Cutting Carbon with Codes:
Reducing the Worst Climate Impacts of Construction

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ABSTRACT

The Paris Agreement has policymakers seeking carbon-cutting opportunities everywhere within the built environment, from highways and power stations to carpet and windows. While building codes and policies continue to reduce operational emissions, attention must also be turned to materials' embodied emissions. New construction is expected to account for 50 percent of global building emissions as the total floor area doubles by 2060. As buildings become net-zero, like Denver's 2040 goal, operational emissions disappear, and embodied carbon becomes the project's sole climate impact. Fortunately, the bulk of embodied emissions are mostly traceable to a few high emitting products specified in large quantities (cement, steel, aluminum, glass, and the hydrofluorocarbons in refrigerants and plastic foam insulation), highlighting where to focus reduction efforts. Furthermore, achieving 40-50 percent embodied carbon reduction is possible with low-cost solutions that exist today.

Codes and policies offer a pathway to address the embodied carbon of construction materials. Progressive cities like Denver are analyzing whole-life carbon opportunities and updating codes to address the highest emitting materials and including more ambitious provisions in green codes. Working hand in hand with codes, policies can address sections of whole life carbon at any point in a building's lifecycle, e.g., construction emissions (extraction and transportation) or end-of-life policies (deconstruction, waste, and reuse). Aligning with policies that regulate operational emissions, jurisdictions can guide all aspects of a building's lifecycle to help meet emission goals. With jurisdictional examples, this paper will explore code and policy opportunities to establish whole-life carbon emission backstops, shape industry norms through public purchasing, and adapt rules to local conditions.

Introduction

Since the first U.S. building energy codes in the 1980s, products and construction methods have continued to change as states adopt the newer versions. Designers have selected more energy efficient lighting and insulation, installed system controls and monitoring systems, designed thermal breaks, installed external shading, etc. Yet, even with the gains in building energy efficiency, building operations and construction are responsible for approximately 39 percent of humanity's global greenhouse gas (GHG) emissions. More than one-quarter of those are embodied carbon emissions (Global ABC 2018). Embodied carbon emissions refer to the total impact of all human-induced GHGs emitted from material extraction through the end of their useful life. Embodied carbon is calculated by summing all GHGs from nonrenewable energy sources from sourcing raw materials, manufacturing, transporting, construction and installation activities, ongoing material/product energy use, maintenance, repair, and disposal.

Until recently, embodied emissions have been largely ignored by regulators, manufacturers, architects, engineers, and contractors, but that is fast changing for good reason: emissions from building products constitute a big part of the climate problem.

While energy usage and GHG emissions are related, they don't have a linear connection because energy source emissions profiles are highly variable. For example, steel is a highly energy-intensive product to manufacture. Still, zero-emission steel mills in Europe have low carbon footprints because some plants run on green hydrogen and utilize carbon capture technology. By contrast, other building products, like gypsum board or dimensional lumber, require little energy to produce but have large carbon footprints when their manufacturing energy source is coal, as in Illinois, Ohio, or Texas.

As the understanding of building energy consumption grew, few policymakers, let alone building codes, considered GHG emissions; policies focused on operating energy, and sometimes operating GHG emissions. Not until recently could policymakers confidently develop embodied carbon policy because the documentation standards that manufacturers need to comply with regulations are still evolving. The environmental product declaration (EPD) reports a product's environmental impact, including GHG emissions. The EPD development process uses international standards for each product type, allowing consistency in emissions reporting. Industry consortiums compile industry-wide EPDs to capture the average emissions profile across a subset of manufacturers in a specific product category.

Millions of tons of global GHG emissions can be avoided when code-writers and policymakers write, adopt, and implement policies that regulate the amount of embodied carbon in the most used and highest emitting products, like concrete and metals. Further, by encouraging or regulating the opportunities for materials at the end of their useful life, jurisdictions can continue to reduce regional emissions.

The Carbon Problem

Before 2007, a handful of early green building pioneers studied embodied carbon; they hypothesized that operating energy for most buildings would dwarf the embodied carbon of the products used to construct the building over a few decades of expected service (Chae 2016). Since 2007, research on embodied carbon has increased in popularity. And at the turn of the 21st century, third-party rating systems have supported a growing movement toward better-than-code buildings. However, green building leaders like Bob Berkebile believe that buildings that do a little less damage still have a negative impact (Barth 2018). Researchers started looking more closely at the impact of building products and noticed that the embodied emissions, which were previously assumed insignificant, could no longer be ignored. As operating emissions declined due to increasing efficiency in the building code, the embodied carbon of building products became a larger piece of the pie. Whether a building is super energy efficient or not, embodied emissions are a priority.[1]

As jurisdictions pivot from energy to GHG and carbon emissions with climate-centered goals for buildings like net zero energy (NZE) and building electrification, operational carbon emissions will become nascent, and embodied carbon will become 100 percent of the GHG emission problem.

