Athena Sustainable Materials Institute

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Life Cycle Assessment of MBMA Primary and Secondary Structural Frame Components and Roll formed Metal Wall and Roof Panels

EPD Project Report

This Report may contain **confidential** information and is only available to the MBMA and its members.

Prepared for: The Metal Buildings Manufacturers Association (MBMA)

Prepared by: The Athena Sustainable Materials Institute

April 2021

General Summary

The Metal Buildings Manufacturers Association (MBMA) engaged the Athena Sustainable Materials Institute to conduct a life cycle assessment (LCA) of its structural and panel products used in metal building systems as manufactured by its member companies in the US. This LCA report presents cradle-to-gate industry average results for four key product profiles: primary structural frame components, secondary structural frame components, roll formed metal wall panels and roll formed metal roof panels. The LCA has been conducted to support a Type III Environmental Product Declaration (EPD).

Specifically, this industry average LCA background report (the "*The Project Report*") has been conducted according to the requirements of ISO 21930:2017 [1], in conformance with ISO 14040/44 standards [2], [3], and ULE product category rules (PCR) Part A and B [4], [5], [6] and ULE General Program Instructions for Type III Environmental Declaration [7]. This Project report for EPD development purposes was commissioned by the MBMA and its members and is verified by ULE to conform to the requirements of ISO 14040 [2], 14044 [3],14025 [8], and 21930 [1].

General Summary	
Owner of the EPD	The Metal Building Manufacturers Association (MBMA) 1300 Sumner Ave. Cleveland, Ohio 44115-2851 Link (URL): https://www.mbma.com Fourteen (14) MBMA member facilities provided LCI data and meta data for reference year 2019. *The owner of the declaration is liable for the underlying information and evidence.*
MBMA Members	This EPD was developed for use by MBMA member companies, a complete list of whom can be found here: https://www.mbma.com/Accredited_MBMA_Members.html
Product Group and Name	Primary structural frame components ("primary frames"), Secondary structural frame components ("secondary frames"), Roll formed metal wall panels ("wall panels"), and Roll formed metal roof panels ("roof panels"). *CSI code: 051200 Structural Steel Framing* *CSI code: 074213.13 Formed Metal Wall Panels* *CSI code: 074113.13 Formed Metal Roof Panels* A metal building *system* is made up of primary frames, secondary frames, and metal roof and wall panels.

General Summary	
Product Category Rules (PCR)	UL Environment ***Part A****:* Life Cycle Assessment Calculation Rules and Report Requirements, December 2018, v3.2 [4]. UL Environment, Product Category Rule Guidance for Building-Related Products and Services; ***Part B***: Designated Steel Construction Product EPD Requirements, August 2020 [5]. UL Environment, Product Category Rule for Building-Related Products and Services ***Part B***: Insulated Metal Panels, Metal Composite Panels, and Metal Cladding: Roof and Wall Panels, October 2018 [6].
Declared Unit	1 metric ton of: • 1 metric ton of primary frames • 1 metric ton of secondary frames • 100 m^2 of wall panels • 100 m^2 roof panels

EPD and Project Report Information	
Program Operator	UL Environment
Declaration Holder	Metal Building Manufacturers Association (MBMA)
Product group: Metal Building Systems	**Period of Validity:**5 years
Declaration Type A "Cradle-to-gate" EPD for metal building system components. Activity stages covered include the production stage (modules A1 to A3). The declaration is intended for use in Business-to-Business (B-to-B) communication.	
Applicable Countries: United States	
Content of the Declaration This Project report follows *Section 8*; *Project Report and Supporting Documentation*, as described in UL Environment Part B PCRs [5], [6].	
This EPD was independently verified in accordance with ISO 14025:2006. The UL Environment Part A: Calculation Rules for the Life Cycle Assessment and Requirements on the Project Report, v3.2 (December 2018), in conformance with ISO 21930:2017, serves as the core PCR, with additional considerations from the USGBC/UL Environment Part A Enhancement (2017) **Internal** **External** X (External)	UL Environment
The Project Report *Note that this Project Report is not part of the public communication (ISO 21930, 10.1).*	Life Cycle Assessment of MBMA Primary and Secondary Structural Frame Components and Roll formed Metal Wall and Roof Panels, EPD Project Report, March 2021.
Prepared by	Lindita Bushi, PhD, Mr. Jamie Meil, and Mr. Grant Finlayson Athena Sustainable Materials Institute

EPD and Project Report Information	
Athena Sustainable Materials Institute	280 Albert Street, Suite 404 Ottawa, Ontario, Canada K1P 5G8 info@athenasmi.org www.athenasmi.org
This EPD project report was independently verified by in accordance with ISO 14044, and the reference PCR:	Thomas P. Gloria, Ph.D. Industrial Ecology Consultants 35 Bracebridge Rd. Newton, MA 02459-1728 t.gloria@industrial-ecology.com
PCR Information	
Program Operator	UL Environment
Reference Part B PCR1	UL Environment, Product Category Rule Guidance for Building-Related Products and Services; *Part B: Designated Steel Construction Product EPD Requirements* [5].
Date of Issue	August 2020
PCR review was conducted by:	Thomas P. Gloria, PhD (Chair) t.gloria@industrial-ecology.com Ms. Brandie Sebastien Mr. James Littlefield
Program Operator	UL Environment
Reference Part B PCR2	UL Environment, Product Category Rule for Building-Related Products and Services *Part B: Insulated Metal Panels, Metal Composite Panels, and Metal Cladding: Roof and Wall Panels*.
Date of Issue	October 2018
PCR review was conducted by:	Thomas P. Gloria, PhD (Chair) t.gloria@industrial-ecology.com Lindita Bushi, PhD Bob Zabcik, P.E.

Terms and Definitions

ISO 14040/Amd1:2020 and ISO 14044:2006/Amd1:2017/Amd2:2020 [2], [3] – Clause 3 Terms and Definition.

Allocation: Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Comparative assertion: environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function.

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life Cycle Impact Assessment (LCIA): Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life Cycle Interpretation: Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Life Cycle Inventory (LCI): Phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Product system: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.

System boundary: boundary based on a set of criteria specifying which unit processes are part of the system under study

Uncertainty analysis: Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability.
Note: Either ranges or probability distributions are used to determine uncertainty in the results.

ISO 14021:2016 [9]- Clause 7.8 Recycled content

Recovered material: Material that would have otherwise been disposed of as waste or used for energy recovery but has instead been collected and recovered as a material input, in lieu of new primary material, for a recycling or a manufacturing process.

Pre-consumer material: Material diverted from the waste stream during a manufacturing process. *Excluded* is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Post-consumer material: Material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product that can no longer be used for its intended purpose. This includes returns of material from the distribution chain.

ISO 14025:2006 [8] - Clause 3 Terms and definitions

Type III Environmental Product Declaration (EPD): Providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information
Note 1 the predetermined parameters are based on the ISO 14040 series of standards.
Note 2 the additional environmental information may be quantitative or qualitative.

Product Category Rules (PCR): Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.

ISO 21930:2017 [1] - Clause 3 Terms and definitions

Average data: Data based on a fully representative sample for a construction product or construction service, provided by one or more suppliers, either from their multiple plants or based on multiple similar construction products of the supplier(s).

By-product: Co-product from a process that is *incidental or not intentionally* produced and which cannot be avoided.

Co-product: Any of one or more products from the same unit process, but which is not the object of the assessment.

Declared unit: Quantity of a construction product for use as a reference unit in an EPD based on LCA for the expression of environmental information in information modules.

Information module: Compilation of data to be used as a basis for an EPD, covering a unit process or a combination of unit processes that are part of the life cycle of a product.

Life cycle: All consecutive and interlinked stages in the life of the object under consideration.

Product category: Group of construction products that can fulfill equivalent functions.

Industry average EPD: EPD results for a specific product or group of metal building components weighted and categorized by performance for a specified region and/or group of manufacturers.

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Acronyms and Abbreviations

ADP_f	Abiotic depletion potential for fossil resources
AISC	American Institute for Steel Construction
AISI	American Iron and Steel Institute
AP	Acidification potential
ASTM	American Society for Testing and Materials
AWS	American Welding Society
B2B	Business-to-business
BD+C	Building Design and Construction, LEED
BOF	Basic Oxygen Furnace
CFC-11	Trichlorofluoromethane
CO_2	Carbon dioxide
CRU	Components for re-use
CSI	Construction Specifications Institute
EAF	Electric Arc Furnace
EE	Recovered energy exported from the product system
EP	Eutrophication potential
EPD	Environmental product declaration
FFD	Fossil fuel depletion
FW	Consumption of fresh water
GWP 100	Global warming potential, 100 years' time horizon
LHV	Lower heating value or net caloric value
HLRW	High-level radioactive waste, conditioned, to final repository
HWD	Hazardous waste disposed
IAS	International Accreditation Services
ID+C	Interior Design and Construction, LEED
ILLRW	Intermediate- and low-level radioactive waste, conditioned, to final repository
IPCC	International Panel on Climate Change
ISO	International Organization for Standardization
kg	Kilogram
km	Kilometer
kWh	kilowatt hours
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LEED	Leadership in Energy and Environmental Design
MBMA	Metal Building Manufacturers Association
MC	Moisture content
MER	Materials for energy recovery
MJ	Mega joule
MR	Materials for recycling
N	Nitrogen

NHWD	Non-hazardous waste disposed
$NRPR_M$	Non-Renewable primary energy carrier used as material
$NRPR_E$	Non-renewable primary energy carrier used as energy
NRSF	Non-renewable secondary fuel
O_3	Ozone
ODP	Ozone depletion potential
O+M	Building Operations and Maintenance, LEED
OSHA	Occupational Safety & Health Administration
PCR	Product category rules
PM	Particulate Matter
RCSC	Research Council on Structural Connections
RE	Recovered energy,
RPR_M	Renewable primary energy carrier used as material
RPR_E	Renewable primary energy carrier used as energy
RSF	Renewable secondary fuel
SFP	Smog formation potential
SM	Secondary material
SO_2	Sulfur dioxide
SPSC	The Society for Protective Coatings
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
TRI	United States Toxics Release Inventory (TRI) Program
US EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds

1 Introduction

The US Green Building Council's *Leadership in Energy and Environmental Design* (LEED) v4 and v4.1 green rating system, reward building projects across the LEED rating systems (BD+C, ID+C, ND, and Homes)[1], for selecting products from manufacturers who have disclosed and verified potential environmental impacts. The intent is to encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts.

This life *cycle assessment* (LCA) project report supports a "cradle-to-gate" *environmental product declaration* (EPD) for four components making up a metal building system; namely, primary and secondary structural frame components and roll formed metal wall and roof panels as manufactured by the Metal Building Manufacturers Association (MBMA) members in the USA and has a business-to-business (B2B) focus.

Life cycle assessment is an analytical tool used to comprehensively quantify and interpret the energy and material flows to and from the environment over the life cycle of a product, process, or service [2], [3]. Environmental flows include emissions to air, water, and land, as well as the consumption of energy and material resources. By including the potential impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product. An EPD provides quantified environmental data using predetermined parameters and, where relevant, additional environmental information [7]. The predetermined parameters are based on the ISO 14040 series of standards [2], [3] and the core PCR ISO 21930 [1]. Other additional environmental information may be quantitative or qualitative.

This study demonstrates the Metal Building Manufacturers Association (MBMA) and its members' commitment to transparently sharing the environmental footprint of the major components making up a metal building system. This report underlies and supports the generation of environmental product declarations for primary and secondary structural frame components and roll formed metal wall and roof panels as produced in the US.
In support of the project, annual primary life cycle inventory (LCI) data were collected from 14 geographically representative MBMA member facilities producing all four of the products of interest for the reference production year 2019. Primary data on raw materials and energy use

[1] Building Design and Construction (BD+C); Interior Design and Construction (ID+C); Neighborhood Development (ND). *LEED v4,* MR Credit 2, EPDs- Option 1 applies to *BD+C rating system (*New Construction, Core & Shell, Schools, Retail, Data Centers, Warehouses & Distribution Centers, Hospitality, and Healthcare: 1 point); ID+C rating system (Commercial Interiors, Retail, and Hospitality: 1 point), *ND* rating system (new land developments, land redevelopments, residential, mixed use, commercial, and industrial: 1 point); and *Homes* rating system (Homes, Multifamily Lowrise, Multifamily Midrise: 1 point) [12].
LEED v4.1, MR Credit 2, EPDs- Option 1 (similar to v4): 1 point [13].

and emissions to air, water and land, scrap recycling as well as production output were provided by the MBMA member companies. In addition, secondary sourced LCI data were utilized to model upstream raw and ancillary material inputs, in-bound and out-bound transportation and energy use.

2 Study Goals

2.1 Goals of the Study

This is a sector-driven initiative by the MBMA and its members to conduct an LCA to support the development of an EPDs according to ISO 14025 [7], ULE PCRs [4], [5], and ISO 21930 [1] for four component products making up a metal building system:

- Primary structural frame components
- Secondary structural frame components
- Roll-formed metal wall panels
- Roll-formed metal roof panels

as manufactured in the United States by MBMA members.

2.2 Intended Applications and Audience

This LCA report is intended to support the development of EPDs for use in Business-to-Business (B-to-B) communication. The intended audience for the EPD include MBMA member and non-member companies, their suppliers, architectural, engineering, and specifying professionals, LCA practitioners and tool developers, academia, governmental organizations, policy makers and other interested value chain parties who require reliable information on metal building systems and their main components.

2.3 Comparative Assertions

The resulting industry average EPDs for metal building system components based on this Project Report (underlying LCA report for EPD) is not a comparative assertion. *Environmental impact results based on a declared unit of a steel product do not provide sufficient information to establish comparisons. The results shall not be used for comparisons without knowledge of how the physical properties of the steel product impact the precise function at the construction level. The environmental impact results shall be converted to a functional unit basis before any comparison is attempted* [4].

Per ISO 21930, 10.1 [1], this Project Report shall be made available to the verifier with the requirements on confidentiality stated in ISO 14025 [7]. This Project Report is independently verified by Thomas Gloria, Ph.D., Industrial Ecology Consultants, in accordance with ISO 14025 [7], ISO 14040/44 [2], [3], and the ULE PCR requirements [4], [5].

3 Product Identification

3.1 Product Definition and application

Primary structural steel frame components (*CSI code: 051200 Structural Steel Framing*) used in a metal building system are built-up using three welded steel plates to form an "I" section. The three plates include the uniform width of the two flanges (commonly derived from bar stock) and one tapered web section (commonly derived from hot rolled steel plate). The flanges are welded to the tapered web to form the tapered web I-section for the *beam and columns*, typically by an automatic welder. End plates with bolt holes are welded to the ends of the individual frame sections by a certified welder, along with other weldaments and accessories. The primary frames are often coated with a rust-inhibiting primer or painted to meet project specifications. Once the *columns and roof beams* have been fabricated, completed with holes in webs and flanges for attachment of secondary structural members and bracing, the products are delivered to the jobsite (see Figure 1).

Secondary structural steel frame components (*CSI code: 051200 Structural Steel Framing)* covered by this EPD and commonly used in a metal building system includes (see Figure 1):

- Cold-formed steel "cee" and "zee" shaped *purlins* used in the roof to span the distance between the primary rigid framed rafters in order to support the metal roof panels (standing seam roof or through fastened roof). Purlins typically range from 203.2 mm (8 in) to 304.8 mm (12 in) in depth and can span 6.1 m (20 ft) to 12.2 m (40 ft) depending on the loading, material thickness and bracing methods. The average purlin spacing is 1.5 m (5 ft) on center.
- Cold-formed steel "cee" and "zee" shaped *girts* used on the walls to span the distance between the primary rigid framed columns in order to support the metal wall panels (or other wall cladding materials). Girts typically range from 203.2 mm (8 in) to 304.8 mm (12 in) in depth and can span 6.1 m (20 ft) to 12.2 m (40 ft) depending on the loading, material thickness and bracing methods. The average girt spacing varies based on design parameters.
- Cold-formed steel components used in the endwall framing, such as columns (posts), end rafters, beams, eave struts and girts.
- Framed openings utilizing cold-formed steel components to allow for a door, window, or skylight opening.
- Bracing elements, such as roof and wall 'X' bracing (commonly steel rods or wire rope), along with flange, purlin and girt bracing (commonly angle irons, threaded rods, channels, and metal straps).

Roll formed metal wall and roof panels (also known as wall and roof claddings, *CSI code: 074213.13 Formed Metal Wall Panels*; *CSI code: 074113.13 Formed Metal Roof Panels*) covered by this EPD and commonly used on a metal building system includes (see Figure 1):

- Cold-formed single skin metal *walls* are attached to the girts that spans to the primary rigid framed columns. The metal wall panels are custom roll formed from either cold rolled coils or hot dip galvanized coils and may be either bare steel or painted steel. Additionally, the metal wall panels may be formed from aluminum/zinc coated products that may also be bare steel or painted steel.

- Cold-formed single skin metal *roofs* supported and attached to purlins that spans to the primary rigid framed rafters. The metal roofs may be classified as standing seam roofs that are attached to the purlins via concealed clips or a through fastened roof with exposed fasteners attached to the purlins. These roof panels are custom roll formed from either cold rolled coils or hot dip galvanized coils and may be either bare steel or painted steel. Additionally, the metal roof panels may be formed from aluminum/zinc coated products that may also be bare steel or painted steel.

Metal building systems are used in a wide variety of applications, such as manufacturing plants, industrial and commercial warehouses, shopping centers and retail stores, auto dealerships, educational, transportation and health care facilities, office structures, hangars, churches, community centers, and governmental and recreational buildings.

According to MBMA, "o*ne of the inherent advantages of a metal building system, and one of the key reasons that allows it to be perhaps the best value in construction today, is the industry's ability to utilize "welded up" frames as opposed to mill sections. In this way, the engineer using sophisticated computer programs can design the most efficient shape for a frame. The industry can put the steel material where it is needed and eliminate it where it is not needed, thus effecting economy without compromising design. Another point of interest is that welded shapes are only welded on one side. There is technically no reason for welding to be on both sides unless shear force requires it, and shear force in rigid frames is usually relatively low. The entire building system consists of an integrated set of components and assemblies, including but not limited, to frames that are structural steel members, secondary members that are made with cold-formed steel and steel joists, and roof and wall cladding components systems specifically designed to support and transfer loads and provide a complete or partial building shell. Figure 1 provides a sectional view of a building system including terminology used by the industry for each element of the building.*
Metal building systems can span great widths and lengths with or without additional interior supports. Where very large areas are required, and interior columns are not a problem, the modular rigid frame is an ideal solution. With a roof slope of 1/4 inches to 12 inches, even a 1000-foot building can be designed without excessive height. The roof secondary structural or purlin normally utilizes the lap method for economy and ease of installation. Lapping over the frame allows the purlins to act as a continuous beam with attendant efficiency and greatly reduced deflections compared to simple span purlins. Bay spacing of up to 33 feet is possible when using purlins. The open web joists allow designers to specify bay sizes up to 60' and even longer".

