Sustainability and Beyond

The Untold Life Cycle of a Steel Joist

By Laura Micheli, Ph.D., Bruce Brothersen, P.E., S.E., P.Eng, and Scott Russell, P.E., S.E., P.Eng

The attributes of open web steel joists are well known to the structural engineering and construction community. Their efficiency, high strength-to-weight ratio, versatility, ease of erection, high durability, and cost-effectiveness make steel joists and joist girders a common consideration for today's roofing and flooring systems. However, the manufacturing of open web steel joists and joist girders is often left out of the discussion, leaving engineers and decision-makers wondering what kind of processes occur behind the curtains of the manufacturing plant. This article aims to shed light on the typical life-cycle stages of steel joists, from steel production to building decommissioning, leading the readers into the realm of open web steel joist and joist girder manufacturing and sustainability.

Manufacturing Process

The life cycle of a steel joist starts in the steel mill, where angles, rods, and bars are manufactured. In the mill, steel can be produced with two types of furnaces: 1) a combination of integrated blast furnace (BF) and basic oxygen furnace (BOF), or 2) an electric arc furnace (EAF).

BF/BOF produces steel from mined materials, such as iron ore, coal, and limestone. First, purified coal, limestone, and iron ore are heated in the BF. The resulting product is then passed to the BOF, where oxygen is injected to reduce carbon content and impurities. From there, the liquid steel is cast and created into various steel products.

On the other hand, EAFs produce steel from recycled scrap material by melting the scrap with an electrical current. A small percentage of direct-reduced iron (DRI) and other material inputs can be added to the liquid steel to achieve the desired steel grade. EAFs are remarkably environmentally friendly relative to BF/BOFs, given their electricity usage as an energy source and recycled steel as the primary input. It is estimated that EAFs produce 85% less greenhouse gas (GHG) emissions per ton of steel than BF/BOFs. While BF/BOF are widely spread in other parts of the world, in the United States, steel is mainly produced with EAFs. Specifically, 2019 data estimates that 70% of the total steel produced in the United States was by the EAF route. Products used in steel joist manufacturing are almost exclusively created by the EAF process. The authors limited discussion to processes and products used for steel joists for this article.

Figure 1 schematically depicts the steel production process with an EAF. After the scrap is melted in the EAF, the furnace is de-energized and the liquid steel is poured into a ladle. The ladle transports the liquid steel to a stir station, where it is fed into a tundish through a ceramic tube. Subsequently, the tundish distributes the liquid steel to the caster, where continuous casting occurs, as shown in *Figure 1*. Next, each strand of the caster flows into a mold of the desired semi-finished shape, which is typically cooled with cold water. At this stage, the liquid steel starts to solidify. There are three main types of semi-finished products: blooms, billets, and slabs, which differ in shape and dimensions. Semi-finished products are then passed through a

