Metal Building Manufacturers Association

Sustainability of Metal Buildings: Beyond the Life of the Building

White Paper

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Executive Summary

Metal buildings are material efficient and cost-effective systems that can satisfy sustainability and circular economy design goals in a broad range of applications. Metal building systems are made of steel produced in North America and are inherently circular due to their demonstrated recycled content, durability, adaptability, potential for reuse, and high rates of recycling into new steel products at end-of-life. They have distinct advantages over competing materials, like concrete and wood, when end-of-life and circularity performance is considered. Today, most Environmental Product Declarations (EPDs) for construction materials report only a cradle-to-gate scope, representing the impacts of raw material extraction and processing, transportation, and product manufacturing. This paper highlights the importance of considering end-of-life and circularity, explains the environmental and circularity aspects of leading building assessment frameworks, and describes the attributes of metal buildings that demonstrate their alignment with circularity and sustainability principles.

Introduction

Steel products are inherently circular and sustainable, due to their recycled content, proven strength and durability during use, ability to be reused, and demonstrated high recycling rates at end-of-life. This paper describes and demonstrates the circularity and sustainability attributes of metal buildings, specifically as it pertains to end-of-life of metal building materials. The data and facts contained herein illustrate the benefits of recyclability and reuse, and provides evidence that metals are a truly recyclable material and circularity can be achieved from building with metals versus other building materials.

Metal Buildings Manufacturing and Supply Chain

The term "metal buildings" refers to building systems comprised of primary structural steel frames, secondary structural steel members (girts/purlins), and roll-formed metal wall and roof panels. These building components are illustrated in Figure 1. Metal buildings are commonly used for a range of applications from small offices and medium-sized warehouses to large industrial buildings,[1] in addition to education, retail, community, and religious buildings.[2] They are characterized by design and aesthetic flexibility and known for consistency and speed of construction.[3] In the United States, around one million tons of metal buildings are produced each year.[4]

[1] Walter P Moore, "Athena Impact Estimator Case Studies", prepared for the Metal Building Manufacturers Association, S06.24053.00, May 2, 2025. https://mbma.com/energy-sustainability.
[2] Metal Building Manufacturers Association (MBMA), Primary Structural Steel Frame Components: Industry-wide EPD, April 2021. https://mbma.com/energy-sustainability.
[3] Ibid.
[4] 2017 MBMA member shipments amounted to 1,094,064 tons, from Metal Building Manufacturers Association website, https://mbma.com/industry-trends.

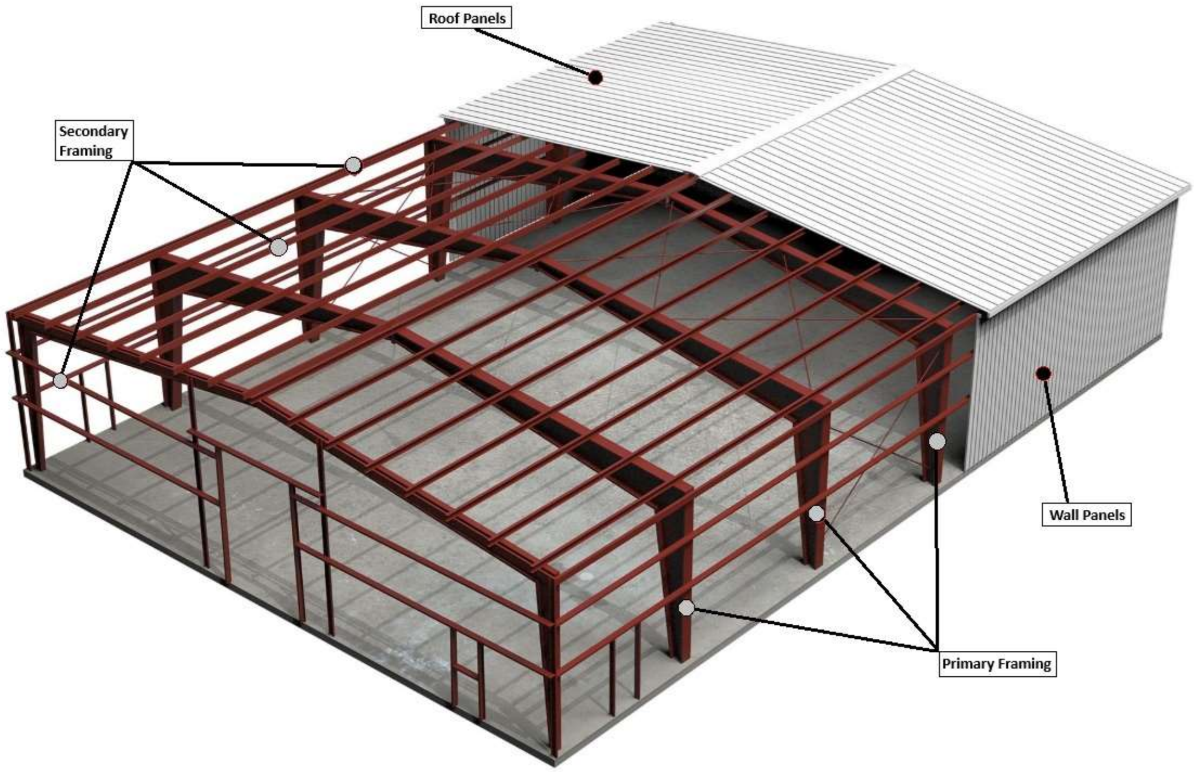

FIGURE 1. METAL BUILDING SYSTEM COMPONENTS.
Source: Metal Building Manufacturers Association.

Primary frames are built-up using three welded steel plates, including a tapered web section. Secondary frame components include cold-formed steel “cee” and “zee” shaped purlins and girts along with endwall framing and bracing elements. are attached. Primary and secondary frames are typically coated with a rust-inhibiting primer or painted. The frames are custom fabricated in a factory prior to shipment to jobsites for assembly. Roof and wall panels are produced from pre-painted or unpainted galvalume, cold-rolled, or galvanized steel coil using coil slitting, de-coiling, punching/shearing, and roll forming processes. Figure 2 shows a simplified process flow diagram for the manufacture of metal building components. Detailed process flow diagrams are included in Appendix A.

