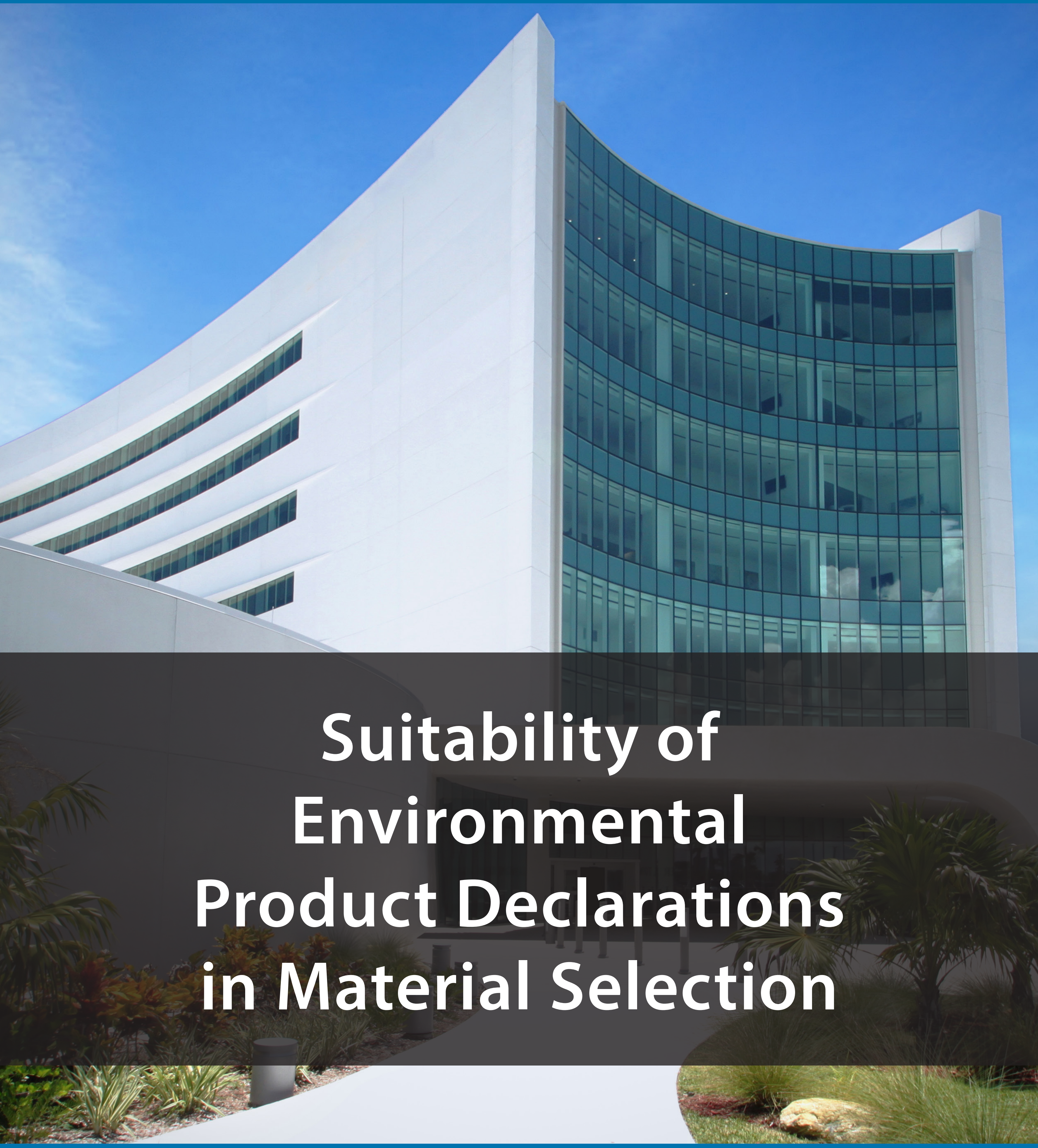

Suitability of Environmental Product Declarations in Material Selection

Precast/Prestressed Concrete Institute

designer's notebook

Suitability of Environmental Product Declarations in Material Selection

Introduction

As owners, architects, structural engineers, and others strive to reduce the environmental impact of their projects, they are increasingly looking to environmental product declarations (EPDs) to inform decisions. However, many stakeholders are unfamiliar with the complexities of the life-cycle assessment (LCA) methodology used to determine the information reported in an EPD. In fact, the American Institute of Architects (AIA) warns in its guide to LCA that "there is a great deal of confusion about LCA, which can inadvertently lead to misuse of LCA tools, techniques, and supporting data."[1]

EPDs seem simple, which was one of the reasons that they were first created. They are meant to provide a simplified summary of the LCA. But the confusion about the LCAs that form the basis of environmental impacts reported in EPDs has contributed to the misuse of EPDs in the marketplace to make product comparisons.

The Carbon Leadership Forum states that EPDs are not comparable if they "were created for different product categories, using different LCA datasets, or if they were published by different program operators."[2] These are just a few reasons why EPDs would not be comparable. Only in rare cases are all requirements met so that EPDs can be compared.

The purpose of this Designer's Notebook is to detail how an EPD is developed and outline best practices and requirements for comparing EPDs. This background information will explain why it is typically inappropriate to use EPDs to compare the environmental impacts of different products.

NFL Building At Hollywood Park, Willis Construction Inc.
Cover Photo Credit: Willis Construction Inc.

What Is an EPD?

An EPD is a simplified summary of an LCA of the environmental impacts of an object. That object can be nearly anything, including a construction product or service, and it is defined by the scope of the LCA. Examples of objects for which an EPD may be developed include a precast concrete hollow-core slab, a lightbulb, or a bridge. According to ISO 14025,[3] EPDs are also known as Type III environmental labels that report a peer-reviewed summary of the results of an LCA. This Designer's Notebook will focus on objects in the category of construction products used in buildings and civil engineering works.

There are international standards, which are described in the section Core and Subcategory Product Category Rules, that serve as core product category rules (PCRs) to standardize all steps of EPD development. These international standards also outline how and when an EPD can be compared with other EPDs, a topic that is discussed later in this Designer's Notebook.