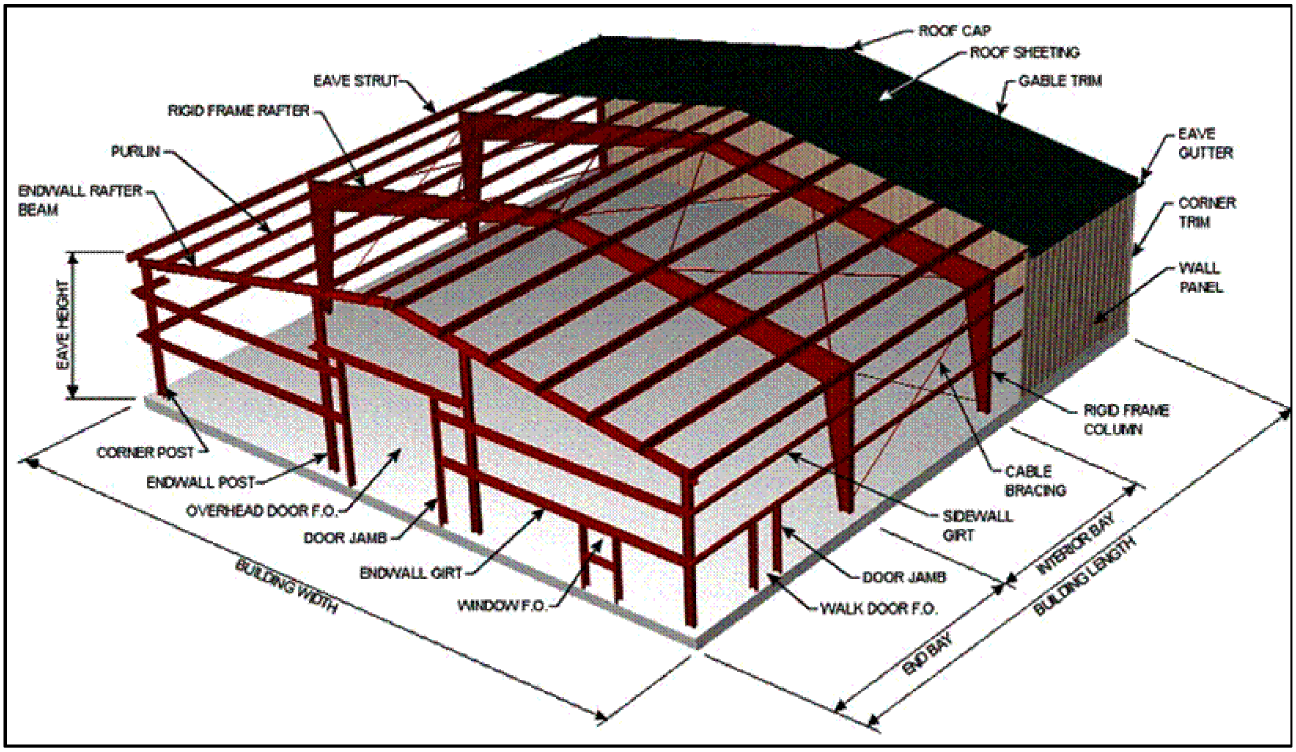

Figure 1 A sectional view of a building system including terminology used by the industry for each element of the building [Photo Courtesy: MBMA 2010]

3.2 Product Standard

The products considered in this LCA meet or exceed one or more of the following codes, specifications, and standards:

Table 1 Primary Frames- Product Codes, Specifications and Standards

Item	Description
Model Codes and Standards	International Building Code State or Locally Adopted Code ASCE/SEI 7 - Minimum Design Loads for Buildings and Other Structures UL - Building Material Directory UL - Fire Resistance Directory
Common Industry Standards	MBMA Metal Building Systems Manual
International Accreditation Services (IAS)	Accreditation Criteria 472 (AC472) - Accreditation Criteria for Inspection Programs for Manufacturers of Metal Building Systems

Item	Description
Specifications and Standards	**American Institute for Steel Construction (AISC)** AISC 360 - Specification for Structural Steel Buildings AISC 341 - Seismic Provisions for Structural Steel Buildings (when appropriate) AISC 303 - Code of Standard Practice for Steel Buildings and Bridges AISC Design Guide 3 - Serviceability Design Considerations for Steel Buildings
	ASTM International (ASTM) ASTM A6/A6M - Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling ASTM A36/A36M – Standard Specification for Carbon Structural Steel ASTM A123/A123M – Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products ASTM A500/A500M – Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes ASTM A529/A529M - Standard Specification for High-Strength Carbon-Manganese Steel of Structural Quality ASTM A572/A572M - Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel ASTM A992/A992M - Standard Specification for Structural Steel Shapes ASTM A1011/A1011M - Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength, Low-Alloy and High-Strength Low-Alloy with Improved Formability and Ultra-High Strength ASTM A1018/A1018M - Standard Specification for Steel, Sheet and Strip, Heavy Thickness Coils, Hot-Rolled, Carbon, Commercial, Drawings, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength ASTM F1554 – Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength
	American Welding Society (AWS) AWS D1.1 / D1.1M - Structural Welding Code - Steel AWS D1.3 / D1.3M - Structural Welding Code - Sheet Steel ASTM F3125 – Standard Specification for High Strength Structural Bolts, Steel and Alloy Steel, Heat Treated, 120 ksi (830 MPa) and 150 ksi (1040 MPa) Minimum Tensile Strength, Inch and Metric Dimensions
	Research Council on Structural Connections (RCSC) Specification for Structural Joints Using High-Strength Bolts
	The Society for Protective Coatings (SPSC) SSPC Paint-15 – Steel Joist Shop Primer / Metal Building Primer

Table 2 Secondary Frames- Product Codes, Specifications and Standards

Item	Description
Model Codes and Standards	International Building Code State or Locally Adopted Code ASCE/SEI 7 - Minimum Design Loads for Buildings and Other Structures UL - Building Material Directory UL - Fire Resistance Directory
Common Industry Standards	MBMA Metal Building Systems Manual
International Accreditation Services (IAS)	Accreditation Criteria 472 (AC472) - Accreditation Criteria for Inspection Programs for Manufacturers of Metal Building Systems
Specifications and Standards	**American Institute for Steel Construction (AISC)** AISC 303 - Code of Standard Practice for Steel Buildings and Bridges AISC Design Guide 3 - Serviceability Design Considerations for Steel Buildings
	American Iron and Steel Institute (AISI) AISI S100 - North American Specification for the Design of Cold-Formed Steel Structural Members
	ASTM International (ASTM) ASTM A653/A653M - Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zink-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process ASTM A1011/A1011M - Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength, Low-Alloy and High-Strength Low-Alloy with Improved Formability and Ultra-High Strength
	American Welding Society (AWS) AWS D1.3 / D1.3M - Structural Welding Code - Sheet Steel

Table 3 Wall and Roof Panels- Product Codes, Specifications and Standards

Item	Description
Model Codes and Standards	International Building Code State or Locally Adopted Code ASCE/SEI 7 - Minimum Design Loads for Buildings and Other Structures UL - Building Material Directory UL - Fire Resistance Directory
Common Industry Standards	MBMA Metal Building Systems Manual MBMA Metal Roofing Systems Design Manual

Item	Description
International Accreditation Services (IAS)	Accreditation Criteria 472 (AC472) - Accreditation Criteria for Inspection Programs for Manufacturers of Metal Building Systems
Specifications and Standards	**American Institute for Steel Construction (AISC)** AISC 303 - Code of Standard Practice for Steel Buildings and Bridges AISC Design Guide 3 - Serviceability Design Considerations for Steel Buildings
	American Iron and Steel Institute (AISI) AISI S100 - North American Specification for the Design of Cold-Formed Steel Structural Members
	ASTM International (ASTM) ASTM A653/A653M - Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zink-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process ASTM A792/A792M - Standard Specifications for Steel Sheet, 55% Aluminum-Zinc Alloy-Coated by the Hot-Dip Process ASTM D2244 - Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates ASTM D4214 - Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films ASTM E72 - Standard Test Methods for Conducting Strength Tests of Panels for Building Construction ASTM E1592 - Standard Test Methods for Structural Performance of Sheet Metal Roof and Siding Systems by Uniform Static Air Pressure Difference ASTM E1646 - Standard Test Method for Water Penetration of Exterior Metal Roof Panel Systems by Uniform Static Air Pressure Difference ASTM E1680 - Standard Test Method for Rate of Air Leakage Through Exterior Metal Roof Panel Systems ASTM E1980 - Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces
	American Welding Society (AWS) AWS D1.3 / D1.3M - Structural Welding Code - Sheet Steel

3.3 Material Content

Annex A, Tables A1, A2, A3 and A4 present the production weighted average LCI input/output flows for 1 metric ton of primary frames, secondary frames, metal wall and roof panels, respectively, as derived from the MBMA facilities LCI data for the reference year 2019. Materially, 1,066 kg of semi-finished steel inputs is required to produce one (1) metric ton of primary frames. Similarly, to produce one (1) metric ton of secondary frames, wall and roof panels the required semi-finished steel inputs were calculated to be 1,038, 1,061, and 1,034 kg, respectively. The resulting fabrication steel scrap is 100% recyclable. Table 4 below lists the major semi-finished steel inputs used in the production of the four metal building system products of interest.

Primary frames produced by MBMA members typically have thicknesses ranging from 0.071 to 1.500 inches, and the semi-finished steel input is sourced from both the electric arc furnace, EAF (88%) and basic oxygen furnace, BOF (12%) process routes. Similarly, secondary frames typically have thicknesses ranging from 11 to 17 ga, and the semi-finished steel input is sourced from both the EAF (80%) and BOF (20%) process routes. Metal wall and roof panels typically have thicknesses ranging from 18 to 29 ga with *26 ga being the weighted average thickness for both wall and roof panels*. For wall and roof panels, the semi-finished steel input is sourced from both the EAF (41%) and BOF (59%) and EAF (42%) and BOF (58%) process routes, respectively. As calculated for this study, one metric ton of wall and roof cladding yields approximately 240 m^2 and 211 m^2 of finished product, respectively.

Table 4 Weighted average material content for four MBMA declared products by metal substrate and thickness

MBMA Selected Products	Metal substrate and thickness	Thickness (in %)	Metal Substrate (%)
Primary Structural Steel Frame Components	Hot Rolled Plate		**38%**
	0.071 - 0.500 inch	81%	
	>0.500 -1.250 inch	11%	
	>1.250-1.500 inch	8%	
	Hot Rolled Flat Bar		**44%**
	0.1875 – 0.625 inch	72%	
	>0.625 - 1 inch	28%	
	Hot Rolled Structural Sections		**19%**
	Total semi-finished steel		**100%**
Secondary Structural Steel Frame Components	Hot Rolled Coil, EAF		**52%**
	17 to 14 ga	53%	
	14 to 11 ga	47%	
	Hot Rolled Coil, Pre-Painted		**33%**
	17 to 14 ga	46%	
	14 to 11 ga	54%	
	Cold Rolled Coil, Pre- Painted		**7%**
	16 to 14 ga	75%	
	14 to 12 ga	25%	
	Hot-Dip Galvanized (bare)		**8%**
	17 to 14 ga	49%	
	14 to 12 ga	51%	
	Total semi-finished steel		**100%**
Roll Formed Metal Wall Panels	Cold Rolled Coil, Pre-Painted		**1%**
	28 ga	0%	
	26 ga	95%	
	24 ga	5%	
	Hot-Dip Galvanized, Pre-Painted		**19%**
	29 ga	1%	
	26 ga	86%	

MBMA Selected Products	Metal substrate and thickness	Thickness (in %)	Metal Substrate (%)
	24 ga	13%	
	22 ga	0%	
	Hot-Dip Galvanized (bare)		**3%**
	26 ga	62%	
	24 ga	38%	
	22 ga	0%	
	Galvalume, Pre-Painted		**68%**
	29 ga	1%	
	28 ga	12%	
	26 ga	70%	
	24 ga	15%	
	22 ga	1%	
	18 ga	0%	
	Galvalume (bare)		**9%**
	26 ga	90%	
	24 ga	10%	
	22 ga	0.3%	
	Total semi-finished steel		**100%**
Roll Formed Metal Roof Panels	Cold Rolled Coil, Pre-Painted		**1%**
	28 ga	0%	
	26 ga	96%	
	24 ga	4%	
	Hot-Dip Galvanized, Pre-Painted		**3%**
	29 ga	1%	
	26 ga	86%	
	24 ga	13%	
	22 ga	0%	
	Hot-Dip Galvanized (bare)		**0.4%**
	26 ga	1%	
	24 ga	98%	
	22 ga	1%	
	Galvalume, Pre-Painted		**38%**
	29 ga	1%	
	28 ga	0%	
	26 ga	71%	
	24 ga	26%	
	22 ga	2%	
	18 ga	0%	
	Galvalume (bare)		**57%**
	26 ga	34%	
	24 ga	64%	
	22 ga	2%	
	Total semi-finished steel		**100%**

4 Scope of the Study

The scope of the study entailed developing a "cradle-to-gate" life cycle assessment for the four main products of the US metal buildings industry on a production weighted average basis for the reference production year 2019.

4.1 Declared Unit

The declared unit is defined as the quantity of a construction product for use as a reference unit in an EPD based on LCA for the expression of environmental information in information modules [1]. Table 5 shows the declared unit for primary and secondary frames and metal wall and roof panels.

Table 5 Declared Unit

MBMA Product	Name	Quantity	Units
Primary Structural Steel Frame Components	Declared unit	1	metric ton
	Density	7,833	kg/m^3
Secondary Structural Steel Frame	Declared unit	1	metric ton
	Density	7,833	kg/m^3
Roll Formed Metal Wall Panels	Declared unit	100	m^2
	Density	417	$kg/100\ m^2$
Roll Formed Metal Roof Panels	Declared unit	100	m^2
	Density	473	$kg/100\ m^2$

4.2 System Boundary

For this Project Report, the boundary is "cradle-to-gate", which is limited to the *Production stage* (modules A1 to A3) as depicted in Figure 2. Downstream activity stages - *Construction, Use, End-of-life*, and Optional supplementary information beyond the system boundary (Module D) - are excluded from the system boundary (see Figure 2). Per ISO 21930, 7.1.7.2.1 [1], the system boundary with nature includes those technical processes that provide the material and energy inputs into the system and the subsequent manufacturing and transport processes up to the facility gate, as well as the processing of any waste arising from those processes.

Figures 3 to 6 depict the four "cradle-to-gate" system boundaries for the selected product manufacturing systems: primary frames, secondary frames, metal wall and roof panels.

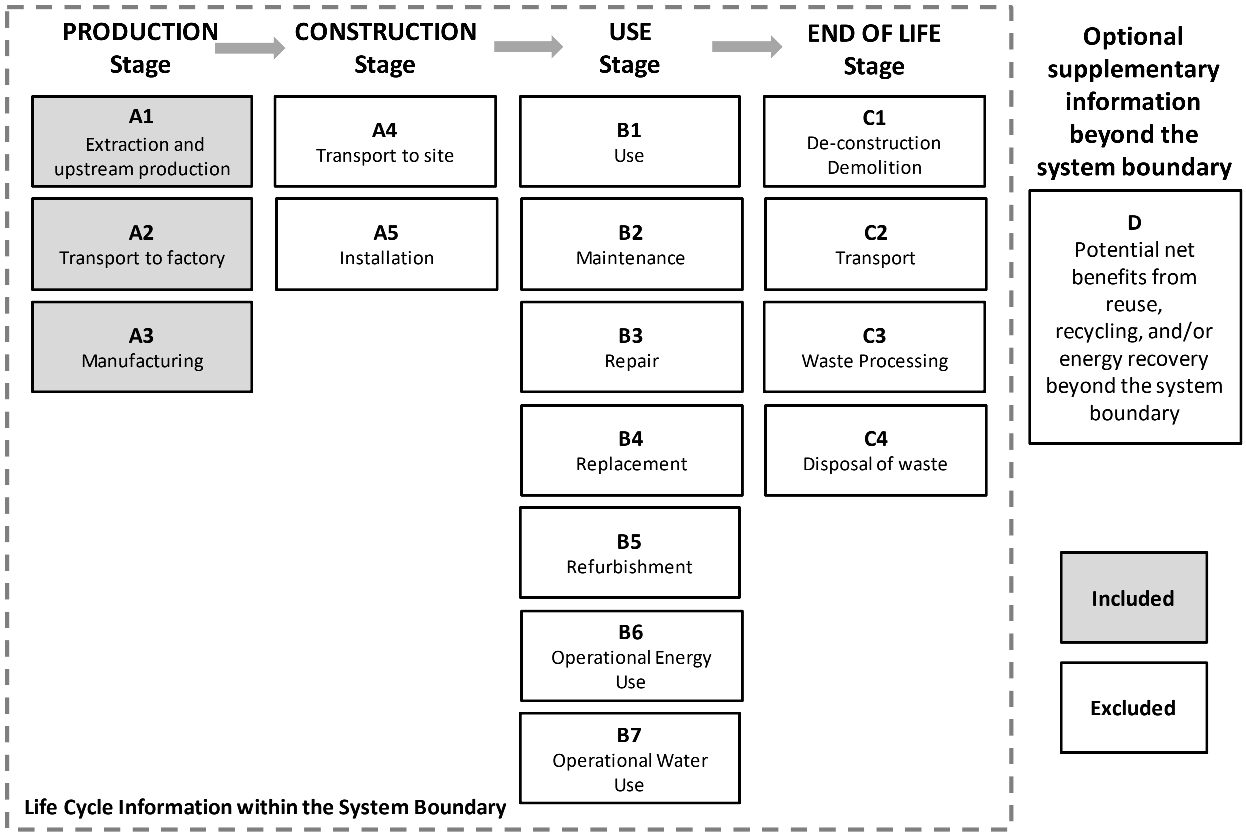

Figure 2 Common four life cycle stages and their information modules for construction products and the optional supplementary module [1]

