EMBODIED CARBON IN CONSTRUCTION MATERIALS PRODUCTION

Key emission sources and evolving processes helping to reduce the industry's carbon footprint.

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This report provides an overview of significant carbon contributors within the production process of construction materials while also exploring the strategies being adopted by the industry to implement mitigating measures, aiming to attain net-zero emissions by 2050.

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As drastic climate change continues to make an impact around the world, the United States Government has responded by setting targetable industry-specific goals with realistic timetables to help negate harmful effects.

Some of the more overarching goals include:

- **reducing United States greenhouse gas emissions 50-52% below 2005 levels in 2030,**
- **reaching 100% carbon pollution-free electricity by 2035,**
- **and achieving a net-zero emissions economy by 2050.**

The United States Government does not currently have a clear-cut plan for reaching climate goals, specifically with construction, as it has with other industries. However, national officials have confidence that with regulated actions and solutions implemented, we can achieve our targets.

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CURRENT EMISSION STATUS IN THE CONSTRUCTION SECTOR

The construction sector is responsible for 27% of total global greenhouse gas emissions,

- **with 10% coming from the embodied carbon emitted during the construction process.**
- **Some studies estimate this number to be higher, with the building sector contributing as much as 38% or 43% of the total global greenhouse gas emissions.**

Concrete, steel, and aluminum manufacturing alone are responsible for 23% of global emissions in 2023.

Materials production is shown to be the largest contributor to the industry's high emissions. International environmental researchers found that more than half of the greenhouse gas emissions are reduced when the best-available technologies and practices, such as material substitution measures, are applied.

The following will break down the divisions for significant emission reduction by material and process type, highlighting specific products and technologies that are gaining traction with environmental advocates and pioneers in the field across the United States.

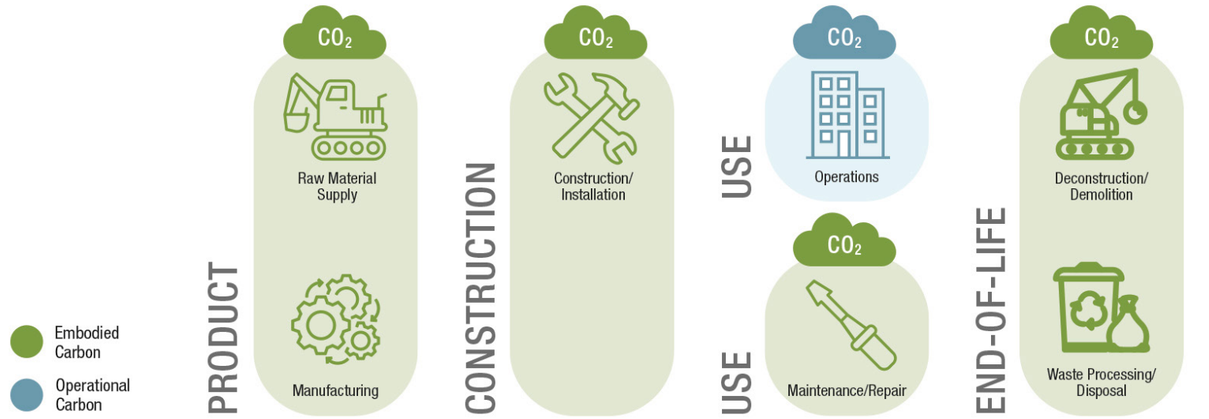
BREAKDOWN BY MATERIAL/PRODUCT (STARTING WITH HIGHEST EMITTING)

CONCRETE I.E. CEMENT:

CURRENT STATE:

Concrete is critical to construction but is also one of the most carbon-intensive materials. Studies show that the cement manufacturing sector is the third largest industrial source of pollution in the United States.

Most negativity associated with concrete stems from the cement that acts as a binder, cement clinker. Clinker is made from heating limestone and other materials (the most emissions-intensive aspect of the whole process), and limestone quarrying uses immense amounts of fuel. The production of just 1kg of clinker cement releases almost 1kg of CO_2. Over half the CO_2 emissions from the cement industry come from clinker production. As a result of this process, cement production accounts for 8% of global greenhouse gas emissions.



AWI Licensing Company

SOLUTIONS:

One of the leading ways to reduce the environmental impact associated with the use of concrete in construction while keeping the performance integrity is to use less cement clinker by substituting it with supplementary cementitious material. These substitutes range from hydraulic materials such as slag and burnt shale oil to pozzolanic materials such as fly ash and silica fume.

