Testimony for the Congress of the United States House of Representatives
Select Committee on the Climate Crisis hearing on "Solving the Climate Crisis: Reducing Industrial Emissions Through U.S. Innovation"

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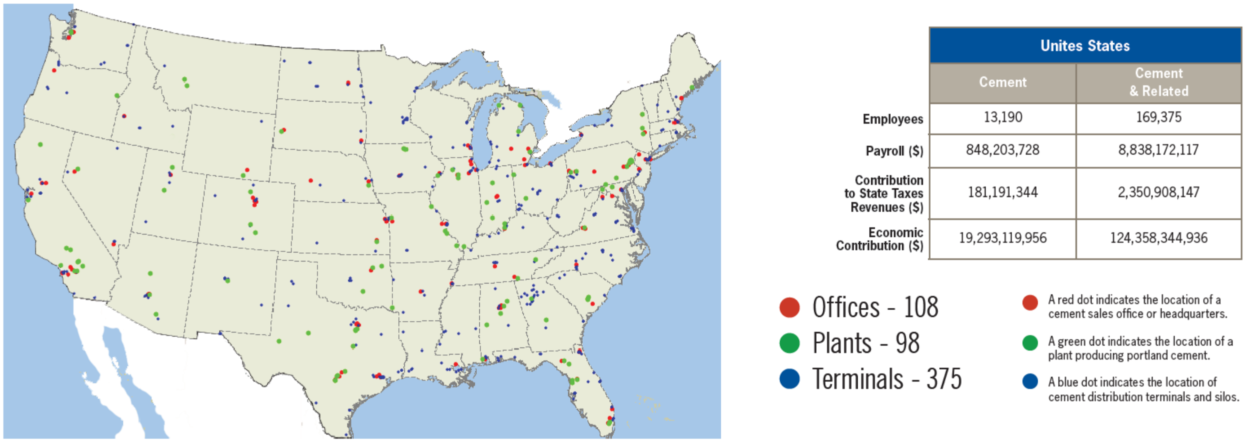
On behalf of the Portland Cement Association

Good afternoon Chairwoman Castor, Ranking Member Graves, and esteemed Members of the House Select Committee on the Climate Crisis. I am pleased to be here on behalf of the Massachusetts Institute of Technology's (MIT) Concrete Sustainability Hub (CSHub) and the Portland Cement Association (PCA) to talk about concrete's role in a sustainable low-carbon economy and how Congress and the cement and concrete industries can work together to address emissions from the industrial manufacturing sector and advance our nation's climate reduction goals. I am Executive Director of the MIT Concrete Sustainability Hub, a dedicated interdisciplinary team of researchers from several departments across MIT working on concrete, buildings, and infrastructure science, engineering, and economics since 2009. The MIT CSHub brings together leaders from academia, industry, and government to develop breakthroughs using a holistic approach that will achieve durable and sustainable homes, buildings, and infrastructure in ever more demanding environments.

We conduct our research with the support of the Ready Mixed Concrete Research and Education Foundation and the Portland Cement Association (PCA). PCA is the premier advocacy, policy, research, education, and market intelligence organization serving America's cement manufacturers. PCA members represent 92 percent of the United States' cement production capacity and have distribution facilities in every state in the continental U.S. Cement and concrete product manufacturing, directly and indirectly, employs approximately 610,000 people in our country, and our collective industries contribute over $125 billion to our economy (see details in Figure 1). Portland cement is the fundamental ingredient in concrete. The Association promotes safety, sustainability, and innovation in all aspects of construction; fosters continuous improvement in cement manufacturing and distribution; and promotes economic growth and sound infrastructure investment. PCA also works hand in hand with our partner associations and companies advancing the interests and sustainability of concrete building materials and products through the North American Concrete Alliance (NACA).



	Unites States	
	Cement	Cement & Related
Employees	13,190	169,375
Payroll ($)	848,203,728	8,838,172,117
Contribution to State Taxes Revenues ($)	181,191,344	2,350,908,147
Economic Contribution ($)	19,293,119,956	124,358,344,936

Figure 1. Statistics on the US cement industry. Source: Portland Cement Association.

In my testimony today, I would like to leave the Committee with five fundamental points about the path to sustainability in the industrial manufacturing sector through the lens of the cement and concrete industries.

First, while cement and concrete are separate and distinct materials, with different manufacturing processes and emissions profiles, they are inherently linked as an end-use building material and should be measured in the context of that end-use sustainability profile. Cement and concrete building materials (CCBMs), like steel, wood, glass, and other building materials, should be considered in terms of their embodied carbon across their full life cycle - from materials sourcing and manufacturing, to productive use, reuse, recycling, or disposal. Anything less than a life cycle approach creates a shell game where carbon emissions just shift from one part of the economy to another, or one nation to another, without solving the global challenge of climate change.

Second, CCBMs are and will continue to be critical and irreplaceable building materials for our national economy, providing sustainable, resilient, safe, and energy-efficient building solutions for the development and maintenance of our nation's infrastructure and built environment. When considered across their full life cycle, CCBMs provide comparable if not superior performance in terms of embodied carbon, resilience, safety, and climate adaptability when compared against other building materials.

Third, CCBM manufacturers are committed to working with policymakers, environmental scientists and engineers, builders, and customers to improve their sustainability and carbon intensity while maintaining the performance characteristics and value that have made CCBMs so important to our economy. CCBM manufacturers already invested billions of dollars to upgrade manufacturing facilities and processes, increase the fuel and energy efficiency of the manufacturing process, and reduce carbon and other air, waste, and water emissions. Where allowed under federal and state regulations, many of our manufacturers have looked for opportunities to incorporate lower-carbon alternative fuels like used tires, biomass, and other non-hazardous secondary materials into the manufacturing process.

Fourth, the CCBM industry faces unique challenges in building upon these initial sustainability efforts. With respect to fuel-related emissions, most of the opportunities for energy efficiency improvements for cement plants have been leveraged, and those remaining are often prohibitively expensive with limited impact. Federal and state regulations discourage the use of many lower-carbon alternative fuel sources, treating non-hazardous secondary materials like non-recyclable paper, plastic, and fibers as dangerous wastes, and cement manufacturers as incinerators. Many cement facilities cannot even transition from coal to lower-carbon natural gas due to the lack of natural gas pipelines and delivery infrastructure.

But fuel emissions are only part of the emissions reduction challenge. Cement manufacturers face a heretofore unsolved basic chemical fact of life - the industrial process for manufacturing cement from limestone results in the chemical release of carbon dioxide. No level of investment in additional energy efficiency technology or alternative fuels will address these process emissions, which constitute the majority of the cement industry's emissions. Only innovation and new technologies for carbon capture, transport, use, and/or storage will address these emissions, and these technologies are still years, if not decades away from plant-scale deployment in the cement industry. Bringing these technologies to market will require billions of dollars of additional investment in research, development, pilot scale testing, and infrastructure.

Fifth, any national carbon reduction strategy will need to recognize the economic realities of today's global market economy. Cement is a fungible global commodity, and domestic cement manufacturers are price takers rather than price makers, with limited ability to pass additional costs on to customers who can easily switch to lower-cost, often higher carbon imported cement. Domestic cement manufacturers cannot compete in a global market against foreign importers and countries who are not doing their fair share to reduce emissions. If the U.S. is to maintain a healthy domestic cement industry and the jobs and contributions to the domestic economy it provides, policymakers will need to address the risk of trade leakage head on. Policymakers in the EU, Canada, and California have recognized the need to protect energy-intensive trade exposed industries from trade leakage, and Congress needs to provide for a level competitive playing field for cement, concrete, and other industrial manufacturers.

With these facts in mind, the concrete and cement industries will need help from Congress to do their part. Congress can start by reducing the barriers manufacturers face to taking early action:

- reform and streamline federal and state permitting regulations under the Clean Air Act's New Source Review program to update facilities with more energy efficient manufacturing equipment;
- reform federal air and waste laws to treat non-hazardous secondary materials like non-recyclable paper, plastic, and fibers as fuel sources, not just waste products destined for landfills;
- expedite the permitting process for energy infrastructure projects, including pipelines to transport natural gas and other lower-carbon fuels to cement plants; and
- perhaps most important, provide dedicated funding for research, development, and deployment of commercial scale carbon capture, transport, use, and storage technologies needed to manage industrial process emissions and other hard-to-abate emissions from industrial manufacturing.

