	730	367	386
6,000 psi	184	311	332	356	410	467	617	386	408
8,000 psi	179	322	361	388	468	553	739	430	487

Figure 14. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.03 United States, Rocky Mountains

Number of applicable product EPDs: 719

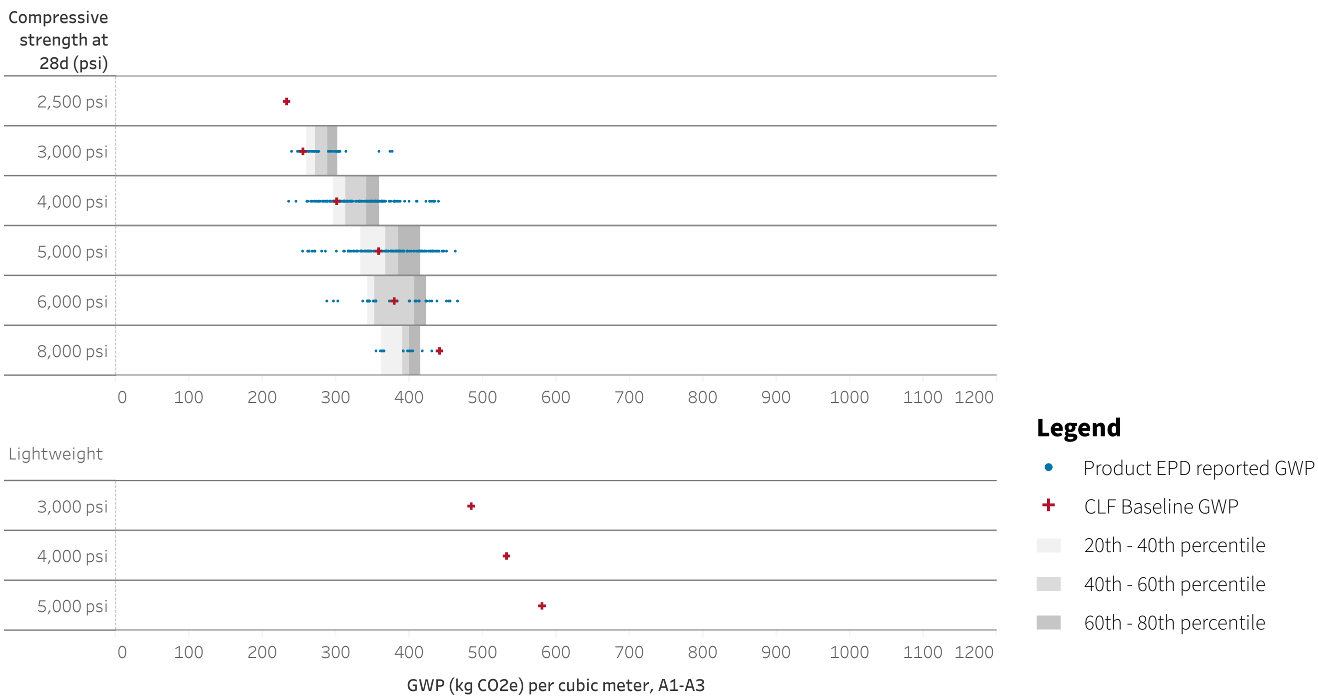


Figure 15. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
3,000 psi	239	261	271	274	289	301	376	284	255
4,000 psi	235	297	314	327	341	359	439	329	301
5,000 psi	254	334	368	380	386	416	462	373	358
6,000 psi	287	344	353	378	407	423	465	381	379
8,000 psi	354	362	391	397	400	414	441	393	440

Figure 16. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.04 United States, South Central

Number of applicable product EPDs: 229

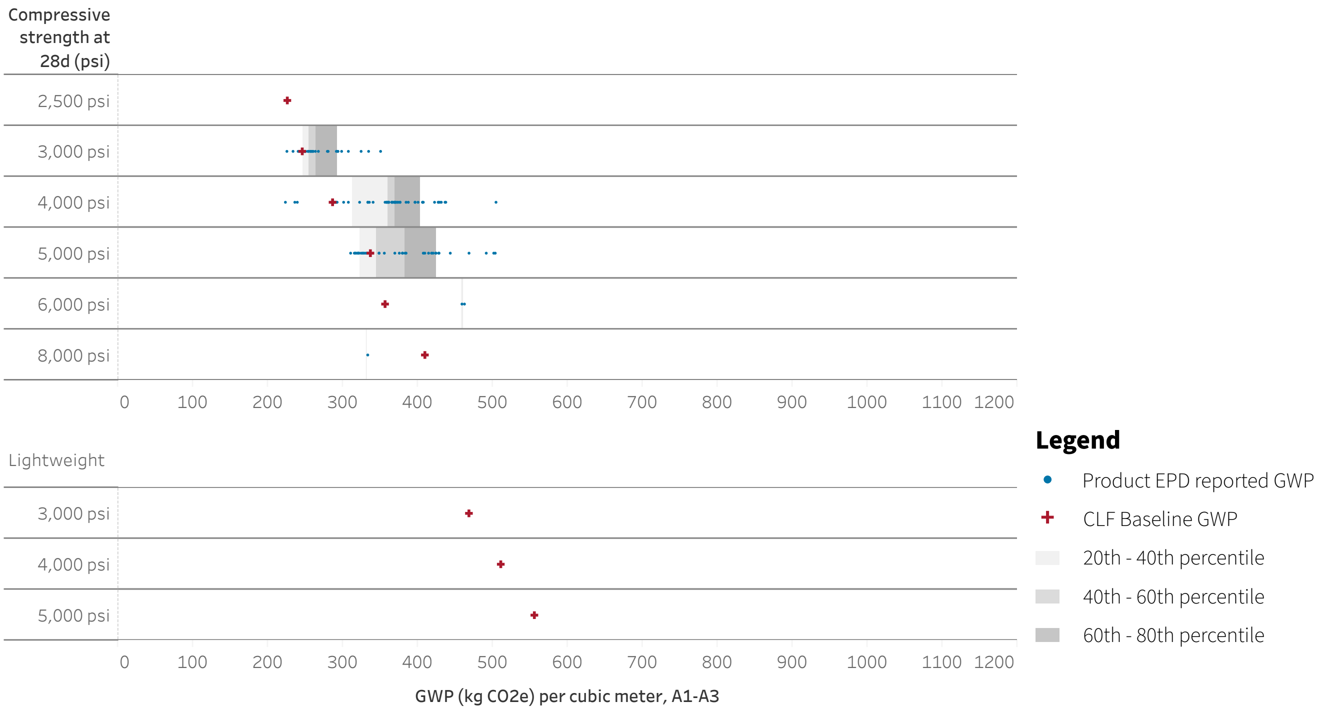


Figure 17. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
3,000 psi	225	248	256	259	264	293	350	270	245
4,000 psi	223	313	361	367	370	404	504	360	286
5,000 psi	310	322	346	372	383	424	503	377	336
6,000 psi	459	459	460	460	461	461	462	460	356
8,000 psi	333	333	333	333	333	333	333	333	409

Figure 18. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.05 United States, North Central

Number of applicable product EPDs: 654

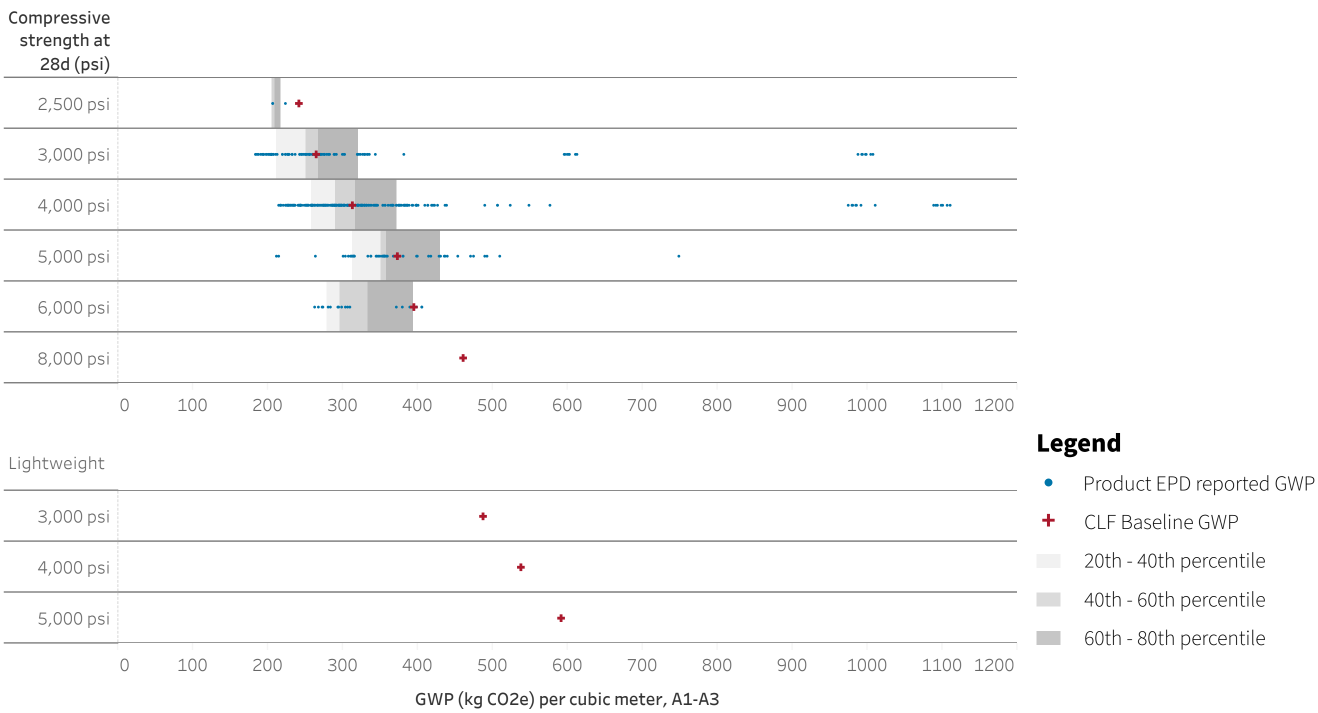


Figure 19. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
3,000 psi	183	210	251	262	268	321	1,007	316	264
4,000 psi	214	259	291	301	316	371	1,110	344	312
5,000 psi	211	314	350	355	359	430	748	372	372
6,000 psi	262	279	296	305	334	394	405	329	394

Figure 20. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.06 United States, Southeastern

Number of applicable product EPDs: 1,843

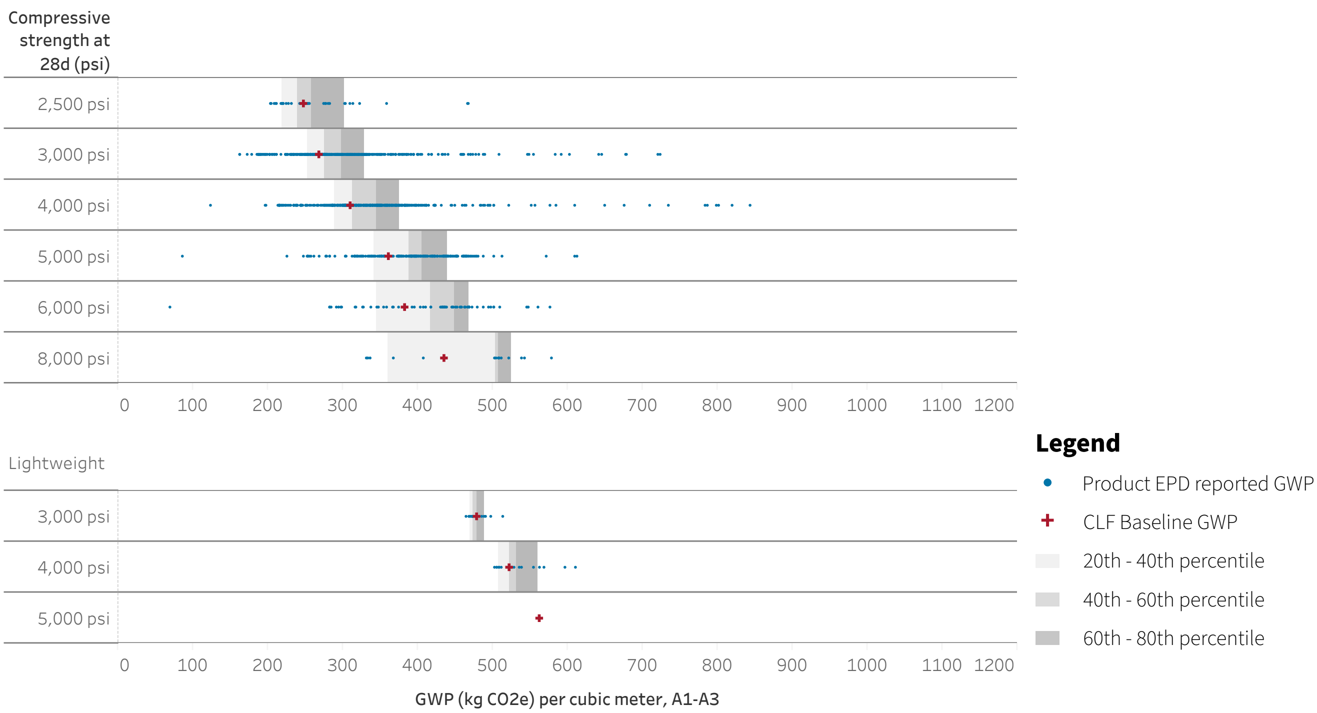


Figure 21. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
2,500 psi	203	218	240	250	259	303	467	266	247
3,000 psi	162	253	275	284	298	329	723	299	268
4,000 psi	123	289	314	331	345	375	843	341	309
5,000 psi	86	342	389	396	405	439	612	391	360
6,000 psi	69	345	417	435	449	468	576	415	382
8,000 psi	331	361	503	507	508	524	578	466	435
Lightweight									
3,000 psi	464	470	473	475	479	488	513	479	478
4,000 psi	502	508	522	525	532	560	610	535	521

Figure 22. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.07 United States, Great Lakes

Number of applicable product EPDs: 189

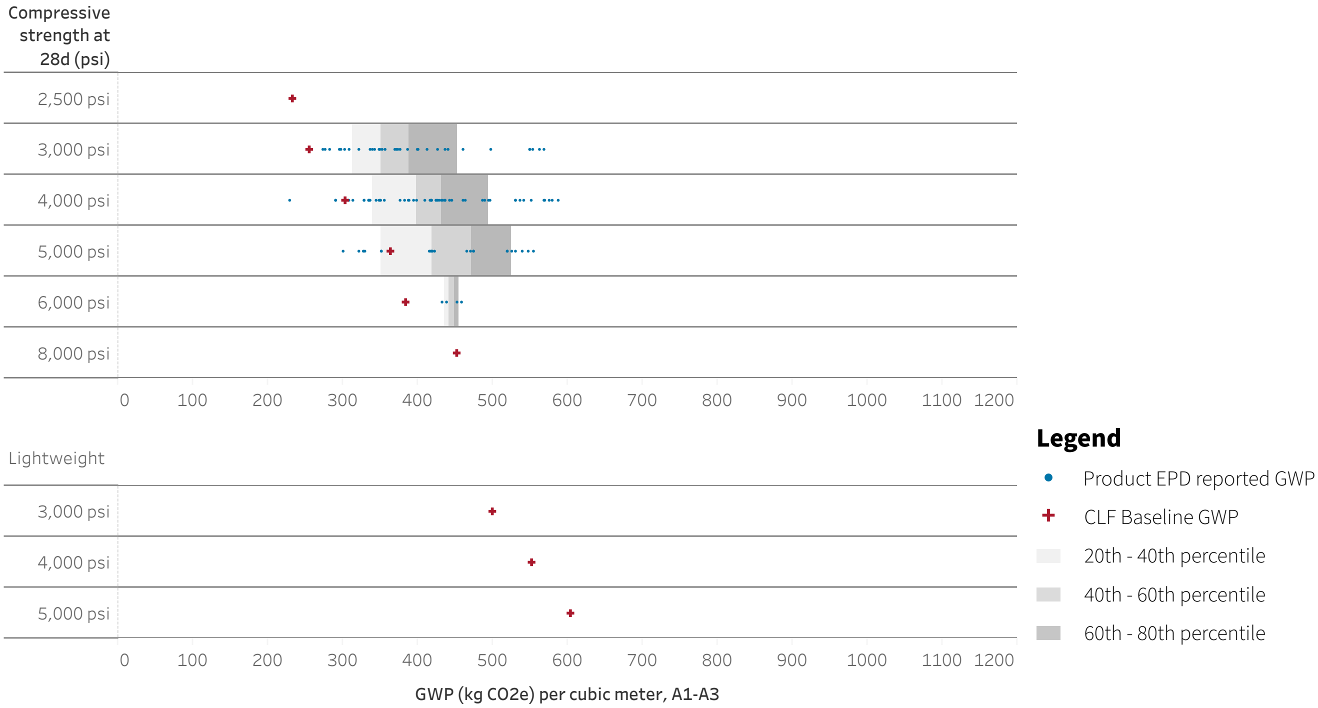


Figure 23. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
3,000 psi	273	313	351	371	389	452	568	391	255
4,000 psi	229	339	397	418	431	495	587	422	303
5,000 psi	300	351	418	444	472	524	554	440	363

Figure 24. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.08 United States, Eastern

Number of applicable product EPDs: 8,992

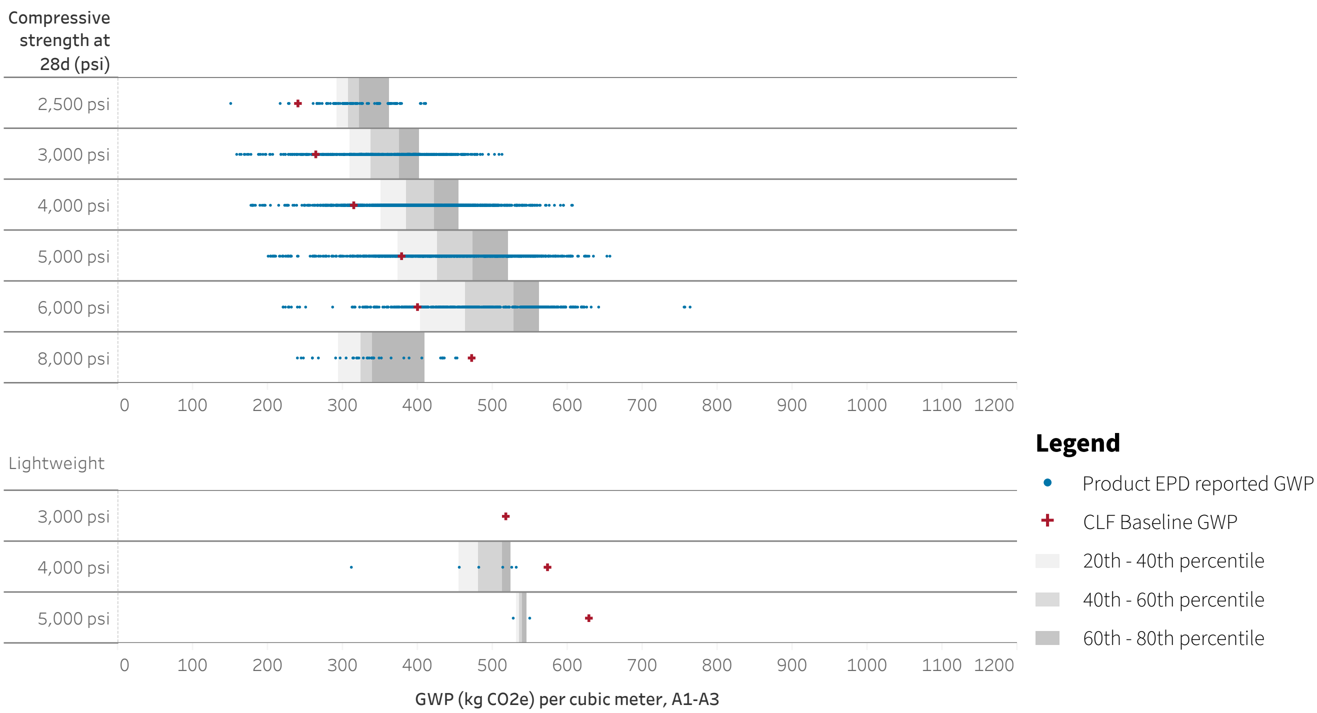


Figure 25. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
2,500 psi	150	293	307	313	323	362	410	322	240
3,000 psi	158	309	337	353	375	402	512	354	264
4,000 psi	177	351	385	403	423	455	606	402	314
5,000 psi	200	373	427	448	474	520	656	446	378
6,000 psi	220	403	465	491	529	563	763	486	399
8,000 psi	239	295	325	335	340	410	452	342	472
Lightweight									
4,000 psi	311	455	481	497	513	525	531	469	573
5,000 psi	527	531	536	538	540	545	549	538	628

Figure 26. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3).

B2.5.10 Canada, British Columbia

Number of applicable product EPDs: 541

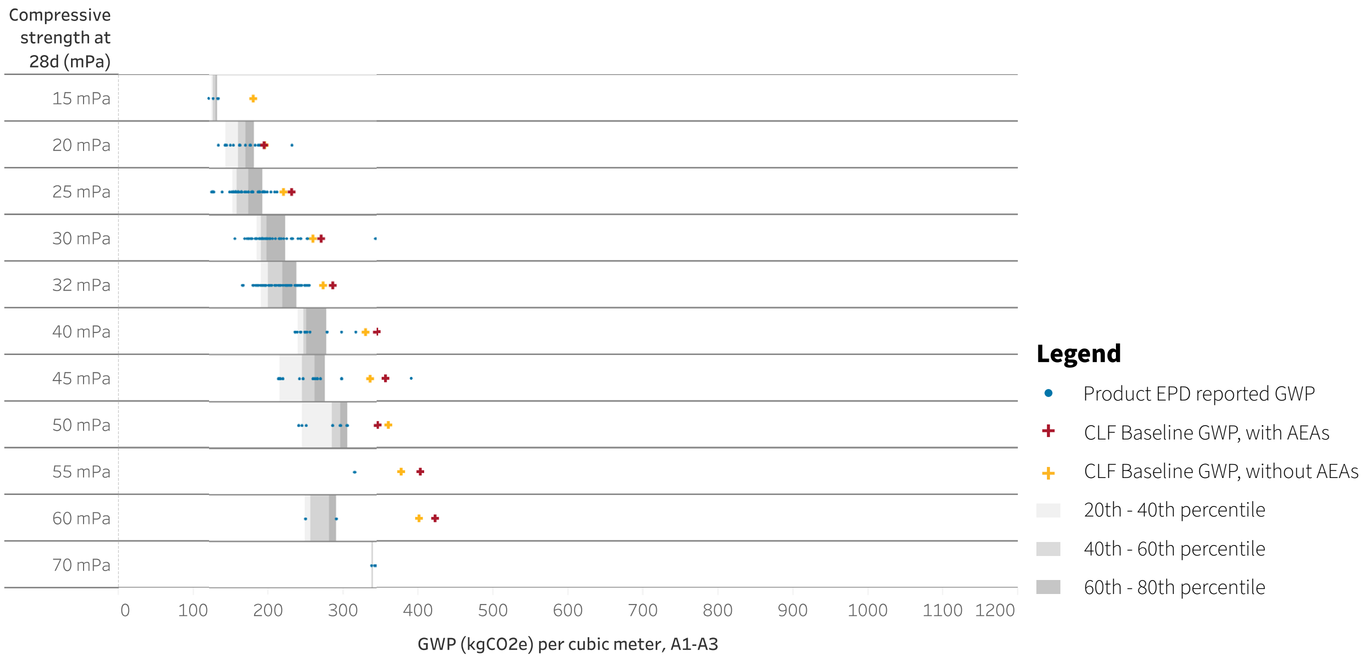


Figure 27. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (mPa)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline (Mix with AEAs)	Baseline (Mix w/o AEAs)
15 mPa	120	124	127	129	131	132	133	128	--	179
20 mPa	133	144	161	162	169	182	231	166	194	195
25 mPa	124	153	159	164	173	192	211	167	231	220
30 mPa	155	184	191	193	198	222	342	203	270	259
32 mPa	165	191	200	210	219	238	254	212	285	272
35 mPa	171	197	208	211	243	258	345	228	311	294
40 mPa	235	240	248	249	251	278	316	258	344	329
45 mPa	213	216	246	259	263	275	390	256	356	335
50 mPa	240	245	285	290	296	305	342	286	345	359
60 mPa	249	249	257	270	282	290	290	270	422	400

Figure 28. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3). Baselines for concrete mixes with and without air-entraining admixtures (AEAs) are included.

B2.5.11 Canada, Alberta

Number of applicable product EPDs: 228

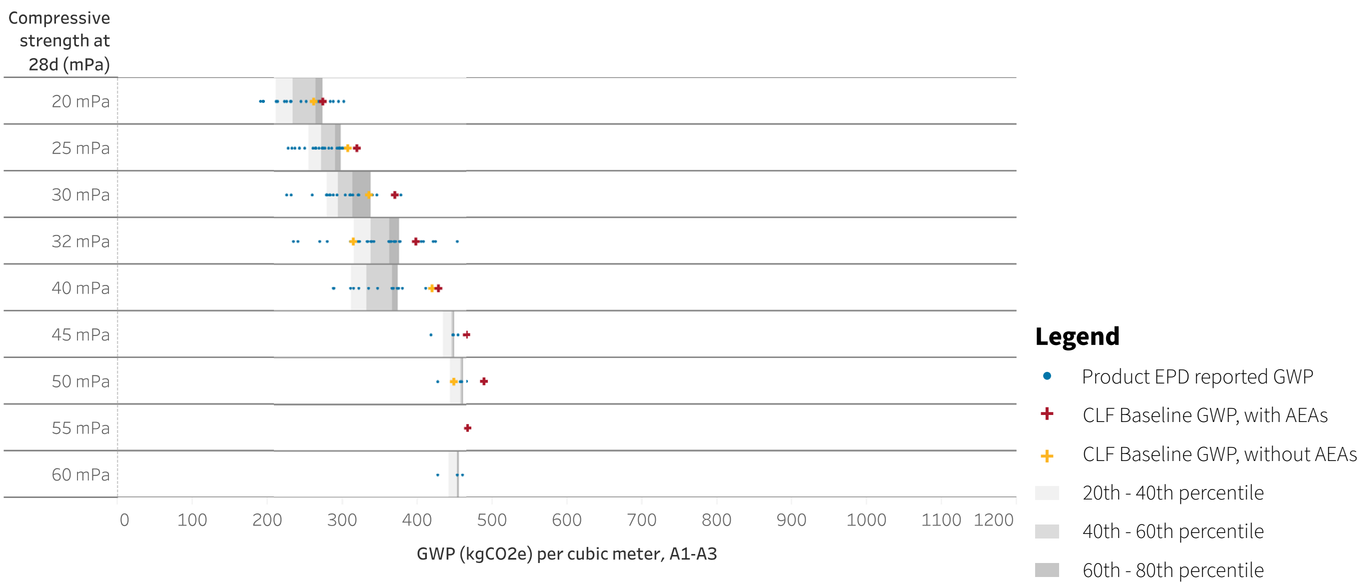


Figure 29. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (mPa)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline (Mix with AEAs)	Baseline (Mix w/o AEAs)
20 mPa	190	212	234	257	265	274	301	246	273	261
25 mPa	227	256	272	276	291	298	306	276	318	306
30 mPa	225	279	294	310	312	338	377	306	369	334
32 mPa	234	316	338	351	362	376	452	347	397	314
35 mPa	255	292	348	360	366	387	417	346	410	328
40 mPa	287	312	331	346	365	373	410	344	427	418

Figure 30. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3). Baselines for concrete mixes with and without air-entraining admixtures (AEAs) are included.

B2.5.12 Canada, Saskatchewan

Number of applicable product EPDs: 51

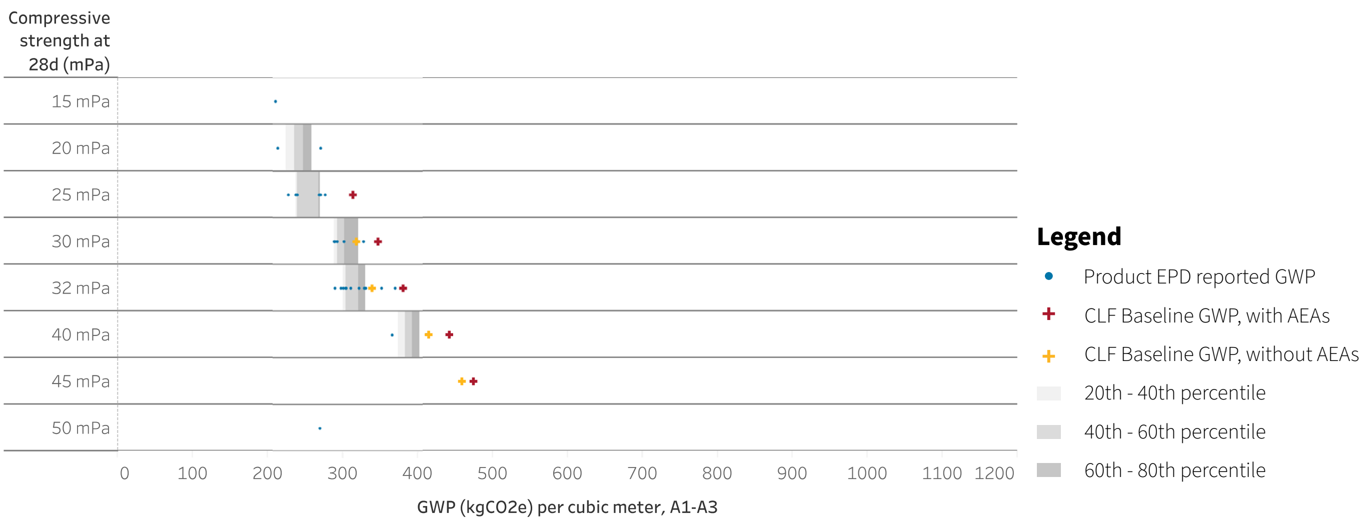


Figure 31. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (mPa)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline (Mix with AEAs)	Baseline (Mix w/o AEAs)
25 mPa	227	237	239	254	268	270	276	253	313	--
30 mPa	288	289	292	297	301	320	327	303	346	317
32 mPa	289	300	304	310	321	330	369	318	380	338
35 mPa	291	306	309	314	318	384	477	348	417	327

Figure 32. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3). Baselines for concrete mixes with and without air-entraining admixtures (AEAs) are included.

B2.5.13 Canada, Manitoba

Number of applicable product EPDs: 151

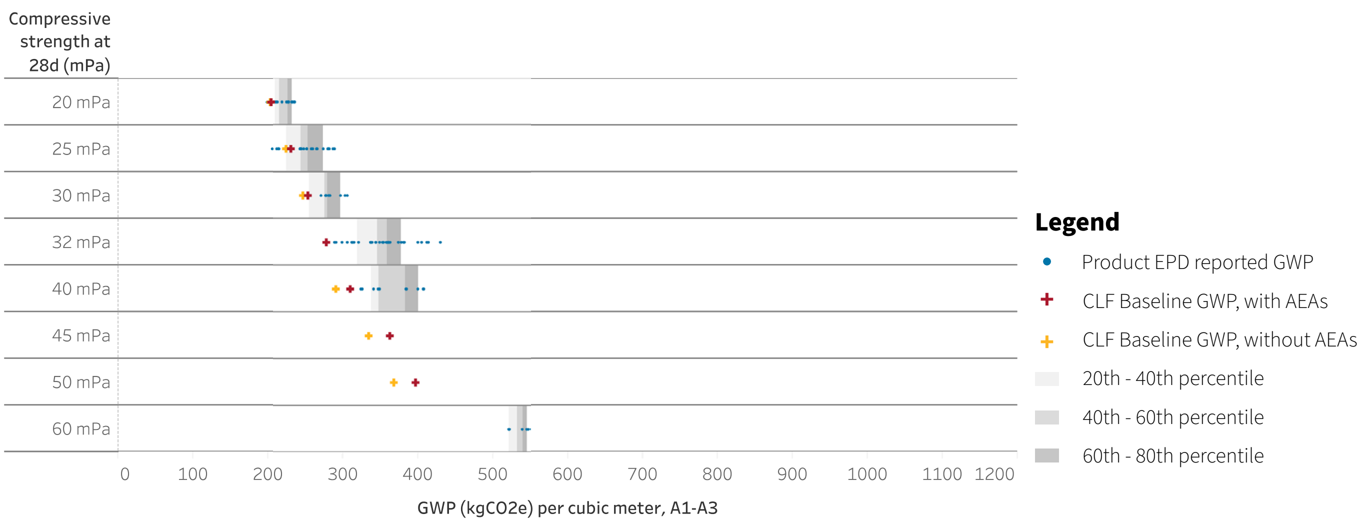


Figure 33. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (mPa)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline (Mix with AEAs)	Baseline (Mix w/o AEAs)
20 mPa	198	209	216	224	226	231	235	219	204	202
25 mPa	205	224	243	247	253	274	288	248	230	223
30 mPa	247	255	276	277	280	296	305	277	253	246
32 mPa	288	319	346	353	359	378	429	352	277	--
35 mPa	321	334	345	373	401	417	424	373	298	268
40 mPa	323	337	347	366	383	400	407	366	309	290
60 mPa	520	521	531	538	540	544	546	534	--	--

Figure 34. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3). Baselines for concrete mixes with and without air-entraining admixtures (AEAs) are included.

B2.5.14 Canada, Ontario

Number of applicable product EPDs: 0

As there are no applicable Ontario ready-mixed concrete EPDs, this section does not have the figure or table included in the sections for the other regions.

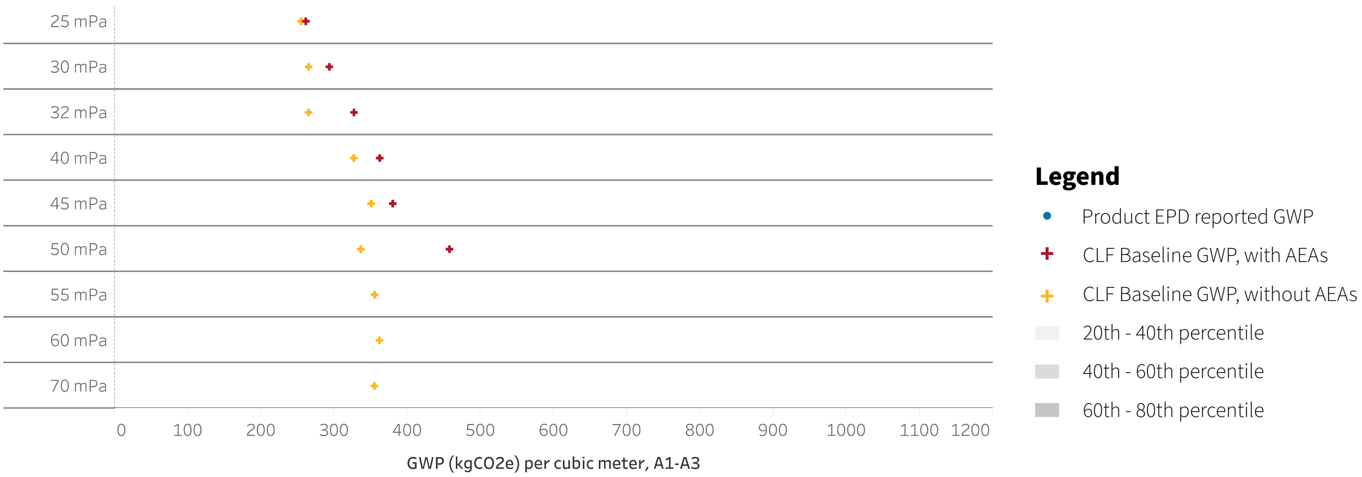


Figure 35. **Range of applicable product EPDs and CLF Baselines.**

B2.5.15 Canada, Quebec

Number of applicable product EPDs: 455

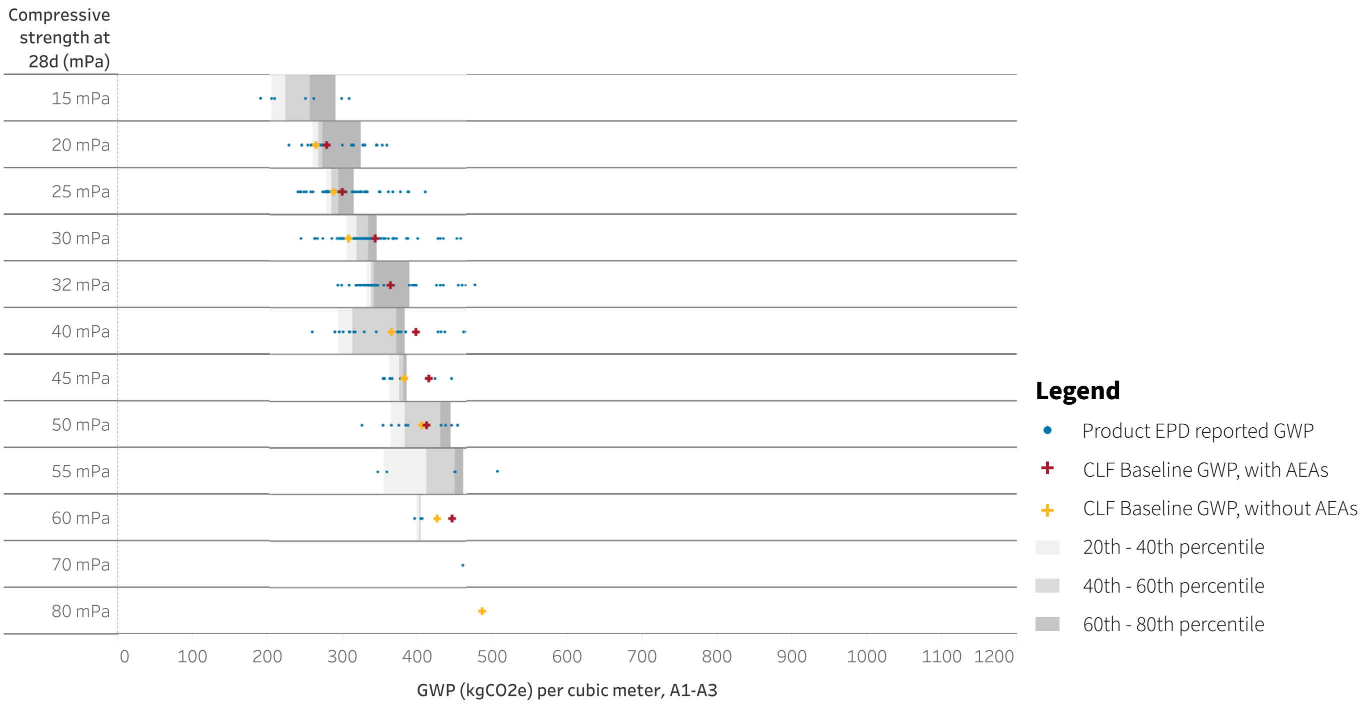


Figure 36. Range of applicable product EPDs and CLF Baselines.

Compressive strength at 28d (mPa)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline (Mix with AEAs)	Baseline (Mix w/o AEAs)
20 mPa	228	260	268	270	274	324	358	285	278	264
25 mPa	240	279	284	290	294	315	409	296	299	287
30 mPa	244	306	319	327	333	346	456	331	343	307
32 mPa	293	332	337	338	341	390	476	355	363	--
35 mPa	225	327	353	360	372	391	513	368	393	345
40 mPa	259	295	314	328	372	383	460	347	397	364
45 mPa	353	362	376	380	381	384	444	382	414	381
50 mPa	325	364	383	386	430	444	452	400	411	404

Figure 37. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3). Baselines for concrete mixes with and without air-entraining admixtures (AEAs) are included.

B2.5.16 Canada, Atlantic

Number of applicable product EPDs: 20

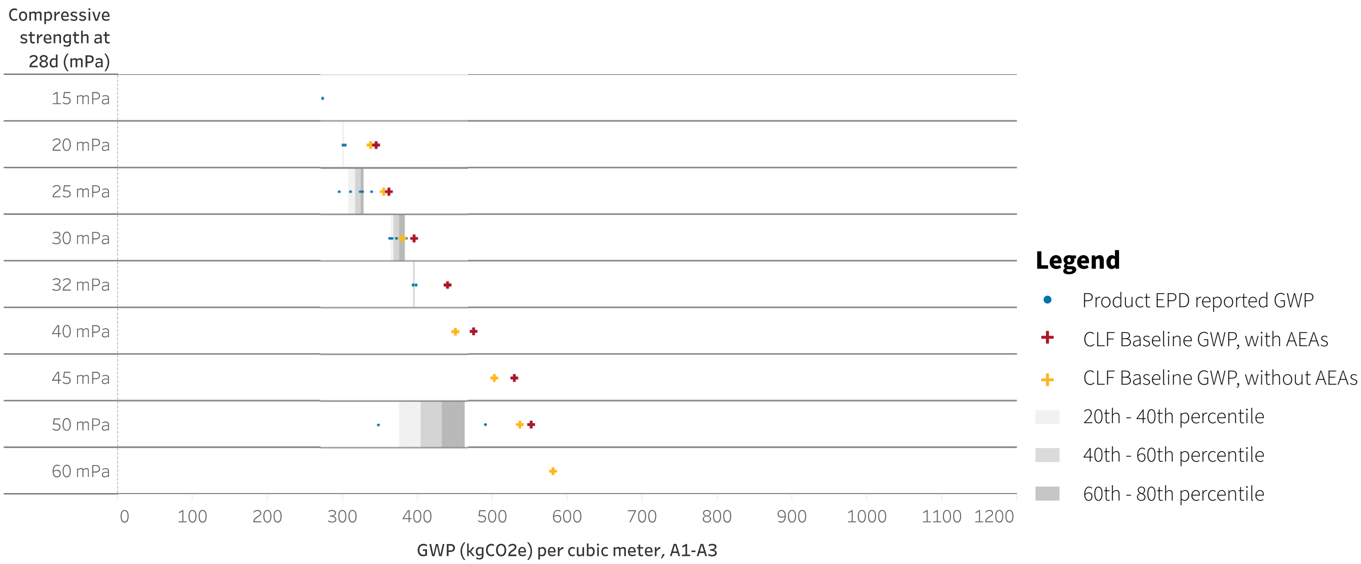


Figure 38. Range of applicable product EPDs and CLF Baselines

Compressive strength at 28d (mPa)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline (Mix with AEAs)	Baseline (Mix w/o AEAs)
25 mPa	295	307	318	323	324	328	338	318	361	354
30 mPa	362	364	369	371	376	383	384	373	394	379

Figure 39. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/m^3, A1-A3). Baselines for concrete mixes with and without air-entraining admixtures (AEAs) are included.

B3: CONCRETE – FLOWABLE FILL

B3.1 Category Overview

Category Description

Flowable fill, also known as controlled density fill (CDF) or controlled low-strength materials (CLSMs), is a flowable, low-strength cementitious mixture that sets with no compaction. These non-structural concrete mixes typically have low compressive strengths (under 1,200 psi) and are used in tight spaces where compacting fill is difficult. Applications include filling large voids such as abandoned underground storage tanks, basements, or tunnels. It may also be used as a paving subbase, bridge abutment, and retaining wall backfill. Flowable fill mixtures are usually made of combinations of cement, water, fine aggregate, and fly ash or slag.[1]

This report divides the flowable fill material category by discrete 28-day compressive strengths for normal-weight flowable fill: 100 psi, 150 psi, 200 psi, 500 psi, and 1,000 psi.

Production Processes and Key Drivers of Carbon Emissions

Like general ready-mixed concrete (Appendix B2), flowable fill's main manufacturing steps include A1 – raw materials acquisition: cement, supplementary cementitious materials, admixtures, water; A2 – transport of raw materials; and A3 – flowable fill manufacture: the energy used to store, move, batch, and mix the concrete and operate the concrete plant as well as the transportation and processing of wastes from these core processes.

Portland cement production is the main driver of flowable fill's carbon emissions.

B3.2 Data Availability and Representativeness

PCR

NSF. (2019). *NSF International Product Category Rule (PCR) for Concrete Version 2.1.*[2]

Industry EPDs

There are currently zero North American IW-EPDs for flowable fill.

Product EPDs

The CLF's dataset has 454 applicable product EPDs* for this category, including the following counts by strength class: 100 psi (37), 150 psi (45), 200 psi (72), 500 psi (56), 1,000 psi (82), and other strengths (162).

> ***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

1. National Ready Mixed Concrete Association. (2011). "Flowable Fill" [website]. https://www.flowablefill.org/index.html.

2. At the time of publication, some product EPDs referenced the expired PCR: *North American PCR for Concrete* (2013). The counts provided in this appendix do not include product EPDs that reference this expired PCR or non-North American PCRs.

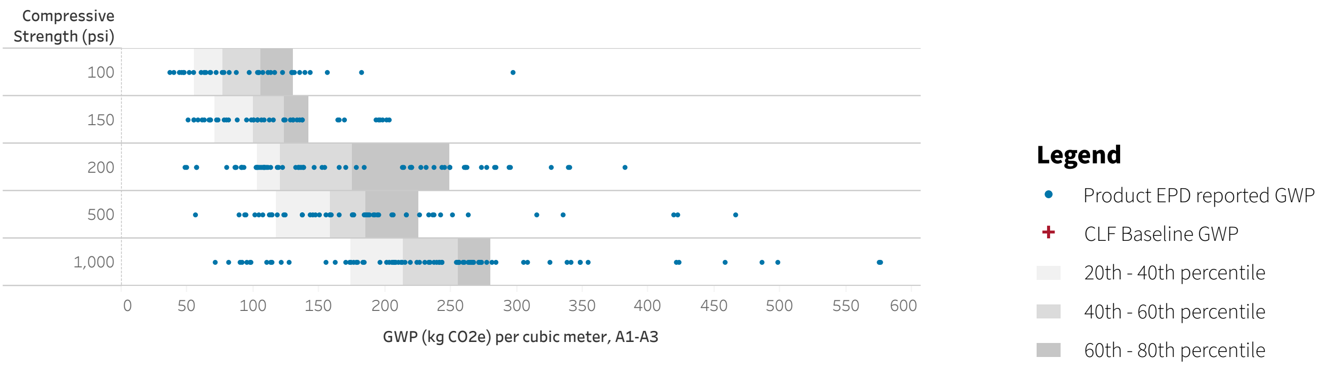


Figure 1. Range of applicable product EPDs.

Compressive Strength (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
100	37	56	77	97	106	130	297	98	--
150	50	71	100	106	123	142	203	114	--
200	48	103	120	138	175	249	382	170	--
500	56	118	158	175	186	226	466	184	--
1,000	71	174	214	238	256	280	576	243	--

Figure 2. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per 1 m³), A1-A3.