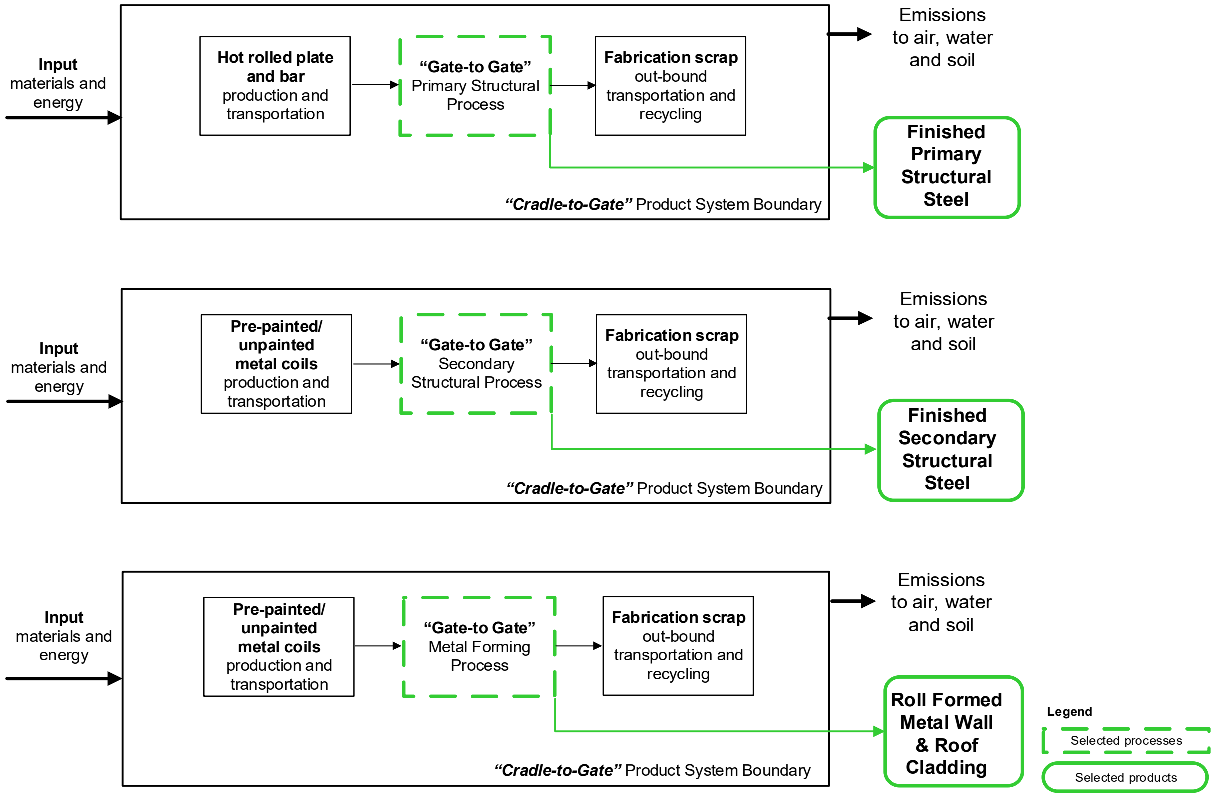

FIGURE 2. SIMPLIFIED PROCESS FLOW DIAGRAM OF METAL BUILDING SYSTEM COMPONENT MANUFACTURING.
Source: MBMA Industry-wide EPDs.[5]

They are designed and engineered to use materials efficiently by enclosing large volumes of space with optimized use of steel and to minimize materials waste, which both improves environmental performance and avoids unnecessary costs.[6] By design, metal buildings are also time efficient to construct, which enables building owners to achieve their occupancy goals.[7]

Metal buildings are constructed from steel produced in North America. In 2020, approximately 71% of the steel produced in the U.S. was made via the electric arc furnace (EAF) process, which melts mainly steel scrap along with smaller amounts of virgin iron using electricity.[8] In contrast, only 26% of the steel produced globally was made via EAF technology. On average, steel produced via EAF mills in the U.S. in 2019 had 82% recycled content.[9] EAFs are less energy intensive and emit fewer greenhouse gas (GHG) emissions on average than blast furnace / basic oxygen furnace (BF/BOF)

[5] MBMA, "Primary Structural Steel Frame Components", "Secondary Structural Steel Frame Components", and "Roll Formed Metal Wall and Roof Panels", Environmental Product Declarations, April 1, 2021. https://mbma.com/energy-sustainability.
[6] MBMA website, https://mbma.com/.
[7] MBMA, "2024 Metal Building Manufacturers Association Annual Report", https://mbma.com/annual-reports.
[8] American Iron and Steel Institute (AISI), "AISI Industry Profile Book", updated March 2023, https://www.steel.org/wp-content/uploads/2024/01/AISI-Profile-Book_updated-3.2023.pdf.
[9] American Iron and Steel Institute and Steel Manufacturers Association (AISI and SMA), "Determination of Steel Recycling Rates in the United States", July 2021, https://www.steel.org/wp-content/uploads/2021/08/AISI-and-SMA-Steel-Container-Recycling-Rates-Report-Final-07-27-2021.pdf.

mills.[10] Steel produced by BF/BOF production route begins with the reduction of iron ore to form steel with an average of 23% recycled content in 2019.[11] However, EAF impacts can vary based on electricity source and the share of scrap inputs.[12,13] The U.S. steel industry has relatively low-GHG-intensive electricity mixes and the domestic steel industry uses a greater share of natural gas in place of higher GHG-intensive energy sources than other regions, resulting in the domestic steel industry having the lowest GHG intensity of all major steel producing regions in the world.[14]

Current industry-average data is limited regarding the share of EAF versus BF/BOF and the associated amounts of recycled content at the product level. In the U.S., all hot-rolled structural steel sections and rebar are produced by EAF mills. Flat products, including the plate and steel sheet that supply metal building systems, are produced via both steelmaking routes. Facility-specific EPDs are becoming increasingly available for these products; however, the data are reported on a per ton of product basis and do not report the production quantities that are needed to develop average values. See page 6 and Table 1 for the EAF share and recycled content at the component level for metal building systems.

Metal buildings are durable and repairable enabling a long service life due to their use of steel materials, as well as design and construction practices. At the end of the building's useful life, metal buildings can be reused, disassembled for component reuse, or recycled in their entirety. All structural steel is recycled at historically demonstrated high rates in the U.S., namely 97% based on data for 2019.[15,16] During fabrication and construction, any scrap generated is collected and returned to steel producers for recycling.

This is in sharp contrast to most other materials that are typically landfilled or downcycled,[17] as shown in Figure 3. Metal products are recycled at high rates into other "manufactured products", meaning recycled back into metal products, whereas the majority of wood (69%) and bricks (85%) are landfilled. A significant share of wood products (20%) is combusted as fuel, thereby removing the resource from circulation and also releasing the carbon contained in the wood into the atmosphere. Concrete comprises the largest share at over 50% of C&D waste that ends up in a landfill as shown in Figure 4. The end-of-life concrete that is not landfilled is mainly downcycled into aggregate. Only a small share of concrete (8%) is used as a raw material for new concrete production. The majority of environmental impact associated with concrete is attributed to cement, which must still be added to form new concrete. In fact, using crushed concrete

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[10] World Steel Association, "Sustainability Indicators Report 2025", https://worldsteel.org/wider-sustainability/sustainability-indicators/.
[11] American Iron and Steel Institute and Steel Manufacturers Association (AISI and SMA), "Determination of Steel Recycling Rates in the United States", July 2021, https://www.steel.org/wp-content/uploads/2021/08/AISI-and-SMA-Steel-Container-Recycling-Rates-Report-Final-07-27-2021.pdf.
[12] World Steel Association, "Sustainability Indicators Report 2025".
[13] Global Efficiency Intelligence (GEI), "Steel Climate Impact An International Benchmarking of Energy and CO_2 Intensities", April 2022, https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities.
[14] Ibid.
[15] AISI and SMA, July 2021.
[16] Smart EPD, Part A Product Category Rules for Building and Construction Products and Services, Standard 1000, version 1.2, March 14, 2025. Table 3. https://smartepd.com/pcr-library.
[17] U.S. Environmental Protection Agency (EPA), "Construction and Demolition Debris Management in the United States, 2015", March 2015. https://www.epa.gov/sites/default/files/2020-03/documents/final_cd-eol-management_2015_508.pdf.

demolition waste over natural aggregates increase the water demand, and therefore requires higher cement demand, in a given concrete mix.[18]