The remainder of this document provides background on CCBMs and opportunities, barriers, and solutions for enabling low-carbon pathways in the sector.

1 Background on concrete and cement

1.1 Concrete is critical for sustainable development

Concrete plays a critical role in achieving societal goals for sustainable development. It is required for nearly all aspects of our built environment including buildings, pavements, bridges, dams, and other forms of infrastructure. Infrastructure is required to achieve all 17 of the United Nation's sustainable development goals [1]. As growth in urban and suburban areas of the US significantly outpaces growth in rural areas (13%, 16%, and 3%, respectively since 2000)[2], demand for buildings and infrastructure will increase to meet the needs of migration and immigration. Calls for increased housing to address affordable housing shortages and more resilient buildings and infrastructure to mitigate the impacts of natural disasters will also lead to increased construction using concrete. While this development is inevitable, it is possible to make it sustainable.

1.2 Concrete is the most used building material in the world

Concrete's critical role in our built environment is manifest in how much it is used. Figure 2 shows global production (per capita) of common building materials [3]. Production volumes for cement, the binding agent in concrete, are nearly three times as much as steel, and concrete production is approximately seven times as much as cement (as shown in the chart). This significant consumption means it is also important to address when setting industrial emission targets.

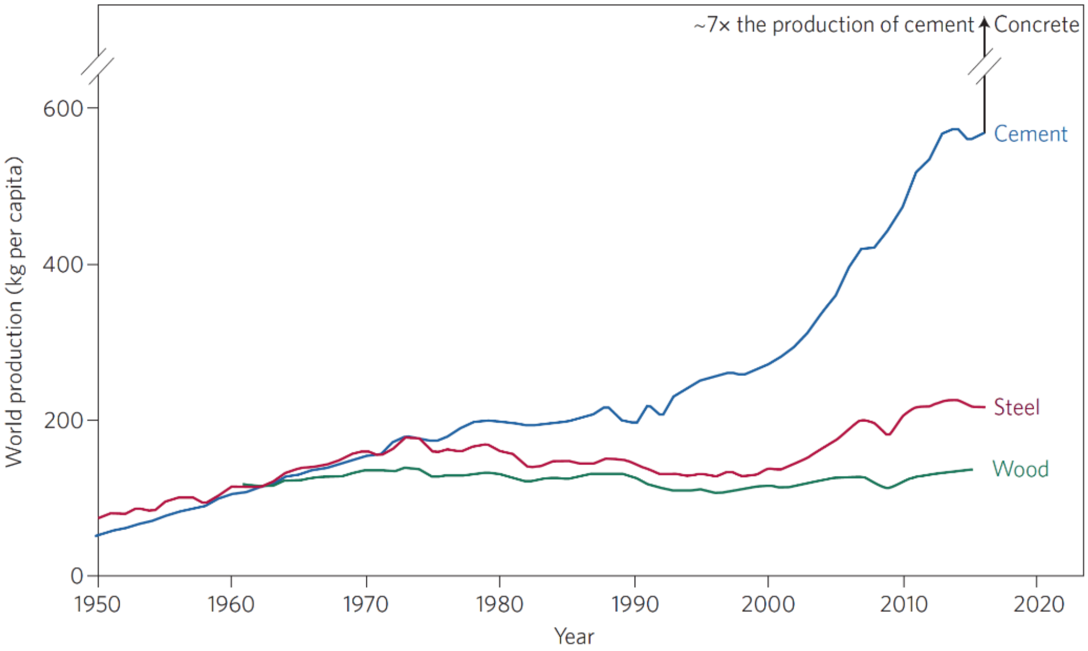


Figure 2. World production (per capita) of cement (the binder in concrete), steel, and wood [3]. Concrete production is about seven times higher than cement, so it is not shown on the chart.

1.3 Concrete is a mixture that usually includes cement as a binder

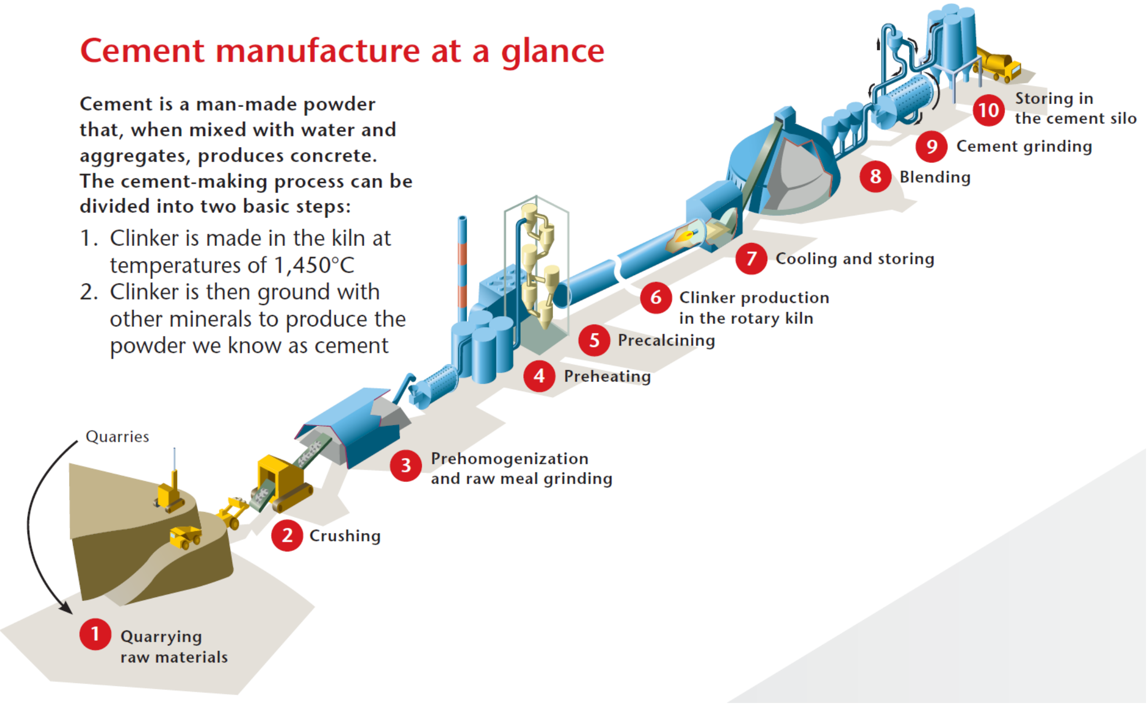
Concrete is made using five basic ingredients: coarse aggregates (gravel), fine aggregates (sand), binder (including cement), water, and admixtures (chemicals that can change concrete properties). These can be combined in infinite ways to meet performance requirements including strength, stiffness, density, constructability, and durability. When the binder is mixed with water it hardens to create a paste that keeps the aggregates in place.

There are numerous types of binders that can be used in concrete, as shown in Figure 3. Some are based on materials that can be mined and transformed into binders, whereas others are derived from waste materials. The most common binder used is portland cement (the name derives from the type of mineral first mined from the Isle of Portland in the UK when the process was developed in the 1800s). Portland cement is primarily made using limestone, which is abundantly available all over the world, can be produced within tight and reliable specifications, and has been used extensively for over 150 years, thereby making it the preferred binder for producing concrete. Alternative binders to portland cement are referred to as supplementary cementitious materials (SCMs). These include naturally occurring materials, such as natural pozzolans or calcined clays, and waste materials, such as fly ash from coal fired power plants, granulated slag from steel production, and more recently ground post-consumer glass. Availability and composition of SCMs can vary significantly, and they can have a different impact on the performance of concrete than portland cement.

Figure 3. Examples of binders that can be used to make concrete. Binders in the top row are created from materials mined in the earth, whereas those in the bottom row are derived from waste.

1.4 Cement production has energy and process-related emissions

The cement production process is shown in Figure 4 [4]. Limestone and other raw materials are mined and then go through a series of treatment steps before entering the kiln (step 6), which requires significant amounts of energy to maintain at 1,450 °C (these are referred to as energy or thermal emissions). The limestone is transformed into clinker in the kiln in a process called calcination that emits carbon dioxide (these are referred to as process emissions). The clinker may be blended with other cementitious binders and then ground to create the final cement product.



