The Road to Industrial Buy-in for Embodied Carbon Building Standards

Pavitra Srinivasan, American Council for an Energy-Efficient Economy
R. Neal Elliott, III, American Council for an Energy-Efficient Economy
Edward G. Rightor, American Council for an Energy-Efficient Economy
Nora W. Esram, American Council for an Energy-Efficient Economy

ABSTRACT

Construction materials represent an intersection between buildings and industry for meeting decarbonization goals in both sectors. Manufacturer support is essential for successful efforts to label, report, and track the embodied carbon content of building materials, effect a market transformation, and support development of codes and standards for building materials.

The authors engaged key materials manufacturers and trade associations (i.e., steel, cement, wood products, insulation, chemicals, aluminum), along with stakeholders from the buildings and codes/standards communities to propose a market transformation approach for embodied carbon that includes its characterization, reporting, and procurement. Hurdles to overcome, in advancing the greater use of low-carbon materials and promoting market transformation, include strengthening the underlying knowledge infrastructure, ensuring robust industrial commitments, creating supportive government policy, economic incentives, codes, and standards, and advancing technology innovations.

In making the business case for low-carbon material production, this paper describes the economic demand, policy, and regulatory market drivers, assesses the risks of business-as-usual versus making the switch to low-carbon products, presents a rationale for change that describes a future vision for industry, and describes a pathway toward transformation.

Introduction

The buildings and construction sectors are responsible for approximately 39% of global energy-related carbon emissions annually as of 2018, with 28% due to building operations (from energy needed to heat, cool, and power buildings) and the remaining 11% (referred to as “embodied carbon”) from the manufacture of building materials and products such as steel, cement, aluminum, and the construction process itself (GABC 2019, 2020). In the United States, the production of iron and steel, cement, and aluminum accounts for 7%, 6%, and 2% of carbon emissions, respectively, although the produced materials are used in many applications in addition to building construction (IEA 2021, EPA 2021a, WEF 2020). Targeting and reducing the embodied carbon of building materials represents an effective mechanism for reducing carbon emissions in the buildings and industrial sectors simultaneously. In addition, materials like steel and concrete are heavily used in the construction and maintenance of infrastructure such as roads, bridges, and water systems, which further expands the potential impacts of embodied carbon reduction efforts.

This paper assesses how a market transformation approach could enable the increased production and availability of low-embodied-carbon materials by the manufacturing sector while encouraging the more-consistent use of such materials in building construction. Further, it makes the case for why change is required, considers how the change may be made by identifying the elements needed for a market transformation, and broadly proposes the business case for including embodied carbon in building codes.

What Is Embodied Carbon and Why Is It Important?

Embodied carbon refers to carbon emissions associated with the manufacture of building products and construction, from raw material extraction to manufacturing, transportation, and installation, to product use stages, to end-of-life disposal or recycling. These activities correspond to the A1-A5, B1-B5, C, and D life stages in a product lifecycle as shown in Figure 1. Embodied carbon is responsible for 11% of global greenhouse gas (GHG) emissions, 23-28% of global building sector emissions, and potentially up to 72% of emissions associated with global new construction between now and 2030 (Architecture 2030).

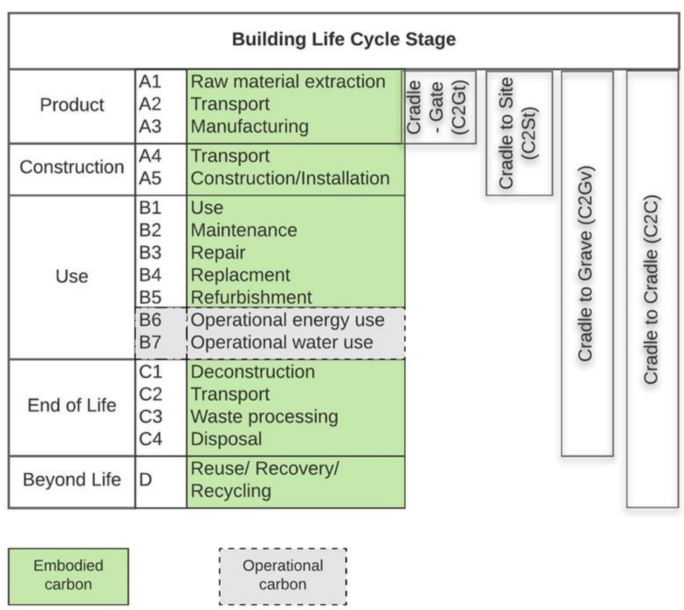

Figure 1. Embodied carbon definition and life cycle stages (Esram and Hu 2021).

The world population is projected to grow dramatically over the next 40 years, and the global building floor area is expected to double by 2060 with the addition of 2.4 trillion ft^2 (230 billion m^2) of new floor area to the global building stock. This is the equivalent of adding an entire New York City to the world every month for 40 years (GABC 2017, Architecture 2030). The projected increase in new construction is tied to the increased use of building materials and an associated increase in embodied carbon emissions.