B3.3 CLF Baselines

There is no 2023 CLF Material Baseline for flowable fill since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

B3.4 Additional Notes and Guidance

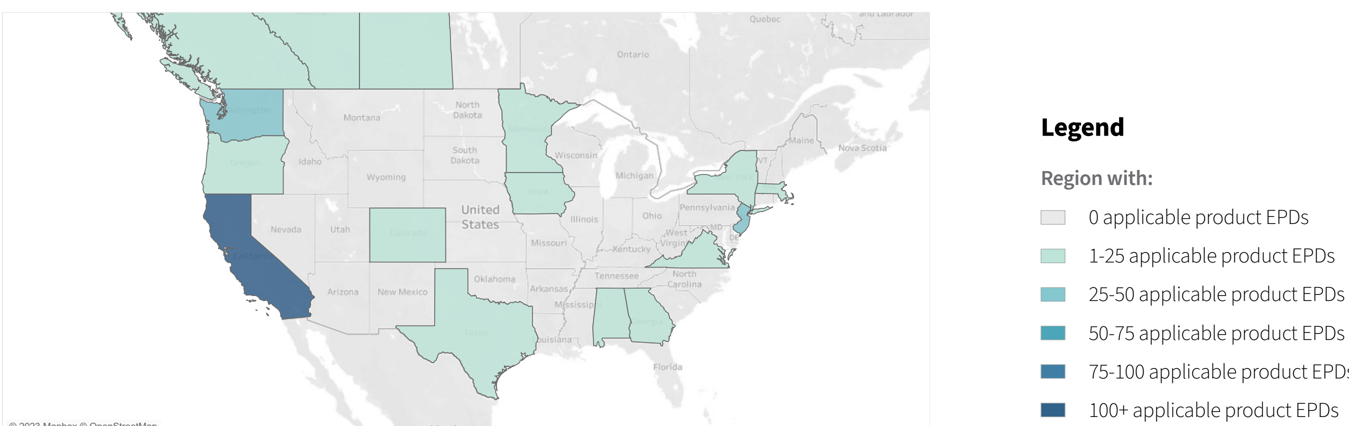


Figure 3. Product EPDs by location.

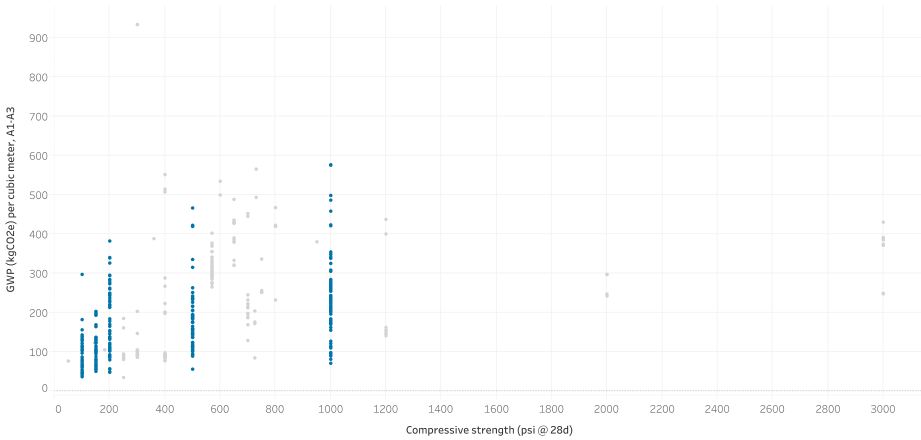


Figure 4. All applicable product EPDs. This figure includes the EPDs for the mixes at the discrete strength classes shown in Figure 1 (blue) and EPDs for mixes at other strengths not included in Figure 1 (grey). [3]

Legend

- Product EPD - common strength class
- Product EPD - other strength class

3. These data points are from the EC3 database, and EC3 does not always have the means to appropriately categorize EPDs when they originate as PDFs with varying formats and content. EPDs are not generally designated as "flowable fill" or "cement grout" – these are categories that EC3 applies where relevant based on the available information. As there is a large number of concrete EPDs, CLF did not confirm the mix type for each one. Therefore, some may be inappropriately categorized here in Appendices B3 and B5.

B4: CONCRETE – SHOTCRETE

B4.1 Category Overview

Category Description

Shotcrete, also known as gunite, is concrete that is applied through a pressure hose, producing a dense layer of concrete. Because it requires less formwork, shotcrete can be faster and more economical than conventional cast-in-place concrete. It is commonly used in new construction and repairs and is suitable for curved and thin elements. Common scenarios where shotcrete is used rather than cast-in-place concrete include where formwork is impractical or unnecessary, where it is difficult to access the work area, and where thin and/or variable-thickness layers are needed.[1]

This report divides the shotcrete material category by discrete 28-day compressive strengths for normal-weight shotcrete: 3,000 psi, 4,000 psi, 5,000 psi, 6,000 psi, and 8,000 psi.

Production Processes and Key Drivers of Carbon Emissions

Shotcrete can be applied using a wet- or dry-mix process. The wet-mix shotcrete process mixes cement, sand, and water before introduction into the delivery hose. The dry-mix shotcrete process adds water to the mix at the nozzle.

Like general ready-mixed concrete (Appendix B2), shotcrete's main manufacturing steps include A1 – raw materials acquisition: cement, supplementary cementitious materials, admixtures, and water; A2 – transport of raw materials; and A3 – shotcrete manufacture: the energy used to store, move, batch, and mix the concrete and operate the concrete plant as well as the transportation and processing of wastes from these core processes. The pressure hose application process is considered A5 – installation, and not typically included in shotcrete EPDs.

Portland cement production is the main driver of shotcrete's carbon emissions.

B4.2 Data Availability and Representativeness

PCR

NSF. (2019). *NSF International Product Category Rule (PCR) for Concrete Version 2.1.*[2]

Industry EPDs

There are currently zero North American IW-EPDs for shotcrete.

Product EPDs

The CLF's dataset has 2,082 applicable product EPDs* for this category, including the following counts by strength class: 3,000 psi (115), 4,000 psi (752), 5,000 psi (534), 6,000 psi (234), 8,000 (37), and other strengths (410). This collection of EPDs is based on mixes from 139 plants operated by 20 producers

1. American Concrete Institute (ACI). (2016). *ACI 506-16*: Guide to Shotcrete.

2. At the time of publication, some product EPDs referenced the expired PCR: *North American PCR for Concrete* (2013). The counts provided in this appendix do not include product EPDs that reference this expired PCR or non-North American PCRs.

***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

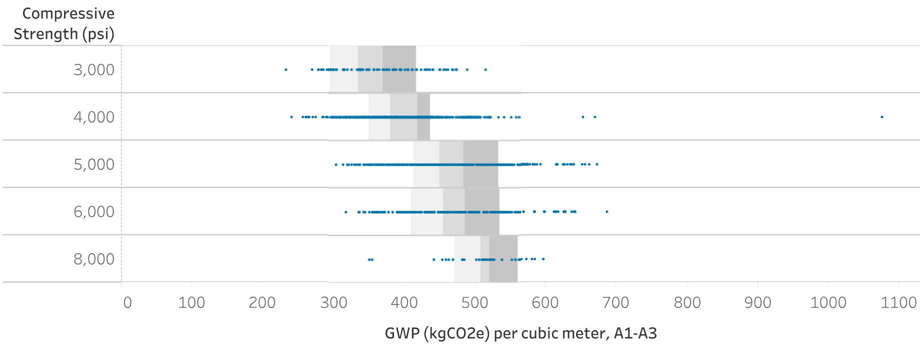


Figure 1. Range of applicable product EPDs.

Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

Compressive Strength (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
2,500	316	324	333	337	344	359	373	342	--
3,000	232	296	336	341	370	416	514	358	--
4,000	240	350	380	395	418	437	1075	399	--
5,000	303	413	449	473	484	533	672	470	--
6,000	317	409	455	472	485	535	686	474	--
8,000	350	471	507	512	520	560	596	509	--

Figure 2. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per 1 m³), A1-A3.

B4.3 CLF Baselines

There is no 2023 CLF Material Baseline for shotcrete since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

B4.4 Additional Notes and Guidance

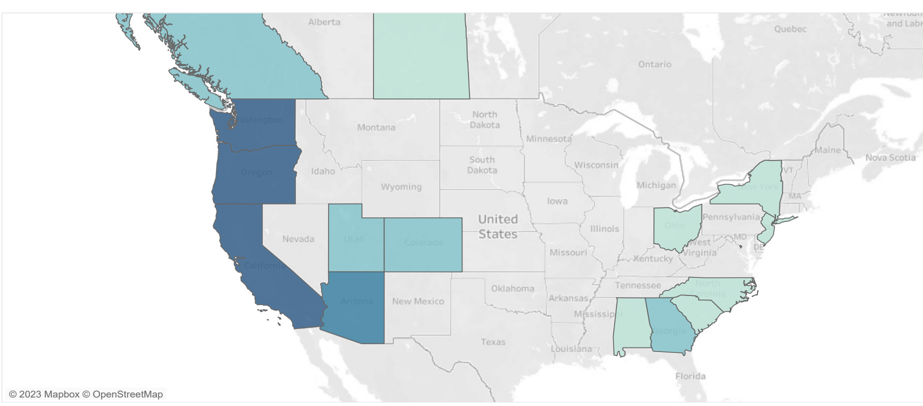


Figure 3. Product EPDs by location.

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

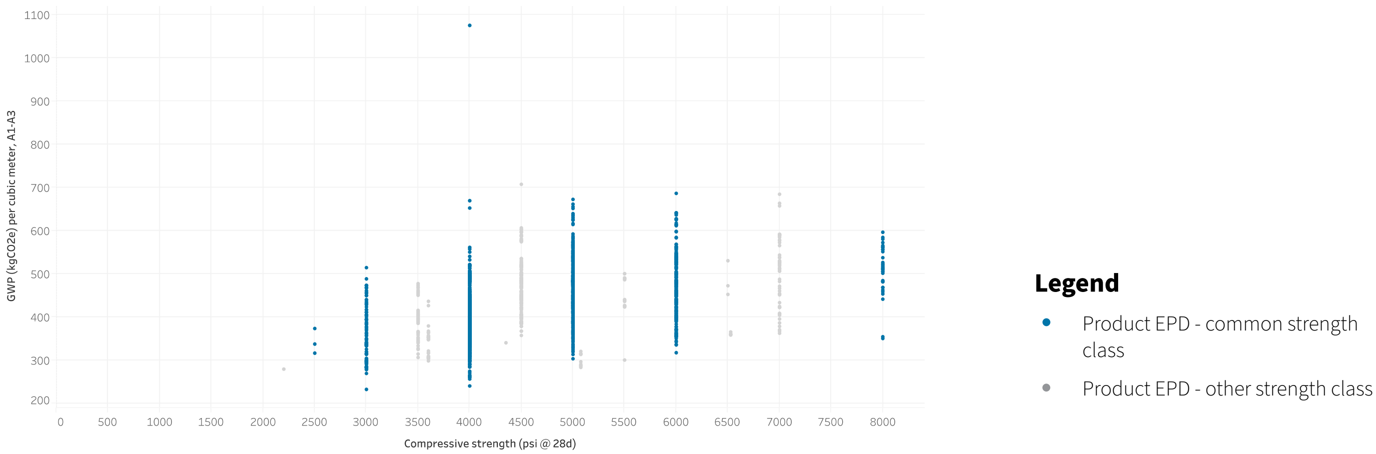


Figure 4. All applicable product EPDs. This figure includes the EPDs for the mixes at the discrete strength classes shown in Figure 1 (blue) and EPDs for mixes at other strengths not included in Figure 1 (grey).

B5: CONCRETE – CEMENT GROUT

B5.1 Category Overview

Category Description

Cement grout, also known as structural grout, is a flowable, high-strength cementitious mixture used to reinforce existing structures, fill voids, stabilize soil, and facilitate load transfers among structural elements. While commonly used for structural purposes, grout can also be used to improve fire ratings, security, acoustical performance, termite resistance, thermal storage, and anchorage capabilities. Grout is made up of cement, aggregate, and sufficient water to ensure the complete filling of the grout space.

This report divides the cement grout material category by discrete 28-day compressive strengths for normal-weight cement grout: 2,500 psi, 3,000 psi, 4,000 psi, 5,000 psi, and 6,000 psi.

Production Processes and Key Drivers of Carbon Emissions

Like general ready-mixed concrete (Appendix B2), cement grout's main manufacturing steps include A1 – raw materials acquisition: cement, supplementary cementitious materials, admixtures, water; A2 – transport of raw materials; and A3 – cement grout manufacture: the energy used to store, move, batch, and mix the concrete and operate the concrete plant as well as the transportation and processing of wastes from these core processes.

Portland cement production is the main driver of cement grout's carbon emissions.

B5.2 Data Availability and Representativeness

PCR

NSF. (2019). *NSF International Product Category Rule (PCR) for Concrete Version 2.1*.[1]

Industry -wide EPD

There are currently zero North American IW-EPDs for cement grout.

Product EPDs

The CLF's dataset has 545 applicable product EPDs* for this category, including the following counts by strength class: 2,500 psi (48), 3,000 psi (75), 4,000 psi (76), 5,000 psi (76), 6,000 psi (67), and other strengths (203).

> ***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

1. At the time of publication, some product EPDs referenced the expired PCR: *North American PCR for Concrete* (2013). The counts provided in this appendix do not include product EPDs that reference this expired PCR or non-North American PCRs.

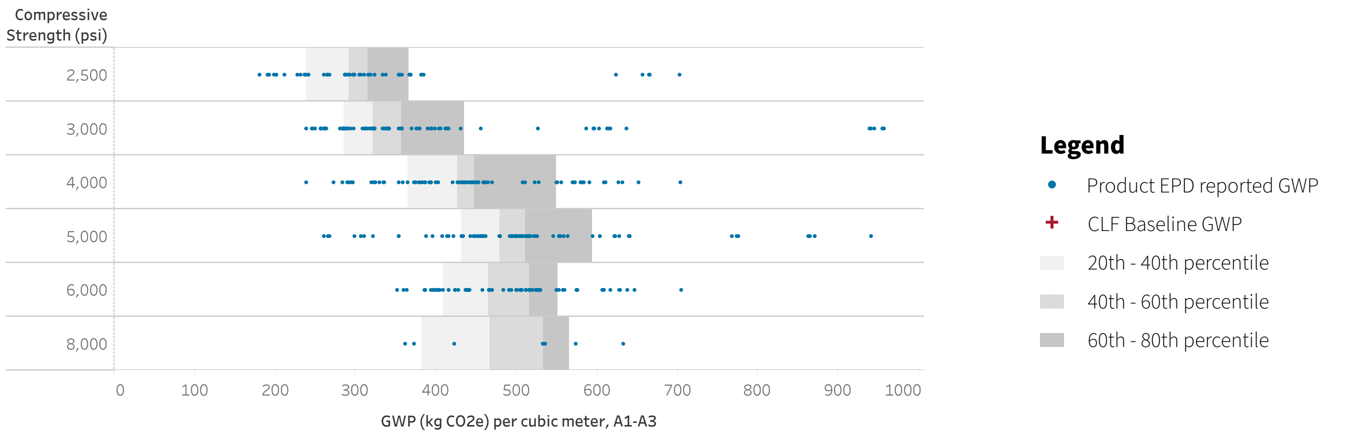


Figure 1. Range of applicable product EPDs.

Compressive Strength (psi)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
2,500	180	239	291	298	315	367	702	329	--
3,000	238	285	322	339	356	435	956	401	--
4,000	238	364	426	437	447	550	703	444	--
5,000	260	431	479	500	511	594	940	511	--
6,000	351	409	465	500	516	551	704	491	--
8,000	361	382	466	532	534	565	632	490	--

Figure 2. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per 1 m³), A1-A3.

B5.3 CLF Baselines

There is no 2023 CLF Material Baseline for cement grout since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

B5.4 Additional Notes and Guidance

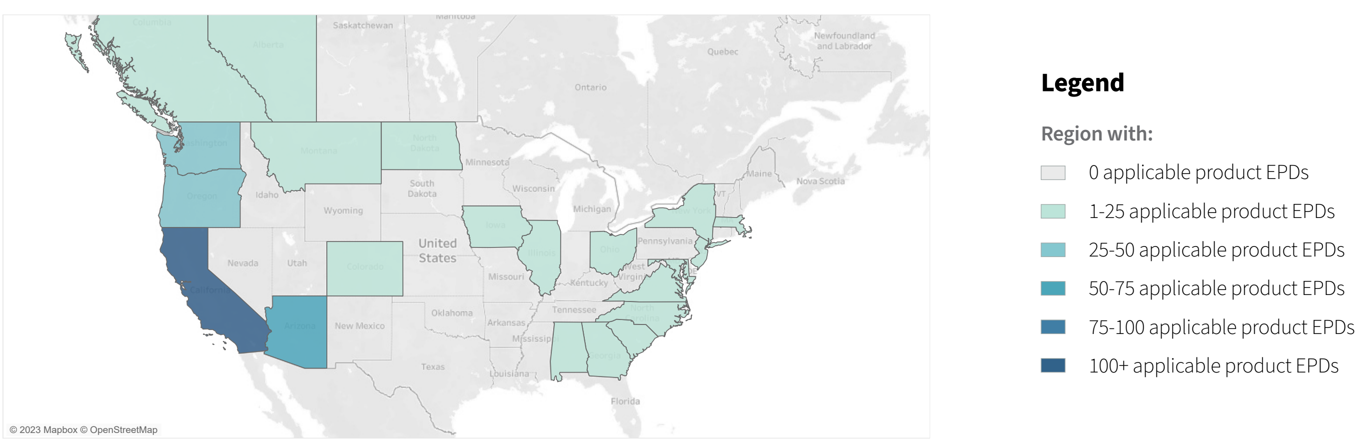
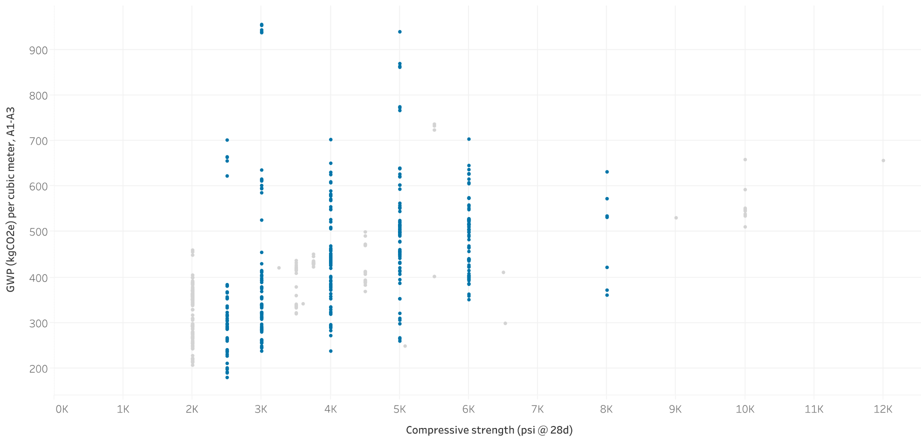


Figure 3. Product EPDs by location.



Legend

- Product EPD - common strength class
- Product EPD - other strength class

Figure 4. All applicable product EPDs. This figure includes the EPDs for the mixes at the discrete strength classes shown in Figure 1 (blue) and EPDs for mixes at other strengths not included in Figure 1 (grey).[2]

2. These data points are from the EC3 database, and EC3 does not always have the means to appropriately categorize EPDs when they originate as PDFs with varying formats and content. EPDs are not generally designated as “flowable fill” or “cement grout” – these are categories that EC3 applies where relevant based on the available information. As there is a large number of concrete EPDs, CLF did not confirm the mix type for each one. Therefore, some may be inappropriately categorized here in Appendices B3 and B5.

B6: CEMENT

B6.1 Category Overview

Category Description

Cement is a binder that adheres to and binds sand and aggregates to form concrete and mortar. Most cements used in construction – including all of the categories below – are hydraulic cements, ones that become adhesive through a chemical reaction between water and the dry ingredients in the cement.

Portland cement is the most commonly used type of cement and can be combined with limestone and/or supplementary cementitious materials (SCMs) such as fly ash or slag to influence the cost, carbon footprint, and performance of the concrete or mortar. These ingredients (portland cement, fly ash, etc.) can be combined by the ready-mixed concrete producer when making concrete (the most typical scenario in North America), or by cement manufacturers to produce blended cements (more common outside of North America). The CLF Material Baselines include the following cement categories, in alignment with the Portland Cement Association (PCA) industry-wide EPDs:

- **Portland cement:** a hydraulic cement produced by pulverizing clinker (see clinker description in the following section) and typically mixed with small amounts of water, gypsum, and limestone (up to 5% of the total mass).[1] Portland cement includes multiple subtypes with some variation in performance and conforms to ASTM C150 (USA)[2] and CSA-A3001 (Canada).[3] Outside of North America, where blended cements are more common, (unblended) portland cement is often referred to as ordinary portland cement.
- **Blended hydraulic cements:** a hydraulic cement that typically includes both portland cement (or portland cement clinker) and one or more additional constituents that contribute to the cement's strength-gaining properties.[1] Includes sub-types per ASTM C595: Type IP, Portland-pozzolan cement; Type IS, Portland-slag cement; Type IL, Portland-limestone cement; Type IT, Ternary blended cement. See CSA-A3001 for Canada designations.[3]
- **Portland-limestone cement (PLC):** a particular type of blended hydraulic cement where the limestone content is greater than 5% and up to 15% by mass.[4] PLC is designated in ASTM C 595 as Type IL. See CSA-A3001 for Canadian designations.[3] The PCA developed an industry EPD specifically for PLC (one subtype of blended hydraulic cement) in addition to an EPD for the broader category of blended hydraulic cement. Of the blended cement types, PLC is most similar in performance to ordinary portland cement, with the benefit of a reduced carbon footprint.
- **Masonry cement:** a hydraulic cement for use in mortars or plasters and contains a plasticizing material.[1] This includes masonry cements Types N, S, and M which have different applications (e.g., exterior vs. interior, above vs. below grade, and load-bearing vs. non-load-bearing).[5] See CSA-A3002 for Canadian designations.[6]

1. ASTM C219 - Standard Terminology Relating to Hydraulic Cement.
2. ASTM C150 / C150M – 20 Standard Specification for Portland Cement.
3. CSA-A3001-18 - Cementitious materials for use in concrete.
4. ASTM C595 / C595M – 20 Standard Specification for Blended Hydraulic Cements.
5. ASTM C91 / C91M – 18 Standard Specification for Masonry Cement
6. CSA-A3002-18 - Masonry and mortar cement.

Production Processes and Key Drivers of Carbon Emissions

Cement is typically the dominant contributor to concrete and mortar GWP.

Clinker is the primary intermediate manufactured product that goes into cement, and is the largest contributor to cement's GWP. Clinker is produced by heating ground limestone and other ingredients in a kiln. The carbon emissions from clinker production are due to both: the production of energy (electricity and thermal fuels) used to heat the raw ingredients, and calcination – a thermo-chemical process where the heated limestone's calcium carbonate ($CaCO_3$) – the primary compound in limestone – is converted into lime (CaO) and carbon dioxide (CO_2). The Portland Cement Association's (PCA) industry EPD reports that over half of portland cement's A1-A3 GWP is due to calcination.

The PCA found in the study underlying their industry-wide EPDs that the US industry-average portland cement is 91.4% clinker by weight. Their reference industry-average portland-limestone cement and blended hydraulic cement products were 82.7% and 70.7% clinker by weight, respectively. Other standard ingredients to cement include gypsum and uncalcined limestone. See Figure 7 (Industry-average cement mix ingredient proportions) for more data regarding their reference product constituent ingredient quantities. Cement products of a given product type vary in their constituent ingredients. For example, a cement product can be classified as portland-limestone cement with anywhere from 5 to 15% uncalcined limestone content. This variation in ingredients corresponds to variation in product performance and GWP.

Blended cements may contain clinker, limestone, fly ash, slag, and other SCMs. SCM content of a blended cement or concrete mix affects functional performance and embodied carbon of the mix (where, generally, the more that SCMs allow for reduction of portland cement content, the lower the GWP of the mix).

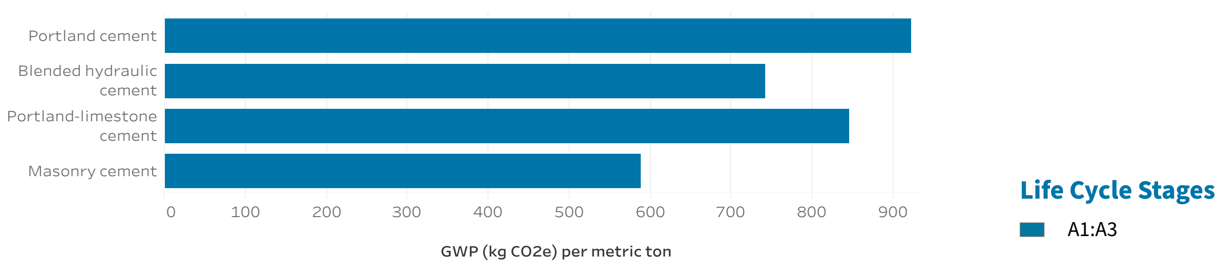


Figure 1. GWP contribution by life cycle stage. The IW-EPDs provide total A1-A3 GWP only, not disaggregated by life cycle stage.[7]

7. Portland Cement Association (PCA). (2021). *Environmental product declarations - Portland cement, Portland-limestone cement, Blended hydraulic cement, Masonry cement*. ASTM. https://www.cement.org/docs/default-source/default-document-library/pca_epds_2021_rev01312022.pdf?sfvrsn=d26ffbf_2

B6.2 Data Availability and Representativeness

PCR

NSF International. (2020). *Product category rule for preparing an environmental product declaration for portland, blended hydraulic, masonry, mortar, and plastic (stucco) cements. V3.1.* ASTM International.

Industry EPDs

Portland Cement Association (PCA). (2021). *Environmental product declaration - Portland cement.* ASTM.

> About 64% of total USA portland cement industry production in 2019 (by mass) is included in the dataset, based on data from 56 plants (this is 55,685,182 metric tons in the dataset out of a total of 86,000,000 metric tons). Clinker, the main ingredient in cement, can be produced by one or a combination of multiple technologies. The industry-average clinker assumed in the EPD is based on the spread of production in the dataset, which constitutes about 68% of total USA clinker production.

Portland Cement Association (PCA). (2021). *Environmental product declaration - Blended hydraulic cement.* ASTM.

> About 80% of total USA blended cement industry production in 2019 (by mass) is included in the dataset, based on data from 22 plants (this is 1,637,140 metric tons in the dataset out of a total of 2,000,000 metric tons). Clinker, the main ingredient in cement, can be produced by one or a combination of multiple technologies. The industry-average clinker assumed in the EPD is based on the spread of production in the dataset, which constitutes about 68% of total USA clinker production.

Portland Cement Association (PCA). (2021). *Environmental product declaration - Portland-limestone cement.* ASTM.

> The percent of total portland-limestone cement production represented in the dataset is not disclosed, as there are no national or North American statistics on total PLC production. The dataset captures 820,551 metric tons of production, reported by 15 plants, which is roughly half of all blended cement reported by PCA member study participants (see below.) Clinker, the main ingredient in cement, can be produced by one or a combination of multiple technologies. The industry-average clinker assumed in the EPD is based on the spread of production in the dataset, which constitutes about 68% of total USA clinker production.

Portland Cement Association (PCA). (2021). *Environmental product declaration - Masonry cement.* ASTM.

> About 46% of total USA blended cement industry production in 2019 (by mass) is included in the dataset, based on data from 32 plants (this is 1,109,471 metric tons in the dataset out of a total of 2,400,000 metric tons). Clinker, the main ingredient in cement, can be produced by one or a combination of multiple technologies. The industry-average clinker assumed in the EPD is based on the spread of production in the dataset, which constitutes about 68% of total USA clinker production.

The CLF Material Baselines aim to describe North American production. These PCA industry EPDs are specific to USA production, and so exclude Mexico and Canada. There are expired Canadian industry-wide EPDs for general use (GU) and portland-limestone (GUL) cements, but no valid ones at the time of this writing.[8]

Other Industry Data

US EPA. (2021). *U.S. cement industry carbon intensities* (2019). https://www.epa.gov/system/files/documents/2021-10/cement-carbon-intensities-fact-sheet.pdf

Product EPDs

In the EC3 database, there are currently 57 applicable* product EPDs for portland cement, 16 for portland-limestone cement, 27 for blended hydraulic cement (including the 16 PLC EPDs), and 5 for masonry cement.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

In alignment with the PCA industry EPD categorization, the blended hydraulic cement product EPD data displayed in the scatter plots, summary statistics table, and histogram below include the set of portland-limestone cement EPDs.

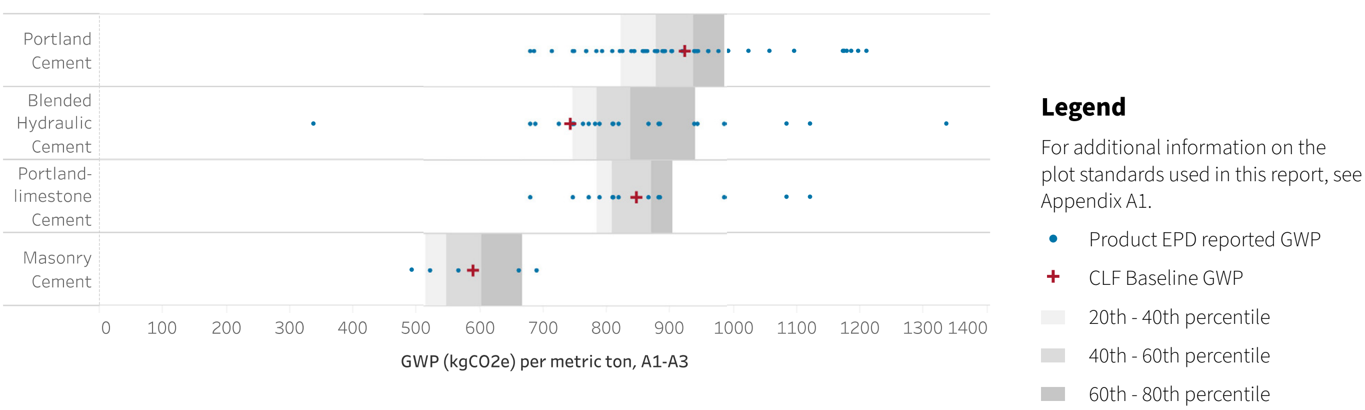


Figure 2. Range of applicable product EPDs and CLF Baselines.

	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
Portland Cement	679	822	878	891	937	985	1209	915	922
Blended Hydraulic Cement	337	746	785	809	837	938	1335	837	794
Portland-limestone Cement	679	785	809	818	871	903	1120	862	846
Masonry Cement	492	516	548	566	604	667	689	586	589

Figure 3. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per 1 metric ton, A1-A3).

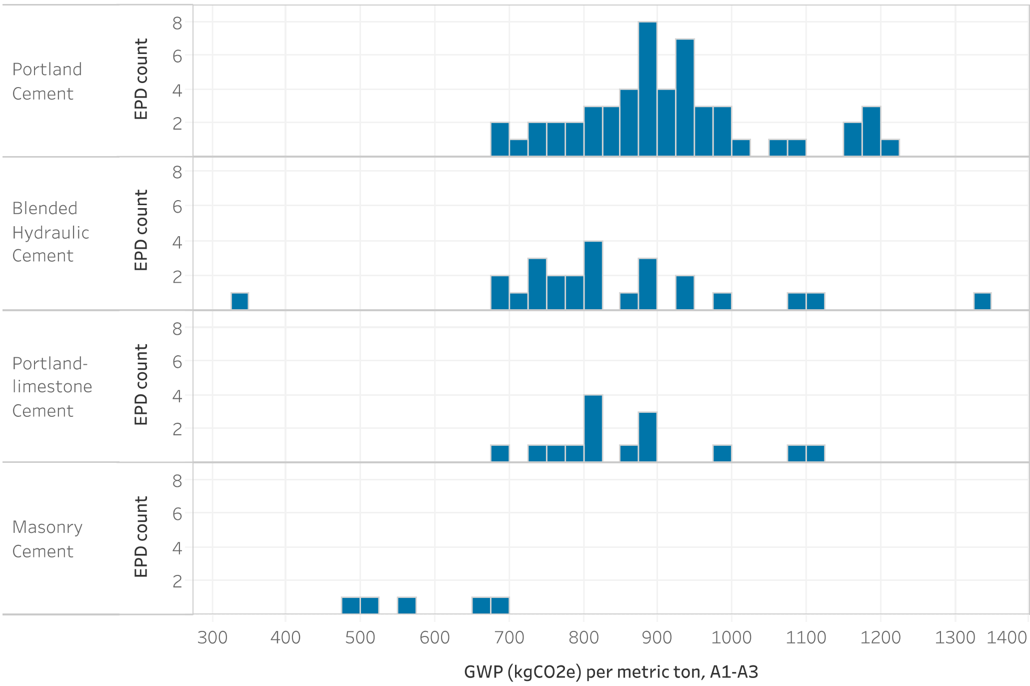


Figure 4. Distribution of applicable product EPDs.

B6.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Portland cement	922	Industry	PCA. (2021). *Environmental product declaration - Portland cement.*
Blended hydraulic cement	742	Industry	PCA. (2021). *Environmental product declaration - Blended hydraulic cement.*
Portland-limestone cement	846	Industry	PCA. (2021). *Environmental product declaration - Portland-limestone cement.*
Masonry cement	589	Industry	PCA. (2021). *Environmental product declaration - Masonry cement.*

Figure 5. CLF Baselines for cement.

B6.4 Additional Notes and Guidance

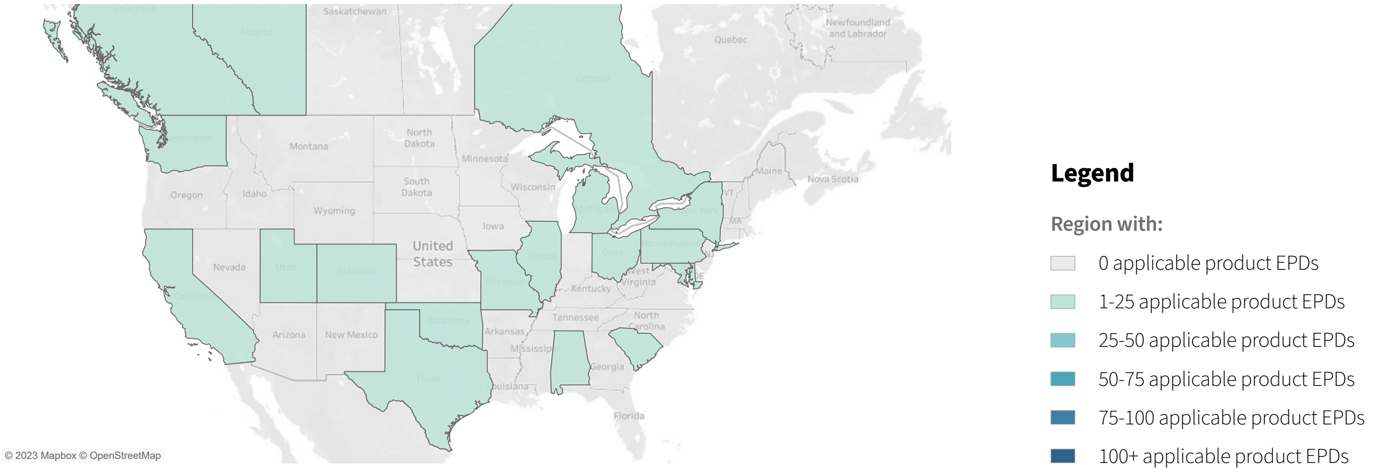


Figure 6. Product EPDs by location.

	Portion of cement product (by weight)			
Cement Ingredients	**Portland cement**	**Portland limestone cement**	**Blended hydraulic cement**	**Masonry cement**
Clinker	91.4%	82.7%	70.7%	55.2%
Gypsum	5.2%	5.8%	5.4%	6.7%
Uncalcined limestone	2.7%	10.8%	6.1%	34.9%*
Slag	-	-	10.7%	1.4%
Fly ash	-	-	6.0%	-
Other Ingredients	<1.0% each	<1.0% each	<1.0% each	<1.0% each

Figure 7. Industry-average cement mix ingredient proportions.[9,10,11,12] The asterisk (*) indicates that the cement ingredient may be hydraulic lime instead of uncalcined limestone.

9. Portland Cement Association (PCA). (2021). *Environmental product declaration - Portland cement.* ASTM. https://www.cement.org/docs/default-source/epds/pca_epd_portland_athena_final_revised_04082021.pdf?sfvrsn=3e4affbf_2

10. Portland Cement Association (PCA). (2021). *Environmental product declaration - Blended hydraulic cement.* ASTM. https://www.cement.org/docs/default-source/epds/pca_epd_blendedhydraulic_athena_final_revised_01312022.pdf?sfvrsn=4a4affbf_2

11. Portland Cement Association (PCA). (2021). *Environmental product declaration - Portland-limestone cement.* ASTM. https://www.cement.org/docs/default-source/epds/pca_epd_plc_athena_final_revised_04082021.pdf?sfvrsn=424affbf_2

12. Portland Cement Association (PCA). (2021). *Environmental product declaration - Masonry cement.* ASTM. https://www.cement.org/docs/default-source/epds/pca_epd_masonry_athena_final_revised_04082021.pdf?sfvrsn=3a4affbf_2

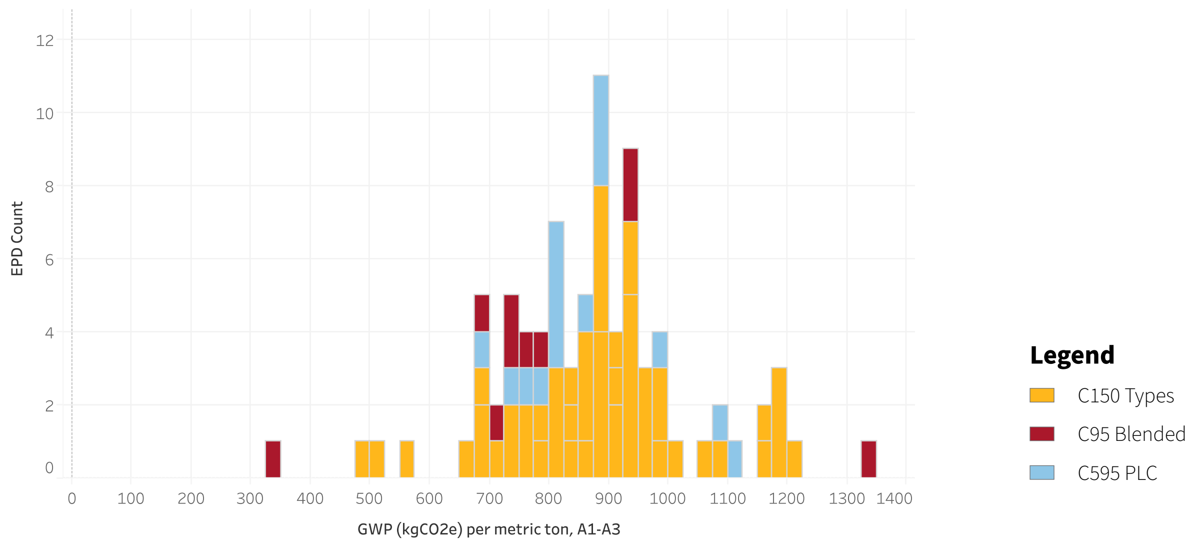


Figure 8. GWP distribution of EPDs - combined. While these product types – portland cement, portland-limestone cement, and blended hydraulic cement – have separate CLF Material Baselines, they are combined in this chart to provide further context for their comparative GWP values.

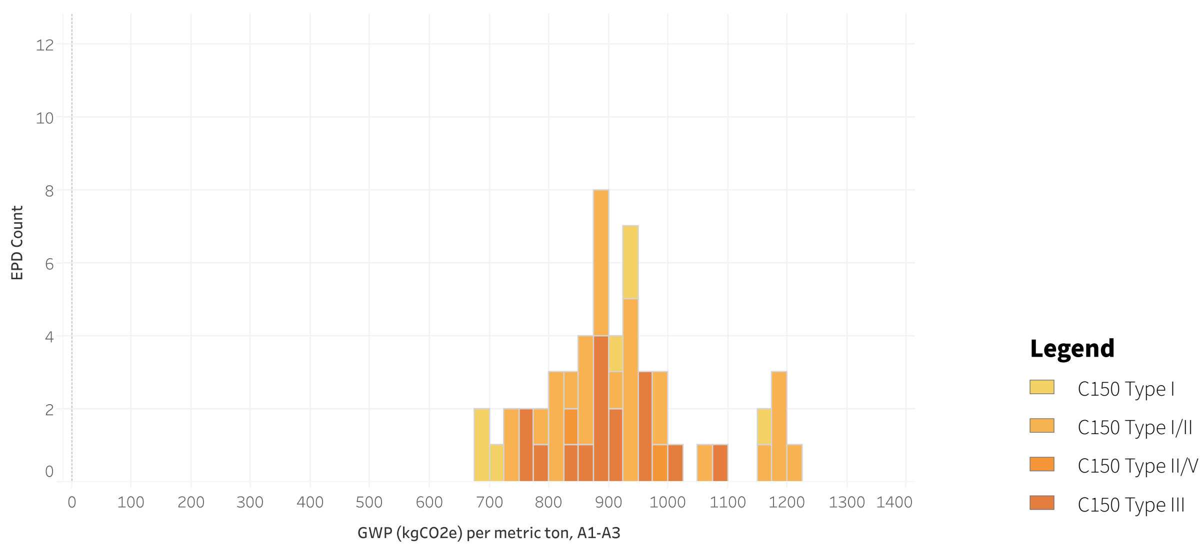


Figure 9. Portland cement EPD GWP distribution by ASTM C150 type.

C1: MASONRY - CMU

C1.1 Category Overview

Category Description

This category covers manufactured concrete masonry units (CMU) suitable for load-bearing purposes, generally adhering to ASTM C90, Concrete Masonry Unit, Load-Bearing. The category includes a range of weight classes (normal-, medium-, and light-weight), compressive strengths, shapes, surface treatments, and ingredients (particularly related to cementitious materials such as portland cement, portland-limestone cement, fly ash, slag, and glass powder). CMU is sometimes referred to as “concrete block” or “concrete block masonry units.”

Production Processes and Key Drivers of Carbon Emissions

A1 includes the production and transport of raw materials: cement, aggregate, supplementary cementitious materials, admixtures, and water. The production of cement is the largest contributing factor to CMU’s total cradle-to-grave GWP, and CMU block produced with only portland cement tends to have higher GWP than CMU block produced with portland-limestone cement and/or supplementary cementitious materials such as fly ash or slag. A2 includes the transport of raw materials to the CMU manufacturing facility. A3 includes CMU manufacture: batching, mixing, forming, curing, finishing, and packaging.[1]

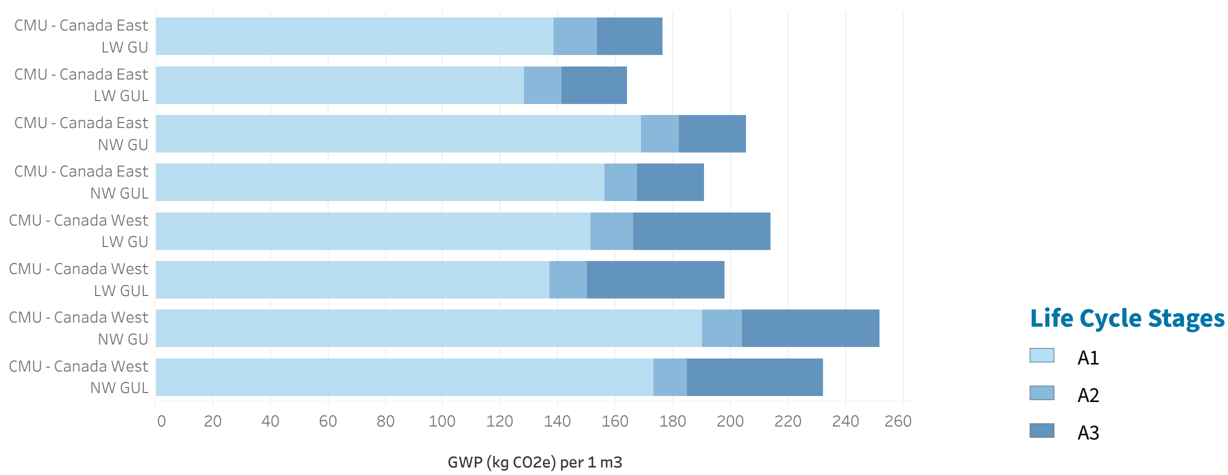


Figure 1. GWP contribution by life cycle stage. “NW” = normal weight. “LW” = lightweight. “GU” = general use (portland) cement. “GUL” = portland-limestone cement. The product types shown are based on the eight valid IW-EPDs in North America, from the Canadian Concrete Masonry Producers Association (CCMPA).[1]

C1.2 Data Availability and Representativeness

PCR

UL Environment. (2020). *Product category rule (PCR) guidance for building-related products and services part B: Concrete masonry and segmental concrete paving product EPD requirements.*

1. Canadian Concrete Masonry Producers Association (CCMPA). (2022). *Environmental product declaration: Normal weight and lightweight concrete block masonry units as manufactured by members of the Canadian Concrete Masonry Association (CCMPA).* ASTM International. https://ccmpa.ca/wp-content/uploads/2022/09/CCMPA-EPD-20220913.pdf

Industry EPDs

Canadian Concrete Masonry Producers Association (CCMPA). (2022). *Environmental product declaration: Normal weight and lightweight concrete block masonry units as manufactured by members of the Canadian Concrete Masonry Association (CCMPA).* ASTM International.

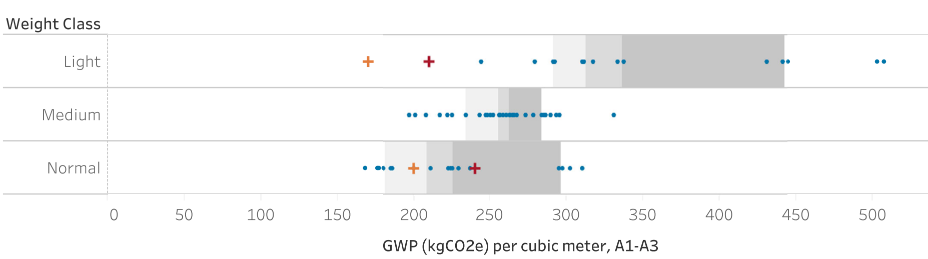
> This document contains eight EPD results for each combination related to three factors: geography (eastern vs. western Canada), weight (normal weight vs. lightweight), and cement type (GU vs. GUL).
>
> The EPD does not disclose the proportion of total industry-wide CMU production used as primary data. However, it does state that 100% of the cement data used in the study is manufacturer-specific based on EPD data for specific suppliers.[1]

There are no other currently valid industry EPDs for CMU in North America. A new National [USA] Concrete Masonry Association (NCMA) industry EPD is expected in 2023.[3]

Product EPDs

There are 63 applicable EPDs* for CMU in the EC3 database as of fall 2022.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.



