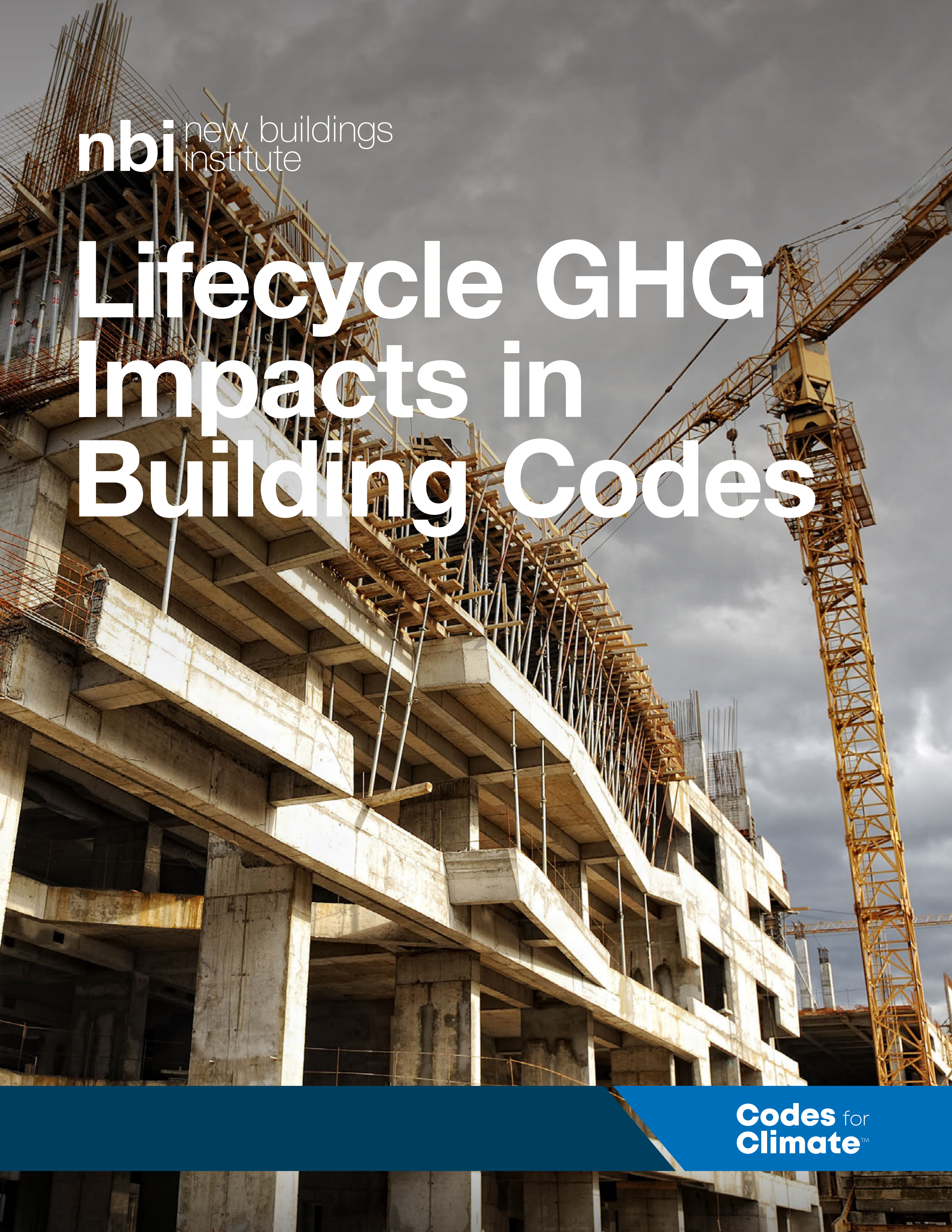
nbi new buildings institute

Lifecycle GHG Impacts in Building Codes



Codes for Climate™

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Acknowledgments

We gratefully acknowledge all of the individuals and organizations who have provided insights and thought leadership into the development of this research to move embodied carbon regulation in code.

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Introduction

Building operations and construction are responsible for approximately 39% of humanity's global greenhouse gas (GHG) emissions. More than a fourth of those are embodied carbon emissions, those associated with the production of building materials and construction activities.[1] In addition, fluorinated gases (F-gas) used to make refrigerants are responsible for another 2% of all GHG emissions.[2] Embodied emissions have been largely ignored until recently by regulators, manufacturers, architects, engineers and builders, but that is fast changing for obvious good reason: they constitute a big part of the climate problem.

This document introduces the need to address the embodied carbon of the highest emitting materials: concrete, steel, and refrigerants; and presents what regulation on embodied carbon would look like in a U.S. base code. Staged regulation moves from material disclosure, to GWP limits, and finally to whole building performance, as industry data is available. The provided code amendments (page 12) are presented as unlined text, as is standard in the code amendment process. The language can be adopted to decrease the carbon impact of the building construction industry, support local economic development towards low carbon business models, and meet the goals of the Paris Climate Accord and Glasgow Climate Pact.

Embodied carbon rises quickly in prominence when examining the lifetime of buildings, from the extraction of resources for construction through service life and on to demolition or recycling. Because embodied emissions mark the start of any project, they are sometimes called **upfront embodied carbon,** and have a time-weighted value because they are up in the air altering the climate from before the building is ever occupied. Further, as the operational efficiency of buildings increases, the embodied carbon rises in prominence and can account for nearly half of a building's total carbon footprint over its lifetime. Some have estimated that 3/4 of the climate impacts of a construction project built today, over

Building operations and construction are responsible for approximately

39%

of humanity's global greenhouse gas (GHG) emissions

1 International Energy Agency for the Global Alliance for Buildings and Construction, *2018 Global Status Report, Towards a Zero Emission, Efficient, and Resilient Buildings and Construction Sector,* United Nations Environment Programme, 2018. https://www.worldgbc.org/sites/default/files/2018 GlobalABC Global Status Report.pdf

2 United States Environmental Protection Agency, 2021 *Global Greenhouse Gas Emissions Database,* November 2021. https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

CO_2 emissions resulting from material use in buildings account for 28% of the annual buildings-related CO_2 emissions. Most of these emissions are a result of cement and steel manufacturing, which have high process emissions and are used in large quantities. Aluminium, glass and insulation materials are secondary contributors.

2018 Global Status Report, International Energy Agency (IEA) with the Global Alliance for Buildings and Construction the next two crucial decades, are due to the embodied carbon.[3] This outsized importance is why policy makers are—or should be—moving quickly to reign in embodied emissions.

The climate impact of construction materials can be inferred from their **global warming potential (GWP),** the most common metric for measuring embodied carbon. Accounting tools have been developed to measure products' environmental performance, the most common being the **environmental product declaration** or EPD, which lists GWP along with other impacts. As more and more EPDs come to light, the industry can see how material manufacturing can be carbon-intensive and use large quantities of fossil fuels before ever reaching a construction site. And, unlike **operational carbon** emissions which can be improved over the lifespan of a building through deep-energy retrofits and the decarbonization of the electric grid, the majority of embodied carbon emissions occur before a building is occupied and cannot be reduced over time. Addressing embodied carbon in the built environment is an urgent and critical part of global decarbonization efforts.