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[1] Note: portions of this section are excerpted with permission from the forthcoming book *Build Beyond Zero*, due out from Island Press in June 2022.

GHG Emissions

The climate effect is much more than the amount of the emissions; when they went into the air mattered, too. The equation is simple: Climate effect = (amount of GHG emissions) x (the time they are in the air)

The sooner the GHG enters the sky, the greater its global warming effect. Time value is enormous when averaged over multiple building types and climate zones, 75 percent of the GHG impact from a project built today will result from the building materials chosen (Architecture 2030 2022). Designers still need to consider operating emissions and understand that materials matter and both operational and embodied emissions must be considered.

Building Materials and Products

Regardless of building types, location, or size, two materials dominate nearly every analysis: steel and concrete. Steel production amounts to six percent of global emissions, and 2 percent in the U.S., about half of the steel goes into the built environment. Concrete accounts for eight percent of global emissions, nearly all of which is architectural or infrastructure-related. Those two categories alone tag buildings with eleven percent of global emissions, and the total (including all other building materials) is several percentage points higher. Combined with the increasing amount of fossil fuel-based plastic in buildings (which has a near-zero percent recycling rate), experts estimate the whole life emissions are likely much higher than eleven percent (ASBP 2021). Savvy policymakers saw the need to address embodied carbon and put the opportunity to test on their government projects. Since jurisdictions are responsible for funding both buildings and infrastructure, they are one of the largest purchasers of concrete, second only to residential construction (PCA 2016). Low carbon procurement policies can make the most significant GHG reduction impact on new building materials (CNCA 2020).

The Carbon Material Problem

Today's opportunities for building embodied carbon reduction exist because building professionals have voluntarily requested lower carbon products, and innovative manufacturers have responded. Owners can seek building reuse projects; designers can select lower carbon products and practice material efficiency; policymakers can use existing frameworks like the building code, and municipal procurement processes to reduce embodied carbon in the built environment.

Building Materials

Using existing products and technology, multiple pathways already exist to dramatically reduce the embodied carbon in building materials. Some strategies are easy to accomplish immediately and cost less. For example, when cement usage in concrete is reduced, it lowers its total carbon footprint. Others may cost more in the near term, or are not fully arrived yet, such as procuring steel made with clean hydrogen.

Policies to address materials may include:

- Building codes
- Federal emissions policies
- Procurement policies
- Construction transportation policies
- Waste diversion policies
- Construction material recording policies

Very often, GHG emissions can be reduced through thoughtful design. The concrete industry has been long habituated to "throwing in a little extra cement" as inexpensive insurance for quality. But now, designers and contractors are paying much more attention to curing times, exposure and durability requirements, actual strength needs, and other factors determining a concrete mixture. Steel and many other industries, unable to improve energy efficiency beyond a certain point in manufacturing, look to renewable energy or low-carbon fuels like hydrogen to drive their operations emissions reductions in the longer term. Toxic, high carbon foam insulation can replace cellulosic products made from recycled newspapers or straw. With the approval of tall wood buildings in the 2021 International Building Code (IBC), mass timber structures can step in and replace the higher carbon steel and concrete structures that define the urban skylines of the past century.

Whole Life Carbon

Procurement policies and other embodied carbon regulations, as listed in Table I, have focused on cradle-to-gate emissions (extraction of resources and manufacturing of the product; stages A1-A3 in lifecycle analysis, as defined in EN 15978 and seen in Figure 1) because that's where most of the embodied carbon emissions happen, and where measurement can most easily occur. Still, other stages in a building's life deserve scrutiny, such as durability and reparability (how long will it last and can it be repaired?) and recyclability (can it be reused or repurposed without excessive further labor or energy inputs?). Accessing and utilizing reclaimed materials or products has been difficult or expensive to effectively use materials taken from a deconstructed building. As such, within the broader intention to develop circularity (endless recyclability) within or between all industries, manufacturers and policymakers are looking at making building products with reuse in mind.