Legend

- Product EPD reported GWP
- CLF Baseline GWP, Eastern Canada
- CLF Baseline GWP, Western Canada
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

Figure 2. Range of applicable product EPDs and CLF Baselines.

Weight Class	Region	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
Light	North American	244	292	312	325	336	442	507	360	
	Eastern Canada									170
	Western Canada									207
Medium	North American	197	234	256	258	263	284	331	257	
Normal	North American	168	182	209	223	226	296	310	230	
	Eastern Canada									199
	Western Canada									241

Figure 3. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per m^3, A1-A3).

2. UL Environment. (2020). *Product category rule (PCR) guidance for building-related products and services part B: Concrete masonry and segmental concrete paving product EPD requirements.* https://www.ul.com/services/product-category-rules-pcrs

3. National Concrete Masonry Association (NCMA). (2022, August 15). Personal communication.

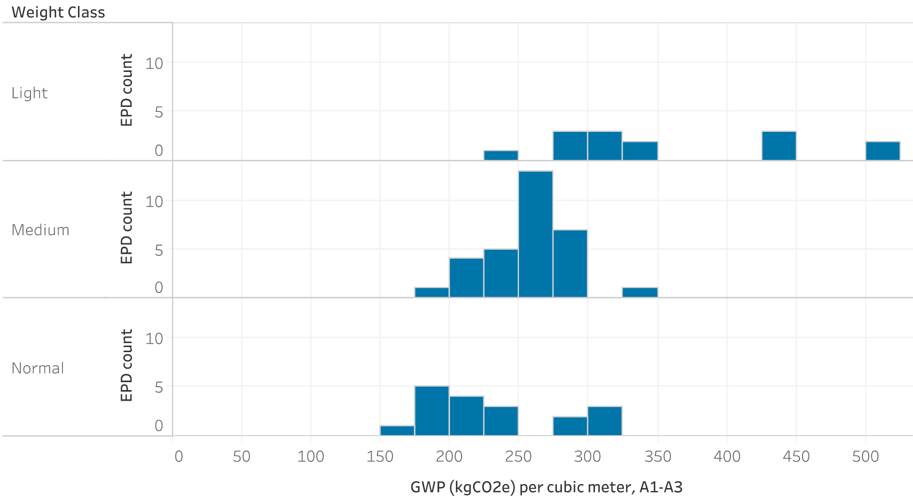


Figure 4. Distribution of applicable product EPDs.

C1.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 m^3)	Method	Data Source and Notes
CMU - Eastern Canada, lightweight	170	Industry	CCMPA. (2022). *Environmental product declaration - Normal weight and lightweight concrete block masonry units as manufactured by members of the Canadian Concrete Masonry Association (CCMPA).* Average of Canada East, Lightweight CMU results: 176.54 kg CO_2e (GU SCM) and 164.16. kg CO_2e (GUL SCM).
CMU - Eastern Canada, normal weight	200	Industry	CCMPA. (2022). *Environmental product declaration - Normal weight and lightweight concrete block masonry units as manufactured by members of the Canadian Concrete Masonry Association (CCMPA).* Average of Canada East, Normal weight CMU results: 205.38 kg CO_2e (GU SCM) and 190.58 kg CO_2e (GUL SCM).
CMU - Western Canada, lightweight	210	Industry	CCMPA. (2022). *Environmental product declaration - Normal weight and lightweight concrete block masonry units as manufactured by members of the Canadian Concrete Masonry Association (CCMPA).* Average of Canada West, Lightweight CMU results: 213.94 kg CO_2e (GU SCM) and 197.93 kg CO_2e (GUL SCM).
CMU - Western Canada, normal weight	240	Industry	CCMPA. (2022). *Environmental product declaration - Normal weight and lightweight concrete block masonry units as manufactured by members of the Canadian Concrete Masonry Association (CCMPA).* Average of Canada West, Normal weight CMU results: 251.64 kg CO_2e (GU SCM) and 232.28 kg CO_2e (GUL SCM).

Figure 5. CLF Baselines for CMU.

There is currently no CLF Baseline for general North American CMU since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information. Rather, there are a pair of CLF Baselines (by weight) for each of two Canadian regions based on the available industry EPDs.

CLF Calculations: The industry EPDs for Canadian CMU are divided by: region (reflected in the CLF Baseline categories, as regionality affects product availability), weight class (reflected in the CLF Baseline categories, as weight class affects performance), and cement ingredients (NOT reflected in the CLF Baseline categories, as these different ingredients provide alternative production paths to make functionally equivalent products). For each region–weight-class combination, there are two functionally equivalent subtypes of CMU – one made with GU (portland) cement and the other made with GUL (portland-limestone) cement. Given the functional equivalence, the CLF considers these two subtypes as one product type in this report.

To approximate an industry-average GWP value based on these two subtypes, the CLF calculated a simple unweighted average of the reported GWP from each industry EPD, rounded to two significant digits. While a production-weighted average of the reported GWP values for the two subtypes would be the best representation of the industry average, the CLF does not have production weighted data by subtype.

C1.4 Additional Notes and Guidance

Figure 6. Product EPDs by location.

Weights: Within the collection of product EPDs, the data are scattered between weight classes (normal-, medium-, and light-weight). See Figure 7.

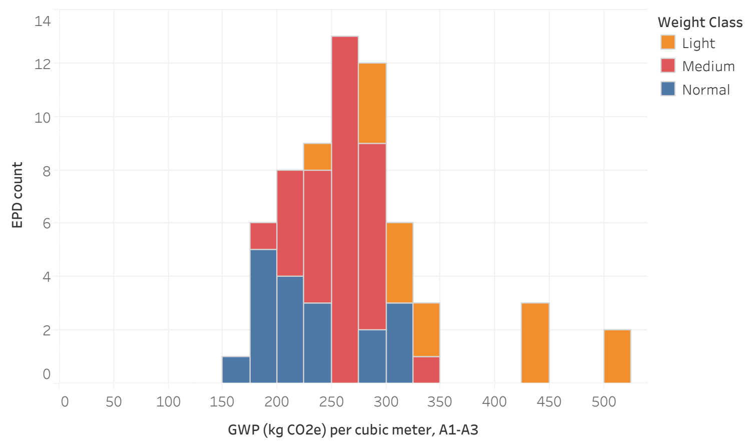


Figure 7. Distribution of product EPD GWP by weight class.

D1: STEEL FABRICATION

D1.1 Overview

This appendix provides background information and calculation methods related to steel product fabrication and its GWP impacts

Description

After a steel product is manufactured to its final shape (wide flange beam, HSS, etc.) and before it is installed at a construction project, it undergoes fabrication (cutting, drilling, bending, welding, bolting, etc.) to meet the particular requirements of the project where the product will be used.

Some EPDs – including both industry-wide and product EPDs – are for unfabricated products (sometimes referred to as cradle-to-gate mill products) and some are for fabricated products. There are two important differences between unfabricated and fabricated EPDs:

- **The scopes and corresponding lifecycle stages used to represent the analysis are different**, described below and in Figure 1.
    - **For an unfabricated product EPD:** A1 = steelmaking – the processing of input feedstock materials (e.g., iron ore, steel scrap) and transforming them in the furnace (BF/BOF or EAF) to produce semi-finished products such as steel billets or coil; A2 = transport of those semi-finished products to the steel product manufacturer; A3 = steel product manufacture from semi-finished product (e.g., billet) to final shape (e.g., wide flange beam) at the rolling mill (though the process is somewhat different depending on the product type – hot-rolled sections, HSS, etc.).
    - **For a fabricated product EPD:** A1 = the complete production of the unfabricated product (all of A1-A3 processes for the unfabricated product EPD described above); A2 = transport of the unfabricated product to the fabricator; A3 = fabrication to meet project-specific requirements.

	Steelmaking Iron ore and scrap to semi-finished products (e.g., billet)	**Transport**	**Shape manufacture** Semi-finished products to final unfabricated shapes	**Transport to fabricator**	**Fabrication** Specific to project needs (e.g., fabricated rebar)
Unfabricated product EPD	A1	A2	A3	N/A	N/A
Fabricated product EPD	A1	A1	A1	A2	A3

Figure 1. Major steps in steel product production and corresponding life cycle stages in EPDs. Depending on the product type and the facility, there may be intermediate steps not listed here, and in some cases, the steelmaking mill and rolling mill are situated at the same facility.

- **Fabrication scrap and quantity of material:** During the fabrication process, scrap is generated from cut-offs, drilling, etc., meaning it takes more than one metric ton of unfabricated product to ultimately yield one metric ton of fabricated product. This means that the quantity of material in a fabricated EPD's A1 stage is different from (i.e., more than) the quantity of material in an unfabricated EPD's A1-A3 stages. And because of this difference in quantity, it also means that a fabricated product's A1 GWP result does not align 1:1 with the A1-A3 GWP result of an unfabricated product EPD for the same product. This is because the fabricated product EPD accounts for additional material produced that will ultimately become scrap generated during fabrication. A fabricated product EPD assesses 1 metric ton of fabricated product. A1 inputs include:
  - the production of 1 metric ton unfabricated product that will ultimately be the 1 metric ton of fabricated product, and
  - the production of the additional unfabricated product that will ultimately become fabrication-generated scrap

For a fabricated product EPD, A3 (fabricator impacts) accounts only for the operational emissions related to the bending, welding, cutting, etc., and does NOT account for the scrap material generated during fabrication. That scrap is accounted for in A1 of a fabricated product EPD. This is diagrammed in Figure 2 below.

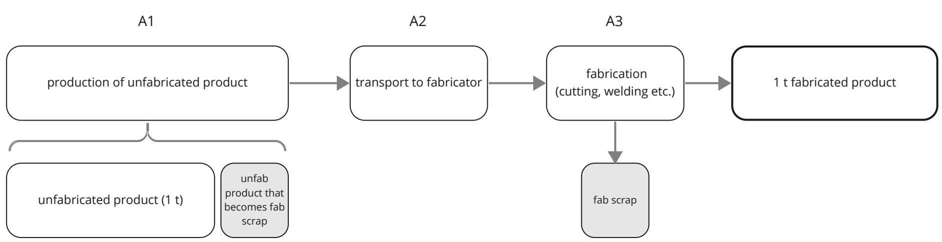


Figure 2. Life cycle stages and fabrication scrap in fabricated steel product EPDs.

D1.2 Calculation Methods

Given the relationship of data for unfabricated and fabricated products as reported in EPDs, there are scenarios where it is useful to convert between the two – i.e., to start with an unfabricated EPD and estimate the additional impacts for fabrication, or to start with a fabricated EPD and estimate the impacts attributable only to the unfabricated product. This conversion may be to allow for an apples-to-apples comparison between EPDs or between an EPD and a baseline/threshold. Or it may be to estimate impacts for modeling a project or assembly.

While the CLF developed the equations and variable names presented here, the underlying methods presented here are well established in the industry.[1] Default industry-average values and source references used in the calculations are provided in Figure 3.

1. California Department of General Services (DGS). (2022). *Buy Clean California Act legislative report.* https://www.dgs.ca.gov/Resources/Legislative-Reports

Category	GWP_FabA2A3 Industry-Average (kg CO_2e / metric ton)	FabScrapRate Industry-Average (unitless)	Sources
Rebar	76	1.033	GWP_FabA2A3: CRSI. (2022). Environmental product declaration - Steel reinforcement bar.[2] Fab scrap rate: Trugestad / CRSI personal communication.[3]
Hot-rolled sections	141	1.077	GWP_FabA2A3: AISC. (2021). Environmental product declaration - Fabricated hot-rolled structural sections.[4] Fab scrap rate: Sphera. (2021). EPD Background Report: Fabricated hot-rolled sections, plates, and hollow structural sections.[5]
Plate	141	1.077	GWP_FabA2A3: AISC. (2021). Environmental product declaration - Fabricated steel plate.[6] Fab scrap rate: Sphera. (2021). EPD Background Report: Fabricated hot-rolled sections, plates, and hollow structural sections.[5]
Hollow Structural Sections	141	1.082	GWP_FabA2A3: AISC). (2021). Environmental product declaration - Fabricated hollow structural sections.[7] Fab scrap rate: CLF calculation = IW-EPD_HSS_Fab_GWP_A1 / IW-EPD_HSS_Unfab_GWP_A1-A3 [7,8]

Figure 3. Industry-average values by steel category. GWP_FabA2A3 (GWP impacts for transport to fabricator and fabrication) and FabScrapRate (units of unfabricated product to yield 1 unit of fabricated product)

The industry-average values provided in Figure 3 are based on a very wide range of data points. Fabrication impacts and scrap rates vary significantly depending on the needs of the particular project. To illustrate the huge variability associated with fabrication-related impacts, the AISC's IW-EPDs for structural steel use 77.1 kg/t as an industry-average value for scrap generated during fabrication (i.e., for every 1000 kg of fabricated structural steel, there is on average 77.1 kg of fabrication-generated scrap). This industry-average value lies between a very spread-out distribution, where the 10th percentile is 7.77 kg/t and the 90th percentile is 158 kg/t. [5]

Calculation 1: Unfabricated Impacts to Fabricated Impacts

To start with an EPD for unfabricated product and estimate the impacts of that product after fabrication, the calculation involves: (1) accounting for the additional unfabricated material that would ultimately become fabrication scrap (by multiplying the unfabricated EPD's A1-A3 GWP value by an industry-average scrap rate factor) and then (2) adding on default (industry-average) impacts for A2 (transport to fabricator) and A3 (fabrication). The equation is:

$$GWP_{Fab} = \mathit{FabScrapRate} \times GWP_{UnFab} + GWP_{FabA2A3} \qquad (1)$$

where:

GWP_{Fab} = estimated GWP of fabricated product (kg CO_2e / metric ton)

GWP_{UnFab} = GWP of unfabricated product (kg CO_2e / metric ton)

2. Concrete Reinforcing Steel Institute (CRSI). (2022). *Environmental product declaration - Steel reinforcement bar. ASTM International.* https://www.crsi.org/wp-content/uploads/CRSI_Industry-Wide_EPD_Sep2022.pdf

3. Trygestad, A. (2022, December 4). CRSI, Personal communication [Personal interview].

4. American Institute of Steel Construction (AISC). (2021). *Environmental product declaration - Fabricated hot-rolled structural sections.* UL Environment. Retrieved from https://www.aisc.org/globalassets/why-steel/epd-aisc-hr-sections-2021.pdf

5. Sphera. (2021). *EPD Background Report: Fabricated hot-rolled sections, plates, and hollow structural sections.* AISC.

6. American Institute of Steel Construction (AISC). (2021). *Environmental product declaration - Fabricated steel plate. UL Environment.* Retrieved from https://www.aisc.org/globalassets/why-steel/epd-aisc-plate-2021.pdf

7. American Institute of Steel Construction (AISC). (2021). *Environmental product declaration - Fabricated hollow structural sections.* UL Environment. Retrieved from https://www.aisc.org/globalassets/why-steel/aisc_epd_fab-hss.pdf

8. Steel Tube Institute (STI). (2021). *Environmental product declaration - Hollow structural sections.* UL Environment. Retrieved from https://steeltubeinstitute.org/sti-hss-epd-26jul2021/

$FabScrapRate$ = industry average rate of scrap material generated during fabrication, expressed as the quantity of units (e.g., metric tons) of unfabricated steel needed to yield 1 unit of fabricated steel product.

$GWP_{FabA2A3}$ = industry-average impacts for A2 (transport from manufacturer to fabricator) and A3 (fabricator impacts) (kg CO_2e / metric ton)

Industry average GWPFabA2A3 and FabScrapRate values per material type are provided in Figure 3.

Example: To estimate the total fabricated product impact based on an EPD for unfabricated hot-rolled sections, use the EPD's A1:A3 GWP value for GWPUnFab in the following equation.

$$GWP_{Fab} = 1.077 \text{ X } GWP_{UnFab} + 0.141$$

Calculation 2: Fabricated impacts to unfabricated impacts

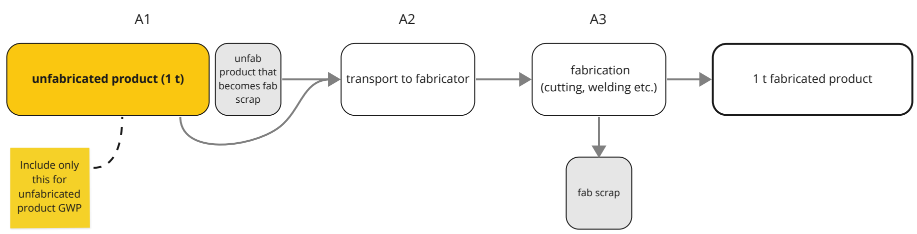


Figure 4. Isolating the unfabricated impact from a fabricated product EPD. A1 in the fabricated product EPD includes more than 1 metric ton of unfabricated product to account for fabrication-generated scrap.

To start with an EPD for fabricated product (1 metric ton) and convert to the impacts of that product before fabrication (1 metric ton), the calculation involves the following two steps that correspond to the two notable differences between unfabricated and fabricated EPDs described above:

- Isolate the A1 GWP value of the fabricated product EPD. This describes the production of unfabricated (cradle-to-gate mill) product before any fabrication. This A1 GWP value accounts for more than 1 metric ton of unfabricated product (as it includes the production of additional material that ultimately becomes scrap generated during fabrication).
- Account for the fabrication scrap, in order to arrive at the GWP for 1 metric ton of unfabricated product. To account for this difference, divide the A1 GWP value by the assumed fabrication scrap rate.

The general equation is:

$$GWP_{UnFab} = GWP_{FabA1} / FabScrapRate \qquad (2)$$

Where:

GWP_{UnFab} = GWP of unfabricated product (kg CO_2e/ metric ton)

GWP_{FabA1} = reported A1 GWP for a fabricated product EPD (kg CO_2e/ metric ton)

FabScrapRate = industry average rate of scrap material generated during fabrication, expressed as the number of units (e.g., metric tons) of unfabricated steel needed to yield 1 unit of fabricated steel product.

Example: Convert GWP of 1 metric ton unfabricated product using the AISC hot-rolled sections IW-EPD.

GWP_{FabA1} = 1080 kg CO_2e (reported in the IW-EPD)

FabScrapRate = 1.077 (as documented in Figure 3)

Thus,

GWP_{UnFab} = 1080 / 1.077 ≈ 1003 kg CO_2e / metric ton unfabricated hot-rolled sections

Note: This equation (2) is the calculation method the CLF used to estimate CLF Baseline GWP values for unfabricated hot-rolled sections and unfabricated steel plate.

D1.3 Steel Fabrication and CLF Baselines

The CLF provides separate baseline GWP values for unfabricated and fabricated products for the categories of rebar, hot-rolled sections, steel plate, and hollow structural sections (HSS). This is different from past versions of the CLF Material Baselines which did not distinguish between these data sources. The distinction aims to provide more well-defined, accurate, and comparable baseline GWP values.

D2: REBAR

D2.1 Category Overview

Category Description

Steel reinforcement bar (rebar) is used in buildings and infrastructure to resist tension forces in reinforced concrete and reinforced masonry structures. The rebar surface is often deformed with ribs or indentations to promote a better bond with concrete and reduce the risk of slippage.[1] The CLF Baseline GWP value applies to carbon steel and low-alloy steel bars of varying sizes and grades. Zinc-coated, stainless steel, and epoxy-coated bars for specialty applications are not included in the scope due to a lack of available information.

Production Processes and Key Drivers of Carbon Emissions

In North America, rebar is produced primarily from secondary steel in electric arc furnaces (EAFs).[2] Molten steel is cast into billet shapes, which go to the rolling mill. At the rolling mill, these shapes are typically re-heated and passed through rollers to reduce the shape to the appropriate size and add ribs. Coatings are added if applicable. The unfabricated rebar goes to the fabricator for final fabrication (cutting, bending, welding, etc.) based on the needs of the particular project where it will be used. There are CLF Baseline GWP values for both unfabricated and fabricated rebar.

The type of furnace used to produce steel is the most important driver of total GWP for rebar. Steel can be produced using either an electric arc furnace from recycled steel or using a basic oxygen furnace (BOF) with primary steel produced in a blast furnace. EAF-produced steel generally has a much lower carbon impact than BOF-produced steel. The hot-rolling process also contributes to the GWP of the final product. Other factors that influence GWP for steel production are the percentage of scrap steel used and the emissions intensity of the electric grid where the steel is produced (when an EAF is used) and milled. According to the industry-wide EPD, nearly all rebar produced in the USA is made with a high percentage of recycled steel (~98%) in an electric arc furnace.[1]

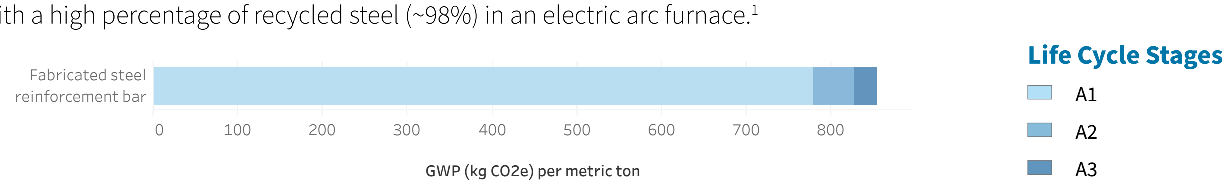


Figure 1. GWP contribution by life cycle stage. Based on the industry EPD for fabricated rebar, where A1 = steelmaking and hot-rolling to produce unfabricated rebar; A2 = transport to fabricator; and A3 = fabrication.

D2.2 Data Availability and Representativeness

PCR

UL Environment. (2002). *Product category rule (PCR) guidance for building-related products and services part B: Designated steel construction product EPD requirements*.[3]

1. Much of the language in the first two sections of this appendix comes directly from the CLF's 2022 BCCA Limits report.

2. Carbon Leadership Forum. (2022). *Buy Clean California Limits.* https://carbonleadershipforum.org/buy-clean-california-limits/

Industry EPDs

Concrete Reinforcing Steel Institute (CRSI). (2022). *Environmental product declaration - Steel reinforcement bar.* ASTM International. [4]

> This industry EPD is based on data from 19 steel mills (5 companies) and 17 fabrication facilities (10 companies) in the USA, including a mix of geographic locations in all four continental US time zones. The proportion of total North American production is not disclosed. The EPD provides the range of fabrication facility GWP results, including the minimum, maximum, mean, and median facility GWP across all facilities in their study.

Product EPDs

There are currently 20 applicable* product EPDs for unfabricated rebar and 14 for fabricated rebar. This count excludes some North American product EPDs that use a different PCR from the primary one listed above.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

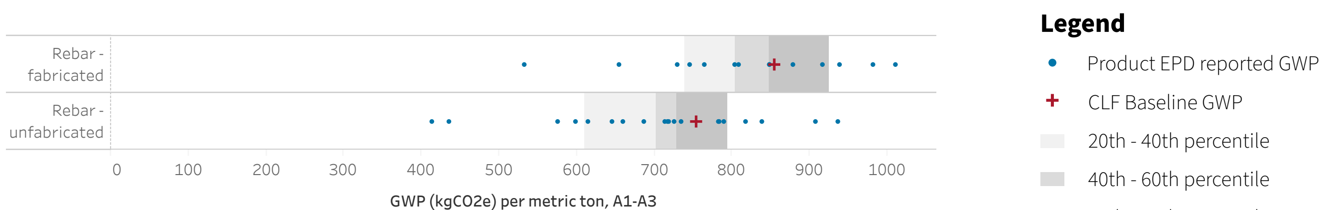


Figure 2. Range of applicable product EPDs and CLF Baselines.

	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
Rebar - fabricated	532	739	804	828	848	925	1010	818	854
Rebar - unfabricated	413	611	702	717	729	795	936	704	753

Figure 3. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per metric ton, A1-A3).

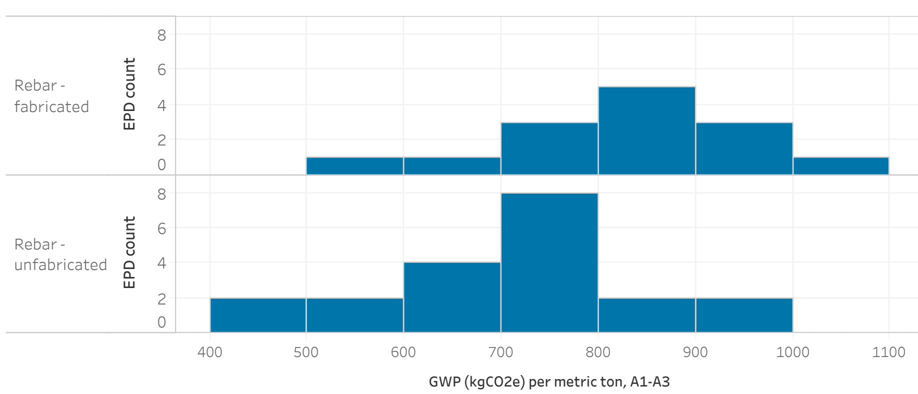
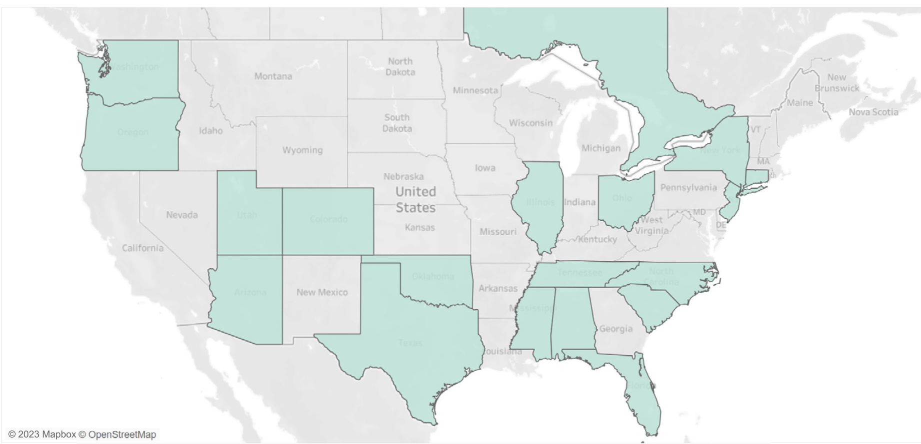


Figure 4. Distribution of applicable product EPDs.

D2.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Unfabricated rebar	753	Industry	CRSI. (2022). *Environmental product declaration - Steel reinforcement bar.* Converted to unfabricated product GWP.
Fabricated rebar	854	Industry	CRSI. (2022). *Environmental product declaration - Steel reinforcement bar.*

Figure 5. CLF Baselines for rebar.



Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 6. Product EPDs by location.

Conversion to unfabricated product GWP. The CLF used the following calculation method to convert from the industry-wide EPD's published GWP value for fabricated rebar to the industry-average GWP value for unfabricated rebar.

$$GWP_{UnFab} = GWP_{FabA1} \, / \, FabScrapRate$$

Where:

GWP_{UnFab} = GWP of unfabricated product (kg CO_2e/ metric ton)

GWP_{FabA1} = reported A1 GWP for a fabricated product EPD (kg CO_2e/ metric ton)

FabScrapRate = industry average rate of scrap material generated during fabrication, expressed as the number of units (e.g., metric tons) of unfabricated steel needed to yield 1 unit of fabricated steel product.

Figure 7 provides each of these three values for rebar. See Appendix D1 Steel Fabrication for further discussion on fabricated and unfabricated steel product EPDs and the calculation method.

Product Type	GWP_Fab_A1 (kg CO_2e per metric ton)	Fab Scrap Rate	GWP_UnFab (kg CO_2e per metric ton)
Rebar	778	1.0327	753
Source	CRSI. (2022). *Environmental product declaration - Steel reinforcement bar.*	Trygestad, A. (2022). Personal correspondence from CRSI.	GWP_Fab_A1 / FabScrapRate

Figure 7. Reported and converted GWP for steel product types, including scrap rate.

D3: STEEL WIRE AND MESH

D3.1 Category Overview

Steel wire and mesh (also called welded reinforcement concrete mesh and welded construction mesh) is typically used for concrete reinforcement to provide tensile strength, similar to rebar. Mesh is made from the semi-finished product hot-rolled steel wire (also called wire rod), which generally is produced in coils.

D3.2 Data Availability and Representativeness

PCR

UL Environment. (2020). *Product category rule (PCR) guidance for building-related products and services part B: Designated steel construction product EPD requirements*. [1]

Industry EPDs: None

Product EPDs

This category is pilot in the EC3 database (i.e., not visible to most users). There is currently one marginally applicable* product EPD for this category. There is one additional North American EPD based on a European PCR. Both of the EPDs are for wire rod (and not the finished product of steel wire mesh).

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

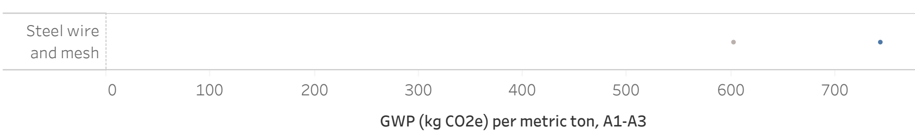
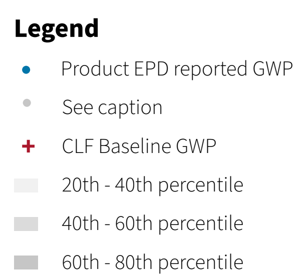


Figure 1. Range of marginally applicable product EPDs. The blue dot is for the EPD conforming to the North American PCR. The grey dot is for the EPD conforming to a different PCR, shown for reference. Neither are for steel wire and mesh, but are for wire rod (a precursor product to wire and mesh).



Due to the lack of applicable product EPDs for this category, this appendix does not include the summary statistics table, histogram, or map that appears in many of the other appendices in this report.

D3.3 CLF Baseline

There is no 2023 CLF Material Baseline for steel wire and mesh since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

D3.4 Additional Notes and Guidance

Past versions of the CLF Material Baselines have provided Baseline GWP values for steel wire and mesh using the rebar category as proxy. CLF was unable to confirm whether this is an appropriate proxy for this report and may have more time and resources to consult with industry professionals in future updates of this report.

D4: STRUCTURAL STEEL

D4.1 Category Overview

Category Description

Structural steel is a broad family of carbon steel product types for structural uses, specified by ASTM standards for building construction, including the following main categories:

Hot-rolled sections: a family of hot-rolled structural steel products of various sizes and (non-hollow) shapes including: wide flange beams, standard beams, miscellaneous beams, channels, angles, and tees.

Plate: a family of flat steel products commonly produced through hot rolling and with multiple layers compressed together, generally thicker than 6 mm or ¼”.

Hollow structural sections (HSS): a family of hollow structural shapes of varying cross-section shapes – typically circular, square, or rectangular – used in various structural applications.

Production Processes and Key Drivers of Carbon Emissions

In North America, structural steel is produced primarily from secondary steel in electric arc furnaces (EAFs), where molten steel is cast into semi-finished products such as billets. These billets go to the rolling mill where they are reheated and rolled into structural shapes (in the case of hot-rolled sections) or steel coil, which is later transformed into steel plate or HSS.

The unfabricated product goes to a fabricator who transforms (e.g., cuts, bends, welds, etc.) the standard shape to produce the fabricated product that meets the particular needs of the construction project where it will be used. There are CLF Baseline GWP values for both unfabricated and fabricated structural steel products.

Of the three types, hot-rolled sections typically have the lowest GWP per unit of mass, as their production process has fewer steps. For plate and HSS, there are additional intermediary steps, and these product types typically have relatively higher GWP per unit of mass. Plate is often composed of multiple hot-rolled sheets produced from coil, which are then compressed and heated to form a single plate. HSS is produced from steel coil that is flattened, roll-formed into the appropriate shape, then welded along a seam.

For unfabricated product EPDs, A1 accounts for steelmaking using blast furnace/basic oxygen furnace (BF-BOF) and/or electric arc furnace (EAF) technologies to transform inputs of iron ore and/or scrap into semi-finished products such as steel billets or coil.

A3 accounts for the manufacture of the final shapes, involving re-heating, rolling, and additional processes depending on the product type.

For fabricated EPDs, A1 includes steelmaking AND rolling into final shapes. A3 accounts for fabricating the final shapes for the specific application of the building project – cutting drilling, bolting, welding, bending, etc. See Appendix D1 Steel Fabrication for further discussion of steel fabrication impacts.

In all cases, the vast majority of impacts are due to the steelmaking process, where inputs of scrap and ore are heated in a furnace. EAF – the steelmaking route most commonly used in North America – is a lower-GWP process than BF-BOF. Products may contain a mix of steel from upstream suppliers, meaning that a given product may include a mix of BOF- and EAF-produced steel. On average, fabrication makes up a relatively small contribution to overall impacts. But fabrication-related impacts (including impacts from fabrication operations and the additional steel production for the cut-off material that becomes fabrication-generated scrap) vary significantly depending on the particular needs of the project.

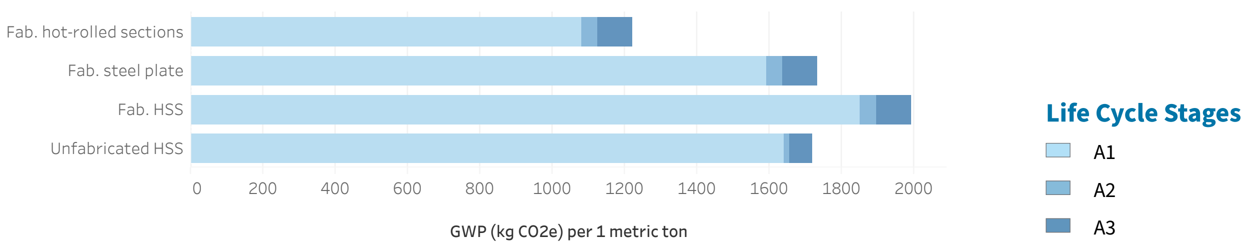


Figure 1. GWP Contribution by Life Cycle Stage. For the three fabricated product types, A1 = making of the steel shape including steel production, hot rolling, and additional production steps for plate and HSS; A2 = transport to fabricator; A3 = final fabrication. For the unfabricated HSS, A1 = steelmaking to coil production; A3 = HSS manufacture.

D4.2 Data Availability and Representativeness

PCR

UL Environment. (2020). *Product category rule (PCR) guidance for building-related products and services part B: Designated steel construction product EPD requirements*.

Industry EPDs

American Institute of Steel Construction (AISC). (2021). *Environmental product declaration - Fabricated hot-rolled sections.* UL Environment.

> This IW-EPD is based on three North American producers which together constitute 90% of North American production.[1]

American Institute of Steel Construction (AISC). (2021). *Environmental product declaration - Fabricated steel plate.* UL Environment.

> This IW-EPD is based on three (out of four total) major US producers, which constitute approximately 70-80% of North American steel plate production (including for construction and non-construction uses). [2]

1. Cross, J. & Puchtel, M. (2021, November 29). AISC, Personal communication [Personal interview].

2. Cross, J. & Puchtel, M. (2022, January 12). AISC, Personal communication [Personal interview].

American Institute of Steel Construction (AISC). (2021). *Environmental product declaration - Fabricated hollow structural sections.* UL Environment.

Steel Tube Institute (STI). (2021). *Environmental product declaration - Hollow structural sections*. UL Environment.

The two IW-EPDs for HSS (unfabricated and fabricated) are based on eight (out of approximately 10-12 total) North American manufacturers which together constitute approximately 60-65% of North American production.[1]

For each of the fabricated steel product industry EPDs listed here, the EPD includes information about the distribution of GWP across the facilities studied, including minimum, maximum, mean, and median (though this only reflects the range of fabricator data points, with steelmaking impact considered consistent across fabricator facilities).

Product EPDs

In the EC3 database there are currently 21 applicable* product EPDs for structural steel, including 2 for unfabricated hot-rolled sections, 4 for fabricated hot-rolled sections, 3 for unfabricated plate, 2 for fabricated plate, 5 for unfabricated HSS, and 5 for fabricated HSS (the HSS EPDs are all from one manufacturer.) This count excludes some North American product EPDs that use a different PCR from the primary one listed above.

*Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

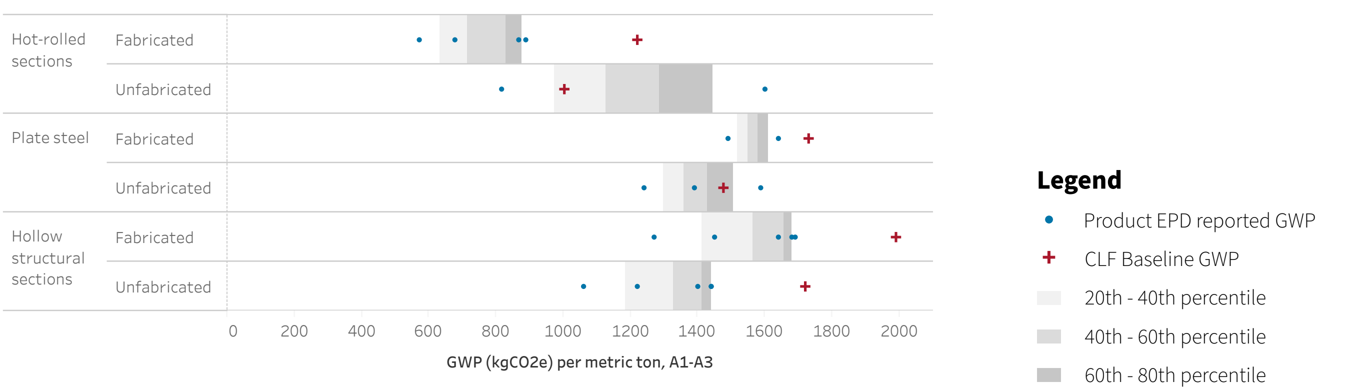


Figure 2. Range of marginally applicable product EPDs.

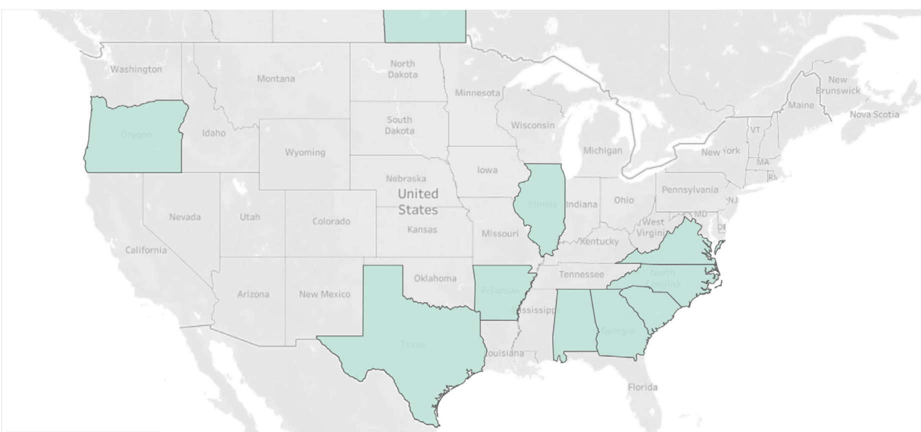
Due to the low number of applicable product EPDs for these product types, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

D4.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Hot-rolled sections - unfabricated	1,000	Industry	AISC. (2021). *Environmental product declaration - Fabricated hot-rolled sections.* Converted to unfabricated product GWP.
Hot-rolled sections - fabricated	1,200	Industry	AISC. (2021). *Environmental product declaration - Fabricated hot-rolled sections.*
Plate steel - unfabricated	1,480	Industry	AISC. (2021). *Environmental product declaration - Fabricated steel plate*. Converted to unfabricated product GWP.
Plate steel - fabricated	1,730	Industry	AISC. (2021). *Environmental product declaration - Fabricated steel plate*.
Hollow structural sections - unfabricated	1,710	Industry	STI. (2021). *Environmental product declaration - Hollow structural sections.* Converted to unfabricated product GWP.
Hollow structural sections - fabricated	1,990	Industry	AISC. (2021). *Environmental product declaration - Fabricated hollow structural sections.*

Figure 3. CLF Baselines for Structural Steel.

D4.4 Additional Notes and Guidance



Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 4. Product EPDs by location.

Conversion to unfabricated product GWP. The CLF used the following calculation method to convert from the industry-wide EPDs' published GWP values for fabricated hot-rolled sections and steel plate to the industry-average GWP values for unfabricated hot-rolled sections and steel plate.

$$GWP_{UnFab} = GWP_{FabA1} / \mathit{FabScrapRate}$$

Where:

GWP_{UnFab} = GWP of unfabricated product (kg CO_2e/ metric ton)

GWP_{FabA1} = reported A1 GWP for a fabricated product EPD (kg CO_2e/ metric ton)

FabScrapRate = industry average rate of scrap material generated during fabrication, expressed as the number of units (e.g., metric tons) of unfabricated steel needed to yield 1 unit of fabricated steel product.

Figure 5 provides each of these three values for the two product types where CLF followed this conversion method to establish CLF Baseline values for unfabricated structural steel products. See Appendix D1 Steel Fabrication for further discussion on fabricated and unfabricated steel product EPDs and the calculation method.

Product Type	**GWP_Fab_A1** (kg CO_2e per metric ton)	**Fab Scrap Rate**	**GWP_UnFab** (kg CO_2e per metric ton)
Hot-rolled sections	1,080	1.077	1,000
Seel plate	1,590	1.077	1,480
Source	AISC. (2021). *Environmental Product Declaration: Fabricated Hot-Rolled Structural Sections*. (Industry AISC. (2021). *Environmental Product Declaration: Fabricated Steel Plate*.	Sphera. (2021). *EPD Background Report: Fabricated hot-rolled sections, plates, and hollow structural sections*.	GWP_Fab_A1 / FabScrapRate

Figure 5. Reported and converted GWP for steel product types, including scrap rate.

D5: COLD-FORMED STEEL FRAMING

D5.1 Category Overview

Category Description

This category includes hot-dipped galvanized cold-formed steel framing members for walls, floors, ceilings, and roofs. This includes C-shape studs and track, joists, rafters, channels, angles, flat straps, and other shapes.[1]

Production Processes and Key Drivers of Carbon Emissions

The primary contributor to cold-formed steel framing GWP is the steelmaking process – a combination of electric arc furnace (EAF) and basic oxygen furnace (BOF). The steel is rolled into coil and undergoes hot-dip galvanization. The hot-dipped galvanized steel coil is transported to the framing manufacturing facility, where the coil is slit and fed into a rollformer which forms the studs, track, and other framing product shapes.[1]

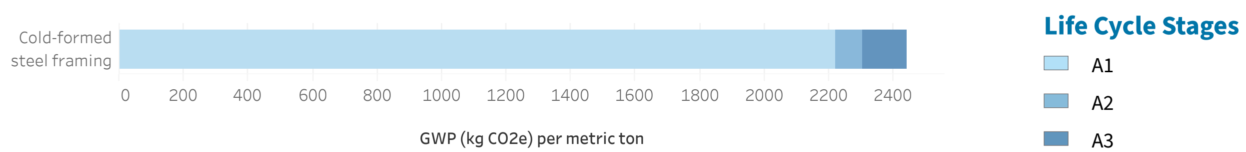


Figure 1. GWP Contribution by Life Cycle Stage. A1 = steelmaking, rolling into coil, hot-dip galvanization; A2 = transport of hot-dipped galvanized coil to manufacturing facility; A3 = manufacture of steel framing members via roll forming.

D5.2 Data Availability and Representativeness

PCR

UL Environment. (2020). *Product category rule (PCR) guidance for building-related products and services part B: Designated steel construction product EPD requirements.*

Industry EPDs

Steel Framing Industry Association (SFIA). (2021). *Environmental product declaration - Cold-formed steel framing. UL Environment.*

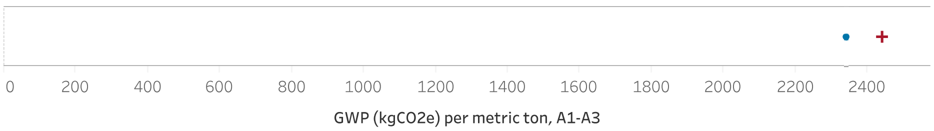
> This industry EPD is based on a production-weighed average of data from ten North American cold-formed steel framing manufacturing companies, with one manufacturing facility for each company. The proportion of total North American production used as primary data in the EPD is not disclosed. The EPD provides the range of facility GWP results in their data set, including the minimum, maximum, mean, and median facility GWP across all facilities in their study.

Product EPDs

There is currently one applicable* product EPD for cold-formed steel framing. There are four additional currently valid North American EPDs that are based on an expired PCR.

1. Steel Framing Industry Association (SFIA). (2021). *Environmental product declaration - Cold-formed steel framing.* UL Environment. https://www.cfsteel.org/assets/TechFiles/SCS-EPD-07103_SFIA_012522.pdf

*Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.



Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

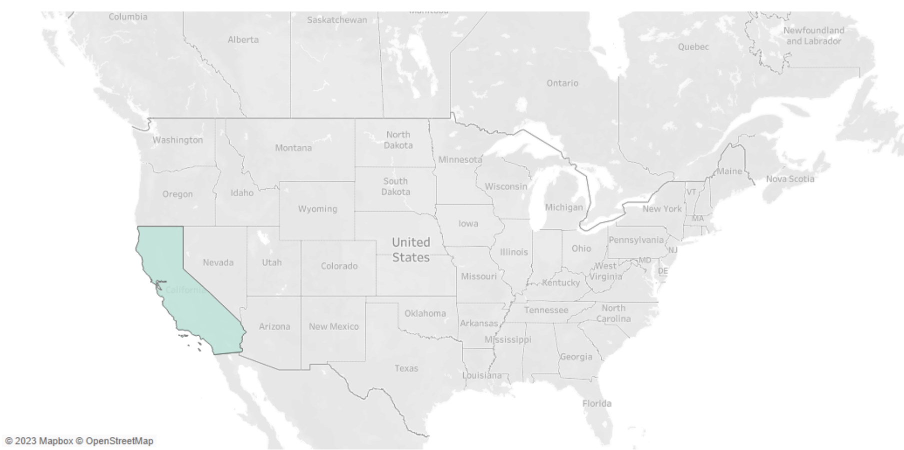
Figure 2. Range of applicable product EPDs and CLF Baseline.

Due to the lack of product EPDs in this category, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

D5.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Cold-formed steel framing	2,440	Industry	Steel Framing Industry Association (SFIA). (2021). *Environmental product declaration - Cold-formed steel framing.*

Figure 3. CLF Baselines for cold-formed steel framing.



Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

D5.4 Additional Notes and Guidance

Figure 4. Product EPDs by location.