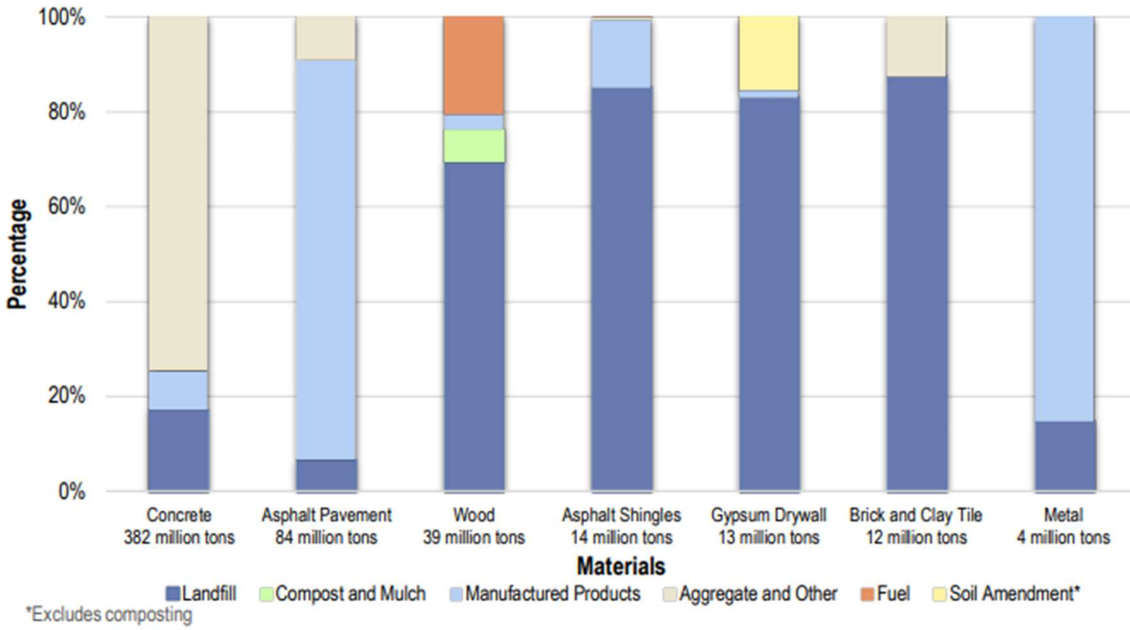

FIGURE 3. C&D MANAGEMENT BY MATERIAL TYPE IN THE U.S. IN 2025.
Source: U.S. Environmental Protection Agency.[19]

In terms of quantity of material that ends up in U.S. landfills, wood makes up the second largest share at over 20%. Steel, due to its mature recycling markets and favorable economics, makes up the smallest share at only 2.6%.

[18] Sika Group, "Can Concrete Be Recycled?", undated, https://www.sika.com/en/knowledge-hub/can-concrete-be-recycled.html.
[19] U.S. EPA, "Construction and Demolition Debris Management in the United States, 2015", March 2015. Figure ES-3. https://www.epa.gov/sites/default/files/2020-03/documents/final_cd-eol-management_2015_508.pdf.

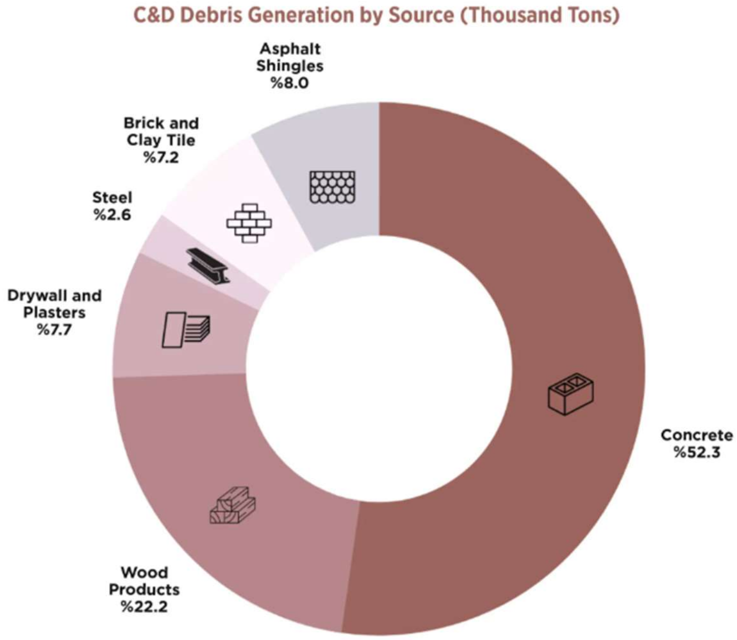

FIGURE 4. PROPORTIONAL LANDFILL PERCENTAGES FROM C&D WASTE MATERIAL TYPES.
Source: LMN Architects.[20]

Measuring Sustainability and Embodied Carbon

The concept of sustainability was defined in 1987 by the United Nations Brundtland Commission as "meeting the needs of the present without compromising the ability of future generations to meet their own needs".[21] While sustainability also includes social and economic aspects, it is most often considered and assessed in terms of environmental impact. Sustainability is evaluated in various ways, including attributes such as recycled content, energy intensity, strength and durability, repair/replacement requirements, and end-of-life recycling rates. More holistic approaches like life cycle assessments (LCAs) quantify potential life cycle environmental impacts of products. These metrics are considered alongside datapoints like product availability and upfront costs to enable informed decision making.

Products used in the construction sector are often assessed using LCA and reported in concise summary documents called Environmental Product Declarations (EPDs). EPDs report on a set of life cycle environmental impacts associated with the production of products from cradle-to-gate, meaning from the extraction of raw materials, transportation, and manufacturing of those materials into products. The most commonly referenced environmental impact category reported in an EPD is Global Warming Potential (GWP), which is a measure of aggregated greenhouse gas emissions reported on the basis of carbon dioxide-equivalents (CO_2eq). This metric is often termed "embodied carbon" and is the basis of material selection decisions and green procurement

[20] Pete Seeger, LMN Architects, "09 – Circular Economy + Products", edited March 25, 2025, https://lmnarchitects.com/lmn-research/09-circular-economy-products.
[21] United Nations Brundtland Commission, "Report of the World Commission on Environment and Development: Our Common Future", 1987, http://www.un-documents.net/our-common-future.pdf.

policies at the state and formerly federal level in the U.S.[22,23] While embodied carbon can inform potential climate-related impacts of producing or manufacturing building products, additional life cycle stages and metrics are necessary to understand potential trade-offs with processes downstream of the manufacturing facility gate, potential waste management issues in the future, and with other environmental impacts throughout the life cycle.

As defined in ISO 21930:2017[24] and illustrated in Figure 5, EPDs transparently report potential impacts in a modular format enabling a reader to understand the impacts of raw materials (in Module A1) separately from the transportation of raw materials (A2) and the manufacturing of products (A3). Most EPDs only report Module A1-A3 impacts in accordance with Product Category Rules (PCR) and procurement requirements. PCRs are product or material-specific documents that establish the requirements for LCA studies and EPDs. Some EPDs are also beginning to quantify the impacts of transporting products to job sites (A4), construction/installation (A5), product use (Module B1-B7), end-of-life (Module C1-C4), and the benefits or burdens associated with reuse and recycling of products (Module D). The disclosure of downstream modules for steel construction products is done voluntarily for increased transparency and to highlight the high recyclability and low end-of-life impacts of steel. The governing PCRs and ISO 21930:2017 only require Modules A1-A3; however, the latest steel PCR (Smart EPD Part B v3)[25] encourages the reporting of life cycle impacts beyond production, i.e., downstream of Module A3, for steel construction products produced and sold in the North American market.