Policy Regulation Options

The design and construction industry is rapidly waking up to the need and the possibilities for reducing embodied carbon, driven by the demands of a changing marketplace and the rapid interest in governmental regulations and purchasing guidelines aimed at climate restoration. Table 1 introduces active policies that address embodied carbon for jurisdictional and/or private construction. Several states, like Minnesota and Washington, are pursuing regulation though it's not active as of June 2022. Regulating products' GHG emissions is possible within policy mechanisms, as jurisdictions understand how their purchasing behaviors support increased GHG emissions. Embodied carbon policies can directly or indirectly address building products from the demand and/or supply sides. Supply-side strategies advance low-carbon industrial practices by building product manufacturers and suppliers. Demand-side measures are similar to building energy efficiency policies, setting prescriptive or performance targets to be met by end-users such as building portfolio owners, developers, designers, or contractors.

Table 1. Embodied Carbon Policies

Location	**Policy**	**Embodied Carbon Approach**
Vancouver, BC	Rezoning Requirement	Rezoning permits require a commitment to Passive House or WB LCA embodied carbon reporting.
Portland, OR	Low-Carbon Concrete Purchasing Program	Concrete in city construction projects must meet specific GWP limits.
Oregon DOT	Department of Transportation (DOT) GHG Program	Program to reduce GHG emissions associated with concrete, asphalt pavement, and steel in DOT projects.
Marin County	Low-Carbon Concrete code	All concrete to meet specific GWP or cement limits.
California	Buy Clean California (BCCA)	State agencies, the University of California, and California State University systems construction projects must meet specific GWP limits for structural steel, concrete reinforcing steel, and light and medium density mineral wool board insulation.
Colorado	Buy Clean Colorado	State-funded construction projects must meet specific GWP limits for asphalt, concrete, glass, post-tension steel, concrete reinforcing steel, wood structural elements
Austin, TX	Green Building Program	The City rating system includes credits/points for WB LCA and embodied carbon reduction.
New Jersey	Port Authority of N.Y. & N.J. Low Carbon Concrete Program	Requires EPD reporting for concrete, steel, and asphalt. Require low GWP limits for concrete.
Toronto, ON	Waterfront Toronto Green Building Requirements -	Buildings can choose to use 50 percent recycled metal in steel and rebar, low-carbon concrete (with 25 percent Supplementary Cementitious Materials), or timber products certified by the Forest Stewardship Council.
New York	Low Embodied Carbon Concrete Leadership Act (LECCLA)	State-funded projects are required to procure low embodied carbon concrete.

Regulating Embodied Carbon

With most building policymakers focused on building operations, whole life building GHG emission reduction actions haven't been fully explored. For example, recent building GHG regulation has included disallowing natural gas use in new facilities like Berkeley's Municipal

Code Prohibiting Natural Gas Infrastructure in New Buildings, switching from gas to electric equipment like SMUD's Go Electric program, or requiring carbon reporting and reduction as with Local Law 97 in New York City (Berkeley 2019, SMUD 2022, NYC 2019). However, these policies still focus on operational carbon and ignore the millions of tons of carbon dioxide equivalent (CO2e) that could be avoided by addressing building materials through supply-side or demand-side policies.

Material Supply-Side Regulation

Federal environmental policy addresses product manufacturing GHG emissions through the U.S. Clean Air Act. The Act could be expanded to require lower emissions for cement or metal production. Still, such a policy would likely include a multi-year phase-in period, allowing business-as-usual emissions for years to come. Similarly, cap-and-trade programs can target industrial emitters. Regulations by the U.S. Environmental Protection Agency (EPA) or incentive programs can bolster the adoption of low carbon industrial technology that can also be deployed to mitigate the upfront emissions from material extraction and production.

Material Demand-Side Regulation

Demand-side measures are similar to commonplace energy efficiency policies - setting prescriptive or performance targets for end-users such as building portfolio owners, developers, designers, or contractors. Just as building energy codes and emerging building performance standards have successfully spurred dramatic energy efficiency and emissions reductions in building operations, a range of embodied carbon-focused policies have the potential to address the climate impact of building products. Figure 1 presents the different lifecycle stages and modules correlating to the policy opportunities. Demand-side policies have the potential to address not only the upfront manufacturing lifecycle stage of building products (A1-A3) but also the construction (A4-A5), operational (B), and end of life (C1-C4) stages. As a result, demand-side measures can be impactful to transform the market, as targets can be made stringent over time and ultimately drive broader change in the industrial sector.

