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Concrete & Climate Change

How Does Concrete Stack Up Against Other Building Materials?

By Lionel Lemay
NRMCA Senior Vice President, Technical Resources

The U.S. concrete industry is committed to continuous environmental improvement through process innovation and product standards that lead to reduced environmental impact.

What is climate change?

Climate change or global warming is the increase in the average temperature of the Earth's atmosphere and oceans as a result of the buildup of greenhouse gases in our atmosphere. Greenhouse gases can either be released by natural events such as volcanic eruptions or human activity such as deforestation or burning fossil fuels to manufacture products, power our cars and trucks, or to create the energy to heat and cool the homes and buildings in which we live and work. Livestock, agriculture, landfill emissions and use of chlorofluorocarbons in refrigeration systems are other sources of greenhouse gases resulting from human activity.

Carbon dioxide is one of several greenhouse gases that can cause global warming by trapping the Sun's radiant energy in our atmosphere. This process is called the greenhouse effect. In general, carbon dioxide, or CO_2, is exhaled by humans and animals and utilized by plants during photosynthesis. Additionally, carbon dioxide is created by the combustion of fossil fuels or plant matter, among other chemical processes. Greenhouse gases include water vapor (36-70%), carbon dioxide (9-26%), methane (4-9%) and ozone (3-7%), among others. The percentages indicate the approximate range of the greenhouse effect resulting from these greenhouse gases. Water vapor, the most abundant greenhouse gas, is not affected by human activity.[1]

Atmospheric concentrations of CO_2 are expressed in units of parts per million by volume (ppm). Since the beginning of the Industrial Revolution in the late 1700s, the concentration of CO_2 in our atmosphere has increased by about 100 ppm (from 280 ppm to 380 ppm). The first 50 ppm increase took place in about 200 years, from the start of the Industrial Revolution to around 1973; the next 50 ppm increase took place in about 33 years, from 1973 to 2006. It is estimated that 64% of the CO_2 in the atmosphere is due to burning fossil fuels.[2]

Many scientists believe global warming will cause a rise in sea level, increase the intensity of extreme weather and change the amount and pattern of precipitation. Other effects could include changes in agricultural

The amount of CO_2 produced during the concrete manufacturing process is relatively small when compared with that of other building materials.

yields, glacier retreat, species extinctions and increases in disease. These effects could severely impact the Earth's ability to support life. Many scientists believe recently observed global warming is partially caused by greenhouse gas emissions from energy production, transportation, industry and agriculture.

Does concrete manufacturing produce CO_2?

Water, sand, stone or gravel, and other ingredients make up about 90% of the concrete mixture by weight. The process of mining sand and gravel, crushing stone, combining the materials in a concrete plant and transporting concrete to the construction site requires very little energy and therefore only emits a relatively small amount of CO_2 into the atmosphere. The amounts of CO_2 embodied in concrete are primarily a function of the cement content in the mix designs.

Figure 1 – CO_2 Concentrations in Earth's atmosphere during the last 400,000 years.[3]

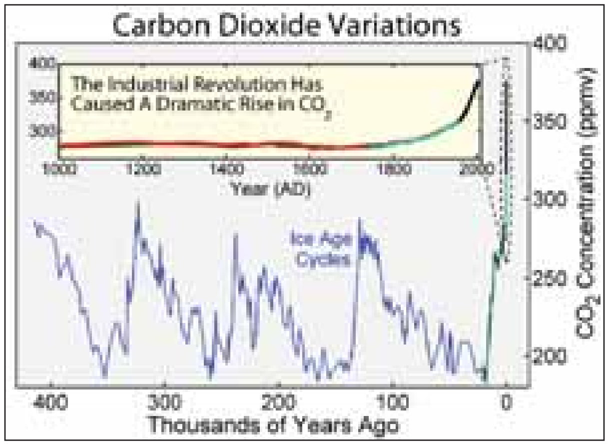
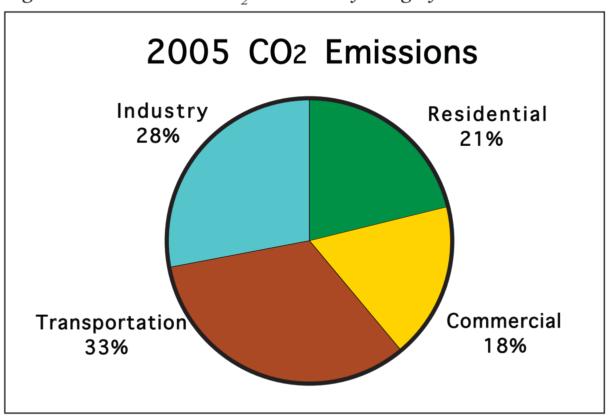