3 Architecture 2030, Why the Building Sector, December 2021. https://architecture2030.org/why-the-building-sector/

Glossary

Embodied carbon refers to the total impact of all human-induced greenhouse gases emitted from material extraction through the end of its useful life (Stages A1-A5, B1-B5, and C1-C4). **Embodied carbon** is calculated by summing all greenhouse gases emitted from non-renewable energy sources resulting from sourcing raw materials, manufacturing, transporting, construction and installation activities, ongoing material/product energy use, maintenance, repair, and finally, disposal. Sub definitions may be used to distinguish a specific focus on a product's lifecycle stage, as defined by EN 15978.[4] However, many U.S.-based professionals use "embodied carbon" when discussing **upfront embodied carbon.**

Operational embodied carbon represents the emissions associated with the operations and use of a building, including use, maintenance, repair, replacement, refurbishment, including operational energy, and water consumption (Stages B1-B7.)

Upfront embodied carbon (or emissions) refers to the sum of total GHG emissions and removals associated with a product from the extraction of raw materials through manufacturing (Stages A1-A3). Also referred to as cradle-to-gate. Upfront embodied carbon is often responsible for 50% of a product's emissions.

Whole life carbon is the sum of a product's related GHG emissions, including upfront, operational, end of life, and into the reuse and recovery stage (Stages A1-A5, B1-B7, and C1-C4, D.) Also referred to as cradle-to-grave. This definition captures all stages of a material's life and the associated emissions.

Environmental Product Declarations (EPDs) are a summary of a product lifecycle analysis and disclose the impacts of materials, including the material's carbon dioxide equivalent (CO_2e), as represented as global warming potential (GWP).

4 European Standards, BS EN 15978:201 Sustainability of Construction Works. Assessment of Environmental Performance of Buildings. Calculation Method, 2011, January 31. https://www.en-standard.eu/bs-en-15978-2011-sustainability-of-construction-works-assessment-of-environmental-performance-of-buildings-calculation-method/

FIGURE 2: GLOBAL CO_2 EMISSIONS BY SECTOR

Building Operations 28%

Building Materials & Construction 11%

Industry 30%

Transportation 22%

Other 9%

Data sources: Global ABC Global Status Report 2018 EIA

FIGURE 1: LIFECYCLE STAGES
Data source: BS EN 15978:2011

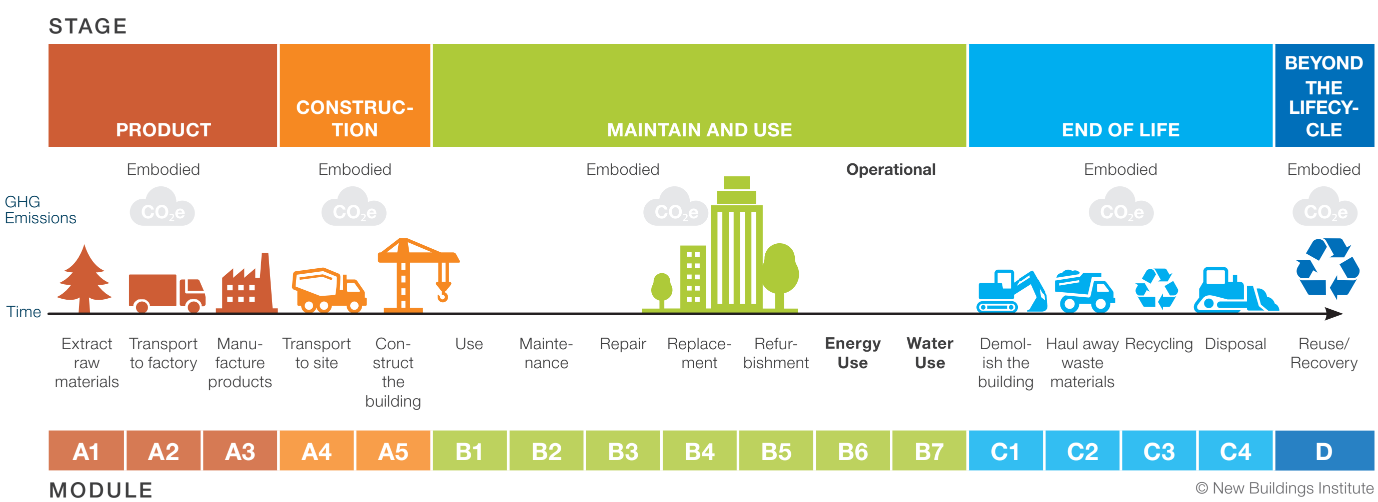
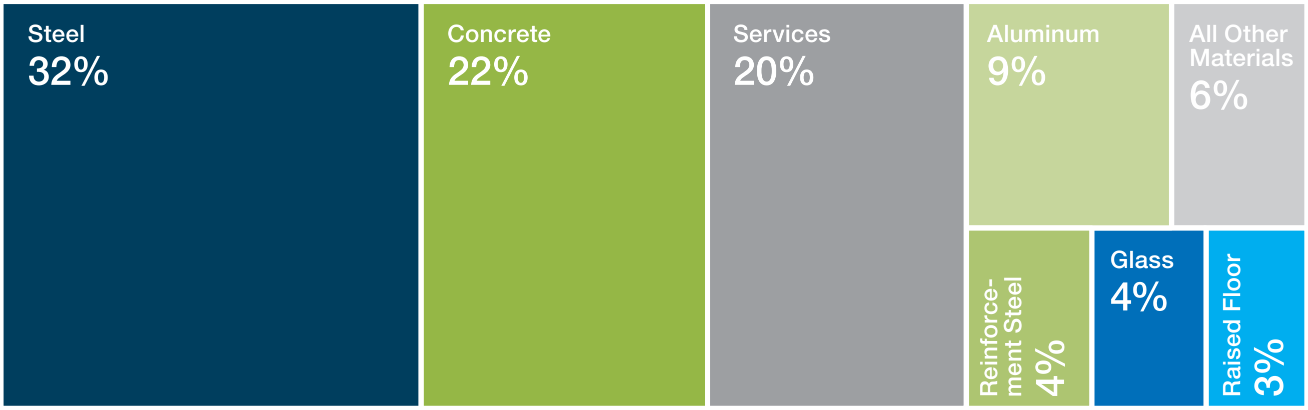


FIGURE 3: TOTAL CO_2e PER MATERIALS ACROSS FIVE ARUP PROJECT CASE STUDIES
Source: Net-zero Buildings Where do we Stand



Global warming potential (GWP) is the most common metric for measuring and evaluating materials' greenhouse gas emissions over a product or building's lifecycle, also called embodied carbon.

Lifecycle assessment (LCA) is an independently verified study of a product or building. Product-level LCAs must be done in accordance with ISO 14040 and ISO 14044 for incorporation in a product's environmental product declaration.[5,6]

Environmental product declaration (EPD) presents the information from a product's LCA to communicate the environmental performance over the lifecycle.

Whole building LCA (WB LCA) evaluates all the products and materials used in a building, or scope, to determine the carbon emissions associated with the materials.