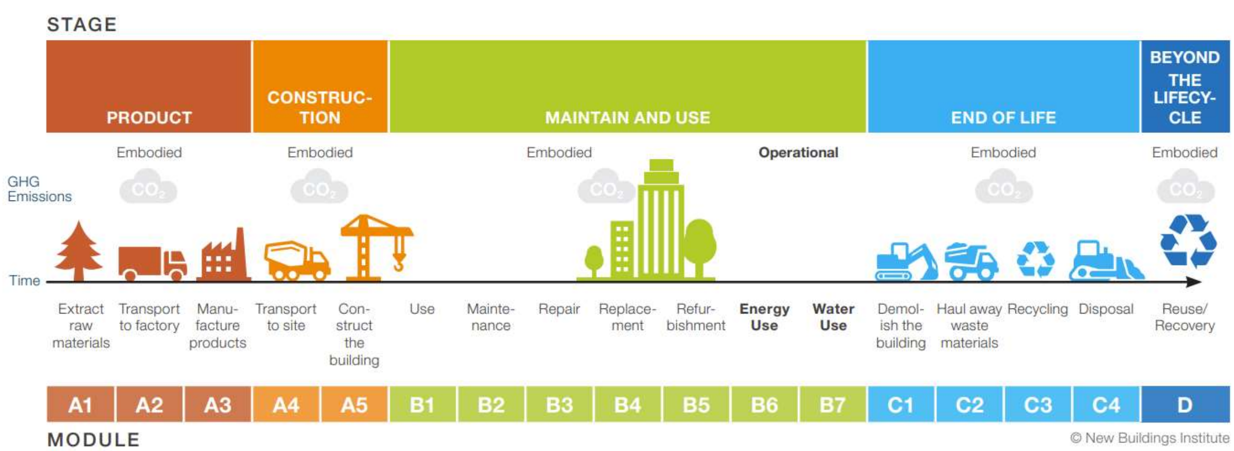

Figure 1: Lifecycle stages of building carbon. Data source: BS EN 15978:2011
Source: Bowles, Cheslak, and Edelson 2022

The EPD is the industry documentation standard manufacturers use to comply with demand-side regulations to report product-related emissions. Guidelines for EPDs are standardized for each standardized product category, allowing consistency in emissions reporting. Industry-wide EPDs are compiled by industry consortiums to capture the emissions profile across a subset of manufacturers in a specific product category.

A limitation of EPD reporting and optimization standards is that they typically focus on cradle-to-gate emissions (A1-A3), meaning that emissions from transportation and construction activities (A4, A5) as well as end-of-life (C1-C4) are not disclosed. A number of additional policies can address the impacts from these lifecycle stages in lieu of whole project lifecycle impact assessment standards.

Cradle to gate emissions mitigation (A1-A3). Upfront embodied carbon is undoubtedly the phase of a product's lifecycle with the most significant percentage of embodied carbon compared to the whole life emissions. Due to the considerable carbon reduction opportunity, a robust demand-side embodied carbon policy ecosystem is emerging today, with Europe and North American jurisdictions leading the way. These policies range from those focusing on mitigating embodied carbon in public projects to building code criteria that apply to a broader pool of new buildings. In the U.S., momentum is building for a materials-focused approach to embodied carbon mitigation, starting with publicly funded projects.

Procurement policies, often called Buy Clean, are adopted by state and local governments to catalyze supply chain transparency and emissions reductions through public sector procurement. First, governments establish a set of priority products that will fall under the purview of a procurement policy. These are typically commonly procured products with high embodied carbon value, such as concrete, steel, flat glass, or aluminum. An emissions reporting requirement (EPDs) and/or global warming potential (GWP) limits are set for each product, with the intent of tightening the standard over time to reduce the climate impact of public projects. Emissions standards in procurement policies typically target only the upfront lifecycle stage of building material extraction and production (A1-A3) before the products are brought to the site.

While procurement policies only regulate projects funded by jurisdictions, the entire construction industry benefits. Due to the demand for low-carbon products, more such products are on the market. City, state, and federal procurement policies can be developed, approved, and implemented fairly quickly. Procurement policies do not require all manufacturing to change. Still, they can encourage a quicker path to market transformation through competition.

Procurement policies typically require product-specific EPDs, which document a lifecycle impact assessment for one product's manufacturing process. Therefore, surveys of the availability of EPDs for target products should be conducted to set GWP limits in Buy Clean policies. While there are other approaches to mitigating embodied carbon emissions from buildings, specifying GWP limits for common construction products is an efficient and practical first step to reducing upfront embodied carbon in the built environment.

Transportation and construction activity emissions mitigation (A4-A5). Emissions from construction activities include transportation of building materials and products and the use of on-site construction equipment. Policies and incentives can encourage regional material procurement to limit transportation-related emissions. In the global economy, building materials can travel thousands of miles to project sites, making regional material standards a valuable emissions reduction measure. Local product procurement is a win-win from an environmental and economic standpoint, creating a powerful political narrative for embodied carbon policymakers.

