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Sustainable Building Materials

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As the global population has increased and billions of people worldwide have been brought out of poverty, the demand for building materials and resources has increased, placing an increasing burden on the natural environment. While hundreds of millions still face poverty,[1] we all face the threats of climate change and the destruction of biodiversity around the globe. As long as billions struggle for a better life, it is critical to accommodate the increasing needs of a growing population, while promoting the reduction of carbon emissions in order to protect the environment and a global economy threatened by climate change.

The human population has exploded, along with an increase in the consumption of resources and materials for development. According to the United Nations, the world's population has more than tripled since the mid-twentieth century.[2] As the human population continues to increase, billions will strive for a better life and consume more resources and materials. The production, transport, consumption, and disposal of food, raw materials, consumer goods, and manufactured products continue to erode the natural environment. Due to the growth of cities, increased demand for materials, agricultural cultivation, and industrial food production, less than one third of the land on Earth remains to support the natural ecosystems upon which life depends. In 2012, it was suggested that if every person on Earth lived like a United States ("U.S.") citizen, it would take four Earths to sustain them.[3] Since that time, the Earth has added two billion people. As the demand for buildings, infrastructure, and materials has continued to increase, pollution from development and construction has increased as well.

In light of the conflict between economic development and preservation of the environment, the need for "sustainable development" has emerged. Although the concept of sustainable development has been aspirational for decades, only recently have environmental impacts of material production been considered. Within the past two years, historic legislation in the U.S. has been enacted to fund the construction of infrastructure, investments in energy, and most significantly, clean building technology. With this funding, the U.S. is beginning to address the problem of carbon emissions from buildings, infrastructure, and development. This legislation will have an immediate impact on public works construction in the U.S., and could have a long-term impact on the supply of building materials and the creation of new markets for advanced building materials and processes. This paper will address recent developments in sustainable building materials, with a focus on the problems of carbon pollution, evolving new technologies, regulations, and markets for low-carbon emitting materials.

1. Role of Buildings and Infrastructure in Carbon Pollution

Global population growth and urbanization will necessitate significant amounts of new infrastructure and building construction. As the world's human population approaches 10 billion, the global building stock is expected to double in size.[4] Capital investments in infrastructure across the sector are forecast to grow by 40–70% between 2020 and 2040. By 2060, the total global floor area of buildings will double, with more than 50% of this increase anticipated within the next twenty years. The growth in new buildings will be particularly rapid in Asia and Africa.

Buildings are currently responsible for approximately 40% of global energy-related carbon emissions: approximately 28% from operational emissions (energy needed to heat, cool, and power buildings), and the remaining 12% from materials and construction. However, it is estimated that embodied carbon emissions ("CO_{2e}") from materials and construction will be responsible for approximately 75% of all CO_2 emissions from new buildings in the next ten years.[5] In the building industry, embodied carbon refers to the greenhouse gas ("GHG") emissions arising from the mineral extraction, manufacturing, transportation, installation, maintenance, and disposal of building materials.[6] Embodied carbon is the sum impact of all GHG emissions attributed to building materials throughout their life cycle.

Traditionally, the reduction, reuse, and recycling of materials have been common methods of carbon reduction and resource conservation.[7] A preliminary question to ask with respect to any project is whether new construction is needed, or whether existing assets can be repurposed or modernized. By avoiding the use of new materials, their impacts can be avoided altogether. Building reuse and incorporation of salvaged building materials can greatly reduce embodied carbon emissions from construction. Further reductions in emissions and increases in productivity can be achieved through material waste reduction, local procurement, and improved building technologies, such as building modeling, prefabrication, and electrification of fabrication, transportation, and construction equipment. While these practices have been major considerations in green construction, this article focuses upon the significant additional reductions that can be achieved through the selection of low-carbon emitting building materials, which will be a major component in the effort to halt climate change.

The increasing needs for more infrastructure, housing, and building in general will be a major challenge to the construction industry, which will require a radical transition to sustainable building materials in order to avoid degradation of the environment. Presently, the embodied carbon from building materials contributes anywhere from 15 to 20% of the energy used by a building over a fifty-year period.[8] This is distinguished from operational carbon from buildings, which is the carbon pollution from the energy sources used to heat, cool, ventilate, light, and power buildings. As operational carbon pollution is reduced through energy efficiency and transformation to renewable energy, embodied energy will be more important in reducing a building's carbon footprint. The relative percentage of embodied carbon to operational carbon is even greater when applied to infrastructure and landscaping.

New construction is inevitable, but the release of carbon emissions from such construction is not. Designers have tremendous influence in determining which materials are used in buildings. They can specify materials with low embodied carbon, thus reducing the amount of fossil-fuel energy and other resources expended during production, transportation, and construction. The development of low-carbon materials is now of major interest to the building industry.

