Mitigating Carbon Dioxide Emissions in the Cement Industry Through Carbon Capture and Storage

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The cement industry is responsible for 7% of industrial energy use, the third largest energy consumer in the world. The industry is also responsible for 7% of global carbon dioxide emissions, the second largest industrial emitter. With current trends continuing, global cement usage will rise with population and urbanization. The low-carbon transition of the cement industry requires innovative technologies and producer cooperation. Carbon capture and storage, known as CCS, is a safe and sustainable solution to significantly reduce the amount being released into the atmosphere. Through CCS, carbon dioxide reacts with natural alkaline minerals, such as fly ash, to create carbonate (a mineral). Carbonate is then stored in concrete as an aggregate where it will never the atmosphere.

Key-words: Carbon Capture, Carbon Dioxide, Cement, Concrete, Sequestration

Introduction

For hundreds of years, concrete has been used as an extremely versatile building material for building structures, roadways, bridges, and dams. It is strong, durable, low-maintenance, fire resistant, can be formed into any size and shape, and relatively cheap compared to other building materials. Concrete is composed of three main ingredients: Water, aggregate (water and rock), and cement. Of these three components, cement is only material that holds any complexity as aggregate and water occur naturally on Earth. Cement is the main binding material that holds together the aggregate, transforming concrete from a liquid state into a solid. This is done through a chemical reaction called hydration. The hydration reaction cement forms bonds with water, causing the sand and rock aggregates to be held together in place.

Creating Cement

The cement making is a complex process that requires control of chemical formulation and involves multiple steps with specialized equipment. Cement manufacturing can be simplified to a three-part process. The raw material is ground and sent through a high-temperature kiln. The material is heated in a kiln to produce a grey nodular material called clinkers. Once the clinkers are produced, they are ground into a fine powder. This powder is raw cement. Figure 1 below shows in detail the full extent of the cement making process. The raw material for cement is limestone, otherwise known as calcium carbonate (CaCO3). During the heating process, calcium carbonate releases two carbon dioxide molecules with calcium carbon (CaCO) remaining (Judy Brewer, 2014). This is the chemical process that ensues:

$$CaCO3(s) \rightarrow CaO(s) + CO2(g)$$

The CO2 released at this time is referred to as “process CO2 emissions.” Approximately 60-70% of the total carbon dioxide emissions during the cement making process occurs during this stage (The International Energy Agency 2018). This is twice the amount of CO2 that is released from the energy used for the production of cement. The energy is used in the form of electricity for the grinding and loading equipment, and fuels to provide thermal energy in the kiln. Clinker production generates the majority of both direct and process CO_2 emissions, due to fuel combustion and CO_2 released from raw materials.