Emissions from construction activities are only a small portion of projects' overall whole-life carbon impact. However, mitigating GHG emissions from on-site equipment use has broader health and air quality benefits for construction workers and neighbors. Jurisdictions can request construction activity carbon reduction plans from large construction projects during permitting, just like construction stormwater pollution prevention plans. A plan would cover the general contractors' plans to document off-road vehicles and equipment use, crew transport to the job site, and mitigation strategies such as equipment electrification, biofuels, and on-site solar charging for small equipment. The plan could also establish protocols to reduce the idling of vehicles on-site, to mitigate air pollution and GHG emissions.

Operational embodied carbon (B). More and more building policies are considering operational emissions. Building environmental performance standards require buildings to reduce energy and/or carbon over a set period. Refrigerant policies like EPA's Significant New Alternatives Policy (SNAP), American Innovation in Manufacturing Act of 2020 (AIM Act), and California Air Resources Board (CARB) Stationary Refrigeration and Air Conditioning Rulemaking (SR&ACR) target low-GWP refrigerants and leak minimization seek to reduce millions of tonnes of GHG emissions (EPA 2014, EPA 2020, CARB 2020).

Few policies address the embodied carbon emissions from tenant improvement renovations that do not trigger code compliance. Procurement policies can be expanded to include tenant improvements that remove more than 200 square feet.

End-of-life emissions mitigation (C1-C4). The fundamental goal of improving end-of-life outcomes for building products is increasing diversion rates from landfills. The estimated end-of-life carbon emissions are small relative to the whole life carbon. However, the potential benefits of material recovery (Stage D) offer a carbon benefit equivalent to 25 percent of the total A-C lifecycle phases (Hunziker and Carroll 2021). The actual impact and value of building material recovery and reuse may be underestimated in standard, linear whole building lifecycle assessment (WB LCA) methodologies.

Reusing structure and envelope components is the most carbon-efficient end-of-life scenario for a building. Renovation of existing buildings minimizes demolition, transportation, and disposal impacts and prevents emissions associated with building new. Avoided emissions resulting from building reuse are allocated to the new project and evaluated against a counterfactual condition where the project was built new. Jurisdictions should consider policy opportunities to accelerate this type of embodied carbon mitigation strategy, allowing developers to achieve the functional needs of new projects while repurposing existing structures.

Other policies that address end-of-life emissions include construction and demolition waste management ordinances, extended producer responsibility programs, and material documentation in new construction projects. The California Green Building Standards Code requires a construction and demolition (C&D) waste management with a 65 percent diversion of construction and demolition waste from landfills. Added activities like source-separated waste diversion can streamline the recycling of building materials when supported by local recycling. Extended producer responsibility (EPR) policies place the product disposal responsibility with the manufacturers. For example, California's carpet recycling program puts a $0.35 per square yard fee on all carpets sold in the state to fund increased reuse and recycling

(Dubois 2016; CARE 2022). Material passports detail information about the construction materials and assemblies, demonstrating the embedded value of these materials for future recovery

The upstream value to the manufacturing processes is more significant for many materials than the avoided downstream landfill impacts. Increasing building materials' circularity and whole building reuse provides valuable avoided emissions in product supply chains and should be a focus of policymakers for job creation. Jurisdictions are progressing material circularity by increasing waste diversion and establishing policies that incentivize manufacturers to participate in the circular economy.

Whole life embodied carbon (A1-C4). Policies can require design teams to use WB LCA tools and set maximum WB LCA carbon intensity values for newly constructed buildings by type, similar to an energy use intensity (EUI) target to indicate building energy efficiency. With design phase WB LCA modeling, project teams could demonstrate that buildings have been designed to meet these established lifecycle targets at any stage. Project teams can use material efficiency optimization measures, such as more-efficient structural systems, and procurement of low-carbon products during construction, to meet WB LCA building standards.

For now, however, there is not enough industry consensus or consistency around baselining typical WB LCA impacts to set absolute performance standards for policy. Relative performance targets are currently used to measure percentile improvements from project-specific baseline models. In the building industry, WB LCA has been increasingly adopted by leaders in recent years. Third-party rating systems include WB LCA in their frameworks, accelerating design and construction practitioners' adoption of and familiarity with WB LCA. It may pave the way to its broader application and use in codes and policies.

Building Code Regulation

Building codes provide a unique opportunity to move the whole building market, while procurement policies generally only apply to jurisdictional policies. All buildings in jurisdictions that adopt the code must comply with the requirements. The scope of the International Energy Conservation Code (IECC) is intended to address building operational energy with the benefit of "cost savings, reduced energy usage, conservation of natural resources, and the impact of energy usage on the environment" (ICC 2021a). Because there is no mention of carbon, and since lower embodied carbon does not provide operational cost savings or directly change the energy usage in the built environment, embodied carbon cannot be addressed in the IECC, as chartered today.