Furthermore, as operational carbon from existing and new buildings decreases with the use of energy efficiency measures, building energy upgrades, and use of renewable energy to power buildings, the share of embodied carbon emissions in total building emissions is set to increase proportionally (Architecture 2030, GABC 2017). A study published in 2016 looking at 90 case studies showed that for low-energy buildings, embodied carbon accounted for 30-60% of total lifecycle carbon, while in net-zero-energy buildings, embodied carbon accounted for 75-100% of total lifecycle carbon (Chastas, Theodosiou, and Bikas 2016).

It is important to recognize that low-carbon materials need to meet the same performance parameters (e.g., structural, thermal) as conventional materials and the embodied carbon emissions in building materials are fixed in the building structure once the construction process is completed. That means it is critical to reduce the embodied carbon at the point of manufacture and during the design and construction phases. This opens the door for the industrial sector to play a leading role in reducing building GHG emissions and help reach Paris Agreement GHG reduction goals.

Three high impact building materials account for 23% of total global emissions from the built environment—steel (10%), concrete (11%), and aluminum (2%)—so reducing the embodied carbon from the production of these materials is an important area of focus for policy, design, material selection, and specification to help reductions for buildings (GABC 2018). While there was a temporary reduction in energy-related emissions from the buildings sector in 2020 due to the COVID-19 pandemic, emissions have rebounded in 2021 as economies reopen and building construction activities ramp up (GABC 2021).

Collaborative Pathways to Reduce Embodied Carbon

With growing calls for building owners and real estate companies to take climate actions (Boland et al. 2022), leading engineering firms are looking to significantly reduce carbon emissions from energy-intensive building materials through initiatives such as MEP 2040 and SE2050 (CLF 2020, 2021). One emerging and promising route is to require manufacturers to report and disclose the embodied content of these materials through Environmental Product Declarations (EPD)[1], which can aid building designers and policymakers in setting purchasing specifications and building standards associated with embodied carbon, while enabling material suppliers to respond to customer demands for lower-carbon products. It also gives the buildings and manufacturing communities the opportunity to collaborate on practices for assessing and tracking embodied carbon through their supply chains. EPDs serve as an important tool for the public and private sectors to support discussions on building codes to reduce embodied carbon.

Several efforts are currently building momentum in this arena, including voluntary rating systems, "Buy Clean" initiatives, and voluntary reporting and disclosure protocols. Building codes and standards can be an effective tool to influence design and construction practices in the building community and accelerate reductions in embodied carbon from the built environment. However, two central questions are whether industry has the capacity and necessary tools to collect, track, and report embodied carbon data through the supply chain, which is needed for a robust knowledge infrastructure underpinning standards and codes development, and whether industry has bought into the business case for producing low-carbon materials. Thus, creating

[1] An EPD is defined by the International Organization for Standardization (ISO) 14025 as a Type III declaration that "quantifies environmental information on the lifecycle of a product to allow comparisons of different products with the same function based on standard LCA principles" (ISO 2006a, ISO 2006b).

market pull for the production of low embodied carbon building materials represents another market challenge linking the buildings and industrial sectors. The growing demand for materials is due to the increasing need for buildings and floor area (GABC 2018, OECD 2019) and replacement of aging or climate-related damaged infrastructure (ASCE 2021, NOAA 2021). Additionally, bills passed by the U.S. Congress in 2021 are set to upgrade roads, bridges, and water infrastructure (WEF 2021). Thus, switching to lower embodied carbon materials is important to limit emissions from these construction activities. Other federal legislation is also expected to impact the manufacturing sector's transition to low carbon fuel sources and consequent production of innovative, lower embodied carbon building materials (ACA 2022).

A Market Transformation Approach

Changing a complex market involving multiple actors is challenging. It is important to engage all market players to shift decisions and incentives for all actors to transition to a new, preferred state. This concept has been implemented many times over the past 30 years with energy-efficient appliances and equipment, using an approach referred to as market transformation.

Market transformation is defined as "a set of strategic interventions that aim to alter the market by removing identified barriers and leveraging opportunities in an attempt to cause lasting changes in the structure or function of a market, or the behavior of market participants, resulting in an increase in the adoption of energy-efficient products and services and making it a matter of standard practice" (ACEEE 2016). The term "market transformation" appears to have first been used at the 1992 ACEEE Summer Study in a paper on energy efficiency in buildings (Eckman, Benner, and Gordon 1992).

The marketplace for construction materials represents an intersection between the building design and construction industry and the construction material manufacturers and involves an interconnected supply chain that provides the information needed to select products and deliver them to the construction site. For a market transformation effort to be successful, all these market participants must be engaged, and their needs and concerns must be addressed. It is also important for all market actors to have clear and consistent information on which they can act. In comments shared during interviews, most materials manufacturers noted they have not been very engaged in this process and they expressed concerns about policymakers' expectations of the industrial sector and uncertainty about compliance with forthcoming requirements and regulations.