EPDs can be developed for one or more products and for one or more manufacturers. According to Sustainable Minds, a cloud software and services company focused on "greener" design,[4] EPDs can be categorized as manufacturer declarations or manufacturers' group declarations. Those EPDs classified as "manufacturer declarations" represent data from

- a specific product from a manufacturer's plant;
- a specific product as an average from several of a manufacturer's plants;
- an average product from a manufacturer's plant; or
- an average product as an average from several of a manufacturer's plants.

EPDs that are considered manufacturers' group declarations, which include industry-average EPDs, are a declaration of

- a specific product as an average from several manufacturers' plants; or
- an average product as an average from several manufacturers' plants.

EPDs that declare results from groups of manufacturers typically report on an average basis or report a range of values.

How Are EPDs Developed?

To develop an EPD, one must first determine whether there is a subcategory PCR for the product to be assessed. If there is one, it sets the rules for how an LCA must be conducted and how results are presented in an EPD.

Subcategory PCRs exist for precast concrete, ready-mixed concrete, concrete masonry units, structural steel, wood, windows, and many other construction products. They are considered "subcategory" PCRs because they are categorized under the core PCR for construction products.

Core and Subcategory Product Category Rules

Subcategory PCRs are always subordinate to one or more core PCR. As noted previously, a core PCR is an international standard used to develop EPDs. The requirements in a core PCR ensure that EPDs are verifiable, consistent, and clearly communicated, and that they are comparable with other EPDs under certain conditions. Core PCRs that govern the development of subcategory PCRs for products used in buildings and civil engineering works include the International Organization for Standardization's ISO 14025 *Environmental Labels and Declarations—Type III Environmental Declarations;* ISO 21930, *Sustainability in Buildings and Civil Engineering Works—Core Rules* *for Environmental Product Declarations of Construction Products and Services*;[5] and European Standard EN 15804, *Sustainability of Construction Works. Environmental Product Declarations. Core Rules for the Product Category of Construction Products*.[6]

- ISO 14025 is the core PCR for *all* products. All rules contained in ISO 14025 must be followed when developing an EPD for any product.
- ISO 21930 and EN 15804 are the core PCRs for development of EPDs specifically for products used in buildings and civil engineering works. They are intended to complement the requirements in ISO 14025. For products used in the European Union, EPDs must follow EN 15804. It is more common for products in the United States and Canada to follow ISO 21930. Increasingly, international product manufacturers are developing EPDs that conform to both ISO 21930 and EN 15804 so that the EPDs will meet requirements for different project locations and jurisdictions.

Subcategory PCRs are typically developed by industry associations or collaborations between manufacturers and stakeholders for a given product category. Product categories are typically established based on a Construction Specifications Institute (CSI) MasterFormat designation or standard manufacturing specifications such as those from ASTM International or the American Association of State Highway and Transportation Officials.

The scope of a subcategory PCR typically describes not only what products are allowed to use it but also what products are *not* covered by a given subcategory PCR. It is important to note such details about exclusions in PCRs for construction product categories, where there can be confusion among users as to which subcategory PCR is applicable.

A program operator is responsible for supervising subcategory PCR development. According to ISO 14025, program operators are defined as "bodies that conduct a Type III environmental declaration program." Each program operator is an independent entity that, in addition to overseeing subcategory PCR development, ensures that EPDs conform to the PCRs in the program operator's library and assists in ensuring that subcategory PCR development conforms to the applicable international standards (core PCRs). A program operator can be a company or a group of companies, industrial sector or trade association, public authorities or agencies, or an independent scientific body or other organization. Trade associations, industry research organizations, and product-neutral certification bodies are the primary types of program operators in North America.[7] There is no certification body for program operators, but program operators must have published program rules and guidelines, ideally developed with input from stakeholders.

If a subcategory PCR does not exist for a given product category, industry groups or manufacturers will typically contact program operators to develop one. Alternatively, a program operator can choose to develop a subcategory PCR to fill a market need with notification to relevant stakeholders.

Life-Cycle Categories and Modules

As noted previously, the requirements in a core PCR ensure that the data provided in EPDs are verifiable, consistent, and clearly communicated, and that EPDs are comparable with other EPDs under certain conditions. One of the ways that the core PCR facilitates consistent reporting is through a standard format for categorizing life-cycle stages in the LCA and EPD. **Figure 1** shows how various life-cycle stages are categorized in the life of a construction product. This format is helpful in clearly communicating which life-cycle stages are included in an EPD.

According to ISO 21930, there are four life-cycle stages for construction products: production, construction, use, and end-of-life. These four life-cycle stages are subdivided into the following alpha-numeric modules:

Figure 1. Life-cycle stages.

Construction product life-cycle system boundary																
Product stage			Construction stage		Use stage							End-of-life stage				D
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	
Extraction and upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport to waste processing or disposal	Waste processing	Disposal of waste	Potential net benefits (beyond system boundary)

- **Production Stage**: extraction and upstream production (A1), transport to factory (A2), and manufacturing (A3)
- **Construction Stage**: transport to site (A4) and installation (A5)
- **Use Stage**: use (B1), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5), operational energy use (B6), and operational water use (B7)
- **End-of-life Stage**: deconstruction/demolition (C1), transport to waste processing or disposal (C2), waste processing (C3), and disposal of waste (C4)

The core and subcategory PCRs determine the minimum life-cycle modules that must be analyzed and reported in the LCA used to create an EPD. At a minimum, all EPDs must include life-cycle modules A1, extraction and upstream production; A2, transport to factory; and A3, manufacturing.

Photo Credit: ©Inspiro 8 Studios, Jasper

These life-cycle modules encompass the "cradle-to-gate" impacts of a construction product. Any life-cycle modules beyond module A3 are outside of the manufacturer's gate. When all life-cycle modules are included in an analysis (A1–A5, B1–B7, and C1–C4), the analysis is said to have a "cradle-to-grave" scope.

A benefit of a cradle-to-gate scope is that environmental impacts reported in an EPD are generated solely from primary and secondary data supplied by the manufacturer; no scenarios or estimations are needed (see sidebar for definitions). Some subcategory PCRs explicitly detail which background data sets shall be used for common inputs to evaluate the manufacturing process for the subcategory of product. Subcategory PCRs also may document standard industry practice related to how waste materials are considered or allocated.