Brimstone:

A firm focused on producing a carbon-neutral or negative and cost-competitive product nearly identical to cement. Brimstone's carbon-negative process is a breakthrough in cement production, making ordinary portland cement with carbon-free calcium silicate rock instead of limestone. This material eliminates emissions from the start with the addition of magnesium and is more abundant than limestone.

C-Crete Technologies:

C-Crete is a leading materials science company committed to inventing, building, and scaling up the next generation of infrastructure materials with an ultra-low or negative CO_2 footprint. The company has developed two low-cost, prevalent binders for portland cement-free concrete, slag and zeolite, which is a naturally occurring non-carbonate rock. Being produced without heat, these binders save approximately one ton of CO_2 emissions for each ton of portland cement they replace.

Sublime Systems:

Sublime is a company developing a breakthrough process to make ASTM C1157-compliant low-carbon cement. The technology replaces the industry's legacy fossil-fuel-intensive thermal calciner process with an electrochemical process that can turn abundantly available non-carbonate rocks and centuries of industrial waste that don't release CO_2 when they are decomposed into cement at ambient temperature with renewable electricity. They're currently working with infrastructure owners, engineers, architects, contractors, and ready-mix concrete plants to make sure the cement performs to quality and industry standards.

CASE STUDY: FORM-UP FOUNDATIONS AT PATTERSON-SCULLEY HOUSE (RESIDENCE LIFE PROJECT) AT ST. MARK'S SCHOOL

Form-Up Foundations is a concrete contractor located in Rindge, New Hampshire, dedicated to craftsmanship and building a greener future starting from the ground up, quite literally. Through meticulous research and innovation, Form-Up Foundations has developed a concrete blend that significantly reduces CO_2 emissions during flatwork installation. On the Patterson-Sculley House (Residence Life Project), the substitution of 30% slag in the concrete mix resulted in a reduction of 278,600 kgCO_2eq of global warming potential. Equivalent to the embodied carbon of 262 acres of forest for one year.

STEEL:

CURRENT STATE:

Primary steel is currently the main type of steel used in the industry. The reaction of iron ore with carbon to create steel is the greatest contributor to CO_2 emissions in the production process, making it responsible for 70-80% of total emissions from steel manufacturing and 7% of global CO_2 emissions.

SOLUTIONS:

By implementing greener technologies and processes to decarbonize steelmaking, the industry can lower emissions and reduce pollution.

Boston Metal:

Based in Woburn, Massachusetts, Boston Metal has moved away from the use of coal in steel production through its Molten Oxide Electrolysis (MOE) process that utilizes renewable energy to turn iron ore into liquid metal without producing coke. Since they use inert anodes in electrolysis, the only byproduct is oxygen. The inert anode is placed in an electrolyte containing iron ore such that when it is electrified, pure liquid metal is produced from splitting the bonds of iron oxide.

Nucor:

Nucor is a North Carolina-based steel manufacturer that formed in the mid-20th century. In 1989, their Indiana mill became the first to produce sheets of steel using thin-slab technology. A 2002 innovation called Castrip technology, the process casts molten steel directly into sheet steel at or near its final thickness, eliminating the need for large hot and cold rolled reductions. Compared to the casting and rolling process of an integrated steelmaking facility, the Castrip process consumes about 95% less energy and emits less than one-tenth of the greenhouse gases. In 2021, Nucor released ECONIQ, the first net-zero carbon steel in the world using 100% renewable energy. Thanks to their use of electric arc furnaces over traditional blast furnaces, their greenhouse gas emissions were 79% less than the global average for steel mills in 2022.

ALUMINUM:

CURRENT STATE:

As with concrete and steel, the production of aluminum uses large amounts of electricity—responsible for the greenhouse gas emissions associated with the resource's production. Aluminum is the second most used metal in the world, and the industry contributes to 2% of global greenhouse gas emissions. 96% of emissions associated with aluminum production come from turning aluminum ore into alumina and then using electrolysis to turn alumina into aluminum (electrolysis contributes 80% of total emissions from the aluminum sector), as well as gas released from the addition of carbon anodes.

SOLUTIONS:

Recycled aluminum manufacturing uses just 5% of the energy that primary aluminum production uses. With the ability to be infinitely recyclable and the fact that it does not lose its material properties, it can sustainably be reused overtime. In fact, 75% of all aluminum ever created is still in circulation.