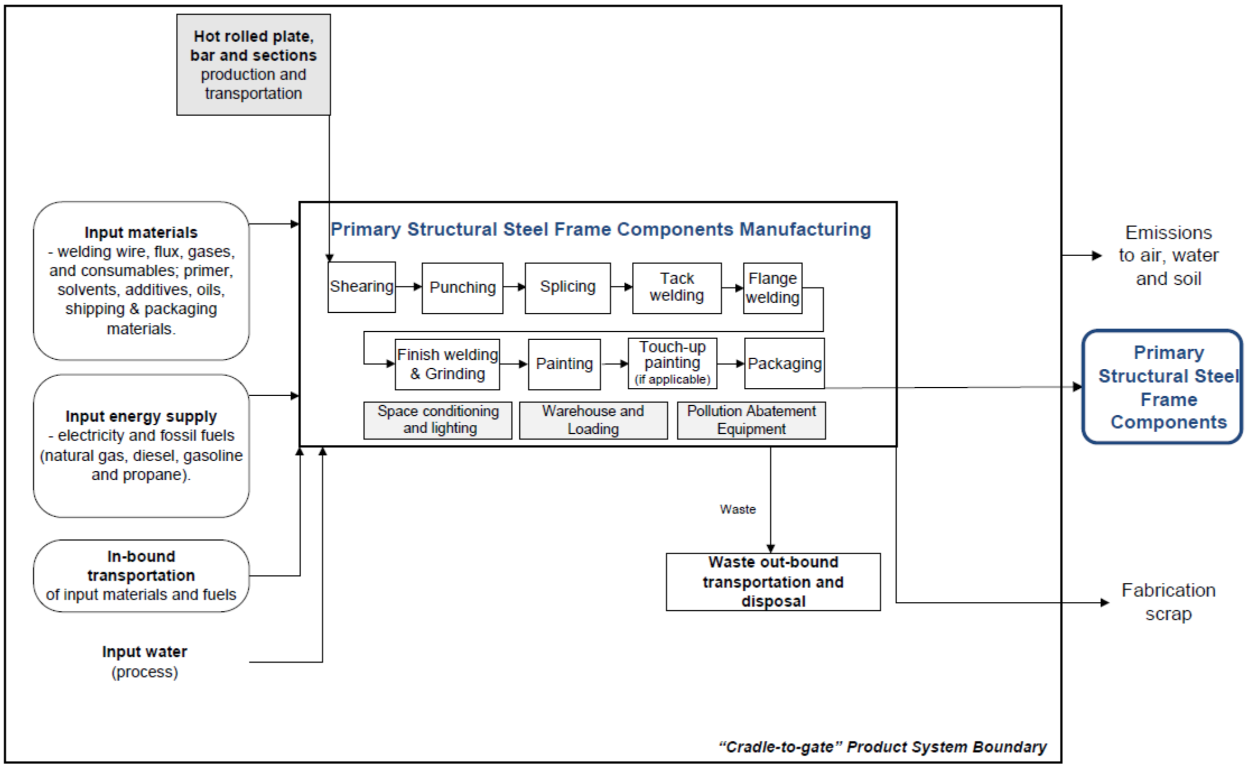

Figure 3 ***"Cradle-to-Gate" System Boundary for Primary Frames***

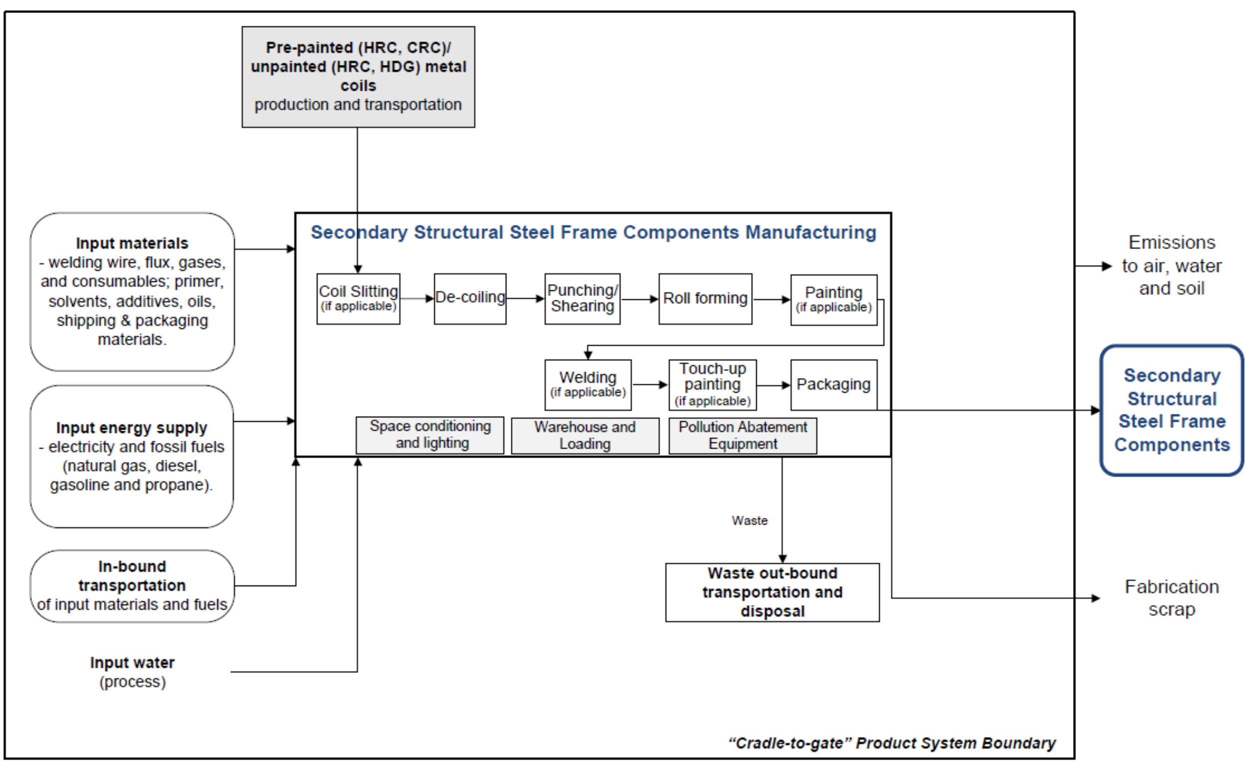

Figure 4 ***"Cradle-to-Gate" System Boundary for Secondary Frames***

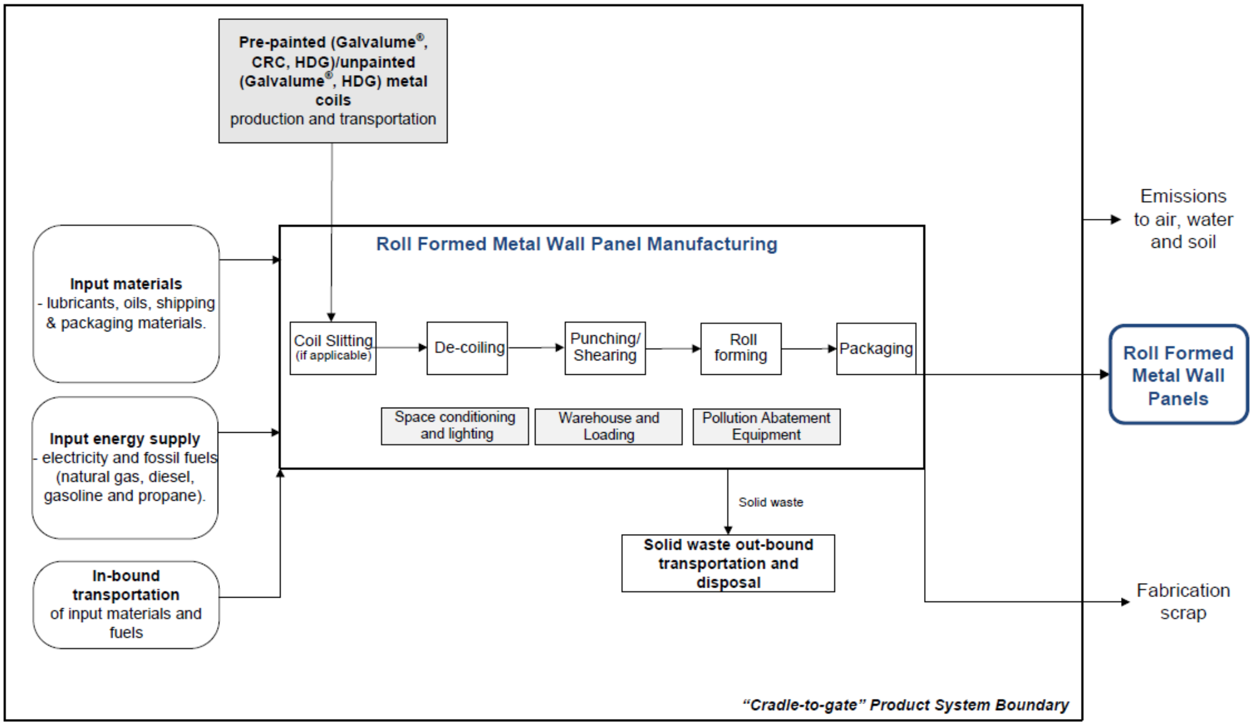

Figure 5 ***"Cradle-to-Gate" System Boundary for Wall Panels***

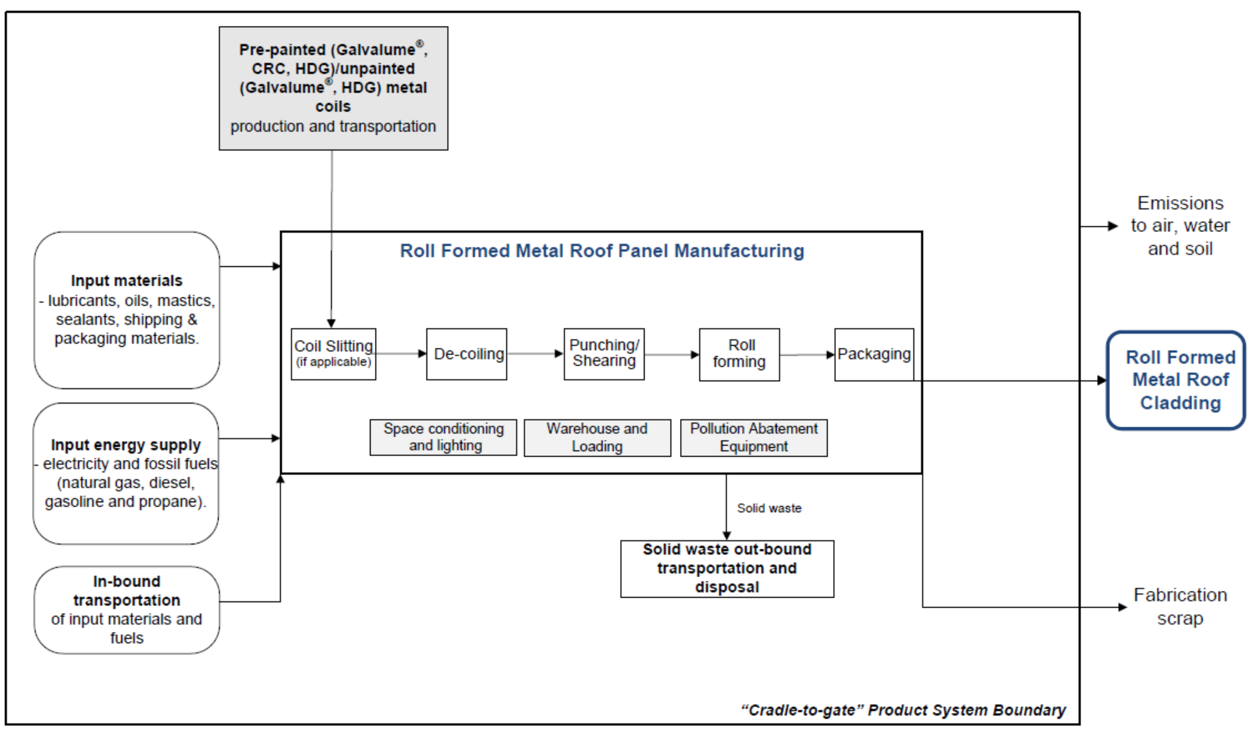

Figure 6 ***"Cradle-to-Gate" System Boundary for Roof Panels***

Per ISO 21930, Section 7.1.7.2 [1], *the* ***Production Stage*** includes the following processes:

A1, Extraction and upstream production

This information module includes:

— A1, cradle-to-gate production of semi-finished steel products;

— A1, reuse of products or materials from a previous product system- not applicable;

— A1, treatment of secondary materials used as input for manufacturing the product, but not including those processes that are part of the waste processing in the previous product system- not applicable;

— A1, cradle-to-gate generation of electricity and heat used for extraction and upstream production;

— A1, cradle-to-gate process fuel supply (diesel, gasoline, propane, fuel oil) used for extraction and upstream production, including on-site fuel combustion;

— A1, waste management from extraction and upstream production including transport up to the disposal.

A2, Transport to factory

This information module includes weighted average transportation data of all input materials and products to the facility, and including empty backhauls and transportation to interim distribution centers or terminals.

A3, Manufacturing

This information module includes:

— A3, cradle-to-gate production of *shipping and packaging materials*;

— A3, cradle-to-gate production of *ancillary materials* (welding wire, welding consumables, welding flux core, primer, solvent, additive, touch up paint, argon-, oxygen-, carbon dioxide-, nitrogen-, acetylene-, propylene- cutting gases; tube grease and hydraulic oil; gear and motor oils, machining lubricants, mastics, and sealants);

— A3, cradle-to-gate generation of *electricity, and heat* used in manufacturing;

— A3, cradle-to-gate *fuel supply for mobile plant support equipment* (diesel, gasoline, and propane) used in manufacturing, including on-site fuel combustion;

— A3, manufacturing of MBMA products and co-products;

— A3, any on-site internal scrap grinding (if applicable);

— A3, waste management from manufacturing packaging and manufacturing wastage including weighted average transportation data up to the recycler or disposal.

No energy recovered from secondary fuels and/or waste combustion is used in MBMA manufacturing facilities.

4.3 Cut-off Criteria

The cut-off criteria as per ULE PCR, Part A [4] and ISO 21930, 7.1.8 [1] were followed for this Project Report. Per ISO 21930, 7.1.8 [1], all input/output data required were collected and included in the LCI modelling (see Annexes A and B). All known mass and energy flows are reported. No known flows are deliberately excluded. No substances with hazardous and toxic properties that pose a concern for human health and/or the environment were identified in the framework of this EPD. Any plant specific data gaps for the reference year 2019 e.g., input hydraulic fluids, lubricants, greases, or motor oil, were filled in with plant generic data from previous years or industry average data.

This LCA report and the resulting EPDs e*xcludes* the following processes:

- Capital goods and infrastructure flows' contributions are less than 10%, and therefore have been excluded from the product system boundary.
- Personnel related activity (travel, furniture, office operations and supplies).

4.4 LCA Software

The LCA model was developed using SimaPro v.9.1.1.1 2020 (https://simapro.com/), an LCA software used by industry and academics in more than 80 countries for 25 years [10]. SimaPro LCA software contains recognized databases (e.g., U.S. LCI database and ecoinvent v3.6 database, Allocation, Cut-off by classification) that provide LCI datasets for upstream, core, and downstream material and processes. It also contains the U.S. EPA TRACI 2.1 LCIA methodology and the Cumulative Energy Demand, LHV version 1.0 which are used for this LCA study.

5 Life Cycle Inventory

5.1 Data Collection, Representativeness, Sources, and Calculations

Primary gate-to-gate LCI manufacturing and input/output transportation data were collected for primary and secondary structural steel frame components as well as roll formed metal wall and roof panels for the reference year 2019. These data were collected from 14 MBMA member facilities from three discrete regions (East, Midwest and Western US), to represent the US industry average geographic mix. These 14 plants were deemed representative of the specific processes and the MBMA's membership. The MBMA represents 41 different production facilities; as a result, the plant sample represents about 25% of all establishments. The 14 plants were combined on a production weighted basis to provide a weighted average profile for US production of each product of interest.

LCI data collection was based on one customized LCI survey for the MBMA manufacturing facilities. The LCI survey covered the following *primary data* for each facility for the 2019 reference year:

- Total manufactured products, and co-products (by-products);

- Main unit processes;
- Excluded processes;
- Pollution abatement equipment;
- Raw materials;
- Secondary materials (if applicable);
- Pre- and post-consumer materials (if applicable);
- Ancillary materials;
- Packaging materials;
- Electricity and fuel consumption;
- Water consumption (fresh and recycled);
- Inbound transportation distances and modes for all inputs;
- Emissions to air, water and land (if applicable);
- Solid waste;
- Wastewater and other liquid waste;
- Waste outputs and their respective outbound transportation distances and modes.

Source of data is specified as (see Annex A, Tables A1 to A4):
Direct (D) *based on measurements or purchasing/selling records of the surveyed facilities*;
Indirect (I) *based on calculations made by the personnel of the surveyed facilities*;
Estimated (E) *based on the industry average data and/or expert judgment*.

Annex A, Tables A1 to A4 summarizes the weighted average LCI data for the four product systems including the source of data. Annex A, Tables A5 to A8 show the transportation modes and weighted average distance (in tkm) for all inputs and outputs per each product system. Transportation activities are included consistently in the respective life cycle modules. Trucking is the primary mode of transport for all input/output flows followed by rail transport.

All facility specific LCI data were weighted based on total annual production to calculate the weighted average LCI profile for each product system of interest (per metric ton) - see Annex A, Table A10 for weighting methodology. All LCI data (including meta-data) were verified and benchmarked with 2012 plant specific and/or MBMA industry average LCI data for each product system by the Athena Institute. Note that the [minimum; maximum] range data are also calculated for each LCI flow (but not reported due to confidentiality reasons) to facilitate Monte Carlo uncertainty analysis (see Annex D).

This LCA study draws on appropriate LCI datasets provided by (see Annexes A and B):

- MBMA and its members manufacturing of metal building components (see Annex A, Tables A1 to A4); and
- North American and global LCI databases such as the U.S. National Renewable Energy Laboratory LCI database, September 2015 (http://www.nrel.gov/lci/), and ecoinvent 3.6,

allocation, cut-off database, Dec 2019 (http://www.ecoinvent.org/). Both are included in the LCA software SimaPro v.9.1.1.1 2021.

- Semi-finished steel products are integral commodities used in the production of the MBMA metal building products. This project draws on the most recent North American peer-reviewed “cradle-to-gate” LCI data, provided by American Iron and Steel Institute (AISI) in December 2020. 2019 North American semi-finished steel LCI data were provided confidentially by the AISI to support this EPD project. Based on these data, the Institute calculated some additional ISO 21930:2017 reporting metrics not summarized in the information provided by AISI.

Data calculation procedures follow ISO 14044 [3], and ULE PCR [4], [5], [6]. The same calculation procedures are applied throughout this LCA study. Per ISO 21930, 7.2.2 [1], when transforming the inputs and outputs of combustible material into inputs and outputs of energy, the *net calorific value* (*lower heating value*) of fuels is applied according to scientifically based and accepted values specific to the combustible material. SI units are used for the LCA data and results.

5.2 Data Quality Requirements and Assessments

Per UL PCR [4], [5], and [6], and ISO 21930, 7.1.9 [1], appropriate activity and LCI primary and secondary data shall be used to model the metal building product systems. LCI data should be as representative (technologically, geographically, and time-specific), complete, consistent, reproducible and transparent as possible with regards to the goal and scope of the study [2], [3]. A detailed description of collected data and the data quality assessment regarding the ULE PCR requirements [4] and ISO 14044 [3] is provided in Annex B. Data quality is assessed based on its representativeness (technology coverage, geographic coverage, time coverage). completeness, consistency, reproducibility, transparency, and uncertainty (see Table 6).

Table 6 Data Quality Requirements and Assessments

Data Quality Requirements	Description
Technology Coverage	Data represents the prevailing technology in use in US. Whenever available, for all upstream and core material and processes, North American typical or average industry LCI datasets were utilized (see Annex B). *Technological representativeness is characterized as “high”.*
Geographic Coverage	The geographic region considered is US. The geographic coverage of all LCI databases and datasets is given in Annex B. *Geographical representativeness is characterized as "high".*

Data Quality Requirements	Description
Time Coverage	Activity data are representative as of 2019 (see Annex A). - metal building system manufacturing process- primary data collected from 14 facilities: reference year 2019 (12 months); - In-bound/ out-bound transportation data- primary data collected from 14 facilities: reference year 2019 (12 months); - Background semi-finished steel LCI/LCIA provided by AISI (reference year 2019); - Generic data: the most appropriate LCI datasets were used as found in the US LCI Database, ecoinvent v.3.6 database, Dec 2019. *Temporal representativeness is characterized as "medium" to "high".*
Completeness	All relevant, specific processes, including inputs (raw materials, energy and ancillary materials) and outputs (emissions and production volume) were considered and modeled to provide an industry average for each of the product systems. The relevant background materials and processes were taken from the AISI semi-finished steel data, US industry data for metal coil painting process, US industry data for Galvalume® coating process, US LCI Database, ecoinvent v 3.6 LCI database for US, and modeled in SimaPro software v.9.1.1.1, 2019 (see Annex B). The completeness of the cradle-to-gate process chain in terms of process steps is rigorously assessed for all four products of interest and documented in Section 4.2. Crosschecks concerning the completeness and plausibility of input and output flows were continuously conducted. The LCA team conducted mass and energy balances at the facility level and product levels, stoichiometry checks, as well as benchmarking at the company and industry average level. Whenever data gaps, outliers, or other inconsistencies were identified, Athena engaged with the data provider to clarify and/or resolve any open issues.
Consistency	To ensure consistency, the LCI modeling of the production weighted input and output LCI data for each metal building product component used the same LCI modeling structure across the participating MBMA member facilities, which consisted of input raw, secondary, ancillary and packaging materials, intermediate products, energy flows, water resource inputs, product outputs, co-products, by-products, emissions to air, water and soil, and solid and liquid waste disposal (if applicable).
Reproducibility	Internal reproducibility is possible since the data and the models are stored and available in *Athena MBMA LCI database* developed in SimaPro, 2021. A high level of transparency is provided throughout the report as the weighted average LCI profile is presented for each of the declared products as well as major upstream inputs. Key primary (manufacturer specific) and secondary (generic) LCI data sources are summarized in Annex B. External reproducibility is also possible as a high level of transparency is provided throughout the Project Report and LCI data and sources are summarized in Annexes A and B.
Transparency	Activity and LCI datasets are transparently disclosed in the project report, including data sources (see Annexes A and B).