Considering the whole life emissions of high performance commercial buildings, concrete and steel consistently represent 40-50% of embodied carbon in buildings.[7]

Material Impact 101

Concrete and steel are the two most widely used materials in the construction of new buildings. These materials are also responsible for the majority of the more than 11% of global emissions associated with building materials, while aluminum, glass, and insulation materials are the next-highest major contributors.[7] Considering the whole life emissions of high performance commercial buildings, concrete and steel consistently represent 40-50% of embodied carbon in buildings.[8]

5 International Organization of Standards, *ISO 14040: 2006 Environmental Management—Life Cycle Assessment—Principles and Framework,* 2006. https://www.iso.org/standard/37456.html

6 International Organization of Standards, *ISO 14044: 2006 Environmental Management—Life Cycle Assessment—Requirements and Guidelines,* 2006. https://www.iso.org/standard/38498.html

7 International Energy Agency for the *Global Alliance for Buildings and Construction, 2018 Global Status Report, Towards a Zero Emission, Efficient, and Resilient Buildings and Construction Sector,* United Nations Environment Programme, 2018. https://www.worldgbc.org/sites/default/files/2018 GlobalABC Global Status Report.pdf

8 Roland Hunziker, Chis Carroll, *Net-zero Buildings Where Do We Stand,* World Business Council for Sustainable Development, July 2021. https://www.wbcsd.org/contentwbc/download/12446/185553/1

TABLE A: MATERIALS ADDRESSED BY VARIOUS POLICIES AND PROGRAMS

	Clean Future Act	GSA	Buy Clean CA	LEED*
Aluminum	X	X		
Rebar	X	X	X	X
Stone and Masonry	X	X		
Concrete	X	X		X
Steel	X	X	X	X
Wood		X		X
Insulation	X	X	X	X
Openings	X	X	X	X
Finishes		X		X

* Procurement of Low Carbon Construction Materials (pilot credit)

FIGURE 4: MAP OF STATES WITH TYPE OF POLICIES: https://carbonleadershipforum.org/clf-policy-toolkit/

When looking at CO_2e at a building level instead of the industry level, we find that together, steel, concrete, aluminum, steel and glass typically account for approximately 75% of the overall upfront embodied carbon emissions.[7]

It's important to note that more product documentation and research are needed on WB LCAs to account for all building materials accurately. For example, mechanical systems consist of multiple products which do not have EPDs; therefore, a general kg CO_2e per floor area can be applied, or mechanical scopes are excluded from the analysis. Before WB LCA can be used widely in the U.S. more research on mechanical, electrical, and plumbing systems is necessary.

Embodied Carbon Policies

Buy Clean procurement policies like the U.S. General Services Administration's (GSA) Recommendations for Procurement of Low Embodied Carbon Materials and the Committee on Energy and Commerce's Climate Leadership and Environmental Action for our Nation's (CLEAN) Future Act, and third party rating systems have put pressure on building product manufacturers to disclose the environmental impacts of their products.[9,10]

9 Victor Olgyay, Clay Nesler, Jane Rohde, Fernando Arias, Kent Peterson, *GSA Green Building Advisory Committee Advice Letter: Policy Recommendations for Procurement of Low Embodied Energy and Carbon Materials by Federal Agencies,* 2021, February 17. https://www.gsa.gov/governmentwide-initiatives/federal-highperformance-green-buildings/policy/green-building-advisory-committee/advice-letters-and-resolutions

10 Summary of the Climate Leadership and Environmental Action for our Nation's (CLEAN) Future, U.S. House Committee of Energy and Commerce, 2021 March. https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/Section-by-Section of CLEAN Future Act 117th.pdf

Currently local embodied carbon purchasing policies allow advanced jurisdictions and organizations to reduce embodied carbon and deliver on climate action plan goals in limited capacities. Policies provide flexibility to respond to local conditions and gain stakeholder input.

Embodied carbon policies typically fit into two different camps—material-specific embodied carbon or whole-building LCA evaluation. Both policies require embodied carbon disclosure. These policies also align with the key life cycle stages presented in Figure 1.

Buy Clean policies (also referred to as embodied carbon procurement) are the most common type of policy addressing greenhouse gas emissions in individual construction materials. The procurement policy approach incorporates low-carbon construction purchasing requirements for any project receiving jurisdiction funds. Policy components include disclosure (GWP), incentives (bid bonus), and standards (GWP limits.) The Buy Clean approach can be applied at the federal, state, or local level and even used by private building owners.

Carbon Leadership Forum tracks the growing number of embodied carbon policies in the Policy Toolkit.[11] While most policies are procurement policies, others address specific materials or construction practices. These policies have set the foundation for material based approaches in code that would apply to a larger segment of the building population.

The procurement policy approach incorporates low-carbon construction purchasing requirements for any project receiving jurisdiction funds.

11 Carbon Leadership Forum, *CLF Embodied Carbon Policy Toolkit,* November 2021. https://carbonleadershipforum.org/clf-policy-toolkit/

Developing Code for Lifecycle GHG Regulation

In the United States only one jurisdiction has successfully incorporated embodied carbon regulation into its code, Marin County, California. The code requires that all new building projects use low-embodied carbon concrete, allowing two different compliance pathways: either a prescriptive cement limit or a GWP limit (as stated in a certified EPD) for each strength category.

To develop the code, an advisory committee evaluated cement and embodied carbon (GWP) impacts of different design mixes in Northern California and used data from National Ready Mixed Concrete Association's (NRMCA) life cycle assessment (LCA) reports for the U.S. and Pacific South West (PSW), which includes California, data from ClimateEarth, and data collected by structural engineers in the Structural Engineer's Association of Northern California (SEAONC).[12]

The Marin approach included a highly engaged local group where even concrete manufacturers disclosed data that is difficult to find publicly. In addition, Marin has the added benefit of strong aggregate that allows for less cement, or cement alternatives than other regions. Therefore, Marin's conditions do not allow for simply duplicating their code without first comparing the aspects that define low-embodied carbon in other regions.

Addressing Embodied Carbon in Code

Climate advocates have long been focused on the energy code as the only solution to solving climate change—asking that code alone to shoulder the responsibility for all things energy, carbon, and climate-related. Because the scope of the energy code is intended to address the way the building operations use energy, it is likely the wrong place to deal with embodied carbon regulations.

Codes have numerous opportunities to seamlessly incorporate material regulations, as many already have specific requirements on the materials.

12 National Ready Mixed Concrete Association (NRMCA), NRMCA Industry Average LCA Project Report—Version 3, Athena Sustainable Materials Institute, February 2020. https://www.nrmca.org/wp-content/uploads/2020/02/NRMCA_LCA_ReportV3_20200416.pdf

TABLE B: MATERIAL MAPPING OF BUILDING CODES

	Building Code	Residential Code	Mechanical Code	Plumbing Code	Electrical Code	Green Code	Energy Code
Primary Systems							
	Structural, envelope	All	Air supply, distribution, conditioning	Water supply, disposal, hot water	Electrical service, wiring, and systems	Site, Materials, Energy, IAQ,	
Materials Covered							
Concrete	X	X	X	X		X	
Steel	X	X	X	X			
Glass	X	X					
Aluminum	X		X				
Wood	X	X					
Copper			X	X	X		
Plastic	X	X	X	X			
Insulation	X	X	X				
Refrigerants			X			X	

Consequently, the remaining suite of codes have numerous opportunities to seamlessly incorporate material regulations, as many already have specific requirements on the materials used under those codes most frequently. For example, the International Building Code has an entire chapter dedicated to concrete. Because the IBC focuses on structural safety, this is not surprising and presents the clearest choice for introducing new material requirements.