2. Measuring Embodied Carbon in Materials

There is growing recognition that embodied carbon is not addressed by "operational carbon" policies and energy efficiency measures. Unlike operational carbon, which can be reduced over the life of a building, embodied carbon is locked in once construction is completed. There is a further recognition of a "carbon loophole," or emissions offshoring, which fails to consider embodied carbon through the entire global economy. As developed countries phase out regional production-based emissions and move toward meeting national emissions targets, some rely on developing countries to provide materials and products produced by carbon-intensive manufacturing practices, an outcome that results in a mere redistribution of carbon emissions.[9]

There is an old adage: "If you can't measure it, you can't manage it." While people debate the truth of this principle, it is obvious that if you can measure and compare the amount of embodied carbon in materials, it will be easier to manage and reduce the amount of CO_2e in new construction. The disclosure of carbon data and publication of Environmental Product Declarations ("EPDs") in the U.S. are currently voluntary, outside of state and local "Buy Clean" laws and federal governmental procurement regulations. EPDs are intended to measure greenhouse gas ("GHG") emissions attributed to construction materials and products, including emissions from mining raw materials, transportation, factory operations, and manufacturing processes. Because manufacturers are not required to publish the global warming potential ("GWP") of their products in public databases, the GWP ranges voluntarily reported will vary and likely underestimate the carbon impacts of the full material supply chain. However, as discussed below, government procurement policies and laws are beginning to generate a market for low-carbon materials and a need for accurate reporting of GWP data. Over the past few years, hundreds of EPDs have been published for building materials in order to comply with these laws. Various private operators throughout the U.S. offer EPD certification and consulting services.[10] For LEED certification reporting purposes, a third-party verified declaration is required based on International Organization for Standardization ("ISO") standards.[11] EPDs are defined by the California Department of Transportation ("Caltrans") as an "independently verified document created and verified under International Organization for Standardization (ISO) 14025 for Type III environmental declarations that identifies the global warming potential emissions of the facility-specific material or product through a product stage life cycle assessment."[12]

EPDs should be based upon a full life cycle assessment ("LCA") of building products and materials. LCA is a method used to calculate environmental impacts, including embodied carbon. EPDs based on LCAs are typically measured from raw material extraction to the point at which the product or material leaves the factory (cradle to gate), although some EPDs measure impacts through use and disposal (cradle to grave).

In 2021, the Carbon Leadership Forum ("CLF") published a Material Baseline Report which can be used to set measurable targets.[13] The number of baselines and other tools to measure embodied carbon are evolving. The availability of embodied carbon data for materials and products is also growing as more manufacturers produce EPDs for their products. The CLF estimates the cost to generate facility specific EPDs can range from $5,000 to over $50,000, depending on material types, complexity of the manufacturing, and methods used to calculate GWP data.[14]

3. Decarbonization of Building Materials

Just three materials—concrete, steel, and aluminum—are responsible for approximately 23% of total global carbon emissions. These are the most significant sources of material-related emissions in construction. Cement production is responsible for approximately 8% of global carbon emissions, with steel contributing 7–9% of the global total. These emissions constitute a greater percentage of annual global emissions than vehicle pollution.[15]

Concrete

Concrete is globally the most common building material after water. There have been a number of studies attempting to provide an overview of the environmental impacts from concrete.[16] Portland cement is the primary ingredient in concrete and is responsible for the majority of concrete's carbon emissions. Carbon emissions are released at two points during cement production: roughly 40% of the CO_2 generated is from the burning of fossil fuels in the manufacturing process, and the remaining 60% is from naturally occurring chemical reactions during processing.[17]

There are a number of ways to reduce carbon emissions from concrete. A commonsense approach is to use less concrete in project designs. Changing the concrete mix design to use less cement is another common way to reduce carbon emissions. The proportion of ingredients in a concrete mixture can greatly influence its carbon emissions. Supplementary cementing materials ("SCMs") are often used to harden concrete. Typical examples of SCMs are fly ash, slag cement (ground, granulated blast-furnace slag), and silica fume. SCMs are often added to concrete to make concrete mixtures more economical, reduce permeability, increase strength, or influence other concrete properties. Replacing a portion of the cement in concrete mix with fly ash byproduct from burnt coal is a popular embodiment reduction method. The use of fly ash concrete reduces input energy, but is dependent on ongoing operations of coal plants.[18]

There is a great deal of innovative research focused on reducing emissions from concrete, and companies that are actively developing and marketing low-carbon concrete. One company is developing methods to sequester carbon in concrete by injecting CO_2 into the concrete mix.[19] Another company is promoting a "carbon negative" cement, which substitutes calcium silicate in place of limestone.[20] The increased costs of using low-carbon cement vary widely from as much as 45% to "negligible."[21]