Data Quality Requirements	**Description**
Uncertainty	A *sensitivity check* was conducted to assess the reliability of the EPD results and conclusions by determining how they are affected by uncertainties in the data or assumptions on calculation of LCIA and energy indicator results. The sensitivity check includes the results of the *sensitivity analysis* (see Annex C) and *Monte Carlo uncertainty analysis* (see Section 7 and Annex D).

5.3 Allocation Rules

Per ULE PCR, Part A [4], *allocation, if required, shall follow the requirements and guidance of ISO 14044:2006, Section 4.3.4 and ISO 21930, Section 7.2.4 and 7.2.5.*

Per ISO 21930, 7.2.4, *Consistent allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration. For example, the approaches of allocation to co-products or to secondary materials crossing the system boundary between product systems should use the same procedure used for co-products or to secondary material flows entering the product system.*

MBMA manufacturing facilities produce all four metal building system components of interest as well as other co-products (e.g., clips for primary frames, secondary frames, and roof panels; closures for roof panels; building trim parts- trim and roof flashings, cable bracing and other miscellaneous items) and as such allocation was necessary. “Mass” was deemed the most appropriate physical parameter for allocation of the selected inputs/outputs of the plant production system between primary frames, secondary frames, and roof and wall panel manufacturing lines (and other co-products where applicable). On average, the mass contribution of all co-products was less than 5%. The Data collection participants provided input and output data specific to each of four selected manufacturing lines. Then inputs/outputs were allocated over the total outputs of panels or framing on a mass basis. LCI modeling accounts for the plant specific fabrication yields in accordance with ISO 14044, 4.3.4.2, “*Some outputs may be partly co-products and partly waste. In such cases, it is necessary to identify the ratio between co-products and waste since the inputs and outputs shall be allocated to the co-products part only*”.

Semi-finished steel products are integral commodities used in the production of upstream and the primary MBMA metal building products. As a result, 2020 peer-reviewed North American LCI data, according to the ISO 14040 series for these metal products, as generated by the American Iron and Steel Institute were applied in this LCA study. Semi finished steel product LCIA results and LCI data based on physical allocation approach are used. The physical allocation approach follows the partitioning methodology developed by worldsteel [16]. It is also noted that no burden or credit is allocated to the fabrication scrap (burden free) for the four selected product system. In addition, allocation related to transport is based on the mass of transported inputs and outputs.

6 Life Cycle Impact Assessment

6.1 Impact assessment indicators describing main environmental impacts derived from LCA

Per ULE Part A PCR [4], the following impact assessment indicators are reported as described in Table 7.

Table 7 LCIA category indicators

Impact category	Category indicator	Unit (per Declared Unit)	Source of the characterization method	Level of site specificity selected	Environ-mental media
Climate change	Global warming potential (GWP 100)[1)]	kg CO_2 – equiv.	TRACI 2.1, July 2012 /IPCC 2013, AR5[1)]	Global	Air
Ozone depletion	Depletion potential of the stratospheric	kg CFC-11 equiv.	TRACI 2.1, July 2012/WMO:2003	Global	Air
Acidification	Acidification potential (AP)	kg SO_2 equiv.	TRACI 2.1, July 2012	North America	Air, Water
Eutrophication	Eutrophication potential (EP)	kg N equiv.	TRACI 2.1, July 2012	North America	Air, Water
Smog	Smog formation potential (SFP)	kg O_3 equiv.	TRACI 2.1, July 2012	North America	Air
Abiotic depletion potential,elements	Abiotic depletion potential,elements ADPelements	kg Sb eq	CML-baseline, v4.7 August 2016	Global	Resource use
Abiotic depletion potential, fossil	Abiotic depletion potential, fossil ADP_f	MJ, LHV	CML-baseline, v4.7 August 2016	Global	Resource use

Note:
[1)] 100-year time horizon GWP factors (also known as GWP 100a) are provided by the IPCC 2013 Fifth Assessment Report (AR5). GWP 100 indicator results *exclude* biogenic CO_2 removal and emissions associated with any biobased products.

6.2 Inventory indicators describing resource use, waste categories and output flows

Per ULE Part A PCR A [4], the following mandatory resource use, waste categories and output flows are reported as described in Table 8.

Table 8 Parameters describing resource use, waste categories and output Flows

Parameter	Unit (per Declared unit)
Resource Use	
RPR_E: Renewable primary resources used as energy carrier (fuel)	MJ, LHV
RPR_M: Renewable primary resources with energy content used as material	MJ, LHV
$NRPR_E$: Non-renewable primary resources used as an energy carrier (fuel)	MJ, LHV
$NRPR_M$: Non-renewable primary resources with energy content used as material	MJ, LHV
SM: Secondary materials	kg
RSF: Renewable secondary fuels	MJ, LHV
NRSF: Non-renewable secondary fuels	MJ, LHV
RE: Recovered energy	MJ, LHV
FW: Consumption of freshwater	m^3
Waste Categories	
HWD: Hazardous waste disposed	kg
NHWD: Non-hazardous waste disposed	kg
HLRW: High level radioactive waste, conditioned, to final repository	m^3
ILLRW: Intermediate and low level radioactive waste, conditioned, to final	m^3
Output Flows	
CRU: Components for re-use	kg
MR: Materials for recycling	kg
MER: Materials for energy recovery	kg
EE: Exported energy	MJ, LHV

6.3 LCA results for EPD

This section summarizes the life cycle impact assessment (LCIA) results including resource use and waste generated metrics based on the cradle-to-gate life cycle inventory inputs and outputs analysis (Tables 9 to 12). This LCA supports several metrics related to resource consumption and waste generation. These data are informational as they do not provide a measure of impact on the environment. *It should be noted that LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks [2], [3].*

In addition, comparisons cannot be made between product-specific or industry average EPDs at the design stage of a project, before a building has been specified. Comparisons may be made between product-specific or industry average EPDs at the time of product purchase when product performance and specifications have been established and serve as a functional unit for comparison. Environmental impact results shall be converted to a functional unit basis before any comparison is attempted.

Any comparison of EPDs shall be subject to the requirements of ISO 21930. EPDs are not comparative assertions and are either not comparable or have limited comparability when they have different system boundaries, are based on different product category rules or are missing relevant environmental impacts. Such comparison can be inaccurate and could lead to erroneous selection of materials or products which are higher-impact, at least in some impact categories.

Table 9 Cradle-to-gate Production stage (A1-A3) EPD Results – 1 metric ton of primary frames

Impact category and inventory indicators	Unit	A1	A2	A3	Total
Global warming potential, GWP 100[1)]	kg CO_2 eq	1,231.2	99.6	137.2	**1,468**
Ozone depletion potential, ODP[1)]	kg CFC-11 eq	3.9E-12	6.8E-07	1.7E-05	**1.8E-05**
Smog formation potential, SFP[1)]	kg O_3 eq	42.4	33.3	9.3	**84.9**
Acidification potential, AP[1)]	kg SO_2 eq	2.8	1.3	0.4	**4.5**
Eutrophication potential, EP[1)]	kg N eq	0.13	0.08	0.61	**0.82**
Abiotic depletion potential, elements, ADP elements[2)]	kg Sb eq	7.9E-03	1.9E-07	9.6E-04	**8.9E-03**
Abiotic depletion potential, fossil ADPf[2)] *	MJ LHV	13,956	1,355	1,773	**17,084**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	893	0	690	**1,583**
Renewable primary resources with energy content used as material, RPR_M[3)]	MJ LHV	0	0	0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	15,662	1,370	2,150	**19,182**
Non-renewable primary resources with energy content used as material, $NRPR_M$[4)]	MJ LHV	0	0	0	**0**
Secondary materials, SM[5)]	kg	974	0	0	**974**
Renewable secondary fuels, RSF[6)]	MJ LHV	0	0	0	**0**
Non-renewable secondary fuels, NRSF[7)]	MJ LHV	0	0	0	**0**
Recovered energy, RE[8)]	MJ LHV	0	0	0	**0**
Consumption of freshwater, FW[9)]	m^3	6.7	0	0.2	**6.7**
Hazardous waste disposed, HWD[10)]	kg	0.001	0	0	**0.136**
Non-hazardous waste disposed, NHWD[11)]	kg	8.7E-04	0.0	2.7	**2.7**
High-level radioactive waste, conditioned, to final repository, HLRW[12)]	m^3	1.5E-07	3.1E-11	2.3E-07	**3.8E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[13)]	m^3	2.7E-04	2.3E-07	4.4E-06	**2.7E-04**
Components for re-use, CRU[14)]	kg	0	0	0	**0**
Materials for recycling, MR[15)]	kg	0.0	0.0	66.4	**66.4**
Materials for energy recovery, MER[16)]	kg	0	0	0	**0**
Recovered energy exported from the product system, EE[17)]	MJ LHV	0	0	0	**0**

Table 10 Cradle-to-gate Production stage (A1-A3) EPD Results – 1 metric ton of secondary steel frames

Impact category and inventory indicators	Unit	A1	A2	A3	Total
Global warming potential, GWP 100[1)]	kg CO_2 eq	1,779.8	62.1	86.8	**1,929**
Ozone depletion potential, ODP[1)]	kg CFC-11 eq	6.2E-06	1.4E-06	1.1E-05	**1.9E-05**
Smog formation potential, SFP[1)]	kg O_3 eq	65.5	20.9	5.5	**91.9**
Acidification potential, AP[1)]	kg SO_2 eq	9.2	0.8	0.2	**10.2**
Eutrophication potential, EP[1)]	kg N eq	0.42	0.05	0.37	**0.84**
Abiotic depletion potential, elements, ADP elements[2)]	kg Sb eq	1.3E-02	3.7E-07	2.3E-04	**1.3E-02**
Abiotic depletion potential, fossil ADPf[2)] *	MJ LHV	20,109	853	1,137	**22,099**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	959	0	635	**1,594**
Renewable primary resources with energy content used as material, RPR_M[3)]	MJ LHV	0	0	0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	21,725	862	1,389	**23,976**
Non-renewable primary resources with energy content used as material, $NRPR_M$[4)]	MJ LHV	0	0	0	**0**
Secondary materials, SM[5)]	kg	473	0	0	**473**
Renewable secondary fuels, RSF[6)]	MJ LHV	0	0	0	**0**
Non-renewable secondary fuels, NRSF[7)]	MJ LHV	0	0	0	**0**
Recovered energy, RE[8)]	MJ LHV	0	0	0	**0**
Consumption of freshwater, FW[9)]	m^3	4.5	0	0.03	**4.5**
Hazardous waste disposed, HWD[10)]	kg	0.690	0.000	0.009	**0.699**
Non-hazardous waste disposed, NHWD[11)]	kg	0.0	0.0	1.9	**1.9**
High-level radioactive waste, conditioned, to final repository, HLRW[12)]	m^3	1.3E-07	6.3E-11	1.5E-07	**2.9E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[13)]	m^3	2.4E-04	4.6E-07	2.9E-06	**2.4E-04**
Components for re-use, CRU[14)]	kg	0	0	0	**0**
Materials for recycling, MR[15)]	kg	11.6	0.0	37.6	**49.2**
Materials for energy recovery, MER[16)]	kg	0	0	0	**0**
Recovered energy exported from the product system, EE[17)]	MJ LHV	0	0	0	**0**

Table 11 Cradle-to-gate Production stage (A1-A3) EPD Results – 100 m^2 (417 kg) of metal wall panels

Impact category and inventory indicators	Unit	A1	A2	A3	Total
Global warming potential, GWP 100[1)]	kg CO_2 eq	1,173.6	29.8	29.6	**1,233**
Ozone depletion potential, ODP[1)]	kg CFC-11 eq	2.1E-05	5.6E-07	3.5E-06	**2.5E-05**
Smog formation potential, SFP[1)]	kg O_3 eq	49.3	10.2	1.61	**61.1**
Acidification potential, AP[1)]	kg SO_2 eq	9.24	0.39	0.09	**9.7**
Eutrophication potential, EP[1)]	kg N eq	1.271	0.024	0.141	**1.44**
Abiotic depletion potential, elements, ADP elements[2)]	kg Sb eq	4.5E-01	1.4E-07	1.0E-04	**4.5E-01**
Abiotic depletion potential, fossil ADPf[2)] *	MJ LHV	12,704	411	371	**13,486**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	990.9	0.0	363.4	**1,354**
Renewable primary resources with energy content used as material, RPR_M[3)]	MJ LHV	0	0	0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	13,819	415	465	**14,699**
Non-renewable primary resources with energy content used as material, $NRPR_M$[4)]	MJ LHV	0	0	0	**0**
Secondary materials, SM[5)]	kg	159	0	0	**159**
Renewable secondary fuels, RSF[6)]	MJ LHV	0	0	0	**0**
Non-renewable secondary fuels, NRSF[7)]	MJ LHV	0	0	0	**0**
Recovered energy, RE[8)]	MJ LHV	0	0	0	**0**
Consumption of freshwater, FW[9)]	m^3	2.1	0.0	0.0	**2.1**
Hazardous waste disposed, HWD[10)]	kg	1	0	0	**0.646**
Non-hazardous waste disposed, NHWD[11)]	kg	0.00	0.00	0.45	**0.5**
High-level radioactive waste, conditioned, to final repository, HLRW[12)]	m^3	6.3E-08	2.7E-11	5.8E-08	**1.2E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[13)]	m^3	1.1E-04	1.9E-07	1.0E-06	**1.2E-04**
Components for re-use, CRU[14)]	kg	0	0	0	**0**
Materials for recycling, MR[15)]	kg	16.1	0.0	25.6	**41.7**
Materials for energy recovery, MER[16)]	kg	0	0	0	**0**
Recovered energy exported from the product system, EE[17)]	MJ LHV	0	0	0	**0**

Table 12 Cradle-to-gate Production stage (A1-A3) EPD Results – 100 m² (473 kg) of metal roof panels

Impact category and inventory indicators	Unit	A1	A2	A3	Total
Global warming potential, GWP 100[1)]	kg CO_2 eq	1,260.3	31.4	34.6	**1,326**
Ozone depletion potential, ODP[1)]	kg CFC-11 eq	2.4E-05	4.3E-07	5.1E-06	**2.9E-05**
Smog formation potential, SFP[1)]	kg O_3 eq	54.0	10.5	1.85	**66.4**
Acidification potential, AP[1)]	kg SO_2 eq	4.57	0.41	0.11	**5.1**
Eutrophication potential, EP[1)]	kg N eq	1.500	0.025	0.154	**1.68**
Abiotic depletion potential, elements, ADP elements[2)]	kg Sb eq	6.0E-01	1.1E-07	9.9E-05	**6.0E-01**
Abiotic depletion potential, fossil ADPf[2)] *	MJ LHV	13,615	422	544	**14,580**
Renewable primary resources used as an energy carrier (fuel), RPR_E	MJ LHV	1,111.5	0.0	367.4	**1,479**
Renewable primary resources with energy content used as material, RPR_M[3)]	MJ LHV	0	0	0	**0**
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$	MJ LHV	14,744	426	648	**15,819**
Non-renewable primary resources with energy content used as material, $NRPR_M$[4)]	MJ LHV	0	0	0	**0**
Secondary materials, SM[5)]	kg	172	0	0	**172**
Renewable secondary fuels, RSF[6)]	MJ LHV	0	0	0	**0**
Non-renewable secondary fuels, NRSF[7)]	MJ LHV	0	0	0	**0**
Recovered energy, RE[8)]	MJ LHV	0	0	0	**0**
Consumption of freshwater, FW[9)]	m^3	2.3	0.0	0.0	**2.3**
Hazardous waste disposed, HWD[10)]	kg	0	0	0	**0.346**
Non-hazardous waste disposed, NHWD[11)]	kg	0.00	0.00	0.42	**0.4**
High-level radioactive waste, conditioned, to final repository, HLRW[12)]	m^3	6.4E-08	2.1E-11	6.3E-08	**1.3E-07**
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW[13)]	m^3	1.2E-04	1.5E-07	1.5E-06	**1.2E-04**
Components for re-use, CRU[14)]	kg	0	0	0	**0**
Materials for recycling, MR[15)]	kg	12.8	0.0	16.0	**28.8**
Materials for energy recovery, MER[16)]	kg	0	0	0	**0**
Recovered energy exported from the product system, EE[17)]	MJ LHV	0	0	0	**0**

Notes to Tables 9 to 12:
1) Calculated as per U.S EPA TRACI 2.1, v1.05, SimaPro v 9.1.1.1 [10].
GWP 100, excludes biogenic CO_2 removals and emissions associated with any biobased products; 100-year time horizon GWP factors are provided by the IPCC 2013 Fifth Assessment Report (AR5).
2) Calculated as per CML-IA Baseline V3.05, SimaPro v 9.1.1.1 [10]. ADP_f is also required in LEED V4.1 MR Credit: Building Product Disclosure and Optimization – Environmental Product Declarations [13].
3) Calculated as per ACLCA ISO 21930 Guidance [11], 6.2 *Renewable primary resources with energy content used as a material, RPR_M*. N/A for this product system.
4) Calculated as per ACLCA ISO 21930 Guidance [11], 6.4 *Non-renewable primary resources with energy content used as a material, $NRPR_M$*.
5) Calculated as per ACLCA ISO 21930 Guidance [11], 6.5 Secondary materials, SM; it includes iron and steel scrap used in the production of semi finished steel products (A1).
6) Calculated as per ACLCA ISO 21930 Guidance [11], 6.6 *Renewable secondary fuels, RSF*. N/A for this product system.
7) Calculated as per ACLCA ISO 21930 Guidance [11], 6.7 *Non-renewable secondary fuels, NRSF.* N/A for this product system.
8) Calculated as per ACLCA ISO 21930 Guidance [11], 6.8 *Recovered energy, RE*. N/A for this product system.
9) Calculated as per ACLCA ISO 21930 Guidance [11], 9 *Inventory indicators describing consumption of freshwater*.
10) Calculated as per ACLCA ISO 21930 Guidance [11], 10.1 *Hazardous waste disposed*.
11) Calculated as per ACLCA ISO 21930 Guidance [11], 10.2 *Non-hazardous waste disposed*.
12) Calculated as per ACLCA ISO 21930 Guidance [11], 10.3 *High-level radioactive waste, conditioned, to final repository*. It should be noted that the foreground system (MBMA manufacturing processes) do not generate any HLRW. High-level radioactive waste, e.g., when generated by electricity production, consists mostly of spent fuel from reactors." (ISO 21930:2017, clause 7.2.14).
13) Calculated as per ACLCA ISO 21930 Guidance [11], 10.4 *Intermediate- and low-level radioactive waste, conditioned, to final repository*. It should be noted that the foreground system (MBMA manufacturing processes) do not generate any ILLRW. Low- and intermediate-level radioactive wastes, e.g., when generated by electricity production, arise mainly from routine facility maintenance and operations (ISO 21930:2017, clause 7.2.14).
14) Calculated as per ACLCA ISO 21930 Guidance [11], 10.5 *Components for re-use*. N/A for this product system.
15) Calculated as per ACLCA ISO 21930 Guidance [11], 10.6 *Materials for recycling*, i.e. fabrication scrap and slag from flux (A3) used in the next product system.
16) Calculated as per ACLCA ISO 21930 Guidance [121, 10.7 *Materials for energy recovery*, i.e. secondary fuels used in the next product system. N/A for this product system.
17) Calculated as per ACLCA ISO 21930 Guidance [11], 10.8 *Recovered energy exported from the system*. N/A for this product system.
18) Note that data may not add up to totals due to rounding.
19) EPD results are rounded to an appropriate number of significant digits (2 to 4).

7 Interpretation

Interpretation is the phase of LCA in which the findings from the inventory analysis and the impact assessment are brought together and significant issues are identified and considered in the context of the *study goal and scope* [1]. In addition, the study's completeness, consistency of all applied information, and sensitivity to key assumptions or parameters as they relate *to the goal and scope of the study* are evaluated. Lastly, the interpretation phase ends by drawing conclusions, stating the study's limitations, and making recommendations [3].