Other options exist to offer solutions to increase material efficiency (i.e., reduce the amount of any material used), address end of life and deconstruction, and consider whole building components (i.e., walls, floors, etc.), in addition to whole building analysis. This first pass consideration of the codes provides a prescriptive-based solution to help reduce embodied carbon and increase data availability, a critical step to whole building life cycle analysis.

Embodied Carbon Code Development

Data availability and environmental impact combine to make concrete a good candidate for building code requirements. By using the existing data from EPDs, limits can be applied in the code to lower the embodied carbon in construction projects through straightforward, material-specific requirements.

A materials-based policy offers the best, market-ready option to achieve meaningful embodied carbon savings in building codes today.

The material approach has been proposed here instead of a whole building approach. Whole building regulation may make more sense conceptually, as it allows design and construction teams flexibility to optimize the dozens or hundreds of materials and systems in a building project to get the overall lowest carbon footprint (or, better, and anticipating ever more carbon-storing materials, the most positive climate impact). However, the yet-developing state of the lifecycle assessment, industry knowledge in general of carbon accounting, and whole building LCA data makes this problematic: How do we set a limit on a building's footprint? As the saying goes, compared to what? Compared to what do we set limits, or verify compliance? The comprehensive material and product data, calculation tools and market expertise necessary to implement WB LCAs in code are not yet sufficiently available to support a code requirement. Material-specific regulations constraining embodied carbon are (relatively) easy to write and enforce. Therefore, a materials-based policy offers the best, market-ready option to achieve meaningful embodied carbon savings in building codes today.

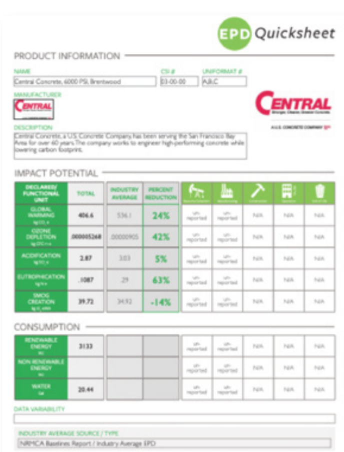
The intent in this first phase of code is not to shift the building industry away from specific materials, such as concrete or steel. Rather, the code acknowledges the importance of these materials in the construction industry and aims to achieve practical reductions in climate impact from their use in buildings. By requesting disclosure of environmental impact for materials, and optimization of concrete mixes, the code will advance the regional construction industry to be a national leader in environmental sustainability. Over time, the code will expand the market for low-GWP concrete and steel and spur competition to achieve further embodied carbon reductions for these materials. In addition, the code will encourage domestic sourcing of materials, as American manufacturers typically have lower embodied carbon impacts than their foreign counterparts, due to source energy used in manufacturing. It should be noted that mass timber, and other emerging low-carbon building material supplies, are not directly addressed in this code language.

Because there is a lack of understanding of what a regulation on embodied carbon would look like in a base code in the U.S., and a lack of current publicly available data to set targets for every building material, a staged approach is recommended, moving from disclosure to whole building performance. Efficiency advocates and policy makers will recognize this as similar to the way that jurisdictions have moved from benchmarking policies to building performance standards, and a very similar set of steps can be used to move the embodied carbon market.

Because there is a lack of understanding of what a regulation on embodied carbon would look like in a base code in the U.S., and a lack of current publicly available data to set targets for every building material, a staged approach is recommended, moving from disclosure to whole building performance.

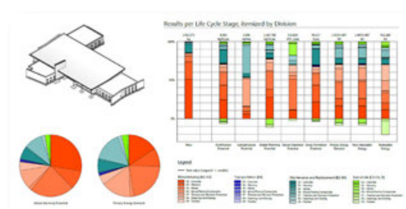
FIGURE 5: STAGES OF EMBODIED CARBON REPORTING IN BUILDING CODE

1: Disclosure



2: Material Targets

3: Whole Building LCA



Credit: Browning Day Mullins Dierdorf

Stage 1: Disclosure

Provide EPDs for specific products in a publicly available database. This step helps prime the market for what's coming and allows a jurisdiction to collect data to inform target setting in future steps. Code language for this stage may look like:

International Building Code, Chapter 22 Steel
Section 2205 Structural Steel

Add new section as follows:

2205.3 EPD Disclosure. Product-specific Type III EPDs shall be submitted for 75% of steel products. EPDs used for compliance with this section shall be certified as complying with the goal and scope for the cradle-to-gate requirements in accordance with ISO Standards 14025 and 21930 and be available in a publicly accessible database.

EPD reporting is the first step and bare minimum. EPDs are a summary of a material LCA and quantifies the impact of a product on the environment. They include information about the manufacturer, product, LCA methodology, material content, emissions, waste, chemical content, valid date, etc. EPD is only data. The existence of an EPD does not mean that it can meet a specific environmental standard. The EPD discloses information on the product, and that might include environmental certifications (like Green Guard) or recycled content.

Language like this recognizes the lack of data around certain products and product types and should be applied to material products in alignment with other regulations, like those recognized in the Clean Future Act to increase the amount of data for future updates to model code language. Jurisdictions can revise the percentage of materials subject to the requirements as necessary to meet their own needs.

Stage 2: Targets for High Embodied Carbon Materials

This step will target materials with good publicly available data sets and high impact materials. Code language for this stage may look like:

International Building Code, Chapter 19 Concrete
Section 1903 Specifications for Tests and Materials

Add new section as follows:

1903.5 Embodied CO2e of concrete materials. *Concrete* products used in the building project shall be in accordance with Sections 1903.5.1 or 1903.5.2.

Exceptions:

1. Precast concrete.
2. *Masonry units* complying with Section 2103.1.2.
3. Projects where no concrete suppliers with product-specific environmental product declarations (EPD) for *concrete* are located within 100 miles of the project site, where Type III industry-wide EPDs and an inventory of CO2e values for all concrete mixes are provided to the AHJ.

1903.5.1 CO2e Limit Method - Mixture. The total CO2e of the concrete mixes used in the project shall not exceed the value given in Table 1903.5.1 based on the compressive strength of the product. CO2e content shall be documented by a product-specific Type III Environmental Product Declaration (EPD) for each product. EPDs used for compliance with this section shall be certified as complying with the goal and scope for the cradle-to-gate requirements in accordance with ISO Standards 14025 and 21930 and be available in a publicly accessible database.

Table 1903.5.1 CO2e Limits in Mixture

Specified compressive strength f'_c, psi	Maximum kg/m^3(SI)	High-early strength Maximum kg/m3 (SI)	Lightweight concrete Maximum kg/m3 (SI)
up to 2499	302	408	578
2500-3499	382	516	578
3500-4499	432	583	626
4500-5499	481	649	675
5500-6499	505	682	N/A
6500 and greater	518	680	N/A

1903.5.2CO2e Limit Method - Project. Total CO2e (CO2eproj) of all concrete placed at the building project shall not exceed the project limit (CO2eallowed) determined using Table 1903.5.1 and Equation 1903.5.2.