Figure 2 – 2005 U.S. CO_2 emissions by category.



As with all industrial processes requiring energy, manufacturing cement does result in the generation of CO_2. For the most part, CO_2 is generated from two different sources during the cement manufacturing process: 1) use of fossil fuels in the burning process, and 2) calcination, when calcium carbonate is heated and broken down to calcium oxide with the release of CO_2.

According to the Department of Energy, cement production accounts for 0.33% of energy consumption in the U.S. The current level is low compared with other industries, such as petroleum refining at 6.5%, steel production at 1.8% and wood production at 0.5%.4 On average, 927 kg (2044 lb) of CO_2 are emitted for every 1000 kg (2205 lb) of Portland cement produced in the U.S.[5]

The U.S. cement industry accounts for approximately 1.5% of U.S. CO_2 emissions, well below other sources such as heating and cooling our homes (21%), heating and cooling our buildings (18%), driving our cars and trucks (33%) and industrial operations (28%).[6] Global CO_2 emissions from cement production (298 million metric tons of carbon in 2004) represent 3.8% of total global CO_2 emissions.[7] Global emission contributions from cement production are likely to decrease as countries like China replace inefficient kilns. The U.S. cement industry has made considerable strides to improve its energy efficiency and reduce emissions.

How much CO_2 is embodied in concrete?

Concrete uses between 7% and 15% cement by weight depending on the performance requirements for the concrete. The average quantity of cement is around 250 kg/m3 (420 lb/yd^3). As a result, approximately 100 to 300 kg of CO_2 is embodied for every cubic meter of concrete (170 to 500 lb per yd^3) produced or approximately 5% to 13% of the weight of concrete produced, depending on the mix design.

A significant portion of the CO_2 produced during cement manufacturing is reabsorbed into concrete during the product life cycle through a process called carbonation. One research study estimates that between 33% and 57% of the CO_2 emitted from calcination will be reabsorbed through carbonation of concrete surfaces over a 100-year life cycle.[8]

How does concrete compare to other building materials?

Concrete compares favorably to other building materials such as steel, wood and asphalt when analyzing energy consumption and CO_2 emissions. Concrete building systems such as insulating concrete forms and tilt-up concrete incorporate insulation, high thermal mass and low air infiltration to create energy efficient wall systems that save energy over the life of a building. The result is significantly lower CO_2 emissions related to building occupancy when compared to wood and steel frame construction.

In one research study comparing energy performance of various concrete wall systems to wood frame and steel frame structures, concrete wall systems reduced energy requirements for a typical home by more than 17%. By comparison, a stick-frame house would have to be built with 2x12 lumber and R-38 insulation to achieve the same energy performance as the insulated concrete wall comprised of 150 mm (6 in) of concrete and two layers of 60 mm (2 in) thick rigid insulation.[9]

Another research study compared the energy cost of a steel framed building with lightly framed exterior walls to that of a concrete framed building with concrete exterior walls to determine the benefit of thermal mass. The analysis was conducted for six different cities in the U.S. Energy cost savings for the concrete frame building were 5% in Miami, 10% in Phoenix, 16% in Memphis, TN, 18% in Chicago, 21% in Denver, and 23% in Salem, OR.[10]

Another research study compared the energy of production for concrete and other common building materials for raw material extraction, transportation and manufacturing. The study concludes that the energy required to produce one metric ton of reinforced concrete was 2.5 GJ/t (2.2 million BTU/ton) compared to 30 GJ/t (25.8 million BTU/ton) for steel and 2.0 GJ/t (1.7 million BTU/ton) for wood. The same study compared the CO_2 emissions of several different building materials per 1000 kg (2205 lb) for residential construction and concluded that concrete accounted for 147 kg (324 lb) of CO_2, metals accounted for 3000 kg (6614 lb) of CO_2, and wood accounted for 127 kg (280 lb) of CO_2.[11]

