The Commercialization of Low-Carbon Cements through Calcium Silicate Carbonation of Industrial Waste
(Technical Paper)

Too Close to the Sun: Have We Taken Carbon Offsets Too Far?
(STS Paper)

A Thesis Prospectus
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Prospectus

Introduction

We are rapidly approaching the point of no return. Human industrial activity has raised the global average temperature by over one degree Fahrenheit and increased the concentration of carbon dioxide in the atmosphere by 50% (NASA, 2022). These effects are permanent. Even if humans stopped all carbon emissions today, the global temperature would not begin to decline until the end of the millennium (Solomon et al., 2009). There are numerous adverse effects to global temperature rise, the most well-known of which is increasing sea levels, which according to Solomon will incur "substantial irreversible commitments to future changes in the geography of the Earth because many coastal and island features would ultimately become submerged" (Solomon et al., 2009). Obviously, losing land to the ocean is not a great future, especially because the population of the United States is concentrated for the most part along the coasts (United States Census Bureau, 2021).

There are two goals that humanity must achieve in order to combat climate change. First, humans must either stop or limit carbon emissions. Second, we must begin removing carbon dioxide from the atmosphere so as to try to limit the thousand-year-long effects of current-day climate change. The STS portion of this research paper will focus solely on the first item by exploring how carbon offsets have been effective (or ineffective) at mitigating climate change. A carbon offset is a "token" that one can purchase to offset the carbon emissions from, for example, an airline flight. The technical portion of this research will deal with both items. The research lab team will attempt to produce a carbon negative concrete; a building material that, instead of releasing carbon dioxide into the atmosphere, sequesters and stores it in the chemistry of the concrete.

Technical Topic

An issue plaguing the construction world is the use of Ordinary Portland Cement (OPC). OPC alone is responsible for "between 5% and 10% of the total annual anthropogenic CO_2 emissions" (Plattenberger et al., 2020), meaning that the use of OPC is currently a main contributor to climate change. From a quantitative standpoint, for every kilogram of OPC used, 1 kilogram of CO_2 is released into the atmosphere. These large carbon emissions mainly originate in the manufacturing process which requires burning limestone at high temperatures for a long time. Since limestone is just calcium carbonate, the process of heating it up produces the following reaction: $CaCO_3 \rightarrow CaO + CO_2$. This reaction emits CO_2 at an alarming rate, if eliminated from the cement production process, carbon emissions will be reduced greatly (Plattenberger et al., 2020). As the continued development of society is reliant on the construction and maintenance of infrastructure, cement cannot be phased out of use. Humans are thus required to devise a new, carbon friendly building material or climate change will continue to worsen.

To reduce the carbon footprint of cement, an alternative method based on Roman cements has been created. Roman cements create minerals like aluminum tobermorite which are known to be more durable than the carbonates in current day cement (Ahmad, 2017). These minerals can be created by curing pseudowollastonite (PWOL) at high temperatures under a pressurized CO_2 environment. The PWOL is used as the binder in concrete mix, with a low-molarity sodium solution as the liquid. The curing process rearranges the carbon, calcium, hydrogen, aluminum, and silicate in PWOL to create CASH and CCSH gels, which will then crystallize to form the minerals found in Roman cements. The process of curing the cement

under pressurized CO_2 captures CO_2 within the cement as carbonates. The strengths of the cement made with PWOL is comparable to the strengths of OPC and the removal of limestone as a base material greatly reduces the initial carbon footprint of the cement. Both aspects factor into the great potential of this material to be a low-carbon alternative to OPC (Plattenberger et al., 2020).

Previous efforts by the research team involved synthesizing PWOL in the lab, however this process is time consuming and energy intensive, meaning that for the concrete to be a large-scale and life-cycle carbon negative material, another PWOL source must be used. The goal of the capstone project is to use a waste slag from a metals processing plant. The waste slag in question is not pure PWOL but does have a large concentration of the mineral. The use of this material is extremely advantageous, as it requires no dollar cost to manufacture or procure and as a result also incurs no carbon emissions. Therefore, the overall product is expected to be carbon negative because PWOL cements sequester CO_2.

The end goal of the overall research project is to create a concrete alternative to OPC that is a marketable, scalable, and low-carbon building material. A product of this magnitude will require collaboration from industry and technical experts to fully implement at scale. The capstone team will work closely with the UVA research team as well as other industry professionals in accomplishing this goal. The project completed within this thesis will provide large steps towards this overall goal and serve as a foundation for future efforts in this endeavor.

