Climate Change and Concrete
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, concrete and its ingredients do require energy to produce that in turn results in the generation of carbon dioxide, or CO2. But the amount of CO2 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 harvested and manufactured locally which minimizes transportation energy.

Concrete building systems combine insulation and thermal mass 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 the energy required for manufacturing.

Concrete absorbs CO2 throughout its lifetime through a process called carbonation, helping reduce its carbon footprint.

All that being said, the following facts help tell the story of concrete and CO2.
• When looking at carbon footprint, it is important to look at the complete life cycle of the building including material acquisition, manufacturing, construction, operation, and reuse/recycling.

• All phases of a building or product should be considered. Simply looking at the acquisition and manufacturing phases ignores impacts during the operational phase. Reuse/recycling considers new options once the product or building has reached the end of its service life.
What is CO2?

CO2 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 gas sources. Water vapor, the major source, is not affected by human activity.[i]

Atmospheric concentrations of CO2 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 CO2 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 CO2 in the atmosphere is due to burning fossil fuels.[i]

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 caused 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.
Causes of Global Warming

- Many scientists believe global warming caused by greenhouse gas emissions from:
  - Energy production
  - Transportation
  - Industry
  - Agriculture

Many scientists believe recently observed global warming is partially caused by greenhouse gas emissions from energy production, transportation, industry and agriculture.
Cement and concrete?

- Cement ingredient of concrete
- Fine, gray powder
- Mixed with water, sand and gravel to form concrete
- Cement acts as the binding agent
- Cement is produced by cement manufacturers
- Concrete produced by concrete producers

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.
Clinker and Cement

Clinker: product from the burning process during manufacturing process

Cement: clinker is interground with other ingredients to produce cement

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 generate CO₂?

- As with all industrial processes
- Cement generates CO₂
- Made from natural minerals
  - calcium (60%) from limestone
  - silicon (20%)
  - aluminum (10%)
  - iron (10%)
- Heated in large kiln to 1500° C
- Converts raw materials to clinker
- CO₂ generated from two sources
  - Fossil fuels in burning process
  - Calcination - calcium carbonate broken down to calcium oxide with release of CO₂

Does cement manufacturing generate CO₂?

As with all industrial processes requiring energy, manufacturing cement does result in the generation of CO₂.

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, CO₂ 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 CO₂.
Cement and CO₂

- Most common cement is called portland cement
- Contains about 92% to 95% clinker by weight
- Some companies produce blended cements
  - Incorporate industrial byproducts
  - Reduces amount of clinker in the cement
- Mining equipment and transportation emit relatively small amounts of CO₂
- Energy consumption in the U.S.
  - Petroleum refining (6.5%)
  - Steel production at (1.8%)
  - Wood production at (0.5%)
  - Cement manufacturing (0.33%)

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 CO₂.

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%.\[i\]

Does concrete produce CO$_2$?

- Water, sand, stone or gravel and other ingredients make up about 90% of concrete.
- Mining sand and gravel, crushing stone, combining the materials and transportation concrete requires very little energy.
- Emits a relatively small amount of CO$_2$.
- Nearly all the CO$_2$ embodied in concrete is a direct result of the use of portland cement.

Does concrete manufacturing produce CO2?

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 CO2 into the atmosphere.

Consequently, nearly all the CO2 embodied in concrete is a direct result of the use of portland cement in the concrete mixture.
How much CO$_2$ does cement produce?

- Between 900 and 1100 kg of CO$_2$ emitted for every 1000 kg of portland cement produced
- On average 927 kg of CO$_2$ emitted for every 1000 kg of portland cement produced
- 50% to 60% is result of calcination
- remaining is result of burning fossil fuels such as coal and natural gas

How much CO$_2$ does cement manufacturing produce?

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.[i]

According to the Portland Cement Association, 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.[ii]

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. CO2 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%).[ii]

Global CO₂ Production

- Cement accounts for 5% of the global CO₂
- Global cement production in 2005
  - Total: 2300 million metric tons (Mt)
  - China: 1038 Mt
  - India: 145 Mt
  - United States: 100 Mt
- Global emissions will decrease as countries like China replace old kilns

The global cement industry accounts for approximately 5% of the global CO₂ emissions.\[i\] Numbers as low as 3% are also quoted.\[ii\] Global emission contributions from cement production are likely to decrease as countries like China replace old kilns. The U.S. cement industry has made considerable strides to improve its energy efficiency and reduce emissions.

In 2005, the U.S. cement industry manufactured about 100 million metric tons (Mt) (110 million tons) of cement and imported about 28 Mt (31 million tons). In 2005, the U.S. was the third largest cement manufacturing country behind China, 1038 Mt (1144 million tons) and India, 145 Mt (160 million tons.) Total global cement production in 2005 was 2300 Mt (2535 million tons). U.S. cement manufacturing capacity is 4.3% of global capacity.\[iii\]

How much CO₂ embodied in concrete?

- Small percentage embodied in concrete
- Concrete uses 7% and 15% cement by weight
- The average quantity of cement is around 250 kg/m³
- 100 to 300 kg of CO₂ embodied per cubic meter
- That’s 5% to 13% of the weight of concrete
- CO₂ reabsorbed into concrete through carbonation
- 33% to 57% of CO₂ emitted from calcination is reabsorbed through carbonation over 100-year life

How much CO₂ is embodied in concrete?