In another study that compared the embodied CO_2 in concrete and steel framed buildings on a per-square-meter basis, concrete accounted for 550 kg of CO_2 per square meter of floor area (112 lb/ft^2) and steel accounted for 620 kg of CO_2 per square meter of floor area (127 lb/ft^2.)[12]

In fact when it comes to homes and buildings, it's not the manufacturing and construction phase that generates most of the CO_2. It's the operational phase where heating, air conditioning and appliances generate most of the CO_2 throughout a structure's lifetime. In one study, approximately 98% of the CO_2 emissions from a home were from the use of natural gas appliances throughout its 100-year lifetime. Only about 2% was attributed to the manufacturing and construction phase.[13]

Studies conducted by National Resources Council of Canada compared fuel consumption and emissions for a 100 km (62.14 mi) section of a major urban arterial highway, one paved with asphalt and the other paved with concrete. These studies concluded that heavy trucks traveling on concrete pavement accumulate statistically significant fuel savings, ranging from 0.8% to 6.9%. These fuel savings lead to reductions in greenhouse gas emissions and air pollutants.[14,15]

Athena Institute conducted a life cycle analysis on concrete and asphalt roadways to compare embodied energy and global warming potential for construction and maintenance over a 50-year life cycle. The study concluded that for a high volume highway, the asphalt pavement alternative required three times more energy than their concrete pavement counterparts from a life cycle perspective. For a high volume roadway, asphalt generated global warming potential of 738 t/km (1309 tons/mi) of CO_2 equivalents compared to 674 t/km (1196 tons/mi) of CO_2 equivalents for concrete.[16]

What is the cement industry doing to reduce greenhouse gases?

The cement industry was among the first to tackle the issue of climate change. Since 1975, the cement industry has reduced emissions by 33%. Portland Cement Association

Figure 3 – Energy of production for common building materials.

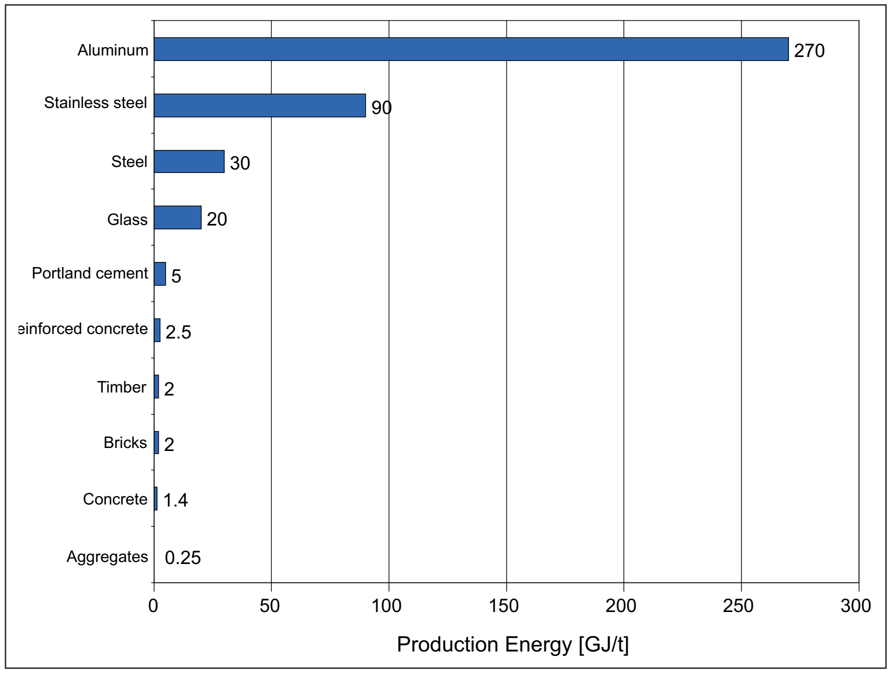


Table 1 – Annual savings and reductions for major urban arterial highway.[14,15]