Cement manufacture at a glance

Cement is a man-made powder that, when mixed with water and aggregates, produces concrete. The cement-making process can be divided into two basic steps:

1. Clinker is made in the kiln at temperatures of 1,450°C
2. Clinker is then ground with other minerals to produce the powder we know as cement

Figure 4. Cement production process [4].

Production of conventional portland cement in the US emits about 1 kg of carbon dioxide for every kg of cement produced [5]. As shown in Figure 5, approximately 50% of these emissions are from the calcination process, and 40% are from thermal or energy generation processes (maintaining the kiln at 1,450 °C).

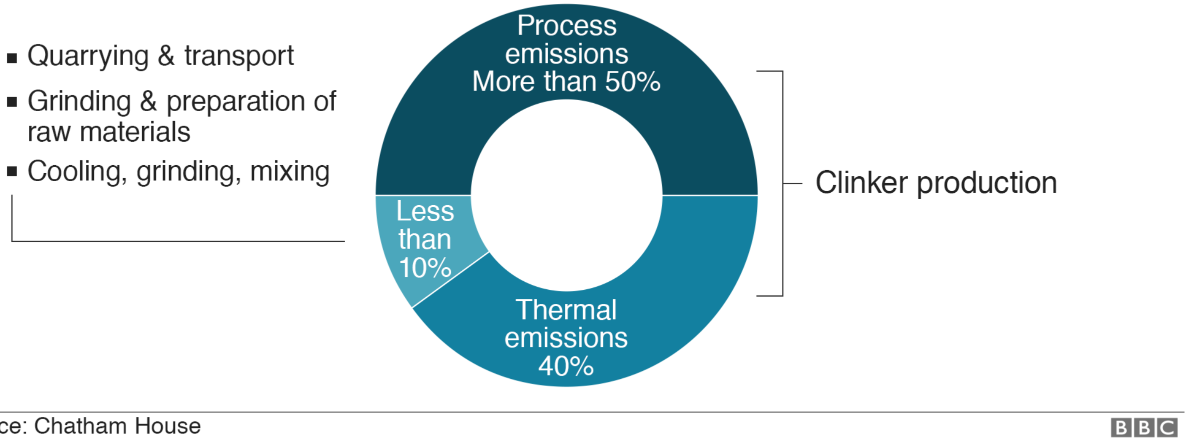


Figure 5. Sources of carbon dioxide emissions in conventional cement production [6].

1.5 Cement drives concrete's environmental impact

Figure 6 shows that by mass, concrete is primarily made up of aggregates. However, the greenhouse gas emissions (which are predominantly carbon dioxide) are from the cement. The aggregates have very low environmental footprint because they are simply mined from quarries without further transformation.

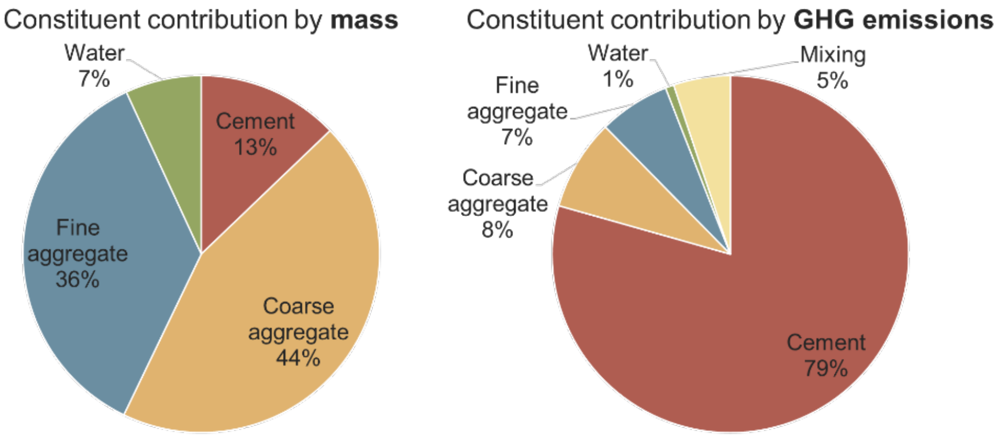


Figure 6. Concrete constituent contributions by mass and greenhouse gas (GHG) emissions for a conventional concrete (3000 psi) without SCMs. Source: CSHub calculations.

1.6 Concrete and cement are low-impact materials

On a per unit weight basis, concrete and cement have low embodied carbon dioxide and energy footprints (i.e., emissions and energy associated with production). Figure 7 compares these measures with those of other industrial materials [7]. Concrete's environmental footprint is so much lower than other materials because it is primarily made from aggregates, which, as noted above, have a low environmental footprint. While cement has significant process and energy emissions, they are smaller than those of other materials such as metals.

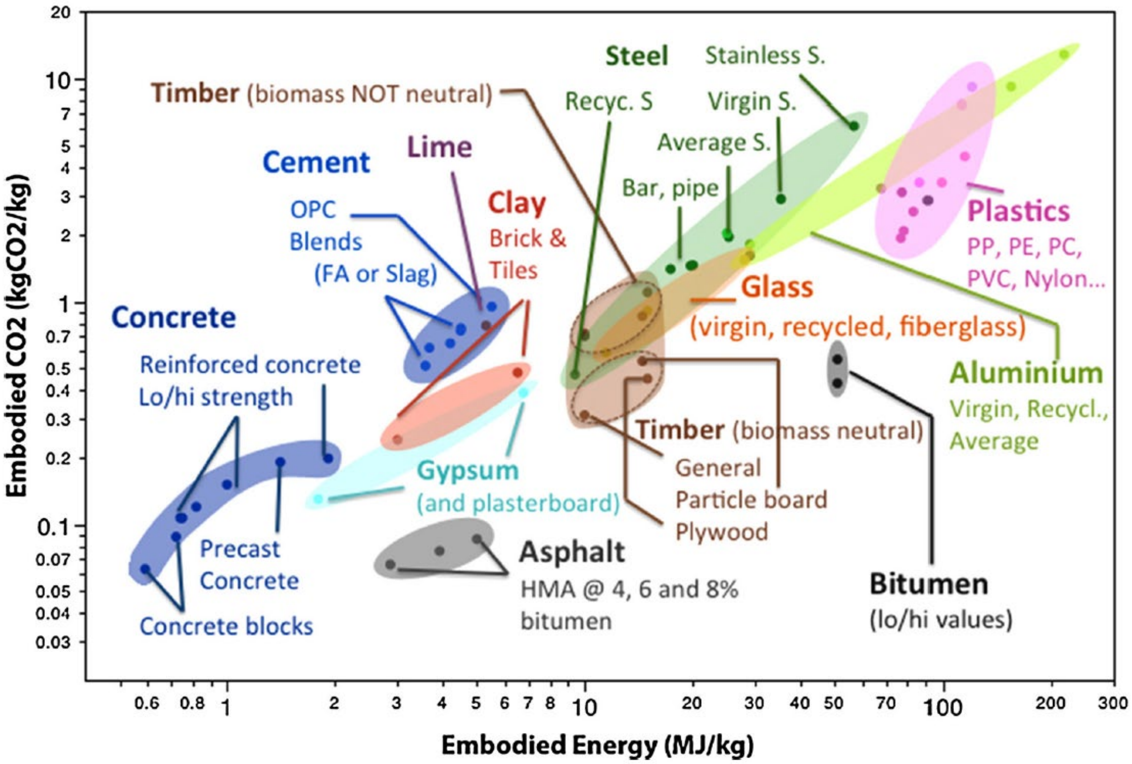


Figure 7. Embodied carbon dioxide emissions and energy from the production of various industrial materials [7]. Note that axes have a log scale.

