The Commercialization of High-Performance and Low-Carbon Cements Through Calcium Silicate Carbonation of Industrial Wastes
(Technical Paper)

Who Holds the Power: An Investigation Into the Power Dynamics of the Energy Industry
(STS Paper)

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Civil Engineering

By
Jacqueline Canning

October 27, 2022

Technical Team Member:
Zachary Abruzzese

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.

ADVISORS

Andrés Clarens, PhD, Engineering Systems and Environment

Bryn E. Seabrook, PhD, Department of Engineering and Society

Introduction

Industrial processes in the United States produce 7.6 billion tons of solid industrial waste per year, as well as almost a quarter of greenhouse gas emissions accounted for in the US ("Controlling industrial", 2022) (EPA). The proper disposal of industrial waste can require significant amounts of land, which takes away from local communities (EPA). Any failure of the waste disposal system can release dangerous chemicals into the ecosystem. One instance was in Tennessee in 2008, the coal ash waste storage system failed and released 5.4 million cubic yards of waste into the surrounding environment (Environmental Protection Agency, 2022a). Storage failures, like the one in Tennessee, are not the only harmful release by industrial processes, consistent greenhouse gas emissions from industries are a large proponent of climate change. Without significant efforts to reduce climate change, the world will continue to make great strides towards being uninhabitable compared to today. It is necessary to find ways to decrease greenhouse gas emissions as well as reduce the levels of industrial waste to enable the world to continue to be habitable.

The capstone project presented in this prospectus is focused on finding a solution that reduces greenhouse gas emissions as well as captures industrial waste. The technical portion of this project is focused on creating a low carbon cement alternative. The low carbon intensity comes from using industrial waste in the mix as a binder or an aggregate as well as the carbon dioxide (CO_2) capture that occurs while curing. In addition to the technical report, a study on the internal and external relationships of the energy industry will be performed. The study will focus on small towns in West Virginia and Wyoming, chosen because they are the top two coal producing states (West Virginia State Energy Profile, 2021). Further understanding of these

relationships in these states will give a foundation for the understanding of relationships within the energy industry nationally and help create a path forward to a more sustainable society.

Technical Topic

An issue plaguing the construction world is the carbon intensity of ordinary Portland cement (OPC), a common construction material. 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. In comparison, the production 1 kg of red brick releases 0.3 kg of CO_2 source ("Recycled Bricks", 2017). These large carbon emissions mainly originate in the manufacturing process which requires heating the cement ingredients to 2700 degrees Fahrenheit (Portland Cement Association, 2022). One of the main ingredients of cement is limestone, formally known as calcium carbonate ($CaCO_3$). The process of heating it up produces the following reaction: $CaCO_3 \rightarrow CaO + CO_2$. The combination of this reaction and the heat it requires emits CO_2 at an alarming rate. Eliminating the calcination of limestone from the cement production process, will reduce the carbon emissions 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.

To reduce the carbon footprint of cement, an alternative method based on Roman cements has been created. The strength in Roman cements comes from 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 minerals similar to those 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 of these 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 as the source of PWOL. 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

Electricity is the vehicle for many of the basic needs a human has in society today. Wars have been fought over stores of oil, traditionally one of the biggest sources of energy, or electricity. This basic need in society, however, is single handedly producing 25% of greenhouse gas emissions (EPA, 2022b). From being a leading factor in climate change, to producing harmful waste that penetrates the ecosystems of the communities it is produced in, the full impact of producing energy must be understood. As climate change progresses and the world turns towards renewable resources for energy production, the relationships in the energy industry must be understood to prevent new energy sources from damaging communities both locally and globally.

The energy industry contains utilities, the regulator, the communities that generate the electricity, and the communities the utility serves. Each of these players looks very different depending on the area that is being described. The utility is typically the generator, transmitter, and distributor, of electricity. However, in many places, the responsibility of generation, transmission, and distribution are given to separate companies to reduce monopolies. In Virginia, the only generator is Dominion Energy, however, Dominion Energy does not own all of the distribution systems for the entire state. Instead, Dominion Energy serves the Richmond, Charlottesville, Virginia Beach, and Northern Virginia areas, while other utilities, such as Allegheny Power, serve the remaining areas. In West Virginia, the further focus of this research, the main utilities are MonPower and Potomac Eddison, sub-companies of First Energy (FirstEnergy).

The regulator in the energy industry is a government organization, specifically, the Federal Energy Regulatory Commission (FERC). The FERC emerged from the Energy Policy Act of 2005 (*What FERC Does)*. In addition to the FERC, the policies made by the local and national

governments largely dictate the actions the utilities themselves take. The EPA provides a separate regulatory body that focuses on the emissions and waste from the utility and dictates the proper treatment and disposal of these wastes (Environmental Protection Agency, 2022c). Each of these government agencies and branches of the government is an essential element of the relationships inside the energy industry.

The last element to focus on is the communities. These communities come in two separate forms: the community that is located around the power plant, and the community that uses the electricity the plant provides. The community that is located around the plant has regular interactions with the plant and may have members of the community working inside the plant. These daily interactions and the jobs the plant provides for the community are heavy shapers of the community's opinion of the plant (Davidson). On the other hand, the large communities that use the electricity the plant provides tend to look at the big picture, they see climate change and energy prices, and bring a different viewpoint (Gross, 2022). It is more difficult to accept the change when it occurs local to ones own community. Each of these elements of the energy industry is complex, varied based on location, and important.