PLASTICS:

CURRENT STATE:

According to the Center for International Environmental Law, plastic refining is one of the most intensive industries in all of manufacturing in terms of greenhouse gas emissions. The EPA claims that 1oz of CO_2 is emitted for each ounce of polyethylene produced. In 2021, Waste360 found that the plastic industry as a whole produces 232 million tons of CO_2 gas a year, which is the equivalent of 116 coal-fired power plants (by their measurements).

Polypropylene is used in many polymers and other construction materials and has been calculated to emit 1.58 kg CO_2 per kg of pellets, proving that the emissions weigh more than the product. PVC production is even more unfavorable than polypropylene, with 1kg of PVC resulting in 7.83kg of CO_2 emitted.

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SOLUTIONS:

To reduce the emissions in the plastic industry, manufacturers should move towards utilizing thermochemical recycling plants to recycle plastic, implement carbon capture in the polymerization processes, and electrify the production process. Since PVC is the main plastic used in many aspects of construction, large emissions abatement progress can come from substituting away from PVC wherever possible. Options include:

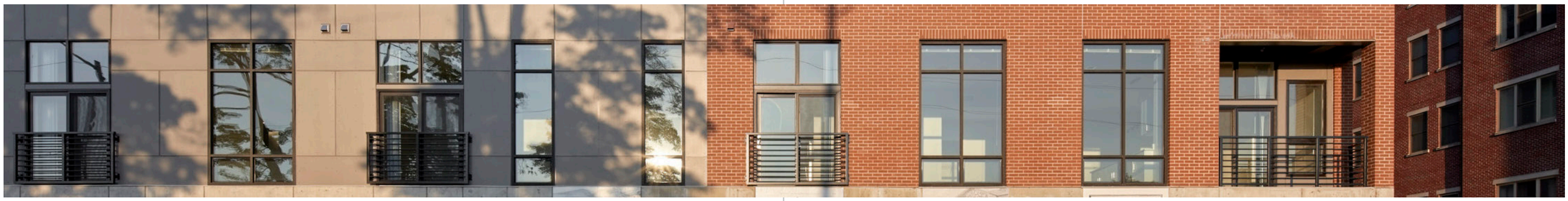
- **For pipes, switch to polyethylene, ductile iron, polypropylene, or stainless steel.**
- **For windows, use wood, aluminum, or fiberglass.**
- **For electrical cables, switch to chlorinated polyethylene, thermoplastic elastomers, or cross-linked polyethylene.**
- **And finally, for flooring, use wood, natural linoleum, and tiles whenever possible.**

WINDOWS/GLASS:

CURRENT STATE:

Windows play an important part in a building's construction with its heating, lighting, cooling, and ventilation characteristics. However, glass manufacturing produces at least 86 million tons of CO_2 a year worldwide due to the extremely high temperatures of the melting furnaces and the raw materials, such as soda ash and limestone, being converted to flat glass. But most of this can be eliminated when glass is recycled, and existing technologies could turn glass manufacturing into a mostly carbon-free process.

With more owners required to meet Stretch Codes and Passive House standards, requiring double or triple-paned windows, it is critical to cut the carbon footprint of glass manufacturing.



SOLUTIONS:

Glass is made by heating limestone, sand, and soda ash to 1,500 °C. This heat comes from natural gas, and it accounts for between 75% and 85% of the carbon emissions from glass manufacturing. The remaining emissions are a by-product of the chemical reactions between the raw materials. But some of these materials can be replaced with crushed recycled glass, known as cullet. When cullet is melted, no CO_2 is released. And furnaces don't have to burn so fiercely to melt glass as to melt the raw materials, offering further carbon savings. According to the European Container Glass Federation (FEVE), an industry group based in Brussels, 10% more cullet in a furnace lowers CO_2 emissions by 5% compared with making glass entirely from raw materials.

There are also alternative options to the process and materials of glass production.

LionGlass (Penn State University):
Engineered by researchers at Penn State, LionGlass requires significantly less energy to produce and is much more damage-resistant than standard soda lime silicate glass. Temperature requirements are lowered by 300-400 degrees Celsius, reducing 30% of typical energy consumption. LionGlass has also been proven to be 10 times more damage-resistant than current glass.

Vitro Architectural Glass:
Vitro Architectural Glass, part of Vitro, North America's largest glass producer, is exclusively dedicated to glass innovation. Vitro is currently taking steps to reduce overall energy consumption in its glass production. Some of these initiatives include adding new low-NOx burners, utilizing recycled cullet (both pre-and post-industrial) to reduce fuel consumption, and using oxy-fuel technology at three plant locations in the U.S., which can reduce energy consumption in glass melting furnaces by as much as 20% and cut greenhouse gas emissions in half.

