Prospectus

Use of Oxy-fuel Combustion and Accelerated Carbonation Curing to Facilitate CO_2 Capture in Concrete Production

(Technical Topic)

Actor Network Theory and Deforestation in the Brazilian-Amazon

(STS Topic)

By

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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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Introduction/Sociotechnical Problem

Greenhouse gases are essential to life on earth. These gases (ex. water vapor, ozone, carbon dioxide, etc.) are necessary to keeping the planet warm by trapping heat from the sun in our atmosphere (Nunez et al., 2019). However, recent decades have shown that these gases are out of balance, with an excess of carbon dioxide (CO_2) and other pollutants, due primarily to the anthropogenic burning of fossil fuels from the Industrial Age to present day (Nunez et al., 2019). In 2015, the United Nations Framework Convention on Climate Change's 21st Conference of Parties adopted the Paris Climate Agreement (Denchak, 2018). The accord, other than outlining support for developing countries to combat climate change and transparent reporting of climate goals and progress, also outlines targets to contain a global temperature rise to 2°C (Denchak, 2018). Part of this objective includes curbing global emissions as soon as possible, which will require action from major emitters, using technologies such as Carbon Capture and Sequestration/Storage (CCS) (Denchak, 2018). Including individual country emissions, concrete is the third largest emitter of CO_2 in the world (Detz, 2019). To address a portion of this problem, my team and I are designing a chemical process that allows concrete to trap CO_2, generated from the production of its cement component, and act as a resource for CCS.

However, it is important to consider the scientific, technological, and societal (STS) aspects of this problem; because the issue of greenhouse gas reduction will not be solved with a simple technological "fix" alone. In the context of Actor Network Theory, I will define a complex network of various rogue actors working to undermine Brazil's plans to rollback incentives for deforestation. Since deforestation destroys trees, a natural method of CCS, this case study will encourage a better understanding of factors that work against the reduction of greenhouse gases and halting climate change. By addressing both technical and STS concepts, the team stands to benefit by forming a marketable CCS design.

In order to develop a viable and marketable CCS technology, both technological and social factors must be considered; because reducing greenhouse gasses is a problem that is socio-technical in nature. Below I will outline a technical process that utilizes oxy-fuel combustion and accelerated carbonation curing to trap CO_2 in concrete produced from the Ordinary Portland Cement-making process. I will also call upon the STS framework of Actor Network Theory to analyze how various rogue actors (such as the President of Brazil, the United States, and China) have worked against Brazil's efforts to end deforestation of the Amazon.

Technical Project Proposal*

***This section was written collaboratively in accordance with the direct and specific requirements of my advisor, Eric Anderson.**

Concrete is the most widely used human-made material in existence. In terms of human consumption, it is second only to water (Rodgers, 2018). Unfortunately, cement, the principal component of concrete, leads to massive carbon dioxide (CO_2) emissions; in fact, approximately 2.2 billion tons of CO_2 per year, making up 8% of all global carbon emissions (Rodgers, 2018). This represents the second-largest single industrial process emitter after iron and steel production (Harvey, 2018). The cement industry is a promising opportunity for industrial sustainability due to its scope and worth. Market projections suggest that the cement market value will grow from $312.5B in 2018 to be worth $682.3B by 2025 (Cement market size worth $682.3 billion by 2025, 2018).

This prospectus will propose an alternative to the clinker-making process as well as a production method for utilizing concrete as a Carbon Capture and Sequestration/Storage (CCS) technology. In terms of cement produced, the de-carbonation of limestone in the kiln produces about 525 kg CO_2 per ton of clinker, and the fuel combustion produces about 335 kg CO_2 per ton of cement (Bosoaga et al., 2009). To meet the standards outlined in the 2015 Paris Agreement, it will require that global carbon emissions associated with cement production drop 16% by 2030 (Rodgers, 2018). Over the last few decades, many advances have been made with regard to kiln and feedstock design in order to make the process more environmentally-friendly. However, only recent studies have explored the possibility of CCS and cement's role in this environmentally-sustainable technology. Additionally, the resulting designs of these studies face adverse market conditions. An economically-viable design will be necessary to garner the support needed to make a substantial shift toward sustainable cement production.