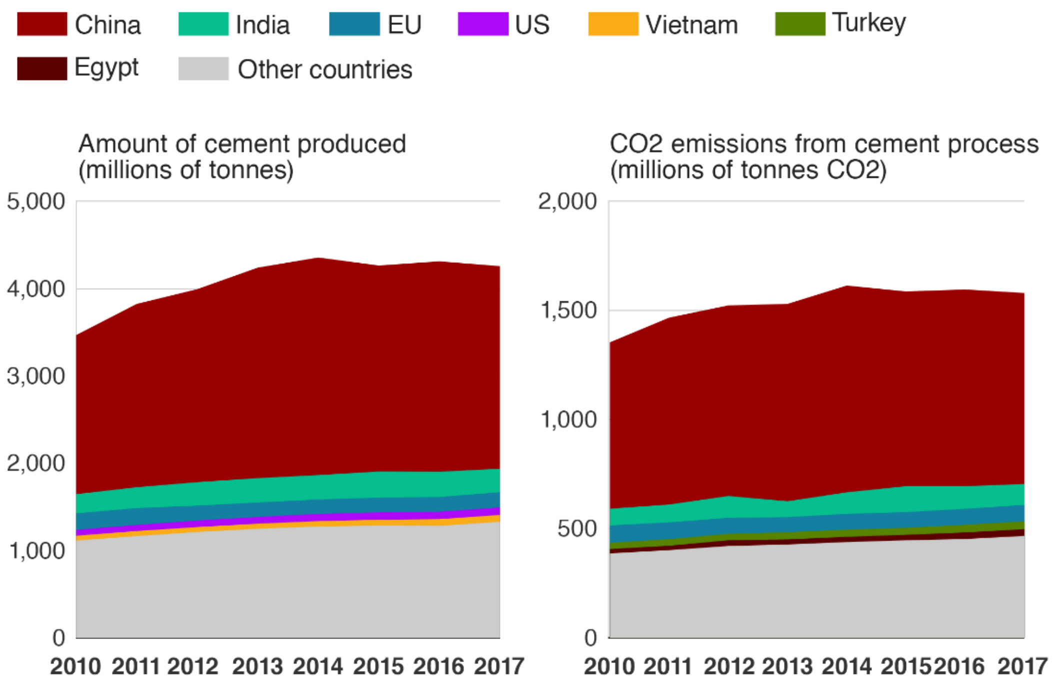
1.7 Cement emissions constitute approximately 1% of US greenhouse gas emissions

Estimating greenhouse gas (GHG) emissions from cement production is difficult because it requires tracking both process and energy-derived emissions, and energy-derived emissions are rarely tracked for a specific industrial sector. For example, the most reputable quantitative estimate of global cement emissions as a fraction of all emissions has been done by the PBL Netherlands Environmental Agency [8]. They stated that process emissions contributed "to about 4% of the total global emissions in 2015" (pg. 64). To estimate total cement emissions, they state: "Fuel combustion emissions of CO2 related to cement production are of approximately the same level, so, in total, cement production accounts for roughly 8% of global CO2 emissions." (pg. 64-5) Their study details how they estimated cement emissions but does not describe how total GHG emissions are estimated. Thus, the 8% figure is an approximation.

Estimating US cement GHG emissions can be done using the US EPA's GHG inventory [9]. Process-derived emissions from cement production were 40.3 MMT CO2 Eq. (million metric tons carbon dioxide equivalent) in 2017, out of 6,456.7 MMT CO2 Eq., or approximately 0.6%. The inventory does not quantify energy-related emissions from cement production, so we are forced to use a similar approximation to the PBL study that energy and process-derived emissions are the same. This would make total cement industry emissions approximately 1.2% of total US GHG emissions in 2017.

1.8 The US produces a small fraction of the world's cement

China produces more than half of the world's cement, as shown in Figure 8 [6,8]. The US produced approximately 2% of global cement in 2015, compared to China's 58%, India's 7%, and the EU's 4% [8]. Thus, while it is important to strive to lower emissions from US cement production, it is also important to consider that the US has lower production than China, India, and the EU.



Source: PBL Netherlands Environmental Assessment Agency

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Figure 8. Global cement production volumes and process-related carbon dioxide emissions [6,8].

1.9 Different standards and practices for cement production worldwide present opportunities for leakage

It is basic economics that in a global market for a commodity product like cement, managing the costs of production is critical to ensuring the continued competitiveness of domestically-manufactured products. Facilities that can produce, ship, and deliver cement to customers at a competitive cost will flourish. Those that cannot maintain cost-competitiveness will fail.

These costs are determined in large part by the design and operating practices of the manufacturing facilities where cement is produced. While every cement manufacturing plant is different, the basic steps in the manufacturing process are the same. Costs of production are not, however, particularly with respect to compliance costs imposed by government entities. Government policies that impose additional costs on manufacturers have a direct impact on the global competitiveness of manufacturers and the risk of trade and carbon leakage.

This is particularly the case for the cement industry for several key reasons:

- The energy intensive nature of the manufacturing process, combined with the significant process emissions resulting from the conversion of limestone to cement makes the cement industry particularly vulnerable to policies that increase the cost to manage carbon emissions
- U.S. cement manufacturers have limited ability to cost-effectively reduce GHG emissions and, therefore, to minimize compliance costs through investments in direct abatement.
- U.S. cement manufacturers have limited ability to pass through compliance costs to customers without a significant loss in market share.

Due to this unique combination of features, carbon pricing is likely to result in significant leakage in the U.S. cement industry unless countervailing measures are applied.

To illustrate this challenge, PCA estimates that given a carbon price of $40 per metric ton, the U.S. cement industry would experience an operating cost increase of more than $2.6 billion per year, representing roughly 50% of the U.S. cement industry's value added ($5.0 billion) and 30% of its total shipments ($8.7 billion) in 2016. Such increases could easily increase the cost of producing cement by more than $30 per ton, making domestic cement uncompetitive in many markets served by imports.

As Congress develops a comprehensive federal climate policy for U.S. manufacturers, this lesson in "economics 101" should be front and center as a consideration. Any comprehensive climate policy that imposes increased operating, compliance, or research and development costs on cement manufacture must include measures to address the risk of leakage from imported products.

2 Opportunities to lower carbon dioxide emissions of cement production

2.1 There are four primary levers for reducing cement production carbon dioxide emissions

The World Business Council on Sustainable Development (WBCSD) and the International Energy Agency's (IEA) Cement Sustainability Initiative (CSI) produced a technology roadmap for the cement sector in 2018 [10]. They identified four *carbon reduction levers*:

- **Improving energy efficiency** in the cement plant.
- **Switching to alternative fuels** that are less carbon intensive than conventional fuels, such as biomass and waste materials.
- **Reducing the clinker to cement ratio** by increasing the use of blended materials (including some of the aforementioned SCMs, among others) in the production of blended cements.
- **Use emerging technologies to capture carbon** and use, store, or sequester it, including in the production of new building materials.

The first three levers are already being used by the cement industry in the US and beyond.

2.2 The US cement industry has made significant efforts to improve energy efficiency and use of alternative fuels

U.S. cement manufacturers continue to invest billions of dollars in technologies to increase the energy efficiency of their plants and reduce carbon emissions associated with the cement manufacturing process. Duke University evaluated the improvement in the cement industry's energy performance over a 10-year period and found that: energy intensity improved 13 percent, the energy performance of the industry's least efficient plants changed most dramatically, total source energy savings were 60.5 trillion Btu annually, and environmental savings were 1.5 million metric tons of energy-related carbon emissions [11]. As a result, today's plants are far more fuel efficient than a generation ago, in many cases approaching the maximum levels of fuel efficiency technically feasible.