D6: OPEN-WEB STEEL JOISTS

D6.1 Category Overview

Category Description

This category includes open-web steel joists (OWSJ) and joist girders which are prefabricated, welded products used to support roof and floor decks in the framing of buildings. They are custom engineered to meet the specific needs of a building application. Open-web steel joints are secondary framing members and range between 254 mm - 3048 mm (10" - 120") deep. Joist girders are primary framing members and range between 508 mm - 3048 mm (20" - 120") deep. This report considers these subtypes as one product type in alignment with the industry EPD.[1]

Production Processes and Key Drivers of Carbon Emissions

Steel joists are manufactured nearly entirely from welded structural steel, with a small amount of paint, and consist of five main components: top and bottom chords, end web and interior web members, and bearing seats. The manufacturer cuts, bends, and finally assembles the component parts to form the joists. The major contributor to OWSJ cradle-to-gate GWP is the production of the rolled steel shapes that form the OWSJ components, corresponding with A1 impacts. The GWP of the production of the shapes, in turn, is dominated by the steel mill process, though the hot-rolling to form the final shapes also contributes (see the structural steel appendix for further details.) OWSJ assembly (A3) – primarily the welding – also contributes to overall GWP. The A3 GWP impact for this category is relatively large compared to other steel product types in this report.[1]

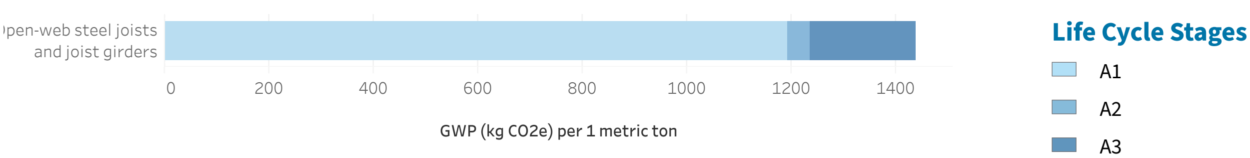


Figure 1. GWP Contribution by Life Cycle Stage. A1 = steel making and hot rolling to produce structural steel shapes; A2 = transport to OWSJ manufacturing facility; A3 = fabrication of OWSJ.

D6.2 Data Availability and Representativeness

PCR

UL Environment. (2020). *Product category rule (PCR) guidance for building-related products and services part B: Designated steel construction product EPD requirements.*

Industry EPDs

Steel Joist Institute (SJI). (2022). *Environmental product declaration - Open web steel joists and joist girders.* UL Environment.

This industry EPD is based on data from three North American OWSJ manufacturing companies and North American-manufactured steel. The proportion of total North American production used as primary data in the EPD is not disclosed. The EPD

1. Steel Joist Institute (SJI). (2022). *Environmental product declaration - Open web steel joists and joist girders. UL Environment.* https://steeljoist.org/wp-content/uploads/2022/02/101.1_SJI_EPD_2022-Steel-Joist_022122.pdf

provides the range of facility GWP results in their data set, including the minimum, maximum, mean, and median facility GWP across all facilities in their study.[1]

Product EPDs

There is currently one applicable* product EPD for open-web steel joists.

*Applicable product EPDs are are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

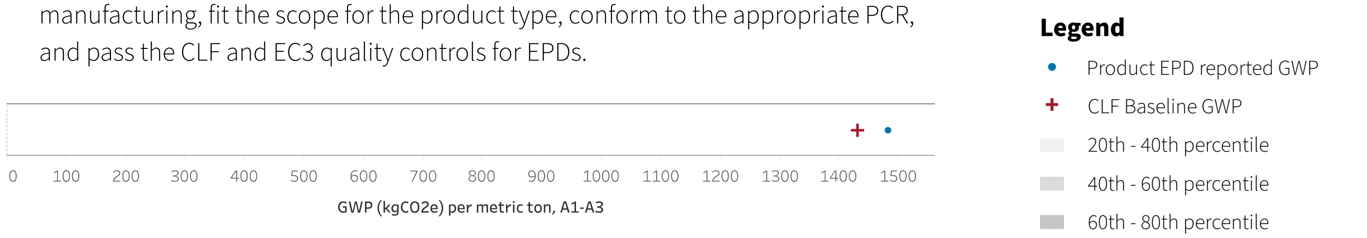


Figure 2. Range of applicable product EPDs and CLF Baseline.

Due to the lack of product EPDs in this category, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

D6.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Open-web steel joists	1,430	Industry	Steel Joist Institute (SJI). (2022). *Environmental product declaration - Open web steel joists and joist girders.*

Figure 3. CLF Baselines for cold-formed steel framing.

D6.4 Additional Notes and Guidance

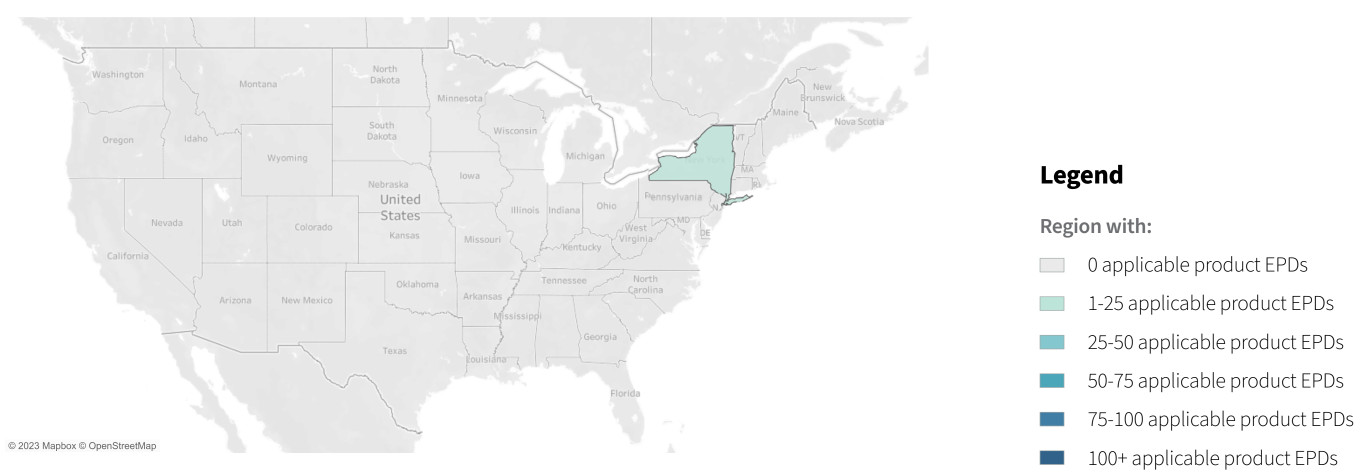


Figure 4. Product EPDs by location.

D7: STEEL DECKING

D7.1 Category Overview

Category Description

Steel deck products are panels with a repeating pattern of parallel ribs that serve as the form and/or positive reinforcement for concrete floor and roof slabs, or as the primary supporting surface for roofing materials. They can be produced as galvanized or uncoated panels (to which paint can be later applied). Typical steel decking panels are 38 - 76 mm (1½" - 3") in depth and manufactured from 22 - 16 gauge material.[1]

Production Processes and Key Drivers of Carbon Emissions

The primary contributor to steel decking GWP is the steel making process. The steel is rolled into coil and in some cases undergoes hot-dip galvanization. (In cases where the decking is manufactured from uncoated steel coil, the decking is eventually painted.) The steel coil is transported to the decking manufacturing facility, where the coil is rolled (or otherwise formed) into specific deck profiles.[1]

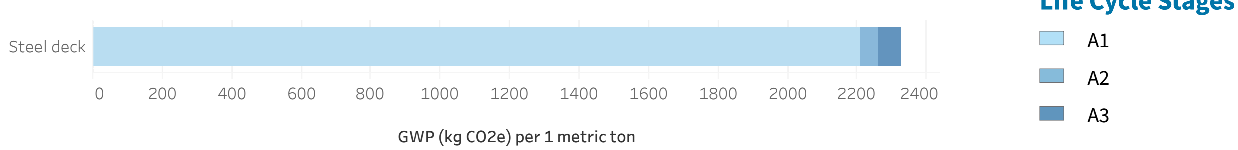


Figure 1. GWP contribution by life cycle stage. A1 = steel making, rolling into coil, hot-dip galvanization; A2 = transport of steel coil to manufacturing facility; A3 = manufacture of steel decking.

D7.2 Data Availability and Representativeness

PCR

UL Environment. (2020). *Product category rule (PCR) guidance for building-related products and services part B: Designated steel construction product EPD requirements.*

Industry EPDs

Steel Deck Institute. (2022). *Environmental product declaration - Steel roof and floor deck.* UL Environment.

> This industry EPD is based on a production-weighted average of data from 18 North American steel deck manufacturing companies in the United States, and based on steel produced in North America. The proportion of total North American production is not disclosed. The EPD provides the range of facility GWP results in their data set, including the minimum, maximum, mean, and median facility GWP across all facilities in their study.[1]

Product EPDs

There are currently 12 applicable* product EPDs for steel decking.

> *Applicable product EPDs are are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

1. Steel Deck Institute. (2022). *Environmental product declaration - Steel roof and floor deck.* UL Environment. https://www.sdi.org/wp-content/uploads/2022/02/101.1_SDI_EPD_2022-Steel-Deck.pdf

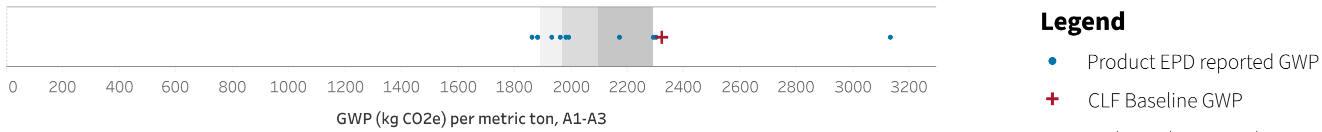


Figure 2. Range of applicable product EPDs and CLF Baseline.

Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
1,860	1,890	1,968	1,985	2,098	2,291	3,130	2,138	2,320

Figure 3. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per metric ton), A1-A3.

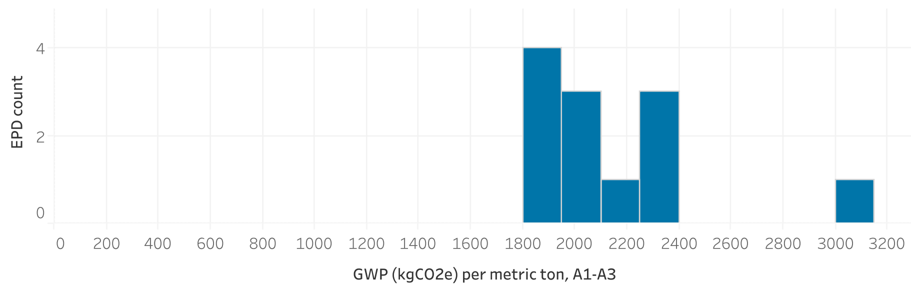


Figure 4. Distribution of applicable product EPDs.

D7.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Steel decking	2,320	Industry	Steel Deck Institute. (2022). *Environmental product declaration - Steel roof and floor deck.*

Figure 5. CLF Baselines for steel decking.

D7.4 Additional Notes and Guidance

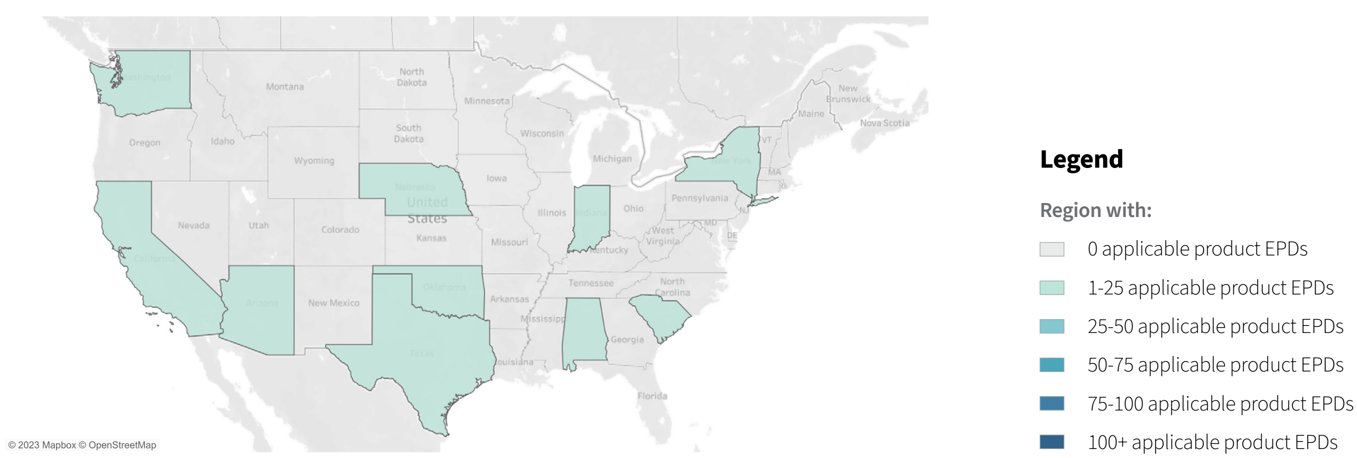


Figure 6. Product EPDs by location.

Comparability

The declared unit for this category is 1 metric ton, as steel production impacts generally scale with mass. However, this category includes galvanized products, and galvanization impacts scale with surface area rather than mass (therefore a relatively thicker decking product will have relatively less galvanization impact per unit mass). So total impact is a function of both mass and surface area. In the future, depending on data availability, the CLF may establish Baselines for this category that account for both mass and surface area. In the meantime, users should be aware of this issue as it relates to the appropriate (or inappropriate) comparability of products based on GWP.

E1: ALUMINUM EXTRUSIONS

E1.1 Category Overview

Category Description

This category includes aluminum extrusion products of various types and surface treatments. In alignment with the industry-wide EPDs, the following categories are included in this report:

- Standard (non-thermally-improved) aluminum extrusions [1]
  - Mill finish
  - Painted (liquid and powder paint)
  - Anodized
- Thermally-improved aluminum extrusions [2]
  - Painted (liquid and powder paint)
  - Anodized

Standard non-thermally-improved extrusion products are used for a variety of applications that do not require thermal insulating qualities, such as in canopies, louvers, and interior partitions. Thermally-improved extrusion products are used in window, door, curtainwall, and other building envelope applications. These products have a non-metal (polyurethane or polyamide) thermal break that limits heat transfer across the assembly.[2]

Production Processes and Key Drivers of Carbon Emissions

Most of the total GWP impact is from the electricity-intensive primary aluminum production process that yields semi-finished products such as billets (A1). The amount of virgin vs. recycled aluminum and the source of the electricity for aluminum production are the largest contributing factors to the variation of GWP between different products. A3 includes the extrusion process (reheating the billet in a furnace, extrusion, cooling, and cutting), surface treatment application (painting or anodizing), and thermal improvement where relevant.

Recycling at the end of a product's useful life is accounted for as a credit in Module D, as seen in Figure 1. The industry EPDs assume an end-of-life recycling rate of 95%. [1,2]

1. Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Aluminum extrusions - mill finished, painted, and anodized.* UL Environment. https://aec.org/sites/default/files/2022-11/102.1_EPD_AEC_2022_Al_Ext_Mill_Paint_Anod.pdf

2. Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Thermally improved aluminum extrusions - painted and anodized.* UL Environment. https://aec.org/sites/default/files/2022-11/101.1_EPD_AEC_2022%20Thermally%20Treated.pdf

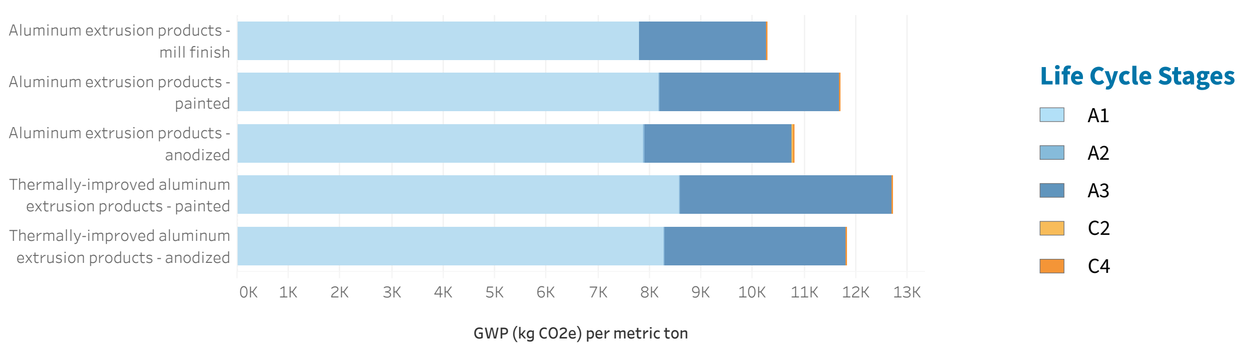


Figure 1. GWP contribution by life cycle stage. A1 = primary aluminum production and processing of recycled aluminum to create semi-finished products; A2 = transport of semi-finished products to extrusion manufacturing facility; A3 = extrusion, thermal improvement, surface treatment; C2 = end-of-life transport; C4 = disposal. A2, C2, and C4 are not visible or barely visible in this chart due to their relatively small values. D stage impacts are also included in the industry EPDs but are excluded here.

E1.2 Data Availability and Representativeness

PCR

UL Environment. (2022). *Part B: Aluminum construction product EPD requirements.*

Industry EPDs

Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Aluminum extrusions - mill finished, painted, and anodized.* UL Environment.

Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Thermally improved aluminum extrusions - painted and anodized.* UL Environment.

> Extrusion production from the two AEC industry EPD participants constitutes 38% of total North American aluminum extrusion production in 2020.

Product EPDs

There are currently two applicable* product EPDs for aluminum extrusions – both for standard (non-thermally improved) painted extrusion products.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

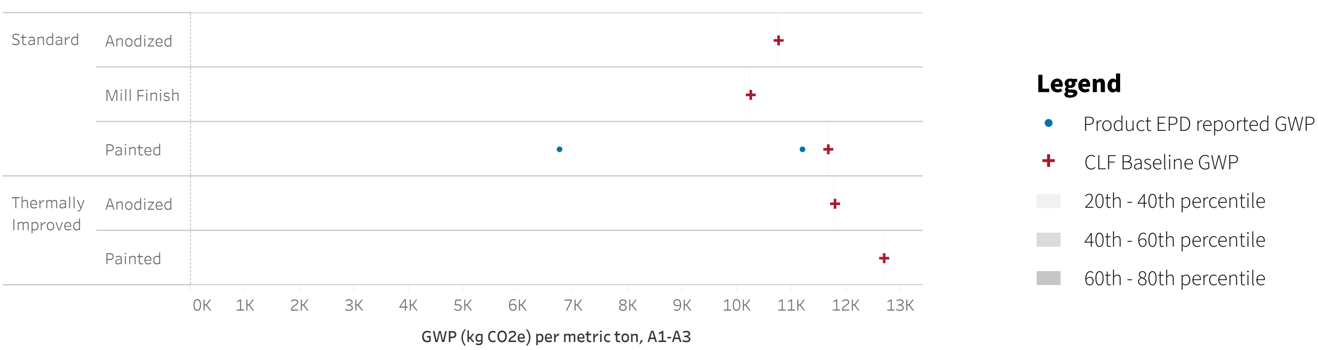


Figure 2. Range of applicable product EPDs and CLF Baselines.

Due to the low number of applicable product EPDs for these product types, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

E1.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 metric ton)	Method	Data Source and Notes
Aluminum extrusions - mill finish	10,250	Industry	Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Aluminum extrusions - mill finished, painted, and anodized.* UL Environment.

Aluminum extrusions - painted	11,670	Industry	Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Aluminum extrusions - mill finished, painted, and anodized.* UL Environment.
Aluminum extrusions - anodized	10,760	Industry	Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Aluminum extrusions - mill finished, painted, and anodized.* UL Environment.
Thermally-improved aluminum extrusions - painted	12,700	Industry	Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Thermally improved aluminum extrusions - painted and anodized.* UL Environment.
Thermally-improved aluminum extrusions - anodized	11,800	Industry	Aluminum Extruders Council (AEC). (2022). *Environmental product declaration - Thermally improved aluminum extrusions - painted and anodized.* UL Environment.

Figure 3. CLF Baselines for aluminum extrusion products.

E1.4 Additional Notes and Guidance

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 4. Product EPDs by location.

Comparability

Depending on the context, painted and anodized products may be functionally equivalent and appropriately compared. Note that different surface treatments (including different types of paints and anodizing) provide similar but not the same performance.

F1: WOOD FRAMING

F1.1 Category Overview

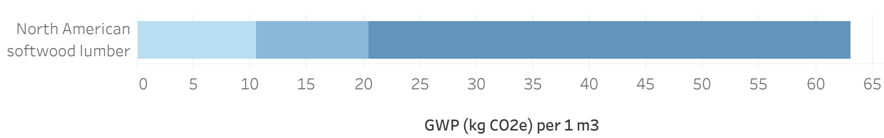
Category Description

Wood framing products are used to frame walls, floors, and roofs in residential and commercial construction. They are available in a range of widths, lengths, and thicknesses and are typically made from softwood lumber. This material category covers a range of dimensional lumber sizes and is weighted towards 2x4s and 2x6s, which comprise the bulk of production.[1]

Production Processes and Key Drivers of Carbon Emissions

The primary scope of the North American industry-wide EPD for softwood lumber is the product stage (A1-A3), with some additional life cycle stage information regarding biogenic carbon. Life cycle stage A1 includes forestry practices such as thinning, fertilization, logging, seedling growth, and replanting. Trees are typically harvested (by chainsaw, harvester, or feller buncher), delimbed, then bucked before they are moved to a landing site. The logs are then transported to the mill by truck, ship, or rail (A2), where they are further processed into lumber products for wood framing (A3).

Manufacturing at the mill consists of three main processes: sawing, kiln-drying, and planing. The sawing process includes all debarking, sawing, chipping, and grinding necessary to convert the logs (roundwood) into rough green lumber and co-products. Cut lumber is then kiln dried, planed, stacked, graded, trimmed, sorted, and packaged.[1]



Life Cycle Stages

- A1
- A2
- A3

Figure 1. GWP contribution by life cycle stage. A1 = forestry operations; A2 = transport of roundwood to mill; and A3 = lumber production at mill.

F1.2 Data Availability and Representativeness

PCR

UL Environment. (2019). *Product category rule guidance for building-related products and services part B: structural and architectural wood products (version 1.1)*.

Industry EPDs

American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American softwood lumber.* UL Environment.

> This IW-EPD is based on softwood lumber production in Canada and the Inland Northwest, Northeast-Northcentral, Pacific Northwest, and Southeast regions of the United States. It includes 11.2% of the combined production volume from those five regions.[1]

1. American Wood Council (AWC). (2018). *2018 National Design Specification (NDS) for Wood Construction. American Wood Council.*

Product EPDs

In the EC3 database, there are currently no applicable* product EPDs for wood framing.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

Due to the lack of applicable product EPDs for this category, this appendix does not include the scatter plot, summary statistics table, histogram, or map that appears in many of the other appendices in this report.

F1.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 m^3)	Method	Data Source and Notes
Wood framing	63.12	Industry	AWC. (2020). *Environmental product declaration - North American softwood lumber.*

Figure 2. CLF Baselines for wood framing.

F1.4 Additional Notes and Guidance

Comparability Within the Material Category

Among wood framing products, structural performance and GWP per declared unit can vary depending on many factors such as the wood species and wood grade.[2]

Other Available Product EPDs

There is one North American product EPD for wood framing that references an expired North American PCR. Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. This can be particularly true for wood products, where over time PCRs have used significantly different methodologies for modeling biogenic carbon emissions and carbon storage. When comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

Biogenic Carbon

The industry-wide EPD models biogenic carbon emissions across the declared modules (A1-A3) as net-neutral (i.e., biogenic carbon removals = biogenic carbon emissions), based on ISO 21930:2017.[3,4] The EPD reports GWP in two separate ways: including biogenic carbon (GWP_{BIO}) and excluding biogenic carbon (GWP_{TRACI}). "Total GWP_{BIO} includes biogenic carbon emissions and removals from the [life cycle] modules A1-A3 and also reports values for modules A5, C3, and C4 to account for the biogenic carbon that is not emitted in the declared modules to ensure a net neutral biogenic carbon balance" over the lifetime of the product.[1] Therefore the results for total GWP_{TRACI} and total GWP_{BIO} are equal. See Section 3.2 "Life Cycle Inventory Results" in the industry-wide EPD for further information.

2. American Wood Council (AWC). (2018). *2018 National Design Specification (NDS) for Wood Construction.* American Wood Council.

3. ISO. (2017). *ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services.* ISO.

4. Salazar, J. (2020). *Wood Carbon Seminars - Discussion Session 2 (LCA and Wood).* Carbon Leadership Forum. Retrieved from https://www.youtube.com/watch?v=4hZBGFTB4Rc

F2: STRUCTURAL COMPOSITE LUMBER (SCL)

F2.1 Category Overview

Category Description

Structural composite lumber (SCL) is a group of engineered wood products made by combining wood veneers, strands, or flakes with moisture-resistant adhesives to create composite materials of uniform composition and high strength. The category can be broken down into products and applications:[1]

Laminated Veneer Lumber (LVL) is commonly used for headers, beams, rafters, and I-joist flange material and is available in lengths far beyond standard lumber lengths. It is made up of wood veneer sheets, which are dried, bonded, and sawn to the desired dimensions.[2]

Laminated Strand Lumber (LSL) is commonly used for headers, beams, wall studs, rafters, truss chords, rim boards, and stair stringers. LSL products are made up of wood strands with a length-to-thickness ratio of approximately 150. The strands are bonded with resin and pressed to form panels up to 3½ inches thick.[3]

Oriented Strand Lumber (OSL) products are very similar to LSL products and are used in similar applications. OSL products are made up of wood strands with a length-to-thickness ratio of approximately 75. The strands are bonded with resin and pressed to form panels.

Parallel Strand Lumber (PSL) is commonly used for headers, beams, and columns. It is made from wood strands with a length-to-thickness ratio of around 300. The strands are bonded with resin and pressed to form panels.

Production Processes and Key Drivers of Carbon Emissions

The primary scope of the North American industry-wide EPDs for LVL and LSL is the product stage (A1-A3), with some additional life cycle stage information regarding biogenic carbon. Life cycle stage A1 includes cradle-to-gate production of the raw materials (logs, veneers, and resins) including forestry practices such as thinning, fertilization, logging, seedling growth, and replanting. Trees are typically harvested (by chainsaw, harvester, or feller buncher), delimbed, then bucked before they are moved to a landing site. The logs are then transported to the mill by truck, ship, or rail (A2), where they are further processed into SCL products (A3).

For SCL products made up of wood veneers, like LVL, the manufacturing process involves arranging the dried veneers for assembly, applying resin, then hot-pressing the uncured LVL billet to bind the veneer layers together. Once pressed, the LVL billet is sawn to the desired dimensions.[2]

For SCL products made up of wood strands, like LSL, OSL, and PSL, the manufacturing process includes debarking the logs, cutting their wood into thin strands, drying the strands, then blending them with adhesive and wax. The blended wood strands are arranged so the wood grain follows the long direction and are pressed under high pressure

1. The Engineered Wood Association (APA). Structural Composite Lumber (SCL). Retrieved January 19, 2023, from https://www.apawood.org/structural-composite-lumber

2. American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American laminated veneer lumber.* UL Environment. https://awc.org/sustainability/epd-tb/

3. American Wood Council (AWC) & Canadian Wood Council (CWC). (2021). *Environmental product declaration - North American laminated strand lumber.* UL Environment. https://awc.org/sustainability/epd-tb/

and high temperature to create billets, which are then cooled, cut to the appropriate dimensions, sanded, and packaged for shipping.[3]

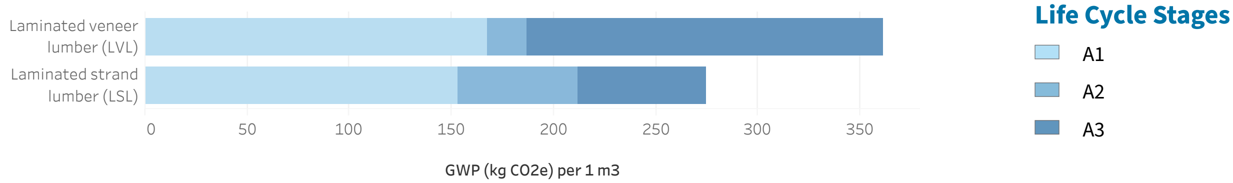


Figure 1. GWP contribution by life cycle stage. A1 = roundwood (including forestry operations), resin, and veneer (where applicable) production; A2 = transport to mill; A3 = SCL manufacturing.

F2.2 Data Availability and Representativeness

PCR

UL Environment. (2019). *Product category rule guidance for building-related products and services part B: structural and architectural wood products (version 1.1)*.

Industry EPDs

American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American laminated veneer lumber*. UL Environment.

> This IW-EPD for North American LVL production aggregates the results from 3 separate regional LCA studies in the US Pacific Northwest, US Southeast, and Canada. A total of 8 mills were sampled, representing a range of 17-53% of the regional production for each area. Regional results were weighted by relative production volume.[2]

American Wood Council (AWC) & Canadian Wood Council (CWC). (2021). *Environmental product declaration - North American laminated strand lumber.* UL Environment.

> Two LSL manufacturers contributed production data that represents 100% of the current North American production for LSL.[3]

At the time of publication, there are no North American IW-EPDs for OSL or PSL.

Product EPDs

In the EC3 database, there is currently one applicable* LVL product EPD. There are zero applicable product EPDs for LSL, OSL, and PSL products.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

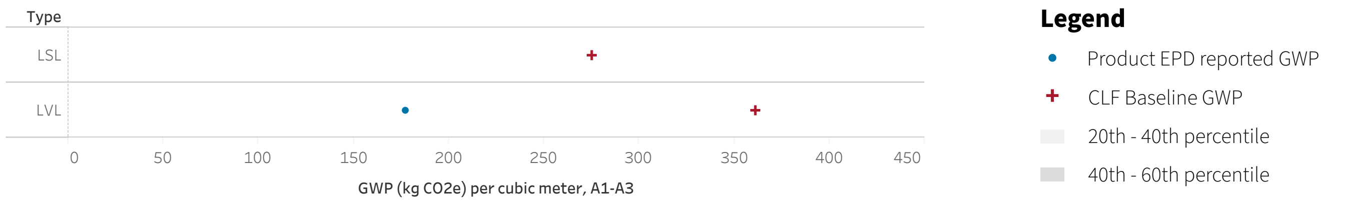


Figure 2. Range of applicable product EPDs and CLF Baselines.

Due to the lack of applicable product EPDs for this category, this appendix does not include the scatter plot, summary statistics table, histogram, or map that appears in many of the other appendices in this report.

F2.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 m^3)	Method	Data Source and Notes
Laminated Veneer Lumber (LVL)	361.45	Industry	AWC. (2020). *Environmental product declaration - North American laminated veneer lumber*.
Laminated Strand Lumber (LSL)	274.9	Industry	
Oriented Strand Lumber (OSL)	none	—	No adequately representative data source.
Parallel Strand Lumber (PSL)	none	—	No adequately representative data source.

Figure 3. CLF Baselines for wood structural composite lumber.

There is no 2023 CLF Material Baseline for OSL or PSL since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

F2.4 Additional Notes and Guidance

Figure 4. Product EPDs by location.

Comparability Within the Material Category

The SCL material category comprises a number of distinct product types: LVL, LSL, OSL, and PSL. However, it would not be appropriate to assume that one type is more or less carbon-intensive than another type based on the information provided in this appendix since each of these product types have very different performance characteristics and building construction application. Therefore, they cannot be compared on a per-m^3 basis.[4]

Similarly, when comparing environmental impacts within a product type, it is important to keep in mind that SCL products are proprietary products, and as a result, the specific structural properties and sizes are unique to each manufacturer. Many SCL products do not have a common standard of production or common design values.[5]

Other Available Product EPDs

For LVL products, there is one additional North American product EPD that references an expired North American PCR and two additional global product EPDs that reference a European PCR. There are no additional product EPDs for LSL, OSL, or PSL that reference PCRs outside of North America or PCRs that are now expired. Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. This can be particularly true for wood products, where over time PCRs have used significantly different methodologies for modeling biogenic carbon emissions and carbon storage. When comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

Biogenic Carbon

The industry-wide EPD models biogenic carbon emissions across the declared modules (A1-A3) as net-neutral (i.e., biogenic carbon removals = biogenic carbon emissions), based on ISO 21930:2017.[6,7] The EPD reports GWP in two separate ways: including biogenic carbon (GWP_{BIO}) and excluding biogenic carbon (GWP_{TRACI}). "Total GWP_{BIO} includes biogenic carbon emissions and removals from the [life cycle] modules A1-A3 and also reports values for modules A5, C3, and C4 to account for the biogenic carbon that is not emitted in the declared modules to ensure a net neutral biogenic carbon balance" over the lifetime of the product.[1] Therefore the results for total GWP_{TRACI} and total GWP_{BIO} are equal. See Section 3.2 "Life Cycle Inventory Results" in the industry-wide EPD for further information.

4. American Wood Council (AWC). (2018). *2018 National Design Specification (NDS) for Wood Construction*. American Wood Council.

5. Canadian Wood Council (CWC). (n.d.). Wood Products. Retrieved January 19, 2023, from https://cwc.ca/en/how-to-build-with-wood/wood-products/

6. ISO. (2017). *ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services.* ISO.

7. Salazar, J. (2020). *Wood Carbon Seminars - Discussion Session 2 (LCA and Wood).* Carbon Leadership Forum. Retrieved from https://www.youtube.com/watch?v=4hZBGFTB4Rc

F3: MASS TIMBER PANELS

F3.1 Category Overview

Category Description

This category includes engineered heavy timber panel products that can be used for a variety of structural purposes, including the following product types:

Cross-laminated timber (CLT): a prefabricated, engineered wood panel used for floors, walls, and roofs. A CLT panel consists of several layers of kiln-dried lumber boards stacked in alternating directions, bonded with structural adhesives, and pressed to form a solid, straight, rectangular panel.[1]

Nail-laminated timber (NLT): a prefabricated, engineered wood panel used for floors, walls, and roofs. An NLT panel is manufactured from nominal dimension (typically 2x, 3x, or 4x) lumber placed on edge and nailed together. Though it can be used in similar applications as CLT, NLT does not provide the same dimensional stability or shear resistance as CLT.[2]

Dowel-laminated timber (DLT): a prefabricated, engineered wood panel used for floors, walls, and roofs. DLT is similar to NLT, but instead of using nails to join the lumber boards, the boards are friction-fit together with hardwood dowels.[3]

Mass ply panel (MPP): a prefabricated, engineereed wood panel used for floors, walls, and roofs. Also called "mass plywood," MPPs are composed of multiple thin wood veneers bonded with resin adhesives.[4]

Production Processes and Key Drivers of Carbon Emissions

In a typical mass timber panel EPD, life cycle stage A1 includes cradle-to-gate production of the input materials (dimensional lumber or veneers and resins/nails/dowels) including forestry practices such as thinning, fertilization, logging, seedling growth, and replanting. Trees are typically harvested (by chainsaw, harvester, or feller buncher), delimbed, then bucked before they are moved to a landing site. The logs are then transported to a mill for dimensional lumber or veneer production. The lumber or veneer is transported to the mass timber panel manufacturing facility (A2), where it is further processed into CLT, NLT, DLT, or MPP (A3). In the case of the single MPP EPD, A1 also includes the bonding of veneers into 1" thick panels that are themselves later bonded together to form MPP panels in A3.[1,2,3,4]

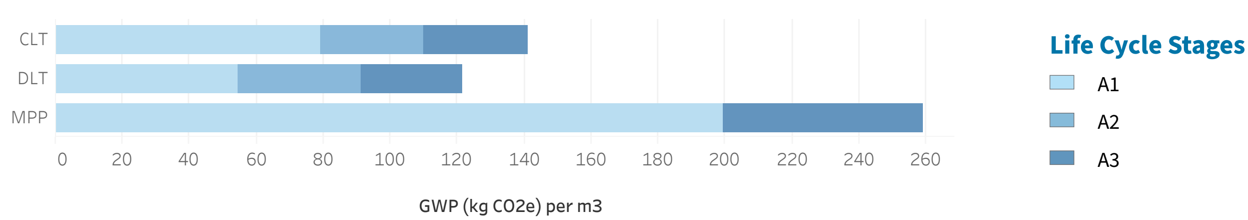


Figure 1. GWP contribution by life cycle stage. As there are no industry EPDs for this product type, the information displayed here is from product EPDs. For DLT and MPP, this is based on the one EPD available for each.[4,5] For CLT, this is based on an average of the collection of applicable product EPDs.

1. APA. (2022). *Cross-laminated timber (CLT)* [website]. https://www.apawood.org/cross-laminated-timber
2. Natural Resources Canada (NRC). (2022). *Nail-laminated timber* [website]. https://natural-resources.canada.ca/our-natural-resources/forests/industry-and-trade/forest-products-applications/taxonomy-wood-products/nail-laminated-timber/23708
3. Natural Resources Canada (NRC). (2022). *Dowel-laminated timber* [website]. https://natural-resources.canada.ca/our-natural-resources/forests/industry-and-trade/forest-products-applications/taxonomy-wood-products/dowel-laminated-timber/23706
4. Freres Lumber Company. (2020). *EPD for mass ply panels produced by Freres Lumber in Lyons, Oregon.* ASTM International. https://corrim.org/wp-content/uploads/2021/06/EPD_For_FinalFreres_Lumber_Company.pdf
5. StructureCraft. (2020). *EPD for dowel laminated timber produced by StructureCraft in Abbotsford, BC Canada*. ASTM International.

F3.2 Data Availability and Representativeness

PCR

UL Environment. (2019). *Product category rule guidance for building-related products and services part B: structural and architectural wood products (version 1.1)*.

Industry EPDs

There are no current North American IW-EPDs for CLT, NLT, DLT, or MPP.

Product EPDs

In the EC3 database, there are currently four applicable* product EPDs for CLT, zero for NLT, one for DLT, and one for MPP.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

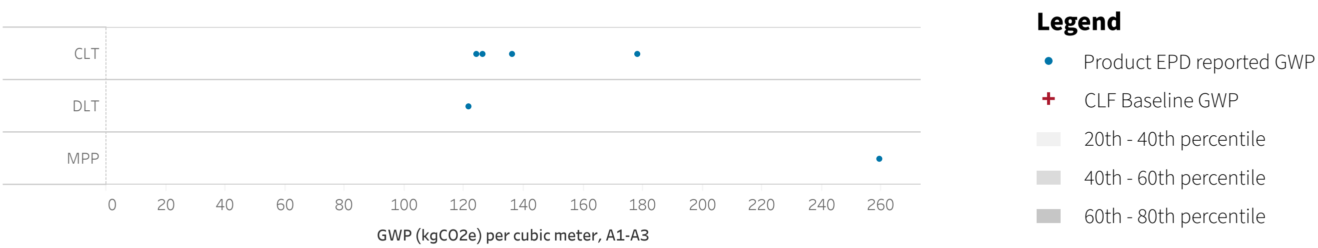


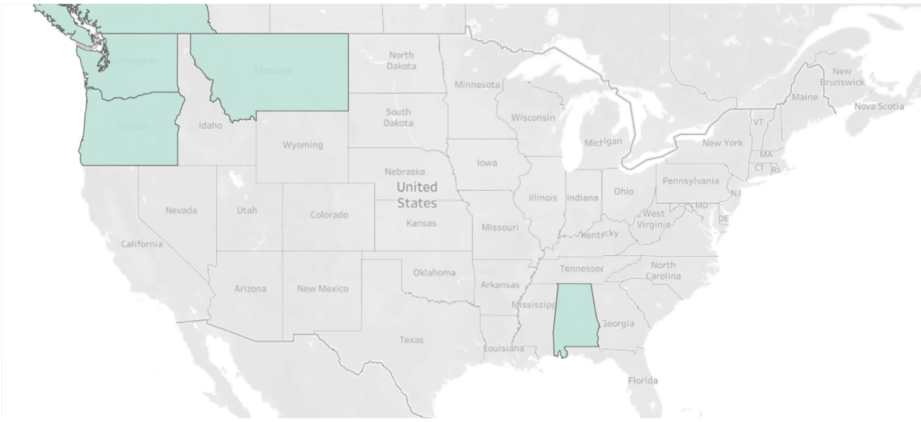
Figure 2. Range of applicable product EPDs. In other appendices, this figure also includes CLF Baseline values. There are no 2023 CLF Baselines for mass timber panel product types.

Due to the low number of applicable product EPDs for this category, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

F3.3 CLF Baseline

There is no 2023 CLF Material Baseline for mass timber panel product types since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

F3.4 Additional Notes and Guidance



Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 3. Product EPDs by location.

Other Available EPDs

In addition to the applicable EPDs listed above, there are four North American and 16 global CLT product EPDs based on PCRs from outside of North America or PCRs that are now expired. Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. This can be particularly true for wood products, where over time PCRs have used significantly different methodologies for modeling biogenic carbon emissions and carbon storage. When comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

Biogenic Carbon

EPDs that conform to the appropriate current North American PCR should model biogenic carbon emissions across the declared modules as net-neutral (i.e., total biogenic carbon removals = biogenic carbon emissions), based on ISO 21930:2017.[6]

6. ISO. (2017). *ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services.* ISO.

F4: GLUE LAMINATED TIMBER

F4.1 Category Overview

Category Description

Glue Laminated Timber (GLT), also known as "glulam," is an engineered wood product commonly used in posts, beams, heavy timber, and mass timber structures. It is made up of two or more layers of dimensional lumber, which is also referred to as laminating stock, or "lamstock." The lamstock is bonded with durable, moisture-resistant adhesives and all wood grain runs parallel to the length of the beam or column. GLT can be manufactured in a wide range of shapes and sizes and can be used for both interior and exterior applications.[1]

Production Processes and Key Drivers of Carbon Emissions

The primary scope of the North American industry-wide EPD for GLT is the product stage (A1-A3), with some additional life cycle stage information regarding biogenic carbon. Life cycle stage A1 includes cradle-to-gate production of the raw materials (lamstock and resins) including forestry practices such as thinning, fertilization, logging, seedling growth, and replanting. Trees are typically harvested (by chainsaw, harvester, or feller buncher), delimbed, then bucked before they are moved to a landing site. The logs are then transported to a lumber mill for lamstock production. The lamstock is transported to the GLT manufacturing facility (A2), where it is further processed into GLT (A3).

In order to create relatively homogenous lengths of wood, lamstock is finger-jointed and joined with resin. The joint is cured under pressure and heat to ensure a stable bond. Then, multiple pieces of finger-jointed lamstock are planed and bonded by applying resin directly to the faces of the lamstock. While pressure is being applied, the assembly cures via cold cure or radio frequency. The GLT faces may be cut, planed, sanded, or further finished as necessary to remove any excess adhesives and achieve final product specifications.[1]

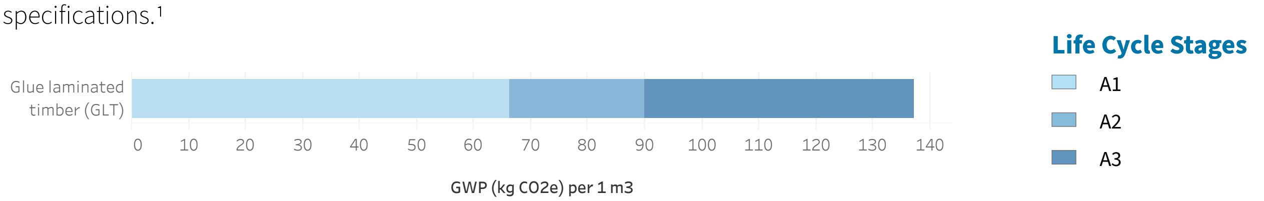


Figure 1. GWP Contribution by Life Cycle Stage. A1 = lamstock production (including forestry operations), resin production; A2 = transport to GLT facility; A3 = GLT manufacturing.

F4.2 Data Availability and Representativeness

PCR

UL Environment. (2019). *Product category rule guidance for building-related products and services part B: structural and architectural wood products (version 1.1)*.

Industry EPDs

American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental*

1. American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American glue laminated timber.* UL Environment. Retrieved from https://awc.org/sustainability/epd-tb/

product declaration - North American glue laminated timber. UL Environment.

> This industry-wide EPD represents the industry average of North American GLT production using the results from three regional LCA studies that assess GLT production from five mills in Canada, four mills in the Pacific Northwest (US), and another four mills in the Southeast (US). The EPD accounts for 32.8% of the combined production volume from those three regions.

Product EPDs

In the EC3 database, there are currently four applicable* product EPDs for GLT.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

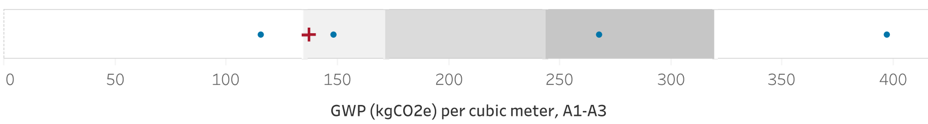


Figure 2. Range of applicable product EPDs and CLF Baseline.

Due to the lack of product EPDs in this category, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

F4.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per 1 m^3)	Method	Data Source and Notes
Glue laminated timber (GLT)	137.19	Industry	AWC & CWC. (2020). *Environmental product declaration - North American glue laminated timber.*

Figure 3. CLF Baselines for cold-formed steel framing.

F4.4 Additional Notes and Guidance

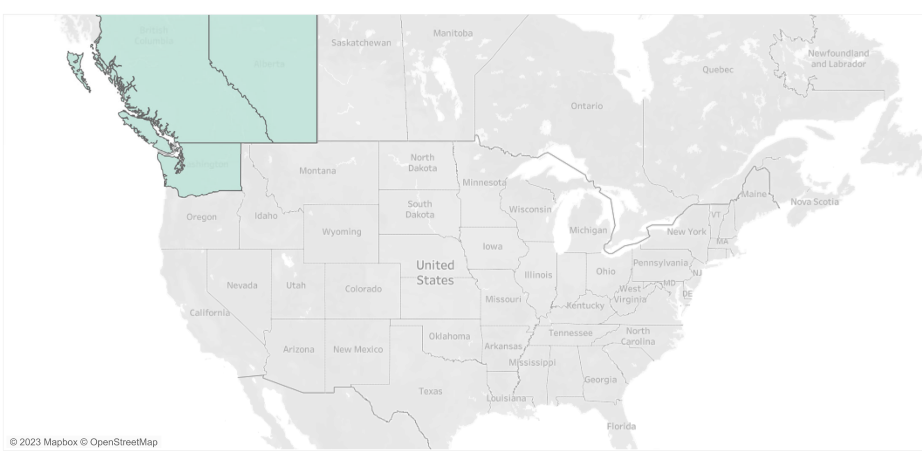


Figure 4. Product EPDs by location.

Comparability Within the Material Category

Among GLT products, structural performance and GWP per declared unit can vary depending on many factors such as the wood species and wood grade.[2] When considering substitutions within this material category, it is important to consider which products are appropriate for use in the project based on the project's location and the intended application.