A relatively small percentage of CO₂ is embodied in concrete since cement is an ingredient of concrete which comprises a relatively small portion of the overall concrete mixture. It is important to note that structures are built with concrete and not cement. Nearly all the CO₂ embodied in concrete is a direct result of the use of cement in the concrete mixture.

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/m³ (420 lb/yd³). One cubic meter (m³) of concrete weighs approximately 2400 kg (1 cubic yard weighs approximately 3800 lb).

As a result of using cement in concrete, approximately 100 to 300 kg of CO₂ is embodied for every cubic meter of concrete (170 to 500 lb per yd³) produced or approximately 5% to 13% of the weight of concrete produced. The quantity is directly related to the quantity of portland cement used.[i]

A significant portion of the CO₂ 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 CO₂ emitted from calcination will be reabsorbed through carbonation of concrete surfaces over a 100-year life cycle.[ii]

How does concrete compare to other building materials?

- Concrete has low energy consumption and CO₂ emissions compared to:
  - Steel
  - Wood
  - Asphalt

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 CO₂ emissions.
Concrete building systems such as insulating concrete forms and tilt-up concrete incorporate insulation and thermal mass energy efficient wall systems that save energy over the life of a building, resulting in significantly lower CO2 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.[i]

Concrete Frame vs. Steel Frame

- Study compared the CO₂ emissions of concrete and steel framed buildings
  - Concrete frame produced 550 kg of CO₂ per square meter of floor area
  - Steel frame produced 620 kg of CO₂ per square meter of floor area

In another study that compared the CO₂ emissions of concrete and steel framed buildings on a per-square-meter basis, concrete produced 550 kg of CO₂ per square meter of floor area (112 lb/ft²) and steel produced 620 kg of CO₂ per square meter of floor area (127 lb/ft²).\[i\]

One 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 CO2 emissions of several different building materials per 1000 kg (2205 lb) for residential construction and concluded that concrete produced 147 kg (324 lb) of CO2, metals produced 3000 kg (6614 lb) of CO2, and wood produced 127 kg (280 lb) of CO2.[i]

Concrete vs. Asphalt Pavements

<table>
<thead>
<tr>
<th>Results based on driving on concrete vs. asphalt pavement</th>
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<tbody>
<tr>
<td>Minimum 0.8%</td>
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<tr>
<td><strong>Fuel Savings (liters)</strong></td>
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<tr>
<td><strong>Dollar Savings ($)</strong></td>
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<td><strong>CO₂ Reductions (t)</strong></td>
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Studies conducted by National Resources Council of Canada compared fuel consumption and emissions for a 100 km (?? 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 also lead to reductions in greenhouse gas emissions and air pollutants.[i],[ii]

Concrete vs. Asphalt

- Life cycle analysis on concrete and asphalt roadways
- Compared embodied energy and global warming potential for construction and maintenance over a 50-year life cycle
- For a high volume highway
  - Asphalt pavement required 3 times more energy than concrete pavement
  - Asphalt generated global warming potential of 738 t/km of CO₂ equivalents compared to 674 t/km for concrete


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 (??? tons/mi) of CO₂ equivalents compared to 674 t/km (??? tons/mi) of CO₂ for concrete.[i]

What other human activities generate CO₂?

Although cement and concrete manufacturing contribute to CO₂ emissions, it is a small fraction of that generated by other human activity. The four largest generators of CO₂ in the U.S. are:

1. Heating and cooling homes (21%)
2. Heating and cooling buildings (18%)
3. Driving cars and trucks (33%)
4. 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 CO₂. It’s the operational phase where heating, air conditioning, and appliances generate most of the CO₂ throughout a structure’s lifetime.

In one study, approximately 98% of the CO₂ 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.[ii]

What is the cement industry doing?

- 33% reduction in CO₂ since 1972
- Additional 10% reduction by 2020 from 1990 levels
- Limestone additions
  - Saves 11.8 Trillion Btus
  - Eliminates 2.5 million tons of CO₂
- Reduce waste by 60%

What is the cement industry doing to reduce and minimize 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%. By the year 2020, the industry plans to voluntarily reduce CO₂ emissions by 10% below 1990 levels. The industry has also committed to reduce cement kiln dust, waste related to the manufacturing process, by 60% by 2020.

The primary options for reducing the quantity of CO₂ generated during cement manufacturing process is 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 CO₂ by more than 2.5 Mt (2.8 million tons) per year in the U.S. Using interground limestone in cement is common practice in Europe and Canada.
What is concrete industry doing?

- Committed to continuous environmental improvement
- P2P Initiative (Prescriptive to Performance Specifications for Concrete)
- The P2P Initiative removes limits on materials
- Allows producers to meet performance requirements
- Minimize environmental impact

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 CO2 emissions.[ii]

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.

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 that 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 CO₂ embodied in concrete by as much as 70%, with typical values ranging between 15 and 40%.
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

- Concrete industry dedicated to continuous environmental improvement
- Through process and product innovation
- Performs well when compared to other building materials
- However, there is always room for improvement
- CO₂ produced is relatively small
- One of the lowest carbon footprints

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 room for improvement. As with any building product, concrete and its ingredients do require energy to produce which in turn produces carbon dioxide or CO₂. But the amount of CO₂ 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.
Questions?