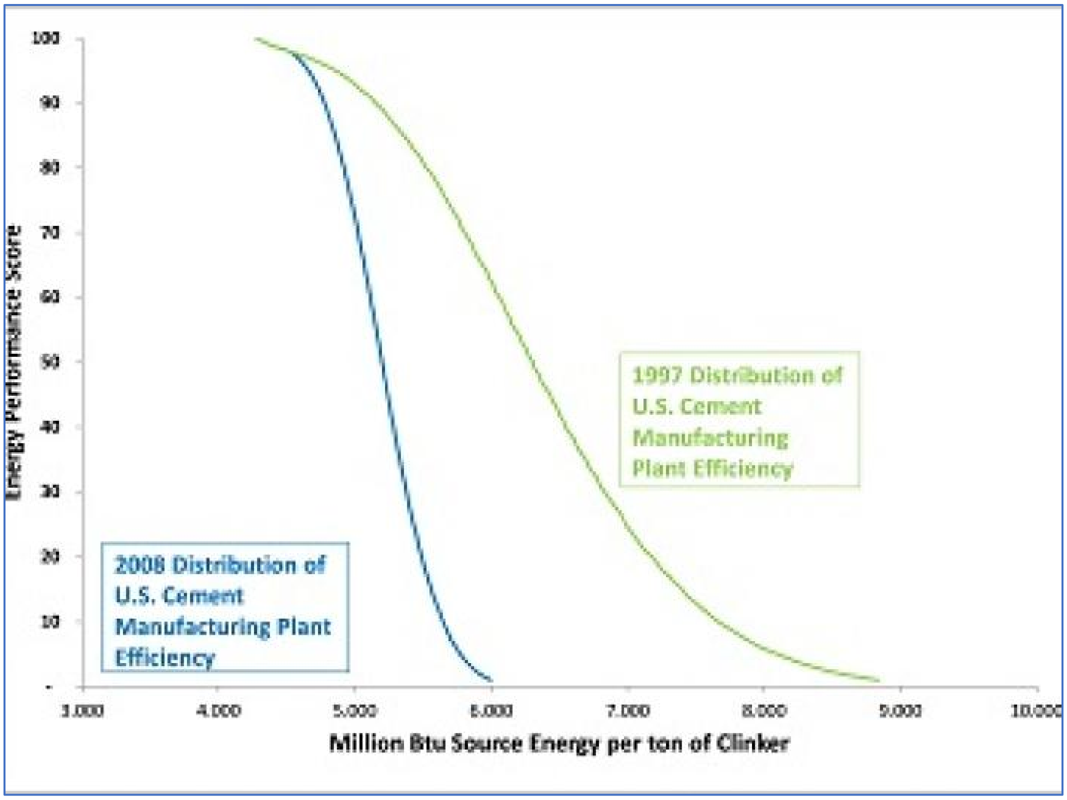


Figure 9. Comparison of 1997 (green) and 2008 (blue) distribution of US cement manufacturing plant efficiency as measured by the ENERGY STAR energy performance indicator [11].

Another key opportunity to reduce fuel emissions is to increase the use of lower carbon alternative fuels. Secondary materials like post-industrial, post-commercial, post-consumer paper, plastic, and other materials have tremendous energy value, providing a cost-effective and sustainable alternative to traditional fossil fuels. The cement industry has a long history of safe and efficient use of alternative fuels, ranging from used tires and biomass to a wide variety of secondary and waste materials. The high operating temperature and long residence times in the kiln make cement kilns extremely efficient at combusting any fuel source with high heating value while maintaining emissions at or below the levels from traditional fossil fuels. For the cement industry, secondary materials that would otherwise have little market value are valuable commodities, offering a cost-effective and environmentally sustainable alternative to traditional fossil fuels. While these efforts are important, there is much more to be done. Today, alternative fuels make up only about 15 percent of the fuel used by domestic cement manufacturers, compared to more than 36 percent in the European Union, including as high as 60 percent in Germany. Legal and regulatory barriers to alternative fuels use prevent the U.S. from having similar alternative fuels utilization rates to Europe.

The CCBM industry faces unique challenges in building upon these initial sustainability efforts. With respect to fuel-related emissions, most of the low-hanging fruit opportunities for energy efficiency improvements for cement plants have been leveraged, and those remaining are often prohibitively expensive with limited impact. Further improvements will also require cooperation by federal and state regulators that determine, through their regulations and permitting programs, whether and when facilities can adopt lower-carbon technologies, facility improvements, operations, and fuels.

2.3 Blended cements are available today

Portland limestone cement (PLC) is an example of a blended cement that is readily available from cement manufacturers. It is made by blending limestone with clinker (Step 8 of Figure 4). The limestone replaces clinker in the cement and therefore, has lower carbon dioxide emissions per unit weight of cement produced.

PLC has been used in Europe for over fifty years [12]. Current European standards allow for up to 35% replacement of cement with limestone, whereas in the US and Canada the limit is 15%. Studies have shown that PLC has nearly the same performance as ordinary portland cement (OPC) [12], but with a 10% reduction in carbon dioxide emissions from production (assuming 15% replacement) [13]. Costs of PLC are similar to OPC, as is its performance. Given, the lower environmental footprint, it would appear to be a strong candidate for increased use. However, PLC is approximately 1% of all cement produced in the US (all types of blended cements make up less than 3% of all cement produced in the US) [14]. This is primarily due to an unwillingness of concrete specifiers (such as engineers) to choose PLC over OPC, which has a longer history of use.

2.4 The technology roadmap for the global cement industry identifies emissions reductions required to meet global targets

CSI's 2018 technology roadmap [10] evaluated the required emissions reductions in the global cement industry required to meet a 2 °C climate scenario (2DS - maximum of 2 °C global temperature increase), as well as a beyond 2 °C scenario (B2DS - lower than 2 °C global temperature increase). They used a reference technology scenario (RTS) that assumed relatively flat direct carbon dioxide emissions until the year 2050 despite increases in cement production. This reference scenario assumes continued progress to reduce emissions associated with cement production at current rates.

As shown in Figure 10, the 2DS represents a 24% reduction in direct carbon dioxide emissions from the RTS by 2050. The B2DS represents an additional 45% reduction in direct carbon dioxide emissions over the 2DS.

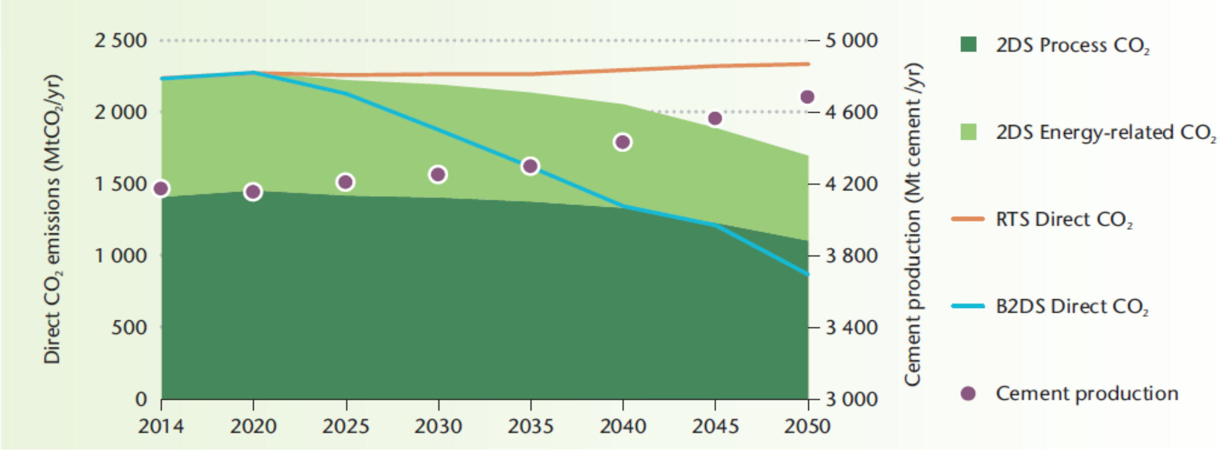
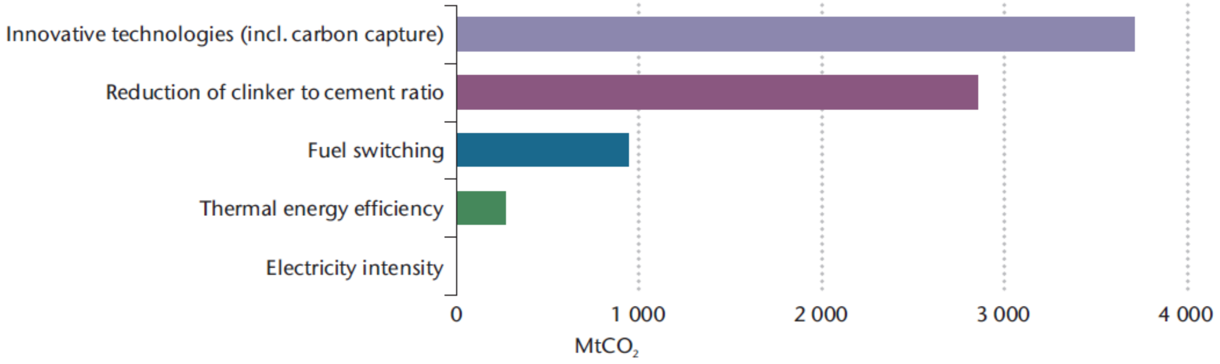


Figure 10. Global direct carbon dioxide emissions from cement production by scenario [10]. RTS = reference technology scenario. 2DS = 2 ℃ scenario. B2DS = beyond 2 ℃ scenario.