7.1 Identification of the Significant Issues

ISO 14044 recommends several possible methods to identify significant issues in an LCA study. Based on established LCA practices, the following analytical techniques were applied for the interpretation phase of this LCA study [3]:

- *Contribution Analysis*, in which the contribution of *information modules* and *processes* to the cradle-to-gate EPD results are examined;
- *Dominance Analysis*, in which *significant* contributions are examined.

Figures 7 to 10 present the impact assessment and energy indicator results for 1 metric ton of primary and secondary frames and 100 m^2 of wall and roof panels, by *information module*, percent contribution basis, respectively. These cradle-to-gate product profiles represent the environmental impacts associated with the extraction of raw materials and energy sources from the earth (cradle) through to the manufacture of the declared unit of each product ready for shipment at the plant (gate).

A contribution analysis revealed that the *Manufacturing* module (A3) generally accounted for 5% to 14% of the total primary energy use and 2% to 9% of the global warming potential (GWP) of the total cradle-to-gate product system. Upstream steel production (A1) is the single and most significant input driving the potential environmental burden of all four products. *Manufacturing* module A3 is the second largest contributor to the Production stage EPD results, followed by the *Transportation* module A2.

Given the special interest of the MBMA members on the cradle-to gate GWP results, a process contribution analysis was conducted to examine the contribution of individual cradle-to-gate processes to the *Production stag*e GWP (in kg CO_2 eq.) of 1 metric ton of frames and 100 m^2 of panels. Table 13 shows that the top four contributors of the MBMA products are, in descending order, semi finished steel production, inbound truck transportation of semi finished steel inputs and electricity use and natural gas processing and combustion at MBMA facility sites.

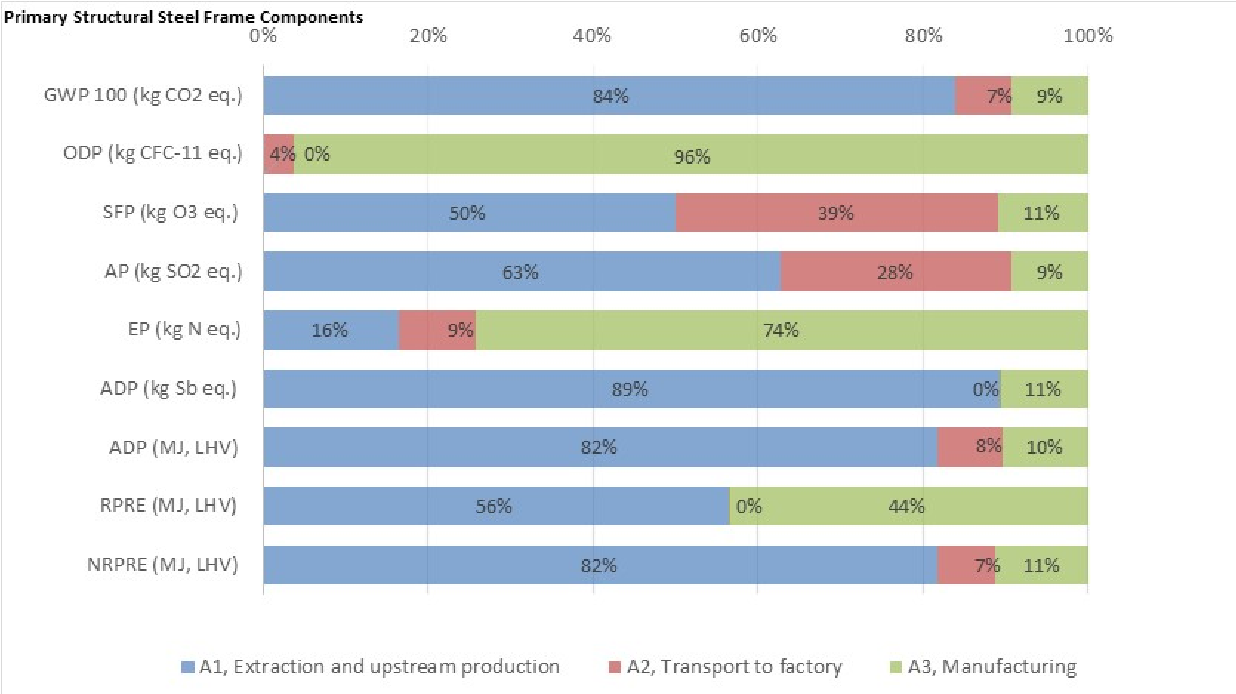

Figure 7 Impact assessment and energy indicator results by stage – 1 metric ton of primary frame – % Basis

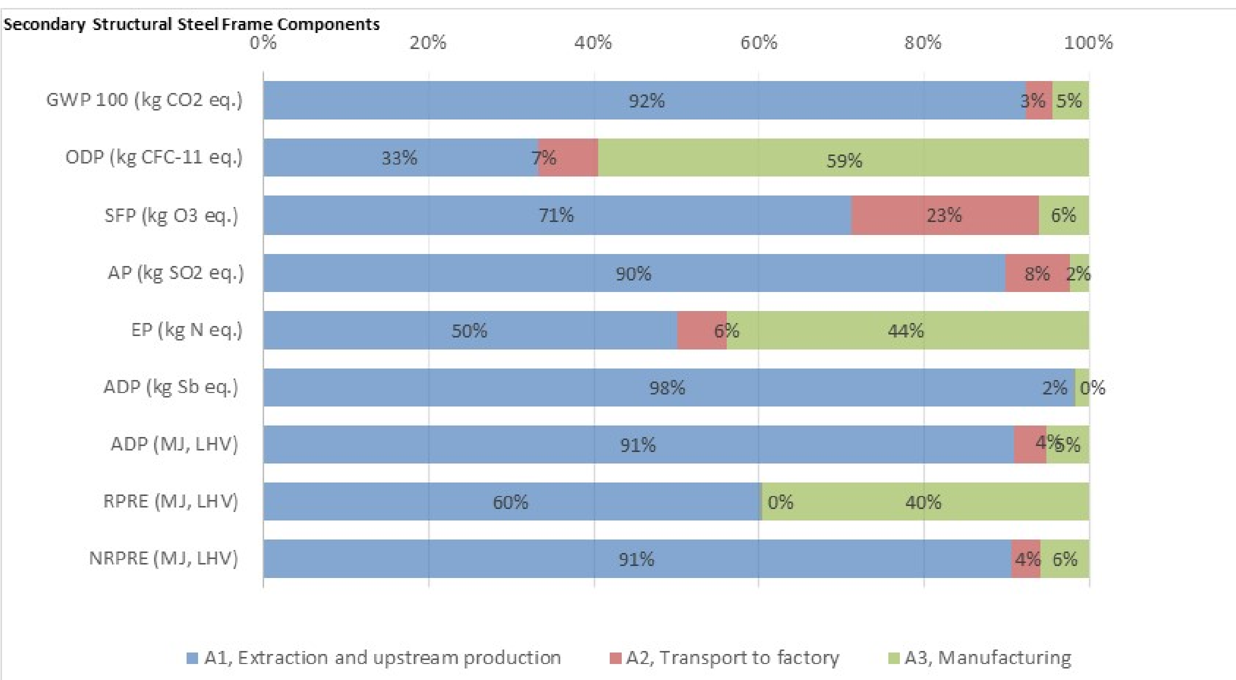

Figure 8 Impact assessment and energy indicator results by stage – 1 metric ton of secondary frame – % Basis

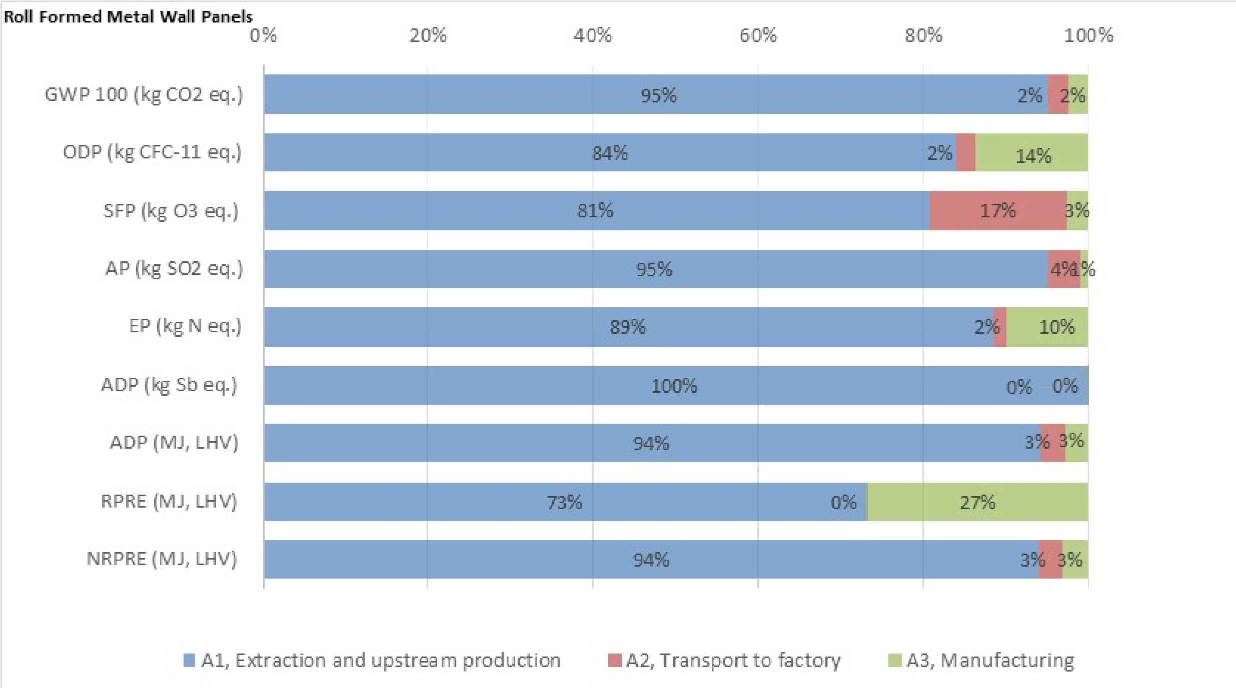

Figure 9 Impact assessment and energy indicator results by stage – 100 m² of wall panels – % Basis

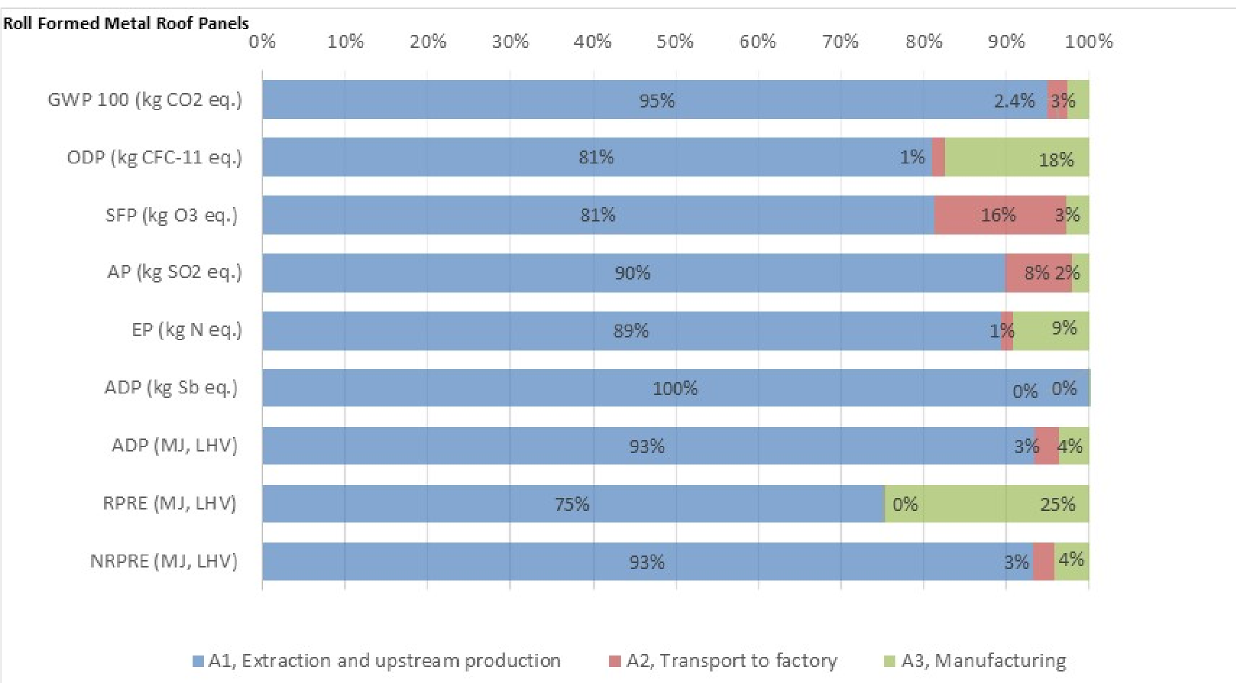

Figure 10 Impact assessment and energy indicator results by stage – 100 m² of roof panels – % Basis

Table 13 Top 4 significant processes contributing to cradle-to-gate Product Stage (A1-A3), GWP Results of four MBMA products

Production Stage	Primary Frames, 1000 kg		Secondary Frames, 1000 kg		Wall Panels, 100 m^2		Roof Panels, 100 m^2	
	kg CO_2 eq.	%	kg CO2 eq.	%	kg CO2 eq.	%	kg CO2 eq.	%
Semi finished steel inputs, A1	1,231	84%	1,780	92%	1,174	95%	1,260	95%
Inbound transportation of semi finished steel inputs, by Truck, A2	86	6%	47	2%	25	2%	25	2%
Electricity use, A3	64	4%	47	2%	17	1%	25	2%
Natural gas processing and combustion, A3	26	2%	20	1%	3	0%	4	0%
Rest of processes, A1 to A3	61	4%	35	2%	14	1%	11	1%
Total	**1,468**	**100%**	**1,929**	**100%**	**1,233**	**100%**	**1,326**	**100%**

7.2 Completeness, Consistency, and Sensitivity Checks

Evaluating the study's completeness, consistency and sensitivity helps to establish and enhance confidence in, and the reliability of, the results of the LCA study, including the significant issues identified in the first element of the interpretation [2].

The objective of the ***completeness check*** is to ensure that all relevant information and data needed for the interpretation are available and complete [2]. Four MBMA product systems were checked for data completeness. All input and output data were found to be complete and no gaps were identified at information modules A1 to A3 (see Tables Annexes A and B).

The objective of the ***consistency check*** is to determine whether the assumptions, methods, models and data are consistent with the goal and scope of the study [2]. Through a rigorous process, consistency was ensured between the four MBMA product systems in terms of calculation rules, methods, models, and data quality, including data source, time-related coverage, technology, and geographical coverage (see Sections 5, and Annex B). Table 6 summarizes the data quality assessment conducted in the framework of this LCA study.

To assess how factors such as *uncertainties in data*, and assumptions would affect the reliability of the results and conclusions, a ***sensitivity check*** was conducted. The sensitivity check includes the results of the *sensitivity analysis* and *uncertainty analysis* [2].

The procedure of ***sensitivity analysis*** is a comparison of the LCA results obtained using certain given assumptions, methods, or data, with the LCA results obtained using altered assumptions, methods, or data [4]. ISO 14044 Clause B.3.3 states: "Sensitivity can be expressed as the *percentage of change* or as the absolute deviation of the results. On this basis, *significant changes* in the results (e.g., larger than 10%) can be identified" [3].

As shown in Annex B, Tables B1, US Electricity grid mix *(Electricity, high voltage {US}| market group for | Cut-off, U) is* used for manufacturing module A3. ecoinvent v3.6 LCI dataset {market for electricity, high voltage} is updated with eGRID 2018 data [15]. This allows for consistent and transparent industry wide comparability and benchmarking of EPDs, while maintaining data confidentiality (MBMA plant specific market share data) and supports all MBMA manufactures to accurately meet the LEED v4 and/or v4.1, MR Credit: Building Product Disclosure and Optimization – Environmental Product Declarations, Option 2 Multi-attribute optimization (1 point) [13], [14].
Scenario analysis was conducted to illustrate the impact of replacing US electricity grid with the *weighted average* electricity grid for all four MBMA products (confidential info). The scenario analysis results are presented in detail in Annex C, Tables C1 and C2 for four declared MBMA products. The positive (+) or negative (-) signs of deviation (in %) depend on the mathematical signs (+/-) of both the value of base case and the deviation of the LCIA and energy indicators. For example, the influence of this scenario to GWP-100 of primary frames compared to the base case is positive (+0.1%); indicating a 0.1% higher GWP-100 compared to the base case. *The scenario analysis indicates that replacing the US generic electricity grid with weighted average LCI profile for electricity grid would insignificantly influence the EPD results (less than 0.1% change) for the LCIA and energy indicators for all four MBMA product systems.*

A ***Monte Carlo uncertainty analysis*** was also conducted to assess the combined uncertainty effect of the data variability on the LCIA and energy indicator results (see Annex D).
Based on the industry sample data, [minimum; maximum] range data was calculated per each input/output flow for the four selected MBMA products. These data are used in the Monte Carlo uncertainty analysis. *This uncertainty analysis assesses the combined uncertainty effect of the inventory data (both foreground and background)* -see Annexes A and B. *It should be noted that U.S. EPA TRACI version 2.1 methodology has not specified any uncertainty information of the characterization factors per impact category*.

As a statistical method to process data uncertainty, Monte Carlo analysis is used to establish the uncertainty range, which expresses the variance between the upper and lower confidence limit [97.5%, 2.5%], in the calculated LCA results (Figures D1 to D4, Annex D). *Based on 1,000 runs, such information provides a quantitative indication of the range of results that are likely for the manufacturer's specific products covered by the industry average EPD for four selected MBMA products*.

7.3 Conclusions, Limitations and Recommendations

Based on the goal and scope of this LCA, life cycle inventory, impact assessment, and interpretation phases, the following ***conclusions*** can be reached:

- Upstream *semi-finished steel inputs* (A1) account for the largest share of the burdens associated with the production of all four metal building system components and hence, the optimized use of these inputs should be a priority for the industry.
- *Inbound transportation of semi finished steel inputs, by Truck* is a significant contributor to the *Transport to factory* stage (A2) burdens across the four metal building system components.
- *Electricity use* (A3) is the largest contributor to the *Manufacturing* stage (A3) burdens across the four metal building system components, making electricity conservation efforts a key consideration for reducing on-site impacts.

LCA addresses *"potential environmental impacts" and does not predict absolute or precise environmental impacts due to (a) the relative expression of potential environmental impacts to a reference unit, (b) the integration of environmental data over space and time, (c) the inherent uncertainty in modeling of environmental impacts, and (d) the fact that some possible environmental impacts are clearly future impacts* [3].

8 Additional Environmental Information

- All 14 MBMA member facilities participating in the study are ISO 9001 and ISO 14001 certified or follow other company specific environmental management systems.

- *Health Protection Manufacture*
  The OSHA standards are applicable and followed.
  - U.S. Department of Labor, Occupational Safety & Health Administration (OSHA),
  29 CFR, PART 1910 Occupational Safety and Health Standards.
  https://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=1910, accessed 03-01-2021.
  No additional health protection measures extending beyond mandatory occupational safety measures for commercial operations are required.

- *No substances of high concern were identified in the framework of this EPD.*

- *Pollution abatement equipment* typically used in the MBMA manufacturing facilities consist of fabric filter– low temperature (baghouse), dry filters and cartridge filters.

9 Declaration Type and Product Average Declaration

The type of EPD based on this *Project Report* is defined as:

- An industry average "*Cradle-to-gate*" EPD of four metal building system components and is intended for use in Business-to-Business communication.