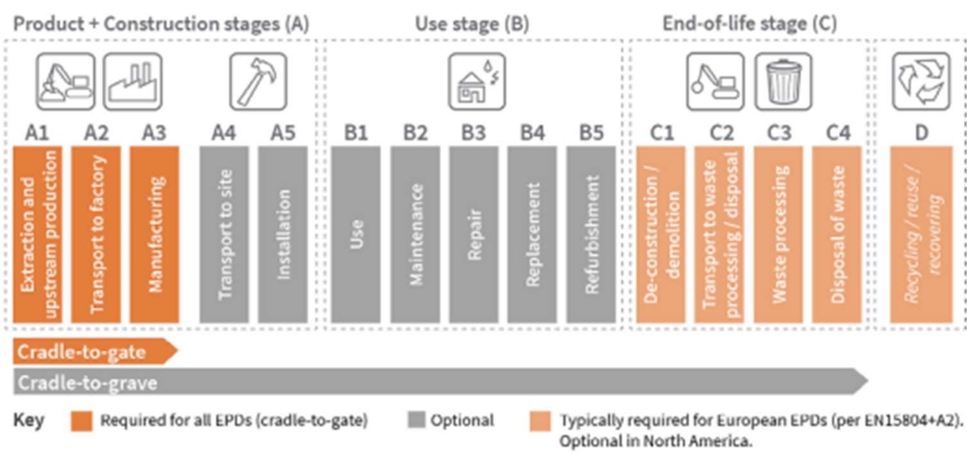

FIGURE 5. LIFE CYCLE STAGES TYPICALLY INCLUDED IN NORTH AMERICAN EPDS.
Note: Module names are in accordance with ISO 21930:2017.[26] PCRs and material procurement programs dictate which life cycle stages are required, excluded, or optional.
Source: Carbon Leadership Forum, 2024[27]

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[22] State Climate Policy Dashboard, last updated July 2025, https://www.climatepolicydashboard.org/policies/industry-materials-waste/buy-clean.
[23] Office of the Federal Chief Sustainability Officer, "Federal Buy Clean Initiative", https://www.sustainability.gov/archive/biden46/buyclean/index.html.
[24] ISO 21930:2017, "Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services", 2017, https://www.iso.org/standard/61694.html.
[25] Smart EPD, "Part B Product Category Rules for Designated Steel Construction Products", Standard 1000-008, version 3, April 3, 2025, https://smartepd.com/pcr-library.
[26] ISO 21930:2017.
[27] Carbon Leadership Forum, "Environmental Product Declarations 101", https://carbonleadershipforum.org/environmental-product-declarations-epd-101/

Steel construction products typically do not require maintenance, repair or replacement during the building's useful lifetime. In fact, the latest Part B steel construction products PCR (v3) stipulates that all B modules for steel construction products with a reference service life of equal to or greater than 75 years are to be declared as zero.[28] The majority of impacts associated with steel construction products are covered in Modules A1-A3.

Steel construction products are recycled at high rates and can be recycled continuously into new steel products. The small share of steel products (approximately 3%)[29] that are abandoned or landfilled do not cause further environmental impact; however, steel scrap is valuable and best managed by recovery and recycling for financial, environmental, and circularity benefit. Across all materials, case studies by the World Business Council for Sustainable Development (WBCSD) found the estimated end-of-life carbon emissions are small relative to the production and construction (A1–A5) phases.[30] On average, the end-of-life phase in these case studies accounted for less than 2% of the total impacts across life-cycle stages A to C. However, the potential benefits associated with material recovery (stage D) offer a carbon benefit equivalent to 25% of the total A–C life-cycle phases.

EPDs for metal building components, namely the primary structural steel frames, secondary structural steel frames, and roll-formed metal roof and wall panels, were published by the Metal Building Manufacturers Association in 2021.[31] These documents transparently report the cradle-to-gate environmental impacts, including embodied carbon and other environmental indicators informing air and water quality impacts, of metal buildings manufactured in the U.S.

In addition to environmental indicators, the EPDs also report quantitative values for several inventory metrics, including freshwater and energy consumption and the amount of secondary material used in manufacturing. Secondary materials are defined by ISO 21930: 2027 as material recovered from previous use or from waste derived from another product system and used as an input, such as recycled scrap metals.[32] Primary structural steel frames are manufactured from steel sourced primarily from EAF mills (88%). Accordingly, for every 1000 kg of primary structural steel frame components manufactured, 974 kg of secondary materials are consumed.[33] Secondary structural steel frame components are made from steel produced primarily from the EAF route (80%) and consume 473 kg of secondary materials for every 1000 kg produced.[34] Wall and roof panels are made from steel produced using a mix of BF/BOF (58-59%) and EAF (41-42%) technologies and consume 159-172 kg of secondary materials for every 100 m^2 of wall (417 kg/m^2)

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[28] Smart EPD, "Part B Product Category Rules for Designated Steel Construction Products", Standard 1000-008, version 3, April 3, 2025. Section 7.1.7.4. https://smartepd.com/pcr-library.

[29] American Iron and Steel Institute and Steel Manufacturers Association (AISI and SMA), "Determination of Steel Recycling Rates in the United States", July 2021, https://www.steel.org/wp-content/uploads/2021/08/AISI-and-SMA-Steel-Container-Recycling-Rates-Report-Final-07-27-2021.pdf.

[30] RMI, " Policy Opportunities to Increase Material Circularity in the Buildings Industry", August 2022, https://rmi.org/opportunities-to-increase-material-circularity-in-the-buildings-industry/

[31] MBMA, "Sustainability Resources" website. https://mbma.com/energy-sustainability.

[32] ISO 21930:2017, "Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services", 2017. https://www.iso.org/standard/61694.html.

[33] MBMA, "Primary Structural Steel Frame Components", Environmental Product Declaration, April 1, 2021. Table 4 secondary materials (SM) results. https://mbma.com/energy-sustainability.

[34] MBMA, "Secondary Structural Steel Frame Components", Environmental Product Declaration, April 1, 2021. Table 4 secondary materials (SM) results. https://mbma.com/energy-sustainability.

and roof (473 kg/m^2) panels produced, respectively.[35] Table 1 shows the quantity of secondary materials consumed, calculated end-of-life materials recycled, and embodied carbon for each metal building component.

TABLE 1. SECONDARY MATERIAL CONSUMED AND MATERIAL RECYCLED AT END-OF-LIFE FOR METAL BUILDING COMPONENTS.

Metal Building Component	Declared unit	Secondary Materials Consumed*	Materials Recycled at End-of-life**	Embodied Carbon (GWP-100, Modules A1-A3)
Primary structural steel frame components	1,000 kg	974 kg	970 kg	1,468 kg CO_2eq
Secondary structural steel frame components	1,000 kg	473 kg	970 kg	1,929 kg CO_2eq
Roll-formed metal wall and roof panels	100 m^2 [417 kg] (wall panels) 100 m^2 [473 kg] (roof panels)	159 kg (wall panels) 172 kg (roof panels)	404 kg (wall panels) 459 kg (roof panels)	1,233 kg CO_2eq (wall panels) 1,326 kg CO_2eq (roof panels)

* Vales as reported in MBMA's 2021 EPDs per ISO 21930:2017 requirements. Secondary materials are materials recovered from previous use or wastes and used as an input into another product system, like steel scrap.

** Calculated using the declared unit mass and a 97% recycling rate for structural steel from AISI and SMA, 2021.[36]

All other data sourced from MBMA 2021 industry-wide EPDs[37]

While EPDs provide transparent data for procurement decisions, building design decisions and comparisons across building material types should only be done at the whole building level where the function of the material is taken into account.[38,39] Walter P Moore conducted whole building LCA case studies on behalf of MBMA in 2025[40] using the Athena Impact Estimator software. The study results showed metal buildings to have generally lower environmental impacts, including embodied carbon, compared to masonry, concrete, tilt up, and conventional steel-framed buildings for a warehouse facility in three U.S. locations, and similar or lower impacts compared to other building types for an industrial facility in the same locations. These competing building material types also typically have higher landfill or downcycling rates at end-of-life as discussed previously.

Small office buildings constructed out of wood showed lower environmental impacts than metal buildings given the biogenic carbon accounting and other methodological and data assumptions built into the Athena tool. Biogenic carbon is carbon derived from biomass, which is a material of biological origin excluding material embedded in geologic formations or transformed to fossilized material and excluding peat.[41] Wood removes CO_2 from the atmosphere while growing and stores the carbon temporarily as biogenic carbon content, only to be re-emitted when the product

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[35] MBMA, "Roll Formed Metal Wall and Roof Panels", Environmental Product Declaration, April 1, 2021. Tables 5 and 6 secondary materials (SM) results. https://mbma.com/energy-sustainability.

