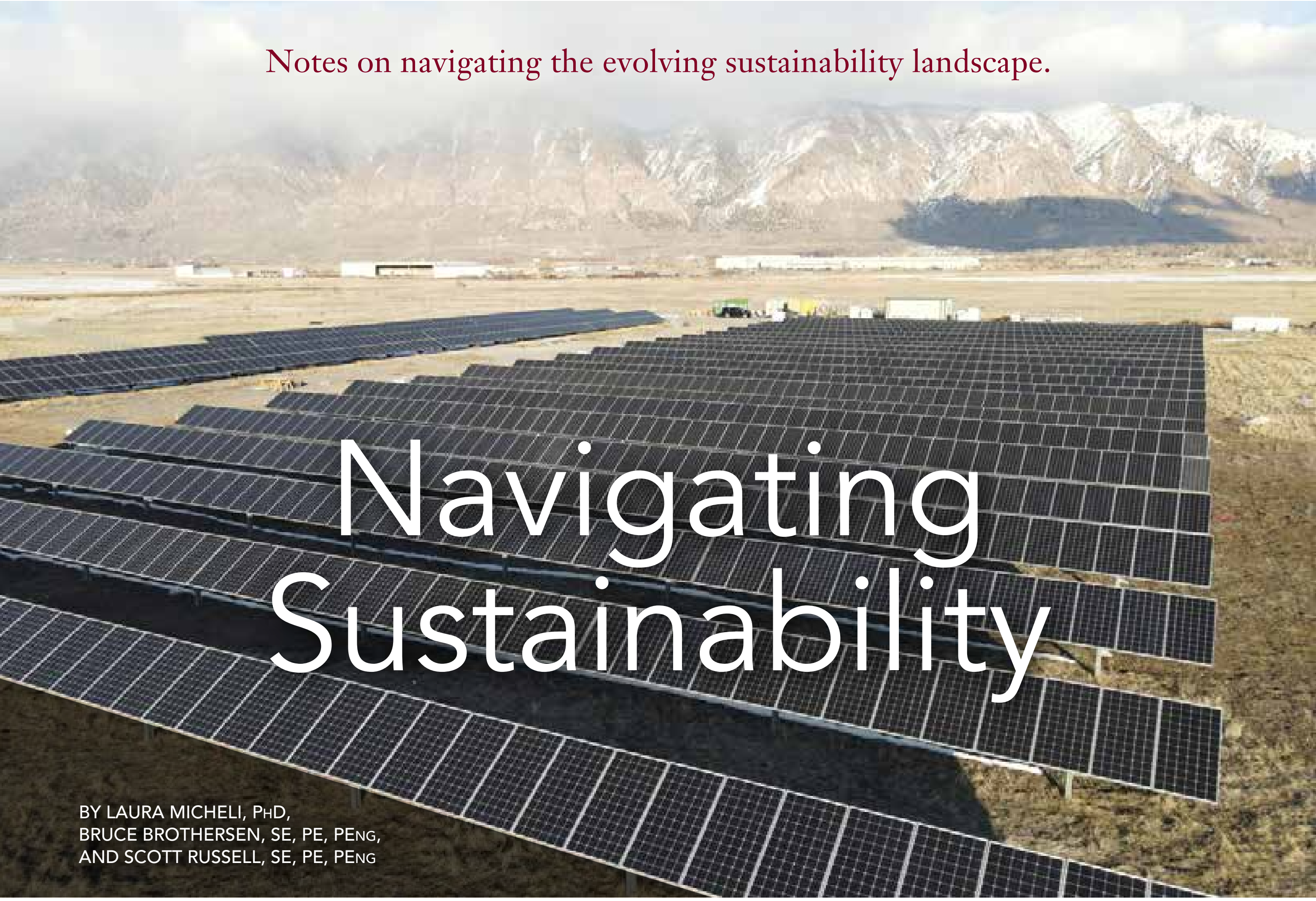


Notes on navigating the evolving sustainability landscape.

Navigating Sustainability

BY LAURA MICHELI, PHD,
BRUCE BROTHERSEN, SE, PE, PENG,
AND SCOTT RUSSELL, SE, PE, PENG

IN THE LAST DECADE OR SO, sustainability and environmental impacts have gained significant relevance in the structural design and construction fields.

As a result, terms such as life-cycle assessment (LCA) and environmental product declaration (EPD) have become part of the common AEC vocabulary. When it comes to designing and building steel buildings, it's important to recognize the meaning of these terms—and other related terminology—and how they can help provide a better understanding of the environmental impacts of steel and how it compares to other structural options. And for those of you who are already familiar with these terms, a refresher never hurts.