Definitions: Primary Data, Product System, Secondary Data, and Scenario

Primary data: Quantified value of a unit process or an activity obtained from a direct measurement or a calculation based on direct measurements at its original source.

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.

Secondary data: Indirectly measured, calculated or obtained quantified value of a unit process or activity and related information within a product system or organization, not based on specific original source measurements.

Scenario: A collection of assumptions and information relevant to possible future events.

When primary and secondary data are unavailable, information related to the construction (A4 and A5), use (B1–B6), and end-of-life (C1–C4) life-cycle stages are developed according to scenarios in the subcategory PCR about the product's potential environmental performance. As noted by the Carbon Leadership Forum, "scenarios describe activities that result in environmental impacts, such as transportation details, material replacement frequencies, energy use, water use, what happens to the building at end-of-life, and the energy involved in all of these processes."[2]

Life-Cycle Assessment

An LCA is conducted to calculate the environmental impacts and life-cycle inventory (LCI) values for a given product or other object. LCAs may be used for purposes other than creating EPDs. However, if the LCA is to result in an EPD, the LCA scope and methodology are established according to core and subcategory PCRs. What is included and excluded from the LCA is defined through the *system boundary*—the boundary established based on a set of criteria within either the LCA study or the PCR to represent which unit processes are part of a product system. The LCA accounts for material and energy flows within the defined system boundary, and then characterizes those flows as potential environmental impacts. LCA methodology is used to assess "a number of environmental impact categories, which are broad measures of environmental change, encompassing the effects of many types of emissions."[2]

LCA can be an effective tool to help interested parties understand the environmental impact of design decisions. But its utility is limited by its complexity, the lack of good data in databases, and the multiple assumptions that must be used.

ISO 14040, *Environmental Management—Life Cycle Assessment—Principles and Framework*,[8] and ISO 14044, *Environmental Management—Life Cycle Assessment—Requirements and Guidelines*,[9] set the minimum requirements for performing an LCA. These requirements are divided into four steps:

- Goal and scope definition
- Life-cycle inventory (LCI) analysis

Photo: Sarah Crowley, ELM 551

- Life-cycle impact assessment (LCIA)
- Life-cycle interpretation

For an LCA that is conducted according to a PCR, the goal and scope of the assessment are defined. However, LCAs created under the same PCR may not necessarily include the same life-cycle stages. All PCRs require that LCAs have a minimum of a cradle-to-gate scope (life-cycle stages A1–A3), but some PCRs allow the party performing the LCA and creating the EPD to choose whether to evaluate and report some or all of the remaining life-cycle stages.

During the LCI phase of an LCA, all the individual environmental flows to and from the product's system boundary—over the life-cycle stages included in the analysis—are tallied. These environmental flows include materials, energy, and emissions to air, land, and water. Thus, an LCI for a cradle-to-gate LCA would account for all of the materials and energy needed, and any emissions that occur, during life-cycle stages A1–A3. According to ISO 21930, examples of LCI data that must be reported for construction products and services include consumption of fresh water and amount of waste generated.

Once LCI data are collected, they are classified and characterized during the LCIA phase. Category definition, which consists of identifying impact categories that are relevant to the product being studied, also occurs in the LCIA phase. However, for an LCA conducted according to a PCR, the environmental impact categories to be studied are explicitly stated in the PCR.

Classification of LCI data requires identification of substances that may contribute to the environmental impact categories. These substances can then be converted into the environmental impact categories using a characterization method. For LCAs used to create EPDs, the governing PCR states the characterization method that shall be used for a given product category. In the U.S., the U.S. Environmental Protection Agency's Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) is the most-common characterization method used. TRACI provides characterization factors to allow calculation of potential environmental impacts from LCI data. Some LCI data must be reported in an LCA without characterization.

In the interpretation phase of an LCA, results of the study are presented and an interpretation is provided. The LCA report includes sensitivity analysis of key assumptions and the identification of environmental "hot spots." These hot spots are material and energy flows that contribute the most to the environmental impact values reported. LCA reports contain more information than what is reported in an EPD.

What Information Is Included in an EPD?

EPDs are reporting instruments for LCAs. They not only summarize a product's environmental impacts but also report information about resource use and product scope, as well as background information related to how the LCA was performed. According to ISO 21930, EPD information is reported in the following categories:

- General information
- Methodological framework
- Technical information and scenarios
- Environmental indicators derived from the LCA
- Additional environmental information

The following sections describe information found in each of these reporting categories.

General Information

According to ISO 21930, all EPDs must disclose general information related to the period of validity (how long the EPD is valid), the EPD program, and a detailed product description. EPD program information identifies the EPD's owner (who sponsored the study). It also provides information about the program operator and the reference PCRs used. It will disclose whether the EPD was verified and list the names of third-party verifiers.

The detailed product description often includes information related to a product's typical application or use, any product identification (such as a United Nations Central Product Classification [CPC] code or CSI MasterFormat designation), and a photograph or schematic image that represents the product. The description will also identify main components or material percentages of the final product, though confidential or proprietary information need not be disclosed.

Finally, all EPDs must include a statement related to comparability per ISO 21930. The intention of this statement is to dissuade individuals from making comparisons that are not appropriate. The statement reads:

> *EPDs are comparable only if they comply with this document, use the same sub-category PCR where applicable, include all relevant information modules and are based on equivalent scenarios with respect to the context of construction works.*

Photo Credit: High Concrete Group, FDNY Firehouse Rescue #2

Methodological Framework

Methodological framework information declared in the EPD largely addresses the scope of the LCA and provides transparency regarding assumptions or background information used. The EPD must state whether a functional or declared unit was used to express the results of the LCA (see sidebar).[10] It also must identify what type of EPD it is, which depends on the life-cycle stages included in the LCA.