Methods and Sources of Knowledge

To gather stakeholder perspectives on how to drive a market transformation toward the selection of low embodied carbon building materials, the authors reviewed the literature and interviewed a range of stakeholders from the industrial, buildings, and codes/standards communities to identify elements needed for the transformation. ACEEE also hosted an initial meeting on how the buildings and industrial sectors might collaborate to tackle embodied carbon together. Interviewees and stakeholders included representatives from trade associations for the steel, cement, insulation, and wood products industry, as well as current and former employees from the steel, aluminum, and chemical industries. The authors also gathered input from members of the structural engineering, architectural, and design communities, some of whom were also members of building codes and voluntary standards development committees. The questions raised during this process focused on the current state of embodied carbon initiatives in each industry or sector, the barriers to adopting low embodied carbon products or codes, and the incentives, partnerships, and pathways required to advance the transformation process.

This research identified several elements that influence the strength and durability of customer demand for low embodied carbon products both globally and in the United States. At minimum, these include the market demand for building materials, the economic environment, and the policy and regulatory environment for low carbon alternatives.

Drivers of Market Transformation

The following factors are expected to influence the demand for low embodied carbon products and consequently drive changes in the market for low embodied carbon materials.

Federal and State Policies on Low-Carbon Construction Materials

Over the past few years, California, Colorado, and Washington have enacted Buy Clean legislation, and at least five more states (Oregon, Texas, Minnesota, New York, and New Jersey) are considering it, all of which will impact building products manufacturers (CA 2017, CGA 2021, WEC 2020, AISI 2022). In late 2021, the White House issued Executive Order 14057, *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*, and an accompanying plan to launch the first-ever federal Buy Clean program (WH 2021, 2022). These Buy Clean initiatives guarantee that low carbon products and materials are used for large-scale public infrastructure projects and will drive increased demand for these products, while also increasing demand in the private sector.

International Agreements and Foreign Policy

Several international treaties and goals could potentially drive the push toward low embodied carbon materials. For example, the 2015 Paris Agreement included goals limiting global warming to well below 2°C and for carbon dioxide (CO_2) emissions to peak as quickly as possible in the coming decades (UNFCCC 2015). To achieve the Paris Agreement goals, there is a push to decarbonize the global buildings and construction sector by 2050 by reducing emissions from the manufacture of building materials and construction and avoiding future embodied carbon emissions by adopting circular economy, reuse, and recycle principles (GABC 2021).

The United Nations Framework Convention on Climate Change along with partner organizations and coalitions have set goals for a sector-wide transformation that includes stipulations such as halving emissions in the building sector by 2030, ensuring 100% of new buildings have net zero carbon operations, ensuring at least 40-50% reduction in embodied carbon, and having all new and existing assets at net zero across the whole lifecycle, including operational and embodied emissions, by 2050 (UNFCCC 2021).

In the past, embodied carbon was addressed largely through voluntary approaches, with many countries, regions, and cities using certification systems, standards, and guidelines, including in Europe and North America. Going forward there is likely to be a greater focus on whole-life carbon and circular economy considerations in policy frameworks (EC 2020). Several countries are introducing GHG emission limits for new buildings, lifecycle assessment requirements for public buildings, or national net zero commitments. Such international efforts have important implications for industries like steel, cement, aluminum, and chemicals, which have transnational business and manufacturing interests and supply chain considerations.

Rationale for Change

In the current policy and market context, increasing the production of low embodied carbon products may be considered a risk mitigation strategy with several potential benefits for a material manufacturer. It insulates manufacturers from the risk of loss that comes with customers switching from regular construction materials to low-embodied-carbon products, changes in codes and standards that specify low-carbon materials, and changes to local, state, national, and international policies, and regulations, including carbon border adjustment mechanisms (KPMG 2021) that favor low-carbon materials. Making the transition to low-carbon material production may increase market competitiveness both domestically and internationally. It also helps manufacturers with corporate climate disclosures and GHG-reduction commitments that are required for scope 1 and scope 2 emissions and possibly scope 3 emissions (SEC 2022). From a cost-benefit perspective, despite substantial financial and capital investments required in the short term to make the switch to new technologies, there are potential benefits to be gained from increased sales in the longer term. Anticipating and responding to economic and regulatory signals supports future business sustainability and brand reputation.

A transformed market will create businesses opportunities, including preparation for and financial protection from climate risks, alignment with market demand, contribution to the reduction in GHG emissions, protection of shareholder investments, and growth of the business in new directions. Participating in a transformed market will allow manufacturers to build strong coalitions of like-minded manufacturers and political groups. A transformed market will also lead to an increase in domestic jobs, ensuring the support of labor groups and unions, and garner the support of environmental groups, all of which will help facilitate policy development that is favorable to industry and the manufacturing sector.

A Vision of the Transformed Market

Future of manufacturing materials. The future of low embodied carbon manufacturing will include many facets, depending on whether new building materials are being produced or previously used materials are being recycled and re-used. There are some differences in the way primary and secondary steel and aluminum are viewed, valued, and handled in the marketplace, and potentially in codes and standards. Alterations in traditional compositions of cement and concrete and reuse of concrete are being assessed for performance to ensure they meet the durability, strength and other requirements established in codes and standards.

