Low-Embodied Carbon Materials Resource Guide

Presented by the City of Ann Arbor in partnership with the Global CO_2 Initiative

Background

In an effort to promote methods of addressing the climate crisis, Ann Arbor has passed the Low Embodied Carbon Materials in Construction Resolution. This resolution recognizes the importance of embodied emissions in construction and outlines goals to educate, innovate, and lobby for the use of low embodied carbon practices. The following resource guide, created in collaboration with the Global CO2 Initiative at the University of Michigan, shares information on low embodied carbon building materials. Concurrently, a Low Embodied Carbon Concrete Task Force was assembled by AIA Huron Valley, Washtenaw Contractors Association, and the A22030 District to promote low embodied carbon concrete and steel in the Washtenaw area. The task force included local stakeholders across the construction landscape, and assembled information included in the resource guide.

Embodied Emissions

Embodied emissions are defined as the emissions associated with all parts of a product's life, outside of operation. In buildings, embodied emissions would include obtaining the raw materials, transporting them, and producing the construction materials, as well as the actual construction process. The deconstruction and disposal/recycling of the building after its lifespan would also be included, but these contributions are much smaller than others. The lights, heating/cooling, water use, maintenance, etc. would not be included as those are associated with the operation of the building.

The majority of the emissions reduction focus has been in the operational sector, however, embodied emissions are currently projected to account for nearly half of the overall building emissions[1] between now and 2050, making the embodied sector just as important. The majority of new construction emissions are due to the utilization of concrete, steel, wood, insulation, carpet, and gypsum board, however, concrete and steel are the dominant embodied emissions sources. Methods to account and reduce concrete emissions will be discussed further in this resource guide.

Source: Carbon Leadership Forum - Embodied Carbon 101, 2021[2]

[1] "New Building: Embodied Carbon." Architecture 2030. Accessed June 23, 2021. https://architecture2030.org/new-buildings-embodied/.

[2] "1 - Embodied Carbon 101." *Carbon Leadership Forum*, 27 June 2021, carbonleadershipforum.org/embodied-carbon-101/.

Carbon Accounting and Environmental Product Declarations (EPD)

A key aspect of minimizing embodied emissions is being able to account for the emissions. The industry standard method of accounting embodied emissions is known as the Environmental Product Declaration (EPD). An EPD is the emissions equivalent of a nutrition label that goes along with a product detailing its global warming potential (GWP) and other climate impact metrics for comparisons between like-products and tracking reductions over time. EPDs provide other important information about the emission of other pollutants. The tools below help with either creating EPDs (with varying levels of complexity and accuracy) or allowing for easier access and comparison of those EPDs.

EPD Comparison and Analysis

EC3 Tool (Website, Video Walkthrough)

A free tool for architects/engineers that should be implemented after the materials for a project have been selected, but not the specific producer. This tool has a database of over 40,000 EPDs (of which many are concrete) that can be browsed through. The GWPs and specifications from these EPDs have been extracted and can be viewed graphically for side-by-side comparisons based on region, type of product, specifications, etc. An entire building project can be built in this program with materials from specific companies, with each part being tracked and added to a GWP total, for comparison with national benchmarks, all based on third-party verified EPDs. This tool also addresses some of the concerns over comparing different EPDs by adding uncertainty bounds and can be used to achieve up to two LEED Pilot credits.

EPD Creation (Mainly Concrete Focused)

ZGF Tool (Press Release, Email Baha Sadreddin at lca-tool@zgf.com for free access)

A tool for concrete producers that creates an EPD based on an inputted mix design and a selected region. It also allows for easy comparison to a benchmark for the selected region. This is a fairly simplistic tool and doesn't not use plant specific emissions data, thus lacking the accuracy of those that do.

Slag Cement Calculator (Website)

A tool for concrete producers that creates an EPD based on an inputted mix design and a selected region. This tool, unlike the ZGF tool, focuses mostly on slag cement, and goes into more detail on those options in particular. This tool also lacks plant specific emissions data, lacking the accuracy of those that do.

GCCA Tool (Website, Introductory Video, Email info@gccassociation.org for access)

A tool for concrete and cement producers that allows for EPD creation from mix designs based on inputted data from the producers and the ecoinvent database, one of the best sources for lifecycle analysis. This tool requires plant-specific LCA data, adding an additional burden, but making the EPD much more robust and useful for comparison. EPDs generated from the GCCA tool can be third-party verified for further confidence in the EPD, although the way in which this tool is set up makes that process expensive.