Definitions: Functional Unit and Declared Unit

Functional unit: "Quantified performance of a product system for a construction product or construction service for use as a reference unit in an EPD based on LCA that includes all stages of the life cycle."[5]

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 needed in information modules."[5]

Procedural information that must be declared for transparency includes allocation and cut-off procedures used in the LCA. As a simplified example, if more than one product is manufactured at a location, the LCA practitioner may allocate (or assign) environmental impacts based on the relative economic cost of the various products produced at that site. If product X sells for twice the price of product Y, product X would be assigned twice the environmental impact of that of product Y. This example of an economic allocation procedure would need to be reported in the EPD. Cut-off procedures refer to the granularity of the LCA related to mass balance, energy balance, and environmental significance of the product system. Common cut-off goals for an LCA are to include 95% or 99% of all unit processes in the product system by mass, energy, or environmental significance. Because these procedures can influence LCA results, they are typically standardized in a subcategory PCR and restated in any resulting EPDs.

Technical Information and Scenarios

The technical information and scenarios section of the EPD provides information on life-cycle stages beyond the product stage (modules A1–A3) that are part of the LCA. If an EPD reports environmental indicators "beyond the gate," the technical information and scenarios used to develop those indicators must be stated in this section.

Environmental Indicators Derived from the LCA

The core PCR and subcategory PCR will state the minimum environmental impact categories and LCI measures that must be evaluated in the LCA and then reported in an EPD. ISO 21930 and EN 15804 require the following environmental impacts be reported in an EPD:

- Global warming potential (GWP)
- Ozone depletion potential
- Eutrophication potential
- Acidification potential
- Photochemical oxidant creation potential

The Carbon Leadership Forum explains that these environmental impact categories were chosen because they are "well established and fairly standardized."[2] Environmental impacts related to human health and ecotoxicity are occasionally reported; however, there is a much greater uncertainty associated with those types of environmental impact compared with the five required impact categories.

Global Warming Potential

GWP, which is also referred to as "climate change potential," is the most commonly used and best understood environmental impact category. This environmental impact category "describes potential changes in local, regional, or global surface temperatures caused by an increased concentration of GHGs [greenhouse gases] in the atmosphere, which traps heat from solar radiation through the 'greenhouse effect.'"[2] Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are considered GHGs; therefore, they can be grouped together in the GWP impact category.

GWP values are relatively easy to calculate. In terms of GWP, 1 pound of CH_4 is 30 times more potent than 1 pound of CO_2, and 1 pound of N_2O is 298 times more potent than 1 pound of CO_2. Therefore, CO_2 is assigned a weighting factor of 1, CH_4 a factor of 30, and N_2O a factor of 298. GWP is reported as a combination of the various GHGs in units of kilograms of carbon dioxide equivalent (CO_2e).

Global Warming Potential, Embodied Carbon, and Life-Cycle Assessment

In a life-cycle assessment (LCA) of a building or infrastructure product, embodied carbon is the global warming potential (GWP) attributed to all life-cycle modules except B6 (operational energy use) and B7 (operational water use). Thus, embodied carbon is a measure of the GHG emissions associated with the product's materials and construction processes.[11]

A full LCA evaluates a complete set of environmental impacts (including, but not limited to, GWP) over the entire life of a product. In a full LCA, the total GWP of the product is the sum of the embodied carbon plus the GWP attributed to the use-phase (operational) energy use.

Various definitions of embodied carbon exist in the marketplace. For example, when only the GHG emissions from the life-cycle stages of raw material extraction, transportation to factory, manufacturing, transportation to site, and installation (modules A1–A5) are considered, this partial calculation of embodied carbon may be referred to as "upfront carbon."As the World Green Building Council notes, the emissions included in upfront carbon "have already been released into the atmosphere before the building is occupied or the infrastructure begins operation."[11]

Making design decisions based on a single environmental attribute (such as GWP) is not recommended because such decisions have a significant potential for unintended consequences. For example, when a design is exclusively optimized to ensure the lowest embodied carbon, it is possible that the design choices could have other environmental impacts or negatively affect resources, a phenomenon known as "burden shifting."

Ozone Depletion Potential

Ozone depletion potential, or stratospheric ozone layer depletion potential, is the environmental impact category related to the degradation of the ozone layer. Ozone depletion is a concern because the stratospheric ozone layer limits the amount of harmful ultraviolet radiation from the sun that can reach the Earth's surface. Certain chemicals and compounds (typically, chlorofluorocarbons and hydrofluorocarbons) can break down the ozone layer. Ozone depletion potential is expressed in terms of chlorofluorocarbon-11 (CFC-11) equivalents.

Eutrophication Potential

Eutrophication potential is the environmental impact category that captures the adverse effect of chemicals that supply excess nutrients such as nitrogen or phosphorus to soil or water. When water or soil is overfertilized, nutrients in the runoff can degrade freshwater systems, putting the survival of some species at risk, diminishing the overall health of the ecosystem, and compromising water quality.[2,12,13] Algae bloom is one example of eutrophication. Eutrophication potential is expressed in terms of phosphate (PO_4) equivalents.

Photo Credit: FINFROCK, MAA Robinson

Acidification Potential

Acidification potential is related to the chemicals that may lower the pH of precipitation, a phenomenon commonly known as acid rain. Chemicals considered in this environmental impact category are ammonia, nitrogen dioxide, nitrogen oxides, sulfur dioxide (SO_2), and sulfur oxides.[14] On a local level, acidification potential also correlates to the acidifying effect of these chemicals in water and soil. Acidification potential is reported in SO_2 equivalents.

Photochemical Oxidant Creation Potential

Photochemical oxidant creation potential, also known as "smog formation potential," relates to the presence of chemicals that react in the troposphere to create smog, which damages both human health and ecosystems (including crops and other plants). It is reported in units of ethene (C_2H_4) equivalent. Many chemicals can contribute to this environmental impact category, but volatile organic compounds and nitrous oxides are two of the commonly known substances.

