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Concrete CO_2 Fact Sheet

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Forward

This publication was written by the National Ready Mixed Concrete Association to help its members understand the complexities of climate change and the greenhouse effect. NRMCA and its members are dedicated to continuous environmental improvement through product and process innovation. This publication provides a brief overview of the concrete industry's role in minimizing environmental impact related to carbon dioxide emissions.

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CONCRETE CO_2 FACT SHEET

Introduction

Concrete is the most widely used building material in the world because of its beauty, strength and durability, among other benefits. Concrete is used in nearly every type of construction, including homes, buildings, roads, bridges, airports and subways, just to name a few. And in an era of increased attention on the environmental impact of construction, concrete performs well when compared to other building materials. As with any building product, production of concrete and its ingredients does require energy that in turn results in the generation of carbon dioxide, or CO_2. The amount of CO_2 produced during manufacturing and the net impact of using concrete as a building material is relatively small. The following features of concrete construction help minimize its carbon footprint:

- Concrete is resource efficient and the ingredients require little processing.
- Most materials for concrete are acquired and manufactured locally which minimizes transportation energy.
- Concrete building systems combine insulation with high thermal mass and low air infiltration to make homes and buildings more energy efficient.
- Concrete has a long service life for buildings and transportation infrastructure, thereby increasing the period between reconstruction, repair and maintenance and the associated environmental impact.
- Concrete, when used as pavement or exterior cladding, helps minimize the urban heat island effect thus reducing the energy required to heat and cool our homes and buildings.
- Concrete incorporates recycled industrial byproducts such as fly ash, slag and silica fume which helps reduce embodied energy, carbon footprint and quantity of landfilled materials.
- Concrete absorbs CO_2 throughout its lifetime through a process called carbonation, helping reduce its carbon footprint.

The following facts help tell the story of concrete and CO_2.

What is CO_2?

- CO_2 is the chemical formula for carbon dioxide, a gas which exists in relatively small amounts (380 parts per million or ppm) in our atmosphere.
- In general, it 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.
- 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.
- 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 14% of the CO_2 in the atmosphere is due to burning fossil fuels. It is also estimated that 64% of the CO_2 added to the atmosphere since 1850 is due to burning fossil fuels.[2]

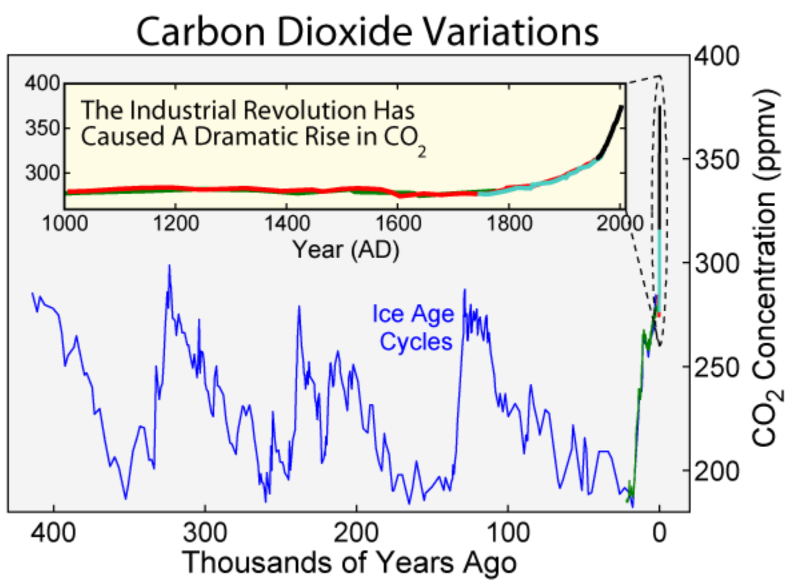

Figure 1 - CO_2 Concentrations in Earth's atmosphere during the last 400,000 years.[3]

What is global warming?