Athena's EPD Tools (Website)

Athena has a series of tools for architects/engineers/producers that allows for the creation of EPDs. These range from simplified EPDs similar to the ZGF tool listed above, as well as very details ones that require plant-specific LCA data and allow for third-party verified EPDs. These tools can be used for more than just concrete and can actually be used to create EPDs for an entire construction project by splitting it into various sections (e.g. walls, columns, foundation, roof) and inputting their geometries and types.

Climate Earth Tool (Website, Introductory Video)
A tool for concrete producers that allows for EPD generation based on plant-specific LCA data, similar to the Athena tool above. As of October 2019, Climate Earth's payment scheme consisted of a one-time payment that provided a set number of EPDs for a plant, and then a monthly payment for unlimited EPDs and an annual data update for new materials or project adjustments

Climate Earth Pricing Scheme (as of October 2019)[3]
10 Plant Operation
$24,700 for set up (including 300 EPDs)
$52/mo/plant (unlimited EPDs and an annual data update)

3 Plant Operation
$13,100 for set up (90 EPDs)
$90/mo/plant (unlimited EPDs and an annual data update)

For more information on all aspects of EPDs, refer to this paper.

CONCRETE

Concrete is Everywhere

Concrete is the second most used material on the planet (behind water). It's an incredibly versatile building material and is used in nearly all construction projects, from roads to buildings to bridges to dams. Due to the large volume being used (>10 billion tonnes/year[4]), there are massive emissions associated with it (7% global emissions)[5]. Luckily, there exist many current and developing methods to drastically reduce concrete embodied emissions.

Cement Production Process

3 Chris Erikson. October 24, 2019. Accessed June 23, 2021. https://www.youtube.com/watch?v=_3knbsNsvLE.

4 Concrete Helper- A Concrete Industry Resource. Accessed June 23, 2021. http://concretehelper.com/concrete-facts/

5 Thomas Czigler, Sebastian Reiter, Patrick Schulze, and Ken Somers. "Laying the Foundation for Zero-carbon Cement." McKinsey & Company. July 21, 2020. Accessed June 23, 2021. https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement.

Cement, the “glue” of concrete, is responsible for the vast majority of the embodied emissions in concrete (despite making up less than 15% of concrete by mass)[6]. This is due to the production process of cement, which involves heating limestone to nearly 1500 ˚C, which requires an energy intensity currently only produced using fossil fuels. Beyond that, the reaction that occurs turns limestone into lime and CO_2, increasing emissions even further.

This production process, paired with the incredible demand, makes concrete an ideal starting point for addressing embodied emissions.

Low-Embodied Carbon Concrete (LECC) Options

Cement Production and Power Generation

Alternative Fuels

Over ⅓ of cement emissions come from fossil fuel heating of the cement kiln[7]. Using alternative fuels such as biomass, waste products, or high energy-intensity renewables could dramatically reduce the GWP of cement production.

Carbon Capture

Over ½ of cement emissions come from the calcination reaction[8], something that, for the foreseeable future, is an unavoidable aspect of cement production. Adding carbon capture systems to cement plants is one of the few ways to mitigate those emissions.

Energy Efficiency

Always a way of reducing emissions further, working on the efficiency of the cement production process has the potential to reduce emissions in all its sectors.

Concrete Production

Supplementary Cementitious Materials (SCMs)

Since cement is the largest source of emissions in concrete, replacing cement with other materials can be very beneficial.

Limestone: Portland Limestone Cement (PLC), made by substituting a certain amount of cement with limestone, is one of the cheapest, easiest, and most widespread ways of reducing the cement content in concrete.

Fly Ash: Fly ash is a byproduct of the combustion of coal and can be used in place of a large portion of the normal cement content.

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[6] MIT CSHub. Slide 76. Accessed June 23, 2021. https://www.architects.org/uploads/BSA-Embodied-Carbon-in-Buildings-conference-5.31.2019_part-2-resize.pdf

[7] Czigler, Reiter, Schulze, and Somers. "Zero-carbon Cement."

[8] Czigler, Reiter, Schulze, and Somers. "Zero-carbon Cement."