Additional Life-Cycle Inventory Data

ISO 21930 also requires that LCI data be reported for all information modules for the following:

- Use of primary resources—that is, "energy or material resources generated by, acquired from or extracted from the environment/nature (the geosphere or biosphere) within the life cycle of the construction product"
- Use of secondary resources—that is, materials or fuels that are recovered from previous use or waste
- Abiotic depletion potential (fossil resources)—that is, "all fossil resource indicators (e.g., coal, oil, fossil gas) used as energy and material"
- Consumption of fresh water
- Waste and output flows

Additional Environmental Information

Manufacturers and EPD owners may choose to declare additional environmental information in EPDs that is not required by the core or subcategory PCRs. That information can relate to a manufacturer's or product's subjective environmental benefits that cannot be easily quantified. Examples of this additional environmental information may include a product take-back program or a manufacturer's environmental management system.

ISO 21930 also requires that any regulated substances of very high concern be declared in this section.

Business-to-Business and Business-to-Consumer EPDs

There are two primary types of EPDs:

- Business-to-business (B-to-B)
- Business-to-consumer (B-to-C)

B-to-B EPDs are frequently created for those products that are manufactured without the manufacturer knowing how the product will be used during its life cycle. A B-to-B EPD may also be created for any product that cannot be assessed for its full life cycle. If an EPD's scope excludes one or more life-cycle stages, the EPD is considered to be B-to-B.

A unit volume of concrete is an example of a product for which a B-to-B EPD would be appropriate. An EPD for a unit volume of concrete could include assessment of all the energy, materials, and emissions related to the manufacture of the concrete. However, there are

Photo Credit: JP Carrara & Sons, Inc., Rockingham I-91 Bridges 24N and 24S - IM 091-1(66) infinite possibilities for the use of that concrete after it leaves the plant gate. It could be used as a sidewalk, in a wall, as a bridge component, as pavement, or many other applications. An EPD for a product such as precast concrete, ready-mixed concrete, concrete masonry units, or steel is typically in a B-to-B format. EPDs for these types of products will account for all the environmental impacts from the cradle to the gate, but they do not include environmental impacts related to the use phase. Thus, B-to-B EPDs should *never* be used for comparisons across product categories.

B-to-C EPDs account for all the environmental impacts for the product's full life cycle. These types of EPDs can be created for products that have a known use in a building or civil engineering works context. For example, B-to-C EPDS may be created for products such as guardrails, carpet, windows, or doors. It is possible to model the full LCA of these products because how these products will be used in the structure is known.

How and When to Compare EPDs

Manufacturers, industry groups, and program operators have responded to requests for additional transparency related to the environmental impacts of products by developing EPDs. As more EPDs for construction products have entered the market, it has become a common, but incorrect, practice to compare EPDs across product categories and to make comparisons without adhering to the rules set forth in ISO 21930. Although the parties making the comparisons may have good intentions, there are unintended consequences of comparing EPDs that were not developed using the same methods, scopes, background data, or tools, or that do not meet all of the requirements for comparability set forth in Section 5.5 of ISO 21930.

ISO 21930 Comparability Requirements

The first sentence in ISO 21930 Section 5.5, "Comparability of EPDs for Construction Products," emphasizes that products should be compared on a full-life-cycle basis and in the context of the construction works. To allow comparisons for the full life cycle at a construction-works level, scenarios must be developed and detailed in the construction product's PCR.

It is possible to compare products at what ISO 21930 refers to as the "sub-construction works level," which means B-to-B EPDs using the same product category rule. However, several requirements must be met to do so. Specifically, ISO 21930 states:

> *In all cases of comparing construction products, the principle that the basis for comparison of the assessment is the construction works level shall be maintained by ensuring that the same function requirements are met and:*
>
> - *the products/systems shall have the same functional performance;*
> - *the comparison is based on the same functional unit;*
> - *the environmental performance and technical performance of any excluded elements of the construction works (e.g., assembled systems, components, construction products or construction services) are the same;*
> - *the type and amount of any materials excluded are exactly the same;*
> - *any excluded processes and life cycle stages are the same;*
> - *equivalent scenarios are used (see Note 2 [excluded from this Designer's Notebook]);*
> - *the elementary flows related to material inherent properties, such as biogenic carbon, the*

potential to carbonate or the net calorific value of a material, are considered completely and consistently within the scope of comparison;

- *the influence of the product systems on the use stage of the construction works, including operational aspects and impacts of the construction works, are taken into account or are the same;*
- *module D [benefits and loads beyond the system boundary] shall not be aggregated with the life cycle information modules A1 to C4 to assess the total impact of the products or construction works being compared, as it is outside the system boundary. It can be taken into consideration as optional supplementary environmental information using equivalent scenarios."*

These requirements are explained further in the following sections.

Functional Requirements, Functional Performance, and Functional Unit

By requiring that products have the same functional requirements, functional performance, and functional unit, ISO 21930 establishes that construction products must meet the same technical requirements if they are to be compared. ISO 21930 defines *functional equivalent* as "quantified functional requirements and/or technical requirements for a construction works or a construction (part of works) for use as a basis for comparison."

Sustainable Minds explains *functional performance* in terms of what a customer buys and how it is measured by the relevant industry: "Functional performance is a measurable expression relating to the magnitude of a particular aspect of the product group relative to specified requirements, objectives or targets. Every product group has its own (set of) performance parameter(s)."[10]

ISO 21930 defines *functional unit* as "quantified performance of a product system for a construction product or construction service for use as a reference unit in an EPD based on LCA that includes all stages of the life cycle." Sustainable Minds lists the elements of a good functional unit, as follows:[10]

- An amount
- A quantity using SI-units
- A description of the application
- The performance parameters, as many as relevant
- The applicable region
- A time period for which the performance is met

The American Society of Civil Engineers' *Whole Building Life Cycle Assessment: Reference Building Structure and Strategies*[15] discusses functional equivalence in terms of structural systems:

> *For two structural systems to be considered functionally equivalent, they must both meet the same minimum code requirements and performance standards, such as loading, life safety, and serviceability requirements (i.e., deflection, vibration, durability noise transmission), which are defined in the building project design criteria. The proposed building should have improved performance over the baseline as long as the life cycle impacts from materials used to achieve the improved performance are included. If one material, product or system has a different service life than another, the impacts of maintenance, repair or replacement must be included in the analysis.*

Note that these explanations emphasize the performance requirements of the product in the context of the construction work. As an example, for a given project in a specific location, certain performance requirements are unique to that combination of project type and geography. A hospital built in a high-seismic zone would have different performance requirements than a parking structure built in a low-seismic zone, and a school built in a hurricane-prone region would have different performance requirements than a single-family residence built in a flood zone.