Steel

By weight, steel has a higher embodied carbon footprint than concrete, and the need to significantly reduce carbon emissions from steel production is critical to battling climate change. According to the World Steel Association, steel production is responsible for 6.6% of GHG emissions globally—more than portland cement. Global production of crude steel has more than doubled over the last two decades, and is projected to increase significantly in the future.[22] While Europe, the United States, and Japan were the largest steel producers in 2000, accounting for more than half (53%) of total production, the main sites of production have now shifted to emerging markets, which presently account for more than 70% of production. China alone accounts for about 55% of global steel production and has generated more than 90% of global production growth over the past twenty years. Outside of China, the top steel-producing countries today are India, Japan, Russia, and the United States.[23]

Lowering the cost of low-carbon emitting steel and renewable energy will be essential to preserving the environment. Steel is manufactured in two types of factories. Large steel mills typically use basic oxygen furnaces ("BOFs"), which burn coal or natural gas to melt iron ore to extract the iron, and then mix the iron with scraps of iron and steel to make new steel. Most of the inputs to a BOF are mined, raw materials, and the recycled content level of BOFs is typically between 25%–37%.[24]

Recycled content is important because virgin steel can have an embodied carbon footprint that is up to five times greater than high-recycled-content steel.[25] Smaller factories normally use electric arc furnaces ("EAFs") to melt scrap iron and steel into new steel. EAFs are powered by electricity, rather than coal and natural gas, and therefore have the ability to be powered by renewable energy sources. EAF steelmaking is effective for smaller sized plants, and is a steel production method that avoids the direct use of gas or coal to melt materials. Some factories do not have the ability to process raw iron ore, so the steel manufactured in EAFs has high levels of recycled content, up to 100%, with an average recycled content of 93% for hot-rolled steel.[26] Structural steel does not lose its metallurgical properties when recycled. As a result, the performance characteristics of recycled steel are similar to virgin steel. Low-temperature electrowinning also presents an innovative new manufacturing method that involves substantially less energy than traditional steelmaking, while also using no onsite coal or gas.[27]

In North America, the steel industry has largely switched to EAF technology. Using steel from EAFs can significantly reduce embodied emissions, because EAFs use high levels of recycled material and can be powered by future renewable energy sources.[28] Although the production of renewable energy is currently limited, renewable energy comprises the majority of new energy production and is an essential component to the reduction of carbon emission from the production of steel and other building materials.[29] For this reason, designers should specify steel produced in North America or recycled steel that employs EAF technology, if economically feasible. While price and availability will always be primary considerations in the procurement of steel for construction, new laws and regulations discussed below will generate product development and new markets for cleaner steel and other building materials.

Aluminum

Aluminum is the most abundant metal on Earth.[30] It is not found freely in nature, meaning that it is always found combined with other elements. Aluminum is often found combined with oxygen, which is known as aluminum oxide and is commonly found in bauxite.[31] The extraction of aluminum is extremely energy intensive, and generates significant carbon emissions. Because of this intense energy usage in the extraction process, the recycling of used aluminum is essential in reducing intense energy consumption and carbon emissions. Recycling aluminum saves 93% of the energy and reduces 94% of carbon footprint compared to producing the metal from bauxite ore.[32]

The more primary aluminum is in the product, the more striking the difference between hydropower smelted aluminum and coal-power smelted aluminum. For instance, the cradle-to-gate (mining to shipment) carbon footprint of automotive aluminum sheet made of Chinese primary aluminum would be 3.2 times higher than if made of Canadian primary aluminum when assuming the same primary aluminum content, due to the type of energy (coal versus hydropower) used in smelting.[33]

On the positive side, almost 75% of all the aluminum produced in the U.S. is still in use today. Aluminum can also be recycled indefinitely if uncontaminated.[34] In addition to a reduction in carbon emissions, recycling aluminum has a secondary benefit. Both open and underground mines can affect the plant and animal life immediately surrounding an area and beyond. The clear-cutting of trees and the destruction of ecosystems both contribute to biodiversity loss, habitat loss, carbon emissions, and erosion. Even assuming that mining operations incorporate plans for the restoration of natural habitats once mining is completed, restoration takes time, and mining operations will nevertheless have an immediate negative impact on the environment. In any case, from an environmental standpoint, the fact that aluminum can be easily recycled makes it superior to plastics for many uses.[35]

Other Building Materials

In addition to steel, concrete, and aluminum, there are other low-carbon building materials being developed, marketed, and specified for projects. For instance, Caltrans publishes product category rules for a number of other materials, including flat glass, mineral wool board insulation, aggregate, and asphalt.[36] Further, there is a growing number of non-profit organizations and for-profit corporations who are invested in the development, production, and promotion of low-carbon emitting building materials.[37]

4. "Buy Clean" Laws and the Regulation of Embodied Carbon

After decades of federal government inaction, the U.S. has recently adopted major infrastructure, energy, and climate change mitigation legislation and is currently developing regulations that will rapidly accelerate construction and impact the release of embodied carbon in North America.