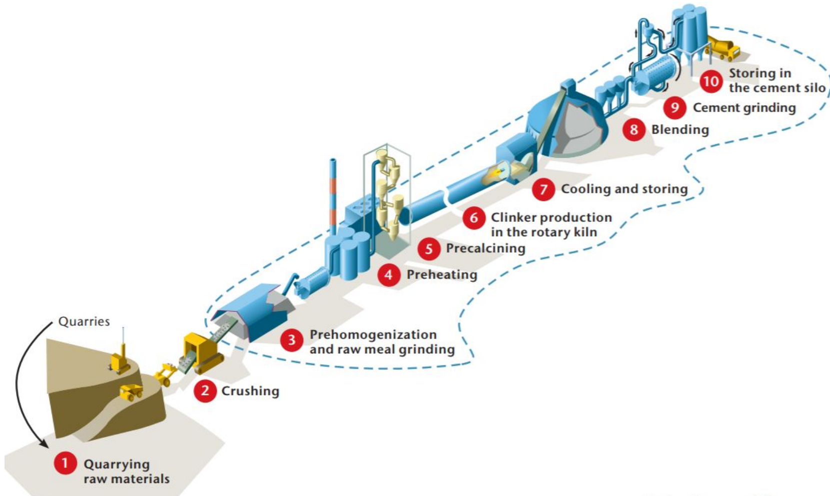

Figure 1: Cement Manufacturing Process
Source: International Energy Agency 2018

Global CO2 Emissions

Greenhouse gasses in our atmosphere help to regulate the global temperature and provide a climate to sustain life on this planet. The most common greenhouse gasses are water vapor, carbon dioxide, methane, nitrous gas, and fluorinated gasses. Carbon dioxide makes up 81.6% of all greenhouse gasses (The Environmental Protection Agency, 2017). CO_2 is naturally present as a part of Earth's carbon cycle, but CO_2 levels are increasing at an alarming rate. The effects are a rise in global temperature through the greenhouse effect. This increase is causing a shift in the carbon cycle and overwhelming the natural circulation.

CO2 Emissions from the Cement Industry

Globally, the population is expected to grow by 34% by 2050, with two-thirds of the world's population living in urban areas. As the world population and economies continue to grow, so will the demand for concrete. It is estimated over the next 30 years, concrete demand will continue to rise 12-23% (The International Energy Agency, 2018). The increased demand for concrete will, in part, increase the demand for cement. This leads to the rise of carbon dioxide emissions in the atmosphere. The cement sector consumes 7% of all industrial energy, making it the third largest industrial energy consumer globally. It is also the second highest emitter of all industrial carbon dioxide, responsible for 7% of all CO_2 emissions. Currently, Figure 2 shows that China, Asia Pacific countries, America, and Europe are the highest concrete producers. Over the next few decades, there will be a shift as China drastically reduces its cement production while America, India, Asia Pacific, and Africa increase. Even with this shift, the demand for cement will steadily rise with the growing population.

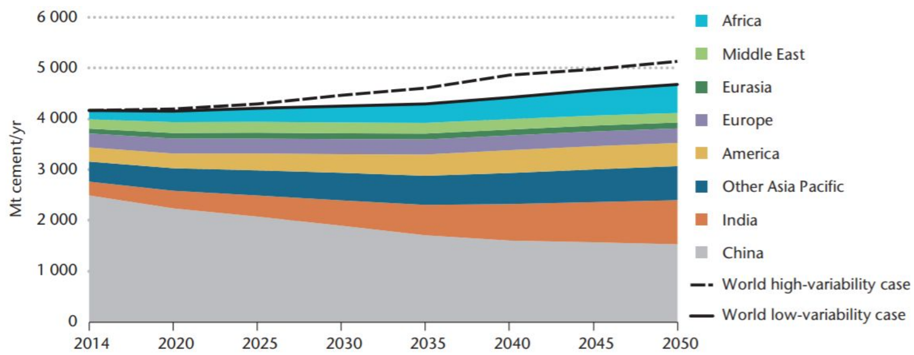

Figure 2: Cement Production by Region
Source: International Energy Agency, 2018

Methodology

The objectives of this research paper are as follows:

- To report on the effects of sequestered CO2
- To highlight the global effects of CO2
- To highlight current actions being taken to reduce CO2 emissions
- To highlight the necessary efforts of the industry to transition to eco-friendly solutions

The methodology for this research was primarily qualitative. The qualitative study was done through intensive research about the cement making process and the impact its carbon dioxide emissions have on the world. The research helped by gaining a better understanding of how the process works and where the underlying problems occur. The knowledge gained from this research will be used to analyze the possible solutions to reducing the amount of CO2 being emitted into the atmosphere by the cement industry. The key issue being addressed in this report is the effects carbon capture and storage has on the environment. The information brought forth from this study will determine the best possible solution for curbing the increasing emissions of CO2 by the cement industry.

Research

Carbon dioxide levels in the atmosphere are reaching new highs. With the cement industry responsible for 7% of annual emissions, a new approach needs to be taken in order to reduce the high volume of CO2 output from the industry. Through a process called carbon capture and storage (CCS), collects released CO2 and deposits it where it could no longer enter into the atmosphere. Hypothetically, massive amounts of CO2 being released could potentially be sequestered in storage sites. These sites are normally underground geological formations, deep below the earth's surface. Instead of pumping CO2 underground in remote locations, new technology is paving a way to sequester CO2 in concrete. The same building material responsible for 7% of the world's CO2 emissions can be used to drastically reduce the amount being emitted into the atmosphere.