It follows that the construction products used in these various scenarios would also have different performance requirements. To meet the performance requirements of multiple scenarios, even the same product type would need to be designed in multiple ways, with different quantities and strengths of materials, and maybe requiring additional ancillary materials in certain cases. Thus, even the same product type in these various cases would likely report different environmental impacts in multiple EPDs.

Related to the importance of comparing products with the same functional unit, the American Institute of Architects states:[1]

> *The functional unit can be defined as the unit of comparison that assures that the products being compared provide an equivalent level of function or service. It is difficult to establish functional equivalence in the building industry.*
>
> *For example, a wood structure is likely to have different cladding and insulation requirements than a steel or concrete structure. Therefore, if wood is being compared with steel or concrete for environmental impact, then all the related decisions, such as for cladding and insulation options, need to be accounted for to achieve functional equivalence.*

Excluded Elements

If EPDs are to be compared, ISO 21930 also requires that any materials, processes, life-cycle stages, or elements excluded from the EPDs be the same. For example, an EPD for a product that includes installation hardware should not be compared to an EPD for a similar product that does not include installation hardware. The included or excluded elements can greatly influence the environmental impact and must be the same to ensure comparability.

As mentioned previously, the PCR for a specific product category gives guidance on many decisions made by a practitioner when conducting an LCA and developing an EPD for a specific product or material. However, many PCRs, including ISO 21930, allow options for various aspects of the LCA, such as which life-cycle stages are included in the assessment. Thus, it is possible for EPDs to be developed from the same PCR but with scopes covering different life-cycle stages. An EPD for a product that was developed from an LCA with a cradle-to-gate scope (life-cycle modules A1–A3) should not be compared to an EPD for a product developed from a full LCA (life-cycle modules A1–A5, B1–B7, and C1–C4).

Equivalent Scenarios

PCRs may provide scenarios for creation of EPDs. However, in cases where multiple scenarios are provided, PCRs do not require that EPDs provide results for all scenarios. If EPDs are to be compared, ISO 21930 requires that the EPDs use equivalent scenarios to ensure that the performance requirements of the construction products are also equivalent.

A PCR might include different exposure scenarios. For example, there may be one scenario for concrete intended to be used in pavement or bridge decks, and another scenario for concrete

Photo Credit: Willis Construction Co. Inc., O Street

intended for an industrial slab-on-grade. One manufacturer might choose to develop a product EPD for the pavement scenario, and a different manufacturer might develop a product EPD for the industrial scenario. Although the concrete product type could be the same in both scenarios, the concrete would need to be designed specifically to meet the requirements of each scenario. These specific designs may require different quantities and strengths of materials, and they may require additional ancillary materials. Thus, even though the same product type is used, the pavement EPD and the slab-on-grade EPD would report different environmental impacts.

When evaluating products according to a PCR and a given scenario, it is important to note that ISO 21930 acknowledges that not all products will have the exact same construction methodology in module A5 (installation). The standard allows the LCA practitioner to model the construction method that is most typical for the product in module A5. It states:

> *The scenarios for information module A5 for two products could be equivalent, as they both model the typical installation of the products and resulting waste management, but not identical, because of, for example, different ancillary material requirements, packaging waste and product wastage generated. The products could show different impacts but could still be compared.*

Elementary Flows

ISO 14040 defines elementary flow as "material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation." The elementary flows requirement relates to the unique, inherent material properties of various construction products. ISO 21930 requires that elementary flows are "considered completely and consistently within the scope of comparison." This means that if the materials can influence the environmental impacts of the construction product, the influences must be treated consistently in any EPDs that are to be compared.

Examples of inherent material properties include the ability of a material to carbonate or sequester carbon dioxide, or the assumed "net calorific value of a material."[5] The PCR for a construction product may include guidance on these unique properties, give options for how to consider these properties, or may be silent on the topic.

Use-Stage Impact

The potential impacts that construction products may have on the construction works during the use stage (life-cycle modules B1–B7) are wide ranging. Given the assumed service life of the structure, some products may have little to no environmental impact during the use stage, whereas other products may need to be replaced or maintained frequently, thus having a significant use-stage environmental impact.

According to ISO 21930, if two EPDs are compared, the underlying LCAs of the products must take into account environmental impacts in the use stage (unless the impacts are assumed to be the same in both EPDs). In short, if the two EPDs only consider life-cycle modules A1–A5 and C1–C4, they cannot be compared unless the use-stage impacts are the same for both products.

The impact of the choice of construction products on the use-stage of a building are illustrated in the following example from the American Society of Civil Engineers:[15]

> *The reduced impacts of integrating the building's systems should be accounted for over the life of the building (e.g., a higher performing building envelope may have a high embodied energy but the building's savings on heating and cooling demands over the life of the building may offset the envelope's initial impact). Thermal mass strategies that reduce a building's heating and cooling demands may be utilized for reducing impacts of the as-designed building, but an energy model must be employed.*

Ensuring that the operating energy requirements are functionally equivalent "prevents the embodied impacts of a building design from being improperly penalized if strategies to reduce operating energy increase material use."[15] When products are evaluated on a limited life-cycle basis, such as only cradle-to-gate (A1-A3) environmental impacts, they may not be chosen *even if* they contribute to a lower, overall environmental impact of the structure over the full life cycle.

Module D

Finally, when comparing EPDs, it is not allowable to add environmental impacts calculated for module D to those for life-cycle modules A1 through C4. Because the environmental impacts included in module D are beyond the system boundary, they are not included in the scope of the LCA. This means that environmental impacts attributed to module D should only be considered as additional or supplemental information.

Best Practices for Comparisons

Earlier in this Designer's Notebook, it was established that EPDs can only be compared if they are created from the same subcategory PCR. However, as also previously discussed, conformance to the same subcategory PCR alone does not ensure that EPDs for two products can be compared. In practice, EPDs must have the same scope, be developed with the same tool, and have the same background data to be comparable.