Annual Savings and Reductions for Major Urban Arterial Highway			
	Results based on driving on concrete vs. asphalt pavement		
	Minimum 0.8%	Average 3.85%	Maximum 6.9%
Fuel Savings (liters)	377,000	1,813,000	3,249,000
Dollar Savings ($)	338,000	1,625,000	2,912,000
CO2 Equivalent Reductions (t)	1,039	5,000	8,950

members adopted a voluntary Code of Conduct, (principles, performance measures and a reporting protocol) to support the Cement Manufacturing Sustainability Program. By the year 2020, the industry plans to voluntarily reduce CO_2 emissions by 10%, energy use by 20% and cement kiln dust by 60% below a 1990 baseline.[17]

The primary options for reducing the quantity of CO_2 generated during cement manufacturing process are to use alternatives to fossil fuels, change the raw ingredients used in manufacture and intergrind additional materials with the clinker. The most recent progress involves newly introduced guidelines that will allow for greater use of limestone as interground material in finished cement. This will have no impact on product performance but will ultimately reduce CO_2 by more than 2.5 Mt (2.8 million tons) per year in the U.S. Using interground limestone in cement is already common practice in Europe and Canada.

What is the concrete industry doing to reduce greenhouse gases?

The U.S. concrete industry is committed to continuous environmental improvement through process innovation and product standards that lead to reduced environmental impact. National Ready Mixed Concrete Association members have implemented the P2P Initiative (Prescriptive to Performance Specifications for Concrete) which provides concrete producers more flexibility to optimize concrete mixtures for intended performance that will also reduce environmental impact, including CO_2 emissions.

Traditionally, construction specifications for concrete have required unnecessarily high quantities of portland cement along with other limits on the use of supplementary cementitious materials. These limits are incorporated in the industry's standards and specifications. The P2P Initiative proposes to eliminate many of these limits and evolve to performance-based standards. This will reduce the environmental impact of concrete as a building material.[18]

The U.S. concrete industry uses a significant amount of industrial byproducts such as fly ash, blast furnace slag and silica fume to supplement a portion of the cement used in concrete. In 2006, the U.S. electric power industry generated a total of about 124.8 Mt (137.6 million tons) of coal combustion ash of which about 43% was used in construction and industrial processes. The cement and concrete industry use accounted for more than 22.5 Mt (24.9 million tons) in 2006.[19]

The use of slag has increased significantly, resulting in large reductions in CO_2 emissions. Besides use as a cementitious material, iron slags are used as raw feed in cement manufacture and aggregates in concrete mixtures. The USGS reports a total of 11.6 Mt (12.7 million tons) of iron blast furnace slag (air-cooled and granulated) produced in 2006 of which 4.2 Mt (4.6 million tons) is granulated and 94% of this is used as a cementitious material.[20]

The concrete industry also incorporates a variety of environmental best management practices in the production of its product. These include the reuse and recycling of waste from concrete manufacture such as water and unused returned concrete. It also incorporates waste byproducts from other industries such as recycled industrial waste water, foundry sands, glass and other materials that would typically end up in landfills.

Conclusion

The concrete industry is dedicated to continuous environmental improvement through process and product innovation. Concrete performs well when compared to other building materials but when it comes to sustainable development there are always opportunities for improvement. As with any building product, concrete and its ingredients do require energy to produce which in turn produces carbon dioxide or CO_2. The amount of CO_2 produced during the manufacturing process is relatively small when compared with other building materials and when compared with other human activities such as heating and cooling our homes and buildings or operating our cars and trucks. Concrete's many benefits help make it an environmentally friendly choice for construction with one of the lowest carbon footprints of any building material. ■

Note: This article was presented at the 2008 Concrete Technology Forum: Focus on Sustainable Development, May 20-22, 2008, in Denver, www.concretetechnologyforum.org. A more detailed discussion of this topic is presented in the NRMCA publication Concrete CO_2 Fact Sheet available for download a www.nrmca.org/greenconcrete.

(Endnotes)
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