- 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. Global warming is sometimes called climate change.
- 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 we live in and the buildings we work in. Livestock, agriculture, landfill emissions and use of chlorofluorocarbons in refrigeration systems are other sources of greenhouse gases resulting from human activity.
- 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 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.

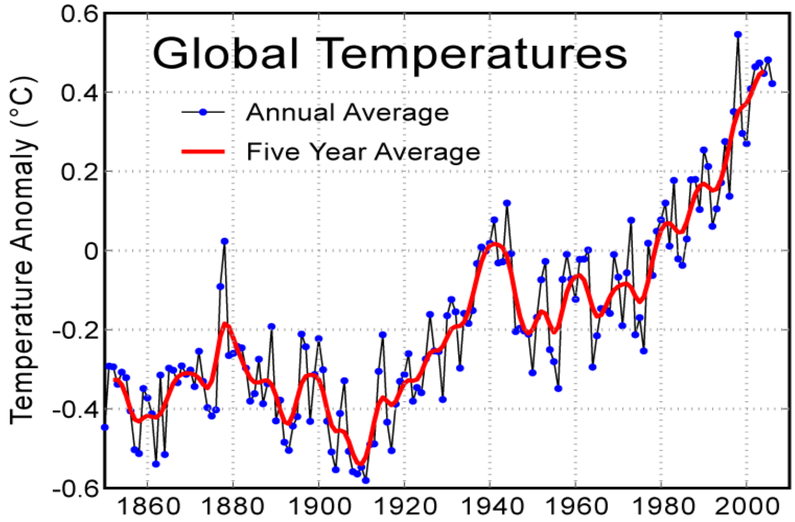

Figure 2 - Variation of global temperatures.[4]

What's the difference between cement and concrete?

- The terms cement and concrete are often used interchangeably. Cement is an ingredient of concrete. It's the fine, gray powder that, when mixed with water, sand and gravel, forms the rock-like mass known as concrete. Cement acts as the binding agent or glue. Cement is produced by cement manufacturers around the world in cement plants.
- The product from the burning process during manufacture of cement, called clinker, is then interground with other ingredients to produce the final cement product.
- Concrete is the rock-like product that is used to build our homes, buildings, roads, bridges, airports and subways, among other critical structures. Concrete is used in almost every form of construction. It's made by concrete producers who combine materials, including cement, water, sand and gravel, along with other chemicals and minerals to create concrete.

Does cement manufacturing generate CO_2?

- As with all industrial processes requiring energy, manufacturing cement does result in the generation of CO_2.
- Cement is manufactured from a combination of naturally occurring minerals - calcium (60% by weight) mainly from limestone or calcium carbonate, silicon (20%), aluminum (10%), iron (10%) and small amounts of other ingredients and heated in a large kiln to over 1500° C (2700° F) to convert the raw materials into clinker.
- For the most part, CO_2 is generated from two different sources during the cement manufacturing process:

- Use of fossil fuels in the burning process;
- Calcination, when calcium carbonate is heated and broken down to calcium oxide with the release of CO_2.

- The most commonly used cement is called portland cement. It contains about 92% to 95% clinker by weight. Some companies produce blended cements that incorporate other industrial byproducts that have cementitious properties, thus reducing the amount of clinker in the cement.
- Other parts of the manufacturing process such as operating mining equipment for extracting the raw materials and transportation of the raw materials to the cement plant emit relatively small amounts 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%.[5]
- According to EPA, between 900 and 1100 kg (1984 and 2425 lbs) of CO_2 is emitted for every 1000 kg (2205 lbs) of portland cement produced in the U.S. This depends on the fuel type, raw ingredients used and the energy efficiency of the cement plant.[6]
- According to the most recent survey of Portland Cement Association (PCA) members, an average of 927 kg (2044 lb) of CO_2 are emitted for every 1000 kg (2205 lb) of portland cement produced in the U.S.[7]
- Between 50% and 60% of the CO_2 emitted is a result of calcination of calcium carbonate raw materials, a necessary part of the manufacturing process. The remaining CO_2 emitted is a result of burning fossil fuels such as coal and natural gas to heat the raw materials in the kiln.
- 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 (19%), driving our cars and trucks (33%) and industrial operations (27%).[8]