The LCA methodology was originally developed for industrial products. It is much more challenging to use this methodology for analysis of buildings and civil engineering works because the functional unit or scope (boundary) for the LCA of a building, bridge, or pavement is difficult to define.

Scope

Establishing that the scopes of the EPDs to be compared are the same is not as simple as identifying the products in terms of the PCR. In most cases, several items reported in the EPDs must be compared to ensure that the EPDs have the same scope. Before comparing EPDs, users should ensure that the following items are the same/equivalent (as reported in the EPDs):

- The functional unit
- The excluded elements
- The types and amounts of excluded materials
- The excluded processes and life-cycle stages
- Any scenarios used
- Considerations of inherent material properties
- Use-stage impacts

Users must also verify that module D is not added to life-cycle information from other modules in the EPDs.

Note that if an EPD is only for a declared unit, not a functional unit, it should never be compared with another EPD.

LCA Tools

Many LCA tools exist to assist users in developing EPDs; however, with any tool, various assumptions are made in the background to simplify the user experience. Because these assumptions may not be evident or disclosed to the user, best practice is to only compare EPDs that were developed using the same version of a tool or software.

The Carbon Leadership Forum[2] notes that "building industry LCA tools often integrate default scenarios within the tools, so you may not have to develop all of the scenarios yourself. Some tools enable users to modify the default values, while other tools are not as flexible." Lewis et al.[16] note that LCI data sets vary among tools, so different tools will generate different results.

The American Institute of Architects recommends that an LCA tool should "adhere closely to relevant ISO standards and other accepted LCA guidelines."[1] Tool selection should be made based on the goal of the LCA: Consider what life-cycle stages are included, whether the evaluation is at a material/product level or structure level, or if the goal is to establish a benchmark.

Background Data

Something as simple as the choice of background data can greatly influence the calculation of the environmental impacts of a product. Some PCRs outline the input data sources that should be used when performing the LCA; however, many PCRs only provide guidance on appropriate data selection, such as ensuring that the data are relevant for the time period, the technology used, the location, or other requirements.

Multiple LCI databases that include material, energy use, and emissions data have been developed by professional organizations and LCA tool creators. Both the Carbon Leadership Forum and American Society of Civil Engineers emphasize the importance of ensuring the consistency of LCI data used in an LCA. The latter organization notes that "the easiest way to ensure consistent LCI data is to use the same tool with the same LCA data choices to analyze both the reference and proposed buildings."[15]

LCI data vary by country/state due to the different mixes of energy sources used to power the electric grid. LCI data also vary depending on whether they are an industry average or specific to one manufacturer or plant location. A best practice is use a data set for the project's geographic location, if possible.

According to the American Institute of Architects, it is best to use industry-average data when performing an LCA during schematic design, when a supplier has not yet been identified. More accurate data, such as supplier-specific data, should be used at later design stages.[1]

As an example of how background data can affect EPDs, let us consider how the choices of two precast concrete manufacturers (A and B) affect the EPDs they develop for wall panels to be used for the same project. All scope items in the EPDs are identical and the two manufacturers intend to use cement from the same cement manufacturer. However, manufacturers A and B make different choices, both permitted by the PCR, regarding the type of environmental impact data to use for cement in the LCA: manufacturer A chooses to use industry-average environmental impact data, whereas manufacturer B chooses to use environmental impact data from its specific cement manufacturer. Because the manufacturers use different data, the calculated environmental impact for manufacturer A's LCA will be different than that calculated for manufacturer B's LCA. This difference may lead the project owner to choose one manufacturer's product over the other's. However, it is important for product decisions to be made based on real differences in manufacturing or material efficiencies rather than skewed results due to differences in background data.

Photo Credit: AECOM., Swift Island Historic Arch Bridge Rehabilitation and Widening

Challenges in Benchmark Setting

Challenges to establishing fair and accurate comparisons of environmental impacts in the real world are abundant. It is common practice to use EPDs to establish benchmarks for products. For purposes of this Designer's Notebook, a benchmark is a goal value (or maximum limit) for environmental impacts that is set with the intention of minimizing environmental impact.

However, establishing benchmarks for some product categories may be easier than establishing them for others. It is relatively easy to establish benchmarks for products that have a simple or limited function, such as carpet tile, because many of the variables related to comparability are either the same for all comparable products or are not relevant to environmental impacts. In contrast, for a product that can serve many functions, such as concrete, it can be difficult to establish a single benchmark. Rather, several benchmarks may be required for a given product category to encompass the range of applications and performance requirements.

At a building or civil engineering works level, setting a benchmark is difficult due variations possible in the design of these complex structures. The Carbon Leadership Forum acknowledges that "efforts to develop building-level LCA benchmarks are not yet widely available in North America." A few specific challenges for the precast concrete industry are noted in the following sections.

Setting Appropriate Benchmarks

Precast concrete is a product that can serve many functions; thus, it is difficult to establish appropriate environmental impact benchmarks for the product. Precast concrete is an engineered product, which means that it is designed to meet the specific performance requirements for a project. Those performance requirements are more detailed than the compressive strength of the concrete. They may also include requirements related to serviceability, thermal effects, geometric specifications, exposure, or many other factors. The many combinations of performance requirements make it nearly impossible to create non-project-specific EPDs.

Creating Cradle-to-Grave Product EPDs

Creating cradle-to-grave EPDs for precast concrete is difficult, and the challenges are similar to the obstacles encountered in efforts to set appropriate benchmarks. Because precast concrete is engineered to meet the performance requirements of specific projects, the parties creating LCAs and EPDs would need to develop many scenarios to encompass the extensive range of applications and performance requirements beyond the manufacturer's gate.

Product Comparisons

The biggest marketplace issue related to EPDs is the improper comparison of products across product categories. Precast concrete is often compared to ready-mixed concrete. However, comparing EPDs for ready-mixed concrete and precast concrete would never be appropriate because key aspects of their life cycles are not functionally equivalent. For both ready-mixed and precast concrete, the A3 module (manufacturing) of the product stage includes all the materials and energy to store, move, batch, and mix the concrete and operate the concrete plant. However, the A3 module for precast concrete also includes energy and material flows related to reinforcement (plain and prestressed), as well as forming and curing the concrete, among other things. For the ready-mixed concrete, these latter items are performed at the job site, not the plant; thus, they would be part of the A5 module (installation) and would not be included in a cradle-to-gate LCA.