LOCAL INITIATIVES.

Massachusetts has started making carbon neutrality a priority, especially when it comes to construction projects. In 2019, Boston rolled out a Climate Action Plan to make the city carbon-neutral by 2050. Part of their strategy is transitioning to net zero carbon new construction and developing carbon targets to improve existing buildings over time. We've also seen similar initiatives in Newton and Somerville and on a national level from the White House with the passing of the Inflation Reduction Act and its clean energy programs.

As carbon neutrality picks up in Massachusetts, various tools have become available for construction projects. National Grid and Mass Save offer net zero energy and Energy Use Intensity (EUI) reduction incentive programs that create long-lasting energy savings and offset the incremental construction and design service costs associated with the inclusion of more energy-efficient equipment and systems. Additionally, Architecture 2030, a non-profit, non-partisan, and independent organization established in 2002 in response to the ongoing climate emergency, has formally launched the CARE (Carbon Avoided Retrofit Estimator) Tool that enables owners, communities, and design teams to quickly quantify the carbon benefits—and understand the value of reuse. Building reuse represents a significant opportunity to avoid carbon emissions in the immediate future, but until recently, quantifying the carbon "savings" in a retrofit or reuse versus new construction has been challenging and not always accurate. The CARE Tool, however, provides clarity and reliability on which project design and construction option would be most beneficial.

CONCLUSION.

The materials and processes above include just a handful of ways to combat climate change in the construction industry. There is always room for improvement and technological innovation to be discovered. However, if the construction industry can work together to implement the changes outlined in this article, one material at a time, the sector can lower the percentage of global emissions it is responsible for, ultimately helping us meet not only Boston's Climate Action Plan but also our global climate goals.

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DEFINITIONS.

Anodes: The negative or reducing electrode that releases electrons to the external circuit and oxidizes during and electrochemical reaction.

ASTM C1157-compliant: Standard performance specification for hydraulic cement.

Biofuel: Liquid fuels produced from renewable biological sources, including plants and algae.

Calcining: A thermal treatment process that uses very high temperatures to change the physical and chemical properties of various materials.

Cement Clinker: The glassy product of fusing together clay and limestone as the first stage in the manufacture of portland cement.

Construction Specification Institute (CSI): A United States national association of more than 8,000 construction industry professionals who are experts in building construction and the materials used therein.

Cullet: Crushed recycled glass.

Electrolysis: The process of using electricity to split water into hydrogen and oxygen.

Energy Use Intensity (EUI): Energy per square foot per year.

Embodied Carbon: Sum of all carbon emitted during the creation of a building (materials extraction, production, transportation, machinery use, and demolition).

Fossil Fuels: An energy source formed in the Earth's crust from decayed organic material. The common fossil fuels are petroleum, coal, and natural gas.

Greenhouse Gas Emissions (GHG): Those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving Earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface.

Hydraulic Materials: Materials that harden by themselves in the presence of water in a similar way to portland cement.

Lifecycle Assessment Approach: A method of evaluating the emissions of a project/building from its creation through its entire operational life and disposal.

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Low-NOx Burners: Low-NOx (nitrogen oxide) burners are designed to control fuel and air mixing at each burner in order to create larger and more branched flames. Peak flame temperature is thereby reduced, and results in less NOx formation.

Net-Zero: A state in which the greenhouse gases going into the atmosphere are balanced by removal out of the atmosphere.

Nitrogen Oxides (NOx): Compounds of nitrogen and oxygen produced by the burning of fossil fuels.
Operational carbon: The emissions associated with energy used to operate the building or in the operation of infrastructure.

Pozzolanic Materials (or pozzolans): Materials that harden only in the additional presence of dissolved calcium hydroxide (Ca(OH)2), is a by-product of the hardening of portland cement.

Polymerization: The process to create polymers. During polymerization, smaller molecules, called monomers or building blocks, are chemically combined to create larger molecules or a macromolecule. Hundreds of such macromolecules collectively form a polymer.

Refineries: Installations that manufacture finished petroleum products from crude oil, unfinished oils, natural gas liquids, other hydrocarbons, and oxygenates.

Smelting Process: The process by which a metal is obtained, either as the element or as a simple compound, from its ore by heating beyond the melting point, ordinarily in the presence of oxidizing agents, such as air, or reducing agents, such as coke.

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