The Federal Buy Clean Initiative is part of the Federal Sustainability Plan based upon the 2021 Executive Order 14057, which requires federal agencies to reduce their GHG emissions by 65% from 2008 levels by 2030.[38] Among other actions, the Plan requires federal agencies to reduce "procurement emissions" to net-zero by 2050. The Order states: "As the single largest landowner, energy consumer, and employer in the Nation, the Federal Government can catalyze private sector investment and expand the economy and American industry by transforming how we build, buy, and manage electricity, vehicles, buildings, and other operations to be clean and sustainable."[39]

The Federal Buy Clean Task Force is charged with developing policies and procedures related to embodied carbon, including the following:

- Prioritizing the Federal Government's purchase of steel, concrete, asphalt, and flat glass that have lower levels of emissions;[40]
- Identifying materials to prioritize for consideration in federal procurement and federally funded projects;
- Increasing the transparency of embodied emissions through supplier reporting, including incentives and technical assistance to help domestic manufacturers better report and reduce embodied emissions; and,
- Launching pilot programs to boost federal procurement of clean construction materials.

The implementation of these policies can be tracked through the Office of the Federal Chief Sustainability Officer.[41] The Federal Buy Clean Initiative will be supported by recent legislation, including the Infrastructure Investment and Jobs Act of 2021 ("Infrastructure Act") and the Inflation Reduction Act of 2022 ("IRA").

Infrastructure Act

In 2021, the U.S. enacted the bipartisan Infrastructure Act.[42] The Infrastructure Act contains provisions for the procurement and sourcing of materials from within the U.S. for federally funded construction projects. These provisions, commonly referred to as "Buy America," are prevalent throughout the text of the legislation.[43] The Infrastructure Act also states that its provisions "shall be applied in a manner consistent with United States obligations under international agreements."[44] Subject to these international agreements, the Infrastructure Act requires that all iron and steel products and construction materials used in a project that receives federal financial assistance be produced in the U.S.[45] With respect to steel, the Infrastructure Act requires that "all manufacturing processes, from the initial melting stage through the application of coatings, occur in the United States."[46] For manufactured products, the manufacture must occur in the U.S. and "the cost of the components of the manufactured product that are mined, produced, or manufactured in the United States [must be] greater than 55 percent of the total cost of all components of the manufactured product[.]"[47] For construction materials, "all manufacturing processes" for such materials must occur in the U.S.[48]

As the regulations implementing the Infrastructure Act are currently being developed, the precise scope of the "Buy Clean" regulations is not yet fully known. However, the procurement of materials for federal projects will likely be subject to the Federal Buy Clean Initiative discussed above. Therefore, the procurement of materials for construction projects under the Infrastructure Act could have a significant impact on the implementation of embodied carbon regulations in the U.S., and the development of markets for low-carbon materials.

Inflation Reduction Act

In 2022, the U.S. enacted the IRA.[49] The IRA provides $2.15 billion in funding to the U.S. General Services Administration ("GSA"), which manages over 1,500 buildings in the U.S., to install low-carbon materials. The GSA has announced a number of construction and renovation projects funded through the IRA. These projects aim to "catalyze clean energy innovation and spur domestic clean manufacturing by incorporating emerging technologies and low-carbon materials into construction and renovation projects at federal facilities across America."[50] The GSA plans to invest $3.4 billion to achieve a net-zero emissions federal building portfolio by 2045.[51]

State Buy Clean Laws

Many states have either enacted or proposed legislation in furtherance of their own "Buy Clean" objectives.[52] California has led in this area, enacting a wide range of procurement requirements for state projects.

In October 2017, California passed the Buy Clean California Act, becoming the first state to require facility specific EPDs and to set GWP thresholds for eligible materials used on public projects. The Buy Clean California Act ("BCCA") (California Public Contract Code sections 3500–3505) was developed to address climate change through the power of procurement.[53] It targets the embodied carbon of construction materials used in infrastructure projects such as roads, bridges, and public buildings.

The BCCA states the Department of General Services ("DGS"), in consultation with the California Air Resources Board ("CARB"), is required to establish and publish the maximum acceptable GWP limit for four eligible materials. The BCCA targets carbon emissions associated with the production of structural steel (hot-rolled sections, hollow structural sections, and plate), concrete reinforcing steel, flat glass, and mineral wool board insulation. When used in public works projects, these eligible materials must have a GWP that does not exceed the limit set by the DGS. In 2020, California initiated the mandatory submission of EPDs. In 2021, California required the four eligible materials listed above to meet published GWP thresholds. State construction contracts require eligible construction materials to have a GWP equal to or lower than a level established by state standards. Beginning July 1, 2022, the awarding authorities will determine GWP limit compliance standards for eligible materials using EPDs. Contractors engaged in public construction projects are now required to report to Caltrans the quantities of such eligible materials delivered to their jobsites.[54]

In September 2022, California enacted the Carbon Intensity of Construction and Building Materials Act.[55] This act requires the development of a framework for calculating and then reducing GHG emissions in the construction of all public and private buildings. The law requires CARB to encourage the production and use of low-carbon construction materials, leveraging state and federal financial incentives where possible to drive market demand. The new law also requires CARB to include a comprehensive strategy to achieve a 20% net reduction in the GHG emissions of building materials by December 31, 2030, and a 40% net reduction no later than December 31, 2035.