Carbon Capture and Storage

Carbon capture and storage (CCS) is a new technology that has yet to be analyzed on an industrial scale. In traditional CCS, CO2 is captured from large point sources, compressed into a liquid, and transported in pipelines to be permanently stored underground. In the cement industry, the point source is the kiln, where CO2 is emitted from fuel combustion and the extreme heating of limestone. This is where the CCS technology will be retrofitted to capture the CO2 before entering the atmosphere (Anusha Kothandaraman, 2010). There are currently three systems for carbon dioxide capture to be applied to the cement making process:

1. Post-combustion capture - This process involves the removal of CO2 from the flue gas after the combustion of the fuel in the kiln. Figure 3 shows the schematic for post-combustion capture. There are multiple methods for capturing CO2 from flue gas including chemical absorption, membrane separation, and carbonate looping. Chemical absorption, also known as carbon scrubbing, seems to be the most promising approach and closest to commercialization as having high CO2 capture rates in other industries. The absorption process makes use of the easily reversible chemical reaction of CO2 with an aqueous alkaline solvent, usually amines, potassium, or other chemical solutions. Membrane separation is the process of using synthetic membranes made from polymers to capture CO2 as it passes through.
2. Oxyfuel combustion - This technique would use oxygen in cement kilns instead of air. Figure 4 shows the schematic for oxyfuel combustion. This would have a result of a comparatively pure CO2 stream. This stream of CO2 would then be ready to store.
3. Pre-combustion capture - This process has many issues associated with it for the implementation on combustion kilns. The main issue is the presence of pure hydrogen in the process. This, combined with the clinker-burning process would require heavy modifications to the cement making process in order for safe usage.

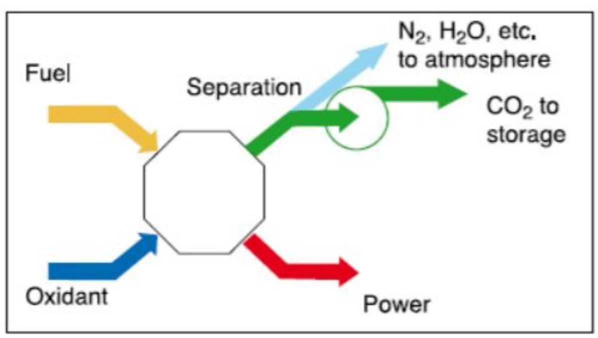

Figure 3: Schematic of Post-Combustion Capture
Source: Anusha Kothandaraman, 2010

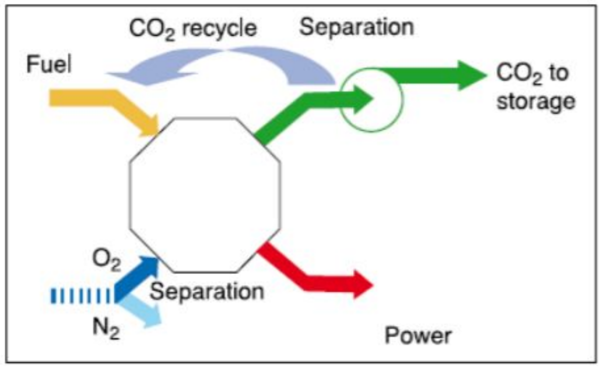

Figure 3: Schematic of Oxyfuel Combustion
Source: Anusha Kothandaraman, 2010

There are numerous implementations for carbon capture processes with many of them still in the developmental stage. These technologies would have to be evaluated before being incorporated into the cement making process. As of current, chemical absorption for post-combustion capture seems like the best option for carbon capture.

Results and Discussion

The following is based on information gained through research about the different options of safely sequestering carbon dioxide before entering the atmosphere. Through a process called carbon capture and storage, new technology will allow CO2 to be forever stored in concrete. It was the goal of this report to collect and present the following information as objectively as possible. Carbon dioxide is the greenhouse gas emitted during the cement making process. Through techniques of carbon capture and storage, CO2 can be injected into a wet batch of concrete and stored forever.