[36] American Iron and Steel Institute and Steel Manufacturers Association (AISI and SMA), "Determination of Steel Recycling Rates in the United States", July 2021, https://www.steel.org/wp-content/uploads/2021/08/AISI-and-SMA-Steel-Container-Recycling-Rates-Report-Final-07-27-2021.pdf.

[37] MBMA, "Sustainability Resources" website.

[38] ISO 21930:2017, "Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services", 2017. https://www.iso.org/standard/61694.html.

[39] Smart EPD, Part A Product Category Rules for Building and Construction Products and Services, Standard 1000, version 1.2, March 14, 2025. Pg. 66. https://smartepd.com/pcr-library.

[40] Walter P Moore, "Athena Impact Estimator Case Studies", prepared for MBMA, S06.24053.00, May 2, 2025. https://mbma.com/energy-sustainability.

[41] ISO 21930:2017, section 3.7.1 and 3.7.2.

reaches its end-of-life as CO_2 during combustion or decomposition or as methane (CH4) during anerobic conditions in a landfill. The assumptions around the amount of wood landfilled at end-of-life and the rate of decomposition of biogenic carbon to form methane vary across whole building LCA tools and have a significant affect on the GWP results for wood products. Furthermore, wood from construction waste tends to have high landfill rates, which also takes the material out of circulation.

The Walter P Moore case study concluded that for the types of buildings where metal buildings are most economical, they typically also perform better in life cycle environmental assessments including lowest embodied carbon impacts.

Measuring Circularity for a Holistic View of Sustainability

Circularity is an emerging assessment method that aims to inform, transform, and accelerate a more circular economy as a compliment and catalyst for a more sustainable economy. Per the Ellen MacArthur Foundation[42]: "*The circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources.*"

In 2024, a series of new ISO standards were published in Technical Committee 323 to define and measure circularity in order to encourage the transition of business models from linear ("take – make – dispose") to circular. ISO 59004:2024[43] defines circularity as "*the degree of alignment with the principles for a circular economy*" (3.1.15), which is an "*economic system that uses a systemic approach to maintain a circular flow of resources by recovering, retaining, or adding to their value, while contributing to sustainable development*" (3.1.1). ISO 59020:2024[44] provides a framework for assessing and reporting on circularity performance, which should be complimented by LCA. The core circularity indicators mandated by ISO 59020 include:

1. Average reused content (A.2.2) – Fraction of input material resources that are reused components and products
2. Average recycled content (A.2.3) – Fraction of input material resources that is recycled material
3. Percent actual reused products and components (A.3.3) – Fraction of outflow that is reused
4. Percent actual recycled material (A.3.4) – Fraction of outflow that becomes recycled material
5. (Optional) Average lifetime of product or material relative to industry average (A.3.2) – Indicator of time that an output resource (e.g. product) will remain in use compared to an industry average for the resource

Circularity has grown in importance, especially in the construction sector where the majority of materials produced are used and the demand for materials is accelerating. The built environment

[42] Ellen MacArthur Foundation, "Circular economy introduction", https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview.
[43] ISO 59004:2024, "Circular economy — Vocabulary, principles and guidance for implementation", May 2024, https://www.iso.org/standard/80648.html.
[44] ISO 59020:2024, "Circular economy — Measuring and assessing circularity performance", May 2024, https://www.iso.org/standard/80650.html.

is responsible for 42% of annual global CO_2 emissions, including 59% of the global steel industry's emissions and 100% of the emissions associated with global cement production[45]. According to Architecture 2030[46], the world is expected to add about 2.6 trillion ft^2 (241 billion m^2) of new floor area to the global building stock, representing a doubling of the global building floor area between 2020 and 2060. According to AIA, under BAU, more than 50% of emissions from new construction will come from CO_2 emitted during the production of materials, primarily cement and steel.[47]

According to the U.S. Green Building Council (USGBC)[48], circular products are "durable and repairable, and contain few toxins". They are manufactured and installed with the future in mind. Circular buildings are "durable, long-lasting, and flexible". Amongst the key strategies identified by USGBC for transitioning to more circular buildings is designing for disassembly, which means using screws and hidden fasteners and selecting durable materials with repairable finishes and those that can be taken apart and recycled when no longer useful. Figure 6 details USGBC's strategies for raw materials, product manufacturing, and building construction.

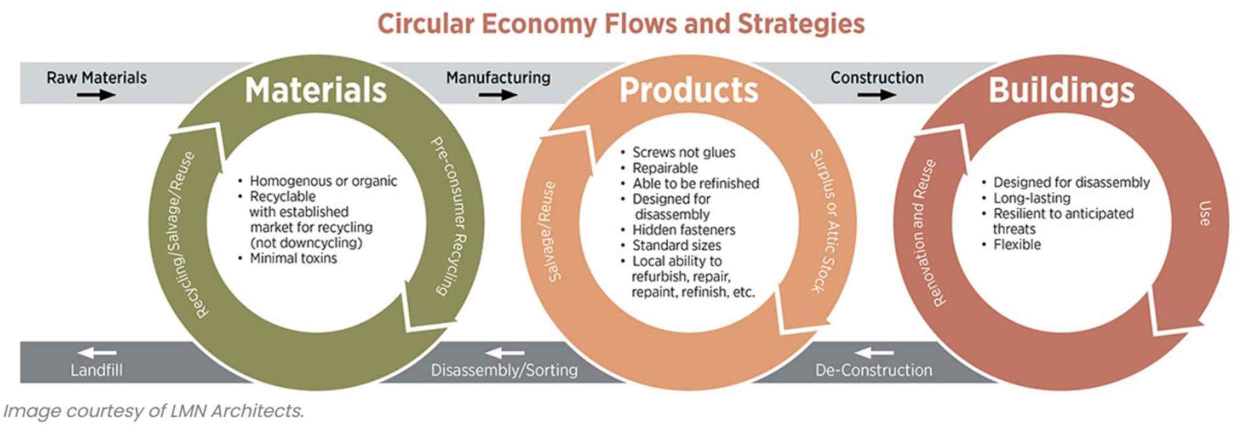

FIGURE 6. USGBC CIRCULAR ECONOMY FLOWS AND STRATEGIES.
Source: USGBC, 2024.[49]

Furthermore, USGBC introduced a pilot credit in LEED v4.1 (MRpc131) for "Circular Products".[50] Projects may achieve this credit by using at least five permanently installed products from three manufacturers that demonstrate achievement of at least one of the circular product reports listed below. No more than four products can come from one category of criteria below.

Circular Product pilot credit categories:

1. Recycled content disclosure – disclose the amount of recycled content, pre- and post-consumer.

[45] Architecture 2030, "Why the Built Environment?", https://www.architecture2030.org/why-the-built-environment/.
[46] Ibid.
[47] AIA Materials Pledge Starter Guide, November 2023. https://www.aia.org/sites/default/files/2024-11/AIA_Materials_Starter_Guide.pdf.
[48] Kjell Anderson, "Toward a circular economy of building materials," U.S. Green Building Council, January 2024, https://www.usgbc.org/articles/toward-circular-economy-building-materials.
[49] Ibid.
[50] U.S. Green Building Council, "Circular Products", https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-data-70?return=/credits/New%20Construction/v4.1

2. Safe & circular – manufacturers of products that contain specific types of recycled content (including steel, plastics, wood, and glass) shall provide a lab analysis of the recycled content that tests for common contaminants.
3. Zero waste manufacturing – select products manufactured in a facility that reduces waste throughout the manufacturing process and is third party verified to divert 90% or more of all waste from landfill and incineration, including GreenCircle Zero Waste to Landfill, NSF Landfill-free, TRUE Certification, and UL 2799.
4. Designed for circularity – Select products that have been designed for disassembly, repair, or reuse at the end of use and for which the manufacturer has provided detailed information on maintenance, reuse, disassembly and recovery options, including a published EPD with a cradle-to-grave scope or Cradle to Cradle certification (Materials Reutilization or Product Circularity categories).