Silica Fume: Silica Fume is a byproduct of the production of silica in electric arc furnaces and can help with reducing curing times[9]

Slag: Slag is a byproduct of both the iron and steel-making processes. Both types of slag can be useful, but blast furnace (iron) slag is able to act as an SCM and thus can replace some amount of cement in a concrete mix.

Pozzolans: Pozzolans such as ground glass pozzolan (see Pozzotive) are siliceous or aluminous minerals that, when ground up and introduced to water, create compounds that can act as SCMs.

Locally Sourced Materials
Acquiring materials from local producers can dramatically reduce the emission associated with transport

Carbon Capture Utilization, and Sequestration (CCUS)
Carbon Curing: Carbon curing is a rapidly developing field where concrete is cured using CO_2 in addition to (or instead of) water. This allows for the storage of CO_2 in the concrete itself, while also adding to its structural integrity. Major players in this field include Solidia, CarbonCure, and CarbiCrete.

Mineralized Carbon Aggregates: Aggregates don't contribute to the GWP of concrete as cement does, but they do make up the majority of concrete by mass, and their contribution isn't insignificant. The ability to not only reduce emissions from aggregates but turn aggregates into a CO_2 storage device which adds to the structural strength of the concrete is an excellent option for reducing embodied emissions. Blue Planet is a leader in this field.

Performance Improvement
Often when more concrete is used, a better option may have been to use stronger concrete. Increasing the performance of concrete rarely dramatically increases its associated emissions, whereas an increased volume does. At the same time, the durability of concrete is incredibly important, as concrete that lasts longer directly reduces emissions due to delayed replacement production and decreased repairs.

Aggregates
Well-Graded Aggregates: Concrete aggregate is often divided into just two groups: coarse and fine. Splitting this further and creating a series of sizes (well-graded) causes the aggregate to pack into the concrete mixture better and can increase the strength of the mix, and decrease the cement usage.

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[9] Blended Cements. accessed July 26, 2021. https://www.lehighhanson.com/products/cement/blended

Recycled Concrete Aggregates: Demolished infrastructure often results in large amounts of broken concrete. This can be recycled and appropriately sized for use in new concrete mixes as an aggregate.

Concrete Procurement

Appropriate Specifications

Stronger concrete is generally created by using more cement in the mix, so when the specs for a project are set higher than is needed (think sidewalks that could support buildings), the embodied emissions of those projects are much higher than necessary. Avoiding overdesigning would make a large impact.

Climate Impact Weighting Based on EPDs

The current process for choosing a concrete mix is based on the offered price, the performance specifications of the concrete, the experience of the bidder, and other things. One potential way to incentivize the production of LECC is to add the GWP of a mix to the selection process. This provides an additional incentive for LECC production, and a version of this is seen in LECCLA, the original version of New York's LECC procurement bill.

For additional LECC pathways, visit the Carbon Smart Materials Palette site.

STEEL

Steel production is much more carbon intensive than concrete by mass, generating roughly 8% of global emissions[10] despite producing less than 20% of the tonnage of concrete[11]. Similarly to concrete, steel has several decarbonization methods including many that overlap including the use of alternative fuels, carbon capture, energy efficiency improvements, locally sourced materials, and performance improvements on the steel production side, as well as appropriate specifications and climate impact weighting based on EPDs for the steel procurement side. Several more steel-specific options are shown below[12], and more pathways can be found here.

Electric Arc Furnaces (EAF)

One of the most effective ways of reducing the GWP of steel production is using an electric arc furnace in place of a blast furnace (BF) or basic oxygen furnace (BOF). Electric arc furnaces use electric heating to melt down scrap metal, increasing the recycling of steel and allows for renewables to power the process through its electrification.

Direct Reduced Iron (DRI) Production

[10] Christian Hoffmann, Michel Van Hoey, and Benedikt Zeumer. "Decarbonization Challenge for Steel." McKinsey & Company. June 3, 2020. Accessed July 26, 2021. https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel.

[11] Carlier, Mathilde. "Steel Production Figures U.S. 2006-2020." *Statista*, 31 Mar. 2021, www.statista.com/statistics/209343/steel-production-in-the-us/.

[12] Hoffmann, Van Hoey, and Zeumer. "Decarbonization Challenge for Steel."