MBMA EPD falls under the description:
- *A production weighted average product EPD, as an average from MBMA member manufacturers' facilities.*

10 Declaration Comparability Limitation Statement

The environmental impact results of steel products in this document are based on a declared unit and therefore do not provide sufficient information to establish comparisons. The results shall not be used for comparisons without knowledge of how the physical properties of the steel product impact the precise function at the construction level. The environmental impact results shall be converted to a functional unit basis before any comparison is attempted.

Environmental declarations from different programs (ISO 14025) may not be comparable.

11 EPD Explanatory Material

For any explanatory material, regarding the MBMA EPD for metal building system components based on this Project Report, please contact:

The Metal Building Manufacturers Association (MBMA)
1300 Sumner Ave.
Cleveland, Ohio 44115-2851
Link (URL): https://www.mbma.com

12 References

1. ISO 21930:2017 Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services.
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4. UL Environment, Part A: Life Cycle Assessment Calculation Rules and Report Requirements, December 2018, version 3.2.
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13. LEED v4.1 July 2019, *Building Design and Construction Guide (BD+C), Getting started guide for beta participant, MR Credit: Building Product Disclosure and Optimization – Environmental Product Declarations, Option 2 Multi-attribute optimization (1 point), pg.170.* https://www.cagbc.org/CAGBC/LEED/LEED%20v4_1/CAGBC/Programs/LEED/LEEDv4/LEED_v4.1.aspx?hkey=36bb5f37-ef20-4ba5-9752-ae640c9de3a2, accessed 03-01-2021.
14. USGBC 2017, PCR Committee Process & Resources- Part B. https://www.usgbc.org/resources/pcr-committee-process-resources-part-b, accessed 03-01-2021.
15. U.S. EPA, Emissions & Generation Resource Integrated Database (eGRID). https://www.epa.gov/egrid, accessed 03-01-2021.
16. worldsteel and EUROFER. (2014). A methodology to determine the LCI of steel industry co-products.

Annex A LCI data for primary and secondary frames and wall and roof panels

Table A.1 Inputs/Outputs for 1 metric tonne (1,000 kg) of Primary Structural Steel Frame Components production

Inputs/Outputs	Per 1 metric tonne		Source of data
	Quantity	**Units**	
Material Input			
Hot Rolled Plate and Sheet	400.8	kg	D
Hot Rolled Flat Bar	464.7	kg	D
Hot Rolled Structural Sections	200.6	kg	D
Solid Welding Wire (MIG Welding)	7.20	kg	D
Welding Consumables	0.14	kg	D
Welding Flux Core (Flux Core Arc Welding)	3.24	kg	D
Primer: water based (avg density=10.7 lb/gal)	4.25	kg	D
Primer: solvent based (avg density=10.7 lb/gal)	2.52	kg	D
Solvent (avg density=7.5 lb/gal)	0.094	kg	D
Additive (avg density=9.4 lb/gal)	0.0052	kg	D
Touch up paint (avg density=11.5 lb/gal)	0.014	kg	D
Argon - shielding gas (0.1034 lb/Scf, standard cubic foot)	2.89	kg	D
Oxygen - shielding gas (0.08281 lb/Scf)	1.13	kg	D
Carbon Dioxide - shielding gas (0.1144 lb/Scf)	0.38	kg	D
Nitrogen - cutting gas (0.07245 lb/Scf)	0.024	kg	D
Acetylene - cutting gas (0.069 lb/Scf)	0.079	kg	D
Propylene - cutting gas	0.0030	kg	D
Tube grease and hydraulic oil; gear and motor oils (avg density=7.2 lb/gal)	0.088	liter	D
Packaging			
Packaging- Dunnage	25.66	kg	E
Packaging- Steel Banding	0.40	kg	E
Nails	0.00	kg	E
Energy Input			
Purchased Electricity	116.2	kWh	D
Natural Gas	10.2	m3	D
Diesel	1.35	liter	D
Liquified Propane Gas (LPG)	1.02	liter	D
Gasoline	0.080	liter	D
Fuel Oil (other than diesel)	0.00024	liter	D

Inputs/Outputs	Per 1 metric tonne		Source of data
	Quantity	Units	
Water Consumption			
Freshwater consumption (or net use)- Process water for painting /E-coating	20.6	liter	I
Discharged water to the sewer	9.2	liter	I,E
Product and By-product Outputs			
Primary Structural Steel Frame Components	1.00	metric tonne	D
Emissions to Air			
Process specific emissions to air (non-combustion)			
Non-Methane VOCs	0.965	kg	D
PM-Filterable (PM-FIL)	0.148	kg	D
PM10-Filterable (PM10-FIL)	0.0112	kg	D
PM2.5-Filterable (PM25-FIL)	1.6E-04	kg	D
Argon	2.89	kg	E
Oxygen	1.13	kg	E
Carbon dioxide	0.65	kg	E
Nitrogen	0.024	kg	E
Acetylene	0	kg	E
Propylene	0	kg	E
Hazardous air pollutant (HAP)	2.5E-02	kg	D
Emissions to Water-N/A			
Solid and Liquid Waste			
Scrap Metal- Recycled	66.1	kg	E
Non-hazardous solid waste- landfill	1.74	kg	D
Slag from flux - recycled	0.34	kg	D
Slag from flux - landfill	0.29	kg	D,E
Plasma/paint waste- landfill	0.66	kg	E
Paint waste- incinerator	0.073	kg	D
Hazardous solid waste- disposal	0.056	kg	D
Packaging Waste- landfill	0.0094	kg	E
Packaging Waste Mix- Recycling	0.23	kg	E
Paper Recycled	0.11	kg	E
Plastic Recycled	0.019	kg	E
Wood Recycled	0.69	kg	E
Waste Oil and Hydraulic Fluid	0.0064	kg	E
Wastewater-n/a			

Notes:
[1)] Data are rounded to an appropriate number of significant digits (2 to 4).
[2)] D, I and E stand for *Direct*, *Indirect* and *Estimated* data, respectively.

Table A.2 Inputs/Outputs for 1 metric tonne (1,000 kg) of Secondary Structural Steel Frame Components production

Inputs/Outputs	**Per 1 metric tonne**		**Source of data**
	Quantity	**Units**	
Material Input			
Hot Rolled Coil	534.7	kg	D
Hot Rolled Coil, Pre-Painted	344.3	kg	D
Cold Rolled Coil, Pre- Painted	73.8	kg	D
Hot-Dip Galvanized	84.79	kg	D
Solid Welding Wire (MIG Welding)	1.03	kg	D
Welding Consumables	0.09	kg	D
Welding Flux Core (Flux Core Arc Welding)	0.10	kg	D
Primer: water based (avg density=10.7 lb/gal)	1.31	kg	D
Primer: solvent based (avg density=10.7 lb/gal)	1.209	kg	D
Solvent (avg density=7.5 lb/gal)	0.0907	kg	D
Additive (avg density=9.4 lb/gal)	0.023	kg	D
Touch up paint (avg density=11.5 lb/gal)	0.01	kg	D
Argon - shielding gas (0.1034 lb/Scf, standard cubic foot)	0.44	kg	D
Oxygen - shielding gas (0.08281 lb/Scf)	0.08	kg	D
Carbon Dioxide - shielding gas (0.1144 lb/Scf)	0.145	kg	D
Nitrogen - cutting gas (0.07245 lb/Scf)	0.000	kg	D
Acetylene - cutting gas (0.069 lb/Scf)	0.0086	kg	D
Propylene - cutting gas	0.000	kg	D
Tube grease and hydraulic oil; gear and motor oils (avg density=7.2 lb/gal)	0.12229	liter	D
Packaging			
Packaging- Dunnage	25.80	kg	E
Packaging- Steel Banding	0.77	kg	E
Energy Input			
Purchased Electricity	84.5	kWh	D
Natural Gas	7.9	m3	D
Diesel	1.36	liter	D
Liquified Propane Gas (LPG)	1.39	liter	D
Gasoline	0.075	liter	D
Fuel Oil (other than diesel)	0.00020	liter	D
Water Consumption			

Inputs/Outputs	Per 1 metric tonne		Source of data
	Quantity	Units	
Freshwater consumption (or net use)- Process water for painting /E-coating	31.3	liter	I
Discharged water to the sewer	34.7	liter	I,E
Product and By-product Outputs			
Secondary Structural Steel Frame Components	1.00	metric tonne	D
Emissions to Air			
Process specific emissions to air (non-combustion)			
Non-Methane VOCs	0.570	kg	D
PM-Filterable (PM-FIL)	0.010	kg	D
PM10-Filterable (PM10-FIL)	0.0002	kg	D
PM2.5-Filterable (PM25-FIL)	3.4E-05	kg	D
Argon	0.44	kg	E
Oxygen	0.08	kg	E
Carbon dioxide	0.17	kg	E
Nitrogen	0.000	kg	E
Acetylene	0	kg	E
Propylene	0	kg	E
Hazardous air pollutant (HAP)	1.5E-02	kg	D
Emissions to Water-N/A			
Solid and Liquid Waste			
Scrap Metal- Recycled	37.6	kg	E
Non-hazardous solid waste- landfill	1.34	kg	D
Slag from flux - landfill	0.04	kg	D,E
Plasma/paint waste- landfill	0.45	kg	E
Hazardous solid waste- disposal	0.00	kg	D
Packaging Waste- landfill	0.009	kg	E
Packaging Waste Mix- Recycling	0.212	kg	E
Paper Recycled	0.0952	kg	E
Plastic Recycled	0.02	kg	E
Wood Recycled	0.68	kg	E
Waste Oil and Hydraulic Fluid	0.005	kg	E
Wastewater-n/a			

Notes:
1) Data are rounded to an appropriate number of significant digits (2 to 4).
2) D, I and E stand for *Direct*, *Indirect* and *Estimated* data, respectively.

Table A.3 Inputs/Outputs for 1 metric tonne (1,000 kg) of Roll Formed Metal Wall Panels production

Inputs/Outputs	**Per 1 metric tonne**		**Source of data**
	Quantity	**Units**	
Material Input			
Cold Rolled Coil, Pre-Painted	15.1	kg	D
Hot-Dip Galvanized, Pre-Painted	198.8	kg	D
Hot-Dip Galvanized	29.8	kg	D
Galvalume, Pre-Painted	722.7	kg	D
Galvalume	95.0	kg	D
Tube grease and hydraulic oil; gear and motor oils (avg density=7.2 lb/gal)	0.047	liter	E
Machining lubricants (avg density=6.6 lb/gal)	0.058	liter	D
Packaging			
Packaging- Dunnage	36.93	kg	D,E
Packaging- Steel Banding	2.37	kg	D,E
Packaging- Nails	0.091	kg	D,E
Packaging- Plastic slip sheets	0.086	kg	E
Packaging- Strippable film	0.048	kg	E
Packaging- Waterproof packing paper	0.18	kg	E
Energy Input			
Purchased Electricity	75.2	kWh	D
Natural Gas	3.16	m3	D
Diesel	1.34	liter	D
Liquified Propane Gas (LPG)	1.56	liter	D
Gasoline	0.077	liter	D
Fuel Oil (other than diesel)	0.00062	liter	D
Water Consumption-n/a			
Product and By-product Outputs			
Roll Formed Metal Wall Panels	1.00	metric tonne	D
Emissions to Air			
Process specific emissions to air (non-combustion)			
Non-Methane VOCs	0.150	kg	D
Emissions to Water-N/A			
Solid and Liquid Waste			
Scrap Metal- Recycled	61.4	kg	E
Non-hazardous solid waste-landfill	1.06	kg	D
Packaging Waste- landfill	0.013	kg	E
Packaging Waste Mix- Recycling	0.35	kg	E
Paper Recycled	0.18	kg	E
Plastic Recycled	0.043	kg	E
Wood Recycled	0.81	kg	E
Waste Oil and Hydraulic Fluid	0.0051	kg	E

Inputs/Outputs	Per 1 metric tonne		Source of data
	Quantity	Units	
Wastewater-n/a			

Notes:
1) Data are rounded to an appropriate number of significant digits (2 to 4).
2) D, I and E stand for *Direct*, *Indirect* and *Estimated* data, respectively.

Table A.4 Inputs/Outputs for 1 metric tonne (1,000 kg) of Roll Formed Metal Roof Panels production

Inputs/Outputs	Per 1 metric tonne		Source of data
	Quantity	Units	
Material Input			
Cold Rolled Coil, Pre-Painted	15.1	kg	D
Hot-Dip Galvanized, Pre-Painted	30.9	kg	D
Hot-Dip Galvanized	4.6	kg	D
Galvalume, Pre-Painted	394.8	kg	D
Galvalume	588.5	kg	D
Tube grease and hydraulic oil; gear and motor oils (avg density=7.2 lb/gal)	0.024	liter	D
Machining lubricants (avg density=6.6 lb/gal)	0.057	liter	D
Mastics (avg density=8.9 lb/gal)	5.47	liter	D
Sealants (avg density=7.5 lb/gal)	0.028	liter	D
Packaging			
Packaging- Dunnage	32.79	kg	E
Packaging- Steel Banding	1.35	kg	E
Packaging- Nails	0.13	kg	E
Packaging- Plastic slip sheets	0.049	kg	E
Packaging- Strippable film	0.232	kg	E
Packaging- Waterproof packing paper	0.11	kg	E
Energy Input			
Purchased Electricity	71.9	kWh	D
Natural Gas	3.70	m3	D
Diesel	1.21	liter	D
Liquified Propane Gas (LPG)	1.15	liter	D
Gasoline	0.092	liter	D
Fuel Oil (other than diesel)	0.00040	liter	D
Water Consumption-n/a			
Product and By-product Outputs			
Roll Formed Metal Roof Panels	1.00	metric tonne	D
Emissions to Air			
Process specific emissions to air (non-combustion)			
Non-Methane VOCs	0.139	kg	D
Emissions to Water-N/A			

Inputs/Outputs	Per 1 metric tonne		Source of data
	Quantity	Units	
Solid and Liquid Waste			
Scrap Metal- Recycled	33.9	kg	E
Non-hazardous solid waste-landfill	0.87	kg	D
Packaging Waste- landfill	0.013	kg	E
Packaging Waste Mix- Recycling	0.25	kg	E
Paper Recycled	0.12	kg	E
Plastic Recycled	0.03	kg	E
Wood Recycled	0.82	kg	E
Waste Oil and Hydraulic Fluid	0.0049	kg	E
Wastewater-n/a			

Notes:
1) Data are rounded to an appropriate number of significant digits (2 to 4).
2) D, I and E stand for *Direct*, *Indirect* and *Estimated* data, respectively.

Table A.5 Inbound/Outbound transportation data for 1 metric tonne (1,000 kg) of Primary Structural Steel Frame Components production

Transportation data	Per metric tonne (1,000 kg) Primary Structural Steel Frame Components				
	Truck t.km	Rail t.km	Ship t.km	Barge t.km	Conveyor t.km
All material inputs (see Table A.1)	941.0	73.6	0.0	0.0	0.0
Single unit truck, diesel, short haul < 200 mi	1.8				
Combination truck, diesel, short haul <200 mi	34.6				
Single unit truck, diesel, long haul > 200 mi	12.1				
Combination truck, diesel, long haul >200 mi	892.5				
All packaging inputs (see Table A.1)	5.7	0.0	0.0	0.0	0.0
Single unit truck, diesel, short haul < 200 mi	2.0				
Single unit truck, diesel, long haul > 200 mi	3.6				
All waste outputs (see Table A.1)	2.8	0.00	0.00	0.00	0.0
Single unit truck, diesel, short haul < 200 mi	0.18				
Combination truck, diesel, short haul <200 mi	2.0				

Transportation data	Per metric tonne (1,000 kg) Primary Structural Steel Frame Components				
	Truck t.km	**Rail** t.km	**Ship** t.km	**Barge** t.km	**Conveyor** t.km
Single unit truck, diesel, long haul > 200 mi	0.21				
Combination truck, diesel, long haul >200 mi	0.43				

Table A.6 Inbound/Outbound transportation data for 1 metric tonne (1,000 kg) of Secondary Structural Steel Frame Components production

Transportation data	Per metric tonne (1,000 kg) Secondary Structural Steel Frame Components				
	Truck t.km	**Rail** t.km	**Ship** t.km	**Barge** t.km	**Conveyor** t.km
All material inputs (see Table A.2)	545.8	147.9	0.0	0.0	0.0
Single unit truck, diesel, short haul < 200 mi	0.5				
Combination truck, diesel, short haul <200 mi	55.2				
Single unit truck, diesel, long haul > 200 mi	4.0				
Combination truck, diesel, long haul >200 mi	486.1				
All packaging inputs (see Table A.2)	5.2	0.0	0.0	0.0	0.0
Single unit truck, diesel, short haul < 200 mi	1.9				
Single unit truck, diesel, long haul > 200 mi	3.2				
All waste outputs (see Table A.2)	1.8	0.00	0.00	0.00	0.0
Single unit truck, diesel, short haul < 200 mi	0.077				
Combination truck, diesel, short haul <200 mi	1.4				
Single unit truck, diesel, long haul > 200 mi	0.0028				
Combination truck, diesel, long haul >200 mi	0.29				

Table A.7 Inbound/Outbound transportation data for 1 metric tonne (1,000 kg) of Roll Formed Metal Wall Panels production

Transportation data	**Per metric tonne (1,000 kg) Roll Formed Metal Wall Panels**				
	Truck t.km	**Rail** t.km	**Ship** t.km	**Barge** t.km	**Conveyor** t.km
All material inputs (see Table A.3)	638.9	113.0	162.8	0.0	0.000
Single unit truck, diesel, short haul < 200 mi	0.5				
Combination truck, diesel, short haul <200 mi	27.1				
Single unit truck, diesel, long haul > 200 mi	0.0068				
Combination truck, diesel, long haul >200 mi	611.2				
All packaging inputs (see Table A.3)	9.6	0.0	0.0	0.0	0.000
Single unit truck, diesel, short haul < 200 mi	2.3				
Single unit truck, diesel, long haul > 200 mi	7.3				
All waste outputs (see Table A.3)	2.8	0.00	0.00	0.00	0.000
Single unit truck, diesel, short haul < 200 mi	0.065				
Combination truck, diesel, short haul <200 mi	2.7				
Single unit truck, diesel, long haul > 200 mi	0.0021				
Combination truck, diesel, long haul >200 mi	0.043				

Table A.8 Inbound/Outbound transportation data for 1 metric tonne (1,000 kg) of Roll Formed Metal Roof Panels production

Transportation data	**Per metric tonne (1,000 kg) Roll Formed Metal Roof Panels**				
	Truck t.km	**Rail** t.km	**Ship** t.km	**Barge** t.km	**Conveyor** t.km
All material inputs (see Table A.4)	590.3	68.8	147.1	0.0	0.000
Single unit truck, diesel, short haul < 200 mi	3.6				
Combination truck, diesel, short haul <200 mi	31.5				

Transportation data	Per metric tonne (1,000 kg) Roll Formed Metal Roof Panels				
	Truck t.km	Rail t.km	Ship t.km	Barge t.km	Conveyor t.km
Single unit truck, diesel, long haul > 200 mi	6.8				
Combination truck, diesel, long haul >200 mi	548.4				
All packaging inputs (see Table A.4)	7.2	0.0	0.0	0.0	0.000
Single unit truck, diesel, short haul < 200 mi	1.4				
Single unit truck, diesel, long haul > 200 mi	5.8				
All waste outputs (see Table A.4)	1.4	0.00	0.00	0.00	0.000
Single unit truck, diesel, short haul < 200 mi	0.078				
Combination truck, diesel, short haul <200 mi	1.3				
Single unit truck, diesel, long haul > 200 mi	0.0011				
Combination truck, diesel, long haul >200 mi	0.089				

Notes to Tables A5 to A8:
1) Data are rounded to an appropriate number of significant digits (2 to 3).