LEED v5[51] released in 2025 has been redesigned to focus on disclosure and reduction of embodied carbon based largely around requirements for EPDs, and will soon be piloting a credit for “Design for Circularity”.

Also in the construction space, the AIA established an Architecture & Design Materials Pledge to advance sustainability and circularity in the built environment. There are five impact categories established by the AIA Pledge, namely Climate Health, Ecosystem Health, Human Health, Social Health and Equity, and Circular Economy. Projects reported through the Pledge must have completed design and issued construction documents in the previous calendar year. Material Pledge “reporting crosswalks” with certification systems, such as LEED and Living Building Challenge, are in development.[52]

The AIA Pledge focuses on priority product types from the Common Materials Framework (CMF)[53], developed by mindful MATERIALS (mM), which forms the foundation for reporting at the product level. Figure 7 shows the sub-impact categories and factors in the Common Material Framework for the Climate Health and Circular Economy impact categories. Figure 8 shows the priority product types and aligned impact categories. Red boxes signify metal building product types, which in all cases cover both climate health and circular economy categories.

[51] U.S. Green Building Council, “LEED v5 Building Design and Construction rating system”, https://www.usgbc.org/resources/leed-v5-rating-system-building-design-and-construction.
[52] AIA A&D Materials Pledge Reporting Guide, 2024. https://www.aia.org/sites/default/files/2025-02/AIA_Materials%20pledge%20guide_Jan25.pdf.
[53] Mindful Materials, Common Materials Framework (CMF). https://www.mindfulmaterials.com/a-common-language.

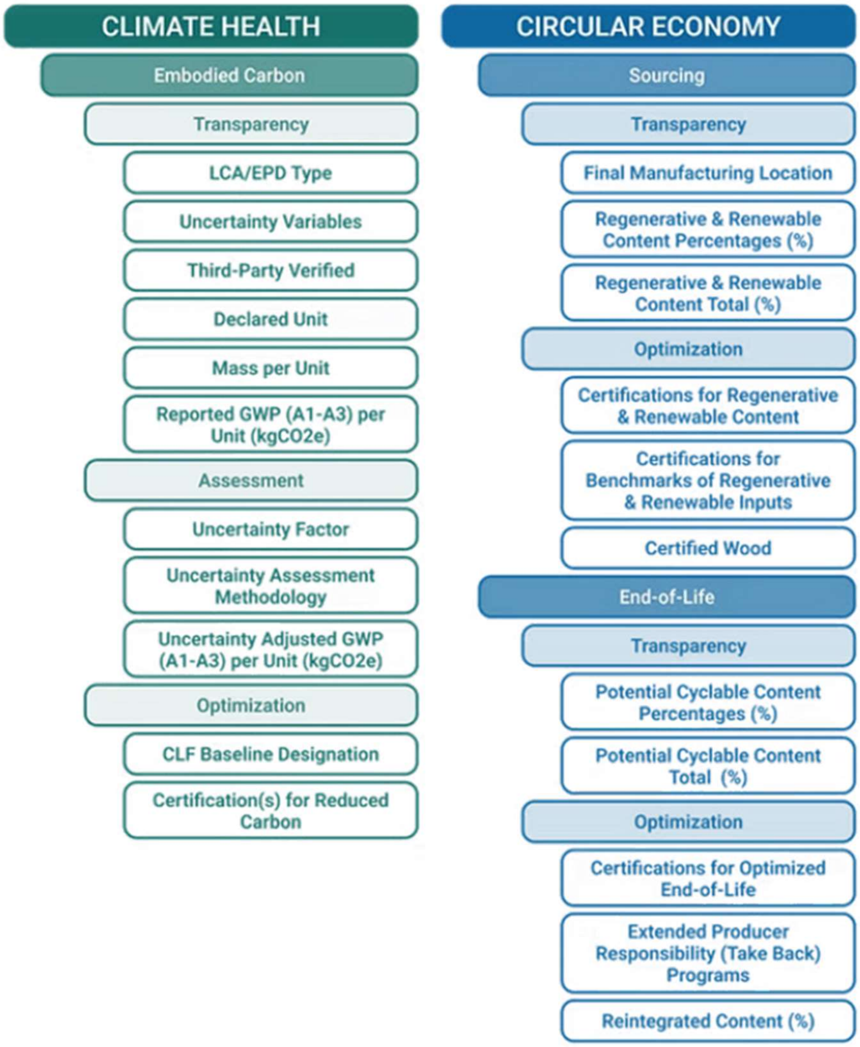

FIGURE 7. AIA MATERIALS PLEDGE COMMON MATERIALS FRAMEWORK FOR CLIMATE HEALTH AND CIRCULAR ECONOMY IMPACT CATEGORIES

Source: AIA Material Pledge Reporting Guide[54]

[54] AIA A&D Materials Pledge Reporting Guide, 2024. https://www.aia.org/sites/default/files/2025-02/AIA_Materials%20pledge%20guide_Jan25.pdf.

PRODUCT TYPES			ALIGNED IMPACT CATEGORIES				
COMMON SPEC DIVISION	CATEGORY	PRODUCT TYPES INCLUDED	CLIMATE HEATH	HUMAN HEALTH	CIRCULAR ECONOMY	SOCIAL HEALTH + EQUITY	ECOSYSTEM HEALTH
033000	Cast-in-place concrete	Concrete mixes, reinforcing steel (rebar)	●				
042000	Unit masonry	Brick, concrete masonry units (CMU)	●				
Various	Stone assemblies	Natural stone cladding, flooring, tiling, etc				●	●
051200	Structural steel	Structural steel columns, beams, and decking	●		●	●	
061000	Rough carpentry	Dimensional lumber					●
061500/061800	Mass timber	Glulams, CLT, DLT, NLT, mass plywood	●			●	●
062000	Finish carpentry	Milwork including trim, base, wood panels		●		●	●
072100	Insulation	Board, batt/blanket insulation	●	●			
074213	Metal wall panels	Exterior envelope metal panels	●		●		
081113	Hollow metal doors and frames	Steel doors and frames	●				
081416	Flush wood doors	Wood doors				●	●
088000	Glazing	Flat glass, insulated glazing units	●				
092116	Gypsum board assemblies	Standard or fire-rated gypsum board, sheathing	●	●			
054000/092216	Non-structural metal framing	Structural cold-formed or interior metal stud framing	●		●		
093000	Tiling	Ceramic, porcelain, stone, glass, etc.	●				
095100	Acoustical ceilings	Ceiling panels (mineral, fiberglass, stone, wool), suspension systems	●	●	●		
096500	Resilient flooring	Resilient tile and Sheet flooring, resilient base		●		●	
096800	Carpeting	Tile carpeting, broadloom/sheet carpeting, rugs	●	●	●	●	
099000	Paint and coatings	Interior paints and primers, standard performance		●		●	
123600	Countertops	Countertops of various types		●			
Various	Fabric	Fabric for wall panels, furniture, curtains, etc.		●		●	
Div 12	Furniture	Various movable furniture items		●	●		●

FIGURE 8. AIA PLEDGE PRIORITY PRODUCT TYPES AND ALIGNED IMPACT CATEGORIES.
Source: AIA Material Pledge Reporting Guide[55]

The Climate Health category signifies a commitment to "design buildings and select materials to accelerate the drive to zero by building less, reusing and retrofitting more, and choosing materials and products that will store carbon in our buildings in the long term."[56] It encourages designers to utilize EPDs to understand carbon impacts of materials and whole building LCAs to select materials and systems that first reduce the carbon impacts of buildings, then other impacts assessed by LCA. The Pledge recommends using "low-carbon" and "carbon sequestering" materials, starting with evaluating highest-impact materials in the building structure, envelope, wallboard, flooring, insulation, ductwork, ceiling panels, etc. It also encourages companies to advocate for policies that "impose greater transparency of, and limits on, the global warming potential impacts of building products". [57]

The Circular Economy category focuses on the reuse and improvement of buildings through designing for "resiliency, adaptability, disassembly, and reuse, aspiring to a zero-waste goal for global construction activities".[58] The Pledge encourages teams to prioritize reusing existing buildings and materials over new construction, including "evolving specifications to design for

[55] AIA A&D Materials Pledge Reporting Guide, 2024. https://www.aia.org/sites/default/files/2025-02/AIA_Materials%20pledge%20guide_Jan25.pdf.
[56] AIA Materials Pledge Starter Guide, November 2023. https://www.aia.org/sites/default/files/2024-11/AIA_Materials_Starter_Guide.pdf.
[57] Ibid.
[58] Ibid.

disassembly and reuse". Recommended actions include promoting modular design to reduce construction waste, selecting materials that "can be recycled into the same type of material", and "requir[ing] manufacturers to publish end-of-life strategies" and encouraging Module D assessment for all building materials.