Equation 1903.5.2

CO2eproj < CO2Eallowed

where: CO2Eproj = ΣO2En vn   and CO2Eallowed = ΣCO2Elim vn

and

n = the total number of concrete mixtures for the project

CO2En = the global warming potential for mixture n per mixture EPD, kg/m3

CO2Elim = the global warming potential limit for mixture n per Table 1903.5, kg/m3

vn = the volume of mixture n concrete to be placed

Language in this draft builds on the success of the Marin County Low Carbon Concrete Code, creating a structure by which jurisdictions can set achievable targets based on current U.S.-based EPDs or on local analysis. The values selected should encourage the lowest of the market's concrete to perform better and report improved performance through EPDs. Alternative cements and supplementary cementitious materials, aggregate sourcing, chemical admixtures, and plant efficiency are a few of the opportunities for creating lower embodied carbon concrete.

Certain materials like concrete and steel may already meet the threshold for data to set appropriate targets. Where that is the case, combining material targets for these in addition to disclosure as a first step is advised. To set specific low-embodied carbon requirements for materials, we need data, like the GWP of hundreds of products. Data allows us to look at regional information compared to national trends. This is an example of an analysis of thousands of concrete EPDs per different regions in the U.S. Evaluating the data, we can set a GWP limits based on regional variations and material properties like strength (concrete) or type of material (steel). If we set the GWP limit too high, it won't do much to reduce the embodied carbon in a given material. If we set it too low, manufacturers won't be able to comply. Additionally, GWP isn't the only data point for every product—we're looking at if the code could allow a specific manufacturing process that reduced carbon in manufacturing. For example, ENERGY STAR certifies cement, concrete, steel, and even cracker plants. By evaluating their metrics, they may be appropriate compliance paths for materials in code.

Stage 3: Whole Building Lifecycle Analysis

This final step is the carbon equivalent of energy modeling. WB LCAs allow projects to take credit for building material reuse or material efficiency, and may also allow for optimizing of embodied carbon against operational carbon.

WB LCA codes may set an absolute GWP value, emissions per area, or percent-better than baseline. These policies may require EPDS for a specific percent of the construction costs or weight of materials. While it is possible to complete WB LCA today, there are additional steps that need to be taken to ensure that a code requirement for WB LCA would be applied and enforced consistently, otherwise the policy would have no effect.

Currently WB LCA baseline buildings vary by project team, making it difficult to compare one project to another. To codify this type of approach, policy makers and code officials need to develop the requirements for a common baseline and rigorous guidelines for WB LCA modeling. We have baselines for energy modeling. We can do the same for whole building embodied carbon, but to do so we need more data on existing materials and their GWP values. Just like in Stage 2, if the GWP limit is too high, it won't do much, and if its too low, manufacturers, designers, and building owners won't be able to comply.

The previous two steps are critical not only to prime the market and gather data, but also to establish a code that allows for both a prescriptive (materials approach) and a performance (WB LCA) path for embodied carbon. Just like energy modeling, not every building uses that approach. One of the largest benefits of WB LCA is the consideration of building reuse. The other two options only look at new materials. WB LCA encourages reuse which has some historic and equity considerations, as well as negatives (considering asbestos, lead, etc.).

We have baselines for energy modeling. We can do the same for whole building embodied carbon, but to do so we need more data on existing materials and their GWP values.

Key Material Impacts

Third-party rating systems like LEED, have put demand on building product manufacturers to disclose the environmental impacts of their products. As more product information is available, consumers request more sustainable products, forcing manufacturers to meet the market demand. With more product information on the market, policymakers have begun to evaluate sets of data and create purchasing policies based on products' embodied carbon. Low embodied carbon procurement policies signal the market that there is long-term demand for their products.

Successful embodied carbon policies require a reliable methodology for measuring and comparing products' embodied carbon. Product lifecycle assessments (LCA) offer the rigor and consistency necessary to create a policy. LCAs are independently verified in accordance with ISO 14040 and ISO 14044.[4,5] Once a manufacturer has an LCA for a product, they create an EPD. EPDs use the information from the LCA to communicate a products' environmental performance over the lifecycle. EPDs are valid for five years and include the following data: GWP, ozone depletion potential (ODP), acidification, eutrophication, ozone depletion, and smog creation, among others. Additional data within the EPD may include ingredients, manufacturing processes and locations, energy sources, water consumption, third-party certifications, and much more.

EPDs are appropriate for use in procurement policies because the third-party verified process already exists with agreed-upon resources for calculating and documenting the embodied carbon of individual products. Product category rules (PCRs) define the product category and are necessary for Type III EPDs, based on ISO 21930:2017—Clause 3 Terms and definitions. The PRC lays out which impacts the manufacturer must include and how to measure each of the impacts. Since manufacturing can change, EPDs are valid for five years and need to be updated to be included in online databases. Because the process is voluntary, EPDs do not exist on every product, making it difficult to set targets or compare all known products.

Types of EPDs:

Type I claims are third-party verified labels based on criteria set by a third-party and governed by ISO 14024.[1]

Type II claims are self-declarations, not third-party verified. Claims are made by manufacturers or retailers and are governed by ISO 14021.[2]

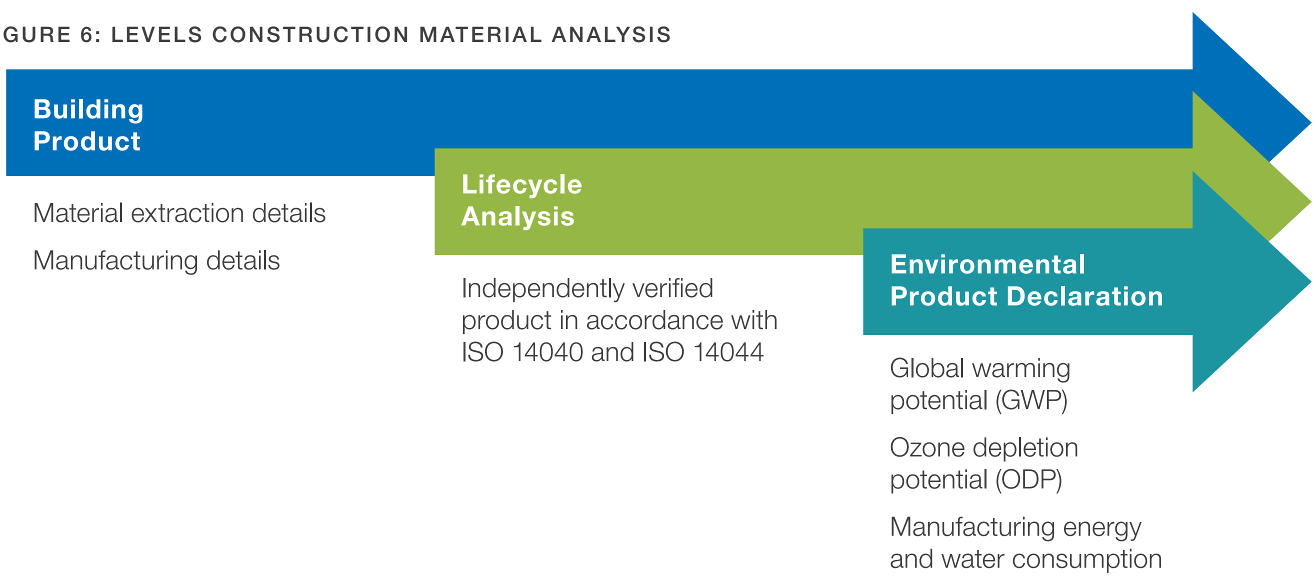
Type III claims are third-party-verified and contain quantified product information based on lifecycle impacts, and are governed by ISO 14025.[3]

1 International Organization of Standards, ISO 14024: 2018 Environmental Labels and Declarations—Type I Environmental Labelling—Principles and Procedures, 2018.