A number of other jurisdictions have also enacted laws related to embodied carbon in building materials. As of September 2022, Buy Clean laws have been passed in Colorado and Oregon, and additional states that have considered Buy Clean legislation include Washington, Texas, Minnesota, New York, and New Jersey.[56] The CLF publishes a regularly updated list of nations, states, and municipalities that have adopted embodied carbon policies and laws; Canada, France, and Finland have done so, and a growing number of nations are considering doing so.[57]

5. Emerging Market for Sustainable Materials and Development

There must be a balanced approach to the transition to sustainable development that recognizes the material needs of the current generation. Buy Clean laws and regulations in the U.S. will initially spur the use of low-carbon emitting materials in federal and state projects. These laws and regulations will result in new products and processes, which will eventually lower the cost of such materials. Laws relating to the regulation of embodied carbon will likely expand to private projects in a number of jurisdictions and will likely be adopted into building codes. As a result of competition and innovation, market forces will eventually drive industry to abandon many high-polluting materials and manufacturing processes.

This transition could result significant additional costs and burdens on development and construction if not implemented wisely. Unfortunately, environmental laws and regulations have often been used to impede needed development, sometimes by parties who have no sincere interest in the environment.[58] For decades, new highways, resource extraction, infrastructure, development, and housing have often faced opposition from local property owners and competing business interests, as well as trade, labor, and industry groups. The misuse of federal, state, and local laws by these groups has increased the cost of development and construction, and impeded desperately needed housing, transportation, renewable energy production, and infrastructure in general. To avoid this result, Buy Clean laws should not be implemented so as to unreasonably impede critical development by unnecessarily increasing the cost of construction.

There is a need for a new generation of leaders, entrepreneurs, and innovators to modernize the construction industry and to provide critical development for the welfare of an increasing population. While labor productivity has increased in numerous industries in the U.S., the productivity of the construction industry has not significantly improved since 1950.[59] Despite growth in productivity for the U.S. economy as a whole, the U.S. construction sector measures of labor and total factor productivity ("TFP") have trended downward. According to a recent study, the sector has become less productive over time: value added per worker in the sector was about 40% lower in 2020 than it was in 1970.[60] Unless the U.S. can reverse this trend, its development of critical infrastructure and manufacturing may fall behind other nations. While an examination of possible solutions for this problem goes beyond the scope of this paper, U.S. investments in new building technology could provide major opportunities to move ahead in efficient and sustainable design, construction, and development.

Fortunately, there are both for-profit and non-profit organizations that are engaged in the development of sustainable materials. While major corporations are concerned with environmental, social, and governance issues, the primary incentives for adopting sustainability will always be the market and the ability to profit from research and innovation.

The role of non-profit organizations in accelerating the development of these markets is critical. For instance, the major requirements for LEED certification of buildings by the U.S. Green Building Council were adopted and mandated by the State of California in its building codes in 2019.[61] California has led the U.S. in building energy efficiency codes, renewal energy development, the transition to electric vehicles, and the promotion of low-emitting materials, while growing to become potentially the fourth-largest economy in the world.[62] However, because California faces major challenges due to the cost of housing and construction, it has wisely initiated Buy Clean laws in the public sector, in order to spur development of cost-effective low-carbon building materials that can be used by the private sector.

Unless we accelerate the change from development as usual, continued environmental degradation may result in potentially irreversible catastrophic consequences and conflicts.[63] Although we must give priority to the implementation of effective solutions to counteract serious environmental damage, the solutions cannot be at the expense of critical development, or the solutions will likely be rejected. The enactment of "Buy Clean" laws and policies will hopefully spur the development of cost-effective non-polluting materials, and facilitate both widespread prosperity and the transition to a more sustainable future.

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[1] In 2021, an estimated 698 million people, or 9% of the global population, lived in extreme poverty. *See* Elana Suckling et al., *Poverty Trends: Global, Regional and National*, DEV. INITIATIVES (Nov. 2021), https://devinit.org/resources/poverty-trends-global-regional-and-national/#:~:text=In%202021%20an%20estimated%20698,live%20below%20%245.50%20a%20day.

