The First Steps – Low Carbon Cement

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1. Introduction

I'm starting a series today. This will be about solutions that can mitigate climate change. This is prompted by an excellent book that I recently read, and other sources as I go along. The book, and section of the content for this paper are referenced below.[1] Although I will edit content for clarity, I would recommend that readers purchase this book and read it, as it is inexpensive (around $22 on Amazon) and an amazing read, especially for readers that are concerned about climate change. Reference 1 points to a reasonable way forward. The first sentence of the book is: "It is now cheaper to save the world than destroy it."

This book's sections each cover methods for reducing greenhouse gas (GHG) emissions or methods to remove GHG from the atmosphere. This paper covers methods to reduce the CO_2 emissions that result from manufacturing cement and concrete.

I have written about this subject before, albeit six years ago. Much has happened since:

Concrete Greenhouse: This paper is about the cement and concrete industries, their energy use, GHG emissions, and how they might reduce the emissions in the future.

https://www.energycentral.com/c/cp/concrete-greenhouse

However, I will start this post (and end this Intro) with an excerpt from the 2018 post:

The above (concrete) is not a new development, "pozzolanic" materials were used in ancient times. Mixtures of calcined lime (Portland cement) and finely rounded, active alumino-silicate materials were pioneered and developed as inorganic binders in the ancient world. Architectural remains of the Minoan civilization on Crete have shown evidence of the combined use of slaked lime and additions of finely ground potsherds for waterproof renderings in baths, cisterns and aqueducts. The use of volcanic materials such as volcanic ashes (tuffs) by the ancient Greeks dates back to at least 500–400 BC, as uncovered at the ancient city of Kameiros, Rhodes. In subsequent centuries the practice spread to the mainland and was eventually adopted and further developed by the Romans. The Romans used volcanic pumices and tuffs found in neighboring territories, the most famous ones found in Pozzuoli (Naples), hence the name pozzolanic.[2]

2. Mitigating Climate Change

Important first steps are moving to net-zero greenhouse gas (GHG) emissions. But assuming we don't wish to wait around for a millennium or two for Mother Nature to clear all of the human-caused GHG from our atmosphere, that is not enough. We also need to actively remove GHG from our biosphere through any of the following methods:

- Direct air capture and sequestration

[1] Akshat Rathi, Climate Capitalism, Section 6, The Billionaire, Greystone Books, Copyright, 2024
[2] Wikipedia Article on "Pozzolan", https://en.wikipedia.org/wiki/Pozzolan

- Removal from the oceans & other large bodies of water (which will in turn absorb GHG from the atmosphere) and sequestration
- Allowing plants (trees, seaweed, algae and other types) to remove it and sequester the plants' biomass.
- Some combination of the above.

The best sequestration methods are burying the carbon-containing material/gas in strata where it is isolated from interacting with the earth's atmosphere, which will keep the carbon out of our biosphere for many thousands to millions of years.

3. Low Carbon Cement

Making cement causes as much as 8% of global emissions, and there aren't yet any economical technologies capable of significantly reducing the product's carbon footprint. Cement plants can last for fifty years or more, lowering the turnover rate for new technologies to enter the market. Cement is also a cheap and bulky product, which means multiple plants have to be distributed geographically. One industry expert said that a cement plant is only able to meet the needs of customers within a 200-mile radius. That's because the cost of transporting a bulky product longer distances quickly becomes unpractical. Thin profit margins have also forced consolidation within the industry, with a few companies controlling the vast majority of global production. That's because large companies are able to distribute the risks to their business and thus tap cheaper pools of capital.

The cement industry also enjoys laxer regulations on emissions compared with, say, power plants. In Europe, for example, offshore wind power is getting cheaper, which allows governments to apply more pressure on coal power plants to cut emissions and eventually drive them out of business. There aren't yet cleaner alternatives to cement, which remains vital to the economic growth of a country, and thus the industry doesn't feel under pressure to innovate.

Cement has been around since antiquity (see the last paragraph in the Intro), but it hasn't been the subject of significant scientific study. It's hard to think of a topic less sexy than cement. Cement as a material is also quite hard to study scientifically. Any two batches of cement are not chemically identical. It's also amorphous, which means its constituent atoms are not well structured, as you would find in a crystalline material such as the metals used in lithium-ion batteries. You can probe metals with methods such as X-ray crystallography. Also, cement has been doing its job so well that scientists have never been called on to fix it, until the world needed to reach net-zero CO_2 emissions.