For the production of new materials, there will be a reduced (or no) reliance on fossil energy sources, with increasing renewable energy use to power the manufacturing process for materials like steel, cement, and aluminum that rely on high process heat and consequently have high embodied carbon. For materials like cement and concrete, strategies to reduce clinker in their composition and the use of blended cements will become increasingly more important. Circularity of material use, reuse, and recycling of building materials will also assume greater value as the circular economy approach gains traction across the building, construction, and manufacturing sectors. Several countries in the UK and the EU are already setting up industrial clusters to promote industrial ecology principles (EU 2021, UK 2022).

Equity considerations. The vision for the future also includes just and equitable considerations in future workforce development and public health for disproportionately impacted and disadvantaged communities that work for or live near industrial and manufacturing establishments and may have heightened environmental exposures.

Role for codes and standards. A transformed market would also result in a new role for building codes. Currently, building codes specify energy provisions and energy consumption in the form of energy conservation codes. In a transformed market, newly enacted building codes would specify material- and manufacturer-agnostic performance requirements for low carbon building materials, which would create market pull for the innovation and production of low-carbon materials by all manufacturers in an industry, without picking winners and losers.

How to Facilitate the Market Transformation

In interacting with stakeholders, the authors noted observations that offer a baseline for the transformation process. Manufacturers from all subsectors are aware of and interested in being engaged on the issue of embodied carbon. However, different industrial, buildings, and codes/standards stakeholders are at different points in the process of innovating and developing their capacity to produce low-embodied-carbon products. These stakeholders have differing viewpoints on the best starting point for the path to market transformation. But, nearly all stakeholders advocated for a unifying and coordinating government role in the market transformation process for embodied carbon.

This research ascertained overarching general considerations that may be slowing the market transformation process. Additional focus or clarity in these areas could serve to accelerate the transition. Institutional inertia exists at various levels stemming from being unsure of where to begin, a lack of knowledge or unwillingness to deviate from choices that have worked historically. Unintended consequences of incomplete or non-responsive embodied carbon policies that arbitrarily include some material categories and omit others create implementation hurdles for companies. Industrial efforts are often ahead of government policy and regulation leading to a mismatch in implementation timelines (e.g., the steel and cement/concrete industries have developed low-carbon alternatives that have not yet been incorporated into codes and standards, which limits their use in the construction sector). There is a lack of accurate, accepted embodied carbon data on which to base lifecycle assessments (LCA), develop EPDs, and ultimately establish codes and standards. Many construction materials industries operate on low margins and require support to make the transition. Existing trade barriers require U.S. manufacturing to be incentivized to stay competitive in the international market. For example, the steel industry has already made the necessary capital investments to develop low-carbon technologies, but it is hampered by the lack of supportive government policy to address carbon border adjustment mechanisms (CBAM), which in turn reduces the competitive strength of the

U.S. steel industry. Lastly, there is a need to level the playing field across small, medium, and large firms to ensure that all can participate in the process and have their concerns addressed.

The research identified the following main elements are required to facilitate a market transformation:

Industrial and Building Sector Strategic Initiatives and Voluntary Commitments

Key manufacturing sectors, including cement, have formally articulated their commitments to lower carbon materials through the development of roadmaps to carbon neutrality (PCA 2021), while others are shifting to the production of low carbon materials (steel) or advertising low carbon alternatives (wood products). Some industries are promoting and supporting emission reductions across the entire value chain (cement) and advocating for natural carbon sink qualities offered by their products (cement, wood) as a means of offsetting carbon emitted during the manufacture and transportation stages of the lifecycle.

Stakeholders from the structural engineering community highlighted ongoing voluntary commitment programs such as the SE2050, through which 75 firms have committed to work toward net zero carbon over the next 30 years. Additionally, initiatives such as the SE2050 Database project are collating data from low embodied carbon building projects to inform and create benchmarks and targets for use of low carbon materials in prototype or archetypal buildings to reduce embodied carbon emissions and fill acknowledged data gaps at the whole-building level (Esram and Hu 2021). These kinds of commitments from the industrial and building communities show the interest and motivation within these sectors and should be further leveraged and amplified in the market transformation.

Role for Government in Policy Support

Several stakeholders shared that the industrial and buildings sectors lacked a level playing field. Typically, only elite or large firms, savvy building owners, or flagship construction projects tend to consider embodied carbon issues. Additionally, building products, design, and construction firms tend to have very thin margins and may not be able to answer the call for improvements purely on a voluntary basis. Not everyone participates unless there is a requirement to do so. A key element required for market transformation for embodied carbon is an active leadership role by government agencies to support development of whole-building databases, protocols, standards, benchmarks, and goal setting.

Stakeholders sought government support, with industry input, for the development of whole-building LCAs and EPD regulatory frameworks, systems, and policies that are transparent and trustworthy, based on accurate measurements, allow equivalent comparisons, and eliminate the risk of gaming and greenwashing. Other possible areas for government involvement include: the creation of a mandate in the form of standards or requirements for the use of low embodied carbon materials that include minimum prescriptive elements coupled with performance-based requirements, advancing the research and development of innovative low embodied carbon technologies, and supporting the development of common, widely accessible databases and tools that consider both operational and embodied carbon in a balanced whole-building approach.