[2] The world's population is more than three times larger than it was in the mid-twentieth century. The global human population reached 8.0 billion in mid-November 2022 from an estimated 2.5 billion in 1950, adding 1 billion people

since 2010 and 2 billion since 1998. The world's population is expected to increase by nearly 2 billion people in the next thirty years, from the current 8 billion to 9.7 billion in 2050. For a comprehensive population analysis and forecast, see *Global Issues: Population*, UNITED NATIONS, https://www.un.org/en/global-issues/population#:~:text=Our%20growing%20population,and%202%20billion%20since%201998 (last visited Jan. 24, 2023).

[3] *See* Charlotte McDonald, *How Many Earths Do We Need?*, BBC NEWS (June 16, 2015), https://www.bbc.com/news/magazine-33133712.

[4] *See Why Population Growth Matters for Sustainable Development*, UNITED NATIONS: DEP'T OF ECON. AND SOC. AFFS. (Feb. 2022), https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2022_policy_brief_population_growth.pdf (providing estimated building growth models in relation to population growth trends).

[5] *See Why the Built Environment?*, ARCHITECTURE 2030, https://architecture2030.org/why-the-building-sector/ (last visited Mar. 23, 2023) (detailing the projected growth of embodied carbon amid a large wave of urban growth over the next forty years).

[6] *See generally Embodied Carbon 101*, CARBON LEADERSHIP F., https://carbonleadershipforum.org/embodied-carbon-101/#:~:text=Embodied%20carbon%20refers%20to%20the,urgent%20action%20to%20address%20it (last visited Mar. 23, 2023).

[7] *See* Erin McDade & Lori Ferriss, *CarbonPositive: Carbon Intelligence for Reuse Decisions*, ARCHITECT MAG. (Dec. 16, 2022), https://www.architectmagazine.com/carbon-positive/carbonpositive-carbon-intelligence-for-reuse-decisions_o.

[8] *See Frequently Asked Questions: The 2030 Challenge*, ARCHITECTURE 2030, https://architecture2030.org/about/faq/#toggle-id-16 (last visited Jan. 24, 2023).

[9] *Carbon Dioxide Emissions Embodied in International Trade*, OECD (Nov. 2021), https://www.oecd.org/sti/ind/carbondioxideemissionsembodiedininternationaltrade.htm (demonstrating through empirical data that net exports of embodied carbon from non-OECD member countries have rapidly increased in pace over recent years).

[10] *See generally About Us*, PROGRAM OPERATOR CONSORTIUM, https://programoperators.org/goals/ (last visited Jan. 24, 2023) (listing companies qualified to provide EPD evaluations).

[11] *See generally LEED v4 & EPDs*, CANADIAN INST. OF STEEL CONSTR., https://cisc-icca.ca/ciscwp/wp-content/uploads/2017/03/Leedv4-EPD-Flyer-en-PRESS_v4.pdf (last visited Mar. 23, 2023) (providing EPD requirements for steel procurement to meet LEED standards).

[12] *See* CAL. PUB. CONT. CODE § 3500 (Deering 2023) (enabling language for the Buy Clean California Act), https://dot.ca.gov/-/media/dot-media/programs/construction/documents/policies-procedures-publications/cpd/cpd21-3-attachment-1-a11y.pdf.

[13] Stephanie Carlisle et al., *2021 Material Baseline Report*, CARBON LEADERSHIP F. (July 2021), https://carbonleadershipforum.org/2021-material-baseline-report/.

[14] *See EPD Requirements in Procurement Policies*, CARBON LEADERSHIP F., https://carbonleadershipforum.org/epd-requirements-in-procurement-policies/ (last visited Mar. 23, 2023).

[15] *See Global Emissions*, CTR. FOR CLIMATE AND ENERGY SOLS., https://www.c2es.org/content/international-emissions/ (last visited Mar. 23, 2023).

[16] Jane Anderson & Alice Moncaster, *Embodied Carbon of Concrete in Buildings, Part 1: Analysis of Published EPD*, BLDGS. & CITIES (2022), http://doi.org/10.5334/bc.59.

[17] *See Carbon Impacts of Concrete*, CARBON SMART MATERIALS PALETTE, https://materialspalette.org/concrete/ (last visited Jan. 24, 2023).

[18] *See Supplementary Cementing Materials*, PCA: AM.'S CEMENTING MFRS., https://www.cement.org/cement-concrete/concrete-materials/supplementary-cementing-materials (last visited Jan. 24, 2023).

[19] Carbon Cure, a Novia Scotia-based alternative cement manufacturer, is investing heavily in technologies to convert concrete itself into an effective carbon sink. *See Cleaner Concrete, Better Business*, CARBON CURE, https://www.carboncure.com/ (last visited Jan. 24, 2023).

[20] Brimstone Energy, a California-based cement technology engineering firm, created the proprietary "Brimstone Process," through which portland cement can be manufactured with carbon-free calcium silicate rock. *See Carbon Negative from Rock to City Block*, BRIMSTONE, https://www.brimstone.energy/ (last visited Jan. 24, 2023).