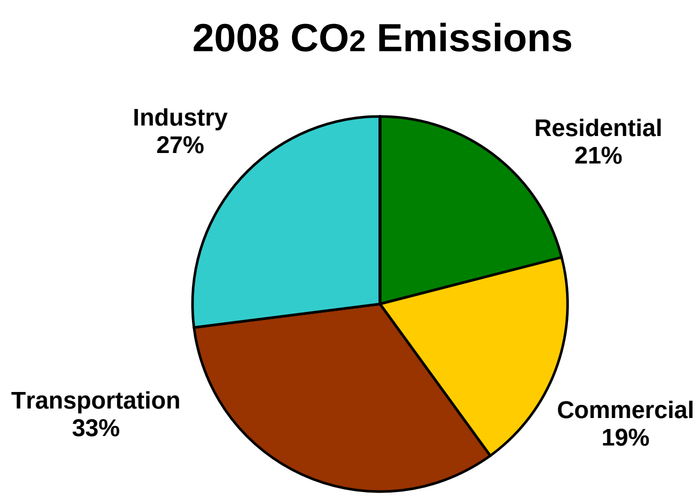

Figure 4 – 2008 U.S. CO_2 emissions by category.

- Global CO_2 emissions from cement production (377 million metric tons of carbon in 2007) represent 4.5% of global CO2 releases from fossil-fuel burning and cement production.[9]
- In 2010, the U.S. cement industry manufactured about 62 million metric tonnes (Mt) (68 million tons) of cement and imported about 5.5 Mt (6.1 million tons).
- In 2010, the U.S. was the third largest cement manufacturing country behind China, 1,814 Mt (2,000 million metric tonnes) and India, 191 Mt (210 million tons.) Total global cement production in 2010 was 3084 Mt (3,400 million tons). U.S. cement manufacturing capacity is 4.3% of global capacity.[10]

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. It is important to note that structures are built with concrete and not cement.

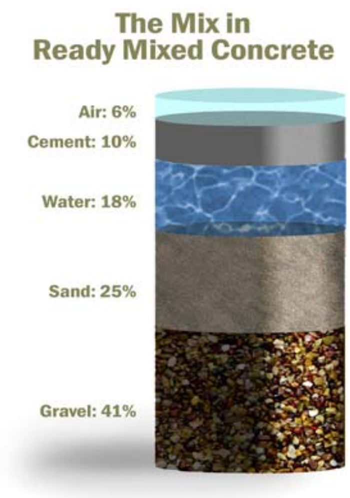

Figure 3 - Typical composition of hydraulic cement concrete.

How much CO_2 is embodied in concrete?

- Concrete uses about 7% and 15% cement by weight depending on the performance requirements for the concrete. The average quantity of cement is around 250 kg/m^3 (420 lb/yd^3). One cubic meter (m^3) of concrete weighs approximately 2400 kg (1 cubic yard weighs approximately 3800 lb). 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.[11]
- A significant portion of the CO_2 produced during manufacturing of cement 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.[12]

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.[13]
- 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.[14]