At the same time, industry stakeholders highlighted important barriers to relevant and robust policy development such as the lack of inclusion of material manufacturers in the policy development process from the beginning to inform what is feasible and the need to work together in creating policy that will constructively advance low-carbon initiatives. Several groups along the market value chain, including industry and the building architecture and engineering communities, noted they have not always been engaged in the policymaking process, at either the federal or state levels. This lack of involvement of all impacted market entities at the state and federal levels has resulted in potential implementation hurdles, including lack of awareness, longer timelines, and feasibility concerns for small and medium-sized entities.

Technology Innovation

With respect to technology research, development and demonstration (RD&D) and pilot deployment projects, stakeholders advocated for elements such as: the deployment of innovative technologies to reduce emissions while simultaneously working on other elements such as building the knowledge infrastructure to reduce the time required to bring low-carbon technologies to market; the involvement of as many stakeholders as possible in the market transformation process, which will spur innovation by applying pressure at multiple points along the market value chain; and the establishment of a mandate by government or the codes and standards community to reduce product carbon intensity through the use of low carbon technologies that create low embodied carbon building materials and ensuring these new low carbon materials are rapidly incorporated into the generally lengthy codes and standards development process.

Strong Knowledge Infrastructure

While LCAs and EPDs are a key pathway for advancing low embodied carbon materials, the knowledge infrastructure (data, methodologies, and tools) that underpins LCAs and EPDs contains significant gaps that remain to be addressed. A recent study (Esram and Hu 2021) found: many LCA databases rely on secondary (not primary) data; there is a lack of standardization and transparency of databases (documentation not readily available); there is limited whole-building-level assessment data, methodologies, and tools for benchmarking and goal setting; there are discrepancies in embodied carbon results between different tools and a lack of standardized procedures to benchmark tools; there is greater focus on upfront embodied carbon and less on use-phase and end-of-life stages; and there is a lack of supply chain data and insufficient understanding of how to integrate recycling/reuse data.

Industry stakeholders also expressed several specific concerns with the existing knowledge infrastructure and barriers to its reliability and use such as: the inability to rely on EPDs for an apples-to-apples comparison between products and the need for data harmonization and elimination of potential gaming of the system by EPD creators; the failure to recognize the historic/stored/sequestration benefits of certain materials such as wood and cement and accounting for stored carbon in buildings long term; a siloed approach in considering operational and embodied carbon that limits significant, accurate, whole building and total carbon dataset, and LCA method development; the lack of a database of projects and simple tools to help architects and designers assess embodied carbon; the need for a mandate to create design and data consistency with EPDs and to level the playing field and bring firms of all types and sizes into the transformation process, not merely elite, large ones; and the need for a tool (similar to energy modeling) that allows varying data inputs to show how a project can balance operational and embodied carbon to meet optimal goals.

Despite these barriers, industry stakeholders pointed to promising, current efforts to strengthen the knowledge infrastructure, such as: the insulation subsector, which is leading EPD development and advocating for reliable LCAs and data on which to base EPDs; and the wood products subsector, which has committed to transparent interactions with stakeholders and partners, robust dataset development (representing 86% of the wood market) to facilitate creation of comparable EPDs, and collaboration with the forest sector (upstream supply chain), NGOs, and LCA tool developers to share data and identify issues of concern.

Economic Incentives

Economic incentives can take many forms, including incentives for manufacturers and the industrial sector to make low carbon products, for end-use consumers to purchase low carbon products, and to increase overall demand for low carbon products across the market spectrum from supply to demand and all points in between. Institutional investors and the financial marketplace may also motivate low carbon product development and adoption based their exposure to the financial risks of climate change.

Standards and Building Codes

Stakeholders from the building sector and codes/standards communities noted that it could take a decade or more to develop new ANSI standards and codes and have them adopted by local jurisdictions. Therefore, code development should occur simultaneously while the knowledge infrastructure that underpins standards and codes is being clarified and strengthened. Additionally, standards currently being developed may offer clues to where manufacturers and builders can focus their efforts to identify, manufacture and use low embodied carbon products.

Stakeholders from the architect, designer, and codes/standards communities noted that AIA 2030, SE2050, and MEP2040 have already established various goals to reach operational zero and net (whole life) zero carbon emissions between 2030 and 2050. The most recent ASHRAE 90.1 Appendix G (ASHRAE 2019) took the initial step of including the conversion of energy consumption to carbon emissions, so both energy and carbon may be considered. California's Marin County uses a material-based approach that offers both a performance-based compliance path and a prescriptive concrete strength-based limit for builders to meet concrete emission requirements (Marin 2019).