[21] *See* Sebastian Reiter, *Cement*, MCKINSEY Q.: TRANSITION TO NET ZERO (Aug. 1, 2022), https://www.mckinsey.com/capabilities/sustainability/our-insights/spotting-green-business-opportunities-in-a-surging-net-zero-world/transition-to-net-zero/cement (detailing opportunities for value creation among supply chain members seeking to lower carbon emissions).

[22] *See Iron and Steel Technology Roadmap*, INT'L ENERGY AGENCY: ENERGY TECH. PERSPS. (Oct. 2020), https://www.iea.org/reports/iron-and-steel-technology-roadmap.

[23] WORLD STEEL ASSOCIATION, https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2022/ (last visited Feb. 19, 2023) (presenting a wide variety of steel production and usage statistics).

[24] *See* Larry Strain, *10 Steps to Reducing Embodied Carbon*, AM. INST. ARCHITECTS, https://www.aia.org/articles/70446-ten-steps-to-reducing-embodied-carbon (last visited Jan. 24, 2023).

[25] AM. INST. STEEL CONSTR., MORE THAN RECYCLED CONTENT: THE SUSTAINABLE CHARACTERISTICS OF STRUCTURAL STEEL (2017), https://www.aisc.org/globalassets/aisc/publications/white-papers/more-than-recycled-content.pdf.

[26] *E.g.*, AM. IRON AND STEEL INST., STEEL TAKES LEED WITH RECYCLED CONTENT (2006), https://strucsteel.com/docs/Steel-Recycling.pdf (providing various sustainability metrics for EAF process uses).

[27] *See generally* Qiang Wang et al., *Low Temperature Electrolysis for Iron Production via Conductive Colloidal Electrode*, 1 RSC ADVANCES 5 (2015).

[28] *See* Paula Melton, *The Urgency of Embodied Carbon and What You Can Do About It*, BLDG. GREEN (Sept. 10, 2018), https://www.buildinggreen.com/feature/urgency-embodied-carbon-and-what-you-can-do-about-it.

[29] *See generally Renewable Power's Growth is Being Turbocharged as Countries Seek to Strengthen Energy Security*, INT'L ENERGY AGENCY (Dec. 6, 2022), https://www.iea.org/news/renewable-power-s-growth-is-being-turbocharged-as-countries-seek-to-strengthen-energy-security.

[30] *See Aluminum*, PERIODICTABLE.COM, http://periodictable.com/Elements/013/ (last visited Jan. 24, 2023).

[31] *See The Element Aluminum*, THOMAS JEFFERSON NAT'L ACCELERATOR FACILITY: OFF. SCI. EDUC, http://education.jlab.org/itselemental/ele013.html (last visited Jan. 24, 2023).

[32] *See* MARSHALL JINLONG WANG, THE ALUMINUM ASS'N, THE ENVIRONMENTAL FOOTPRINT OF SEMI-FABRICATED ALUMINUM PRODUCTS IN NORTH AMERICA 8 (2022), https://www.aluminum.org/sites/default/files/2022-01/2022_Executive-Summary_Semi-Fab_LCA.pdf.

[33] *Id.* at 7.

[34] *Id.* at 6–7.

[35] *See generally* Konstantinos Georgitzikis et al., *Sustainability Aspects of Bauxite and Aluminum*, EUR. COMM'N: JRC TECH. REP. (July 2021), https://rmis.jrc.ec.europa.eu/uploads/library/jrc125390_sustainability_profile_bauxite__aluminium_online.pdf (analyzing various emissions and sustainability metrics for aluminum, including a full LCA report for primary aluminum).

[36] *Environmental Product Declarations (EPD)*, CALTRANS (Dec. 29, 2022), https://dot.ca.gov/programs/engineering-services/environmental-product-declarations.

[37] ASS'N GEN. CONTRACTORS, RES. LIBR.: ENERGY & ENV'T, https://www.agc.org/learn/resource-library (last visited Feb. 25, 2023); *AIA 2030 Commitment*, AM. INST ARCHITECTS, https://www.aia.org/pages/6464938-the-aia-2030-commitment (last visited Feb. 25, 2023); *see, e.g.*, Nadine Post et al., *New Technologies for Reduced-Carbon Concrete Are on the Horizon: Startups Gearing Up but Production to Scale is a Ways Off*, ENG'G NEWS-R. (Sept. 15, 2022), https://www.enr.com/articles/54809-new-technologies-for-reduced-carbon-concrete-are-on-the-horizon.

[38] Exec. Order No. 14,057, 86 Fed. Reg. 70935 (Dec. 8, 2021).

[39] *Id.*

[40] These four construction materials account for nearly half of all U.S. manufacturing GHG emissions and represent 98% of the government's purchased construction materials. *See FACT SHEET: Biden-Harris Administration Announces New Buy Clean Actions to Ensure American Manufacturing Leads in the 21st Century*, WHITE HOUSE (Sept. 12, 2022), https://www.whitehouse.gov/briefing-room/statements-releases/2022/09/15/fact-sheet-biden-harris-administration-announces-new-buy-clean-actions-to-ensure-american-manufacturing-leads-in-the-21st-century/.