Life-Cycle Assessments

Let's start with LCA, which is a standardized method to evaluate the environmental impact of consumer products throughout their lifetimes, as defined by the International Organization for Standardization (ISO). While still gaining traction in the AEC industry, LCAs are widely used in the consumer product manufacturing world to quantify the carbon emissions associated with different stages of a product's life, ranging from raw material extraction to end-of-life. The environmental impact is typically estimated based on the energy inputs and greenhouse gas (GHG) emissions at each stage of the product's production, construction, use, and end-of-life.

Typical life-cycle stages are depicted in Figure 1, including production (A1-A3), construction (A4-A5), use (B1-B5), and end-of-life (C1-C4) stages. An LCA can include all or only some of the life-cycle stages, depending on the scope and intended use of the assessment. When the LCA comprises only the production stage, the term "cradle-to-gate" is usually employed to designate the boundaries of the LCA, from resource extraction (cradle) to leaving the manufacturing facility (gate). The gate is typically the steel fabricator in the case of buildings and structures. If all four life-cycle stages are included, the LCA is referred to as "cradle-to-grave." (Note that steel can be thought of as a "cradle-to-cradle" material, given that it is infinitely recyclable.)

The results of the LCA are presented in a tabular format, which includes six impact categories, namely global warming potential (GWP), ozone depletion potential, acidification potential (AP), eutrophication potential (think oxygen-hungry algae blooms in bodies of water), smog formation potential, and abiotic depletion potential (the usage of nonrenewable resources for energy production). The most well-known impact category indicator is the GWP, which is measured in kilograms of carbon dioxide equivalent (kg CO_2 eq.) and represents the amount of energy/heat the emissions of one ton of a given gas will absorb over a given period of time, relative to the emissions of one ton of carbon dioxide. The larger the GWP value, the more a given gas warms the earth compared to carbon dioxide over a period of time, usually taken as 100 years.