2 International Organization of Standards, ISO 14021: 2016 Environmental Labels and Declarations—Self Declared Environmental Claims (Type II Environmental Labelling),—Amendment 1: Carbon Footprint, Carbon Neutral, 2016.

3 International Organization of Standards, ISO 14025: 2006 Environmental Labels and Declarations—Type III Environmental Declarations—Principles and Procedures, 2006.

FIGURE 6: LEVELS CONSTRUCTION MATERIAL ANALYSIS



Concrete

Concrete is one of the most widely used materials in building construction and a primary contributor to embodied carbon in buildings. Construction professionals procure concrete (which contains cement used with water as a binder to adhere particles of sand and rock, known as aggregate) from a ready-mix supplier. Concrete is considered a local product because the sand, rock, and other aggregates are often procured locally. Although each of concrete's constituent materials offers opportunities for reductions of up to 33% in embodied carbon, the high embodied carbon of concrete is primarily driven by the manufacture of one key ingredient—ordinary Portland cement.[13] Portland cement is the most common cementitious binder used in concrete mixtures in the U.S., and the U.S. cement industry is one of the most significant contributors to emissions at 68.3 million metric tons (MMT) of CO_2e per year.[14] The building construction industry's demand for concrete accounts for an estimated 51% of total Portland cement produced in the U.S.[15]

In April 2021, NBI collected over 36,000 U.S.-based ready-mix concrete EPD data from Building Transparency to evaluate the ready-mix concrete's CO_2e as represented as GWP. The data were representative of 6 strength mixes found in 23 states. California, New Jersey, New York, and Washington have the most number of ready mix concrete EPDs. With 4000 and 5000 psi being the most common concrete mixes, this chart reflects the trend with the majority of the EPDs in the 3500 and 4500 psi strength classes. See Table C.

Concrete GWPs were evaluated to identify the GWP of different percentiles: 90%, 80%, 75%, 50%, 25%, and 20%. The 75th percentile of the concrete GWPs means that 75% of the GWP values (not 75% of the EPDs) comply with the limits set. Since 100 EPDs of the same strength class could have the same GWP, the 75th percentile does not equate to 75% of the EPD count to comply. In many

TABLE C: NUMBER OF COMPLYING EPDS PER CONCRETE STRENGTH CLASS PER STATE

State	2499 psi	2500 psi	3500 psi	4500 psi	5500 psi	6500+ psi
AL	1	6	5	4	0	0
CA	569	4237	6012	5427	2041	785
CO	2	30	113	214	28	36
DC	1	4	4	3	3	4
FL	3	11	67	16	14	9
GA	8	115	135	75	22	11
IA	2	10	55	21	0	0
IL	0	6	70	52	32	15
MA	0	0	15	12	5	2
MD	5	25	20	15	16	20
NC	1	92	107	71	4	6
NE	0	16	63	25	0	0
NJ	60	883	1515	1014	204	16
NM	4	23	24	3	2	0
NV	2	1	0	5	1	1
NY	11	132	303	164	36	1
OH	10	26	19	12	0	0
OK	1	2	12	12	3	0
OR	24	299	529	197	42	4
SC	0	39	31	13	1	0
TX	0	26	16	29	6	0
VA	1	6	4	3	3	4
WA	42	164	451	412	250	87
	747	6,153	9,570	7,799	2,713	1,001

13 Matt Jungclaus, Rebecca Esau, Victor Olgyay, and Audrey Rempher, *Low-Cost, High-Value Opportunities to Reduce Embodied Carbon in Buildings,* RMI, 2021. https://rmi.org/insight/reducing-embodied-carbon-in-buildings

14 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018,* U.S. Environmental Protection Agency, 2020, https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf; and "Manufacturing Energy and Carbon Footprint," US Department of Energy, https://www.energy.gov/sites/prod/files/2018/10/f56/2014_mecs_cement_energy_footprint.pdf.

15 *2019 U.S. Cement Industry Annual Yearbook, Portland Cement Association,* https://www.cement.org/morereports/2018-us-cement-industry-annual-yearbook, 2019.

TABLE D: CO_2e LIMITS IN CONCRETE MIXTURE

	CO_2e Limits in Mixture (75% percentile)*			**Marin County**	**NRMCA[12]**	**2021 CLF Baselines[16]**		
Specified 28-day compressive strength f'_c, psi	Maximum kg/m³ (SI)	**High-early strength**** Maximum kg/m³ (SI)	**Lightweight concrete** Maximum kg/m³ (SI)	Maximum kg/m³ (SI)	NRMCA Average 50%	Achieable (low) kg/m3 (SI)	Typical (Median) kg/m3 (SI)	Baseline (high)
≤ 2499	302	393	578	260	266	190	266	340
2500-3499	382	497	578	289	291	210	291	380
3500-4499	432	562	626	313	342	260	343	470
4500-5499	481	625	675	339	405	320	406	580
5500-6499	505	657	N/A	338	429	330	429	610
≥ 6500	518	655	N/A	394	498	380	498	710

* Values in this table represent limits for concrete produced in the United States and are based on the 75th percentile of EPDs collected by Building Transparency as of April, 2021. They may or may not pertain to concrete production in other countries, and therefore CO_2e, is always based on the unique availability in any location at any particular time of aggregate, cement, supplements, admixtures and other factors.

** Early high early strength concrete was provided a 130% GWP increase. This allowance derives directly from extensive stakeholder talks with ready mix producers, general contractors, engineers, the cement industry, and public procurement agencies that led to the Marin Code.

cases, the complying EPD count is higher than 75%. In the proposed values presented in Table D, over 26,000 EPDs confirm compliance with the values.

Comparing the 75 percentile GWP values against the National Ready Mixed Concrete Association (NRMCA) industry average GWP, the proposed GWP limits are higher, or more conservative, allowing more products to comply. The national GWP at the 75% percentile is also higher than Marin County's concrete code GWP limits, the only other concrete GWP limit in code. Comparing the values to the 2021 Carbon Leadership Forum's Material Baseline Report, the high baseline values (estimated to be at 80% of the median), are slightly higher than the values set at the 75th percentile of NBI collected EPDs, while the typical median value tracks with the NRMCA's industry average.[12,16] Note that the "achievable (low)" value is the 20th low percentile. See Table D.

In Marin County, local data (the greater San Francisco area) was collected to set the ready-mix GWP, understanding that Northern California's concrete is generally of higher quality than the national average, which allows for lower cement in the standard mixes. As other regions collect project-level ready-mix concrete EPDs, the data can be analyzed based on regional information and adjust the GWP limits for the local concrete.