BACKGROUND ON STANDARD CEMENT MANUFACTURING PROCESS

Ordinary Portland Cement (OPC) is the industry standard cement. The following description of the process commonly used to manufacture OPC comes from "How cement is made" (n.d.). OPC is produced when limestone, or another source of calcium carbonate, is crushed and mixed with other ingredients, such as clay, shale, or slag, and subsequently heated in a cylindrical, rotary kiln. The kiln reaches temperatures as high as 2,700 degrees Fahrenheit. The solid ingredients have a chance to thoroughly mix and incorporate as they move from the top of the kiln downward, exposed to even heating. The product of this kiln firing are small and circular pellets, called clinkers:

$$CaCO_3 \rightarrow CaO + CO_2$$

These hot molten pellets are sent through multiple coolers until they reach a cold enough temperature to be handled by humans. The clinkers are then ground and combined with small amounts of gypsum and limestone. After this mixing process, water can be added to the mixture to form concrete. The process is outlined below in Figure 1:

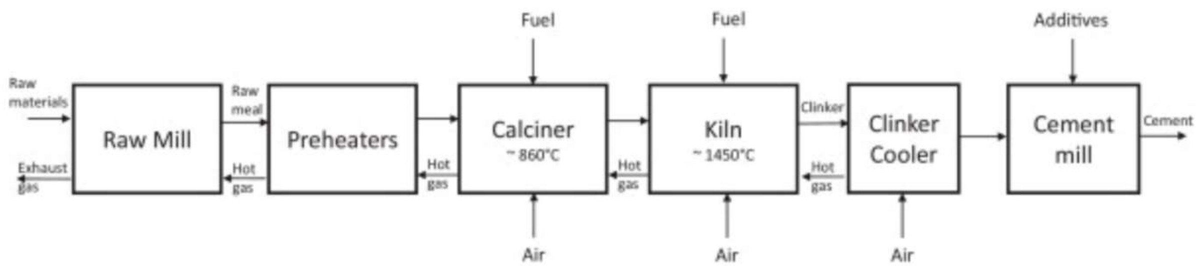


Fig. 1. Simplified diagram of the conventional cement production process.

OBTAINING CO_2: THE ROLE OF OXY-FUEL COMBUSTION

Oxy-fuel combustion is a CCS technology. The following paragraph describes the oxy-fuel combustion process as it is described in "Oxy-fuel combustion systems" (n.d.).

The process begins with an air separator, which produces a pure O_2 feed to the combustion process. The oxygen is then fed, in conjunction with a hydrocarbon fuel, to the boiler which facilitates combustion. CO_2 and H_2O are the main products of this process and are taken off as flue gas. The stream then splits into two, one which recycles part of the flue gas back into the boiler, and one which leads to cooling, compressing, and dehydrating the stream to produce pure CO_2.

Part of what sets oxy-fuel combustion apart from other CCS technologies is that the process utilizes a pure O_2 stream and recycles flue gas back into the combustion process. This is as opposed to feeding air into the process, which presents inert nitrogen to dilute the O_2 in the boiler. Using flue gas to dilute oxygen instead allows for higher conversion to the products. The process is also one of the most viable and efficient CCS technologies available today.

IMPLEMENTING ACCELERATED CARBONATION CURING

Carbonation naturally occurs over time when cement paste and atmospheric CO_2 meet.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