Other Available EPDs

In addition to the EPDs listed above, there is one North American industry EPD, one North American product EPD, and five global product EPDs for GLT that reference PCRs from outside of North America or PCRs that are now expired. Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. This can be particularly true for wood products, where over time PCRs have used significantly different methodologies for modeling biogenic carbon emissions and carbon storage. When comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

2. American Wood Council (AWC). (2018). *2018 National design specification (NDS) for wood construction. American Wood Council.*

F5: WOOD SHEATHING

F5.1 Category Overview

Category Description

Wood sheathing products are engineered wood panels used for structural sheathing in floor, wall, or roof assemblies. This material category includes softwood plywood and oriented strand board (OSB) product types. Softwood plywood panels are made of cross-laminated layers of softwood veneers, which are bonded together with thermoset resins.[1] OSB panels are made of layers of wood strands. The strands run parallel to the length of the panel on the outer layers and perpendicular to the length of the panel on the middle layers. Wood strands are bonded with resins, and wax is commonly added to the panel to increase water resistance.[2]

Production Processes and Key Drivers of Carbon Emissions

The primary scope of the North American industry-wide EPDs for plywood and OSB is the product stage (A1-A3), with some additional information regarding biogenic carbon. Life cycle stage A1 includes cradle-to-gate production of the raw materials (logs and resins) including forestry practices such as thinning, fertilization, logging, seedling growth, and replanting. Trees are typically harvested (by chainsaw, harvester, or feller buncher), delimbed, then bucked before they are moved to a landing site. The logs are then transported to the mill by truck, ship, or rail (A2), where they are further processed into plywood or OSB panels (A3).

For plywood products, the logs are conditioned with hot water and then sent to the lathe where the logs are peeled to make veneer. The wood veneer is then trimmed, sorted, and dried. Once dry, the veneers are bonded with resin, cross-laminated, pressed, and cut down to the desired panel dimensions.[1]

For OSB products, the logs are first cut into thin strands, dried, and sorted. The wood strands are then coated with resin and wax and arranged to create a three-layer mat of cross-directional wood strands. The mat is then pressed under a high temperature to produce the OSB board. Once cooled, sawn, and grade stamped, the OSB boards are ready to be packaged.[2]

1. American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). Environmental product declaration - North American softwood plywood. UL Environment. https://awc.org/sustainability/epd-tb/

2. American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). Environmental product declaration - North American oriented strand board. UL Environment. https://awc.org/sustainability/epd-tb/

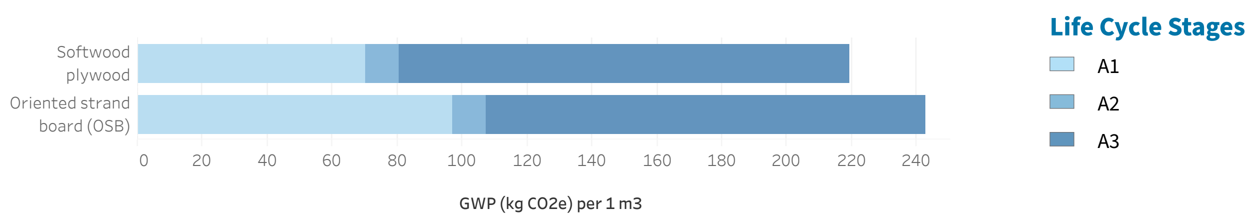


Figure 1. GWP Contribution by Life Cycle Stage. A1 = roundwood (including forestry operations) and resin production; A2 = transport to mill; A3 = plywood / OSB manufacturing.

F5.2 Data Availability and Representativeness

PCR

UL Environment. (2019). *Product category rule guidance for building-related products and services part B: structural and architectural wood products (version 1.1)*.

Industry EPDs

American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American softwood plywood.* UL Environment.[1]

> This IW-EPD is based on softwood plywood production in Canada, the Pacific Northwest (US), and the Southeast (US). It includes 53.7% of the combined production volume from those three regions.

American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American oriented strand board.* UL Environment.[2]

> This IW-EPD is based on OSB production in Canada and the Southeastern United States. It includes 34.1% of the combined North American production covered within those regions.

Product EPDs

In the EC3 database, there are currently no applicable* product EPDs for wood sheathing.

> *Applicable product EPDs are are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

Due to the lack of applicable product EPDs for this category, this appendix does not include the scatter plot, summary statistics table, histogram, or map that appears in many of the other appendices in this report.

F5.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per 1 m^3)	Method	Data Source and Notes
Softwood plywood	219.32	Industry	AWC. (2020). *Environmental product declaration - North American softwood plywood.*
Oriented strand board (OSB)	242.58	Industry	AWC. (2020). *Environmental product declaration - North American oriented strand board.*

Figure 2. CLF Baselines for wood sheathing.

F5.4 Additional Notes and Guidance

Comparability Within the Material Category

The wood sheathing material category is broken into two product types: softwood plywood and OSB. In many building applications, these two product types can be functionally equivalent. However the different product types have different performance characteristics (i.e., structural performance, durability, and response to moisture), and it is not always appropriate to directly substitute one dimension of one wood sheathing product for the same dimensions of a different wood sheathing product.

Other Available Product EPDs

Although there are currently zero North American product EPDs for wood sheathing products that follow the current North American PCR, there are many more product EPDs available that reference PCRs outside of North America or PCRs that are now expired. There are two product EPDs for plywood that reference the expired North American PCR,[3] and 10 for OSB that reference an expired European PCR. Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. This can be particularly true for wood products, where over time PCRs have used significantly different methodologies for modeling biogenic carbon emissions and carbon storage. When comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

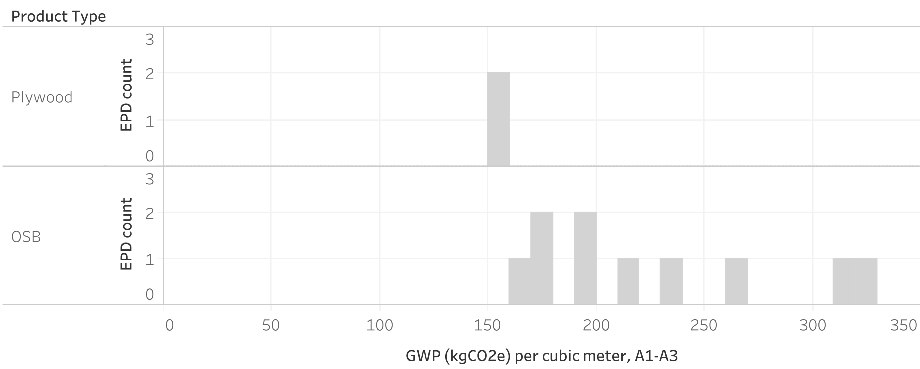


Figure 3. Range of global wood sheathing product EPDs. These are not applicable to the CLF Baselines and are shown here for reference only.

Biogenic Carbon

The industry-wide EPD models biogenic carbon emissions across the declared modules (A1-A3) as net-neutral (i.e., biogenic carbon removals = biogenic carbon emissions), based on ISO 21930:2017.[4,5] The EPD reports GWP in two separate ways: including biogenic carbon (GWP_{BIO}) and excluding biogenic carbon (GWP_{TRACI}). "Total GWP_{BIO} includes biogenic carbon emissions and removals from the [life cycle] modules A1-A3 and also reports values for modules A5, C3, and C4 to account for the biogenic carbon that is not emitted in the declared modules to ensure a net neutral biogenic carbon balance" over the lifetime of the product.[1] Therefore the results for total GWP_{TRACI} and total GWP_{BIO} are equal. See Section 3.2 "Life Cycle Inventory Results" in the industry-wide EPD for further information.

3. FP Innovations. (2015). *North American Structural and Architectural Wood Products.* FP Innovations.

4. ISO. (2017). *ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services.* ISO.

5. Salazar, J. (2020). *Wood Carbon Seminars - Discussion Session 2 (LCA and Wood).* Carbon Leadership Forum. Retrieved from https://www.youtube.com/watch?v=4hZBGFTB4Rc

F6: GLASS-MAT GYPSUM BOARD

F6.1 Category Overview

Category Description

Glass-mat gypsum boards consist of a non-combustible water-resistant gypsum core, with a glass mat surface on each side that is partially or completely embedded in the core. The panels are typically used as exterior building envelope sheathing, providing a substrate for weather barriers and mold and fire resistance. Panels are commonly 4' wide by 8' long and are available in multiple thicknesses depending on the application. CLF Baselines for this category, in alignment with the industry EPD and the most commonly used products in North America, are divided into two product types by thickness: 1/2" regular and ⅝" type X glass-mat gypsum board panels.

Production Processes and Key Drivers of Carbon Emissions

The major processes in glass-mat gypsum board production include gypsum ore mining, glass matting production, gypsum core production, and manufacture of the final panels including core and matting. The primary contributors to total A1-A3 GWP are the production of the glass matting (accounted for in A1, 41% of total GWP for the ½" product and 36% for the 5/8" product) and onsite natural gas consumption for heating and drying the crushed natural gypsum (accounted for in A3, 37% of total GWP for the ½" product and 39% for the ⅝" product).[1]

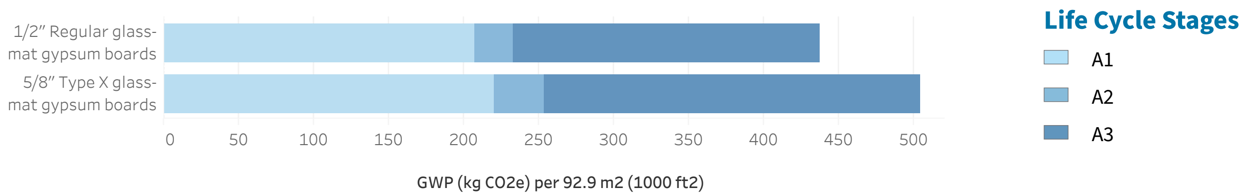


Figure 1. GWP Contribution by Life Cycle Stage. A1: extraction and upstream production, including mining to procure gypsum ore and cradle-to-gate glass matting production. A2: transport to factory. A3: glass-mat gypsum board product manufacture. See Section 4.2 System Boundary in the IW-EPD background LCA report for further discussion of all processes and where they are accounted for.[1]

F6.2 Data Availability and Representativeness

PCR

NSF International. (2020). *Product category rule for environmental product declarations - PCR for gypsum panel products*.

Industry EPDs

Gypsum Association (GA). (2021). *An industry-wide cradle-to-gate EPD for 1/2" and 5/8" glass-mat gypsum boards. ASTM International*.[2]

> The industry-average LCA report that underlies the EPD describes the study's approach to selecting a representative sample for each primary production process, including representation of manufacturing companies, plant size, geography,

1. Athena Sustainable Materials Institute (ASMI). (2021). *An industry average cradle-to-gate life cycle assessment of 1/2" regular and 5/8" type X glass-mat gypsum board for the USA and Canadian markets.* Gypsum Association. https://gypsum.org/life-cycle-resources/

2. Gypsum Association (GA). (2021). *An industry-wide cradle-to-gate EPD for 1/2" and 5/8" Glass-mat Gypsum Boards.* ASTM International. https://www.astm.org/products-services/certification/environmental-product-declarations/epd-pcr.html

and other significant factors. The EPD does not disclose the percentage of North American production covered. The study aims to represent USA manufacturing.[1]

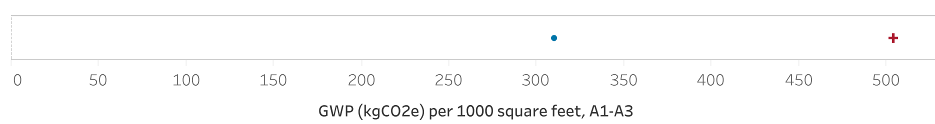
Product EPDs

There is currently one applicable* product EPD for ⅝” glass-gypsum board and zero for 1/2” board. This count excludes eight currently-valid North American product EPDs that use a different PCR (one expired North American PCR and one European PCR) from the primary one listed above.[1]

> *Applicable product EPDs are are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

EC3 Categorization

As of January 2023, there is an EC3 category *Sheathing>>Gypsum Sheathing*, within which is the filterable option for glass-mat facing. Some glass-mat gypsum board EPDs may also be found in EC3’s *Finishes>>Gypsum Board* category.



Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

Figure 2. Range of applicable product EPDs and CLF Baseline.

F6.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per 92.9 m² [1000 ft²])	Method	Data Source and Notes
Glass-mat gypsum board: 1/2” (12.7 mm)	437.4	Industry	Gypsum Association. *(2021). An industry-wide cradle-to-gate EPD for 1/2” and 5/8” glass-mat gypsum boards.*
Glass-mat gypsum board: 5/8” (15.9 mm)	503.9	Industry	Gypsum Association. *(2021). An industry-wide cradle-to-gate EPD for 1/2” and 5/8” glass-mat gypsum boards.*

Figure 3. CLF Baselines for 1/2” and 5/8” glass-mat gypsum board.

F6.4 Additional Notes and Guidance

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 4. Product EPDs by location.

F7: WOOD I-JOISTS

F7.1 Category Overview

Category Description

Wood I-joists (sometimes called “composite I-joists”) are structural members comprised of top and bottom chords (softwood lumber or LVL) and a web in the middle (OSB or plywood). The size of the chords varies by material, and the web can be a range of sizes. Common dimensions include I-joists that directly replace 2x10 and 2x12 structural lumber.[1]

Production Processes and Key Drivers of Carbon Emissions

A1 includes the production of the upstream ingredients – lumber or LVL for the chords and OSB or plywood for the web. At the I-joist manufacturing facility (A3), these input ingredients are processed and then assembled, where resins are applied and the web and chords are pressed together. The materials and cross-sectional dimensions significantly affect product GWP, and these factors are not accounted for in the category’s declared unit of 1 linear meter.[1]

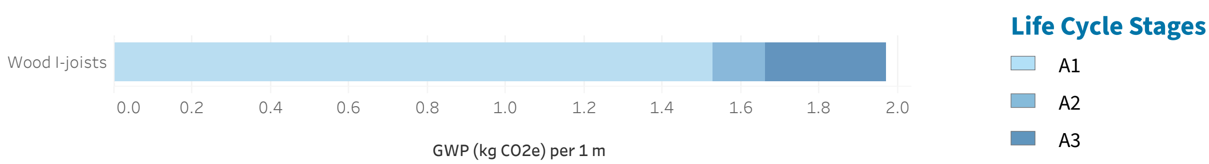


Figure 1. GWP Contribution by Life Cycle Stage. A1 = production of input materials: chord and web materials and resins; A2 = transport to manufacturing facility; A3 = manufacture of I-joists.

F7.2 Data Availability and Representativeness

PCR

UL Environment. (2019). *Product category rule guidance for building-related products and services part B: structural and architectural wood products (version 1.1)*.

Industry EPDs

American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American wood I-joists*. UL Environment.[1]

> This EPD is based on samples from three regions - Canada, USA Pacific Northwest, and USA Southeast. The data constitutes approximately 60% of the total production volume for the regions under study.

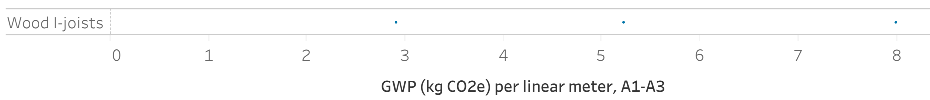
Product EPDs

There are currently three applicable* product EPDs for wood I-joists. They are from one manufacturer’s facility, for each of three different products that vary by size and structural capacity.

> *Applicable product EPDs are are EPDs that are valid, represent North American

1. American Wood Council (AWC) & Canadian Wood Council (CWC). (2020). *Environmental product declaration - North American wood I-joists.* UL Environment. https://awc.org/wp-content/uploads/2021/11/AWC_EPD_NorthAmericanWoodIJoists_20200605.pdf

manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.



Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

Figure 2. Range of applicable product EPDs and CLF Baseline.

Due to the lack of product EPDs in this category, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

F7.3 CLF Baseline

There is no 2023 CLF Material Baseline for wood I-joists since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

While there is an industry EPD for this category, the variation of product technical characteristics (material types and cross sections) and the associated variation in performance (structural capacity) and GWP within the category is too large to set a single baseline number. In the future, with more data, it may be feasible to set one or more baseline GWP values for products of specific cross-sectional dimensions or structural capacity.

F7.4 Additional Notes and Guidance

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 3. Product EPDs by location.

Biogenic Carbon

The industry-wide EPD models biogenic carbon emissions across the declared modules (A1-A3) as net-neutral (i.e., biogenic carbon removals = biogenic carbon emissions), based on ISO 21930:2017.[2,3] The EPD reports GWP in two separate ways: including biogenic carbon (GWP_{BIO}) and excluding biogenic carbon (GWP_{TRACI}). "Total GWP_{BIO} includes biogenic carbon emissions and removals from the [life cycle] modules A1-A3 and also reports values for modules A5, C3, and C4 to account for the biogenic carbon that is not emitted in the declared modules to ensure a net neutral biogenic carbon balance" over the lifetime of the product.[1] Therefore the results for total GWP_{TRACI} and total GWP_{BIO} are

2. ISO. (2017). *ISO 21930:2017 Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services.* ISO.

3. Salazar, J. (2020). *Wood Carbon Seminars - Discussion Session 2 (LCA and Wood).* Carbon Leadership Forum. Retrieved from https://www.youtube.com/watch?v=4hZBGFTB4Rc

equal. See Section 3.2 “Life Cycle Inventory Results” in the industry-wide EPD for further information.

G1: BOARD INSULATION

G1.1 Category Overview

Category Description

Board insulations are rigid or semi-rigid products that can be applied to many parts of the building envelope. They are commonly applied as continuous insulation (sometimes called "insulation sheathing") across the framing, sheathing, structural concrete, masonry, or other surfaces in wall, roof, and floor assemblies.[1] Typical board insulation product types include:

- Expanded polystyrene (EPS)
- Extruded polystyrene (XPS)
- Polyisocyanurate (Polyiso or ISO)
- Mineral wool heavy-density board

Other less common board insulation types include: graphite polystyrene (GPS), fiberglass board (more commonly used for mechanical insulation than for the building envelope), and wood fiberboard (currently more common in Europe).

These products all serve the primary function of insulating a building envelope, often as continuous exterior insulation. Other performance attributes such as air permeability, vapor permeability, fire resistance, acoustic performance, moisture resistance, and compressive strength vary depending on the particular product.

Production Processes and Key Drivers of Carbon Emissions

Expanded polystyrene (EPS) is a closed-cell rigid foam board insulation. The production of EPS resin (upstream of the EPS insulation manufacturing plant, typically accounted for in A1) is the most GWP-intensive part of EPS production, accounting for roughly 75% of the overall A1:A3 impact. At the EPS manufacturing facility, the resin is expanded when exposed to steam and molded into a solid homogenous block, which is cut into boards and typically left unfaced. Scrap is reground and converted for re-use. Some plants combust captured blowing agents that escape the manufacturing process. One common blowing agent for EPS is pentane, a chemical with low global warming potential.[2]

Polyiso is a closed-cell rigid foam board insulation that consists of a foam core sandwiched between two facers. The rigid foam is produced through the reaction of methylene diphenylene diisocyanate (MDI) with polyester polyol, along with other ingredients such as catalyst, flame retardant, and blowing agent (pentane or pentane blends). For wall applications, products typically have a glass-reinforced aluminum foil facer (GRFF). For roofing applications, products most commonly have a glass-fiber-reinforced cellulosic facer (GRF), while some have a polymer-bonded coated glass facer (CGF). In all cases, the facers are critical for allowing a continuous manufacturing process.[3,4] The facer can have a significant impact on the product's overall GWP. In polyiso wall boards, the aluminum-based facer is often the major contributor to that product's GWP.[5]

1. Energy Saver. Types of insulation. U.S. Department of Energy. https://www.energy.gov/energysaver/types-insulation
2. EPS Industry Alliance (EPS-IA). (2017). *Environmental product declaration - Expanded polystyrene insulation.* UL Environment.
3. Polyisocyanurate Insulation Manufacturers Association (PIMA). (2020). *Environmental product declaration - Polyiso wall insulation boards.* NSF. https://www.polyiso.org/page/EPDs
4. Polyisocyanurate Insulation Manufacturers Association (PIMA). (2020). *Environmental product declaration - Polyiso roof insulation boards.* NSF. https://www.polyiso.org/page/EPDs
5. PIMA. (2022). Personal correspondence.

Extruded polystyrene (XPS) is a closed-cell rigid foam board insulation consisting primarily of polystyrene (PS) resin and a blend of blowing agents. During manufacturing, PS resin, additives, and blowing agents are blended and melted into a liquid. The liquid is sent through a die and then expanded into foam, which is shaped, cooled, trimmed, printed, and packaged. XPS is often unfaced, though some XPS products have facers.[6]

XPS produced in North America has been extremely emissions-intensive compared to other insulation products, due to the use of hydrofluorocarbon (HFC) blowing agents. For the last decade, North American manufacturers have conventionally produced XPS with blowing agent blends of HFC-134a (GWP100 = 1,300) and HFC-245fa (GWP100 = 858).[7] Globally, the Kigali Amendment of the Montreal Protocol calls for a total phase-out of HFCs, which have been banned from use in Europe since 2020. Currently, there are laws in a handful of US states and Canada that ban or limit the use of HFCs in foam insulation prompting a shift towards blowing agent blends with hydrofluoroolefins (HFOs) that have significantly lower GWP.[8] GHG emissions from foam blowing agent leakage occur during initial manufacturing (A3), gradually over a product's useful lifetime (B1), and at disposal when further emission occurs while the product sits in a landfill (C4). The conservative approach in EPDs is to assume that 100% of the original blowing agent ultimately emits into the atmosphere.

Mineral wool heavy-density board is a rigid or semi-rigid fibrous board insulation made from slag and natural rock such as basalt or feldspar. At the manufacturing facility, a furnace melts these raw ingredients and the molten mixture is spun to create fine fibers. The fibers are coated with a binder, and then the fiber-binder composite is formed into boards or blankets. Facings such as kraft paper may be added to some products. The blankets are then cooled, trimmed, and packaged.

The primary contributor to overall GWP is the energy consumption to melt the feedstock materials (stone and/or slag) at the furnace. This energy use is either through the direct burning of fossil fuels (typically natural gas) or indirect grid electricity. The two primary mineral wool feedstock materials have very different origins and different LCA considerations. Stone such as basalt is produced through hard-rock quarrying which involves digging, blasting, and crushing of bedrock. Slag is produced as a waste product from iron and steel smelting, and is often treated in EPDs (including in the IW-EPD cited here) as "burdenless" (i.e., without environmental impact) when entering the mineral wool production process.[9,10]

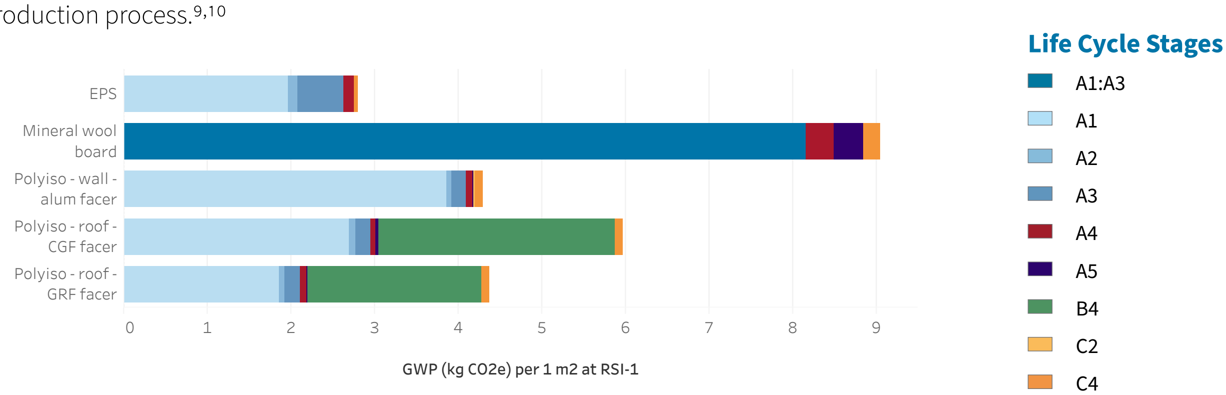


Figure 1. GWP contribution by life cycle stage. Board insulation, excluding XPS. Data for EPS, polyiso wall and roof boards, and heavy-density mineral wool boards are from the industry-wide EPDs.

6. Progressive Foam. (2018). EPS vs. XPS vs. GPS: The definitive comparison guide [website]. https://www.progressivefoam.com/eps-vs-xps-vs-gps/#:~:text=XPS%20insulation%20begins%20as%20polystyrene,cooled%2C%20and%20finally%2C%20trimmed

7. These are the 100-year GWP values based on the IPCC's fifth assessment report (AR5). Greenhouse Gas Protocol. 2018. Global warming potential values. https://ww2.arb.ca.gov/sites/default/files/2018-06/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf

8. HFCBANS.COM. (2021).[website] https://www.hfcbans.com.

9. North American Insulation Manufacturers Association (NAIMA). (2018). *Environmental product declaration - Mineral wool board*. https://www.jm.com/content/dam/jm/global/en/building-insulation/Files/BI%20Toolbox/Mineral-Wool-Environmental-Product-Declaration.pdf

10. Much of this paragraph was adopted from: Carbon Leadership Forum. (2022). *Buy Clean California Limits*. https://carbonleadershipforum.org/buy-clean-california-limits/

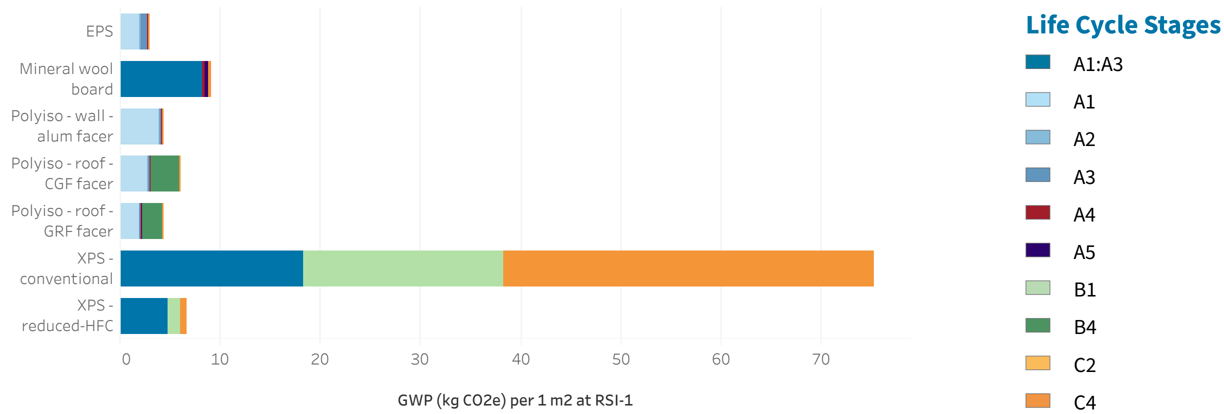


Figure 2. GWP contribution by life cycle stage. Board insulation, including XPS. Data for EPS, polyiso wall and roof boards, and heavy-density mineral wool boards are from the industry-wide EPDs. The data for XPS (one set for conventional blowing agent mix, one set for reduced-HFC blowing agent mix) are averages from a collection of product EPDs.

G1.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product category rule (PCR) guidance for building-related products and services part B: Building envelope thermal insulation EPD requirements*.

Industry EPDs

EPS Industry Alliance (EPS-IA). (2017). *Environmental product declaration - Expanded polystyrene insulation*. UL.

> This EPD is based on primary data from 29 insulation manufacturing plants (23 in the USA, six in Canada) and three EPS resin manufacturers (one in each of the USA, Canada, and Mexico, with one plant from each manufacturer and where a straight average from the three was used for the average EPS resin data in the assessment). The percentage of total North American EPS production is not disclosed.[2]

Polyisocyanurate Insulation Manufacturers Association (PIMA). (2020). *Environmental product declaration - Polyiso wall insulation boards. NSF.*

Polyisocyanurate Insulation Manufacturers Association (PIMA). (2020). *Environmental product declaration - Polyiso roof insulation boards.* NSF.

> The two polyiso industry EPDs are based on primary data from 36 polyiso manufacturing facilities in USA and Canada. The percentage of total North American polyiso production is not disclosed.

North American Insulation Manufacturers Association (NAIMA). (2018). *Environmental product declaration - Mineral wool board.* UL Environment.

> This document includes results for both light- and heavy-density mineral wool boards. The CLF Material Baselines report considers heavy-density mineral wool board products – which are relatively rigid – as "board insulation". (This report considers the more flexible light-density products as "blanket insulation.") This EPD

is based on primary data from four facilities in Alabama, Indiana, and Mexico. The percentage of total North American production is not disclosed.[9]

There is currently no North American industry EPD for other board insulation types, such as XPS, GPS, fiberglass board, or wood fiber.

Product EPDs

There are currently 104 applicable* product EPDs for this category. This includes: 1 for EPS, 19 for XPS, 6 for polyiso, 81 for heavy-density mineral wool board, and 2 for others (one each for GPS and fiberglass board).

*Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

Different PCR

All of the noted mineral wool EPDs come from two major North American manufacturers: Rockwool and Owens Corning. Current Rockwool EPDs for mineral wool insulation produced in North America are based on a European PCR , rather than the North American PCR listed above.[11] Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. Comparing environmental impacts among product EPDs that reference different PCRs may lead to inaccurate conclusions.

XPS Product EPD Representativeness of the Industry

While there is no industry-wide EPD for XPS, the CLF determined that a collection of six product EPDs are adequately representative of the range of North American production based on the following factors that address the representativeness criteria for using a set of product EPDs to establish a CLF baseline GWP value, as outlined in the main narrative of this report.

- **Manufacturer and production volume representation:** three major North American manufacturers included that collectively manufacture more than 95% of all XPS used in the North American construction.[12]
- **Ingredients representation:** Each manufacturer produces a standard XPS product line with conventional HFC blowing agents and a lower-GWP XPS product line with reduced-HFC blowing agent mix. For each manufacturer, a representative product for each of these product lines (standard and reduced-HFC blowing agent blend) was chosen.
- **Compressive strength representation:** Most manufacturers have a product line of XPS products with a range of density and compressive strength, where GWP scales with compressive strength. The CLF chose reference product EPDs of average compressive strength. For the FOAMULAR and Styrofoam EPDs, these are the reference values provided in the EPDs, and the impacts for other products can be calculated based on scaling factors, also provided in the EPDs.
- **Production weighting:** While a production-weighted average would provide a more accurate industry-average GWP value, there is not publically available

11. Institut Bauen und Umwelt e.V. (IBU). (2018). *Product category rules part B: Mineral insulating materials*. https://epd-online.com/

12. Extruded Polystyrene Foam Association (XPSA). (2022). [website]. www.xpsa.com

production volume data associated with the XPS EPDs. Therefore, the CLF uses a simple unweighted average approach as the best approximation given the current data limitations.

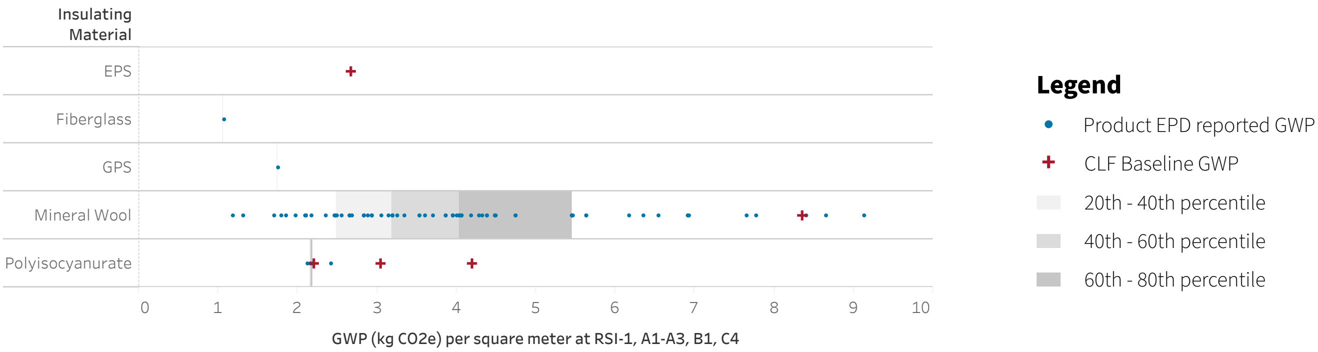


Figure 3. Range of applicable product EPDs and CLF Baselines, excluding XPS. Scope includes A1-A3, B1, and C4, unlike most categories in this report. For non-XPS products, B1 generally equals zero and C4 is negligible (approximately 1% or less of total GWP). XPS is excluded here to better see the data points on a horizontal axis scale of 0 - 10.

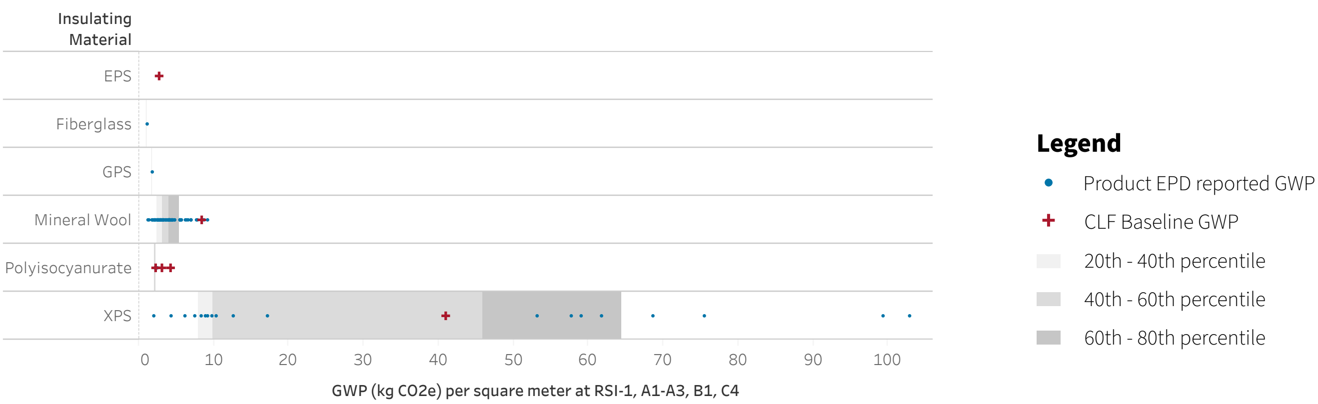


Figure 4. Range of applicable product EPDs and CLF Baselines, including XPS. Scope includes A1-A3, B1, and C4, unlike most categories in this report. For non-XPS products, B1 generally equals zero and C4 is negligible (approximately 1% or less of total GWP).

Insulating Material	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
Mineral Wool	1.2	2.5	3.2	3.7	4.0	5.5	9.1	4.0	8.3
Polyisocyanurate	2.1	2.2	2.2	2.2	2.2	2.2	2.4	2.2	3.1
XPS	2.0	7.9	9.8	12.6	45.9	64.5	102.8	35.4	40.9

Figure 5. Summary statistics of product EPDs and CLF Baselines (kg CO2e per m² at RSI-1, A1-A3, B1, C4).

Life cycle stages in product EPD data

The summary statistics in Figure 5 aim to represent life cycle stages A1-A3 (product stage), B1 (to account for blowing agent emissions during building life), and C4 (to account for blowing agent emissions during disposal). For XPS, B1 and C4 impacts are significant. For non-XPS board insulation products (that are not responsible for GHG emissions due to blowing agent leakage after manufacturing), B1 GWP is zero and C4 is negligible.[13]

13. Life cycle stage GWP information beyond A1-A3 is not regularly available in EC3 (the primary source for this report's EPD data). For XPS, the CLF manually retrieved B1 and C4 GWP results from the EPDs. For most non-XPS product EPDs in the dataset, C4 impacts were not factored into the calculation due to the additional effort it would take to manually retrieve that information. This exclusion limits the precision of the results displayed (especially the summary statistics in Figure 5), but does not practically affect the overall accuracy as C4 impacts are assumed to be negligible for these product types (typically 1% or less of total emissions based on a sample of non-XPS EPDs of different product types).

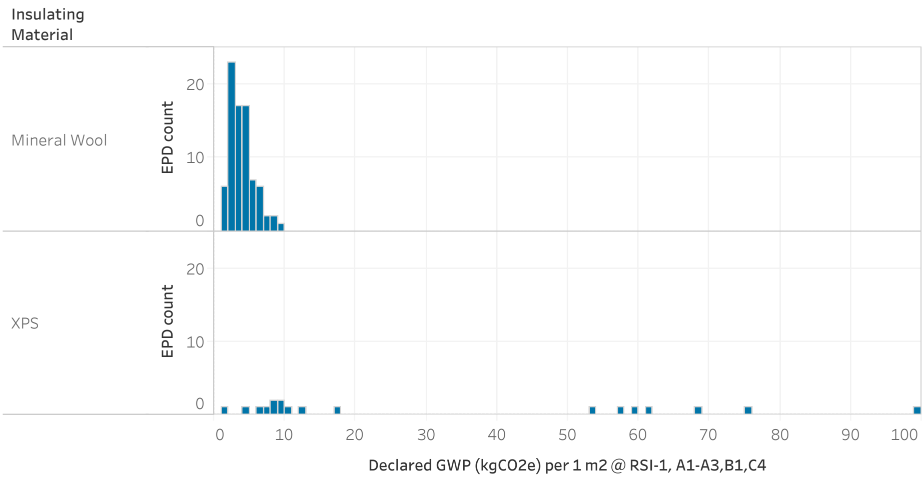


Figure 6. Distribution of applicable product EPDs. Life cycle stages in product EPD data. The summary statistics in Figure 4 aim to represent life cycle stages A1-A3 (product stage), B1 (to account for blowing agent emissions during building life), and C4 (to account for blowing agent emissions during disposal). For XPS, B1 and C4 impacts are significant. For non-XPS board insulation products (that are not responsible for GHG emissions due to blowing agent leakage after manufacturing), B1 GWP is zero and C4 is negligible.

G1.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 m² at RSI-1)	Method	Data Source and Notes
Expanded polystyrene (EPS)	2.67	Industry	EPS-IA. (2017). *Environmental product declaration - Expanded polystyrene insulation*.
Polyiso - wall	4.19	Industry	PIMA. (2020). *Environmental product declaration - Polyiso wall insulation boards*.
Polyiso - roof - GRF facer	2.20	Industry	PIMA. (2020). *Environmental product declaration - Polyiso roof insulation boards*.
Polyiso - roof - CFG facer	3.04	Industry	PIMA. (2020). *Environmental product declaration - Polyiso roof insulation boards*.
Extruded polystyrene (XPS)	41	Industry	Average calculated from collection of 6 product EPDs. See Figure 9.
Heavy density mineral wool board	8.35	Industry	NAIMA. (2018). *Environmental product declaration - Mineral wool board*.

Figure 7. CLF Baselines for board insulations. All categories are based on a scope that includes A1-A3, B1, & C4 to support comparison with other board insulation products with cradle-to-grave blowing agent emissions.

Notes: Declared unit: 1 m2 @ RSI-1 equals 1 m2 at the thickness required to achieve an RSI value of 1.0. RSI, also commonly written as Rsi, is the SI/metric unit of R-value, which measures a material's thermal reistance. An RSI value of 1.0 is equivalent to approximately R-5.68 in I-P/Imperial units (conventionally used in North America).

Product Type	A1	A2	A3	A1:A3	A4	A5	B1	B4	C2	C4
Heavy density mineral wool board	NA	NA	NA	8.16	0.333	0.351	NA	NA	0.0103	0.189
Expanded polystyrene (EPS)	1.9674	0.11	0.55	NA	0.13	0	0	NA	NA	0.038
Polyiso - wall	3.86	0.0699	0.166	NA	0.0693	0.0269	NA	NA	0.00389	0.0951
Polyiso - roof, GRF facer	1.86	0.0646	0.184	NA	0.0712	0.0235	NA	2.07	0.00372	0.091
Polyiso - roof, CGF facer	2.7	0.0646	0.184	NA	0.0712	0.0235	NA	2.83	0.00372	0.091

Figure 8. Industry-Wide EPD GWP data by life cycle stage (kg CO_2e per 1 m² at RSI-1). The green shaded stages are those included in the CLF Baseline GWP values for this category. Mineral wool board provides an aggregated A1:A3 value. The others here provide individual values A1, A2, and A3. The EPS IW-EPD provides an aggregated C2+C4 value, which are combined here in the C4 column. The polyiso roofing board EPDs provide B4 values based on modeled roof replacements over the life of the building.

Data Source	A1-A3	B1	C4	Total
Conventional XPS				
Owens Corning. (2019). *Environmental product declaration - FOAMULAR XPS insulation*.	21.9	28.5	7.3	57.7
Kingspan. (2021). *Environmental product declaration - XPS insulation board, 40 psi.* [standard]	3.6	0.0	65.0	68.6
DuPont. (2021). *Environmental product declaration - Styrofoam brand XPS products.*	29.4	31.4	38.5	99.3
CLF-calculated average Conventional XPS	18.3	20.0	36.9	**75.2**
Reduced-HFC XPS				
Owens Corning. (2021). *Environmental product declaration - FOAMULAR NGX XPS insulation*.	6.9	2.7	0.0	9.6
Kingspan. (2021). *Environmental product declaration - XPS insulation board, 40 psi.* [low-GWP]	3.8	0.0	0.5	4.3
DuPont. (2021). *Environmental product declaration - Styrofoam brand ST-100 XPS products.*	3.5	1.2	1.4	6.1
CLF-calculated average Reduced-HFC XPS	4.7	1.3	0.6	**6.7**
CLF-calculated average Overall XPS	11.5	10.6	18.8	**40.9**

Figure 9. XPS product EPD data and CLF calculations. The CLF used six EPDs – a conventional and a reduced-HFC product from each of the three major North American manufacturers – to generate averages for conventional XPS, reduced-HFC XPS, and XPS (overall). The standard approach to accounting for blowing agent emissions is to allocate the emissions during manufacture to A3, during the life of the building (75 years) to B1, and the rest during disposal - C4. Kingspan's EPDs use a non-standard accounting approach, allocating all blowing agent emissions to C4 and not to A3 or B1. This differing approach should not affect the totals in the right-hand Total column, but does affect the distribution and averages within the given lifecycle stages. All values are kg CO_2e per 1 m² at RSI-1.

G1.4 Additional Notes and Guidance

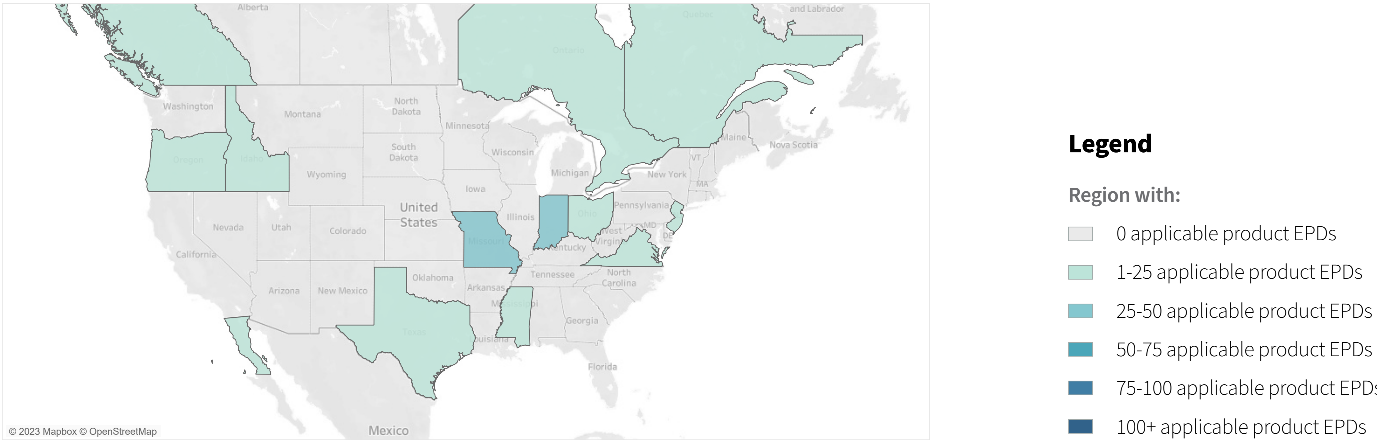


Figure 10. Product EPDs by location.

Comparison of similar product types

In order to support comparability across products, insulation EPDs use a functional unit based on thermal resistance (R-value). However, insulation types vary in other performance characteristics such as resistance to fire, mold, airflow, vapor diffusion, etc. Similar board insulation product types may be functionally equivalent, depending on the performance criteria of the given application in a building project. Figure 11 displays the board insulation EPD data points grouped together to highlight their comparative GWP values.

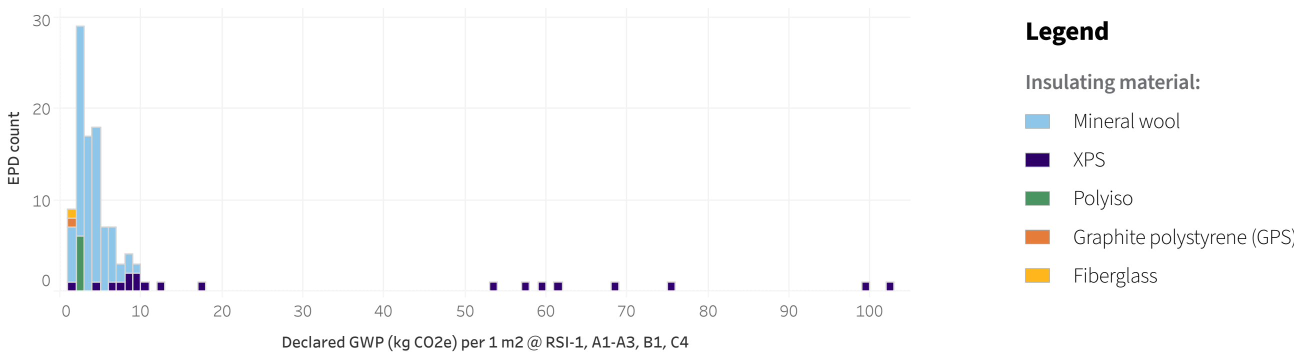


Figure 11. Board insulation product EPDs by insulating material.

Compressive Strength vs. GWP of XPS

XPS products are produced in a range of compressive strengths. Different strength products are appropriate for different applications (e.g., exterior walls or low-slope roofing) and GWP roughly scales with strength. Therefore, any policies or programs that aim to set thresholds, targets, or limits related to XPS ought to take this into account. Figure 12 illustrates the relationship of strength to GWP using one manufacturer's product line as an example.