The International Building Code (IBC) successfully regulates many different building materials and products for life safety and non-life safety, including concrete, steel, and wood. The intent of the IBC "preserves public health and safety to provide safeguards from hazards associated with the built environment" (ICC 2021b). Similar to how a site-built window may need a certification, or structural clay tile must meet specific fireproofing requirements to protect the community from the impacts of fire, code-based low embodied carbon material requirements would need to meet particular requirements to protect communities from the effects of GHG emissions.

Embodied carbon can be addressed in building code through a materials or building-level approach. A materials-level approach sets prescriptive or performance requirements for individual products. Products could comply with either an EPD or use the EPD to prove that the product meets a specific GWP threshold. Requiring GWP limits on products with the highest embodied carbon and those used most often will provide immediate, quantifiable carbon benefits.

Due to the number of EPDs available, the data allows policymakers to set the GWP limits for many products, specifically those most used. Policymakers can survey product-specific or industry-wide EPDs to set GWP limits suitable to desired market change. For example, a product GWP limit may be set at 175 percent above the industry average for ~90 percent of products to comply. Or the GWP could be the industry-wide average, as is required with Buy Clean California and Colorado.

Conceptually, whole building regulation offers the most comprehensive approach to understanding a building's embodied carbon, at any lifecycle stage. After all, WB LCA allows design and construction teams the flexibility to optimize the thousands of products and systems to get the overall lowest carbon footprint, or better, carbon-storing materials. A building-level performance-based approach would require a WB LCA, with an option for setting an absolute CO2e or CO2e per square foot value per building type. WB LCA data is not yet a viable regulation option because of the developing state of the WB LCA accounting and industry knowledge of consistent carbon accounting. When the market has evolved further to include comprehensive material and product data, standardized and consistent calculation tools, and market expertise necessary to implement WB LCAs in code, policymakers can confidently incorporate WB LCA requirements in building codes. Material-specific regulations for embodied carbon are (relatively) easy to write and enforce. Currently, a materials-based policy offers the best, market-ready option to achieve meaningful embodied carbon savings in building codes today.

The main drawback with addressing embodied carbon through code is that the U.S. does not have a national building code adopted by all jurisdictions simultaneously; instead, states or local governments adopt the dozen national model codes independently. Since building code updates are on a three-year national development cycle, the market may evolve faster than the products' code-required carbon limits. It's not guaranteed that every jurisdiction will adopt the newest code, and the manufacturing industry can change drastically in a three-year time period. A multiple-pronged jurisdictional procurement policy and building code approach will be the best path toward market transformation.

WHEN CHALLENGE BECOMES OPPORTUNITY: EXAMPLES

Carbon Storage

Getting to zero emissions misses the possibility of carbon-storing architecture. As tools and material palettes grow, examples have shown that designers can store gigatons of carbon each year in the built environment.

Trent University's Forensic Crime Scene Facility on its campus in Peterborough, Ontario, illustrates the potential of carbon-storing. Built in 2020, the building was designed to meet the International Living Future Institute's (ILFI) Zero Carbon Certification. The requirements demanded a high-performance building enclosure, particularly for a building in a climate zone that includes both high heating and cooling demands at different times of the year. The team used proven strategies for super insulation, air tightness, and efficient, electrified mechanical equipment to reduce the building's energy demands to the absolute minimum and a 43 kW roofmounted solar array.

Aiming beyond net zero operational emissions, the lowest emitting materials were prioritized in all parts of the building. They specified biogenic, carbon-storing materials to surpass the whole building 500 kg-$CO2_e/m^2$ embodied carbon limit of the certification.

The structure is a one-story wood frame with a tall shed roof for the solar array. The early WB LCA showed that the concrete foundation and slabs had the largest carbon footprint. By reducing the amount of cement needed and the specification of lower-carbon concrete mixes, the embodied carbon was reduced from 32 tons to 14 tons. With hempcrete block walls, cellulose insulation, and sustainably harvested framing lumber, the project stored 16 kg $CO2_e/m^2$.

Figure 2: Finished Trent Forensic Crime Scene Facility. *Source: Trent University. 2020.*

Marin County Low Carbon Concrete Code

Marin County, California, was the first to adopt a code amendment addressing embodied emissions. The County elected to focus exclusively on concrete because it's generally the chief emitting material on construction projects and is the easiest product to reduce carbon footprint.