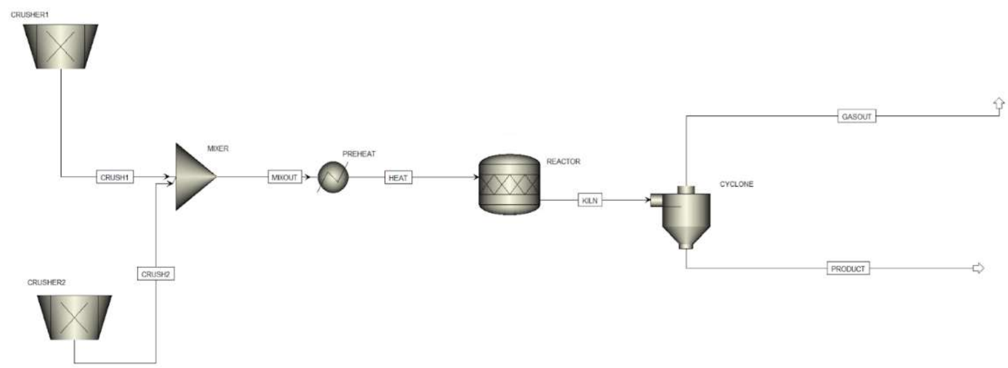
However, this process can be accelerated for precast concrete to significantly increase carbon storage capacity, minimizing the cement-making process' overall carbon footprint. Accelerated carbonation occurs when CO_2 gas diffuses into the porous concrete. The solvation of gaseous CO_2 occurs before it is hydrated to H_2CO_3. Once H_2CO_3 forms it is then ionized. The newly formed H^+ ions cause the pH of the concrete to decrease. Finally, the nucleation of the $CaCO_3$ occurs, and C-S-H gel forms. Instead of hydrating, CO_2 could instead react with silicate phases, dicalcium silicate and tricalcium silicate, to dissolve exothermically and form stable calcium carbonates. The $CaCO_3$ then precipitates out of the solution.

BARRIERS TO IMPLEMENTATION

Barriers to implementing a CCS process in concrete production are mostly in the oxy-fuel combustion component. High combustion temperatures and costs associated with using oxy-fuel combustion (more fuel, energy to increase temperature) are issues associated with our design that should be taken into account. The introduction of a pure O_2 stream to the kiln, instead of an air stream, also increases the partial pressure of CO_2 in the kiln, and changes the reaction from a gradual to a threshold reaction (threatening re-carbonation of lime to limestone, and making the reaction much more fickle) (Zeman, 2009).

THE TEAM'S PLAN

The team plans to use AspenPlus to simulate the process. This will come together in a fashion similar to the Process Flow Diagram on the following page:



This process flow diagram will be built upon to properly model the entire process including the oxy-fuel combustion, CCS, and various coolers beyond the kiln. For this diagram, the rotary kiln is represented by the combination of a reactor and cyclone solid-gas separator. The team will focus on adding oxy-fuel combustion to the kiln, and creating a carbon capture stream off the kiln.

The process begins with the formation of OPC. Then, oxy-fuel combustion will be used in the kiln to provide pure CO_2 for carbon capture. This specific kiln set-up is known as a Reduced Emission Oxygen (REO) kiln, according to Zeman, whose work will be used to guide the team in the use of oxy-fuel combustion in the kiln (Zeman, 2009). In addition, a study on oxy-fuel combustion by Ditaranto and Bakken (2019), which utilizes a scale of 3000 tons of clinker production per year, and a kiln of 60 m long with an inner diameter of 3.76 m (which can be revised and scaled up in later calculations by the team) will be used. CO_2 from the REO kiln will be taken off as a stream fed to the concrete, with excess CO_2 from contact with the concrete led out of the plant and to an alternative method of CCS (ex. geologic formation storage).

In terms of process variables for this technical project, the team hopes to experiment with cement composition (limestone, fly ash, etc.), clinker quantity (dependent on kiln size), and CO_2 exposure time, as well as kiln temperature and kiln fuel, while monitoring the percent recovery of CO_2 in the recycle stream and percent of CO_2 absorbed by the concrete. The team will assume that the factory where the cement is manufactured generates precast concrete slabs so that CO_2 exposure can be manipulated in the designed plant.

This project will be worked on over the course of two semesters in CHE 4438/4476 under the advising of professor Eric Anderson. The team will meet once a week at minimum to discuss advances made and establish new goals for the following week of research, modeling, and analysis. The team has also recently discovered companies, for example, Central Concrete and Solidia Technologies, that are producing carbonated concrete using similar (though not fully identical) methods. The team plans to reach out to a representative from these companies to see if they can establish a partnership for the Spring 2021 semester.