STS Topic

Carbon offsets allow “carbon to be reduced in the global atmosphere by compensating for excess emissions in one location through carbon reductions in another” (Lovell & Liverman, 2010). The practice of carbon offsetting came into existence because of the Kyoto Protocol of 1997, which set emissions standards for most developed countries. However, the protocol included fines for noncompliance with the emissions standards, meaning that countries agreeing to the protocol wanted a way to ensure that they were always able to comply with the emissions standards (Lecocq & Ambrosi, 2007). The solution was to create the Clean Development Mechanism (CDM), whose job is to support eco-friendly development in developing countries by allowing developed countries to “credit their greenhouse gas inventory with the emissions captured from afforestation or reforestation” and “promote the development of carbon pollution reduction projects such as hydroelectric dams and industrial gas destruction factories (Wilman & Mahendrarajah, 2002 & Bryant et al., 2015). These two techniques work to reduce overall global carbon emissions despite limited emissions reduction from these developed countries.

Though the CDM “left many ambiguities unresolved”, it does have a strict set of rules and regulations for emission targets and what constitutes a carbon credit (Lovell & Liverman, 2010). However, with the introduction of the CDM came a separate issue: the voluntary carbon offset. Carbon offsets under the CDM are counted as compliance offsets because countries use these offsets to comply with the Kyoto Protocol. Voluntary offsets, however, have no formal regulations or even a definition of what a carbon credit truly represents. Since climate change has become a hot button issue, companies, especially airlines, across the world have begun to take advantage of voluntary offsets by using marketing campaigns that promise net-zero carbon emission operations (Watt, 2021). For example, Southwest has an entire webpage complete with a Frequently Asked Questions section dedicated solely to their carbon offset program (Southwest

Airlines, 2022). However, since companies and individuals utilize the voluntary offset market, there is little evidence that these methods are truly helping mitigate climate change. Instead, they at best push the problem off to developing nations and at worst fail to mitigate carbon emissions at all. Southwest, on their website, has a description of some of the projects that their carbon offsets go towards, one of which is titled "The Guatemalan Conservation Coast". The description of this project says that it "supports existing natural forest, avoiding carbon emissions that would result from unplanned deforestation and degradation" (Southwest Airlines, 2022). This statement appears extremely vague, and again highlights one of the problems with the under-regulated voluntary carbon offset market. Supporting existing forest could mean any number of things and "unplanned deforestation and degradation" again is as close to meaning nothing as it is to meaning anything. Thus, it can be very difficult to judge which forms of carbon offsets, if any, provide an effective method for beginning to address climate change.

One of the STS theories used in this project will be technological momentum. Technological momentum is the summation of the social construction of technology and technological determinism. It is the theory that when technologies are first developed, they are shaped by society. As the technology "ages" and becomes a larger and larger part of the society, it will then begin to shape society (Hughes, 1994). Technological momentum, however, is not without flaws. One critique of using only technological momentum to describe how society functions is that the framework is too broad. Since technology that has become deterministic is often ubiquitous across society, for example, the internet, it can be difficult to describe how exactly the technology shapes society because society is too diverse to be grouped into one category (Ekbladh, 1999). Each facet of a technology affects different groups of people differently. In addition, there are also several other factors that influence how technology is

implemented into society, such as politics, wealth, investment, and environment to name a few. For my purposes, however, the aforementioned factors will not drastically affect my analysis. Carbon offsets are still a relatively new technology and therefore only affect a small section of both industry and society. They are, however, becoming a more and more prominent fixture of climate activism and climate science, so I will be able to utilize both aspects of technological momentum in my analysis.

The other STS theory will be the technological fix. The technological fix is the theory that some technologies should not be implemented because they do not address the root cause of the problem. It is the technological equivalent to the proverbial band-aid on a bullet hole. According to Byron Newberry, technological fixes "run the risk of proliferating into universal *easy ways out*" (Mitcham, 2005). These easy ways out can create their own problems in addition to not fully addressing the original problem they were meant to solve, which is a bad feature of any technology. However, there is a point at which problems must be solved via technology, where the problem is so vast and so multi-faceted that societal change is not enough.

Research Question and Methods

Are carbon offsets an effective method for mitigating climate change, and not, why are they so popular? I will utilize documents and case studies to guide my research on this question. I plan on using scholarly articles written during the beginning of carbon offsets, soon after the Kyoto Protocol was implemented in 1997, as well as articles written later about how they have evolved over the years. It is important to take articles from different time periods because I plan on using technological momentum as a framework for analysis, and technological momentum is time dependent. I also plan on using news articles from different time periods to try to understand the public view on the matter. Company websites that detail their carbon offset

programs will also be useful. I will look for case studies related to specific instances of carbon offsets either working or not working, as well as case studies regarding the countries where the physical carbon offsets end up being located.

Conclusion

Ideally, at the end of this capstone project, we will have produced the world's first carbon negative concrete. This product would have to be able to be mass-produced and mass-cured while sequestering carbon and mimicking the strength of Ordinary Portland Cement. This product would seek to revolutionize the building world by providing a green alternative to an extremely carbon emission intensive process.

At the end of STS, I will have a research paper exploring how carbon offsets work, if they are effective, and how technological momentum and the technological fix can be used to describe why carbon offsets are so popular. This paper will seek to bring attention to a lot of the misleading preconceptions about carbon offsets, and could help ensure that people and companies are using them correctly, which would be an overall win for the climate.

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