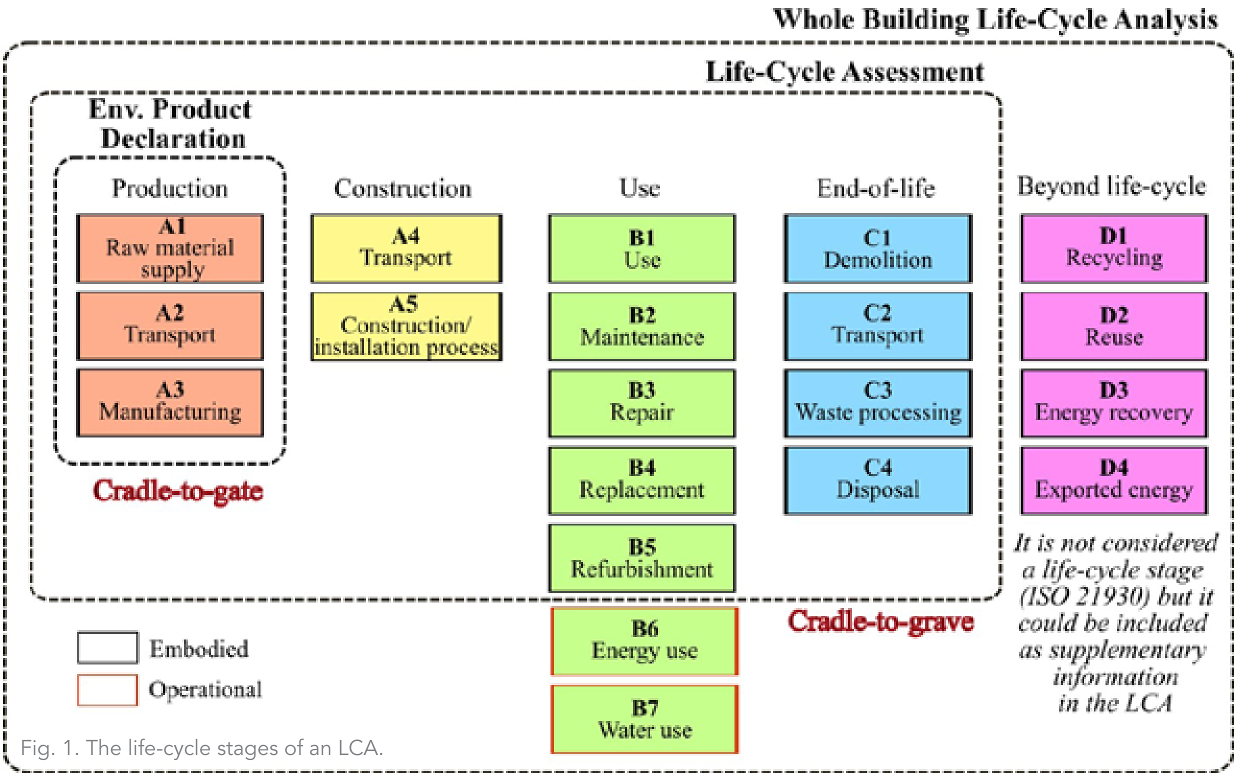


Fig. 1. The life-cycle stages of an LCA.

Environmental Product Declarations

Another important sustainability term is an EPD, which is a report that summarizes the LCA results of a given product, communicating its carbon footprint in a transparent and comprehensive way. For construction materials, EPDs are regulated by ISO 14025, ISO 21930, and EN 15804; in addition, the EPD must follow the guidelines and requirements of the appropriate product category rule (PCR); the PCR governing EPDs for structural steel is the "Product Category Rule (PCR) Guidance for Building-Related Products and Services." While all the stages reported in Figure 1 could be included in the background LCA, EPDs typically include life stages A1 through A3 (cradle-to-gate). Note that the beyond end-of-life stage (D1-D4) is not considered a life-cycle stage by ISO 21930 but it could be included in the LCA as additional information.

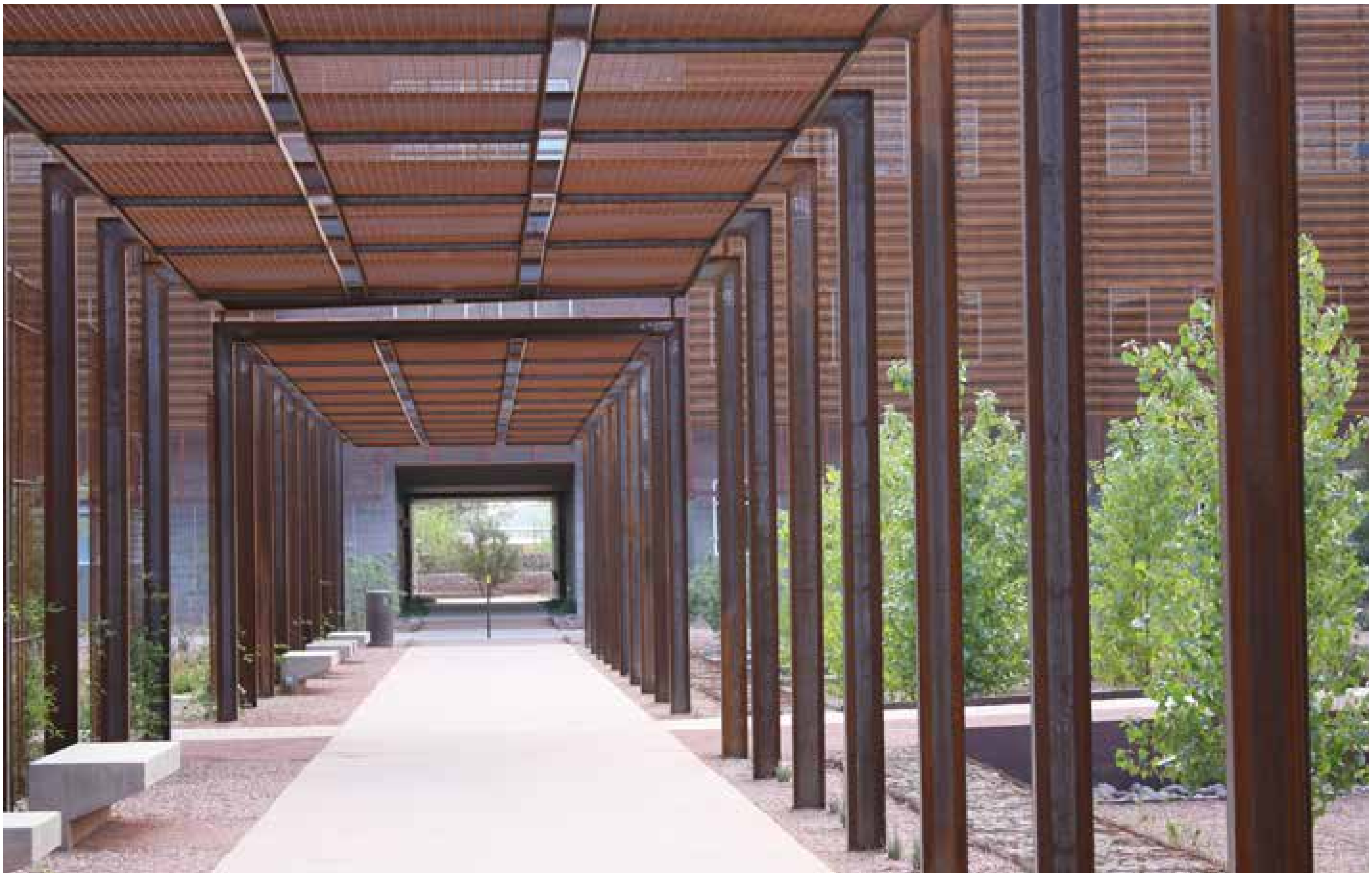
An EPD must contain a description of the product and the life-cycle stages considered in the analysis, referred to as system boundaries. The LCA results are expressed in terms of environmental impact indicators, calculated based on a declared unit, such as one ton of product, as is the case of steel products EPDs. To ensure a transparent process, the EPD study commissioner must rely on a third-party company (the LCA practitioner) to perform the LCA study, which feeds data into an EPD, as well as an additional third-party company (the program operator) to review and verify the EPD. On the other hand, industry-average EPDs report the weighted industry average production for a number of companies manufacturing the same product. As an example, Table 1 summarizes the industry average EPD of fabricated hot-rolled structural sections. Industry average EPDs of steel products can be found on the following websites:

- Fabricated hot-rolled structural sections, fabricated steel plate, and fabricated hollow structural sections: aisc.org/dg
- Open-web steel joists: steeljoist.org/about-us/environmental-product-declarations
- Primary structural steel frame components (columns, rafters), secondary structural steel frame components (cold-formed steel purlins), roll-formed wall panels, and roof panels: mbma.com/Environmental_Product_Declarations.html
- Steel roof and floor decks: sdi.org/publications-2/epd

It should be noted that EPDs of different construction materials (e.g., timber, steel, and concrete) are based on different PCRs and declared units. Therefore, a direct comparison between the data reported in their EPDs may lead to inaccurate results. Furthermore, choosing the material with the lowest GWP in the

Table 1

Industry Average EPD of Fabricated Hot-rolled Structural Sections (LCA results per one metric ton of product)			
Parameter	Symbol	Unit	Total (A1+A2+A3)
Global warming potential	GWP 100	kg CO_2 eq.	1.22E+03
Ozone depletion potential	ODP	kg CFC 11 eq.	1.63E-09
Acidification potential	AP	kg SO_2 eq.	2.98E+00
Eutrophication potential	EP	kg N eq.	1.56E-01
Smog formation potential	SFP	kg O_3 eq.	4.58E+01
Abiotic depletion potential	ADP_{fossil}	MJ surplus	1.43E+03



EPD doesn't necessarily imply selecting the product that will yield the lowest overall carbon emissions since the entire life cycle of a building needs to be considered in the analysis. An accurate comparison of different construction materials can be achieved by accounting for the difference in declared units and considering all the life stages of the structure, from raw material supply to end-of-life. Using manufacturer-specific EPDs in lieu of industry average values can also lead to more accurate estimates of embodied carbon. An example of this in the steel industry is the EPD difference between an electric arc furnace (EAF) recycling steel from scrap and a blast furnace making steel from ore. Another distinction is the country in which the steel is manufactured. In most cases, domestic steel production has less of a carbon footprint than imported steel.

Whole Building Life-Cycle Analysis

Taking the concept of a product LCA to a different level, the whole building life-cycle analysis (WBLCA) has emerged as a tool to estimate carbon emissions and energy consumption for an entire building. WBLCAs employ the same principles outlined above for LCAs and enable engineers and other stakeholders to compare the environmental impact of different design solutions by providing information on embodied carbon and operational energy. In addition to stages A, B, and C, WBLCAs can also include stage D, which considers the carbon emissions related to recycling or reusing construction materials at the building's end of life. Lastly, stages B6 and B7 (Figure 1) can be added to a WBLCA to account for operational energy, such as energy and water consumption.

WBLCA is usually performed by inputting the bill of materials for a given design into specialized software. The software output will be a summary of the six above-mentioned environmental impact indicators. Commonly used software packages are Athena, Tally (Revit), and One-Click LCA. In addition, the SEI Sustainability Committee has developed ECOM, a web-based platform that allows users to approximate the embodied carbon for construction materials and structural frames. The carbon footprint of various design scenarios can be compared by performing the WBLCA of different design solutions.