Summary and Recommendations

Metal buildings are well aligned with sustainability and circularity assessment methods and design strategies as outlined by AIA, USGBC, and ISO. The following attributes, as detailed throughout this paper, highlight the role metal buildings play in a sustainable and circular economy:

1. The metal buildings industry is transparent about its environmental impacts, including embodied carbon, through its published industry-wide EPDs for primary structural steel frame components, secondary structural steel frame components, and roll formed metal roof and wall panel EPDs. These EPDs present potential environmental impacts separately for raw materials, transportation, and manufacturing as required by AIA's Material Pledge and USGBC's LEED v5 frameworks.
2. Metal buildings are manufactured from steel with high recycled content and demonstrated high recycling rates at end-of-life. Steel recovered from construction applications is reused or recycled into new steel buildings and other steel products while maintaining its inherent material properties.
3. Competing building materials, such as wood, masonry, and concrete, typically have higher landfilling rates or are downcycled.
4. Metal buildings manufactured from steel produced in the U.S. benefit from a supply chain with the lowest GHG intensity of all major steel producing regions in the world.
5. Metal buildings are designed to efficiently use materials and minimize waste during construction, thereby using only the material where it is needed and leading to an embodied carbon efficient building.
6. For the types of buildings where metal buildings are most economical, including warehouses and industrial buildings, they typically also perform better in life cycle environmental assessments including lowest embodied carbon impacts compared to competing materials.

Designers and architects are encouraged to take a holistic view inclusive of embodied carbon and other environmental metrics throughout the building life cycle, including consideration of Module D, along with circularity assessments for informed decision-making. When circularity and sustainability are part of a decision-maker's toolbox, alongside economic and timeline considerations, metal buildings are a proven solution.

Appendix A. Detailed Process Flow Diagrams for Metal Building System Component Manufacturing

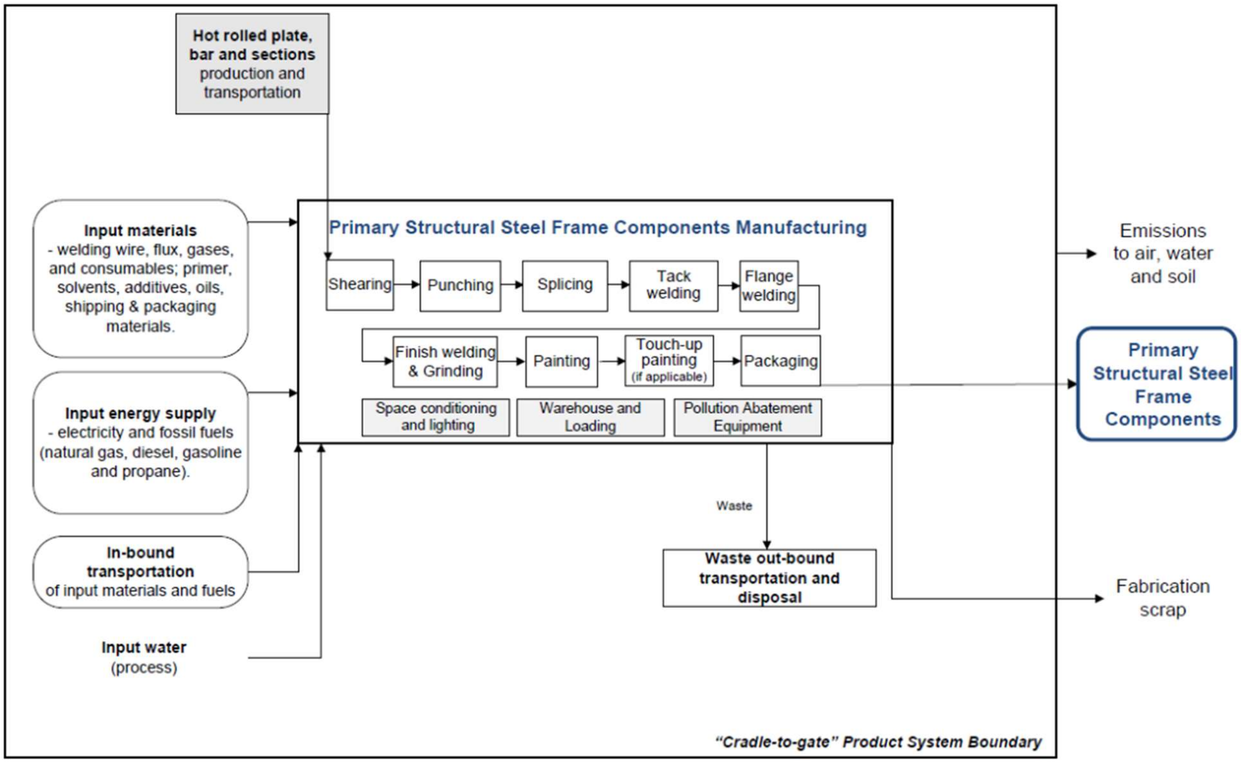

FIGURE 9. PRIMARY STRUCTURAL STEEL FRAME COMPONENTS MANUFACTURING PROCESS.
Source: MBMA Industry-wide EPD.[59]

[59] MBMA, "Primary Structural Steel Frame Components", Environmental Product Declaration, April 1, 2021. https://mbma.com/energy-sustainability.