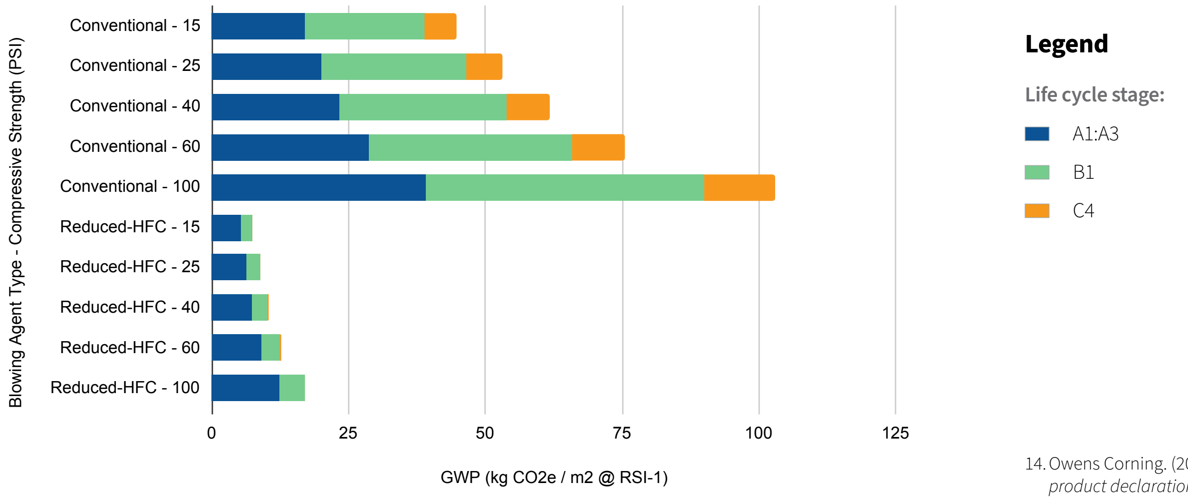


Figure 12. XPS compressive strength vs. GWP (kg CO_2e per 1 m² at RSI-1). One manufacturer's conventional and reduced-HFC blowing agent products are included.[14]

14. Owens Corning. (2019). *Environmental product declaration - FOAMULAR XPS insulation*.
Owens Corning. (2021). *Environmental product declaration - FOAMULAR NGX XPS insulation*.

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G2: BLANKET INSULATION

G2.1 Category Overview

Category Description

Blanket insulation products are flexible, semi-rigid insulating batts or rolls that generally fit in framing cavities of a building envelope – i.e., between wall studs, floor joists, or ceiling rafters. This category includes multiple product types distinguished by insulating material, each with similar (but not identical) form and function.

The two most common insulating blanket materials are (i) mineral wool (produced from stone and/or slag, also called “stone wool” or “slag wool” or “rock wool”) and fiberglass (produced from glass, also called “glass wool”).[1] Other materials may also be produced in blanket form, including sheep wool and cotton. Products may have a facer such as kraft paper or foil on one side or be unfaced.

Production Processes and Key Drivers of Carbon Emissions

Mineral wool: The primary material ingredients for mineral wool insulation are slag and natural rock such as basalt or feldspar. During manufacturing, a furnace melts these raw ingredients and the molten mixture is spun to create fine fibers. The fibers are coated with a binder, and then the fiber-binder composite is formed into boards or blankets. Facings such as kraft paper are added to one face of some products. The blankets are cooled, trimmed, and packaged.

The primary contributor to overall GWP is the energy consumption to melt the feedstock materials (stone and/or slag) at the furnace during manufacturing (A3). This energy use is either through the direct burning of fossil fuels (typically natural gas) or indirect grid power generation. The two primary mineral wool feedstock materials have very different origins and different LCA considerations. Stone such as basalt is produced through hard-rock quarrying which involves digging, blasting, and crushing of bedrock. On the other hand, slag is produced as a byproduct of iron and steel smelting, and is often treated in LCAs (including in the IW-EPD cited here) as “burdenless” (i.e., without environmental impact) when entering the mineral wool production process.[2]

Fiberglass: Similar to the process for mineral wool above, fiberglass insulation is produced by melting feedstock at high temperatures and the molten glass is then spun or drawn through very small holes to create fibers. Binder coatings are added, and the mixture is cured to the proper shape on a conveyor. Facings such as kraft paper are added to one face of some products. The cured product is cut to size and packaged. Off-cuts and scrap are recycled on-site by re-entering the production process.[3]

Fiberglass insulation feedstock includes a blend of recycled glass (“cullet”) and raw ingredients: sand, borax, soda ash, and limestone. The largest contributor to overall GWP is the energy consumption – onsite natural gas or grid electricity – to power the furnace during manufacturing (A3).[4]

1. This report uses the term “mineral wool” as is common in the USA to refer to products made from stone and/or slag. Some sources use “mineral wool” to describe the broader category that includes stone-, slag-, and glass-derived products, and use the term “glass mineral wool” to describe what this report refers to as “fiberglass.”

2. Carbon Leadership Forum. (2022). *Buy Clean California Limits.* https://carbonleadershipforum.org/buy-clean-california-limits/

3. National Institute of Standards and Technology (NIST). (2011). *Generic fiberglass.* https://ws680.nist.gov/bees/ProductListFiles/Generic%20Fiberglass.pdf

4. CertainTeed Saint-Gobain. (2019). *Environmental product declaration: Sustainable insulation unfaced and kraft faced batts.* UL Environment. https://www.certainteed.com/resources/CertainTeed_Sustainable_Insulation_EPD.pdf

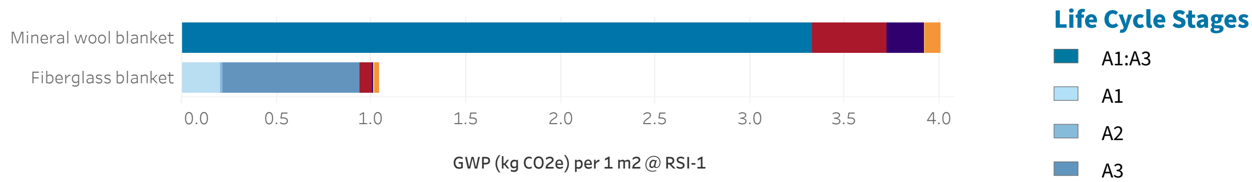


Figure 1. GWP Contribution by Life Cycle Stage. The IW-EPD for mineral wool light-density board (considered as "blanket" for this study). There is no IW-EPD for fiberglass blanket insulation. The data included here for fiberglass is from one product EPD and may not be representative of the industry.[4]

G2.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product category rule (PCR) guidance for building-related products and services part B: Building envelope thermal insulation EPD requirements.*

Industry EPDs

North American Insulation Manufacturers Association (NAIMA). (2018). *Environmental product declaration - Mineral wool board.* UL Environment.

> This document includes light- and heavy-density mineral wool board. The CLF Material Baselines report considers light-density mineral wool board products – which are flexible, semi-rigid products – as "blanket insulation." This EPD is based on primary data from four facilities in Alabama, Indiana, and Mexico. The percentage of total North American production is not disclosed.

Product EPDs

In the EC3 database there are currently 77 applicable* product EPDs for blanket insulation, including mineral wool (72), fiberglass (4), and sheep wool (1).

> *Applicable product EPDs are are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

All of the North American mineral wool product EPDs come from two major manufacturers: Rockwool and Owens Corning. The current Rockwool EPDs for mineral wool insulation produced in North America are based on a different PCR from the primary North American PCR listed above.[5]

There are significantly more EPDs listed here than there are applicable EPD documents (i.e., published PDFs). As described in Appendix A1, in this report an "EPD" corresponds to a specific GWP result. Some blanket insulation EPD documents cover a product family that includes multiple similar products that vary by density, thickness, and facer option, and the EPD document reports unique GWP values for each. Thus there are multiple EPDs (as defined here and in EC3) included in one EPD document. Also, for some blanket insulation EPD documents that cover multiple facilities, EC3 has separate EPDs for each facility (even if the EPD document provides averaged GWP results).

5. Institut Bauen und Umwelt e.V. (IBU). (2018). *Product category rules part B: Mineral insulating materials.* https://epd-online.com/

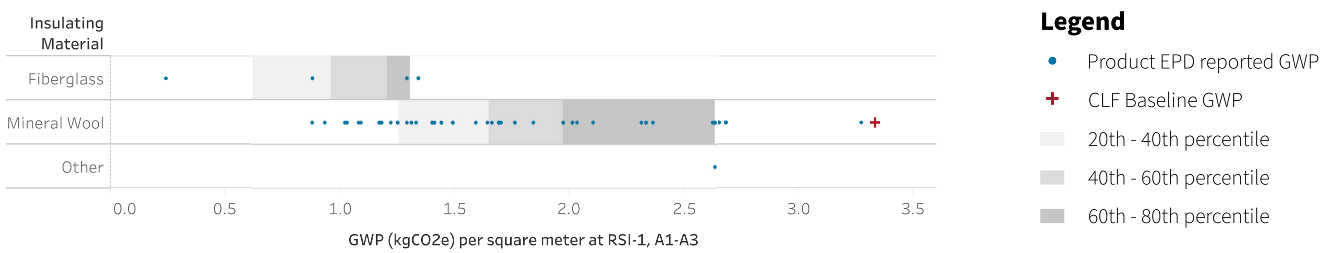


Figure 2. Range of applicable product EPDs and CLF Baseline.

Insulating Material	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
Mineral Wool	0.88	1.26	1.65	1.69	1.97	2.63	3.27	1.85	3.33

Figure 3. Summary statistics of product EPDs and CLF Baseline (kg CO_2e per m² at RSI-1, A1-A3).

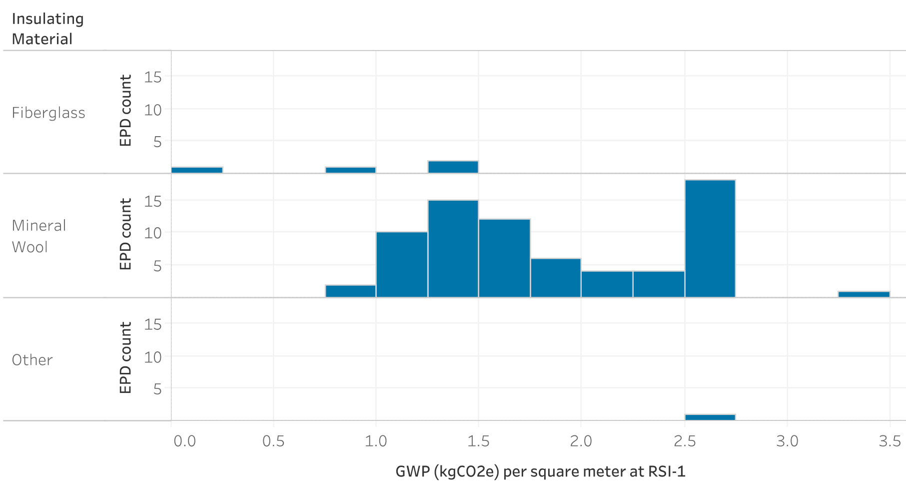


Figure 4. Distribution of applicable product EPDs. The one EPD with “other” insulating material is for sheep wool.

G2.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per m² at RSI-1)	Method	Data Source and Notes
Mineral wool blanket	3.33	Industry	NAIMA. (2018). *Environmental product declaration - Mineral wool board.*
Fiberglass blanket	None	—	No adequately representative data source.

Figure 5. CLF Baselines for blanket insulation.

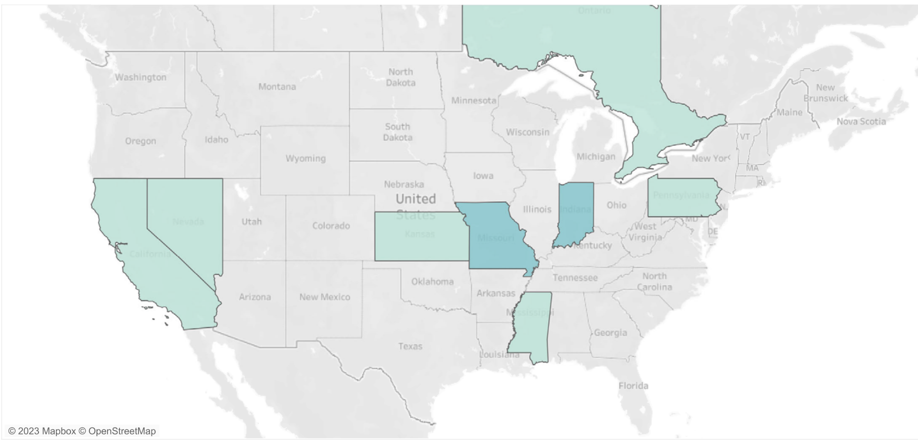
Declared unit: 1 m² @ RSI-1 means 1 m² at the thickness required to achieve an RSI value of 1.0. RSI (sometimes written as Rsi) is the SI/metric unit of R-value, which measures a material’s thermal resistance. An RSI value of 1.0 is equivalent to approximately R-5.68 in I-P/Imperial units (conventionally used in North America).

There is no 2023 CLF Material Baseline for fiberglass blanket insulation since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

Product Type	A1:A3	A4	A5	B1	B4	C2	C4
Mineral wool blanket	3.33	0.392	0.199	NA	NA	0.004242	0.0778

Figure 6. Industry EPD data for GWP by life cycle stage (kg CO_2e per 1 m² @ RSI-1). The green-shaded stages are those included in the CLF Baseline GWP values for this category.

G2.4 Additional Notes and Guidance



Legend

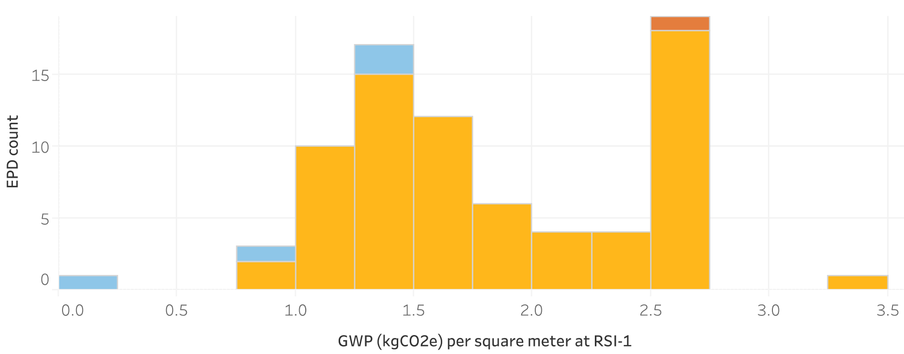
Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 7. Product EPDs by location.

Functionally similar product types

The blanket insulation category consists of multiple functionally similar product types that share the same primary function (i.e., slowing the heat transfer through a building's envelope). The functional unit for insulation EPDs – based on R-value – ensures that any compared products have equivalent performance related to thermal resistance. However, there are functional differences between the product types related to other performance characteristics such as resistance to fire, mold, vapor diffusion, etc.



Legend

- Mineral Wool
- Sheep wool
- Fiberglass

Figure 8. Blanket insulation product EPDs by insulating material. Given the functional similarity of the different blanket insulation product types, this chart displays the same data points as the charts above but grouped together to provide further context for their comparative GWP values.

GWP difference between mineral wool industry EPD and product EPDs

The North American industry EPD for light-density mineral wool board (considered "blanket" in the context of the CLF Material Baselines) reports significantly different GWP than the range of applicable product EPDs. The IW-EPD reports an A1-A3 GWP of 3.33 kg

CO_2e per declared unit, while the average A1-A3 GWP of applicable product EPDs is 1.85 kg CO_2e per declared unit. This significant difference is likely due to some combination of the following factors:

- Variation between manufacturers: the IW-EPD uses primary data from some smaller manufacturers whose plant operations may not benefit from the same economies of scale that the larger manufacturers have. The available product EPDs are only from large manufacturers.
- Variation in the supply chain: the ratio of the two primary ingredients – slag (which LCAs generally treat as burden-free) and natural stone (which involve quarrying-related impacts) – may differ between the IW-EPD and product EPDs. This ratio could affect product GWP.
- Variation in the physical characteristics of the product: the density and/or thickness of the average product used in the IW-EPD may be greater than those of the product EPDs (for insulation EPDs, the R-value of the declared unit is standardized, and different products require different thicknesses to achieve that standard R-value). This would translate to a higher mass for the IW-EPD average product declared unit. And higher-density insulation products – since they have more material in a given declared unit – will generally have higher GWP.
- Variation in geography: due to differences such as electrical grid mix and transport distances, similar plants that operate in different parts of North America may produce products of different GWP profiles. The IW-EPD is based on a relatively small sample size of plants.
- Age of data: the IW-EPD is older than all of the product EPDs and reaches the end of its five-year validity in 2023. Data sets may have changed in the interim.

Implications of Insulation Facers

Blanket insulation products are produced with a variety of facer options, including unfaced. Different facer options have different performance attributes and different GWPs are not always functionally equivalent. Currently, the different facer options are not captured in the CLF Baselines categorization.

This is also a category with non-linear scaling between quantity and GWP. Although the insulating material does scale linearly, the facer does not scale linearly. For example, a blanket insulation with twice the thickness would have twice the GWP but the facer GWP would remain constant.

Because many product EPDs include detailed methods for calculating the impacts for any product in the family (any R-value and facer type), this issue of non-linear scaling would generally not limit one's ability to determine the impacts of a particular product. But it does complicate the use of a single static baseline for the type (e.g., mineral wool blanket) that does not account for the overall R-value and facer type of a given product.

In the future, with more data availability, it may be feasible to establish baseline GWP values that account for facers in addition to area and R-value.

G3: FOAMED-IN-PLACE INSULATION

G3.1 Category Overview

Category Description

Foamed-in-place insulations are spray-polyurethane foam (SPF) products that are made at the time of installation by combining two chemical components. When combined, these components react and expand quickly into foam at the point of application. They provide thermal insulation and air sealing to the building envelope – in framing cavities (such as between studs or rafters), continuously (such as over roof decks), or to fill specific gaps between elements (such as between window frames and wall framing).

Primary types of foamed-in-place insulation, based on functional performance and as differentiated in the industry EPDs, include the following, which align with the CLF Material Baselines categorization:[1,2]

- **Medium density SPF** (referred to simply as "closed-cell SPF" in the IW-EPDs). This closed-cell foam is typically used in stud cavities or for air-sealing and can provide continuous insulation.
- **Roofing SPF** is a high-density closed-cell foam typically used for low-slope roofs and can provide continuous insulation.
- **2k-LP SPF** (two-component low-pressure SPF) products are typically closed-cell and can be used for sound dampening, in addition to the primary functions of insulation and air sealing. These often have the same requirements as medium-density SPF products.
- **Open-cell SPF (ocSPF)** is a low-density foam that provides insulation and air sealing. Unlike closed-cell foams which cure to a hard texture, open-cell foams tend to stay "spongy."

Name	Roofing	2K-LP	Closed cell	Open cell
Density [lb / ft^3]	2.5 to 4.0	1.8 to 2.0	1.5 to 2.4	0.5 to 0.7
Thermal resistivity [R / in]	6.2 to 6.8	6.1 to 6.2	6.2 to 7.0	3.6 to 4.5
Air impermeable material	✓	✓	✓	✓
Integral vapor retarder	✓		✓	
Water resistant	✓		✓	
Cavity insulation		✓	✓	✓
Continuous insulation	✓		✓	✓
Low-slope roofing	✓			
Structural improvement	✓		✓	

Figure 1. Technical characteristics of the four SPF product types.[1,2]

Production Processes and Key Drivers of Carbon Emissions

Spray polyurethane foam is made from two chemical components (referred to as A-side and B-side), which are themselves made from multiple chemical inputs. The manufacturer produces these components (accounted for in A3), which are delivered to the job

1. Spray Polyurethane Foam Alliance (SPFA). (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFC).* ASTM International. https://pcr-epd.s3.us-east-2.amazonaws.com/450.EPD_for_SPFA_EPD_20181029_HFC.pdf

2. Spray Polyurethane Foam Alliance (SPFA). (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFO).* ASTM International. https://pcr-epd.s3.us-east-2.amazonaws.com/451.EPD_for_SPFA_EPD_20181029_HFO_excl_2K-LP.pdf

site in separate tanks. During installation (A5), the installer mixes together and simultaneously sprays the A-side and B-side components onto the surface of application, where the mixture expands to create foam. Spray foam insulation is unique compared to the rest of the materials in this report in that the cradle-to-gate (A1-A3) product (comprising two tanks of chemical mixtures) bears no physical resemblance to the installed product (foam insulation).

Closed-cell spray foams use a chemical blowing agent to expand the foam. North American manufacturers have conventionally used hydrofluorocarbons (HFC) as the chemical blowing agent, which have a very high global warming potential (GWP). More recently, some spray foams are produced with hydrofluoroolefin (HFO) blowing agents, which have significantly lower GWP. Open-cell spray foams generally do not use a chemical blowing agent, but rather use water as a reactive non-chemical blowing agent.

Chemical blowing agents emit into the atmosphere and contribute to climate change. For both types – HFO and HFC – this occurs during installation (A5).[3] For HFCs, this also occurs while the blowing agent gradually leaks from the installed product during the building lifetime (B1) and after disposal (C4). For HFC-based foams, these three stages are each as significant as A1-A3, and in combination dominate the products' cradle-to-grave embodied carbon.

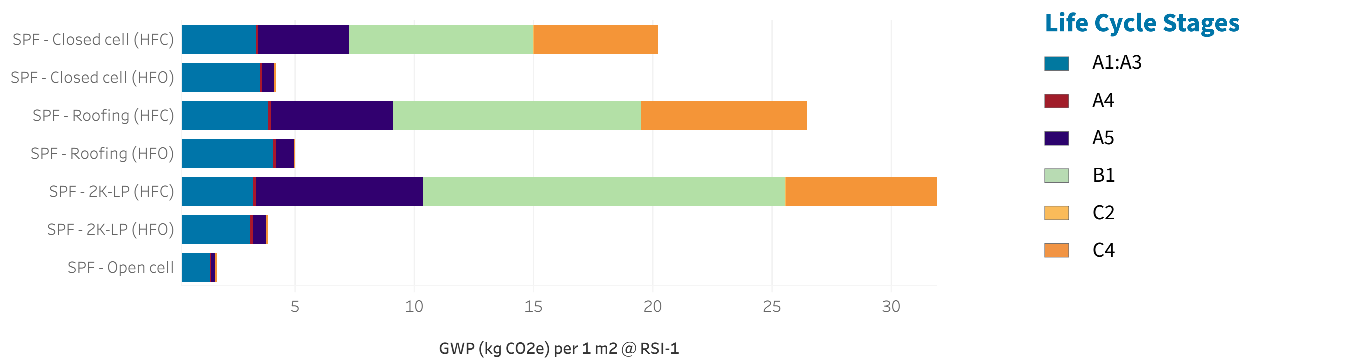


Figure 2. GWP Contribution by Life Cycle Stage. The IW-EPDs for spray polyurethane foam insulation aggregate stages A1-A3, and also include stages A4, A5 (when the foam is produced on-site), B1 (accounting for blowing agent emissions during the life of the building), C2 (negligible impacts), and C4 (dominated by blowing agent emissions after disposal).[1,2]

G3.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product category rule (PCR) guidance for building-related products and services part B: Building envelope thermal insulation EPD requirements.*

Industry EPDs

There are industry-wide EPDs for six product types, published in two EPD documents – one document for foams with HFC-based blowing agents and one document for foams with HFO-based blowing agents. Open-cell spray polyurethane foam (ocSPF) uses neither HFC nor HFO as its blowing agent, and identical sets of LCIA results for

3. This accounting in A5 includes direct emissions to the atmosphere during installation and indirect emissions from the waste product that is disposed of and gradually emits blowing agent to the atmosphere.

ocSPF are included in both of the EPD documents. There is also a publicly available LCA background report to the industry EPDs that includes the six product types in the EPDs as well as 2k-LP (HFO) (not included in the industry EPDs).

Spray Polyurethane Foam Alliance (SPFA). (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFC).* ASTM International.

> This document includes IW-EPDs for: closed-cell, HFC; roofing, HFC; 2k-LP, HFC; and open-cell (identical to the one listed below in the HFO document).[1]

Spray Polyurethane Foam Alliance (SPFA). (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFO).* ASTM International.[2]

> This document includes IW-EPDs for: closed-cell, HFO; roofing, HFO; 2k-LP, HFO; and open-cell (identical to the one listed above in the HFC document).
>
> The SPFA IW-EPDs cover "a range of spray polyurethane foam manufactured at 13 different facilities by participating SPFA members, representing a significant majority of annual production in the US and Canada."[4]

Other industry-wide data

Thinkstep. (2018). *Spray polyurethane foam insulation products – EPD background report*. SPFA.[4]

> This background report to the industry EPDs is also publicly available. It includes LCIA results for an additional product not included in the IW-EPDs: 2k-LP, HFO.

Product EPDs

There are currently 0 applicable* product EPDs for this category.

> *Applicable product EPDs are are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

Due to the lack of product EPDs in this category, this appendix does not include the scatter plot, summary statistics, or histogram that appears in many of the other appendices in this report.

G3.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per m² at RSI-1)	Method	Data Source and Notes
Closed-cell spray polyurethane foam - medium density	12	Industry	Average of: 20.06 kg CO_2e. IW-EPD closed-cell SPF – SPFA. (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFC).* 4.04 kg CO_2e. IW-EPD closed-cell SPF – SPFA. (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFO)*

4. Thinkstep. (2018). *Spray polyurethane foam insulation products – EPD background report.* SPFA. https://www.sprayfoam.org/files/SPFA_EPD%20Background%20Report%2020181029_signed(1).pdf

Closed-cell spray polyurethane foam - roofing	16	Industry	Average of: 26.29 kg CO_2e. IW-EPD roofing SPF – SPFA. (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFC).* 4.80 kg CO_2e. IW-EPD roofing SPF – SPFA. (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFO)*
Spray polyurethane foam - 2k-LP	20	Industry	Average of: 35.7 kg CO_2e. IW-EPD 2k-LP SPF – SPFA. (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFC).* 3.71 kg CO_2e. IW-LCA Report 2k-LP SPF -- Thinkstep. (2018). *Spray polyurethane foam insulation products EPD background report.* SPFA.
Open-cell spray polyurethane foam	1.6	Industry	IW-EPD open-cell SPF – IW-EPD roofing SPF – SPFA. (2018). *Environmental product declaration - Spray polyurethane foam insulation (HFC) and (HFO).*

Figure 3. CLF Baselines for foamed-in-place insulation.

Notes

- **Declared unit:** 1 m² @ RSI-1 equals 1 m² at the thickness required to achieve an RSI value of 1. RSI, also commonly written as Rsi, is the SI/metric unit of R-value, which measures a material's thermal resistance. An RSI value of 1.0 is equivalent to approximately R-5.68 in I-P/Imperial units (conventionally used in North America).
- **Additional life cycle stages:** This category's Baseline GWP values are based on a scope of life cycle stages A1-A3, A5, B1, and C4 to account for foam production (A5) and blowing agent emissions over the complete life cycle of the product (A5, B1, and C4). Figure 4 provides all life cycle stage GWP values reported in the IW-EPDs and IW-LCA report.
- **CLF calculations:** For each of the three closed-cell SPF product types included here (medium density, roofing, 2k-LP), the HFC- and HFO-based versions are functionally equivalent. The two subtypes use different material ingredients to achieve the same functional result. Hence they are considered as one CLF Material Baseline product type (e.g., roofing SPF), as opposed to two separate CLF Material Baseline product types (e.g., roofing SPF - HFC and roofing SPF - HFO). The CLF calculated the baseline GWP values for each of these product types using a simple unweighted average of the two IW-EPD data points per type.[5] Figure 4 provides the IW-EPD reported values and CLF-calculated averages used to generate the CLF Baselines.
- **Foam insulation blowing agent emissions at end-of-life:** Research suggests that a conservative and realistic approach to modeling HFC emissions is to assume that all of the original blowing agent in the foam eventually releases to the atmosphere.[6,7] EPDs for extruded polystyrene (XPS) – the other foam insulation type that is conventionally produced with HFC blowing agents in North America – assume that upon landfilling, all of the remaining original blowing agent in the foam is eventually released to the atmosphere, and this is accounted for in C4. On the other hand, the SPFA EPDs assume that 50% of the original blowing agent remains in the product indefinitely while landfilled. Thus it is reasonable to believe that the C4

5. While the CLF is confident that the industry-average GWP for each product type is somewhere between the two (very different) values of the HFC and HFO versions, a more accurate calculation is not possible at this point without relative production volume information.

6. Harvey, L.D. Danny. (2007). Net climatic impact of solid foam insulation produced with halocarbon and non-halocarbon blowing agents. *Building and Environment*, 42(8), 2860-2879. https://doi.org/10.1016/j.buildenv.2006.10.028

7. Harvey, L.D. Danny. (2020). Personal correspondence.

values reported for the HFC-based spray foam products (and by extension the total values used for the CLF Baseline GWP) undercount true emissions.

Product Type	Blowing Agent	A1:A3	A4	A5	B1	C2	C4	Sum A1:A3, A5, B1, C4
Medium density	HFC	3.31	0.122	3.82	7.73	0.0034	5.2	20.06
	HFO	3.47	0.122	0.525	0	0.0034	0.0417	4.0367
	CLF Average	**3.39**	0.122	**2.17**	**3.87**	0.003	**2.62**	**12.05**
Roofing	HFC	3.83	0.162	5.1	10.4	0.00449	6.96	26.29
	HFO	4.05	0.162	0.693	0	0.00449	0.0551	4.7981
	CLF Average	**3.94**	0.162	**2.90**	**5.20**	0.00449	**3.51**	**15.54**
2k-LP	HFC	3.21	0.098	7.05	15.2	0.00273	10.2	35.66
	HFO	3.12	0.098	0.558	0	0.00272	0.0334	3.7114
	CLF Average	**3.17**	0.098	**3.80**	**7.60**	0.00273	**5.12**	**19.69**
Open-cell	**H20**	**1.42**	0.0506	**0.17**	**0**	0.00141	**0.02**	**1.60**

Figure 4. Life cycle stage GWP (kg CO_2e per 1 m^2@RSI-1). Values in rows marked with HFC, HFO, and H_2O are directly from the IW-EPDs. Rows marked “CLF Average” are calculated by CLF using straight (unweighted) averages of the two subtypes in the category. The green-shaded stages are those included in the CLF Baseline GWP scope for foamed-in-place insulation.

G3.4 Additional Notes and Guidance

Due to the lack of product EPDs in this category, this appendix does not include the map that appears in many of the other appendices in this report.

G4: LOOSE-FILL INSULATION

G4.1 Category Overview

Category Description

The category includes unbonded loose-fill insulations that are typically installed in attics or wall cavities via a blowing machine.[1] Primary material types include: loose-fill mineral wool[2] (produced from stone and/or slag, also called "stone wool," "slag wool," or "rock wool"), loose-fill fiberglass, and loose-fill cellulose. Less common material types, such as cotton and sheep wool, are also available.

Production Processes and Key Drivers of Carbon Emissions

Mineral wool: The primary material ingredients for mineral wool insulation are slag and natural rock such as basalt or feldspar. At the mineral wool insulation manufacturing facility, a furnace melts these raw ingredients and the molten mixture is spun or blown to create fine fibers. Once cooled, these are processed and packaged into the final product.[3]

The primary contributor to overall GWP is the energy consumption to melt the feedstock materials (stone and/or slag) at the furnace. This energy use is either through the direct burning of fossil fuels (typically natural gas) or indirect grid power generation. The two primary mineral wool feedstock materials have very different origins and different LCA considerations. Stone such as basalt is produced through hard-rock quarrying which involves digging, blasting, and crushing of bedrock. Slag is produced as a byproduct of iron and steel smelting, and is often treated in LCAs (including in the IW-EPD cited here) as burdenless when entering the mineral wool production process.[4]

Fiberglass: Similar to the process for mineral wool above, fiberglass insulation is produced by melting feedstock at high temperatures and the molten glass is then spun or drawn through very small holes to create fibers.

Fiberglass insulation feedstock includes a blend of recycled glass ("cullet") and raw ingredients: sand, borax, soda ash, and limestone. The largest contributor to overall GWP is the energy consumption – onsite natural gas or grid electricity – to power the furnace for glass melting during manufacturing (A3).[5]

Cellulose: The primary ingredients in cellulose insulation are recovered (mostly post-consumer) paper, paper fibers, and cardboard. These are processed into fibers, which are blended together and then mixed with fire retardants such as boric acid and ammonium sulfate. Fibers are dried, milled, and packaged.[6]

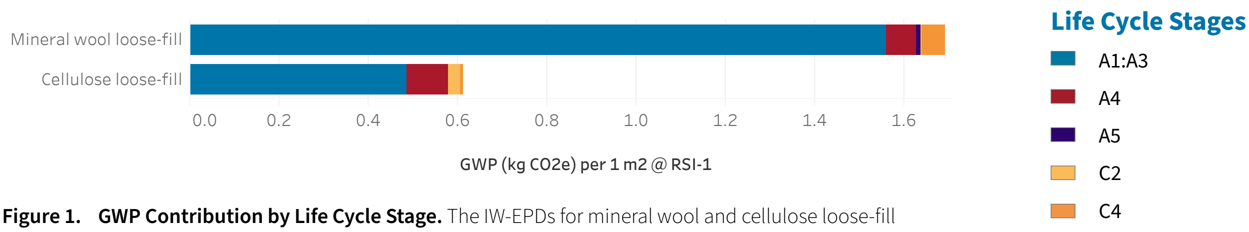


Figure 1. GWP Contribution by Life Cycle Stage. The IW-EPDs for mineral wool and cellulose loose-fill insulation aggregate stages A1-A3, and also include additional stages A4, A5, C2, and C4. There is no IW-EPD for fiberglass loose-fill insulation.

1. Given the typical installation process, EC3 and past versions of the CLF Material Baselines refer to this category as "blown insulation." Some EPDs refer to loose fill insulation products as "blowing wool."

2. This report uses the term "mineral wool" as is common in the USA to refer to products made from stone and/or slag. Some sources use "mineral wool" to describe the broader category that includes stone-, slag-, and glass-derived products, and use the term "glass mineral wool" to describe what this report refers to as "fiberglass."

3. North American Insulation Manufacturers Association (NAIMA). (2018). *Environmental product declaration - Mineral wool loose fill.* UL Environment.

4. Carbon Leadership Forum. (2022). *Buy Clean California Limits.* https://carbonleadershipforum.org/buy-clean-california-limits/

5. Owens Corning. (2018). *Environmental product declaration - Owens Corning unbonded loosefill.* UL Environment. https://dcpd6wotaa0mb.cloudfront.net/mdms/dms/Shared/10018099/10018099-EPD---Unbonded-Loosefill.pdf

6 Cellulose Insulation Manufacturers Association (CIMA) and Cellulose Insulation Manufacturers Association of Canada (CIMAC). (2019). *Conventional loose-fill cellulose insulation.* Sustainable Minds. https://transparencycatalog.com/assets/uploads/pdf/cima-cimac-Conventional-Loose-Fill-Cellulose-Insulation_EPD.pdf

G4.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product category rule (PCR) guidance for building-related products and services part B: Building envelope thermal insulation EPD requirements.*

Industry EPDs

There are two North American industry EPDs – one for mineral wool and one for cellulose. There is also a publicly available background report to the cellulose industry EPD. There is no fiberglass loose fill insulation industry EPD.

North American Insulation Manufacturers Association (NAIMA). (2018). *Environmental product declaration - Mineral wool loose fill.* UL Environment.

> This EPD is based on data from a relatively small sample size of three facilities (Minnesota, Texas, and Mexico). The percentage of total North American production is not disclosed.

Cellulose Insulation Manufacturers Association (CIMA) and Cellulose Insulation Manufacturers Association of Canada (CIMAC). (2019). *Conventional loose-fill cellulose insulation. Sustainable Minds.*

> The cellulose industry EPD is based on data from 13 facilities across the USA and Canada. The percentage of total North American production is not disclosed.

Product EPDs

There are currently five applicable* product EPDs for this category – one for mineral wool, two for fiberglass, one for cellulose, and one for sheep wool.

> *Applicable product EPDs are are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

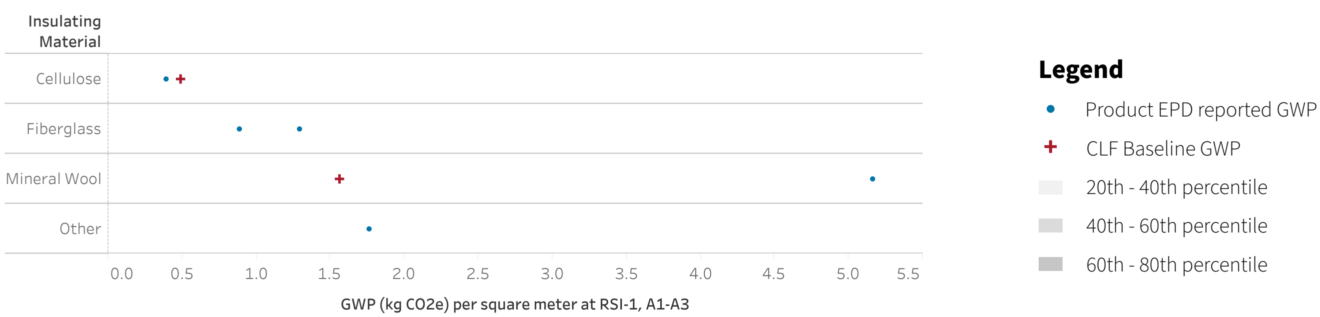


Figure 2. Range of applicable product EPDs and CLF Baseline. The one EPD with “other” insulating material is for sheep wool.

Due to the lack of product EPDs for the product types in this category, this appendix does not include the summary statistics or histogram that appear in many of the other appendices in this report. See a combined histogram in *Additional Notes and Guidance*.

G4.3 CLF Baseline

Product Type	CLF Baseline GWP (kg CO_2e per m² at RSI-1)	Method	Data Source and Notes
Cellulose loose-fill	0.487	Industry	CIMA. (2019). *Industry-wide type III EPD - Conventional loose-fill cellulose insulation*.
Mineral wool loose-fill	1.56	Industry	NAIMA. (2018). *Environmental product declaration - Mineral wool loose-fill.*
Fiberglass loose-fill	None	—	No adequately representative data source.

Figure 3. CLF Baselines for loose-fill Insulation.

Notes

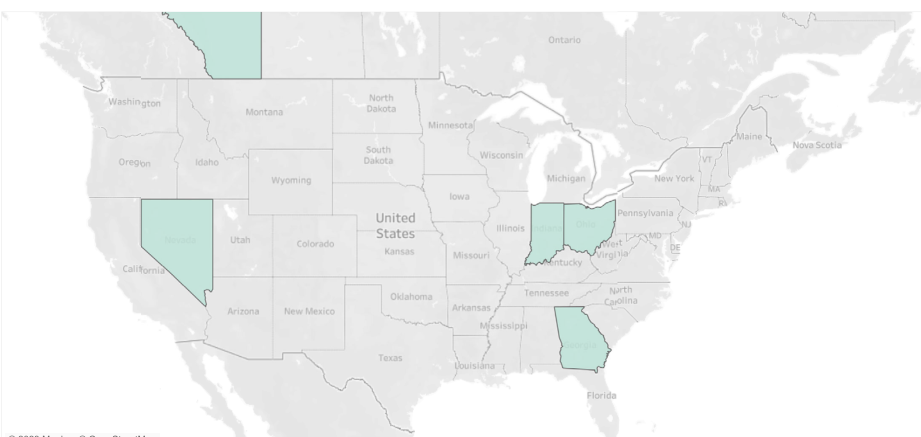
Declared unit: 1 m² @ RSI-1 equals 1 m² at the thickness required to achieve an RSI value of 1. RSI, also commonly written as Rsi, is the SI/metric unit of R-value, which measures a material's thermal resistance. An RSI value of 1.0 is equivalent to approximately R-5.68 in I-P/Imperial units (conventionally used in North America).

There is no 2023 CLF Material Baseline for fiberglass loose-fill insulation since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

Product Type	A1	A2	A3	A1:A3	A4	A5	B1	B4	C2	C4
Loose-fill cellulose	NA	NA	NA	0.487	0.0899	0.0017	NA	NA	0.0262	0.00847
Loose-fill mineral wool	NA	NA	NA	1.56	0.0663	0.0114	NA	NA	0.00266	0.0497

Figure 4. Industry-Wide EPD GWP data by life cycle stage (kg CO_2e per 1 m² at RSI-1). The green-shaded stages are those included in the CLF Baseline GWP values for this category.

G4.4 Additional Notes and Guidance



Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 5. Product EPDs by location.

Functionally similar product types:

The loose-fill insulation category consists of multiple functionally similar product types that share the same primary function (i.e., slowing the heat transfer through a building's envelope). The functional unit for insulation EPDs – based on R-value – ensures that any compared products have equivalent performance related to thermal resistance. However, there are functional differences between the product types related to other performance characteristics such as resistance to fire, mold, etc.

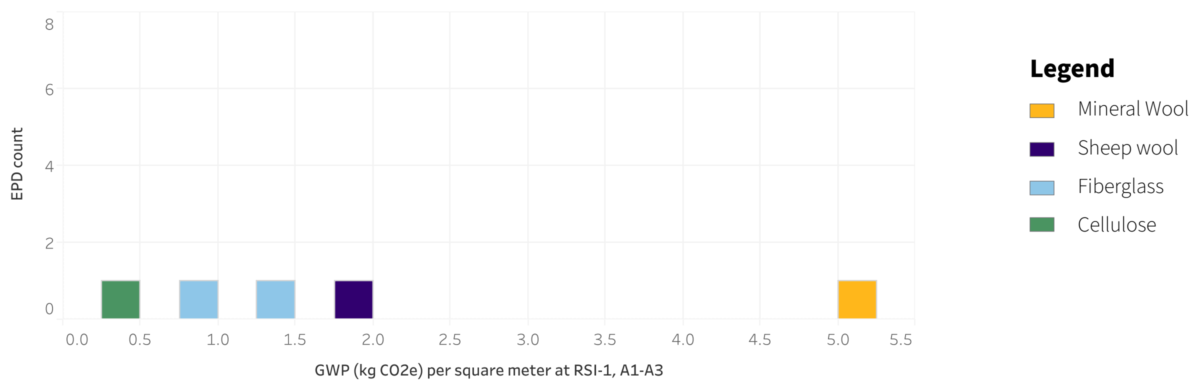


Figure 6. Loose-fill insulation product EPDs by insulating material. Given the functional similarity of the different loose-fill insulation product types, this chart provides context for their comparative GWP values.

H1: METAL PANEL CLADDING

H1.1 Category Overview

Category Description

This category includes non-insulated metal panels for roof and wall cladding. In alignment with the industry-wide EPDs, this report includes the following categories:

- Roll-formed metal cladding panels
  - Steel
  - Aluminum
- Metal composite material (MCM) cladding panels

Production Processes and Key Drivers of Carbon Emissions

Roll-formed metal panels are coated metal profiles such as box rib or standing seam. They are made by feeding coiled steel or aluminum through a roll former. The upstream production of steel or aluminum contributes the overwhelming majority of emissions to the total cradle-to-gate GWP for roll-formed panels. In the industry EPDs, A1 – accounting for the steel or aluminum coil production – is over 98% of the total A1:A3 GWP impact.[1]

Metal composite material (MCM) panels are made of two sheets (sometimes called "skins") of coated metal that sandwich a thin plastic core. Products vary in terms of the metal type (aluminum, steel, etc.), metal thickness, core type, and core thickness (typically 3, 4, or 6 mm). The industry EPD is based on a reference product with 0.02-inch (0.508 mm) thick aluminum skins and 4 mm thick polyethylene (PE) and fire-resistant (FR) core. The metal and core each constitute 50% of the total product by mass. The upstream production of the input materials – particularly the metal coil – is the largest contributor (over 90% in the industry EPD) to the cradle-to-gate GWP.[2]

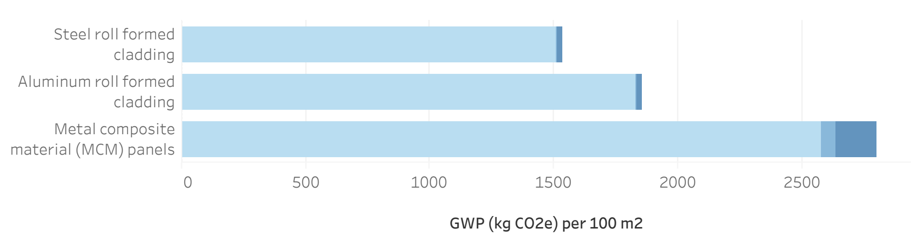


Figure 1. GWP contribution by life cycle stage. A1 = steelmaking and aluminum-making, rolling into coil, plastics production (MCM only); A2 = transport of coil and plastic to roll forming or MCM facility; A3 = manufacture of panels via roll forming or laminating.

H1.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product Category Rule (PCR) for Part B: Insulated metal panels, metal composite panels, and metal cladding: roof and wall panels, v2.0.*

1. Metal Construction Association. (2020). *Environmental product declaration - Roll formed cladding wall and roof cladding systems*. UL Environment. https://metalconstruction.org/index.php/online-education/epd---roll-formed-aluminum-and-steel-cladding-for-roofs-and-walls

2. Metal Construction Association. (2020). *Environmental product declaration - Metal composite material wall and roof panel systems*. UL Environment. https://metalconstruction.org/index.php/online-education/environmental-product-declaration-for-metal-composite-material-panels

Industry EPDs

Metal Construction Association. (2020). *Environmental product declaration - Roll formed cladding wall and roof cladding systems.* UL Environment.

> This industry EPD is based on a sample of primary data from six participating companies, "representing a significant majority of annual production in the US and Canada." The size of the sample in proportion to total North American production is not disclosed.

Metal Construction Association. (2020). *Environmental product declaration - Metal composite material wall and roof panel systems.* UL Environment.

> This industry EPD is based on a sample of primary data from three participating companies, "representing a significant majority of annual production in the US and Canada." The size of the sample in proportion to total North American production is not disclosed.

Product EPDs

There are currently no applicable* product EPDs for the product types in this category. There are many MCM cladding panel EPDs from outside of North America.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

Due to the lack of applicable product EPDs in this category, this appendix does not include the scatter plot, summary statistics table, histogram, or map that appears in many of the other appendices in this report.

H1.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 100 m²)	Method	Data Source and Notes
Steel roll-formed cladding panels	1,530	Industry	Metal Construction Association. (2020). *Environmental product declaration - Roll formed cladding wall and roof cladding systems.*
Aluminum roll-formed cladding panels	1,860	Industry	Metal Construction Association. (2020). *Environmental product declaration - Roll formed cladding wall and roof cladding systems.*
Metal composite material (MCM) panels	2,800	Industry	Metal Construction Association. (2020). *Environmental product declaration - Metal composite material wall and roof panel systems.*

Figure 2. CLF Baselines for metal panel cladding.

H2: INSULATED METAL PANELS

H2.1 Category Overview

Category Description

Insulated metal panels (IMPs) consist of two sheets of coated metal that sandwich an insulating core. They serve as wall and roof cladding, providing vapor, air, and moisture barriers, as well as thermal performance for the building envelope.[1]

Production Processes and Key Drivers of Carbon Emissions

IMP metal skins are made from galvanized steel (or similar metal) coil. The upstream steel production and galvanization processes are major contributors to the panel's cradle-to-gate GWP.