It is essential to understand that uncertainties inherent in the WBLCA results exist, as each software has its own database, inputs, bias, and assumptions. It is advisable to use multiple software programs and compare the results. Analyzing the same building configuration with different software could lead to a different carbon footprint, and failure to include relevant life-cycle stages or processes could yield incomplete results. For instance, when biogenic carbon is included in the LCA of timber structures, it is appropriate to extend the analysis to stage D to avoid considering full carbon sequestration without accounting for the possible CO_2 release in the beyond life-cycle stage. As EPDs, LCA processes, and related software evolve over time, the GWP values they produce may change for a particular building or structure.

Buy-Clean Laws

As the sustainability landscape continues to evolve, so do federal and local regulations aimed at reducing the carbon emissions of new and existing buildings. The Buy Clean California Act

(BCCA) pioneered regulations on embodied carbon reduction, introducing GWP thresholds for four construction materials: structural steel, concrete reinforcing steel, flat glass, and mineral wool board insulation (note that BCCA only applies to federally funded projects). The maximum acceptable GWP values for these materials are reported in Table 2. With public works projects contracted by the State of California, the awarding authorities are responsible for verifying that the four eligible materials have a GWP that does not exceed the BCCA thresholds. Note that the limits reported in Table 2 are valid for "unfabricated products," while the values reported in Table 1 refer to "fabricated products." Thus, a direct comparison between the GWP in Tables 1 and 2 would not yield consistent results.

Table 2

Buy Clean California Act GWP Thresholds for Unfabricated Products	
Material	GWP limit
Hot-rolled structural steel sections	1010 kg CO_2 eq./1 metric ton
Hollowed structural sections	1710 kg CO_2 eq./1 metric ton
Steel plate	1490 kg CO_2 eq./1 metric ton
Concrete reinforcing steel	890 kg CO_2 eq./1 metric ton
Flat glass	1430 kg CO_2 eq./1 metric ton
Light-density mineral wool board insulation	3330 kg CO_2 eq./1 m^2
High-density mineral wool board insulation	8160 kg CO_2 eq./1 m^2

Following California, Colorado passed the HB21-1303: Global Warming Potential for Public Project Materials in 2021. According to this act, the Office of the State Architect and the Department of Transportation will be required to establish GWP thresholds for eligible materials by 2024 and 2025, respectively.

Also, in December 2021, the Biden Administration signed a new federal sustainability executive order. Although specific GWP thresholds have not been set yet, the sustainability order explicitly promotes the use of construction materials with lower embodied carbon in federally funded projects. Additionally, the sustainability executive order supports a transition to a circular economy, aiming to drastically reduce the construction and demolition waste lying in landfills by 2030. Materials that are highly recyclable, like steel, have advantages in the beyond life-cycle stages (D1-D4). The executive order also emphasizes the importance of energy efficiency for new and existing buildings, pursuing net-zero emissions buildings through electrification strategies, deep-energy retrofits, and water conservation measures.

In EAFs, steel is produced from scrap, with the addition of a small percentage of direct reduced iron. At the end of its useful life, steel products can be recycled, remelted, and used to produce new steel products. This circular process makes steel a cradle-to-cradle material, ideal for supporting a circular economy and zero waste policies. Many steel components, such as open-web steel joists and wide flange beams, can also be reused after a building is decommissioned.

It is expected that the new state and federal regulations will fuel a sustainability renaissance in the construction industry, promoting the transition to clean, zero-emission technologies. In the near future, in addition to cost, schedule, constructability, aesthetics, and space usage, decision-makers will likely be required to consider sustainability as well—and in many cases have already been doing so. The demand for LCAs, EPDs, and WBLCA will continue to grow, along with new legislation regulating embodied carbon limits. It is also important to understand the uncertainties inherent in the direct comparison of different construction materials, due to the different PCR assumptions, units of measure, and database variability. Steel has a great sustainability potential, especially regarding how it fits into a circular economy. Sustainability is here to stay, and we should all be familiar with its vocabulary.

For more on structural steel and sustainability, visit aisc.org/sustainability. ■

Laura Micheli (laura.micheli@nucor.com) is a research engineer, Bruce Brothersen (bbrothersen@vulcraft-ut.com) is a senior innovator and Scott Russell (scott.russell@nucor.com) is the manager of innovation services, all with Vulcraft-Verco, Group of Nucor Corporation.