16 Carlisle, S., Waldman, B., Lewis, M., and Simonen, K. (2021). 2021 Carbon Leadership Forum Material Baseline Report (version 2). Carbon Leadership Forum, University of Washington. Seattle, WA. July 2021. http://hdl.handle.net/1773/47141

Structural Steel

Steel products' embodied carbon is primarily a product of the energy related to steel product manufacturing.

Steel is the second highest embodied carbon product in commercial construction, following only concrete which is highest. Steel products' embodied carbon is primarily a product of the energy related to steel product manufacturing. Therefore, products manufactured with electricity, over natural gas, and in regions with lower carbon energy grids, will have lower embodied carbon. U.S. steel generally has lower embodied carbon compared to international steel. Steel exporters to the U.S. emit 50-100+% more CO_2 emissions per tonne than U.S. producers, on average.[9] International steel production's energy is often sourced from locales with more extensive coal and natural gas percentages than what is found in the U.S., making American-made steel lower in carbon than most steel derived from countries with higher emission energy sources.

While zero carbon steel may not be market-ready today, specifying steel produced in ENERGY STAR-certified factories may help reduce production emissions. In combination with cleaner electricity, this step can make significant carbon savings. Design teams can also specify electric arc furnace (EAF) steel as a straightforward way to reduce embodied carbon within structural steel. However, not all of a building's structural steel products can be produced with EAF. Manufacturing facilities can also operate using relatively low-emissions (or no-emissions) energy sources such as hydroelectric, green/renewable/low carbon hydrogen, solar, or wind. EPDs only indicate the on-site renewable energy facilities use and off-site renewables acquired through the local utility or through responsible purchase and retirement of renewable energy certificates (RECs) can support lower carbon products but may not be accounted for until the product category rules are adjusted.

To identify GWP limits for materials, NBI collected and evaluated data from over 100 international steel EPDs from Building Transparency in April 2021. Unfortunately, the EPDs did not provide data sufficiency for all products, only for rebar, which represents over 90% of the industry.

Rebar EPDs were evaluated to identify the GWP of different percentiles: 90%, 80%, 75%, 50%, 25%, and 20%. The 75th percentile of the steel product GWPs means that 75% of the GWP values (not 75% of the EPDs) comply with the limits set. Setting targets at the 75% GWP values encourage the lowest 25% of the market's steel EPDs to perform and report improved performance. These values generally align with the values in CLF's Material Baseline report.[16]

For the remaining steel products, structural steel, hollow steel sections, and plate, the GWP limits were established using industry-wide EPDs (IW-EPD) which represent an average GWP for like products. To set the GWP limit, a percentage of the Type III industry-wide EPDs for each product was used for both mill and fabricated products. The analysis included comparing the industry average values to the percentile of EPDs. The mapping of percent higher than industry average and the percentile of EPDs can be seen in Table F. The GWP values in Tables F-H illustrate the industry average (IW-EPD), the percentile of studied EPDs, Buy Clean California (BCCA) limits, and CLF's Material Baseline value for the 80th percentile. Steel product GWP limits should be set at a value that encourages the highest carbon-intensive products to improve, such as 160% of the industry average or 80th percentile of EPDs. The 160% of industry average values are higher than those within the studied EPD dataset and BCCA steel GWP limits, meaning they are more conservative, and more products can comply.[17]

17 California Department of General Services (DGS), Buy Clean California Act, GWP Limits, January 2022. https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act

TABLE E: STEEL PRODUCT EPD STUDY

	Ton-CO_2e per ton of Milled Products			Ton-CO_2e per ton of Fabricated Product	
	Hot Rolled	Steel Plate	Rebar	Hot Rolled	Rebar
EPD Count:	15	2	51	4	19
90% Percentile	2076	1116	1892	1360	1138
80% Percentile	1270	1082	1074	1360	1094
75% Percentile	1235	1066	1032	1360	1080
50% Percentile	1040	981	852	1360	860
25% Percentile	851	896	728	1360	635
20% Percentile	718	880	728	1360	630
Number of EPDs that comply with 75% percentile	11	1	40	4	14

TABLE F: HOT ROLLED STRUCTURAL STEEL SECTION PRODUCT GWP COMPARISON

	Milled-ton CO_2e/ton			Fabricated-ton CO_2e/ton		
	IW-EPD	EPD	BCCA[17]	IW-EPD	EPD	CLF (80th percentile)[16]
200% of Industry Wide (100th Percentile)	1980			2440		
190% of Industry Wide	1881			2318		
180% of Industry Wide (90th Percentile)	1782	2076		2196	1360	
175% of Industry Wide	1733			2135		
170% of Industry Wide	1683			2074		
160% of Industry Wide	1584	1270		1952	1360	1700
150% of Industry Wide (75th Percentile)	1485	1235		1830	1360	
145% of Industry Wide	1436			1769		
140% of Industry Wide	1386			1708		
135% of Industry Wide	1337			1647		
130% of Industry Wide	1287			1586		
125% of Industry Wide	1238			1525		
Industry Wide EPD (50th Percentile/Industry Average)	990	1040	1010	1220	1360	1160

TABLE G: STEEL PLATE PRODUCT GWP COMPARISON

	Milled-ton CO_2e/ton			Fabricated-ton CO_2e/ton	
	IW-EPD	EPD	BCCA[17]	IW-EPD	CLF (80th percentile)[16]
200% of Industry Wide (100th Percentile)	2940			3460	
190% of Industry Wide	2793			3287	
180% of Industry Wide (90th Percentile)	2646	1116		3114	
175% of Industry Wide	2573			3028	
170% of Industry Wide	2499			2941	
160% of Industry Wide	2352	1082		2768	3000
150% of Industry Wide (75th Percentile)	2205	1066		2595	
145% of Industry Wide	2132			2509	
140% of Industry Wide	2058			2422	
135% of Industry Wide	1985			2336	
130% of Industry Wide	1911			2249	
125% of Industry Wide	1838			2163	
Industry Wide EPD (50th Percentile/Industry Average)	1470	981	1490	1730	1470

TABLE H: HOLLOW STRUCTURAL STEEL SECTION PRODUCT GWP COMPARISON

	Milled-ton CO_2e/ton		Fabricated-ton CO_2e/ton	
	IW-EPD	BCCA[17]	IW-EPD	CLF (80th percentile)[16]
200% of Industry Wide (100th Percentile)	3420		3980	
190% of Industry Wide	3249		3781	
180% of Industry Wide (90th Percentile)	3078		3582	
175% of Industry Wide	2993		3483	
170% of Industry Wide	2907		3383	
160% of Industry Wide	2736		3184	3000
150% of Industry Wide (75th Percentile)	2565		2985	
145% of Industry Wide	2480		2886	
140% of Industry Wide	2394		2786	
135% of Industry Wide	2309		2687	
130% of Industry Wide	2223		2587	
125% of Industry Wide	2138		2488	
Industry Wide EPD (50th Percentile/Industry Average)	1710	1710	1990	2390

Refrigerants

As climate change increases the need for additional heating and cooling, and as heat pump technology is adopted, the demand for refrigerant using equipment will quickly expand. Refrigerants are often thousands of times more polluting than CO_2. For example, a single pound of R-22 is as potent as roughly one ton of CO_2. However, there are tens of thousands of refrigerants and blends with a range from 0 to 12,500 CO_2e.