Table A.9 Module A5 product packaging waste per 1,000 kg MBMA product

Inputs/Outputs	Primary Structural Steel Frame Components	Secondary Structural Steel Frame Components	Roll Formed Metal Wall Panels	Roll Formed Metal Roof Panels	Units
	Quantity	Quantity	Quantity	Quantity	
Material Inputs					
Dunnage	25.66	25.80	36.93	32.79	kg
Steel Banding	0.40	0.77	2.37	1.35	kg
Nails	0	0	0.091	0.13	kg
Plastic slip sheets	0	0	0.086	0.05	kg
Strippable film	0	0	0.048	0.23	kg
Waterproof packing paper	0	0	0.18	0.11	kg

Note:
1) Biogenic C-content of packaging fall below the cut-off criteria (ISO 21930, 7.1.8 [1]), and is therefore excluded. It should be noted that GWP based in biogenic C-content of packaging is not included in the quantification of GWP 100, IPCC 2013 (see Section 3).

Table A.10 Simplified example of the weighted average approach for inputs/outputs (activity data, Tables A1 to A4)

Product type	Metal building product (e.g., primary frames)	
No. of sites	14	
Reference year	2019	
Declared unit	1 tonne	
Selected Parameter	Total annual production of metal building product per plant, (in metric tons)	
No.	Example: Production (mt)	Example: Weighted average factor, WAF (in %)
Plant 1	1,000	7%
Plant 2	1,000	7%
Plant 3	1,000	7%
Plant 4	1,000	7%
Plant 5	1,000	7%
Plant 6	1,000	7%
Plant 7	1,000	7%
Plant 8	1,000	7%
Plant 9	1,000	7%
Plant 10	1,000	7%
Plant 11	1,000	7%
Plant 12	1,000	7%
Plant 13	1,000	7%
Plant 14	1,000	7%
Total	**14,000**	**100%**

Note:
1) Fourteen (14) MBMA facilities provided input/output flows and inbound/outbound transportation data for four (4) declared products.

Table A.11 Wall and Roof Cladding- Sheet Metal Gauge to Density Conversion Chart

Inputs/Outputs	**Wall Panel Cladding**						**Roof Panel Cladding**					**Units**
	29 ga.	**28 ga.**	**26 ga.**	**24 ga.**	**22 ga.**	**18 ga.**	**29 ga.**	**28 ga.**	**26 ga.**	**24 ga.**	**22 ga.**	
Semi-finished steel products												
Cold Roll Coil Pre-Painted Steel		371	435	557			355	392	474	596	757	kg/100 m2
Hot-Dip Galvanized Pre-Painted Steel	344		459	566	688		333		444	566	688	kg/100 m2
Hot-Dip Galvanized Steel			459	566					444	566	688	kg/100 m2
Galvalume Pre-Painted Steel	325	371	435	557	703	923	355	392	474	596	757	kg/100 m2
Galvalume Steel			435	557	703				474	596	757	kg/100 m2

Note:
1) Industry conversion factors; results calculated using a factor of 1 kg/100 m2 = 0.205 lb/100sq.ft.

Annex B Data Quality Assessment

Table B1. LCI datasets used per four declared MBMA products

LCI datasets	Comments
Source: *SimaPro LCA Software, v9.1.1.1, 2020* *ecoinvent v3.6, Allocation, Cut-off by classification, Dec 2019* *US LCI database, Sept 2015.*	Geography: U.S. or adjusted to U.S. Technology: Conventional Timeline: Not older than 10 years.
Primary Structural Steel Frame Components, 2019	**Modules A1 to A3**
Hot Rolled Plate	AISI 2019 data
Hot Rolled Bar	AISI 2019 data
Sections	AISI 2019 data
Solid Welding wire (carbon steel wire)	Based on MSDS
Welding consumables	generic data
Welding Flux Core (flux core arc welding)	Based on MSDS
Primer, water based	Based on MSDS
Primer, solvent based	Based on MSDS
Solvent	Based on MSDS
Additive	Based on MSDS
Touch up paint	Based on MSDS
Argon, liquid {RoW}| market for argon, liquid | Cut-off, U	
Oxygen, liquid {RoW}| market for | Cut-off, U	
Carbon dioxide, liquid {RoW}| market for | Cut-off, U	
Nitrogen, liquid {RoW}| market for | Cut-off, U	
Acetylene {RoW}| market for acetylene | Cut-off, U	
Propane {GLO}| market for | Cut-off, U	
Lubricating oil {RoW}| market for lubricating oil | Cut-off, U	
EUR-flat pallet {RoW}| production | Cut-off, U	Packaging
Steel, low-alloyed, hot rolled {GLO}| market for | Cut-off, U	Packaging
Wire drawing, steel {RoW}| processing | Cut-off, U	Packaging
Transport, single unit truck, short-haul, diesel powered/tkm/RNA	see Table A5
Transport, combination truck, short-haul, diesel powered/tkm/RNA	see Table A5
Transport, single unit truck, long-haul, diesel powered/tkm/RNA	see Table A5
Transport, combination truck, long-haul, diesel powered/tkm/RNA	see Table A5
Transport, freight train {US}| market for | Cut-off, U	see Table A5
Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U	see Table A5
Tap water {RoW}| tap water production, conventional treatment | Cut-off, U	
Electricity, high voltage {US}| market group for | Cut-off, U eGRID 2018	
Heat, district or industrial, natural gas {US}| market for heat, district or industrial, natural gas, | Cut-off, U	
Machine operation, diesel, >= 18.64 kW and < 74.57 kW, steady-state {GLO}| machine operation, diesel | Cut-off, U	
Propane, burned in building machine {GLO}| propane, burned in building machine | Cut-off, U	
Petrol, unleaded, burned in machinery {GLO}| petrol, unleaded, burned in machinery | Cut-off, U	

LCI datasets	**Comments**
Source: *SimaPro LCA Software, v9.1.1.1, 2020* *ecoinvent v3.6, Allocation, Cut-off by classification, Dec 2019* *US LCI database, Sept 2015.* Process-specific burdens, inert material landfill {CH}| process-specific burdens, inert material landfill | Cut-off, U	Geography: U.S. or adjusted to U.S. Technology: Conventional Timeline: Not older than 10 years.
Process-specific burdens, hazardous waste incineration plant {CH}| processing | Cut-off, U	
Waste mineral oil {RoW}| treatment of, hazardous waste incineration | Cut-off, U	
Secondary Structural Steel Frame Components, 2019	**Modules A1 to A3**
Hot Rolled Coil	AISI 2019 data
Hot Rolled Coil, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Cold Rolled Coil, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Hot Dip Galvanized	AISI 2019 data
Solid Welding wire (carbon steel wire)	Based on MSDS
Welding consumables	generic data
Welding Flux Core (flux core arc welding)	Based on MSDS
Primer, water based	Based on MSDS
Primer, solvent based	Based on MSDS
Solvent	Based on MSDS
Additive	Based on MSDS
Touch up paint	Based on MSDS
Argon, liquid {RoW}| market for argon, liquid | Cut-off, U	
Oxygen, liquid {RoW}| market for | Cut-off, U	
Carbon dioxide, liquid {RoW}| market for | Cut-off, U	
Nitrogen, liquid {RoW}| market for | Cut-off, U	
Acetylene {RoW}| market for acetylene | Cut-off, U	
Propane {GLO}| market for | Cut-off, U	
Lubricating oil {RoW}| market for lubricating oil | Cut-off, U	
EUR-flat pallet {RoW}| production | Cut-off, U	Packaging
Steel, low-alloyed, hot rolled {GLO}| market for | Cut-off, U	Packaging
Wire drawing, steel {RoW}| processing | Cut-off, U	Packaging
Transport, single unit truck, short-haul, diesel powered/tkm/RNA	see Table A6
Transport, combination truck, short-haul, diesel powered/tkm/RNA	see Table A6
Transport, single unit truck, long-haul, diesel powered/tkm/RNA	see Table A6
Transport, combination truck, long-haul, diesel powered/tkm/RNA	see Table A6
Transport, freight train {US}| market for | Cut-off, U	see Table A6
Tap water {RoW}| tap water production, conventional treatment | Cut-off, U	see Table A6

LCI datasets	Comments
Source: *SimaPro LCA Software, v9.1.1.1, 2020* *ecoinvent v3.6, Allocation, Cut-off by classification, Dec 2019* *US LCI database, Sept 2015.*	Geography: U.S. or adjusted to U.S. Technology: Conventional Timeline: Not older than 10 years.
Electricity, high voltage {US}| market group for | Cut-off, U eGRID 2018	
Heat, district or industrial, natural gas {US}| market for heat, district or industrial, natural gas, | Cut-off, U	
Machine operation, diesel, >= 18.64 kW and < 74.57 kW, steady-state {GLO}| machine operation, diesel | Cut-off, U	
Propane, burned in building machine {GLO}| propane, burned in building machine | Cut-off, U	
Petrol, unleaded, burned in machinery {GLO}| petrol, unleaded, burned in machinery | Cut-off, U	
Process-specific burdens, inert material landfill {CH}| process-specific burdens, inert material landfill | Cut-off, U	
Process-specific burdens, hazardous waste incineration plant {CH}| processing | Cut-off, U	
Waste mineral oil {RoW}| treatment of, hazardous waste incineration | Cut-off, U	
Roll Formed Metal Wall Panels, 2019	**Modules A1 to A3**
Cold Rolled Coil, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Hot Dipped Galvanized, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Hot Dip Galvanized	AISI 2019 data
Galvalume Coil, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for Galvalume® coating process [US plant 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Galvalume Coil	AISI 2019 data; Gate-to-gate LCI dataset for Galvalume® coating process [US plant 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Lubricating oil {RoW}| market for lubricating oil | Cut-off, U	
Naphtha {RoW}| market for | Cut-off, U	
EUR-flat pallet {RoW}| production | Cut-off, U	Packaging
Steel, low-alloyed, hot rolled {GLO}| market for | Cut-off, U	Packaging
Wire drawing, steel {RoW}| processing | Cut-off, U	Packaging
Packaging film, high density polypropylene {RoW}| production | Cut-off, U	Packaging
Packaging film, low density polyethylene {RoW}| production | Cut-off, U	Packaging
Kraft paper, unbleached {RoW}| production | Cut-off, U	Packaging

LCI datasets	Comments
Source: *SimaPro LCA Software, v9.1.1.1, 2020* *ecoinvent v3.6, Allocation, Cut-off by classification, Dec 2019* *US LCI database, Sept 2015.*	Geography: U.S. or adjusted to U.S. Technology: Conventional Timeline: Not older than 10 years.
Transport, single unit truck, short-haul, diesel powered/tkm/RNA	see Table A7
Transport, combination truck, short-haul, diesel powered/tkm/RNA	see Table A7
Transport, single unit truck, long-haul, diesel powered/tkm/RNA	see Table A7
Transport, combination truck, long-haul, diesel powered/tkm/RNA	see Table A7
Transport, freight train {US}| market for | Cut-off, U	see Table A7
Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U	see Table A7
Electricity, high voltage {US}| market group for | Cut-off, U eGRID 2018	
Heat, district or industrial, natural gas {US}| market for heat, district or industrial, natural gas, | Cut-off, U	
Machine operation, diesel, >= 18.64 kW and < 74.57 kW, steady-state {GLO}| machine operation, diesel | Cut-off, U	
Propane, burned in building machine {GLO}| propane, burned in building machine | Cut-off, U	
Petrol, unleaded, burned in machinery {GLO}| petrol, unleaded, burned in machinery | Cut-off, U	
Process-specific burdens, inert material landfill {CH}| process-specific burdens, inert material landfill | Cut-off, U	
Process-specific burdens, hazardous waste incineration plant {CH}| processing | Cut-off, U	
Waste mineral oil {RoW}| treatment of, hazardous waste incineration | Cut-off, U	
Roll Formed Metal Roof Panels, 2019	**Modules A1 to A3**
Cold Rolled Coil, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Hot Dipped Galvanized, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Hot Dip Galvanized	AISI 2019 data
Galvalume Coil, Pre-painted	AISI 2019 data; Gate-to-gate LCI dataset for Galvalume® coating process [US plant 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019; Gate-to-gate LCI dataset for metal coil painting process [MCA 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Galvalume Coil	AISI 2019 data; Gate-to-gate LCI dataset for Galvalume® coating process [US plant 2012] is updated with ecoinvent v3.6 LCI datasets, Dec 2019.
Lubricating oil {RoW}| market for lubricating oil | Cut-off, U	
Naphtha {RoW}| market for | Cut-off, U	

LCI datasets	Comments
Source: *SimaPro LCA Software, v9.1.1.1, 2020* *ecoinvent v3.6, Allocation, Cut-off by classification, Dec 2019* *US LCI database, Sept 2015.*	Geography: U.S. or adjusted to U.S. Technology: Conventional Timeline: Not older than 10 years.
Mastics	Based on MSDS
Sealants	Based on MSDS
EUR-flat pallet {RoW}| production | Cut-off, U	Packaging
Steel, low-alloyed, hot rolled {GLO}| market for | Cut-off, U	Packaging
Wire drawing, steel {RoW}| processing | Cut-off, U	Packaging
Packaging film, high density polypropylene {RoW}| production | Cut-off, U	Packaging
Packaging film, low density polyethylene {RoW}| production | Cut-off, U	Packaging
Kraft paper, unbleached {RoW}| production | Cut-off, U	Packaging
Transport, single unit truck, short-haul, diesel powered/tkm/RNA	see Table A8
Transport, combination truck, short-haul, diesel powered/tkm/RNA	see Table A8
Transport, single unit truck, long-haul, diesel powered/tkm/RNA	see Table A8
Transport, combination truck, long-haul, diesel powered/tkm/RNA	see Table A8
Transport, freight train {US}| market for | Cut-off, U	see Table A8
Transport, freight, sea, container ship {GLO}| market for transport, freight, sea, container ship | Cut-off, U	see Table A8
Electricity, high voltage {US}| market group for | Cut-off, U eGRID 2018	
Heat, district or industrial, natural gas {US}| market for heat, district or industrial, natural gas, | Cut-off, U	
Machine operation, diesel, >= 18.64 kW and < 74.57 kW, steady-state {GLO}| machine operation, diesel | Cut-off, U	
Propane, burned in building machine {GLO}| propane, burned in building machine | Cut-off, U	
Petrol, unleaded, burned in machinery {GLO}| petrol, unleaded, burned in machinery | Cut-off, U	
Process-specific burdens, inert material landfill {CH}| process-specific burdens, inert material landfill | Cut-off, U	
Process-specific burdens, hazardous waste incineration plant {CH}| processing | Cut-off, U	
Waste mineral oil {RoW}| treatment of, hazardous waste incineration | Cut-off, U	

Notes to Table B1:

1) Source of the LCI datasets with the tags "RNA (Regional North America", "US" or "US adjusted" is US LCI database, Sept 2015.

2) "2019" tag indicates new LCI datasets developed in the framework of this EPD project, and based on data provided by MBMA members and AISI 2019 data for semifinished steel products (confidential).

3) Source of the LCI datasets with the tag "Cut-off, U" is ecoinvent 3.6, Allocation, Cut-off by classification, Dec 2019.

5) Material Safety Data Sheet (MSDSs) are provided confidentially by MBMA plants per each ancillary material e.g., primer. Each ancillary material is then modelled in accordance with the generic MSDS. Any data gaps in the MSDS are filled in with two generic LCI datasets, as appropriate (conservative assumptions): Chemical, organic {GLO}| production | Cut-off, U; Chemical, inorganic {GLO}| production | Cut-off, U. The same approach is consistently applied for all ancillary materials (chemicals) in the framework of this EPD.

Annex C Sensitivity Analysis

Table C1. Sensitivity Analysis Results for 1 metric tonne of Primary and Secondary frames

Impact category	Unit	Base case		Sensitivity case	
		Primary Structural Steel Frame Components	Secondary Structural Steel Frame Components	Primary Structural Steel Frame Components	Secondary Structural Steel Frame Components
GWP	kg CO2 eq	1,468	1,929	1,469	1,930
ODP	kg CFC-11 eq	1.8E-05	1.9E-05	1.8E-05	1.9E-05
SFP	kg O3 eq	84.9	91.9	85.0	91.8
AP	kg SO2 eq	4.5	10.2	4.5	10.2
EP	kg N eq	0.82	0.84	0.83	0.86
ADPe	kg Sb. eq.	8.9E-03	1.3E-02	8.9E-03	1.3E-02
ADPf	MJ	17,084	22,099	17,090	22,108
RPRE	MJ	1,583	1,594	1,577	1,583
NRPRE	MJ	19,182	23,976	19,198	23,990

Impact category	Unit	Difference (in %)	
		Primary Structural Steel Frame Components	Secondary Structural Steel Frame Components
GWP	%	0.10%	0.1%
ODP	%	0.1%	0.2%
SFP	%	0.02%	-0.03%
AP	%	0.2%	0.1%
EP	%	0.7%	2.3%
ADPe	%	0.01%	0.01%
ADPf	%	0.03%	0.04%
RPRE	%	-0.4%	-0.7%
NRPRE	%	0.1%	0.1%

Table C2. Sensitivity Analysis Results for 100 m² of Wall and Roof panels

Impact category	Unit	Base case		Sensitivity case	
		Roll Formed Metal Wall Panels	Roll Formed Metal Roof Panels	Roll Formed Metal Wall Panels	Roll Formed Metal Roof Panels
GWP	kg CO2 eq	1,233	1,326	1,233	1,328
ODP	kg CFC-11 eq	2.5E-05	2.9E-05	2.5E-05	2.9E-05
SFP	kg O3 eq	61.1	66.4	61.0	66.4
AP	kg SO2 eq	9.7	5.1	9.7	5.1
EP	kg N eq	1.44	1.68	1.45	1.68
ADPe	kg Sb. eq.	4.5E-01	6.0E-01	4.5E-01	6.0E-01
ADPf	MJ	13,486	14,580	13,483	14,591
RPRE	MJ	1,354	1,479	1,349	1,471
NRPRE	MJ	14,699	15,819	14,694	15,841

Impact category	Unit	Differences (in %)	
		Roll Formed Metal Wall Panels	Roll Formed Metal Roof Panels
GWP	%	-0.01%	0.10%
ODP	%	-0.05%	0.44%
SFP	%	-0.09%	0.02%
AP	%	-0.03%	0.13%
EP	%	0.73%	0.05%
ADPe	%	-0.05%	0.02%
ADPf	%	-0.02%	0.07%
RPRE	%	-0.41%	-0.53%
NRPRE	%	-0.04%	0.14%

Annex D Monte Carlo Uncertainty Analysis Results

As discussed in Section 7, a Monte Carlo uncertainty analysis was also conducted to assess the *combined uncertainty* effect of the data variability on the LCIA and energy indicator results.

The EPD LCIA and energy indicator results of the four selected MBMA products are shown as 100% in Figures D1 to D4. *With a confidence level of 95%, the confidence interval of cradle-to-gate GWP 100 of the MBMA products (primary frames, secondary frames, wall panels, and roof panels), are [+31%, -39%], [+55%, -40%], [+45%, -46%], and [+48%, -45%], respectively (Figures D1 to D4).*

Based on 1,000 runs, such information provides a quantitative indication of the range of results that are likely for the manufacturer's specific products covered by the industry average EPD for four selected MBMA products.

In addition, Tables D1 to D4 show the summary results of the uncertainty analysis (mean, median, standard deviation, coefficient of variation, 2.5%, 97.5%, and standard error of median values) for "cradle-to-gate" EPD results of the four declared EPD products.