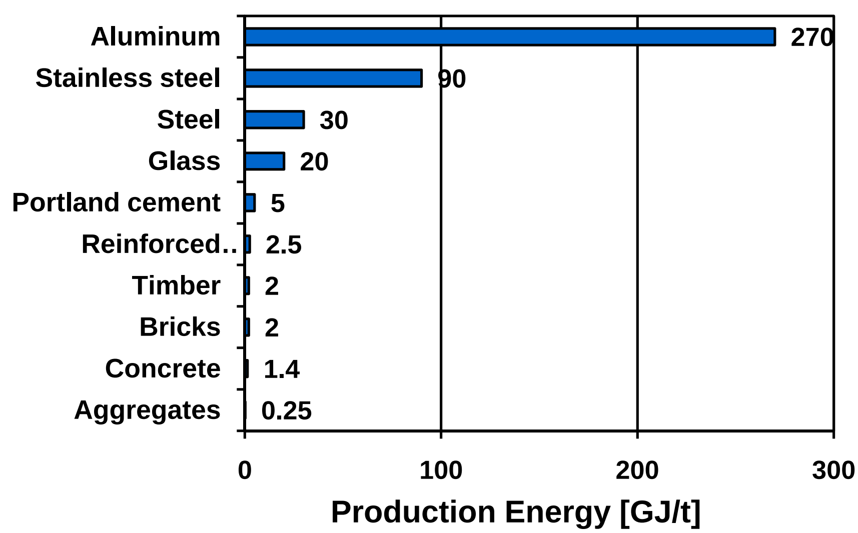

Figure 5 – Energy of production for common building materials.

- 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.[15]

- 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.)[16]
- 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.[17,18]

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
CO_2 Equivalent Reductions (t)	1,039	5,000	8,950

Table 1 – Annual savings and reductions for major urban arterial highway.[17,18]

- 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.[19]

What other human activities generate CO_2?

- Although cement and concrete manufacturing contribute to CO_2 emissions, it is a small fraction of that generated by other human activity. The four largest generators of CO_2 in the U.S. are:
  - Heating and cooling homes (21%)
  - Heating and cooling buildings (18%)
  - Driving cars and trucks (33%)
  - Industrial operations (28%).

- 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.[20]

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%. PCA 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.[21]
- 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.
- The U.S. concrete industry has 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.[22]
- 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. These industrial products, which would otherwise end up in landfills, are called supplementary cementitious materials or SCMs for short. The use of SCMs in concrete work in combination with portland cement to improve strength and durability in addition to reducing the CO_2 embodied in concrete by as much as 70%, with typical values ranging between 15 and 40%.

- Fly ash is the waste byproduct of burning coal in electrical power plants. Generally, 15% to 20% of burned coal takes the form of fly ash. At one time, most fly ash was landfilled, but today a significant portion is used in concrete. Based on NRMCA research, the amount of fly ash used in concrete was about 80 kg (135 lb/yd^3) in 2002, extending cement supply and enhancing concrete performance.
- Blast furnace slag is the waste byproduct of iron manufacture. After quenching and grinding, the blast furnace slag takes on much higher value as a supplementary cementitious material for concrete. Blast furnace slag is used as a partial replacement for cement to impart added strength and durability to concrete. In 2002, when blast furnace slag was used in concrete, the average quantity was about 150 kg/m^3 (250 lb/yd^3), extending cement supply and enhancing performance.
- Silica fume is a waste byproduct of processing quartz into silicon or ferro-silocon metals in an electric arc furnace. Silica fume consists of superfine, spherical particles that when combined with cement significantly increases strength and durability of concrete. It is used for some high-rise buildings to produce concretes which exceed 140 MPa (20,000 psi) compressive strength and in bridge and parking garage construction to help keep chlorides from deicing salts from corroding steel reinforcement.

- In 2010, the U.S. electric power industry generated a total of about 118.1 Mt (130.2 million tons) of coal combustion ash of which about 38% was used in construction and industrial processes. The cement and concrete industry use accounted for more than 12.0 Mt (13.2 million tons) in 2010.[23]
- 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 17.1 Mt (18.8 million tons) of iron blast furnace slag (air-cooled and granulated) produced in 2008 of which 2.7 Mt (3.0 million tons) is granulated and 94% of this is used as a cementitious material.[24,25]
- 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 is always opportunity 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 manufacturing 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.

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