There are different types of insulating materials used for IMPs' insulating cores. Mineral wool is sometimes used as an IMP insulating material. In this case, the insulation is produced upstream of the IMP facility and would be accounted for in A1. In other cases, IMPs use rigid foam insulation, which is produced via foam injection during the panel manufacturing process, and accounted for in A3. The industry-wide EPD represents IMPs with a polyurethane foam insulation core, where the emission of HFC blowing agents during the foam production process contributes to the cradle-to-gate GWP of the panels.[1] Other (non-polyurethane) foam insulations used for IMPs are HFC-free, resulting in relatively lower GWP (see Figure 4.)

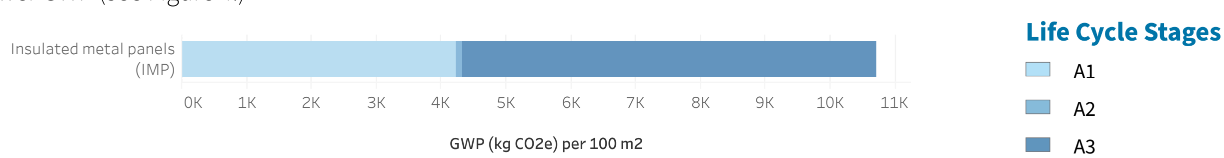


Figure 1. GWP contribution by life cycle stage. A1 = galvanized steel coil production, production of chemical ingredients to polyurethane; A2 = transport of input materials to IMP manufacturing facility; A3 = manufacture of panels, including production of polyurethane foam.[1]

H2.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product Category Rule (PCR) for Part B: Insulated metal panels, metal composite panels, and metal cladding: roof and wall panels, v2.0.*

Industry EPDs

Metal Construction Association. (2020). *Environmental product declaration - Insulated metal panels wall and roof panel systems.* UL Environment.

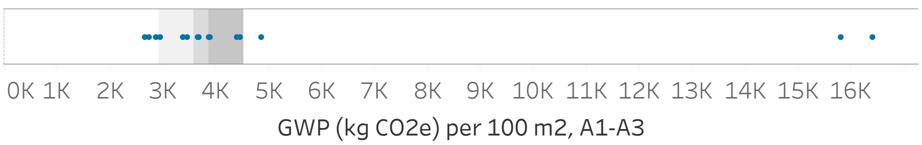
> The EPD describes a range of product types under study, with varying foam thickness (2-6”), metal thickness (22-26 gauge), and types of foam. The proportion of total North American production used in the data set is not disclosed.[1]

1. Metal Construction Association. (2020). *Environmental product declaration - Insulated metal panels wall and roof panel systems.* UL Environment. https://metalconstruction.org/index.php/online-education/environmental-product-declaration-for-insulated-metal-panels

Product EPDs

There are currently 15 applicable* product EPDs for this category (including EPDs from each of EC3's insulated roof panels and insulated wall panels categories).

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.



Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

Figure 2. Range of applicable product EPDs and CLF Baselines. There is no CLF Baseline GWP for this category.

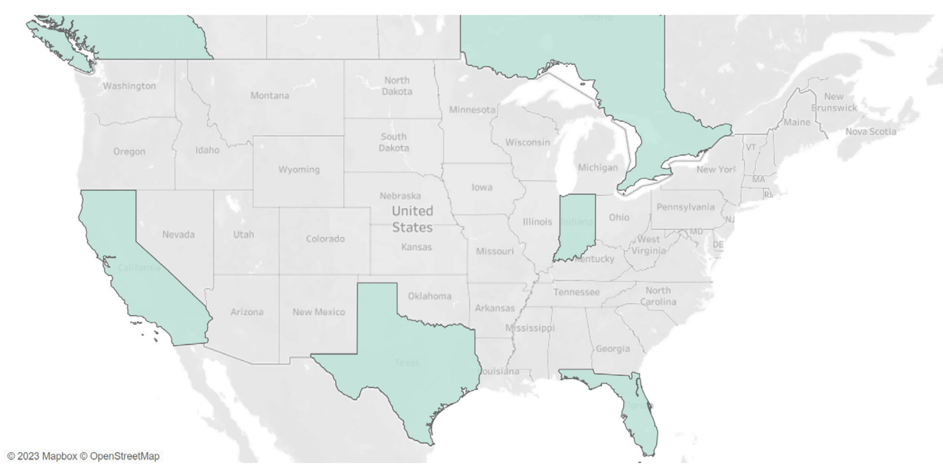
Due to the range of non-functionally equivalent products in this category – particularly related to differences in thickness and R-value – this appendix does not include a table of category summary statistics.

H2.3 CLF Baselines

There is no 2023 CLF Material Baseline for insulated metal panel since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

While there is an industry EPD for insulated metal panels, the variation of product technical characteristics (insulation type and thickness and metal gauge) and the associated variation in performance (especially R-value) and GWP within the category is too large to set a single baseline number. In the future, with more data, it may be feasible to set one or more baseline GWP values that account for R-value.

H2.4 Additional Notes and Guidance



Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 3. Product EPDs by location.

GWP and Insulating Material

Insulated metal panels are produced with a variety of insulating materials. The type of insulating material can significantly affect product GWP. Figure 4 differentiates applicable product EPDs by insulating material.

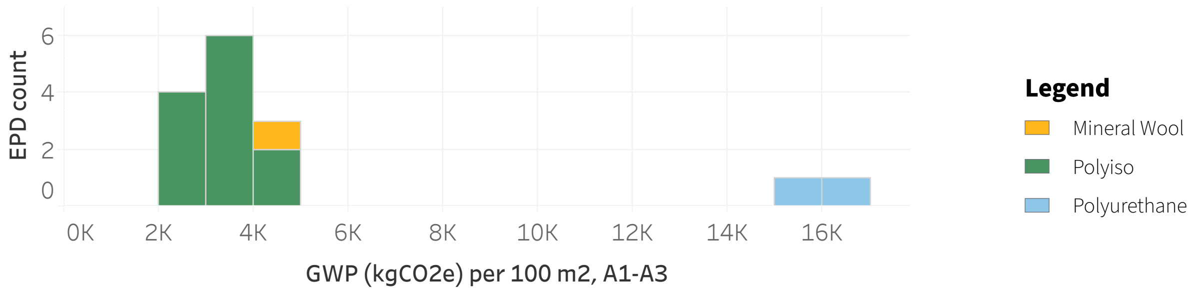


Figure 4. Product EPD GWP by insulating material. Some IMP products with a proprietary hybrid foam core are grouped here with polyiso as polyiso is a similar generic insulating material in terms of R-value and GWP.[2] The polyurethane core products have a much higher carbon footprint due to the use of HFC blowing agents that emit to the atmosphere during foam production.

2. Kingspan. (2023). QuadCore by Kingspan [website]. https://www.kingspan.com/us/en/business-groups/kingspan-insulated-panels/quadcore/

H3: SINGLE-PLY ROOFING MEMBRANES

H3.1 Category Overview

Category Description

Singly-ply roofing membranes are commonly used as the waterproof finish material for low-slope roofing. They are thermoplastic (they have a lower melting point and can be heated and melted again) or thermoset (they can withstand higher temperatures and remain in a permanently solid state) membranes of compounded synthetic materials manufactured in a factory.[1] They are commonly attached to the building by one of two methods: fully adhered or mechanically fastened.

Common single-ply roofing membrane types include single-ply polyester reinforced (SPPR) polyvinyl chloride (PVC) (thermoplastic), ethylene-propylene-diene terpolymer (EPDM) (thermoset), ketone ethylene ester (KEE) (thermoplastic), and thermoplastic polyolefin (TPO) (thermoplastic). Different types of membranes have different chemical compositions and require different installation methods. See section H3.4 “Additional Notes and Guidance” for further information on how these differences might limit product-level comparisons within this material category. Roofing membranes with insulation have been excluded from the scope of this category.

Based on available data, this report identifies baselines for 1m² of PVC roofing membranes with finished nominal thicknesses of 40 mils (1.0 mm), 48 mils (1.2 mm), 60 mils (1.5 mm), and 80 mils (2 mm).

Production Processes and Key Drivers of Carbon Emissions

The primary material ingredients in PVC single-ply roofing membranes are PVC resin (≈45% of total product by mass; derived from fossil fuel and salt), plasticizer (≈26%; contributes to membrane flexibility), and scrim reinforcement (≈13%; polyester fiber (PET)). Other ingredients include pigment (titanium dioxide), fire retardant, stabilizers, and fillers, among others. The manufacturing process combines these ingredients in the factory to form a membrane (A3), which is eventually transported to the construction site (A4) and fastened along with other roof build-up components (e.g., thermal insulation) onto the underlying structure (A5).[2] The typical life expectancy of a single-ply roof membrane is 25-40 years.[3] At the product’s end of life, the industry EPD assumes 70% landfill disposal and 30% diverted as secondary material to be recycled back to the PVC roofing system or to other PVC products such as commercial PVC flooring.[2]

1. Hunt, A. “Understanding single-ply roofing systems” [website]. Continuing Education Center Architecture and Construction. https://continuingeducation.bnpmedia.com/courses/johns-manville/understanding-single-ply-roofing-systems

2. hemical Fabrics and Film Association (CFFA). (2020). *Industry Average EPD of CFFA SPPR PVC Roofing Membranes.* ASTM International.

3. IKO. (2023). “Life expectancy of single ply membranes” [website]. IKO. https://www.ikogroup.co.uk/news-advice/life-expectancy-of-single-ply-membranes/

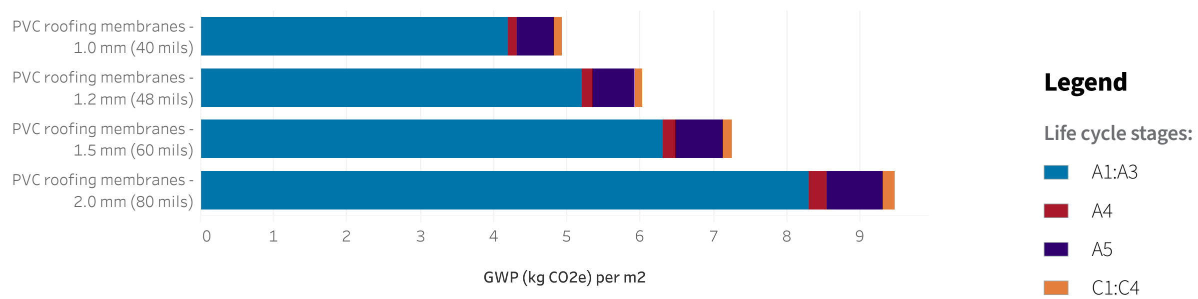


Figure 1. GWP contribution by life cycle stage. A1:A3 raw materials acquisition, transport of raw materials, membrane manufacture; A4 transport to building site; A5 installation (mechanically fastened for this IW-EPD); C1:C4 end-of-life: disposal and recycling.

H3.2 Data Availability and Representativeness

PCR

NSF International. (2019). *PCR for Single Ply Roofing Membranes.*

Industry EPDs

Chemical Fabrics and Film Association (CFFA). (2020). *Industry Average EPD of CFFA SPPR PVC Roofing Membranes*. ASTM International.

This IW-EPD is based on six Chemical Fabrics and Film Association (CFFA) members, which together represent 85% of North American production of SPPR PVC roofing membranes. It contains environmental impacts for SPPR PVC membranes with thicknesses of 40 mils, 48 mils, 60 mils, and 80 mils.

Product EPDs

In the EC3 database, there are currently 39 applicable* product EPDs for single-ply roofing membranes: 23 for PVC, 14 for KEE, and 2 for EPDM.

> ***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

EPDs in this material category represent a range of roof membrane products and product thicknesses. Given the range of different thicknesses in the collection of product EPDs and the extent that membrane roof thickness affects both GWP and product performance, there is significantly limited comparability among the individual products in the data set. Therefore, the summary statistics table included in other sections of this report is excluded here. See H3.4 "Additional Notes and Guidance" for further information on how these differences impact users' ability to compare products within the material category.

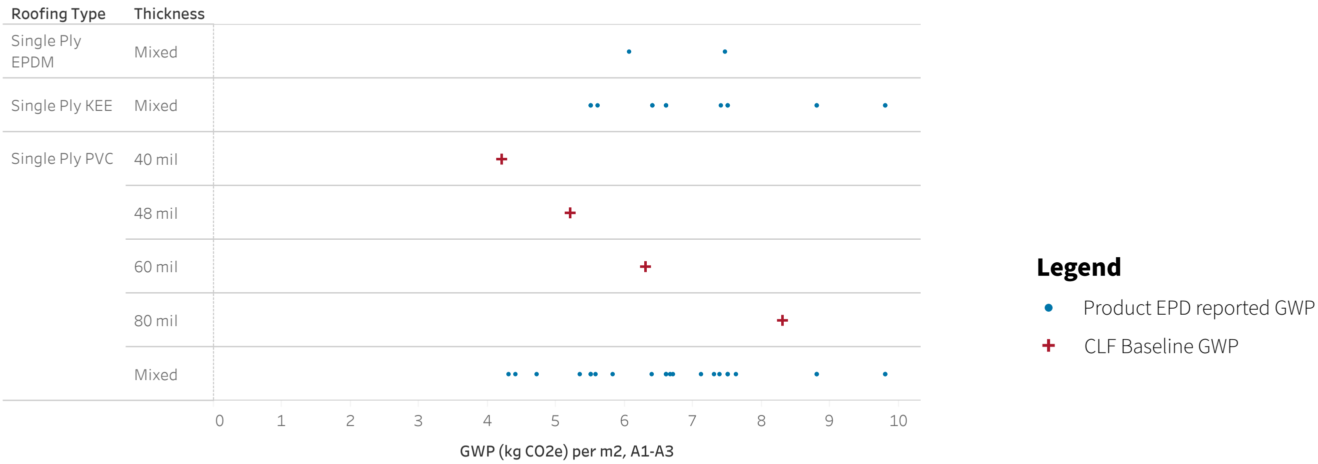


Figure 2. Range of applicable product EPDs and CLF Baselines. The chart shows data for products with a range of different thicknesses.

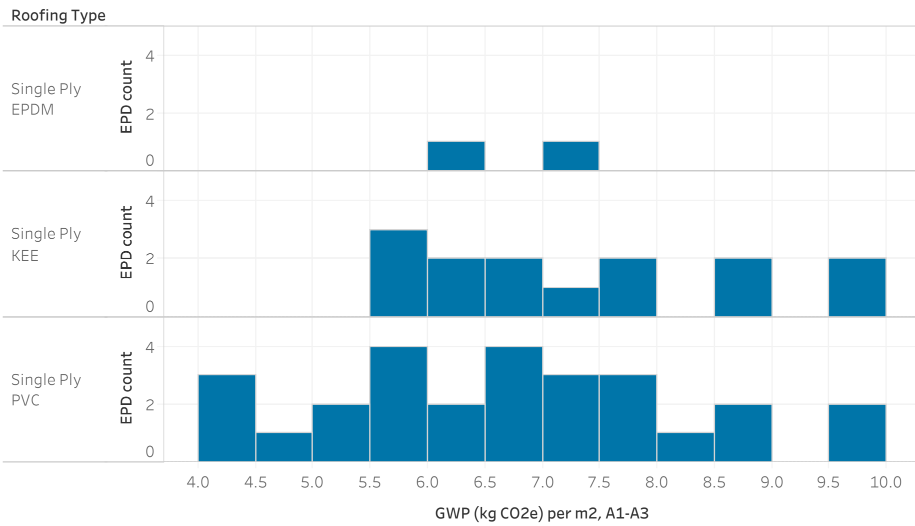


Figure 3. Distribution of applicable product EPDs. The chart shows data for products with a range of different thicknesses.

H3.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 m^2)	Method	Data Source and Notes
Single-ply membrane roofing - PVC (40 mils)	**4.2**	Industry	CFFA. (2020). *Industry average EPD of CFFA SPPR PVC roofing membranes*. ASTM International.
Single-ply membrane roofing - PVC (48 mils)	**5.2**	Industry	CFFA. (2020). *Industry average EPD of CFFA SPPR PVC roofing membranes*. ASTM International.
Single-ply membrane roofing - PVC (60 mils)	**6.3**	Industry	CFFA. (2020). *Industry average EPD of CFFA SPPR PVC roofing membranes*. ASTM International.
Single-ply membrane roofing - PVC (80 mils)	**8.3**	Industry	CFFA. (2020). *Industry average EPD of CFFA SPPR PVC roofing membranes*. ASTM International.

Figure 4. CLF Baselines for single-ply membrane roofing.

H3.4 Additional Notes and Guidance

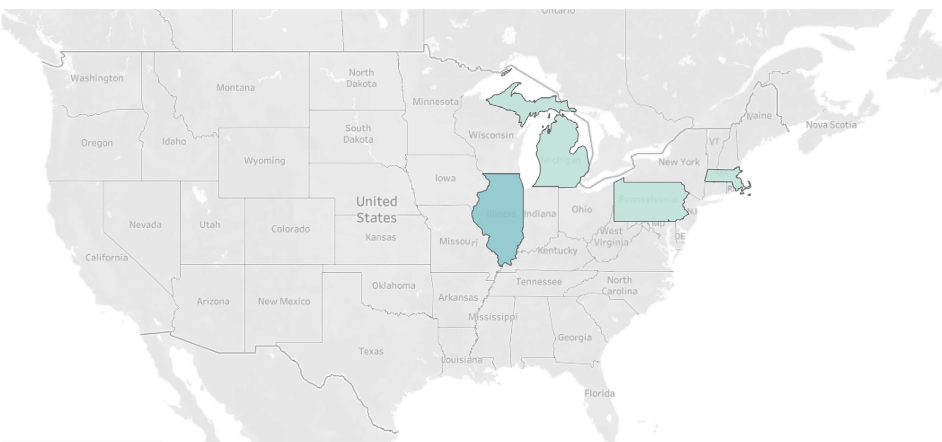


Figure 5. Product EPDs by location.

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Comparability Within the Material Category

The declared unit for single-ply membrane roofing, one square meter, does not account for variations in membrane thickness. Membrane thickness impacts product GWP, as can be seen in Figures 1 and 6, and also impacts product performance (e.g., longevity). Additionally, this category groups together many different types of single-ply roofing membranes. Each type of roofing membrane has slightly different performance characteristics and requires slightly different roof assemblies and installation methods. Before making any comparisons within this material category, users should verify that the products they are comparing are functionally equivalent in terms of thickness, performance, assembly, and installation.

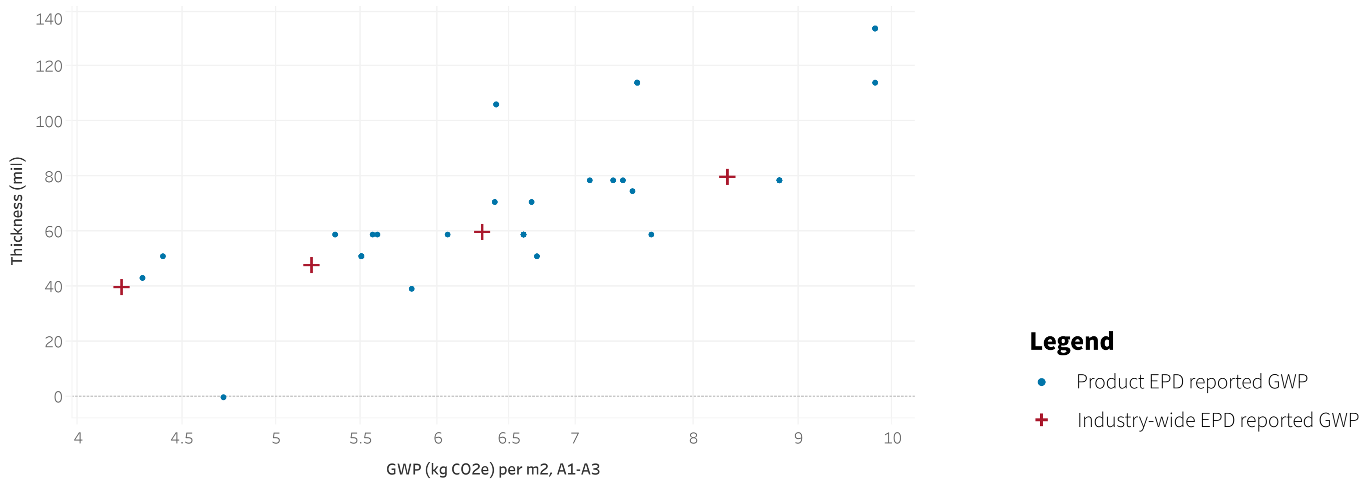


Figure 6. Relationship between roof membrane thickness and GWP.

Reference Service Life and Product Replacement

In this category, the reference service life (RSL) varies from product to product. When a product's RSL is shorter than the estimated service life of a building, the product's RSL determines the estimated number of times a product needs to be replaced over the course of the building's lifespan. EPDs in this category disclose environmental impacts from the construction, use, and end-of-life stages, all of which should be included when making comparisons among products with different RSLs. For users interested in product-level comparisons within this category, environmental impacts related to additional life cycle stages are disclosed in the category's product and IW-EPDs. At this time, all EPD data provided in this appendix (other than in Figure 1) includes cradle-to-gate impacts only.

Other Available Product EPDs

This appendix does not include product or industry-wide EPD data for some roofing membrane types, such as TPO roofs (a type of single-ply membrane) or bituminous. As shown in Figure 7 below, there are many more product EPDs (representing all sub-types of membrane roofing) available for global membrane roofing products, most of which reference a different PCR than the North American sub-category PCR listed in this appendix. It is important to note that different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. Therefore, when comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

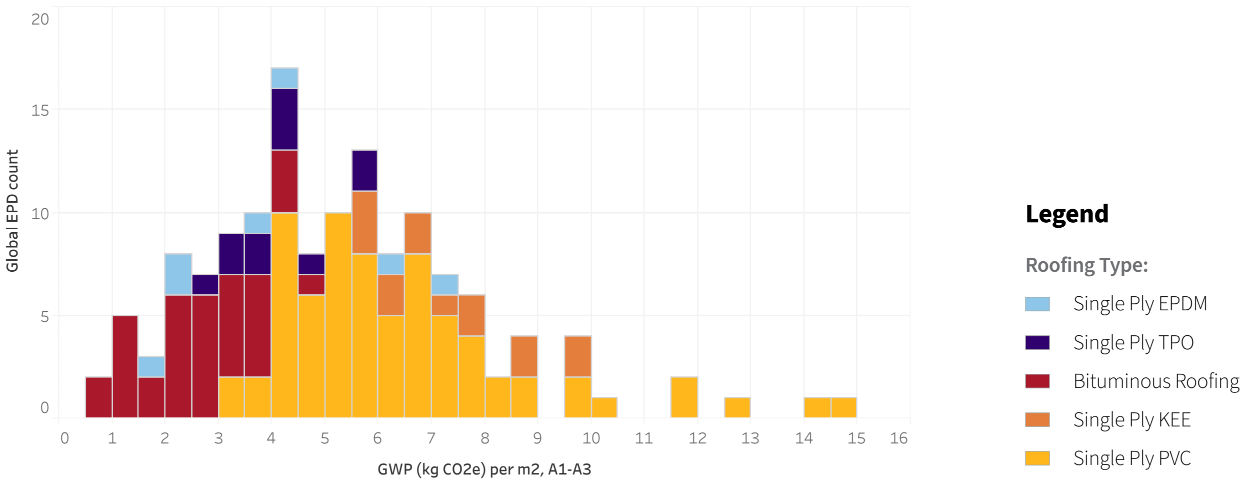


Figure 7. Global roofing membrane product EPDs by type and GWP. These EPDs may not be comparable: some use different PCRs and products may not be functionally equivalent (due to different material type, thickness, service life, etc.)

J1: FLAT GLASS PANES

J1.1 Category Overview

Category Description

Flat glass describes all glass produced in a flat form such as float glass, sheet glass, plate glass, and rolled glass. This material category focuses on clear, low-iron, and tinted glass products that have been manufactured in an unprocessed annealed state. Although flat glass may be installed directly in windows, doors, or glass walls, most glass products used in construction applications have undergone secondary processing (e.g., tempered, coated, heat treated, and/or laminated products). These additionally processed products are covered by the processed glass category and are not within the scope of the flat glass category.[1]

The production process of a typical window or other glazing assembly (curtain wall, storefront, etc.) starts with flat glass (Appendix J1); then the flat glass panes are processed with coatings and/or other treatments to produce processed glass panes (Appendix J2); two or more glass panes (flat or processed) are combined to produce insulated glass units (IGUs, Appendix J3); and finally IGUs are assembled in a frame (typically made of thermally-improved aluminum extrusions, Appendix E1) to produce the final window, curtain wall, etc.

Production Processes and Key Drivers of Carbon Emissions

Most flat glass used in buildings today is made from float glass. To make float glass, silica sand, soda ash, limestone, dolomite, and reused scrap glass are mixed at extremely high temperatures to create molten glass. The molten glass is then poured from the furnace onto the surface of a molten tin bath, where the glass spreads to form a level surface. The thickness of the glass can be controlled by adjusting the speed at which the solidifying glass is drawn off of the bath. As the glass ribbon moves along the annealing lehr, the glass is cooled to room temperature, at which point it can be cut to the desired dimensions. The finished flat glass products are stored for additional processing (e.g., heat-treating or coating) or directly packaged and shipped to customers.[1]

The bulk (about 40%) of the carbon emissions associated with the cradle-to-gate glass production processes can be attributed to the production and combustion of natural gas. Natural gas is used to maintain extremely high temperatures inside the furnaces that melt raw materials that form glass. These furnaces are predominantly natural gas-fired, but there are a small number of electrically-powered furnaces and many gas furnaces use supplementary electric heating systems as well.[2] Process emissions resulting from chemical reactions in the glass manufacturing process contribute to over 20% of cradle-to-gate emissions for flat glass. Another large proportion of emissions (over 20%) can be traced to upstream impacts associated with the extraction and pre-processing of materials used in glass manufacturing. Together, impacts from electricity, transport, process materials, waste materials, and packaging make up the remaining emissions from flat glass production.[1]

1. National Glass Association (NGA). (2019). *Environmental product declaration - Flat glass.* ASTM International.

2. Glass for Europe. (2022). *Continuous energy supply is essential for the flat glass industry*. Retrieved January 31, 2023, from https://glassforeurope.com/continuous-energy-supply-is-essential-for-the-flat-glass-industry/

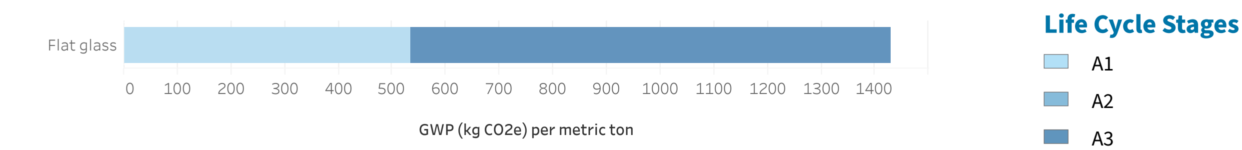


Figure 1. GWP contribution by life cycle stage. The flat glass industry-wide EPD reports cradle-to-gate performance broken down by raw material extraction (including transport of the materials to the glass manufacturer, all shown as A1 in this chart) and flat glass production (A3).

J1.2 Data Availability and Representativeness

PCR

National Glass Association (NGA). (2020). *NGA PCR for flat glass: UN CPC 3711.* NSF International.

Industry EPDs

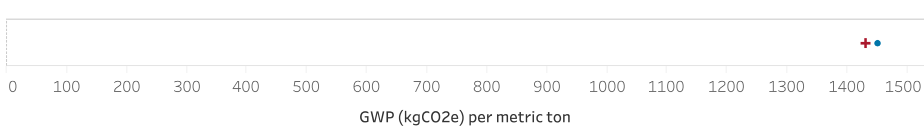
National Glass Association (NGA). (2019). *Environmental product declaration - Flat glass.* ASTM International.

> This IW-EPD is based on flat glass produced by four NGA member companies during 2015. It is based on the previous PCR for flat glass that expired in 2020.[3]

Product EPDs

In the EC3 database, there are currently no applicable* product EPDs for flat glass. There is one valid product EPD for North American flat glass that references the previous, expired PCR for flat glass.[3] This appendix's figures display data related to this non-applicable EPD for reference.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.



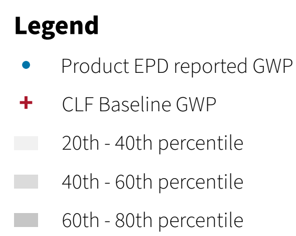


Figure 2. Range of applicable product EPDs and CLF Baseline. The single valid North American product EPD is not applicable, as it does not conform to the latest North American PCR, but is included for reference.

Due to the lack of applicable product EPDs in this category, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

J1.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per metric ton)	Method	Data Source and Notes
Flat glass	1,430	Industry	National Glass Association (NGA). (2019). *Environmental product declaration - Flat glass.*

Figure 3. CLF Baselines for flat glass.

3. Glass Association of North America (GANA). (2014). *GANA PCR for Flat Glass: UN CPC 3711.* NSF International.

J1.4 Additional Notes and Guidance

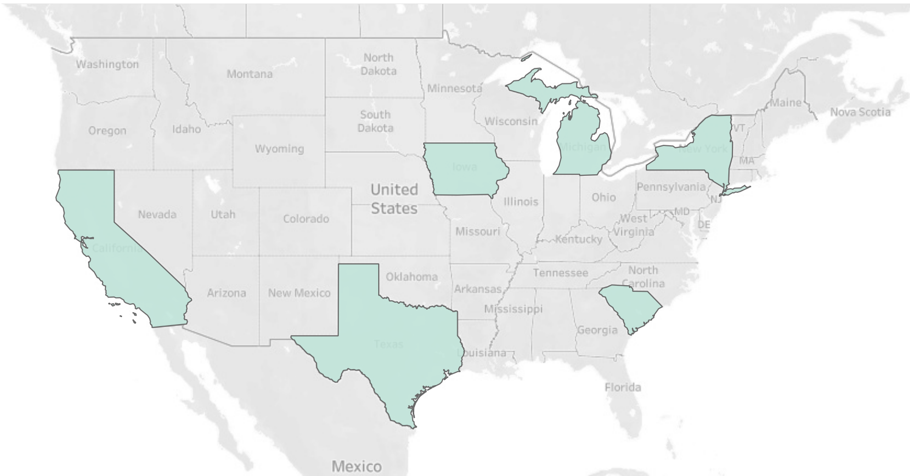


Figure 4. Product EPDs by location. This represents one EPD that covers seven facilities. The EPD does not conform to the latest North American PCR but is included here for reference as it is the only valid North American flat glass product EPD.

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Other Available Product EPDs

Beyond the single North American product EPD that references an expired PCR, there are seven North American EPDs that reference a different PCR from the North American one listed above.[4] All seven represent different glass thicknesses from the same manufacturer in Mexico. There are also six global product EPDs that reference a European PCR. All six represent different glass thicknesses from the same manufacturer in Italy. It is important to note that different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. Therefore, when comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

4. International EPD System. (2020). *PCR 2012:01 Construction products and construction services, version 2.32 2020-07-01.*

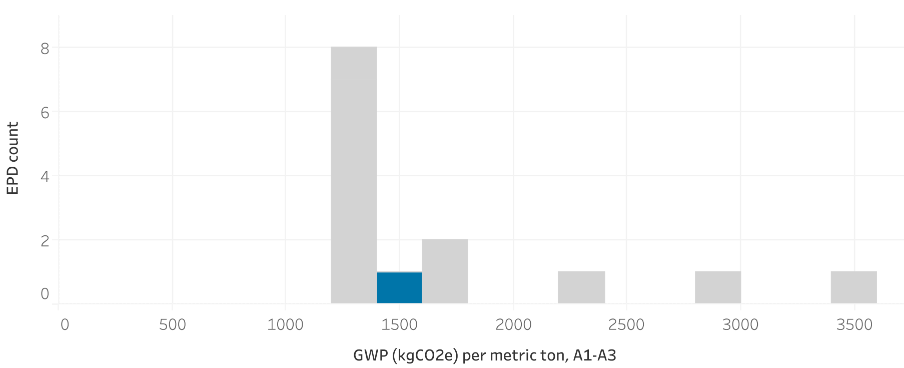


Figure 5. Range of global flat glass product EPDs.

Key

- North American product EPDs that follow expired North American PCR
- Global and North American product EPDs that follow International EPD System PCR

J2: PROCESSED GLASS PANES

J2.1 Category Overview

Category Description

Processed glass describes flat glass that has undergone one or more of the following processing techniques: coating, laminating, heat treatment, or mechanical or chemical processing.[1] These treatments perform a wide range of functions and may be specified to improve the safety, fire rating, energy performance, aesthetics, or other features of the glass product. Some common examples of processed glass used in building applications include low-e glazing, tempered glass, and laminated glass. These processed glass panes may be used in windows, doors, glass walls, and guardrails.

The production process of a typical window or other glazing assembly (curtain wall, storefront, etc.) starts with flat glass (Appendix J1); then the flat glass panes are processed with coatings and/or other treatments to produce processed glass panes (Appendix J2); two or more glass panes (flat or processed) are combined to produce insulated glass units (IGUs, Appendix J3); and finally IGUs are assembled in a frame (typically made of thermally-improved aluminum extrusions, Appendix E1) to produce the final window, curtain wall, etc.

Production Processes and Key Drivers of Carbon Emissions

Flat glass (whose production is detailed in Appendix J1) is the major input for processed glass products, and its production is accounted for in module A1 in processed glass EPDs. A1 also includes the extraction and processing of plastics, frit materials, metallic compounds, recycled materials, and polymers used in the treatment of processed glass. These input materials are transported to the processed glass manufacturer facility (module A2). The manufacturer applies one or more treatments to the flat glass to create the final processed glass product (module A3). These treatments include:

- Coating (of many types and processes)
- Laminating (adhering multiple glass layers together to prevent shattering)
- Heat treatment (such as for heat-strengthened, tempered, or fire-rated products)
- Mechanically or chemically processing or fabricating (e.g., edging, bending, etching, drilling, notching, cutting, polishing, etc.)[1]

Product performance and carbon emissions can vary substantially depending on the types and number of treatments applied.

J2.2 Data Availability and Representativeness

PCR

UL Environment. (2016). *Product category rules for part B: Processed glass EPD requirements.* UL Environment.

> This PCR was originally set to expire in August of 2021, but the expiration date has since been extended to December 6, 2023.[2]

1. UL Environment. (2016). *Product category rules for part B: Processed glass EPD requirements.* UL Environment.
2. UL Environment. (2023). *Product category rules* [website]. https://www.ul.com/services/product-category-rules-pcrs

Industry EPDs

The are currently no industry-wide EPDs for processed glass.

Product EPDs

In the EC3 database, there is currently one applicable* product EPD for processed glass.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

Due to the low number of applicable product EPDs in this category, this appendix does not include the scatter plot, summary statistics table, or histogram that appears in many of the other appendices in this report. Figure 2 provides a graphical representation of valid product EPDs, including the one applicable one mentioned above.

J2.3 CLF Baselines

There is no 2023 CLF Material Baseline for processed glass since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

J2.4 Additional Notes and Guidance

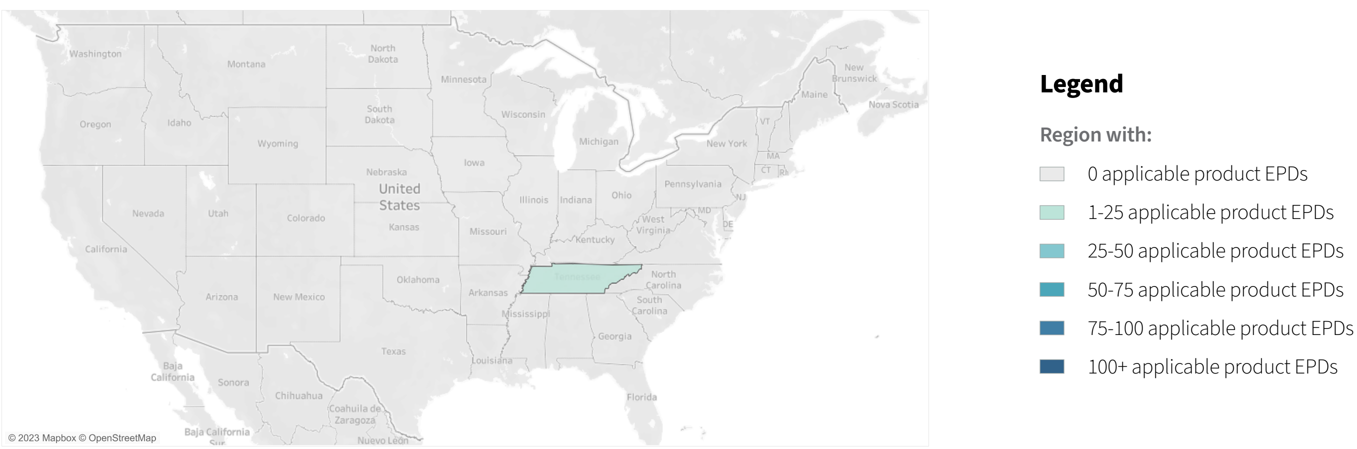


Figure 1. Product EPDs by location.

Comparability Within the Category and Future Baseline Development

There are significant challenges with comparing environmental impacts across products within the processed glass material category. There is a wide range of treatments that can be applied to a glass pane, and each treatment is associated with different manufacturing processes, different levels of carbon emissions, and different performance characteristics.

Also, because the declared unit for the processed glass category is one square meter, it is difficult to understand if differences in reported environmental impacts stem from processing techniques or from the fact that EPDs are reporting impacts for glass panes of different thicknesses.

In the future, it may be possible to set baselines for different types of processed glass, depending on the treatment applied. But in the near term, the data is not available to understand the range of environmental impacts associated with any given treatment.

Towards Improved Comparability of Product EPDs

There is a wide range of treatments that can be applied to a glass pane, making appropriate comparisons difficult. There are currently very few processed glass EPDs, but in the future, there may be many more. If so, a system of (a) digitized EPDs with consistent reporting of processed glass treatments (to be defined in the PCR) and (b) a search tool such as EC3 with corresponding filters will facilitate the use of processed EPDs for appropriate comparisons.

Other Available Product EPDs

Beyond the single applicable North American product EPD, there are six additional North American EPDs that reference a European PCR. There are also five global product EPDs (two that reference the North American PCR, and three that reference the European PCR). Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. Therefore, when comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

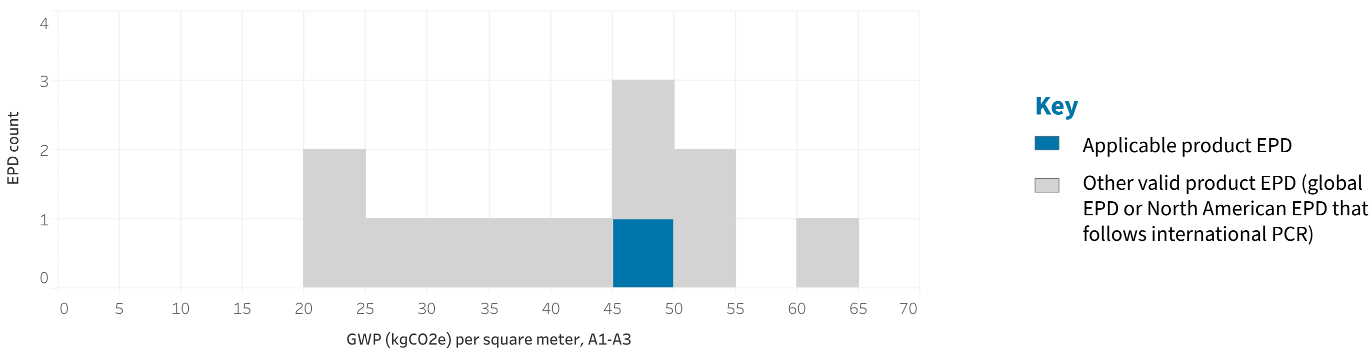


Figure 2. Range of global processed glass product EPDs. The single applicable product EPD represents a laminated glass product made of two layers of tempered glass bonded with a polyvinyl butyral (PVB) interlayer.

Normalizing Flat Glass and Processed Glass EPD Results

For readers who are interested in understanding the relationship between the environmental impacts of flat glass and processed glass, the processed glass PCR provides a calculation method to normalize flat glass LCA results on the basis of the declared unit in the processed glass PCR (1 square meter).[1]

To convert one metric ton of a given thickness of soda-lime float glass to m^2, use the following equation that assumes a glass density of 2500 kg/m^3.

$A = 400/t$

Where

A = Surface area (m^2)

t = Glass thickness (mm)

3. Glass Association of North America (GANA). (2005). *Specifiers guide to architectural glass 2005 edition.* http://syracuseglass.com/E-DOCS/Technical%20Literature/EDOCS/Specifiers%20Guide%20to%20Architectural%20Glass%20-%202005%20Edition.pdf

J3: INSULATED GLASS UNITS

J3.1 Category Overview

Category Description

Insulated glass units (also called insulating glass units or IGUs) are factory-assembled units of two or more glass panes, typically used in a building's exterior envelope. IGUs may be used in windows, doors, and glass walls. The IGU's glass panes are separated by spacers and sealed to trap a layer of inert gas between the panes. This airspace slows heat transfer across the unit, making the assembly more energy efficient. The IGU includes the glass panes, spacer(s), desiccant, sealants, and interlayer materials, but the window (or door, curtainwall, etc.) frame is not included. The glass panes may be flat glass, processed glass, or any combination of the two.[1]

The production process of a typical window or other glazing assembly (curtain wall, store-front, etc.) starts with flat glass (Appendix J1); then the flat glass panes are processed with coatings and/or other treatments to produce processed glass panes (Appendix J2); two or more glass panes (flat or processed) are combined to produce IGUs (Appendix J3); and finally IGUs are assembled in a frame (typically made of thermally-improved aluminum extrusions, Appendix E1) to produce the final window, curtain wall, etc.

Production Processes and Key Drivers of Carbon Emissions

Flat glass (whose production is detailed in Appendix J1) is the major input for IGUs, and its production is accounted for in module A1 in IGU EPDs. A1 also includes the extracting and processing of plastics, frit materials, metallic compounds, recycled materials, polymers, and gases used in the treatment of processed glass or the assembly of IGUs. These input materials are transported to the IGU manufacturer facility (module A2). At the manufacturing site, any necessary treatments are applied to the glass panes (see processed glass Appendix J2), and the panes, spacers, and sealants are assembled into IGUs (module A3).

Key drivers of carbon emissions can vary substantially depending on the types and number of treatments applied to the glass panes that comprise the IGU.[1]

J3.2 Data Availability and Representativeness

PCR

UL Environment. (2016). *Product category rules for part B: Processed glass EPD require-ments.* UL Environment.

> This PCR was originally set to expire in August of 2021, but the expiration date has since been extended to December 6, 2023.[2]

Industry EPDs

The are currently no industry-wide EPDs for IGUs.

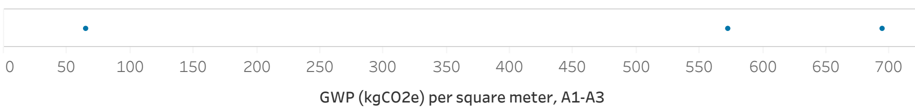
1. UL Environment. (2016). *Product Category Rules for Part B: Processed Glass EPD Requirements.* UL Environment

2. UL Environment. (2023). Product category rules [website]. https://www.ul.com/services/product-category-rules-pcrs

Product EPDs

In the EC3 database, there are currently three applicable* product EPDs from two manufacturers for IGUs. The three applicable product EPDs represent one double-pane IGU, one triple-pane IGU, and one IGU with an unknown number of panes. Two of the three product EPDs are for electrochromic glass, which currently is not widely used in building projects.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.



Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

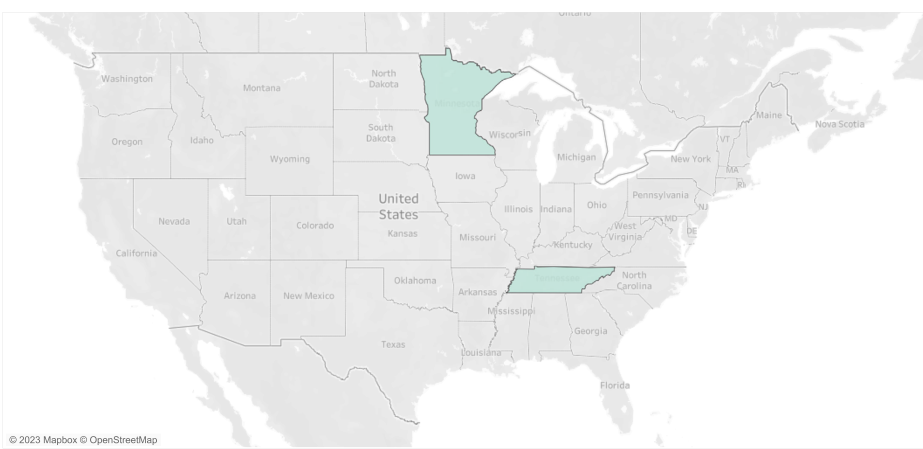
Figure 1. Range of applicable product EPDs.

Due to the low number of product EPDs in this category, this appendix does not include the summary statistics table or histogram that appears in many of the other appendices in this report.

J3.3 CLF Baselines

There is no 2023 CLF Material Baseline for IGU since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

J3.4 Additional Notes and Guidance



Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 2. Product EPDs by location.

Future Material Baseline Development

Without publicly-available data on the production volumes of the IGU industry, it is difficult to understand whether or not the available product EPDs are sufficiently representative of North American production. Of the products with EPDs, many have undergone different glazing treatments and should not be compared directly without considering the similarities and differences in functional performance.

In the future, it may be possible to set unique baselines for different types of IGUs, depending on the treatment applied. But in the near term, the sample sizes for relevant product EPDs are not large enough to understand the range of environmental impacts associated with a specific IGU assembly.

Comparability Within the Material Category

IGUs face the same challenges to appropriate comparison as described in the Processed Glass Panes appendix. IGU EPDs follow the processed glass PCR and IGUs typically use processed glass panes in their assemblies.

Additionally, comparing IGUs in isolation can be difficult. Generally, IGUs are not standalone products but are integrated into a building envelope, which contains additional components such as spacer(s), sealants, and desiccants. All of these materials influence performance that is best judged at a system or assembly level (i.e., for the full building envelope).

This category may be better suited to analysis using a whole building life cycle assessment (WBLCA), in which a functional unit can be established to address the context and performance goals of a specific project.

Towards Improved Comparability of Product EPDs

There is a wide range of assembly options and performance characteristics available for IGUs, making appropriate comparisons difficult. There are currently very few IGU EPDs, but in the future, there may be many more. If so, a system of (a) digitized EPDs with consistent reporting of processed glass treatments and IGU assumbly details (to be defined in the PCR) and (b) a search tool such as EC3 with corresponding filters will facilitate the use of IGU EPDs for appropriate comparisons.