Some stakeholders advocated for a mandate by the codes/standards communities for LCAs and EPDs with minimum prescriptive requirements coupled with performance-based requirements. In the case of concrete for example, performance-based specifications may relate to cement quantities, water-to-cement ratios, supplementary cementitious materials (SCMs) quantities, or low carbon cement alternatives in concrete mixes (CarbonCure 2020). Industry and building sector stakeholders noted that while incorporating embodied carbon into standards and codes may not be the magic bullet, it is an important element in the solution.

Some other potential barriers to the codes development process that industry stakeholders identified include: (1) how lobbying interests argue about building envelope tradeoffs and varying levels of stringency in the development of energy codes; (2) how some subsectors such as insulation are in favor of robust building envelope stipulations in energy codes; and (3) the need to consider and stipulate reductions across the value chain in a whole-of-carbon approach and not merely focus on materials, with inherently unavoidable emissions due to chemical processes, such as in the cement and chemical industries.

Early Purchases

A growing number of national, state, and provincial-level jurisdictions in the United States, Canada, and the EU are adopting Buy Clean procurement policies based on global warming potentials (GWPs) stipulated in EPDs and assessed through LCAs for public infrastructure building projects. These large-scale projects with large buying power have the potential to help transform the market by increasing demand for low embodied carbon building materials and highlights the strategic role of governmental and institutional buying in market transformation. Aggregating public sector demand in this manner sends a powerful market signal to manufacturers and builders to focus on the production and use of low embodied carbon materials and drives the development of building standards and codes.

How to Effect Change?

While the path forward for creating a market transformation includes some required steps, it also illustrates the varied approaches of the industrial, building sector, and codes/standards development communities.

In general, all stakeholders were in agreement with the following common elements in the path forward: giving industry a seat at the table early in the process, in the planning stage, before policy is developed; having industry work out missing details/data gaps across materials; developing a data disclosure mechanism for material and building-level embodied carbon; developing a uniform data system across states, jurisdictions, and communities; bringing all the stakeholders into the process and allowing innovation; starting the code development process while underlying data systems are being clarified due to the lengthy codes process; learning from standards that are currently being developed for clues about where manufacturers and builders can start their low embodied carbon efforts; and ensuring outlier building materials with high impacts are also included in the transformation.

However, stakeholder groups varied in opinion with respect to the timeline and sequence of steps. The main arguments centered around first doing foundational work on harmonizing systems to manage data before moving into policy and standards/codes development versus working on both simultaneously to not lose time and deploying innovative technologies to reduce emissions while simultaneously working on data gaps and harmonization issues instead of choosing to do one after the other.

Some industrial stakeholders highlighted the following specific industry concerns to ensure they are included in any path forward: using a value chain approach to reductions (i.e., considering reductions across the value chain with all parts working together to identify opportunities); needing the federal government/stakeholders to work together to create a regulatory framework (e.g., Buy Clean policies) that promotes transparency, accurate measurement, the same treatment for all products, and equivalent comparisons, not merely being a vehicle for greenwashing or gaming in the marketplace; creating a mandate (from government, industry, or building codes and standards for construction/operation) to spur innovation; using a combination of performance-based requirements with some prescriptive and iterative minimums; and using a whole-building approach and a whole- or total-carbon approach to balance reductions between operational and embodied carbon to meet optimal goals.

The strategy to follow in making the transition to a low carbon future is one that collectively involves multiple sectors of the market, including supply chains, government coordination, building material manufacturers from other industrial subsectors, the investment and financial communities, the codes and standards communities to ensure a clean articulation of the types of materials needed, and the research and innovation communities to create the best possible new technologies so that the transition takes place at a systemic level and in the shortest possible timeframe.

With respect to a timeline for change, a one-size-fits-all approach may not be feasible for all manufacturing subsectors. Depending on the status of embodied carbon thinking and efforts in each industry, differing timelines and sequencing of submarket transformation steps may be required. Additionally, local building codes and standards must be tailored for local context based on stakeholder and environmental needs in each jurisdiction.

Conclusions and Recommendations

The authors' engagement of key construction professionals, material manufacturers, and their trade associations together with members of the buildings and codes/standards communities identified technology, data, policy, and market barriers to expanding adoption of low embodied carbon materials. Strengthening the knowledge infrastructure to support standards and stimulate production of low-carbon alternatives was identified as a critical need, as well as articulating a business case to manufacturers for supporting a market transformation. The elements to create an environment that supports transformation include marketplace and policy actions to accelerate demand for low-carbon products, engaging manufacturing support and commitment, and using a strengthened knowledge infrastructure (e.g., lifecycle assessment) to follow embodied carbon through the supply chain. The latter requires product-level, carbon-related technical standards, purchase specifications, building codes, and environmental product declarations.

The authors suggest engaging building material manufacturers to demonstrate the strategic benefits that would accrue from their support for building the underlying knowledge infrastructure and establishing standards and codes that encourage the adoption of low-embodied-carbon building materials. Since standards and codes are highly dependent on a robust knowledge infrastructure, when the industrial sector and material manufacturers work in concert to contribute high-quality data, they can enable the faster development of standards and codes to standardize products across the building sector. In turn, standards and codes development will allow industry to streamline its product offerings and benefit from the economies of scale that come with standard specifications and large-volume product demand. Thus, engaging manufacturers will help drive the market toward greater adoption of low-carbon building materials for construction. A transformed market will ultimately benefit companies as it opens new lines of business and makes them resilient to future business and economic shocks that come with the global transition to a low-carbon economy.