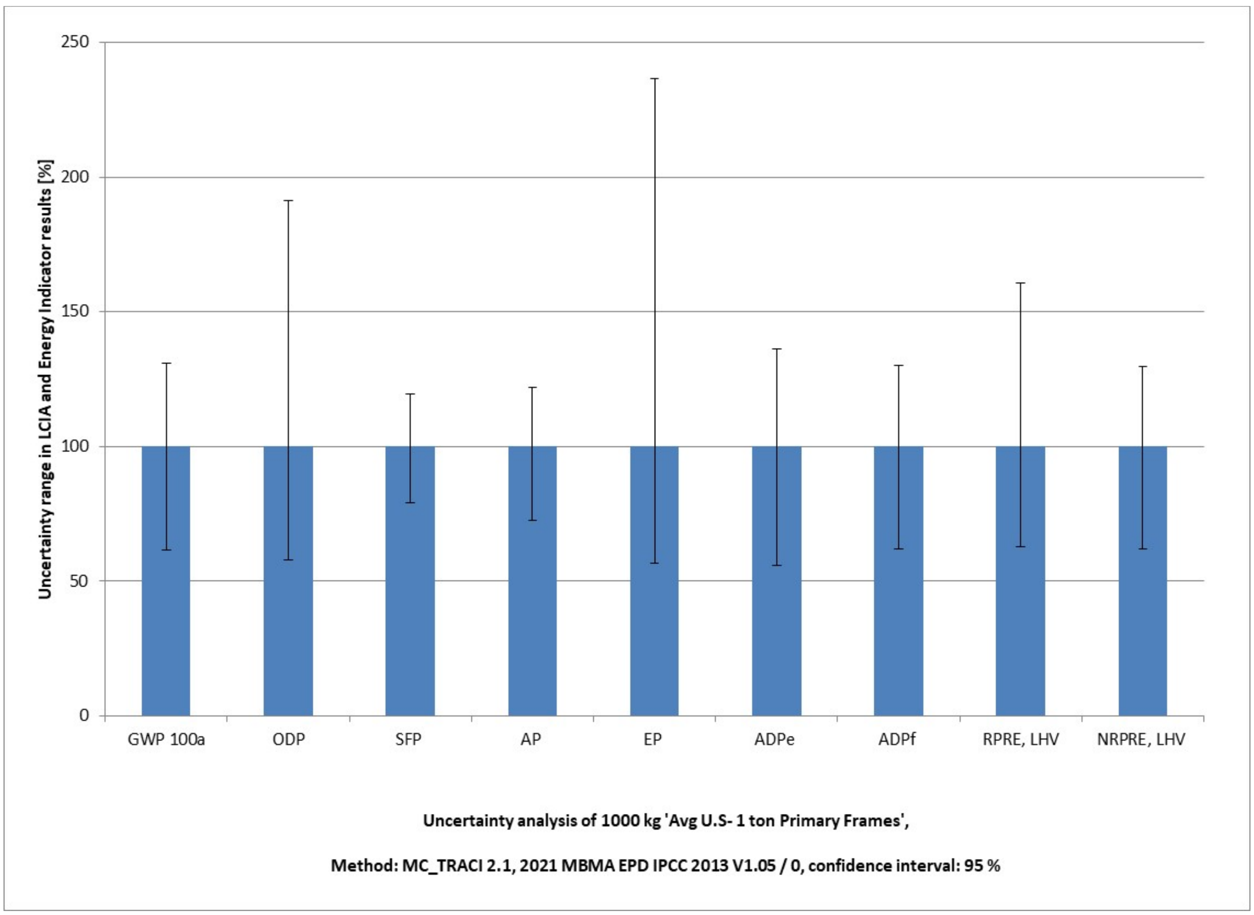

Figure D1 Monte Carlo uncertainty range in the cradle-to-gate LCIA and Energy indicator results of the primary frames (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.1, 2021)

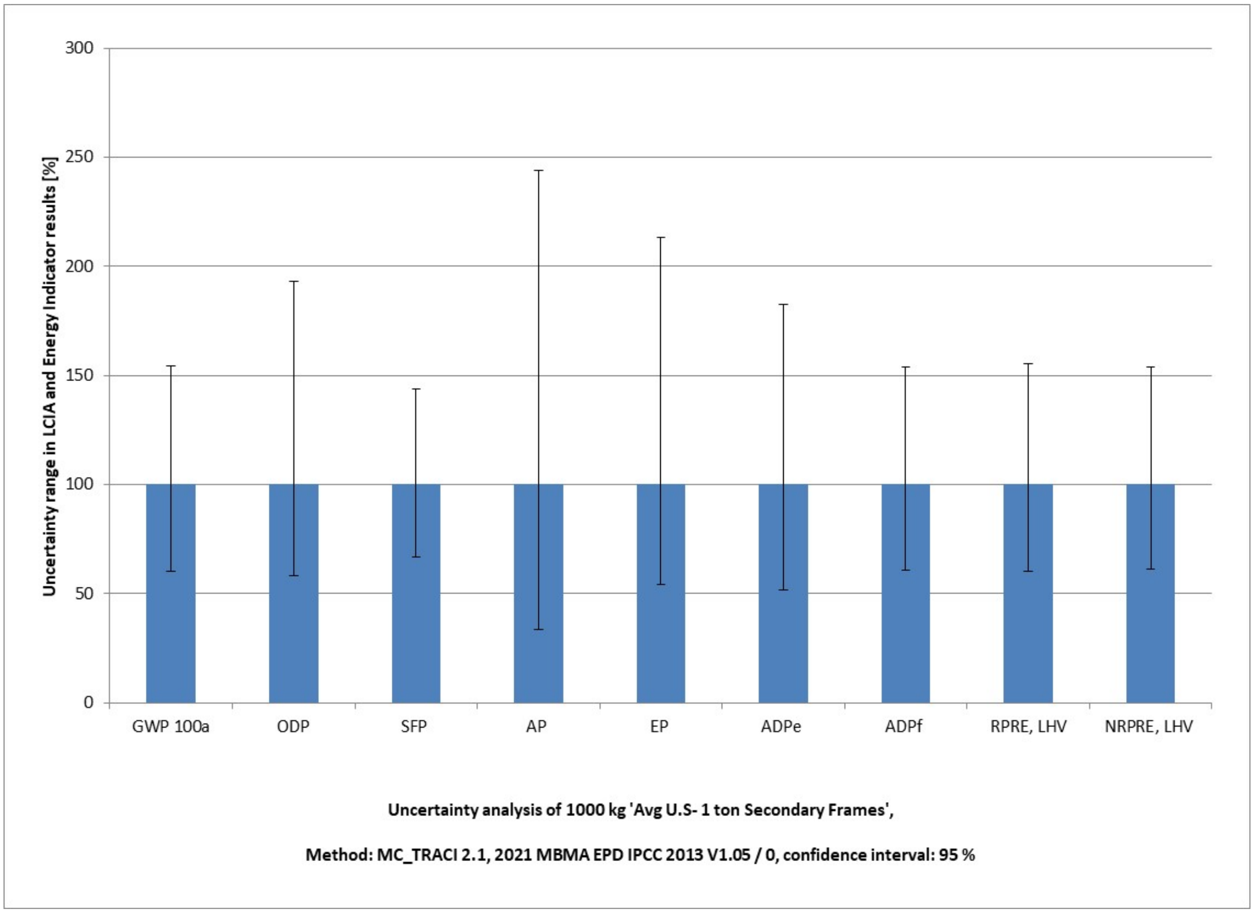

Figure D2 Monte Carlo uncertainty range in the cradle-to-gate LCIA and Energy indicator results of the secondary frames (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.1, 2021)

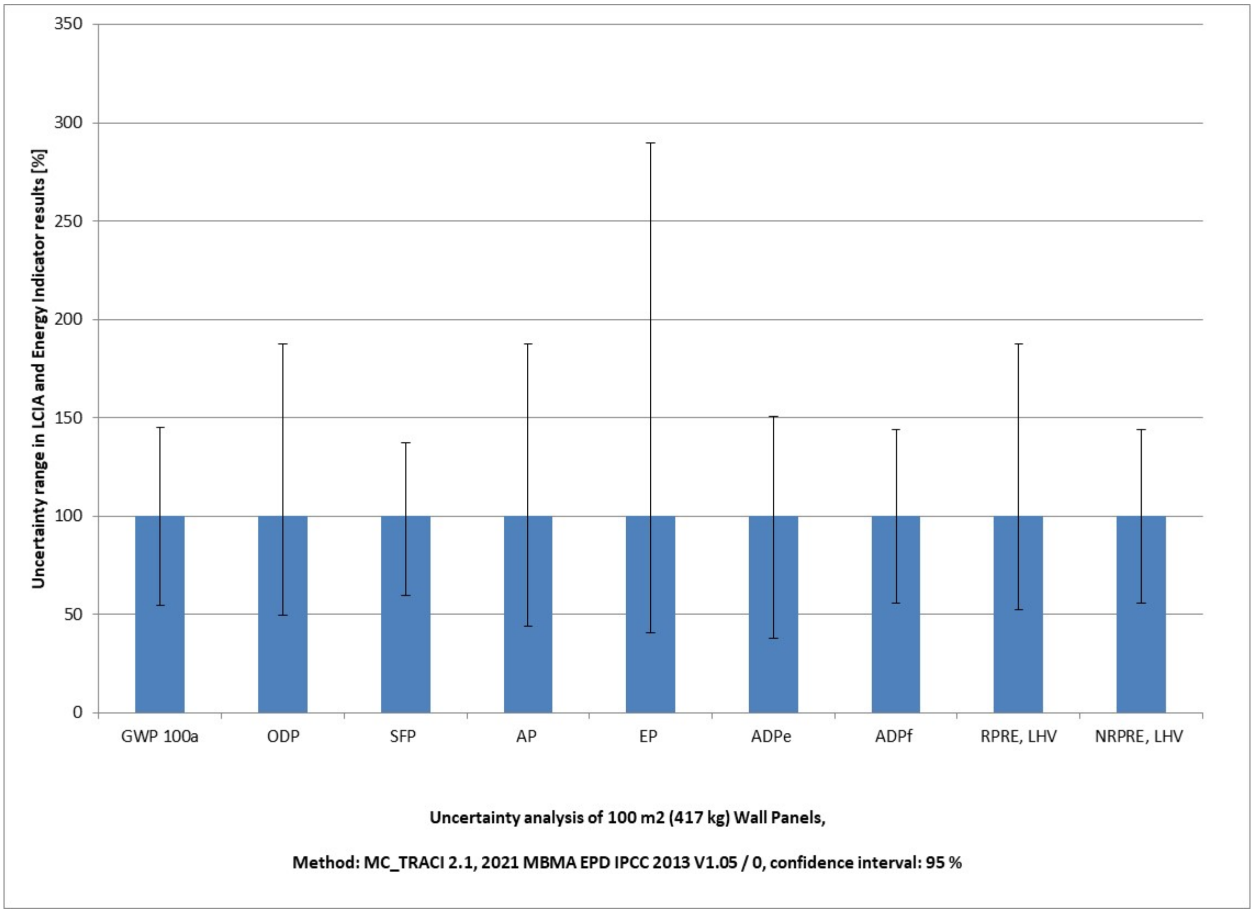

Figure D3 Monte Carlo uncertainty range in the cradle-to-gate LCIA and Energy indicator results of the wall panels (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.1, 2021)

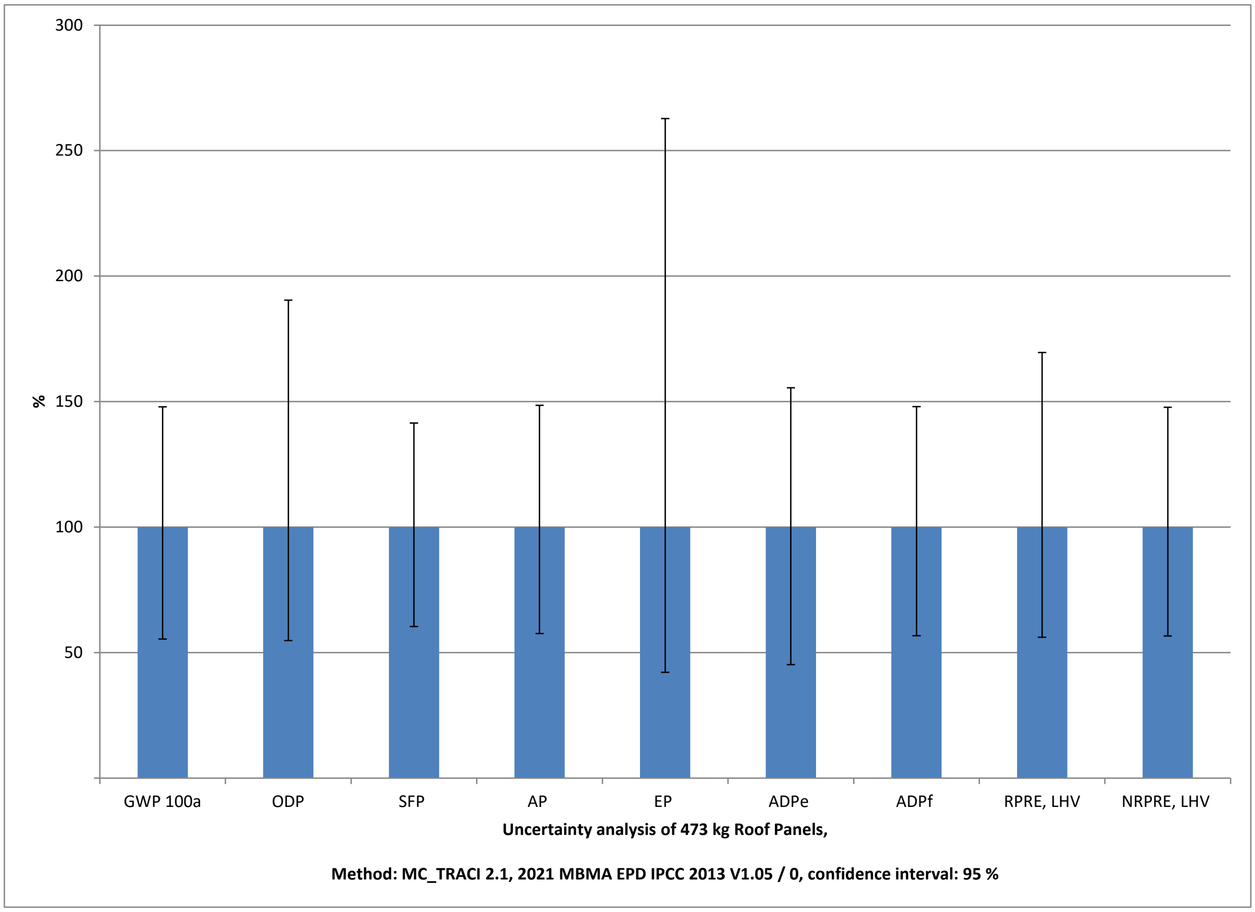

Figure D4 Monte Carlo uncertainty range in the cradle-to-gate LCIA and Energy indicator results of the roof panels (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.1, 2021)

Note: The "high" uncertainty range of EP indicator, is a result of a high uncertainty of the emission factors of "phosphate" and "chemical oxygen demand, COD" (in water) for generic landfill treatments (background LCI datasets) of waste generated during the cradle-to-gate with option life cycle of the four selected products.

Table D1 Monte Carlo uncertainty analysis: Cradle-to-gate LCIA and energy indicator results of 1000 kg primary frames (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.1, 2021)

Impact category	Unit	Mean	Median	SD	CV	0.025	0.975	SEM
GWP 100a	kg CO2 eq	1,223.0	1,229.6	220.3	18.0	755.5	1,609.7	7.0
ODP	kg CFC-11 eq	2.32E-05	2.18E-05	7.75E-06	3.35E+01	1.26E-05	4.16E-05	2.45E-07
SFP	kg O3 eq	80.0	80.1	8.3	10.3	63.2	95.8	0.3
AP	kg SO2 eq	4.0	4.0	0.5	12.8	2.9	4.9	0.0
EP	kg N eq	0.85	0.76	0.35	40.99	0.43	1.79	0.01
ADPe	kg Sb eq	7.2E-03	7.3E-03	1.5E-03	2.0E+01	4.1E-03	9.9E-03	4.7E-05
ADPf	MJ	14,464	14,518	2,495	17	9,010	18,856	79
RPRE, LHV	MJ	1,273	1,237	312	24	776	1,989	10
NRPRE, LHV	MJ	16,225	16,341	2,805	17	10,093	21,197	89

Table D2 Monte Carlo uncertainty analysis: Cradle-to-gate LCIA and energy indicator results of 1000 kg secondary frames, (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.10, 2021)

Impact category	Unit	Mean	Median	SD	CV	0.025	0.975	SEM
GWP 100a	kg CO2 eq	2,877.8	2,822.7	693.8	24.1	1,697.7	4,361.3	21.9
ODP	kg CFC-11 eq	2.75E-05	2.62E-05	9.01E-06	3.27E+01	1.53E-05	5.07E-05	2.85E-07
SFP	kg O3 eq	128.8	126.7	25.1	19.5	84.8	182.0	0.8
AP	kg SO2 eq	30.1	26.6	15.8	52.4	8.9	65.0	0.5
EP	kg N eq	1.13	1.03	0.45	40.13	0.56	2.19	0.01
ADPe	kg Sb eq	2.4E-02	2.3E-02	8.1E-03	3.3E+01	1.2E-02	4.2E-02	2.6E-04
ADPf	MJ	32,724	32,105	7,726	24	19,516	49,412	244
RPRE, LHV	MJ	2,030	1,992	499	25	1,195	3,093	16
NRPRE, LHV	MJ	35,535	34,845	8,378	24	21,349	53,613	265

Table D3 Monte Carlo uncertainty analysis: Cradle-to-gate LCIA and energy indicator results of 100 m^2 wall panels (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.1, 2021)

Impact category	Unit	Mean	Median	SD	CV	0.025	0.975	SEM
GWP 100a	kg CO2 eq	1,602.1	1,603.5	381.1	23.8	872.0	2,328.2	12.1
ODP	kg CFC-11 eq	2.71E-05	2.61E-05	9.44E-06	3.48E+01	1.29E-05	4.89E-05	2.99E-07
SFP	kg O3 eq	74.1	74.7	15.3	20.6	44.6	102.4	0.5
AP	kg SO2 eq	16.2	15.2	5.9	36.5	6.7	28.5	0.2
EP	kg N eq	1.55	1.37	0.80	51.69	0.56	3.97	0.03
ADPe	kg Sb eq	4.1E-01	4.2E-01	1.3E-01	3.1E+01	1.6E-01	6.3E-01	4.0E-03
ADPf	MJ	17,534	17,533	4,130	24	9,744	25,252	131
RPRE, LHV	MJ	1,926	1,826	652	34	959	3,421	21
NRPRE, LHV	MJ	19,117	19,177	4,505	24	10,639	27,651	142

Table D4 Monte Carlo uncertainty analysis: Cradle-to-gate LCIA and energy indicator results of 100 m^2 roof panels (confidence interval: 95%, 1,000 runs, exported from SimaPro LCA software 9.1.1.1, 2021)

Impact category	Unit	Mean	Median	SD	CV	0.025	0.975	SEM
GWP 100a	kg CO2 eq	1,738.2	1,731.4	425.6	24.5	959.8	2,561.3	13.5
ODP	kg CFC-11 eq	3.99E-05	3.82E-05	1.27E-05	3.18E+01	2.09E-05	7.27E-05	4.01E-07
SFP	kg O3 eq	82.5	82.3	17.7	21.5	49.7	116.5	0.6
AP	kg SO2 eq	7.9	7.8	1.8	23.5	4.5	11.6	0.1
EP	kg N eq	2.01	1.78	1.02	50.68	0.75	4.67	0.03
ADPe	kg Sb eq	6.2E-01	6.2E-01	1.8E-01	2.9E+01	2.8E-01	9.7E-01	5.8E-03
ADPf	MJ	19,414	19,300	4,632	24	10,944	28,568	146
RPRE, LHV	MJ	1,889	1,830	527	28	1,027	3,104	17
NRPRE, LHV	MJ	21,093	20,985	5,027	24	11,880	30,999	159