Additionally, refrigerant leakage is one of the most significant contributors to climate change within the building industry and offers one of the greatest possibilities to reduce emissions.[18] Leakage is highest during building operations, ranging from 1-10%, with an average of 3%. Besides selecting lower GWP refrigerants, refrigerant management plans, and leak detection systems offer the greatest opportunity to reduce emissions.

U.S. Department of Energy (DOE) and California Air Resources Board (CARB) are addressing refrigerant GWP through regulation. CARB's regulation, Stationary Refrigeration, and Air Conditioning Rulemaking which was rolled out on January 1, 2022, and will continue through January 1, 2025.[19] These rules require stationary refrigerating systems (grocery store and walk-in freezers) greater than 50lbs (22.7kg) of refrigerants to limit CO_2e-100 yr. GWP to 150. Additionally, room air conditioning and other residential and commercial air conditioning, and variable refrigerant flow system refrigerant GWP-100 year to be not more than 750 GWP.

The lower GWP and zero ozone depleting potential (ODP) refrigerants that are recommended carry a concern about their low flammability level. As seen in Figure 7, ASHRAE classified Safety Group A2L refrigerants have lower GWPs. A2L indicates that they have lower toxicity and lower flammability. However, AHRI and U.L. Firefighter Safety Research Institute have tested the differences between the refrigerants in real-life fire scenarios.[20] The testing aimed to quantify the amount of heat refrigerant added to a fire, called the "heat release rate," found that it was actually higher for R-410A (A1 refrigerant) than for R-32 (A2L refrigerant.) The heat added by refrigerant was about the same as a small plastic trashcan fire, and there was no flash fire or deflagration.

As of January 2022, CARB lists 14 refrigerants lower than 125 CO_2e 100-year and 23 lower than 750 CO_2e 100-year.[21] As regulations implementation nears, industry innovation will bring new mixes and alternatives to the market.

FIGURE 7: ASHRAE STANDARD 34 BASIS OF STANDARD—SAFETY GROUP CLASSIFICATION

SAFETY GROUP

INCREASING FLAMMABILITY

Higher Flammability	A3	B3
Lower Flammability	A2	B2
	A2L*	B2L*
No Flame Propagation	A1	B1
	Lower Toxicity	Higher Toxicity

INCREASING TOXICITY

* A2L and B2L are lower flammability refrigerants with a maximum burning velocity of ≤ 3.9 in./s (10 cm/s).

Additionally, refrigerant leakage is one of the most significant contributors to climate change within the building industry and offers one of the greatest possibilities to reduce emissions.[18]

18 Louise Hamot, Hugh Dugdale, Olivier Boennec, *Refrigerants and Environmental Impacts, A Best Practice Guide,* Integral Group, September 2020. https://www.integralgroup.com/news/refrigerants-environmental-impacts/

19 California Air Resources Board, Prohibitions on Use of Certain Hydrofluorocarbons in Stationary Refrigeration, Chillers, Aerosols-Propellants, and Foam End-Uses Regulation, CARB, 2020, September. https://ww2.arb.ca.gov/rulemaking/2020/hfc2020

20 George Hunter, *A2L Refrigerants and Firefighter Tactical Considerations,* Underwriters Laboratory LLC and Air-Conditioning, Heating, and Refrigeration Institute, 2021. https://www.ahrinet.org/App_Content/ahri/files/RESEARCH/Technical Results/AHRI-8028_Final_Report.pdf

21 California Air Resources Board, High-GWP Refrigerants, CARB, 2021, December. https://ww2.arb.ca.gov/resources/documents/high-gwp-refrigerants

Conclusions

From new construction, renovations, or simple material replacements or additions, each construction event presents an opportunity to drive significant upfront embodied carbon reductions by selecting materials with lower carbon footprints. By implementing considerations in building codes that address the reduction of CO_2e in common materials used in building construction, we can decrease the carbon impact of the building construction industry, support local economic development towards low carbon business models, and meet the goals of the Paris Climate Accord and Glasgow Climate Pact.

Building energy codes are expected to continue to improve building energy efficiency over time, and as operational efficiency increases, building materials embodied and fugitive emissions will become a more significant source of buildings carbon emissions. Incorporating EPD reporting and material embodied carbon limits in building code illustrates materials important role in reducing global GHG emissions. When the building code sets a baseline for a materials embodied carbon, total building emissions will reduce because manufacturers will adapt operations to use more recycled content, find additional manufacturing efficiency, procure local materials, use less carbon-intensive shipping options, and secure more renewable energy.

Today, concrete and steel emissions account for ~50% of a building's embodied carbon. The industry's disclosure has allowed policymakers to understand the material emissions and set GWP targets. It's expected that additional EPD reporting and GWP limits for higher embodied carbon materials will continue to be the focus of codes, even as material efficiencies are gained. Many policies are starting to set GWP limits for products that are used in higher volumes such as: glass, aluminum, insulation, plastics, and wood.

Collaboration between policymakers, and equipment manufacturers, designers, and trade organizations is essential to continue to tackle building material emissions reduction. A two-way push and pull will result in the most successful code and carbon reduction solutions. Code considerations must be balanced with design team know-how, and sensitivity to project budgets and timelines. Similar to improving operational carbon in code, addressing embodied carbon in code will occur over time and seek improved efficiency as the industry evolves. The advancement of embodied carbon code development and implementation depends on trusted data, collaboration with industry, and education. Material manufacturers are already seeking opportunities for carbon reduction and the market will respond to the code with innovative solutions.

In addition to addressing embodied carbon within code material by material, considering material efficiency and options to address end of life and deconstruction will be necessary for further carbon reductions. Building on these foundations, the next step will be to move beyond individual materials and consider the whole building lifecycle analysis. WB LCA provides an introduction to encourage holistic thinking and align with local policies that can further encourage building carbon reduction.

Incorporating EPD reporting and material embodied carbon limits in building code illustrates materials important role in reducing global GHG emissions.

Concrete and steel emissions account for

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Codes for Climate is an initiative of NBI and RMI to deliver the climate-aligned building codes and standards needed by U.S. states and cities in the face of the pressing demands of policy goals. To scale greenhouse gas reductions in the buildings sector to be in step with a 1.5ºC future, the initiative works to support policy makers at multiple levels to move codes and standards forward, making significant reductions in energy consumption and GHG emissions from buildings possible and effective. Research and development of code language to reduce Lifecycle GHG impacts supports the goals of the Codes for Climate Initiative.

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New Buildings Institute (NBI) is a nonprofit organization driving better energy performance in buildings to make them better for people and the environment. We work collaboratively with industry market players—governments, utilities, energy efficiency advocates, and building professionals—to promote advanced design practices, innovative technologies, public policies, and programs that improve energy efficiency. The Getting to Zero website houses over 300 curated resources including guidance, educational webinars, policy models, research, case studies, and more to help all buildings achieve zero energy. Visit **gettingtozeroleadership.org** to learn more.