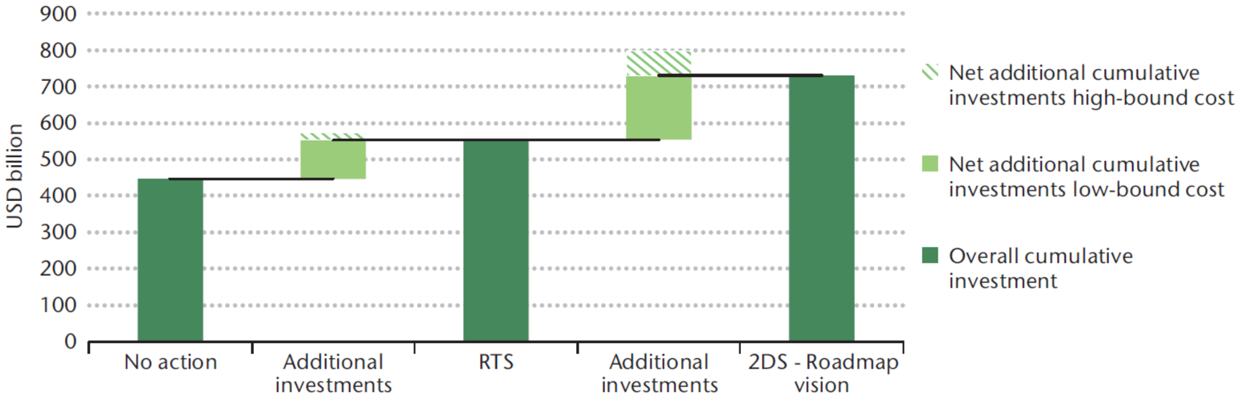
Lowering emissions requires a combination of the four levers mentioned in Section 2.1, as illustrated in Figure 11. Carbon capture technologies contribute 48% of cumulative emissions reductions, followed by use of blended cements (reduction of clinker to cement ratio) at 37%. There are fewer opportunities to improve thermal energy efficiency in cement plants or switch to alternative fuels.



Note: Cumulative CO_2 emissions reductions refer to the period from 2020 to 2050 and are based on the low-variability case of the scenarios.

Figure 11. Global cumulative carbon dioxide emissions reductions by applying the 2 ℃ scenario compared to the reference technology scenario [10].

The CSI roadmap includes estimates of global investments required to meet both the RTS and 2DS (Figure 12). $107 billion to $127 billion are estimated cumulative investments to meet the RTS globally by 2050 (24-28% increase over no action), and an additional $176 billion to $244 billion required to meet the 2DS (32-43% increase over RTS). No investment estimates are available for the US.



Note: Net cumulative additional investment numbers are assessed considering low- and high-bound sensitivity ranges for specific investment costs. Overall cumulative investments displayed in the above graph refer to the low-bound cost range.

Figure 12. Global cumulative investments required to meet RTS and 2DS by 2050 [10].

3 Opportunities to lower carbon dioxide emissions of concrete

The majority of concrete's environmental footprint derives from the footprint of the materials in the concrete, rather than the production of the concrete, which primarily involves mixing (materials represented 95% of the GHG emissions in the case shown in Figure 6). Thus, use of low-carbon (i.e., low carbon dioxide footprint) constituent materials is the primary mechanism for lowering carbon dioxide emissions of concrete. There are three main categories of low-carbon constituent materials.

3.1 Blended cements

Blended cements, such as portland limestone cement, were described in Section 2.3 and are currently produced by cement manufacturers. They make use of many of the same SCMs used in concrete such as fly ash and blast furnace slags (described in Section 1.3). Production of blended cements varies significantly worldwide depending on demand, which is primarily influenced by historical practices for producing concrete, although availability of SCMs is a factor as well (e.g., China and India have significant availability of fly ash from coal fired power plants). There is currently limited demand for blended cements in the US – they make up less than 3% of all cement produced in the US [14].

3.2 Supplementary cementitious materials

SCMs are used more extensively in the US in concrete than in cement. Conventional SCMs include fly ash and blast furnace slag, although other alternatives exist that are used more commonly in other parts of the world including silica fume, natural pozzolans, calcined clays, vegetable ash. More recently, binders made from ground post-consumer glass have become commercially available at small scales. Availability, chemical composition, performance, and cost often determine whether SCMs are used in concrete.

3.3 Cement, aggregate, and concrete made from captured carbon dioxide

The process of *mineralization* involves exposing minerals to carbon dioxide to create a carbonate mineral. It is a natural process that took place over millions of years to create the limestone used in the production of cement. More recently it has been proposed as a form of carbon capture and utilization (CCU) to create materials that can be used in concrete production. This includes the production of binders, aggregates, and concrete (i.e., carbon dioxide is used in the mixing process) using carbon captured from industrial sources, potentially including cement plants. Several companies have been created over the past decade in an attempt to commercialize mineralization for building products [15]. There is significant variation in the degree to which they make use of carbon dioxide. Most of the companies are in a start-up phase with demonstration plants or small production volumes, but several of them have products currently being used in construction projects. In some cases, the technologies can only be used to make concrete blocks in production facilities (as opposed to cast-in-place concrete on job sites) because of the requirements to control the mixing of carbon dioxide with minerals. As such, this limits their application to cases where concrete blocks can be used (such as buildings).

3.4 Considerations for the use of low-carbon constituent materials

It is important to note that substitution of these low-carbon constituent materials for conventional materials in a concrete mixture will not necessarily result in the same performance (strength, stiffness, constructability, durability) of the concrete mixture. Designing a concrete mixture to meet performance targets can be a complicated process that involves trade-offs of many factors that vary depending on the constituents being used. Furthermore, specifications for concrete often limit the use of blended cements or SCMs [16]. Thus, requirements for substitutions of conventional materials for low-carbon alternatives are not straightforward and may not be feasible for many situations.

4 Importance of a life cycle perspective in evaluating environmental impacts of buildings and infrastructure using concrete

The true environmental impact of concrete can only truly be evaluated using a life cycle perspective that encompasses its application in buildings and infrastructure. For example, a life cycle assessment of several building types conducted by our team at MIT has shown that embodied environmental impacts of buildings (associated with material production and building construction) are at most 10% of the total life cycle greenhouse gas emissions (Figure 13); energy use represents the vast majority of environmental impacts [17].

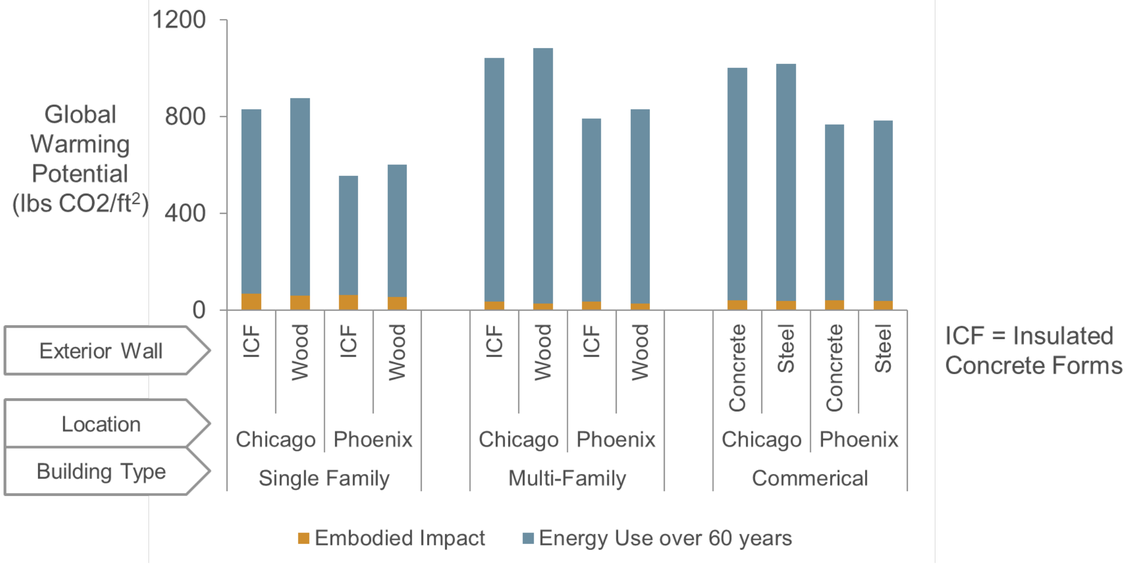


Figure 13. Life cycle global warming potential (greenhouse gas emissions) of three building types in two climates [17]. Embodied impacts include material production and building construction.