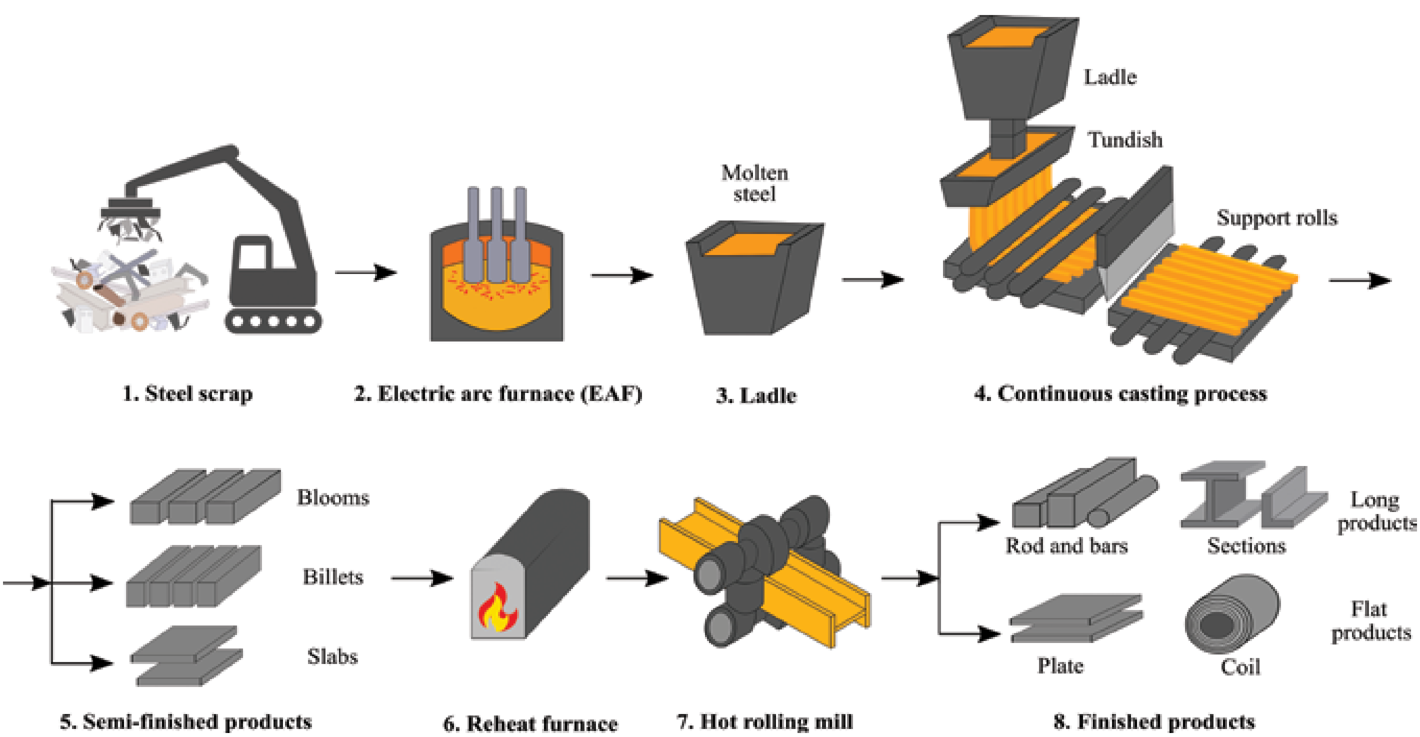

Figure 1. Schematic representation of the steel manufacturing process using an electric arc furnace.

reheat or normalizing furnace, where the steel is brought to the proper temperature before entering the rolling mill. Finally, in the rolling phase, billets are rolled to achieve the selected product shape (e.g., angle, rod, bar, plate) and cut to the desired length.

Angles, rods, plates, and bars produced at the steel mill are transported to the joist manufacturing facility, where they are assembled to form the selected joist series configuration. Joist series include K-series, typically employed for spans up to 60 feet, LH-series for longer spans well over 100 feet, and joist girders. Composite and special joists (e.g., single-pitched, multi-pitched, curved joists) are also regularly used. The steel joist's chord, web, and bearing seat components are carefully designed to achieve the required load-bearing capacity and meet specified design requirements. Joist components are then welded together, as shown in *Figure 2*. Finally, joists are coated with a primer to protect them from weather and corrosive substances during transportation to the site.

Environmental Impact

The above-described manufacturing processes produce GHG emissions. Information on the carbon footprint of the steel joist manufacturing process can be found in the Environmental Product Declaration (EPD), a report summarizing a product's environmental impact. EPDs can be obtained by conducting a life-cycle assessment (LCA) that considers three main life stages: raw material supply (stage A1), transportation (stage A2), and manufacturing (stage A3). The results of the LCA are expressed in terms of six impact category indicators: global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), eutrophication potential (EP), smog formation potential (SFP), and abiotic depletion potential (ADP). Out of these six impact category metrics, the GWP is the metric most commonly used to represent the carbon footprint of a given product. The *Table* reports the industry average values of the six impact category indicators for steel joists, derived from the EPD available on the Steel Joist Institute website (**https://bit.ly/3Fc31qn**). Such values refer to the production of one metric ton of joists and reflect the weighted industry average of different companies that manufacture steel joists. The EPD also reports that the industry average recycled content of open web steel joists and joist girders is 85%. On the other hand, the impact category indicator and recycled content values for a selected joist manufacturer can be found in the manufacturer-specific EPD, which contains information regarding their exact manufacturing process. The EPD also includes a description of the joist production process and the boundaries considered in the LCA.