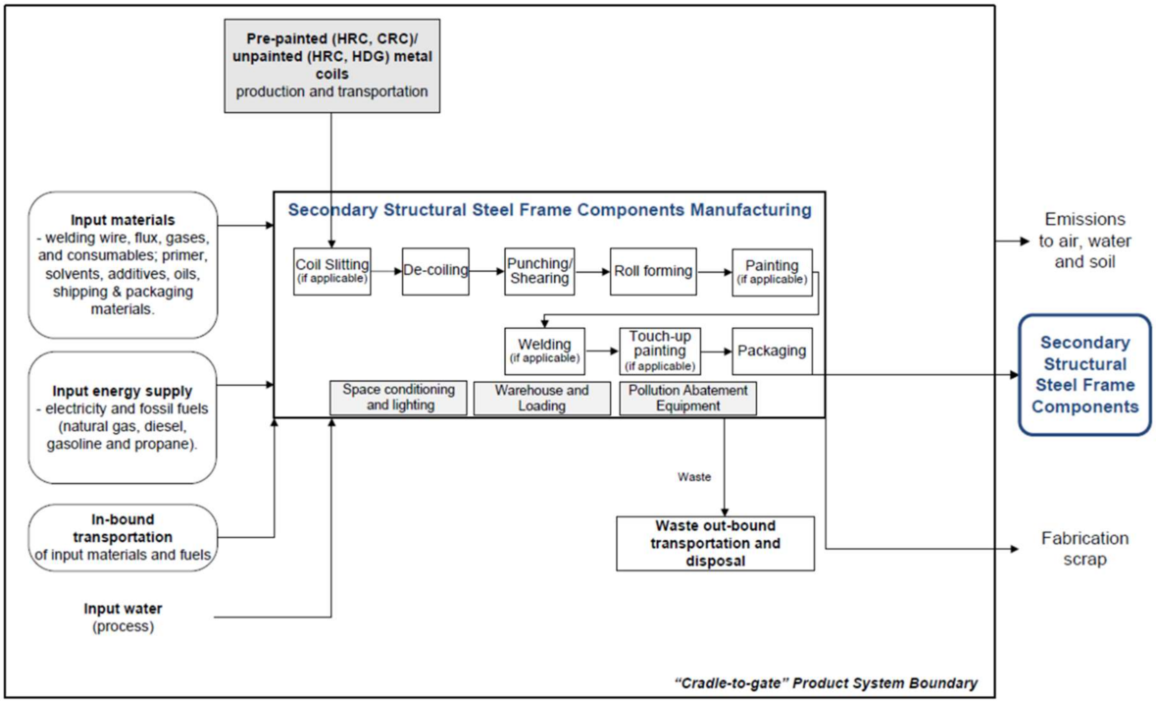

FIGURE 10. SECONDARY STRUCTURAL STEEL FRAME COMPONENTS MANUFACTURING PROCESS.
Source: MBMA Industry-wide EPD.[60]

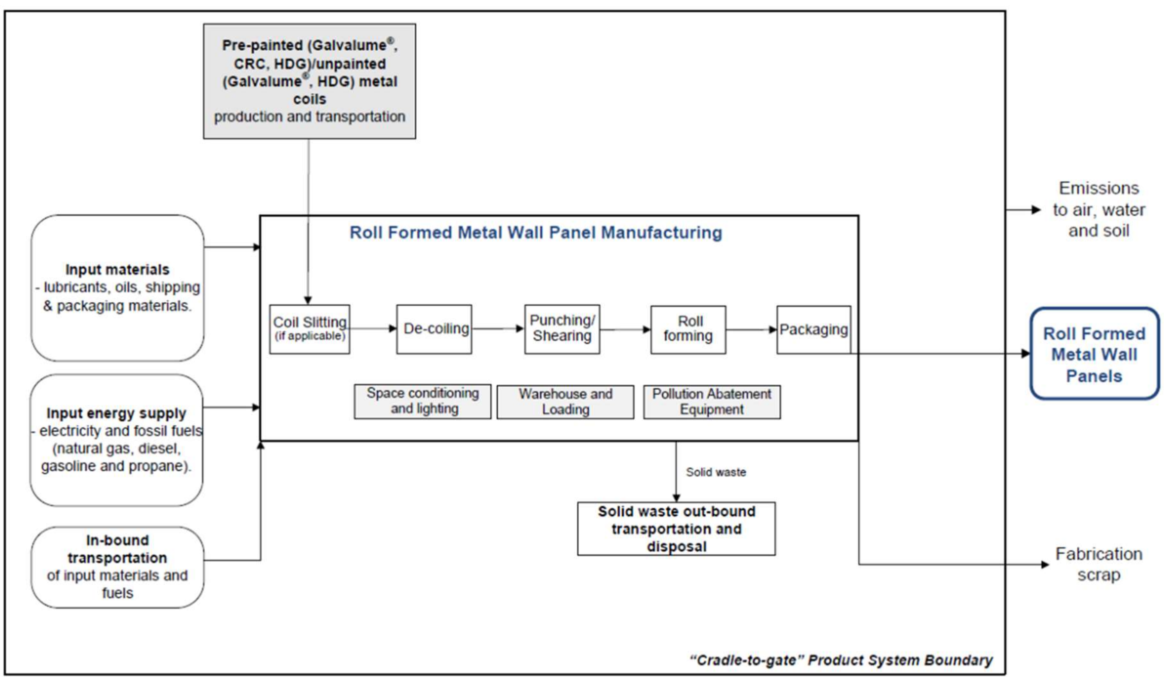

FIGURE 11. ROLL FORMED METAL WALL PANEL MANUFACTURING PROCESS.
Source: MBMA Industry-wide EPD.[61]

[60] MBMA, "Secondary Structural Steel Frame Components", Environmental Product Declaration, April 1, 2021. https://mbma.com/energy-sustainability.
[61] MBMA, "Roll Formed Metal Wall and Roof Panels", Environmental Product Declaration, April 1, 2021. https://mbma.com/energy-sustainability.

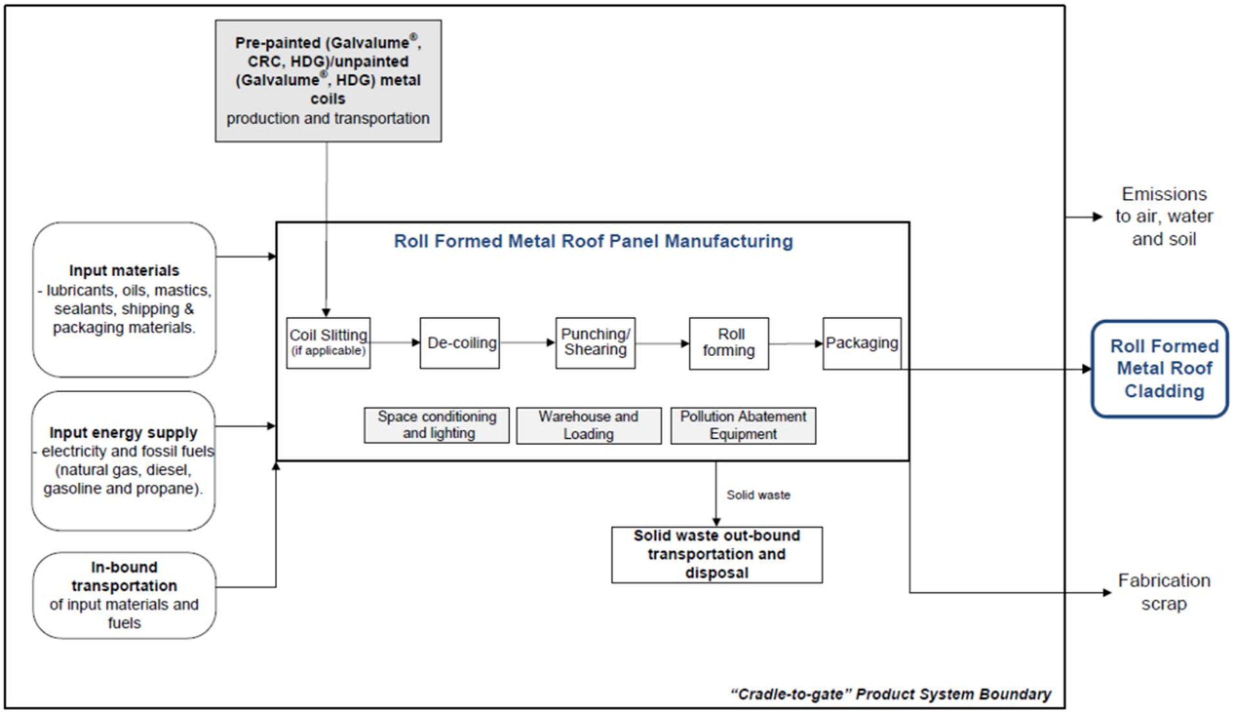

FIGURE 12. ROLL FORMED METAL WALL PANEL MANUFACTURING PROCESS.
Source: MBMA Industry-wide EPD.[62]

[62] MBMA, "Roll Formed Metal Wall and Roof Panels", Environmental Product Declaration, April 1, 2021. https://mbma.com/energy-sustainability.