Working with local designers, contractors, and concrete suppliers, they crafted and adopted a code amendment in 2019 written in the IBC format. The code is freely available for adoption by others with a caveat that the concrete GWP limits established for Marin County (or generally the San Francisco Bay Area) were calculated based on a detailed study of local concrete suppliers. The proponents had a lot of data about the GWP and cement content of concrete mixes of every strength category from many producers in the area, as well as more collected around northern California by the Structural Engineers Association of Northern California (SEONC) and regional average values published by the National Ready Mixed Concrete Association (NRMCA). The stakeholders reviewing the data and code language included the Marin Building Official, local structural engineers, NRMCA, local concrete producers, the cement trade group, several academic engineers, the Sierra Club, general contractors, and more.

The Marin concrete code, now emulated, provides two pathways to compliance. A prescriptive method that limits the cement content for any given strength category (portland cement, the binder that turns gravel and sand into rock, is responsible for the great bulk of concrete's emissions). A performance method requires providing EPDs for every mix used and meet the set GWP limits for each strength of concrete.

Two months after the code was enacted, the COVID pandemic paused the implementation. As a result, it's too soon to provide a summary of the results.

Denver Carbon Policies

In Denver, Colorado, buildings and homes represent 64 percent of the city's 2019 GHG emissions. These emissions are a key component in addressing the impacts of climate change. In response, Denver created the Net Zero Energy New Buildings & Homes Implementation Plan (NZE Plan) with the goal of all new buildings and homes achieving net zero energy by 2030 (City of Denver 2021). In 2021, the City and County of Denver published Denver's Building Sector Embodied Carbon Emissions Report to understand embodied carbon impacts and policy recommendations (Anderson, Thompson, and Managan 2021).

The significance of embodied carbon grows over time as Denver's climate goals to reduce operational emissions through NZE are achieved for both new and existing buildings. Denver's Building Sector Embodied Carbon Emissions Report compares operational to embodied carbon emissions. In 2020, operational carbon emissions in Denver far outweighed emissions from embodied carbon. In 2030, embodied carbon emissions will make up 27 percent of all emissions from buildings built in 2030 compared to annual operational emissions for all buildings in 2030. By 2040, both existing and new buildings will be NZE, so 100 percent of emissions will be from embodied carbon. Refer to Figure 3.

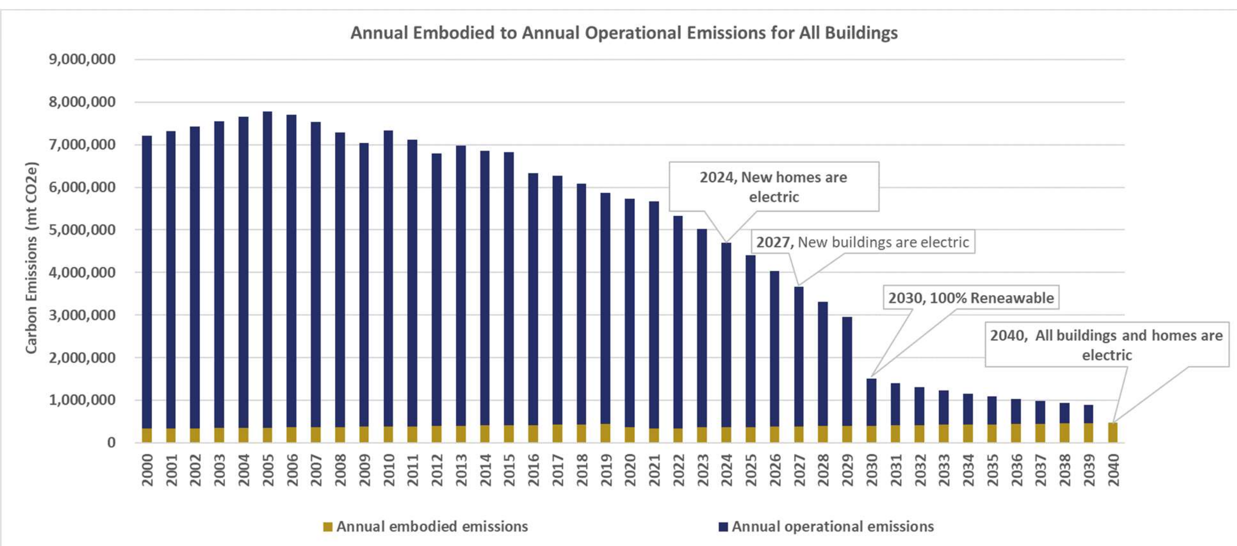

Figure 3: Embodied carbon and operational emissions for all buildings by year. *Source: Anderson, Thompson, and Managan 2021*

By 2030, 100 percent of emissions for buildings constructed that year will be from embodied carbon emissions. The 2030 milestone is approaching, so the significance of addressing embodied carbon increases yearly. Refer to Figure 4.