The background LCA conducted to obtain the EPD of a given product typically spans only the raw material supply, transportation, and manufacturing life stages, referred to as "cradle-to-gate." Selecting the construction material with the lowest GWP in the EPD does not necessarily correspond to the most sustainable solution for the whole building. In civil structures, other life stages (e.g., maintenance, repair, energy use, demolition, recycling) need to be considered to evaluate the global carbon footprint of a building throughout its life cycle. This can be accomplished by performing a whole-building life-cycle analysis (WBLCA). Furthermore, EPDs of diverse construction materials (e.g., wood, steel, concrete) may be derived following different regulations and assumptions and considering different units of a given product. For example, steel EPDs usually refer to one metric ton of product, while wood products refer to one cubic meter of product. Therefore, a direct comparison between the GWP reported in EPDs of different construction materials may lead to incorrect results. The strength-to-weight ratio of steel is greater than wood and concrete, making the comparison based on weight even more complex.

Figure 2. Welding web to chords of an open web steel joist, Vulcraft facility.

Decarbonization Challenge

From the values reported in the *Table*, it is evident that the life-cycle stage contributing most to the GWP is stage A1, which for steel joists is represented by the manufacturing process of the joist components. One strategy to reduce the carbon footprint of steel manufacturing could be to employ renewable sources to energize the electric grid and, thus, EAF mills. The use of solar, hydroelectric, geothermal, and wind power could significantly reduce greenhouse gas production associated with electricity generation, which would lower the GWP values of steel production. However, the usage of renewable energy sources might depend on regional availability. Some steel manufacturing companies in the United States are investing in and promoting the

Table of industry average impact category indicators for one metric ton of steel joists.

Parameter	Unit	A1	A2	A3	Total
GWP 100	kg CO_2 eq.	1.19E+03	4.41E+01	2.03 E+02	1.43E+03
ODP	kg CFC 11 eq.	2.63E-08	8.75E-15	1.68E-09	2.79E-08
AP	kg SO_2 eq.	2.82E+00	2.62 E-01	1.76 E-01	3.26E+00
EP	kg N eq.	1.38E-01	2.31E-02	1.89E-02	1.80E-01
SFP	kg O_3 eq.	4.33E+01	7.45E+00	4.85E+00	5.56E+01
ADP_{fossil}	MJ surplus	1.16E+03	8.21E+01	3.88E+02	1.63E+03

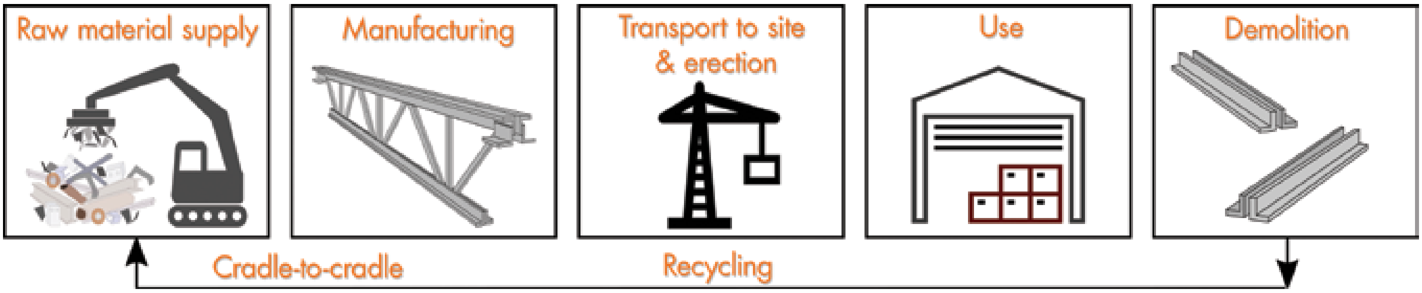

Figure 3. End-of-life of a steel joist: after usage, the joist components can be dismantled and recycled.

creation of solar and wind farms to fuel their manufacturing plants with renewable energy locally.

Another decarbonization strategy is through the use of carbon offset credits. A carbon offset represents a reduction of CO_2 (carbon dioxide) or other GHG in the atmosphere to compensate for emissions created by the manufacturing or transportation process. Typically, carbon offset credits fund projects aimed at decreasing GHG in both the short and long terms, such as constructing wind farms, hydroelectric dams, destruction of landfill methane, and forestry projects. In the steel industry, Nucor pioneered the use of carbon offsets with the Econiq™ trademark. Econiq enables achieving net-zero emission targets by balancing scope 1 emissions with carbon offsets and scope 2 emissions with renewable energy credits via virtual power purchase agreements (VPPA). In this context, scope 1 emissions refer to the direct GHG emissions generated during manufacturing. In contrast, scope 2 emissions refer to the indirect emissions related to energy sources, such as electricity, steam, or cooling.