References

ACEEE. 2016. "National Symposium on Market Transformation." https://www.aceee.org/2016-national-symposium-market-transformation?msclkid=06bc1de7a9a011eca74bb99a38775767

America Competes Act. 2022. H.R.4521 Fact Sheet (January 25). https://www.speaker.gov/sites/speaker.house.gov/files/America%20COMPETES%20Act%20of%202022%20HR%204521.pdf

American Iron and Steel Institute (AISI). 2022. "Sustainability -- Buy Clean Initiatives." https://www.aisc.org/why-steel/sustainability/buy-clean/?msclkid=a9d320d4a9f411ec8ca49d836a217413

American Society of Civil Engineers (ASCE). 2021. *Report Card for America's Infrastructure*. https://infrastructurereportcard.org/resources/investment-gap-2020-2029/

Architecture2030. 2021. "Why the Building Sector?" https://architecture2030.org/why-the-building-sector/?msclkid=b7846568a87611ec9c0b6e4cc140583b

ASHRAE. 2019. "Update of Standard 90.1." https://www.ashrae.org/news/hvacrindustry/2019-update-of-standard-90-1

Boland, B., Levy, C., Palter, R., Stephens, D. 2022. "Climate Risk and the Opportunity for Real Estate: Real Estate Leaders Should Revalue Assets, Decarbonize, and Create New Business Opportunities. Here's How." McKinsey and Company. https://www.mckinsey.com/industries/real-estate/our-insights/climate-risk-and-the-opportunity-for-real-estate

California (CA) Department of General Services (DGS). 2017. "Buy Clean California Act." https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act?msclkid=7b8c276da8bc11ecac08f6b3a720c3f7

CarbonCure. 2020. "Concrete Expert Dr. Michael Thomas Makes the Case for Performance-Based Specs." https://www.carboncure.com/concrete-corner/concrete-expert-dr-michael-thomas-makes-the-case-for-performance-based-specs/

Carbon Leadership Forum (CLF). 2020. "SE2050 Challenge." https://carbonleadershipforum.org/se-2050-challenge/

___. 2021. "MEP 2040 Challenge." https://carbonleadershipforum.org/mep-2040/

Chastas, P., Theodosiou, T., Bikas, D. 2016. *Embodied energy in residential buildings-towards the nearly zero energy building: A literature review*. Building and Environment, Volume 105, Pages 267-282. (https://doi.org/10.1016/j.buildenv.2016.05.040).

Colorado General Assembly (CGA). 2021. "HB21-1303: Global Warming Potential for Public Project Materials." https://leg.colorado.gov/bills/HB21-1303

Eckman, T., N. Benner, and F. Gordon. 1992. *It's 2002: Do You Know Where Your Demand Side Management Policies and Programs Are?* In Proceedings of the 1992 ACEEE Summer Study on Energy Efficiency in Buildings 5: 1–17. Washington, DC: ACEEE. www.aceee.org/files/proceedings/1992/data/papers/SS92_Panel5_Paper02.pdf

Esram, N.W., and Hu, M. 2021. *Knowledge Infrastructure: The Critical Path to Advance Embodied Carbon Building Codes*. Washington, DC: ACEEE. https://www.aceee.org/sites/default/files/pdfs/Embodied%20Carbon%20in%20Buildings%2012-2-21%20final.pdf?msclkid=06ca974ea99f11ec8b77fa000326fb34

European Commission (EC). 2020. *A Renovation Wave for Europe: Greening Our Buildings, Creating Jobs, Improving Lives*. Brussels. https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf

European Union (EU). 2021. "Industrial Cluster Initiatives." http://industrialcluster.eu/en/home/#:~:text=The%20European%20Industrial%20Cluster%20%28EIC%29%20is%20a%20voluntary,market%20positions%20through%20national%2C%20regional%20and%20trans-border%20cooperation.?msclkid=2eed68e9aa0611ec8978e543e84cf619

Global Alliance for Buildings and Construction (GABC), UN Environment Programme (UNEP), International Energy Agency (IEA). 2017. *The 2017 Global Status Report. Towards a Zero Emission, Efficient, and Resilient Buildings and Construction Sector*. https://worldgbc.org/sites/default/files/UNEP%20188_GABC_en%20%28web%29.pdf

___. 2018. *The 2018 Global Status Report: Towards a Zero Emission, Efficient and Resilient Buildings and Construction Sector*. https://wedocs.unep.org/bitstream/handle/20.500.11822/27140/Global_Status_2018.pdf

___. 2019. *The 2019 Global Status Report for Buildings and Construction: Towards a Zero Emission, Efficient and Resilient Buildings and Construction Sector*. https://www.worldgbc.org/sites/default/files/2019%20Global%20Status%20Report%20for%20Buildings%20and%20Construction.pdf?msclkid=edc0cfeba87111ec864c878e2407e9a2