High quality products from EAFs require the use of high quality steel scrap, which, when lacking, can be created using DRI and lower quality scrap. Increasing the production of DRI will allow for a smoother transition to EAF-based steel.

Hydrogen-Based DRI

Current DRI processes use natural gas in the reduction process, but with increased green hydrogen (hydrogen created from renewable sources) this process could be done in a net-zero fashion

OTHER MATERIALS

There are hundreds of construction materials, not all of which can be covered here. All of these, however, have options to reduce the climate impact. The Carbon Smart Material Palette site covers some of the more common materials and provides more ways for reducing their embodied emissions.

ANN ARBOR-SPECIFIC RESEARCH AND RESOURCES

The Ann Arbor Low Embodied Carbon Concrete Task Force was assembled by AIA Huron Valley, Washtenaw Contractors Association, and the A2 2030 District to promote low embodied carbon concrete and steel in the Washtenaw area. The task force included local stakeholders across the construction landscape. The results of the task force are shown below in the white paper and include the outcomes of several locally available low embodied carbon concrete mixes that were tested. One of the chosen concrete mixes was poured in July 2021 at several locations across Ann Arbor as a pilot of these concretes mixes.

Local Resource Links And Map

University of Michigan, Global CO_2 Initiative

The Global CO_2 authored this resource guide and is actively working in the Ann Arbor community and beyond to promote a transition to a net-zero, sustainable economy. We provide information and advice to stakeholders on local to international topics, and work with them to turn carbon capture and use into a mainstream climate solution.

American Concrete Institute

The American Concrete Institute is a great resource for those interested in learning more about anything in the concrete space, including LECC, and members from the organization played a role in helping to create the Ann Arbor resolution.

Doan Concrete

Doan Concrete was instrumental in gathering the data surrounding the LECC mixes, and preformed the mix pours as well. They plan to move forward with these new LECC mixes, and are a great resource for those interested in this field to reach out to about SCMs, EPDs, and many other things in the LECC space.

Edw. C. Levy Slag and Aggregates
Edw. C. Levy is a large slag and aggregate (and more) producer in the area involved, and increasingly interested, in using their various waste streams to reduce embodied emissions in construction.

Michigan Concrete Association
The Michigan Concrete Association can assist with training for the use and implementation of LECC mixes, as well as provide advice on best practices in the concrete space from a sustainability view.

St Marys Cement
St Marys Cement is involved in creating low-GWP cement mixes, and can provide expertise surrounding the use of blended cements (including PLC and the use of silica fume).

University of Michigan, Center for Low Carbon Built Environment
The Center for Low Carbon Built Environment (CLBCE) has created a bendable, CO_2 storing concrete which has been used internationally, including in skyscrapers in Japan, as well as locally on the Grove Street Bridge in Ypsilanti.

Task Force Outcomes

Local Projects

Tri Delta Sorority LECC Pour: A PLC, well-graded aggregate, 40% slag mix was poured in a driveway just south of U-M's Central Campus

South Industrial Highway LECC Pour: A PLC, well-graded aggregate, 40% slag mix was used to patch South Industrial Highway

Leslie Center ECC Pour: A novel concrete mix developed by the Center for Low Carbon Built Environment was used for a sidewalk near the Leslie Center. This mix uses fibers and carbonation to create a flexible, highly durable, low-carbon concrete

OTHER EMBODIED CARBON POLICIES

Hastings-On-Hudson (Website, Resolution)
A resolution to commit to promoting LECC in building projects within the city

Portland (Website, White Paper)

Created a three-step initiative which 1) requires EPDs for city projects, 2) performed pilot testing of LECCs and analyzed historical data, and 3) will create a GWP threshold in June/July 2021 based on the collected and analyzed data

New York State (Press Release, Bill)
A bill to create a task force to establish LECC procurement guidelines with potential GWP- or cement content-based standards and incentives. Passed by the house and senate, and signed by the governor.

Marin County (Low Carbon Concrete Code)
A set of codes which set maximum GWP and cement content of concrete used in the county

Nationwide Policy Map (Website)

City Policy Framework for Reduced Embodied Carbon (PDF)

Carbon Leadership Forum - Embodied Carbon Policy Toolkit (includes a nationwide policy map)

1. *Embodied Carbon 101*
2. *Buy Clean Policy*
3. *EPDs*
4. *Buy Clean Development*
5. *Buy Clean Implementation*