To properly define the energy industry, and fully understand the relationships inside the industry, it is necessary to characterize every player separately and then combine these separate characterizations with relationships. This analysis will be done by applying the Actor Network Theory (ANT). The ANT is a framework used in academia that allows for the analysis of complex relationships between the human and non-human element that may exist inside of a network (Cressman). The ANT will provide a solid foundation for further analysis, however, as many concepts do, it faces some critiques. A major critique of the ANT is that the choice of the actors of the network is up to the author. This freedom in choice could allow the author to shape

their respective network to fully support the basis of the narrative the author is creating. Therefore, when writing and reading a piece based on ANT, the reasoning for the choice of actors must be well established by the author as well as thoroughly critiqued by the reader.

Methodologies

In my STS paper, I will be defining the relationship between the energy industry, the waste it produces, the regulator, and the communities the industry serves and is located in. This relationship changes depending on the community of focus, as well as the time in history the author is discussing. I will be using the method of historical case studies to help define the ANT seen in the energy industry. The focus of this case study will be small coal towns in West Virginia and Wyoming. Information about these towns and the energy industries impact on them will be gathered mainly through podcast interviews with representatives, news articles, government data sheets, policy documents, and academic journals. The proper development of the ANT is imperative on having an unbiased understanding of the basis of each parties' actions and the full repercussions of these actions. Therefore, significant efforts will be taken to find a wide range of sources that will ensure all viewpoints are accurately represented. When complete, using this method of case studies will provide the network for the energy industry on a micro level that can be used as a basis to understand the energy industry on a macro level.

Conclusion

This capstone project will produce two separate but mutually beneficial products. The technical portion will further the research on carbon capture cement with the focus of commercialization. The STS portion will define the energy industry on a micro scale. This micro scale definition can be used to help understand the industry on a macro scale. These projects become a cohesive effort when the better understanding of the energy industry and the wastes

produced there can be used to help capture these wastes in a commercialized product developed through the technical research performed. The effort of this capstone project will make individual strides towards a more sustainable world.

References

Controlling industrial greenhouse gas emissions. Center for Climate and Energy Solutions. (2021, September 15). Retrieved October 22, 2022, from https://www.c2es.org/content/regulating-industrial-sector-carbon-emissions/

Cressman, D. (2009). A Brief Overview of Actor-Network Theory: Punctualization, Heterogeneous Engineering & Translation. https://summit.sfu.ca/item/13593

Environmental Protection Agency. (2022a, January 5). *EPA Response to Kingston TVA Coal Ash Spill*. EPA. Retrieved December 4, 2022, from https://www.epa.gov/tn/epa-response-kingston-tva-coal-ash-spill

Environmental Protection Agency. (2022b, August 5). *Sources of Greenhouse Gas Emissions*. EPA. Retrieved December 5, 2022, from https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Environmental Protection Agency. (2022c, June 21). *Regulatory and Guidance Information by Topic: Waste*. EPA. Retrieved December 6, 2022, from https://www.epa.gov/regulatory-information-topic/regulatory-and-guidance-information-topic-waste

FirstEnergy's West Virginia Utilities remind customers of available assistance programs to help with Winter Bills. (n.d.). Retrieved November 4, 2022, from https://www.firstenergycorp.com/newsroom/news_articles/firstenergy-s-west-virginia-utilities-remind-customers-of-availa0.html

Gross, S. (2022, March 9). *Renewables, land use, and local opposition in the United States*. Brookings. Retrieved December 6, 2022, from https://www.brookings.edu/research/renewables-land-use-and-local-opposition-in-the-united-states/

Guide for Industrial Waste Management, EPA.

K. Davidson, C. S. Shamberg, M. Shamberg, R. Fernandez, D. Levinson (Executive Producer). (2022). *Meltdown: Three Mile Island* [TV Mini-series]. Netflix. https://www.netflix.com/

West Virginia State Energy Profile. West Virginia Profile. (2021, November 18). Retrieved December 5, 2022, from https://www.eia.gov/state/print.php?sid=WV

What FERC does. Federal Energy Regulatory Commission. (2022, August 16). Retrieved November 4, 2022, from https://www.ferc.gov/what-ferc-does#:~:text=The%20Federal%20Energy%20Regulatory%20Commission,well%20as%20licensing%20hydropower%20projects.

Technical Topic References

Ahmad, Z. (2017). Why modern mortar crumbles, but roman concrete lasts millennia. *Science*. https://doi.org/10.1126/science.aan7051

Plattenberger, D. A., Opila, E. J., Shahsavari, R., & Clarens, A. F. (2020). Feasibility of using calcium silicate carbonation to synthesize high-performance and low-carbon cements. *ACS Sustainable Chemistry & Engineering*, *8*(14), 5431–5436. https://doi.org/10.1021/acssuschemeng.0c00734

Portland Cement Association. (2022). *How Cement is Made*. How Cement Is Made. Retrieved December 4, 2022, from https://www.cement.org/cement-concrete/how-cement-is-made#:~:text=Cement%20is%20manufactured%20through%20a,silica%20sand%2C%20and%20iron%20ore.

Recycled bricks reduces co² emissions by 1 million kg. Henning Larsen | Recycled Bricks Reduces CO² Emissions by 1 Million Kg. (2017, September 28). Retrieved December 5, 2022, from https://henninglarsen.com/en/news/archive/2017/09/28-recycled-bricks-reduces-co2-emissions-by-1-millionplus-kg/