___. 2020. *The 2020 Global Status Report for Buildings and Construction: Towards a Zero Emission, Efficient and Resilient Buildings and Construction Sector*. https://globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf

___. 2021. *The 2021 Global Status Report for Buildings and Construction: Towards a Zero Emission, Efficient and Resilient Buildings and Construction Sector*. Nairobi. https://globalabc.org/sites/default/files/2021-10/GABC_Buildings-GSR-2021_BOOK.pdf

International Energy Agency (IEA). 2021. "Tracking Industry." https://www.iea.org/reports/tracking-industry-2021?msclkid=020326eaa93311ec9e41772b5bd039da

International Standards Organization (ISO). 2006a. "ISO 14025:2006. Environmental Labels and Declarations — Type III Environmental Declarations — Principles and Procedures." https://www.iso.org/standard/38131.html?msclkid=50588117ac6811ec9f820ed741e9e6b9

___. 2006b. "ISO 14040:2006 Environmental Management — Life cycle assessment — Principles and Framework." https://www.iso.org/standard/37456.html?msclkid=159f1727ac6811ecb81e0de768d35488

KPMG. 2021. "Insights on the Carbon Border Adjustment Mechanism (CBAM), Tax Measures in the EU Green Deal." https://home.kpmg/xx/en/home/insights/2021/06/carbon-border-adjustment-mechanism-cbam.html?msclkid=1b1e6e62a95311ecbd7810d610c2e408

Marin County (MC). 2019. "Low Carbon Concrete Requirements." https://www.marincounty.org/depts/cd/divisions/sustainability/low-carbon-concrete?msclkid=f955f289a8d511eca2e050223bfd776d

National Oceanic and Atmospheric Administration (NOAA). 2021. "Calculating the Cost of Weather and Climate Disasters." https://www.ncei.noaa.gov/news/calculating-cost-weather-and-climate-disasters?msclkid=f1f0f480a8b411ecad1cca2778dd68bb

Pennsylvania State University (PSU) Libraries. 2022. "Architectural Engineering: Databases and Resources." https://guides.libraries.psu.edu/c.php?g=388626&p=3484426&msclkid=ee518fcda9f611ec95d6e6fd4340258f

Securities and Exchange Commission (SEC). 2022. "SEC Proposes Rules to Enhance and Standardize Climate-Related Disclosures for Investors." https://www.sec.gov/news/press-release/2022-46?msclkid=cb4841f5a95611ec9b82edef05afb253

United Kingdom (UK). 2022. "Industrial Clusters for Decarbonization." https://www.zerocarbonhubs.co.uk/industrial-clusters.html#:~:text=1%20UK%20Industrial%20Clusters.%20The%20UK%20is%20a,energy%2C%20using%20the%20construction%20of%20a%20barrage%20?msclkid=d846ea66aa0511ec84653d4ed3f34aeb

United Nations Framework Convention on Climate Change (UNFCCC). 2015. *Paris Agreement*. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

___. 2021. (n.d.a). Human Settlements – Climate Action Pathway. https://unfccc.int/climate-action/marrakech-partnership/reporting-tracking/pathways/human-settlements-climate-action-pathway

U.S. Environmental Protection Agency (EPA). 2021a. "GHG Emissions – Industry." https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions?msclkid=3f24bd91a93411ecbd20eb7b29a5562f#industry

___. 2021b. "Scope 1, 2, 3 Emissions Inventory Guidance." https://www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance and https://www.epa.gov/climateleadership/scope-3-inventory-guidance

Washington Environment Council (WEC). 2020. *The Buy Clean and Buy Fair Washington Act*. https://wecprotects.org/wp-content/uploads/2022/02/Buy-Clean-Buy-Fair-WA-011822-vFINAL.pdf?msclkid=8485cbf1a8bd11ecb8b0a631d09b9347

White House (WH). 2021. "Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability." https://www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/

___. 2022. "Fact Sheet: Biden-Harris Administration Advances Cleaner Industrial Sector to Reduce Emissions and Reinvigorate American Manufacturing." https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/15/fact-sheet-biden-harris-administration-advances-cleaner-industrial-sector-to-reduce-emissions-and-reinvigorate-american-manufacturing/?msclkid=7ae3832da8b911ec90ecedfa90832645

World Economic Forum. 2020. van Heusden, R., Harry, M., and Puleo, M. "Why Addressing the Aluminum Industry's Carbon Footprint is Key to Climate Action." https://www.weforum.org/agenda/2020/11/the-aluminium-industry-s-carbon-footprint-is-higher-than-most-consumers-expect-heres-what-we-must-do-next/?msclkid=dcb04a53a93711ec80eb151c649ad0ae

World Economic Forum. 2021. Elliot, D. "What is the US Infrastructure Bill? An Expert Explains." https://www.weforum.org/agenda/2021/08/us-infrastructure-bill-explained/?msclkid=4952c2b4a95111ec804898d2b1add566