Lastly, ongoing research is investigating the potential of green hydrogen-based DRI production, where fossil fuels are replaced by hydrogen generated via renewable energy. In combination with EAFs energized with renewable power sources, hydrogen-based DRI can lead to the manufacturing of high-quality steel with a significant reduction in environmental impacts. However, hydrogen-based DRI is still in its infancy and far from widespread implementation due to high costs and low production efficiency.

Steel Joists and the Circular Economy

Open-web steel joists are 100% recyclable at the end of their useful life. After the building is decommissioned, steel joists can be removed, transported to a scrap collection facility, and recycled to produce new steel, as schematically shown in *Figure 3*. This circular process of steel production and recycling truly makes steel a "cradle-to-cradle" material. Steel components can be continuously recycled into new steel, which can be used for new products with no loss of metallurgical properties. This feature makes steel joists and all other steel products ideal for a circular economy. Note that a circular economy supports reusing and recycling a product, avoiding waste, and preventing the material from being discarded after its first use. In a circular economy, resources are kept in a circulatory system, and the materials are returned over and over in the recycling cycle.

In December 2021, the Biden Administration released a new federal sustainability executive order. Although quantifiable targets have not been set yet, the sustainability order explicitly supports a transition to a circular economy, aiming to drastically reduce the construction and demolition waste disposed of in landfills by 2030. Assessing the environmental impact of construction materials from a circular economy perspective could lay the foundation for a more sustainable future. Producing a product housed within a circulatory system may be more sustainable than singular-use products highlighting sustainable attributes and manufacturing practices only from cradle-to-grave, particularly when the grave is a landfill.

Moreover, open web steel joists and joist girders have high durability. They are not sensitive to time-dependent phenomena like wear, creep, or strength loss. In the United States, joist manufacturing dates back to the 1920s. However, steel joists are still in place and functioning as originally intended, regardless of their manufacturing date.

When a building becomes obsolete, either a retrofit is needed, or the building is demolished. Existing joists can be retrofitted and/or reinforced to satisfy design requirements under some conditions for buildings that are being retrofitted. Tools and documented procedures to evaluate existing joists are available on the Steel Joist Institute website (**www.steeljoist.org**). As discussed above, all the steel components can be captured and recycled into new steel products when a building is demolished. Many other construction products "can" be recycled, but the cost is more expensive than just creating new products. This is not the case with steel. Steel scrap is needed in many industries, has a monetary value, and is a commodity traded worldwide.

Not only can steel joists be infinitely recycled, but they may be dismantled for reuse. For example, 446 open-web steel joists were reused to construct the Roy Stibbs School, an elementary school in West Coquitlam, British Columbia. A fire damaged a portion of the original school building, and it needed to be rebuilt. In the same period, a nearby school, the Cassiar, had been decommissioned and needed to be demolished. The steel joists from the Cassiar were dismantled and reused in the new Roy Stibbs School facility to expedite the construction process, leading to remarkable cost savings. Another example of open web steel joists reuse is the Mountain Equipment Co-op in Ottawa, Ontario. The facility was built on a site previously occupied by a 40-year-old two-story grocery store. The existing structure was carefully disassembled, and the majority of the steel components were reused in the new Mountain Equipment Co-op retail store. Among those components, 50% of the total roof joists in the new building were reused joists, supplemented with new open web steel joists to accommodate the rooftop equipment loads.

Open web steel joists are in a promising position to support a circular economy and zero waste policies, given their high recycled content, reuse potential, and cradle-to-cradle properties.▪

References are included in the PDF version of the online article at **STRUCTUREmag.org**.

Laura Micheli is a Research Engineer in the Innovation Services Group, Nucor, St. Joe, Indiana (laura.micheli@nucor.com).

Bruce Brothersen is a Senior Innovator in the Innovation Services Group, Nucor, Brigham City, Utah (bbrothersen@vulcraft-ut.com).

Scott Russell is the Manager of the Innovation Services Group, Nucor, Norfolk, Nebraska (scott.russell@nucor.com).

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