Alternatives to EPD Benchmarks

Creating EPDs for every scenario at a building or civil engineering works level is currently not practical for most manufacturers. Thus, the following strategies are recommended in lieu of setting benchmarks using EPDs for minimizing environmental impact of the overall building or civil engineering work.

Compare Alternatives on a Project Basis

To compare the environmental impacts of alternative component systems for a given structure, it is nearly impossible to create an EPD for every possible combination of performance requirements. Instead, for a given structure, it is best to compare environmental impacts at a full structure level for a full life cycle. Comparing the environmental impacts of alternative structural systems for fewer life-cycle stages than the full life cycle contradicts ISO 21930 requirements.

The American Institute of Architects states that "true [functional] equivalence can only be ensured at the level of a complete building design."[1] This means that the environmental impacts of various alternative designs should only be compared when the designs include detailed and equivalent environmental impact information about structural, enclosure, interior, HVAC, plumbing, and lighting systems, among other essential design elements. "All materials of one system used to achieve functional equivalence of the other system must be included [in the LCA]."[15]

ASTM E2921, *Standard Practice for Minimum Criteria for Comparing Whole Building Life Cycle Assessments for Use with Building Codes and Rating Systems*,[17] includes guidance on how to compare environmental impacts at a full building level.

Reuse or Repurpose Structures and Materials

Avoiding demolition of an existing structure and its replacement with a new structure may be the best ways to reduce the environmental impact of the built environment. Repurposing either an entire structure or structural components (such as precast concrete) is another way to reduce the environmental impact of a structure.

Optimize Structural Design

There are basic best practices for design that can be put to use during the design phase to reduce the environmental impact of a structure. One best practice is to make design choices informed by factors specific to the project's geographic location. For example, if a design specifies locally manufactured products or indigenous materials, the project will be minimally affected by the environmental impact of long-distance transportation of building elements to the construction site. Also, efficiencies may be found by implementing commonly used local construction practices, and passive techniques, such as adding window overhangs or fins in warm climates, can save energy and environmental impact.

Also during the design phase, project stakeholders can begin to evaluate potential environmental impact trade-offs involved in choices for the various design and construction components. For example, choosing a concrete design may reduce HVAC requirements because concrete provides thermal mass effects that reduce heating and cooling demands. Optimizing fenestration area may provide interior daylighting that leads to reduced electricity usage when the building is occupied, but it may also increase energy loss due to thermal losses.

Other ways to reduce a structure's environmental impact include optimizing structural-member efficiency and reducing the total quantity of materials used on the project. One such optimization that has been used for decades is precast concrete hollow-core slabs. While hollow-core slab technology was developed for structural efficiency and optimal material use, a hollow-core slab is also substantially more environmentally friendly than a comparable solid concrete slab.

Reduce the Environmental Impact of Specific Materials

Many strategies to mitigate the environmental impact of buildings and other structures can be applied at the material-specific level. Strategies to reduce the environmental impact of precast concrete include using performance specifications and changing the ingredients and mixture proportions in concrete to reduce the clinker content of concrete.

A common method of to reduce cement use is to replace cement with supplementary cementitious materials (SCMs) such as fly ash or slag. Concrete mixtures in which SCMs replace over 40% of the cement can be functional. To ensure that strength objectives are met but not unnecessarily exceeded, engineers should engage material suppliers to discuss appropriate mixture proportions. In some cases, material suppliers can work with structural engineers to reduce the clinker content of concrete without the need for any additional materials.

Summary

In the face of the climate crisis, decision makers are looking for ways to accurately determine the environmental impact of their choices. EPDs provide environmental impact information, but it is usually not appropriate to compare EPDs of products to determine the best choice.

Decision makers must understand how EPDs are developed to know when it is appropriate to compare them. For example, if EPDs are to be compared, they must be governed by the same

Photo Credit: Clark Pacific, UCSF Housing At the Tidelands

PCR. However, conformance to the same PCR alone does not ensure that two products can be compared. Many additional requirements must be met for the EPDs to be comparable, such as having the same scope, using the same LCA tool, and sharing the same background data.

The Carbon Leadership Forum and the American Institute of Architects have issued several warnings against improper comparisons, such as: "No comparison should be made across material types (e.g., wood vs. concrete structure) without including stages B and C."[16] However, improper comparisons are rampant in practice. A recent toolkit from the Carbon Leadership Forum and the American Institute of Architects includes a checklist to help architects (and others) determine whether two product EPDs can be compared.[16] The checklist includes the following items:

- Functionally equivalent (e.g., strength, stiffness, insulative properties, etc.)
- Created using the same PCR
- Include the same life cycle stages
- Use of one product versus another does not change other aspects of the design or assembly

All items on the checklist must be checked for both EPDs before they can be compared. If all items are not checked, it is better to use LCA rather than EPDs to make design decisions.

Challenges to the precast concrete industry and others in comparing EPDs relate to the complexity and design choices available. These challenges must be understood as we collectively move toward solutions to facilitate structure-level assessments.

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Abbreviations and Acronyms

B-to-B: business-to-business

B-to-C: business-to-consumer

C_2H_4: ethene

CFC-11: chlorofluorocarbon-11

CH_4: methane

CO_2: carbon dioxide

CO_2e: carbon dioxide equivalent

CPC: Central Product Classification

CSI: Construction Specifications Institute

EN: European standard maintained by CEN (European Committee for Standardization)

EPD: environmental product declaration

GHG: greenhouse gas

GWP: global warming potential

ISO: International Organization for Standardization

LCA: life-cycle assessment

LCI: life-cycle inventory

LCIA: life-cycle impact assessment

N_2O: nitrous oxide

PCR: product category rule

PO_4: phosphate

SCM: supplementary cementitious material

SO_2: sulfur dioxide

PCI Precast/Prestressed Concrete Institute

designer's notebook