[41] *Federal Buy Clean Initiative*, OFF. FED. CHIEF SUSTAINABILITY OFFICER: COUNCIL ON ENV'T QUALITY, https://www.sustainability.gov/buyclean/index.html (last visited Jan. 24, 2023) (providing a chronological account and description of all federal actions that support the Buy Clean Initiative).

[42] H.R. 3684, 117th Cong. (2021) [hereinafter *Infrastructure Act*], https://www.congress.gov/bill/117th-congress/house-bill/3684/text.

[43] *See generally* Ethan Davis et al., *Infrastructure Investment and Jobs Act: Key Provisions and Considerations for Project Participants*, KING & SPALDING (Dec. 24, 2021), https://www.jdsupra.com/legalnews/infrastructure-investment-and-jobs-act-8268268/.

[44] Infrastructure Act, § 70925.

[45] Infrastructure Act, § 70912(6).

[46] Infrastructure Act, § 70912(6)(A).

[47] Infrastructure Act, § 70912(6)(B)(ii).

[48] Infrastructure Act, § 70912(6)(C).

[49] H.R. 5376, 117th Cong. (2022) [hereinafter *IRA*], https://www.congress.gov/bill/117th-congress/house-bill/5376.

[50] *See GSA Administrator Visits Arizona to Announce First Inflation Reduction Act Projects at Federal Facilities*, U.S. GEN. SERVS. ADMIN. (Dec. 19, 2022), https://www.gsa.gov/about-us/regions/welcome-to-the-pacific-rim-region-9/region-9-newsroom/pacific-rim-press-releases/gsa-administrator-visits-arizona-to-announce-first-inflation-reduction-act-projects-at-federal-facilities-12192022.

[51] *See Inflation Reduction Act*, U.S. GEN. SERVS. ADMIN., https://www.gsa.gov/governmentwide-initiatives/inflation-reduction-act (last visited Jan. 24, 2023).

[52] *See infra* note 56 and accompanying text.

[53] Buy Clean California Act, CAL. PUB. CONT. CODE § 3500–3505 (Deering 2023).

[54] *See* CALTRANS, *supra* note 36.

[55] Carbon Intensity of Construction and Building Materials Act, CAL. HEALTH & SAFETY CODE § 38561.3 (Deering 2022).

[56] In 2021, Colorado enacted HB21-1303: Global Warming Potential for Public Project Materials (Buy Clean Colorado Act). *See* Colo Rev. Stat. § 24-92-117 (2021). In 2022, Oregon passed the Buy Clean Oregon Act. *See* H.R. 4139, 81st Leg., 2022 Reg. Sess. (Or. 2022), https://olis.oregonlegislature.gov/liz/2022R1/Downloads/MeasureDocument/HB4139/Enrolled.

[57] *See CLF Embodied Carbon Policy Toolkit*, CARBON LEADERSHIP F., https://carbonleadershipforum.org/clf-policy-toolkit/#map (last visited Jan. 24, 2023).

[58] *See generally* J.B. Ruhl & James Salzman, *What Happens When the Green New Deal Meets the Old Green Laws?*, 44 VT. L. REV. 693 (2020).

[59] *See* Austan Goolsbee & Chad Syverson, *The Strange and Awful Path of Productivity in the U.S. Construction Sector* (U. Chi. Becker Friedman Inst. for Rsch. in Econ., Working Paper No. 2023-04, 2023), https://bfi.uchicago.edu/wp-content/uploads/2023/01/BFI_WP_2023-04.pdf (January 2023).

[60] *Id.* at 1.

[61] The California Green Building Standards Code—Part 11, Title 24, California Code of Regulations—known as CALGreen, is the first-in-the-nation mandatory green building standards code. CAL CODE REGS. tit. 24, pt. 11. (2022). For further information and a historical analysis of CALGreen, see *History of the California Green Building Standards Code (CALGreen)*, CAL. BLDG. STANDARDS COMM'N, https://www.dgs.ca.gov/BSC/About/History-of-the-California-Green-Building-Standards-Code-CALGreen (last visited Feb. 19, 2023).

[62] See Matthew A. Winkler, *California Poised to Overtake Germany as World's No. 4 Economy*, Bloomberg October 24, 2022, https://www.bloomberg.com/opinion/articles/2022-10-24/california-poised-to-overtake-germany-as-world-s-no-4-economy.

[63] *See generally* Halvard Buhaug et al., *Climate-Driven Risks to Peace Over the 21st Century*, CLIMATE RISK MGMT. (Dec. 2022), https://www.sciencedirect.com/science/article/pii/S221209632200078X.