Carbon Dioxide Sequestered in Concrete

Carbon dioxide captured from the emissions of a cement processing plant can be sequestered in concrete forever. Once injected, the CO2 reacts with the calcium ions in cement to form nano-sized calcium carbonate minerals that become permanently trapped in the concrete. This is an alternative to the common practice of transporting liquid CO2 to a remote geological formation, often depleted oil and gas reservoirs, to be sequestered deep underground.

Benefits of Sequestering CO2 in Concrete

There are two main advantages of sequestering carbon dioxide in concrete as opposed to an underground reservoir:

1. When mixing CO2 into a batch of concrete, the chemical process that occurs helps to bind the materials together. This is due to the fact that the CO2 reacts with calcium ions. In a mmix test done by Carbon Cure, they were able to conclude that the addition of CO2 into their mix design increased the compressive strength of the concrete. Furthermore, they were able to reduce the amount of the cement, hardening agent

in concrete, and achieve the same compressive strength. This concludes that the process of injecting CO2 into a concrete allows for a lower amount of cement in the mix design. A lower demand for cement in mix designs leads to a lower demand for cement production, ultimately reducing the output of CO2. Figure 5 shows the compressive strength of the CO2 injected mix design.

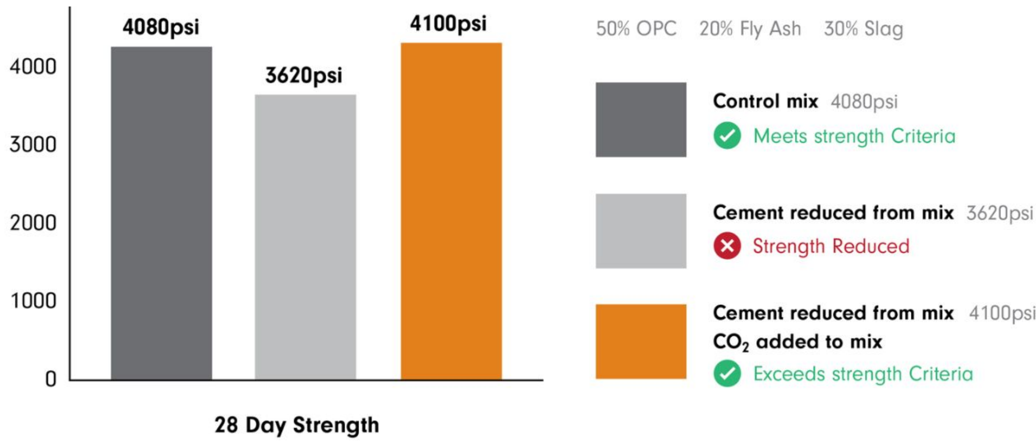

Figure 5: Effectiveness of CO2 as a Cement Replacement
Source: Carbon Cure, 2016

2. Liquid CO2 does not have to be transported nearly as far to be sequestered in a concrete mix. The traditional sequestering of CO2 in underground reservoirs requires liquid CO2 to be transported to the location of the dump site. This is done by truck, pipeline, or a combination of both. Both methods of transportation have their own variables of cost and risk associated.

Conclusions and Future Research

With global population on the rise and demand for concrete increasing, the need for reducing CO2 emissions has become very apparent. Although the technology is new, carbon capture and storage is paving the way for the future of CO2 sequestration. The research shows that the best method for sequestering CO2 is to inject it into concrete mixes for permanent storage. This reduces the risks and costs associated with the traditional storage method of transporting the liquid CO2 to rural underground storage reservoirs. In addition, studies have shown that CO2 has increased the compressive strength of mix designs, while decreasing the need for cement. This decrease in cement will overall reduce the production that emits CO2.

The technology involved with CCS is still in the early stages of development. The results of this paper can be used to understand the need for future research and development of these technologies. Research and development of CCS techniques will improve the efficiency of capturing CO2, reduce the energy needed to compress and transport the liquid CO2, and ultimately reducing the carbon footprint of the cement industry.

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