Similarly, the life cycle impacts of pavements are dominated by the use phase, which includes excess fuel consumption of vehicles due to roughness or deflection in the pavements (which leads to additional energy dissipation in the vehicle) [18]. In the case of the urban interstate pavements in Figure 14, materials and construction make up only 26% of the life cycle GHG emissions.

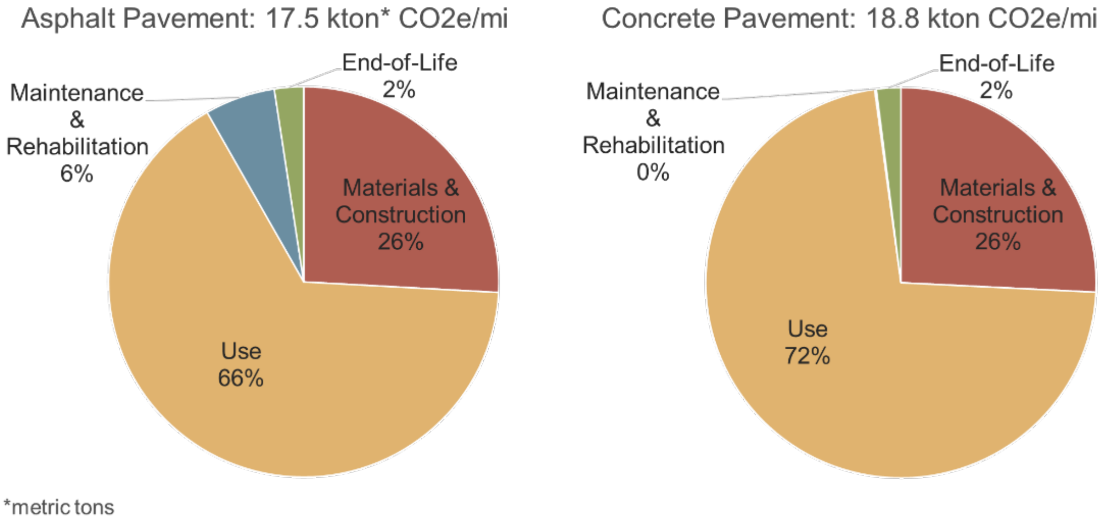


Figure 14. Life cycle greenhouse gas emissions for urban interstate pavements in Missouri.[18] The use phase includes excess fuel consumption from vehicles due to roughness or deflection in the pavements.

Finally, concrete naturally absorbs carbon dioxide over its lifetime as part of a chemical process called carbonation, which is the reverse of the calcination process that leads to process emissions in the production of cement. A study estimated that 4.5 gigatons of carbon dioxide has been sequestered in carbonating cement materials worldwide from 1930 to 2013, offsetting 43% of process CO2 emissions (Figure 15) [19]. Hence, there is significant potential to use cement and concrete as a carbon sink in the future.

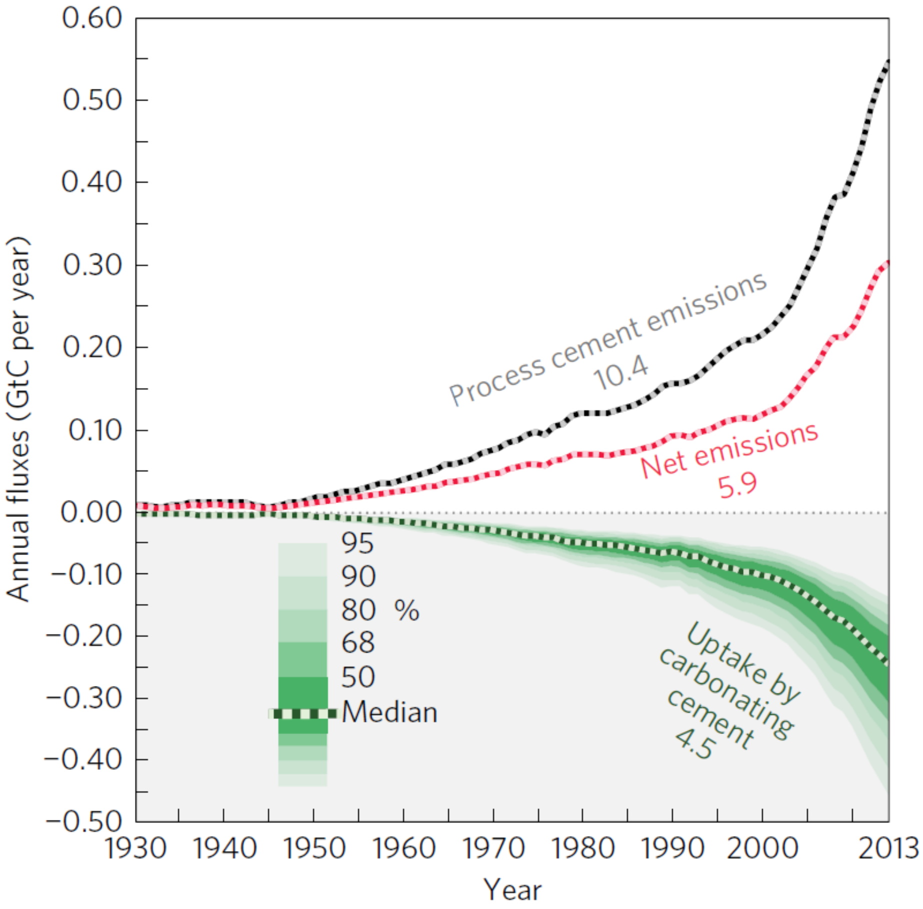


Figure 15. Process carbon dioxide emissions from production of cement (black line), uptake of carbon dioxide by carbonating cement (green line), and net of process emissions and carbon uptake (red line) [19].

Thus, while it is important to seek opportunities to lower embodied emissions in the built environment, it is also important to consider the impact that materials and design choices have on life cycle impacts, particularly if they can enable emissions reductions (e.g., through reduced building energy consumption or lower excess fuel consumption) and carbon uptake.

5 Barriers to adoption of low-carbon solutions

5.1 Regulations prohibit increased use of alternative fuels in cement plants

Federal policies often discourage rather than embrace the use of secondary materials as fuel in the industrial sector. The industry's use of alternative fuels falls under two environmental laws administered by the U.S. Environmental Protection Agency (EPA), the Clean Air Act (CAA), and the Resource Conservation and Recovery Act (RCRA). The CAA addresses ambient air quality and emissions from manufacturers, power plants, and motor vehicles. RCRA governs the management of solid waste and the generation, transport, and disposal of hazardous materials.

In recent years, narrow judicial and regulatory interpretations of RCRA, the CAA, and EPA regulations have discouraged the use of non-hazardous secondary materials and wastes as fuels, treating these materials as dangerous wastes, and facilities using them as incinerators. These policies are contrary to basic science and public policy, discouraging the productive conservation and recovery of resources and increasing the use of emissions-intensive fossil fuels.

EPA recognized this fact in 2011 and issued a regulation known as the Non-Hazardous Secondary Materials (NHSM) Rule, intended to allow for secondary materials to be used for energy recovery if they met specific legitimacy criteria. In theory, the rule provided a way to distinguish between true waste materials with little to no value as fuel and those material streams that, traditionally discarded as a waste, could now be put to far more productive use as alternative fuels. In practice, the rule has become yet another roadblock to sound energy and materials recovery policy.

Manufacturers face a costly and time-intensive process to prove, on a case-by-case basis, why commonly landfilled materials such as unrecycled plastics, paper, fabrics/fibers, and other secondary materials should qualify for treatment as fuels, despite their demonstrably lower greenhouse gas and other air emissions and comparable heat value. The result is predictable. While alternative fuels make up an average of 36 percent of the fuel used to manufacture cement in the European Union (60 percent in Germany), it constitutes only 15 percent of the domestic cement industry's fuel portfolio.