So, when BEV[3] set out to make cement greener, it started by analyzing which aspects of the cement-making process produce emissions. First, limestone is mined and transported to the cement plant, where it is crushed, mixed with clay and fed into a kiln. The kiln is typically a long, horizontal, rotating tube that burns coal to temperatures as high as 2,500°F. That process first converts limestone ($CaCO_3$) to lime (CaO), which releases lots of CO_2. The lime then reacts with silica (SiO_2) in the clay to form calcium silicates - which, in aggregate, is called the clinker, and is the binding element in cement. The clinker is then ground again to become a fine powder and mixed with filler materials, such as limestone and silica, to make cement (which is about 70% clinker).

[3] Bill Gates' Breakthrough Energy Ventures (BEV), a multi-billion-dollar fund that has invested in over 100 climate startups. Reference 1 frequently describes actions by BEV.

That is then packed and transported on trucks or barges to the customer. At or near a construction site, the cement is mixed with gravel and water to make concrete. In the process, some portion of the clinker - that is, the calcium silicate - is converted back to limestone, absorbing carbon dioxide from the air. The newly formed limestone is part of the concrete mix and gives it strength, but cement's carbon footprint remains big because only a small fraction goes through that conversion to reabsorb CO_2. Except for this last step, all aspects of the process produce CO_2. The vast majority - 90% - of the emissions, however, come from what happens inside the kiln. The chemical step. of converting limestone into lime is responsible for about 50% of the emissions of the entire process – about 40% comes from burning coal for heat inside the kiln. The remainder comes from carbon-intensive electricity or fossil fuels used in other steps, such as grinders to make the powder and vehicles to transport the product.

3.1. Calix

BEV is currently evaluating technologies that would create cleaner kilns. It won't disclose the names of all the companies behind them, because those are commercially sensitive details. But Carmichael Roberts, BEV's business lead, confirmed that one of the top candidates ought to be the Australian start-up, Calix.

The conventional kiln burns coal, limestone and clay together, and releases a mixture of nitrogen, carbon dioxide and oxygen. It's possible to build a carbon capture facility that separates the gases and then buries the greenhouse gas underground, but that's quite expensive. Instead, Calix's kiln only produces carbon dioxide. By eliminating the need to separate the gases, the cost of capturing the carbon and then compressing and burying it underground drops significantly.

The way Calix does it is so simple it is ingenious. Its kilns are made up of two concentric barrels: the outer barrel burns gas or uses electricity for heating, providing heat to the inner barrel that contains the limestone and clay. Thus, the only chemical reaction inside the kiln is the conversion of calcium carbonate ($CaCO_3$) into calcium oxide (CaO), which releases a pure stream of carbon dioxide (CO_2). If the heating is done with renewable electricity then cement emissions can be cut by as much as 90%. The startup is currently retrofitting a kiln in Germany; once up and running, in 2023, it will capture 100,000 tons of carbon dioxide each year, Calix says.

Not all companies will be willing to retrofit kilns or acquire a site near the plant where captured carbon dioxide can be buried. In response, BEV is also investing in companies working on reducing the emissions of other aspects of the cement-making process. Ireland's Ecocem, for example, is working on a way to use only 20% of clinker in its mix, compared with the 70% standard. BEV has, to date, invested more than $25 million in the company.

3.2. Ecocem

…Ecocem was founded in 2000, when it began selling granulated ground blast furnace slag, which is a long phrase to describe a by-product of the steel industry that has chemical properties similar to clinker. Ecocem realized that instead of dumping the stuff in a landfill, they could sell it for use as the binding element for cement mixes. As the political will to reduce carbon emissions gained momentum in Europe, so companies in the region began to buy the slag powder from Ecocem to make lower-carbon cement.

But scientists have known for a long time that not all the clinker or slag inside cement is used for its binding properties. Cement companies use clinker or slag for other purposes, such as keeping the concrete mix wet for longer or maintaining the mixture's viscosity. With reductions in carbon dioxide gaining momentum in Europe, in 2013 scientists at Ecocem started working on ideas to drastically reduce clinker content in cement.

After seven years of research, Ecocem found the right mixture that was 20% clinker, 30% slag and filler materials for the rest. It wouldn't share what the filler material is made up of, because that's proprietary, except to say that it has a tiny carbon footprint and its job is to maximize the activation of clinker and slag so they are more effective binding agents. BEV's cash and its global connections are now helping Ecocem to apply for licenses to sell their eco-friendly cement in Europe. Soon it will build small plants in North America and Asia to showcase its cement to potential customers in those regions. It will also look to license its chemistry to existing cement makers, which would make it possible to scale its technology faster.