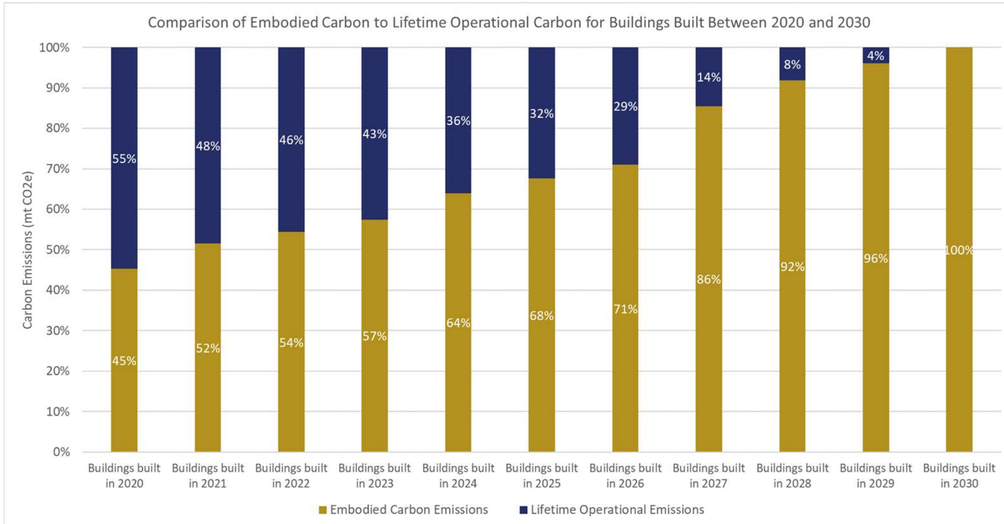

Figure 4: Comparison of embodied to lifetime operational emissions for buildings built between 2020 and 2030.
Source: Anderson, Thompson, and Managan 2021

Denver's Building Sector Embodied Carbon Emissions Report identifies that more than 80 percent of Denver's embodied carbon emissions are produced by the commercial sector, including commercial, industrial, and multifamily buildings. Understanding that commercial buildings have the highest impact can help when developing strategies and policies for targeting embodied carbon emissions. Denver considered a series of code proposals in the mandatory base codes and the Denver Green Code (DGC) to address embodied carbon by requiring EPDs and applying CO2e limits for commonly specified carbon-intensive building products like concrete and steel. Additional proposals have been developed to allow for requirements for a change in occupancy from commercial to residential more practical for adaptive reuse, ensure demolition projects salvage building materials for reuse, and encourage designing for deconstruction. These proposals have been recommended for approval by the technical code committees and will be sent to Denver's City Council for formal approval. If adopted, the DGC will be the second code in the nation to include embodied carbon requirements. Using low-embodied carbon emission product types has the potential to reduce embodied carbon emissions by up to 60 percent, so Denver intends to pair code proposals and regulations with education to help encourage the adoption of low-embodied carbon building products.

Conclusion

The materials and products associated with building construction are becoming a more significant part of a building's carbon footprint. Existing policy mechanisms exist to address whole life building GHG emissions. With the building sector being one of the largest GHG emitters, policies must address both operational and embodied carbon. From federal supply-side policies to local jurisdictional demand-side policies and national building codes, we need all mechanisms to avoid the worst effect of climate change. A multi-pronged approach is essential to limit embodied carbon emissions: voluntary green building rating systems, building energy codes that address operational carbon, innovative manufacturers, and city, state, and federal policies.

The individual policies presented within address carbon impacts at different project lifecycle stages. Some, such as procurement policies, are being implemented across the U.S today. Others, such as material passports, are emerging regulatory concepts. Together, these strategies can have a sizeable effect in reducing the embodied carbon impact of construction projects and benefitting the planet.

The growing adoption of procurement policies has created a favorable environment for expanding materials-specific embodied carbon policy to a broader range of projects. Incorporating embodied carbon standards in building codes is a powerful next step to transforming the sector for a climate-positive future. Innovative projects like Trent University's Forensic Crime Scene Facility prove what is possible. While the Marin County and the Denver Green Code's low carbon concrete requirements lead a community to make what was once innovative, the norm.

Being on the doorstep of building product market innovation, the U.S. will have more cities like Denver that address operational carbon and adopt low embodied carbon codes and policies. Working hand in hand, codes and policies can address sections of whole life carbon at any point in a building's lifecycle. Aligning with policies that regulate operational emissions, jurisdictions can guide all aspects of a building's lifecycle to help meet emission goals and avoid millions of GHG emissions.

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