5.2 New Source Review and other permitting processes discourage energy efficiency and carbon capture improvements and critical infrastructure

One of the common-sense strategies for any industry to reduce GHG emissions is to maintain and improve the operational efficiency of its facilities over time. Unfortunately, the current Clean Air Act New Source Review program, as interpreted by the courts and some prior administrations, actually penalizes companies for increasing the efficiency of its facilities. This forces companies to reject upgrades and investments. To address these process emissions and further reduce industry GHG emissions, manufacturers will need to install carbon reduction and carbon capture, use, and storage (CCUS) technologies, other technological advances developed in the future, and implement process improvements. Under the NSR program, such investments would face the same permitting and regulatory barriers that new facilities would face, particularly where the addition of new emissions control technology for one pollutant has a negative impact on the emissions profile for another. Congress should revise the NSR process to encourage, rather than discourage, investments in energy efficiency and carbon capture, use and storage technologies.

Other energy improvements require investment in infrastructure, like pipelines and distribution networks. Cement kilns operate 24 hours per day and almost 365 days per year, and have historically used fossil fuels, such as coal and petroleum coke, due to the need for plentiful fuel supplies that can easily be stored and are in plentiful supply. In recent years, the cement industry has used more natural gas to reduce GHG and other air emissions. According to the PCA's Labor and Energy Survey, from 2011 to 2016 the industry increased natural gas use from 3.9% to 15.5% of its fuel use, displacing higher carbon fuels like coal and petroleum coke and, as a result, lowering GHG emissions. Natural gas use at cement plants could be further increased if pipelines and related infrastructure were in place to supply these plants. Unfortunately, the permitting process under NEPA, the Clean Water Act, and state standards is preventing many industries from taking advantage of natural gas by preventing or delaying the necessary supply infrastructure. Congress should reform the infrastructure permitting process for badly needed energy infrastructure.

5.3 There is limited room for additional energy efficiency improvements in cement plants

The heat energy required to heat raw materials to the temperatures needed to trigger calcination makes cement manufacturing an inherently energy-intensive process. As noted in Section 2.2, the cement industry has invested significantly to increase the energy efficiency of its kilns, grinding equipment, and other operations. Moving forward, the industry will face increasing challenges in squeezing additional efficiency improvements out of its operations.

Further increases in efficiency improvements in cement manufacturing are not on the horizon without a revolutionary advancement in a completely new technology. The industry's efficiency is already close to the theoretical maximum. Martin Schneider, a cement processing expert has noted, "Taking into account all process-integrated measures, thermal process efficiency [in cement manufacturing] reaches values above 80% of the theoretical maximum." [20] That level of thermal process efficiency is unparalleled.

Any marginal increases in efficiency that could be gained, including technologies such as waste heat recovery, require additional energy. The basic laws of thermodynamics dictate that it takes energy to save energy; there is no free lunch. That additional energy increases the carbon footprint of a cement plant, making each additional joule of energy efficiency that much more difficult to gain. This explains why the CSI technology roadmap shows thermal energy efficiency gains as having the smallest opportunity for carbon dioxide emissions reductions (Figure 11 in Section 2.4).

5.4 Increased cost of low-carbon cement and concrete products

Publicly available data on prices of low-carbon cement and concrete products relative to conventional products is not available. However, anecdotal evidence suggests that there are usually cost premiums for the low-carbon products. Although one would expect there to be increased demand for these products in a place like Europe where a carbon cap and trade system exists, that has so far not been the case. Furthermore, there is at least one case of an American start-up company that created a binder using a mineralization process but never achieved commercial success and had to pivot to other applications [15]. The highly cost-conscious nature of the construction industry will likely make this a key barrier for some time.

5.5 Risk aversion of engineers specifying concrete

Given the high stakes involved in structures that use concrete, it is understandable that civil engineers specifying concrete mixtures would be risk averse. Engineers typically rely on prescriptive-based specifications that detail the types and limits of materials that can be used in concrete mixtures. Following such specifications helps to mitigate risk for them and the concrete producers because they can point to the specifications in case there are unforeseen problems. They also prefer to rely on the use of constituent materials that have been used in the past because of their perceived familiarity with performance. The downside of this practice is that it often limits the use of low-carbon materials, either explicitly or implicitly [16]. As such, prescriptive specifications inhibit opportunities for innovative concrete mixtures that make use of low-carbon materials, included blended cements and SCMs that are available for use today. In addition, there is a significant burden of proof to demonstrate that new low-carbon materials will meet long-term structural and durability requirements.

6 Solutions to enable a low-carbon cement and concrete industry

6.1 Promote adoption of energy efficiency technologies for new and retrofit cement plants

As noted in Section 5.3, it is possible to make energy efficiency improvements in cement plants, but they will require more than a simple federal mandate. Industry will have to partner with government to identify promising new energy efficiency technologies and make the investments in research, development, and deployment to bring them to market.

6.2 Encourage and facilitate increased use of alternative fuels in cement plants

There is a step the Committee could take today to reduce greenhouse gas emissions: provide manufacturers with enhanced flexibility to expand their use of alternative fuels. Congress can and should address this issue as a simple and early first step by amending the definitions of "Recovered Materials" and "Recovered Resources" within RCRA to distinguish them from solid waste. A core mandate of the

Resource Conservation and Recovery Act is to conserve and recover national resources. To do so, it must start by clearly recognizing that materials with energy value are truly "resources," not waste.

In the interim, the Committee should urge EPA to revise the NHSM Rule, implementing guidance, and interpretations to limit the processing requirements for "discarded" materials to those activities necessary to create useful fuel. EPA should not impose processing requirements that add costs to fuel use without materially improving the fuel value or the emissions associated with its use. Finally, Congress should urge EPA to act on PCA's pending petition to provide a categorical exemption for the use of nonrecycled paper, plastics, fiber, and fabrics as fuel, based on the extensive data already provided to EPA.

6.3 Encourage and facilitate use of blended cements

As noted in Section 2.3, several blended cements are produced in the US today, including portland limestone cement and other blended cements that make use of SCMs, but there is limited demand for them, most likely due to risk aversion of engineers specifying concrete. The adoption of performance-based specifications (described below in Section 6.5) would make it easier to use such cements. In addition, sponsoring research on the long-term structural and durability performance of concretes using blended cements will help to mitigate perceived risk by engineers.

6.4 Support development and deployment of emerging and innovative low-carbon technologies for cement production including carbon capture, storage, and utilization

With at least half of the cement industry's greenhouse gas emissions resulting from the chemical conversion of limestone and other ingredients into clinker, any long-term carbon reduction strategy for the cement manufacturing industry will require significant advances in carbon capture, use, distribution, and storage (CCUS) technologies.

But while many promising technologies are under development domestically and overseas, few have reached the commercial stage of development, and most of the research and all of the federal funding has focused on the energy sector (power, oil, gas), not industrial sector solutions. This is an important point because, if the US is going to develop a long-term strategy to reduce carbon emissions from the industrial sector, policymakers must realize there is no one-size-fits-all solution to capturing, transporting, and using or storing carbon emissions. Industrial sources face different and far more complex technical challenges and operating conditions in adopting carbon capture, use, and sequestration technologies.

In short, successful commercialization and deployment of any broadly-applied CCUS carbon mitigation strategy will require targeted funding and financial incentives to move the technology from the demonstration and pilot stage to commercial-scale use – particularly within the industrial sector.

Potential policy mechanisms that can help accelerate these technologies include:

- Provided targeted CCS research, development, and deployment funding for the cement sector.
- Use long-term and predictable tax policy to incentivize R&D and rapid investment in carbon capture, distribution, use, and storage technologies and infrastructure.
- Reward early investment and adoption in new technologies.

6.5 Support deployment of performance-based specifications for concrete to spur innovation in concrete mixtures

In contrast to prescriptive-based specifications, performance-based specifications define performance targets for concrete (strength, stiffness, constructability, durability) with minimal limitations on the constituent materials that may be used [21]. This enables significant opportunities to spur innovation in concrete mixtures by enabling use of low-carbon materials [22]. Although performance-based specifications have been proposed for over two decades, there has been limited adoption within the architecture, engineering, and construction community, most likely due to a preference for using materials and practices that have been used in the past. A shift in paradigm to performance-based specifications will require encouragement and incentives.

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