STS Project Proposal

Beginning in the 1960s, deforestation in the Brazilian-Amazon experienced an increase due to national policy supporting road building and colonization projects through the Amazon, and tax credits and incentives to large corporations and ranches (promoting intensive-land-use agricultural sectors) (Fujisaka et al., 1996). In the 2000s, Brazil received negative attention for their deforestation practices (slash-and-burn agriculture, etc.) (The Earth Observatory, 2009). This is because trees are a natural CCS source; and deforestation is estimated to have a direct causal link to 8-10% of human CO_2 emissions each year (Dean, 2019). Facing this backlash, Brazil began to roll back it's road building and colonization projects, as well as incentives to large corporations and ranches in response (Fujisaka et al., 1996). These events coincided with a large economic downturn beginning in 2013, which saw the devaluation of the Brazilian real and decreased commodity prices (Pravettoni, 2016). Since then, Brazil has seen an increase in illegal deforestation; especially recently, with an over 34% increase observed since August 2019 alone (Fujisaka et al., 1996).

One factor that may have caused the rollback to fail in its objective to decrease deforestation is the extensive reliance of Brazil's economy on its agricultural production. Much of the deforested land in Brazil goes toward agricultural use. Brazil produces over $100 billion USD annually through large-scale crop cultivation and is one of the top three producers of sugarcane, soybeans, and maize, globally (Pravettoni, 2016). Additionally, Brazil produces over 23% of the world's beef and buffalo meat and 21% of the world's poultry (Khan, 2019). Brazil is the largest beef producer globally, and exports millions of tons of animal product per year (Khan, 2019).

While this is a valid assessment, this view overlooks other factors and actors that have caused the rollback to fail. Three examples of such would be the President of Brazil, Jair Bolsonaro, the United States (U.S.), and China. President Bolsonaro, who took office in 2019, has made statements rejecting European countries' assessment of deforestation in the Amazon (Phillips, 2019). Bolsonaro sees the situation like so: "the Amazon is not [Europe's]", and European countries should be focusing on their own environmental projects (Phillips, 2019). He has put his money where his mouth is, and is aiming to open Brazil to partnerships that exploit its biodiversity and mining operations, despite contrary data from his government (Phillips, 2019). The President has also accosted the nation's environmental agencies and plans to undermine their authority by opening indigenous reserves (Khan, 2019). The trade war between the U.S. and China has also increased demand for Brazilian agricultural products. China is now buying soybeans from Brazil instead of the U.S. (Khan, 2019). Soybeans are Brazil's largest commodity export, and Brazil is now exporting more than $25 billion USD worth a year (Khan, 2019).

If we continue to view the failure of the rollbacks as solely a result of economic reliance on agriculture, we will fail to understand the role that other actors played alongside the Brazilian economy in the failure of the rollbacks. For example, the Brazilian economy cannot shift on a dime; if there is not political support from the President for switching gears to an economy less reliant on agriculture and exploiting its natural resources, Brazil cannot hope to find a more suitable method to end deforestation.

Drawing on Actor Network Theory, I argue that it was the Brazilian economy's reliance on agriculture in conjunction with the roles of President Bolsonaro, the United States, and China, that caused the rollbacks of the late 2000s-early 2010s to fail. Actor Network Theory is the combination of social and technical actors within an environment to create a network (Law, 235). This network is formed by a network builder, who's function is to establish roles in the network and solve problems. I will use Actor Network Theory to define the complex network of human and non-human entities that influence each other within an environment, in this case Brazil. I, more specifically, will use Michel Callon's theory of "Translation" to define how this network formed and is maintained, given the differences and power dynamics between various actors; and will examine how rogue actors fit into this framework (1986). To support my argument, I will analyze evidence from various Brazilian, Chinese, and U.S. news outlets, such as *Folha de S.Paulo*, *China Daily*, *The New York Times*, and *The Washington Post*, which provide direct quotes and statements from President Bolsonaro, President Xi, and President Trump on the Brazilian economy and deforestation in Brazil.

Conclusion

The technical portion of this prospectus will provide a process design for a concrete production facility that allows concrete to act as a CCS technology. This will be done by obtaining a pure CO_2 stream from oxy-fuel combustion, and introducing this into concrete via accelerated carbonation curing. The STS portion of this prospectus will address how Brazil's efforts to reduce deforestation in the Amazon have been sabotaged by a few rogue actors through an analysis using Actor Network Theory.

The results of each project will help solve the socio-technical problem of excessive CO_2 emissions by introducing a new process design for developing a CCS technology. The STS paper will provide insight on how to make this technology viable and economical, by exploring the motivations of rogue actors, using Michel Callon's concept of "Translation" in conjunction with the broader concept of Actor Network Theory (1986).

Word Count: 2503

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