Other Available Product EPDs

Beyond the three North American product EPDs, there are two additional North American EPDs that reference a European PCR. There are also two global product EPDs that reference a European PCR. Different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. Therefore, when comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

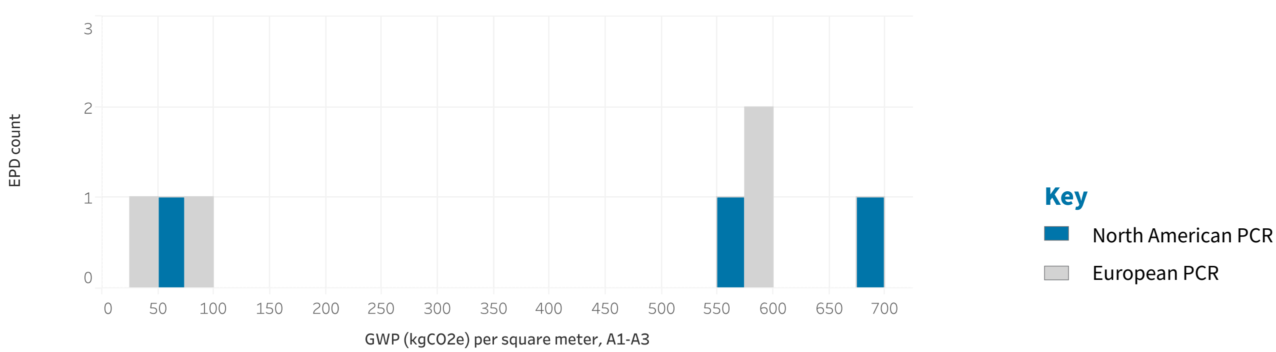


Figure 3. Range of global processed IGU product EPDs.

K1: GYPSUM BOARD

K1.1 Category Overview

Category Description

Gypsum board refers to the family of sheet products with a non-combustible gypsum-based core and a paper facing. It functions as an interior surface for walls and ceilings, can support other finishes such as paint or tile, and provides additional performance characteristics such as mold and fire resistance. The boards are typically 4' x 8' panels and are produced in a range of thicknesses. Gypsum board is also referred to as: "wallboard," "drywall," "plaster board," "sheetrock," and "gypsum panel."[1]

The two most common types in North America, which correspond to the Gypsum Association's industry-wide LCA study and the CLF Baseline categories, include:

- 1/2" (12.7 mm) lightweight gypsum board (regular core), typically used in residential applications; and
- 5/8" (15.9 mm) Type X conventional gypsum board, typically used in commercial applications for its improved fire rating.[2]

The industry LCA study, industry EPD, and CLF Baselines exclude from their scopes gypsum products that are: mold and moisture-resistant (MMR), paper-faced abuse-resistant, paper-faced impact-resistant (fiberglass mesh reinforcement embedded in the core), and have paper-faced plaster-bases.

Production Processes and Key Drivers of Carbon Emissions

Extraction and upstream production processes include gypsum mining to procure gypsum ore and paper production for gypsum facing and backing. At the gypsum board manufacturing facility, crushed natural gypsum is heated and dehydrated, then milled into gypsum powder. The powder is mixed with water and additives to form a slurry that is fed between paper layers on a board machine. Figures 3, 4, and 5 of the industry EPD background LCA report provide more detailed information on these processes.[2]

Onsite natural gas consumption (primarily for heating the gypsum) and electricity consumption in A3 are the primary contributors to total A1-A3 GWP. See the industry-wide LCA report for further information on the breakdown of GWP impacts by production stage.[2]

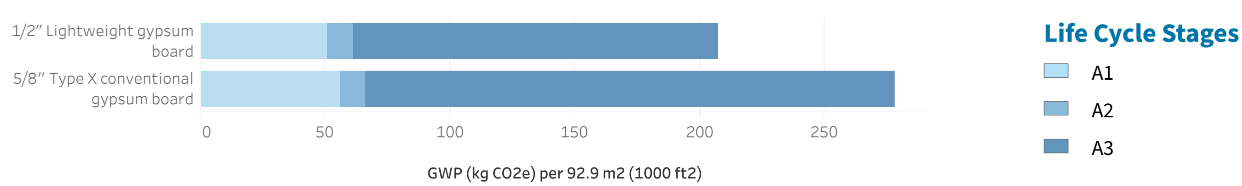


Figure 1. GWP contribution by life cycle stage. A1: extraction and upstream production, including gypsum mining to procure gypsum ore and gypsum facing and backing paper production. A2: transport of gypsum ore and gypsum paper to gypsum board product manufacturing facility. A3: gypsum board product manufacture: heating / dehydrating natural gypsum, mixing, forming into boards, drying.

1. Gypsum Association (GA). (2020). *Industry average EPD for 5/8" type X conventional gypsum board.* NSF. https://gypsum.org/download/14311/?tmstv=1668118221

2. Athena Sustainable Materials Institute (ASMI). (2020). *An industry average cradle-to-gate life cycle assessment of 1/2" lightweight and 5/8" type X conventional gypsum board for the USA and Canadian markets.* NSF. https://gypsum.org/download/14369/?tmstv=1668118221

K1.2 Data Availability and Representativeness

PCR

NSF International. (2020). *Product category rule for environmental product declarations - PCR for gypsum panel products*.

Industry EPDs

Gypsum Association (GA). (2020). *Industry average EPD for 5/8" type X conventional gypsum board*. NSF.

Other Industry Data

Athena Sustainable Materials Institute (ASMI). (2020). *An industry average cradle-to-gate life cycle assessment of 1/2" lightweight and 5/8" type X conventional gypsum board for the USA and Canadian markets.* NSF.

> In developing the EPD, the Gypsum Association (GA) commissioned this background LCA report that provides additional information on the study's methods. Also, the LCA report includes an assessment of ½" lightweight gypsum board that is not included in the industry EPD.
>
> GA member companies and their affiliates produce over 90% of the gypsum board consumed in the USA and Canada. Each member company participated in the study by providing data for at least one of their plants. 17 of a total of 51 gypsum board manufacturing plants were selected to represent the industry, based on representation by company, plant size, and geography. The study aims to represent USA manufacturing only. The EPD and LCA report do not disclose the percentage of North American production covered in the data set.[2]

Product EPDs

There are currently 11 applicable* product EPDs for 1/2" gypsum board and 25 for 5/8" gypsum board.

> *Applicable product EPDs are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

This count excludes EPDs for gypsum board products of other thicknesses. It also excludes 61 currently-valid North American product EPDs that use a different PCR from the primary one listed above – one expired North American PCR and one international PCR.

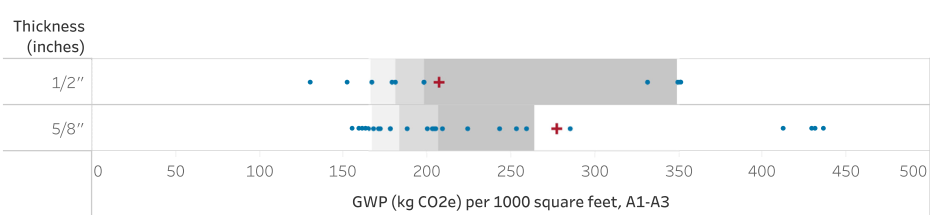


Figure 2. Range of applicable product EPDs and CLF Baselines.

Thickness (inches)	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
1/2″	130	167	181	198	198	349	351	235	207
5/8″	155	167	184	203	207	264	436	234	277

Figure 3. Summary statistics of product EPDs and CLF Baselines (kg CO_2e/ 92.9m² [1,000ft²]).

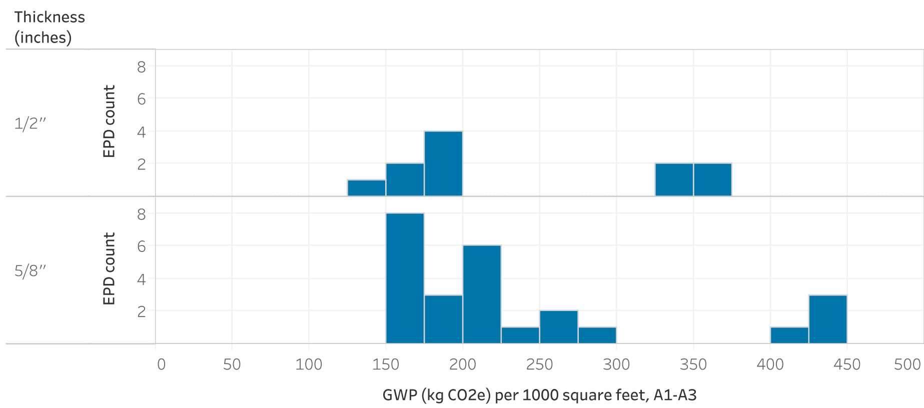


Figure 4. Distribution of applicable product EPDs.

K1.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO₂e per 92.9 m² [1,000 ft²])	Method	Data Source and Notes
Gypsum board: ½" Lightweight	207	Industry	GA. (2020). *Industry average EPD for 5/8" type X conventional gypsum board.*
Gypsum board: 5/8" Type X	277	Industry	ASMI. (2020). *An industry average cradle-to-gate life cycle assessment of 1/2" lightweight and 5/8" type X conventional gypsum board for the USA and Canadian markets.*

Figure 5. CLF Baselines for 1/2" and 5/8" gypsum board.

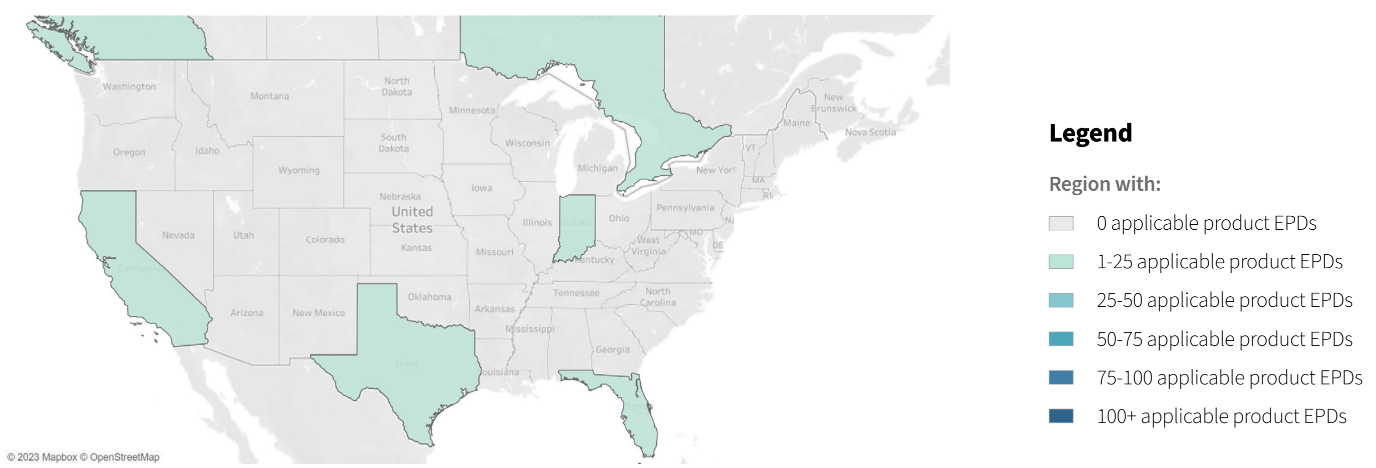


Figure 6. Product EPDs by location.

K2: ACOUSTIC CEILING TILE

K2.1 Category Overview

Category Description

Acoustic ceiling tiles (ACT) are modular panels used as finish material for ceilings. They are typically installed in commercial buildings to improve the acoustic performance of the space. The panels consist of a core material (often mineral fiber, fiberglass, or wood) and facing material. Panels are typically set into a metal frame system and suspended from the structure above (referred to as a "dropped ceiling").

The declared unit for this category is 0.093 m^2 (1 ft^2) of acoustic ceiling tile.

Production Processes and Key Drivers of Carbon Emissions

The production processes and key drivers of emissions depend on the type of panel. Common ingredients for mineral fiber ACT include mineral wool, fiberglass, recycled newspaper, cornstarch, and binding agents.[1] Other types of ACT products include those made with wood fiber combined with a binder, and polyester felt (PET) fiber. Panels come in a range of thicknesses, and thickness significantly affects both acoustical performance and GWP. The metal suspension system is not included in the scope of the EPDs for this category and may have notable impacts.

The current North American PCR for non-metal ceiling panels allows for EPDs with a scope of cradle-to-gate (A1:A3), cradle-to-gate with options (A1:A3 and C-stages, A4, A5, and B-stages optional), or cradle-to-grave (A-C).

K2.2 Data Availability and Representativeness

PCR

UL Environment. (2021). *Product Category Rule (PCR) Guidance for Building-Related Products and Services - Part B: Non-Metal Ceiling and Interior Wall Panel EPD Requirements.*[2]

Industry EPD

There are currently no North American IW-EPDs for ACT.

Product EPDs

In the EC3 database, there are currently 16 applicable* product-specific EPDs for ACT.

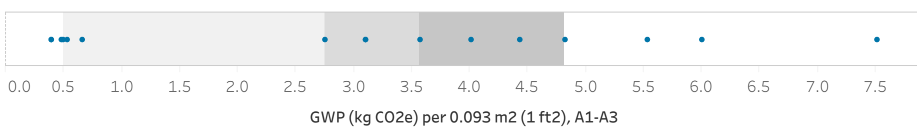
EPDs in this material category represent ACT products with a range of core materials, NRC and CAC ratings, and panel thicknesses. See K2.4 "Additional Notes and Guidance" for further information on how these differences impact users' ability to compare within the material category.

1. Armstrong Ceilings. https://www.armstrongceilings.com/residential/en-us/project-ideas-and-installation/suspended-ceiling.html

2. At the time of publication, the majority of available product EPDs referenced the expired PCR: UL Environment. (2015). *Product Category Rule (PCR) Guidance for Building-Related Products and Services - Part B: Non-Metal Ceiling Panel EPD Requirements.* The counts provided in "Data Availability and Representativeness" do not include product EPDs that reference this expired PCR or non-North American PCRs, besides Figure 3, where they are explicitly differentiated from the applicable EPDs.

> ***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

The majority of current North American product EPDs for ACT reference the expired North American PCR. In addition to the 16 product EPDs that reference the current sub-category PCR, there are 107 product EPDs that reference the expired North American PCR and four that reference a non-North American PCR. These additional EPDs are shown in Figure 3. It is important to note that different PCRs may require different methodologies for calculating and reporting environmental impacts. Therefore, when comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.



Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

Figure 1. Range of applicable product EPDs and CLF Baselines.

Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
0.39	0.49	2.75	3.10	3.57	4.82	7.51	2.98	--

Figure 2. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per 0.093 m^2 (1 ft^2)), A1-A3.

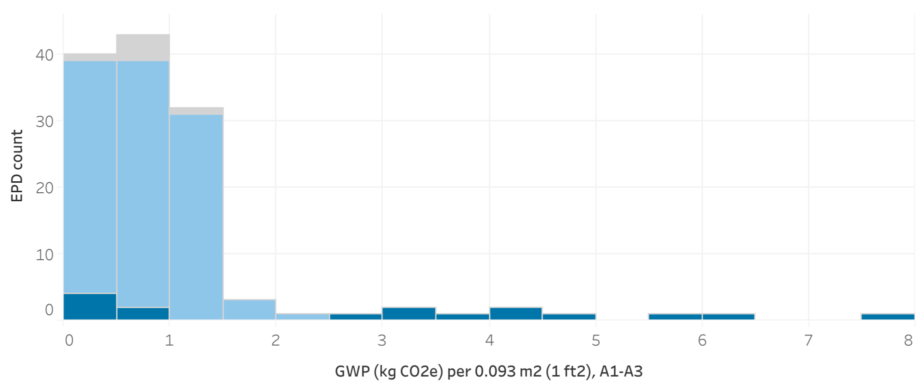


Figure 3. Distribution of product EPDs. Dark blue = applicable EPDs. Light blue = EPDs with expired North American PCR. Grey = EPDs with non-North American PCR.

K2.3 CLF Baselines

There is no 2023 CLF Material Baseline for ACT since CLF was not able to determine if the available data adequately represented all North American production. See the Baseline Methodology section of the report for more information.

K2.4 Additional Notes and Guidance

Legend

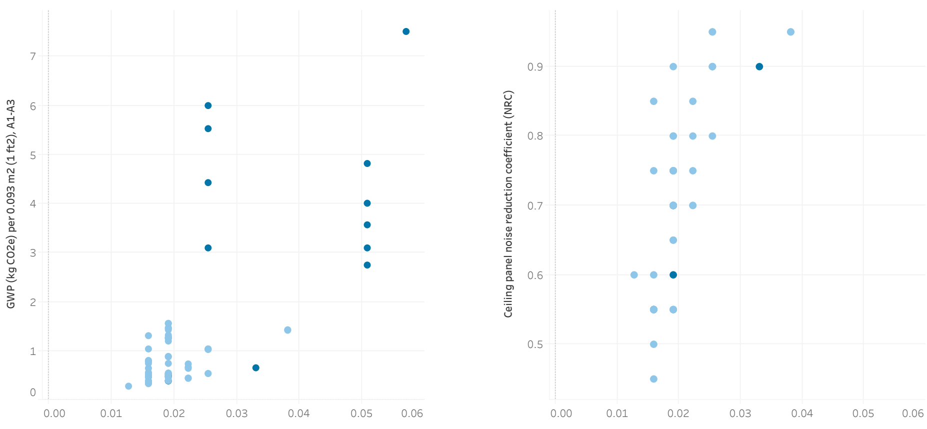
Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Figure 4. Count of applicable product EPDs by location. There are additional EPDs based on expired or non-North American PCRs (excluded from this map) from the following US states: Wisconsin, Illinois, Mississippi, Ohio, Pennsylvania, Georgia, and Florida.

Comparability Within the Material Category

The declared unit for ACT, in area, does not account for variations in panel thickness. Material type, composition, and panel thickness affect the GWP of the panel as well as the noise reduction coefficient (NRC), as shown in Figure 5. Before making any comparisons within this material category, users should verify that the products they are comparing are functionally equivalent in terms of characteristics important to project performance, such as acoustic rating.



Legend

- Applicable EPD
- EPD with expired North American PCR

Figure 5. Relationship between panel thickness and GWP (left) and NRC (right).

K3: RESILIENT FLOORING

K3.1 Category Overview

Category Description

Resilient flooring is defined as a non-textile floor that characteristically bounces back from repeated traffic or compression. These flooring types are most commonly used in commercial buildings that require durable floor finishes such as education and healthcare buildings. Resilient flooring products are available in both roll and tile form and come in a wide range of colors, shapes, and sizes. This report identifies baselines for 1 m² of six types of resilient flooring: homogeneous vinyl flooring, heterogeneous vinyl flooring, rubber flooring, vinyl composition tile, vinyl tile, and rigid core flooring (based on the six available North American industry-wide EPDs). Other common types of resilient flooring include linoleum, cork, and other types of bio-based and synthetic flooring.

Production Processes and Key Drivers of Carbon Emissions

The raw materials for resilient flooring vary depending on the type of flooring but often include fillers, resins, plasticizers, pigments, and additives. Some resilient floors may also incorporate a backing material or recycled content. The raw materials are typically mixed together and consolidated to form a sheet, which can then be formed into rolls or tiles.

The industry EPDs include impacts for stages A1-A3, A4, A5, B2, B4, C2, C4, and Module D. As shown in Figure 1, the use stage (maintenance and replacement) is the largest contributor to cradle-to-grave GWP. If one ranked the resilient flooring types based on GWP data from life cycle modules A1-A3, the flooring ranks would be different than if they were ranked based on GWP from all reported life cycle stages. Because the reference service life varies by product, it is important for users to understand the attributes of the products they are comparing and whether or not the products are functionally equivalent, or suitable for comparison. See "Additional Notes and Guidance" for more information.

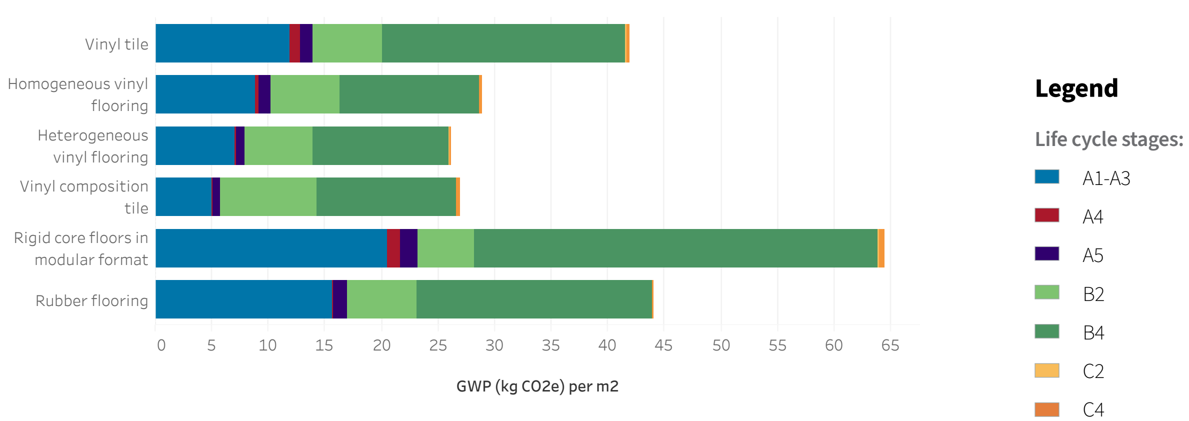


Figure 1. GWP contribution by life cycle stage, over a 75-year building service life. A1–A3: raw materials acquisition and manufacturing; A4: transport to site; A5: installation; B2: maintenance; B4: replacement; C2: end-of-life transport (barely visible in chart); C4: disposal.

K3.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product category rule guidance for building-related products and services – Part B: Flooring EPD requirements.*

Industry EPD

Resilient Floor Covering Institute (RFCI). (2019). *Environmental Product Declaration – Homogeneous vinyl flooring.* UL Environment.

> This IW-EPD is based on data representative of all types of homogeneous vinyl flooring from six manufacturers for the North American market. Products accounted for in this EPD represent around 90% of homogeneous vinyl flooring sold in North America.

Resilient Floor Covering Institute (RFCI). (2019). *Environmental Product Declaration – Heterogeneous vinyl flooring*. UL Environment.

> This IW-EPD is based on data representative of all types of heterogeneous vinyl flooring from 10 manufacturers for the North American market. Products accounted for in this EPD represent around 90% of heterogeneous vinyl flooring sold in North America.

Resilient Floor Covering Institute (RFCI). (2019). *Environmental Product Declaration – Vinyl composition tile.* UL Environment.

> This IW-EPD is based on data representative of all types of VCT from three American manufacturers. Products accounted for in this EPD represent around 90% of VCT sold in North America.

Resilient Floor Covering Institute (RFCI). (2019). *Environmental Product Declaration – Vinyl tile.* UL Environment.

> This IW-EPD is based on data representative of all types of vinyl tile from 12 manufacturers for the North American market. Products accounted for in this EPD represent around 90% of heterogeneous vinyl flooring sold in North America.

Resilient Floor Covering Institute (RFCI). (2019). *Environmental Product Declaration – Rubber flooring*. UL Environment.

> This IW-EPD is based on data representative of all types of rubber flooring from seven North American manufacturers. Products accounted for in this EPD represent around 90% of rubber flooring sold in North America.

Resilient Floor Covering Institute (RFCI). (2019). *Environmental Product Declaration – Rigid core flooring*. UL Environment.

> This IW-EPD is based on data representative of all types of rigid core flooring from seven manufacturers for the North American market. Products accounted for in this EPD represent around 65% of rigid core flooring sold in North America.

Product EPDs

There are currently 27 applicable* product EPDs for this category: 15 for luxury vinyl tile, 8 for rubber, and 4 for other resilient floor types including biobased polyester composition floor tile and stone polymer composite (SPC).

> ***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

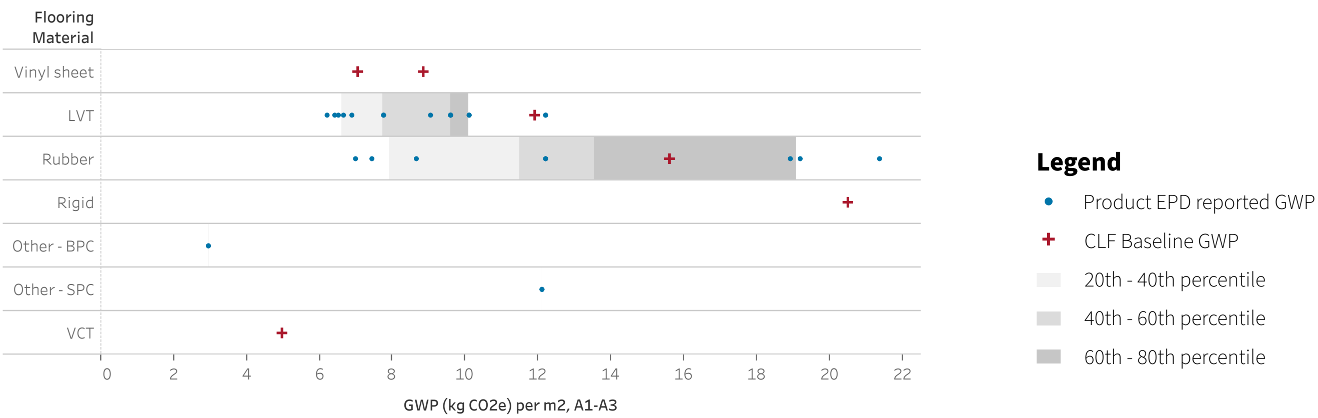


Figure 2. Range of applicable product EPDs and CLF Baselines. "Vinyl sheet" includes both homogenous and heterogenous vinyl flooring. "Other - BPC" refers to biobased polyester composition floor tile (2 identical GWP results). "Other - SPC" refers to stone polymer composite (2 identical GWP results).

Flooring Material	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
LVT	6.2	6.6	7.8	9.0	9.6	10.1	12.2	8.7	11.9
Rubber	7.0	7.9	11.5	12.2	13.5	19.1	21.4	13.4	15.6

Figure 3. Summary statistics of product EPDs and CLF Baselines (kg CO_2e per 1m²), A1–A3.

K3.3 CLF Baselines

Product Type	CLF Baseline GWP (kg CO_2e per 1 m²)	Method	Data Source and Notes
Homogeneous Vinyl Flooring	**8.84**	Industry	RFCI. (2019). *Environmental product declaration – Homogeneous vinyl flooring.*
Heterogeneous Vinyl Flooring	**7.04**	Industry	RFCI. (2019). *Environmental product declaration – Heterogeneous vinyl flooring.*
Rubber Flooring	**15.6**	Industry	RFCI. (2019). *Environmental product declaration – Rubber flooring*
Vinyl Composition Tile (VCT)	**4.96**	Industry	RFCI. (2019). *Environmental product declaration – Vinyl composition tile.*
Vinyl Tile	**11.9**	Industry	RFCI. (2019). *Environmental product declaration – Vinyl tile.*
Rigid Core Flooring	**20.5**	Industry	RFCI. (2019). *Environmental product declaration – Rigid core flooring.*

K3.4 Additional Notes and Guidance

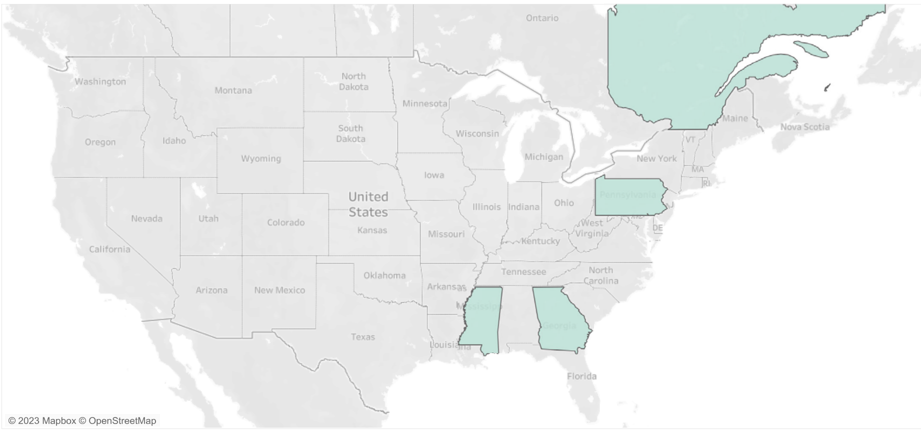


Figure 4. Product EPDs by location.

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Reference Service Life and Product Replacement

In this category, the reference service life (RSL) varies from product to product. When a product's RSL is shorter than the estimated service life of a building, the product's RSL determines how many times a product needs to be replaced over the course of the building's lifespan. EPDs in this category disclose environmental impacts from the construction, use, and end-of-life stages, all of which should be included when making comparisons among products with different RSLs. For users interested in product-level comparisons, environmental impacts related to additional life cycle stages are disclosed in the category's product and IW-EPDs. At this time, all EPD data provided in this appendix includes cradle-to-gate impacts only.

Other Available Product EPDs

This appendix does not include product EPD nor industry-wide EPD data for some resilient flooring types such as linoleum and cork, which are more commonly manufactured outside of North America. As shown in Figure 5 below, there are many more product EPDs (representing all sub-types of resilient flooring) available for global resilient flooring products, most of which reference a different PCR than the North American sub-category PCR listed in this appendix. It is important to note that different PCRs may prescribe different methodologies for calculating and reporting environmental impacts. Therefore, when comparing EPDs that reference different PCRs, it is important for users to understand the differences between the PCRs before drawing any conclusions.

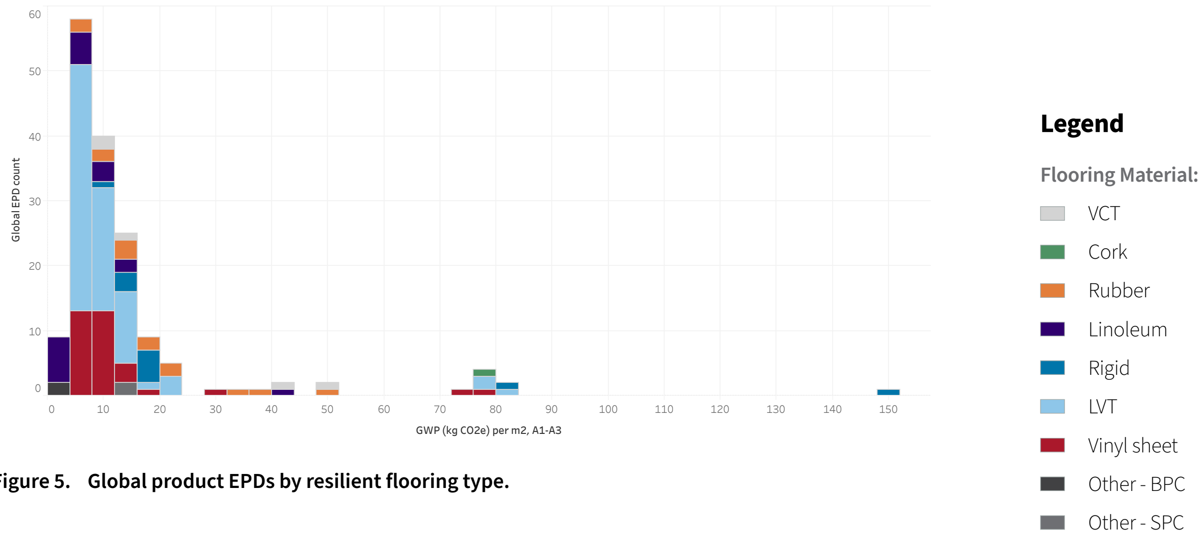


Figure 5. Global product EPDs by resilient flooring type.

K4: CARPET

K4.1 Category Overview

Category Description

Carpet is a textile floor covering that can be further categorized as either broadloom carpet or carpet tile. Broadloom carpet comes in large rolls and is commonly used in residential applications. Carpet tile is more commonly used for finish flooring in commercial applications where heavier traffic is expected. The reported environmental impacts for both carpet sub-types include the yarn material, tufting, precoat, and carpet backing. The declared unit for this category is 1 m^2 of floor covering.

Production Processes and Key Drivers of Carbon Emissions

The current North American flooring PCR requires a cradle-to-grave scope.[1] The following life cycle stages are included as non-zero values in a sample of EPDs the CLF reviewed: A1–A3, raw material extraction through manufacture; A4, transport to installation site; A5, installation (including ancillary materials required for installation and trim-waste disposal); B2, maintenance (for one year of use; includes the energy for vacuuming, extraction cleaning, production and transport of cleaning agents, and wastewater treatment from extraction cleaning); C2, transport of waste to local disposal; and C4, disposal.

While carpet EPDs publish cradle-to-grave results, the current data from EC3 only includes A1:A3 results. Without an industry EPD or a broad view of EPD data by life cycle stage, the CLF does not have sufficient information to describe key drivers of emissions.

K4.2 Data Availability and Representativeness

PCR

UL Environment. (2018). *Product Category Rule Guidance for Building-Related Products and Services – Part B: Flooring EPD Requirements.*

Industry EPD

There are currently zero North American IW-EPDs for carpet.

Product EPDs

There are currently 348 applicable* product EPDs for carpet: 41 for broadloom carpet and 307 for carpet tile.

> ***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

1. UL Environment. (2018). Product Category Rule Guidance for Building-Related Products and Services - Part B: Flooring EPD Requirements..

The following figures include EPDs whose accounting includes a GWP “credit” in A1–A3 related to the biogenic carbon content in the product. Hence some EPDs show a net negative A1–A3 GWP value (and others have a lower A1–A3 GWP than they would without this credit). Negative or reduced A1–A3 GWP can be problematic when other life cycle stages are excluded (as this A1–A3 “credit” is generally balanced out with an equivalent emission in C-stage accounting). Proper comparisons between carpet EPDs should include cradle-to-grave accounting. Although that data is available through individual EPDs, the EC3 tool does not digitize and publish results from other life cycle stages. This is a major limitation for a category like carpet, which has a wide range of GWP results and different reference service lives.

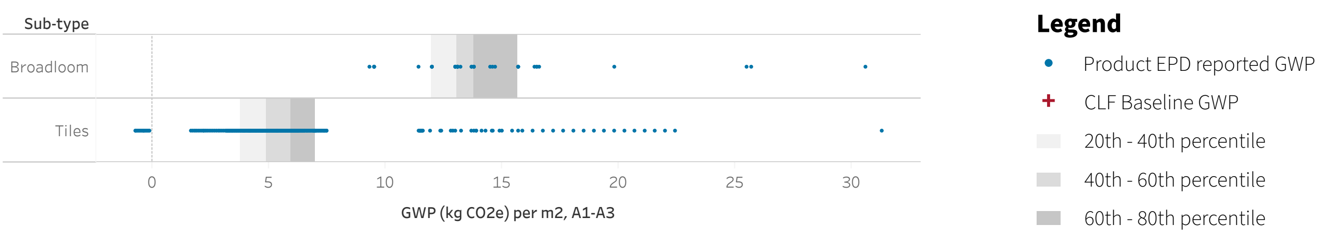


Figure 1. Range of applicable product EPDs and CLF Baselines. See note above about negative GWP values.

Sub-type	Min	20th	40th	Median	60th	80th	Max	Mean	Baseline
Broadloom	9.3	12.0	13.1	13.2	13.8	15.7	30.6	14.5	--
Tiles	-0.7	3.8	4.9	5.4	6.0	7.0	31.3	6.4	--

Figure 2. Summary statistics of product EPDs and CLF Baselines (kg CO2e per m2), A1-A3. See note above about negative GWP values.

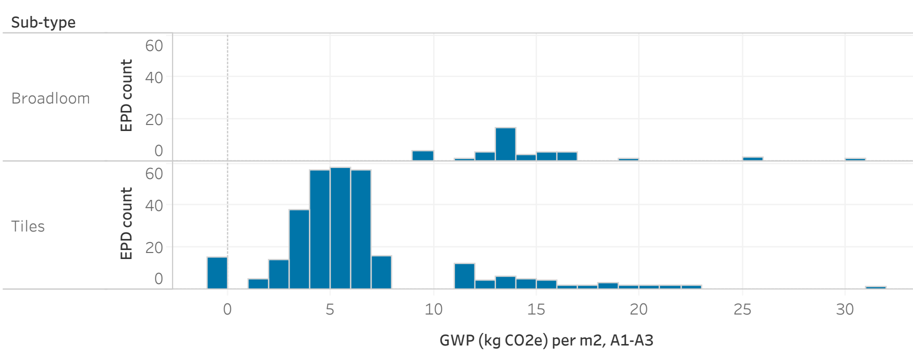


Figure 3. Distribution of applicable product EPDs. See note above about negative GWP values.

K4.3 CLF Baselines

There is no 2023 CLF Material Baseline for carpet since CLF was not able to determine if the available data adequately represents North American production. See the Baseline Methodology section of the report for more information.

While there is a relatively large number of product EPDs, barriers to confidently setting baselines with the available data include the following: (1) there is significant variation in the products (particularly their yarn weights and reference service life values), which inhibits comparability as these factors relate to product performance and cradle-to-grave GWP; and (2) there was no easily accessible production quantity data to inform production-weighted calculations, which is particularly important in a category where the products have such a large range in reported GWP.

K4.4 Additional Notes and Guidance

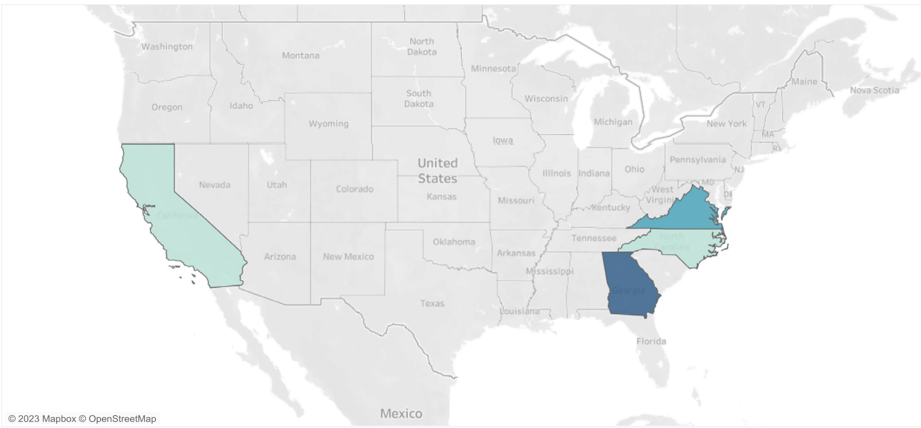


Figure 4. Product EPDs by location.

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs

Reference Service Life and Product Replacement

In this category, the reference service life (RSL) varies from product to product. When a product's RSL is shorter than the estimated service life of a building, the product's RSL is used to estimate how many times a product needs to be replaced over the course of the building's lifespan. EPDs in this category disclose environmental impacts from the construction, use, and end-of-life stages, all of which should be included when making comparisons among products with different RSLs. For users interested in product-level comparisons, environmental impacts related to additional life cycle stages are disclosed in the category's product EPDs. At this time, however, all EPD data provided in this appendix includes cradle-to-gate impacts only, due to lack of data availability through the EC3 tool for other life cycle stages.

Manufacturer Representation and Data Gaps

Most of the carpet product EPDs currently available are for carpet tile products. At the time of publication, there were 307 product EPDs for carpet tile products from eight manufacturers. However, 45% of the product EPDs came from a single manufacturer. In contrast, there were only 41 product EPDs from eight manufacturers for broadloom carpet. Figure 5 shows the count of carpet EPDs by manufacturer. The broadloom carpet EPDs included products made from nylon, olefin, and polyester yarn. While these are some of the more common fibers used in carpet manufacturing, the sample set was missing other common broadloom carpet fibers like polypropylene, acrylic, and wool.

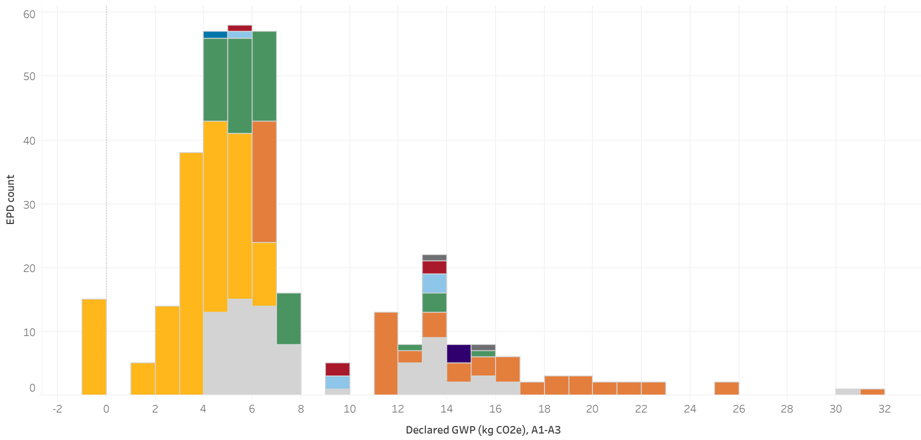


Figure 5. Count of product EPDs by manufacturer.

Legend

Manufacturer:

- Philadelphia Comme..
- J+J Flooring
- Bentley Mills, Inc.
- EF Contract
- Georgia-Pacific
- Patcraft
- Mohawk Industries,..
- Interface, Inc
- Shaw Contract
- Shaw Flooring
- Shaw Industries Gro..

L1: COMMUNICATIONS – DATA CABLING

B5.1 Category Overview

Category Description

This category includes various data cable types for network infrastructure, including:

Fiber data cabling: optical fiber cable with voice, data, and power over ethernet (PoE) applications, with various ratings for plenum or riser environments, such as OFNP, ONFR, OFCP, or OFCR.[1]

Twisted pair data cabling: premises copper cable (Categories 3–7) with voice, data, and PoE applications with various ratings for plenum (CMP) or riser (CMP) environments.[2]

Other data cabling: includes premises composite cables (Coax), patch cords, and other cabling typologies not included in the above types.[3]

Production Processes and Key Drivers of Carbon Emissions

Input materials include the wire or glass fibers that perform the communication function, and a variety of other materials for protection (jacketing, insulation, separator, tight buffering, etc.).[4] As seen in Figures 1 and 2, fiber data cable products in general have significantly higher impacts per meter than twisted pair data cable products.

The CLF does not currently have industry-average information on the relative impacts of the material ingredients or life cycle stages. (There are no IW-EPDs for data cabling, and a sample of product EPDs reviewed do not have disaggregated results for A1-A3.)

L1.2 Data Availability and Representativeness

PCR

There is currently no valid North American PCR for data cabling. The North American data cabling EPDs in the EC3 database conform to one of:

UL Environment. (2014). *Wire and Cable (NA Addendum)*. [now expired]

P.E.P. Association. (2022). P.E.P. *PCR for Wires, Cables and Accessories*. [and/or previous versions]

P.E.P. Association. (2021). *Product Category Rules for Electrical, Electronic and HVAC-R Products*. [and/or previous versions]

CEN. (2019). EN 15804:2012+A2:2019 – *Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.*

1. OPTCORE. (2017). "OFNP, OFNR, OFNG, OFCG and OFCP: How to Choose?" [website]. https://www.optcore.net/ofnp-ofnr-ofng-ofcg-ofcp-how-to-choose/

2. Cmple.com. "Understanding Cable Jacket Ratings: CL, CM, CMR and CMP" [website]. Accessed 2023-02-16. https://www.cmple.com/learn/understanding-cable-jacket-ratings-cl-cm-cmr-and-cmp

3. These three categories and descriptions were provided by Building Transparency for the 2021 CLF Baselines.

4. Superior Essex. (2021). *Environmental product Declaration – Superior Essex 4-pair copper data cable – Indoor/outdoor, riser, and plenum rated. UL Environment.*

Industry-wide EPD

There is currently no North American industry EPD for data cabling.

Product EPDs

There are currently 42 applicable* product EPDs for data cabling, including 14 for fiber and 28 for twisted pair.

> ***Applicable product EPDs** are EPDs that are valid, represent North American manufacturing, fit the scope for the product type, conform to the appropriate PCR, and pass the CLF and EC3 quality controls for EPDs.

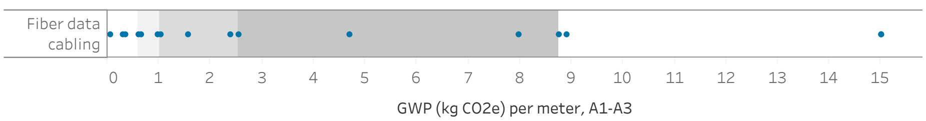


Figure 1. Range of applicable product EPDs. Fiber data cabling.

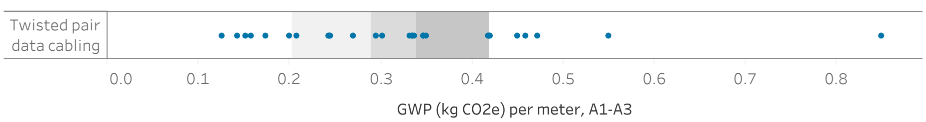


Figure 2. Range of applicable product EPDs. Twisted pair data cabling.

Legend

- Product EPD reported GWP
- CLF Baseline GWP
- 20th - 40th percentile
- 40th - 60th percentile
- 60th - 80th percentile

Given the range of performance characteristics among the product EPDs (and associated limitations to appropriate comparability) in each product type, the summary statistics provided in many appendices of this report are excluded here.

L1.3 CLF Baselines

Due to the lack of an adequately representative data source, there are currently no CLF Baselines for data cabling product types.

L1.4 Additional Notes and Guidance

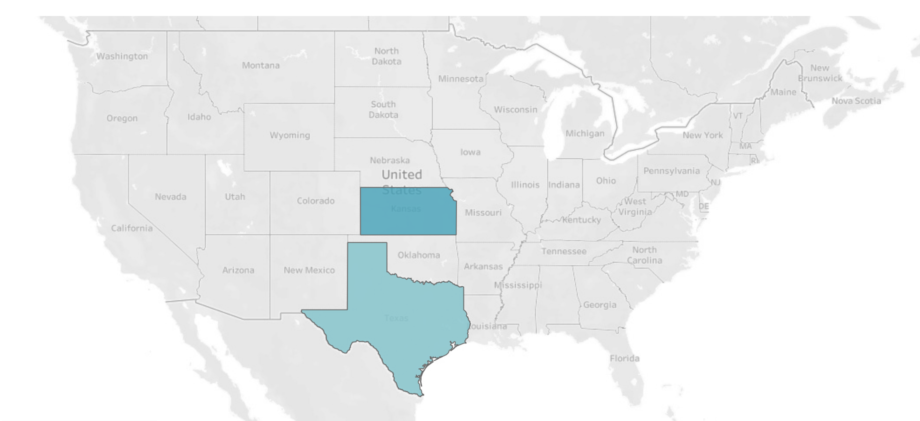


Figure 3. Product EPDs by location.

Legend

Region with:

- 0 applicable product EPDs
- 1-25 applicable product EPDs
- 25-50 applicable product EPDs
- 50-75 applicable product EPDs
- 75-100 applicable product EPDs
- 100+ applicable product EPDs